Mechanism Design for the Fiery Ice:

Civil Liability and Regulations for the Efficient Governance of the Environmental Hazards from Offshore Methane Hydrate Operations

Roy Andrew Partain

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Aansprakelijkheid voor en regulering van de milieurisico's verbonden aan de exploitatie van methaan hydraten

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ABSTRACT

Offshore methane hydrates present a potentially abundant source of energy and fresh water and may open new pathways to green energy. However, there are certain novel harms and hazards present within the circumstances of developing and producing offshore methane hydrates. Both cataclysmic and non-cataclysmic hazards must be integrated into policy planning for the onset of this new energy resource.

The study proceeds in four parts. The first part of the study provides an introduction to the scientific, engineering and commercial characteristics of offshore methane hydrate projects. It also provides reviews of both the potential benefits and the potential hazards of offshore methane hydrates.

The second part of the study provides a review of the law and economics theory of accident law as applied to environmental accidents. Rules of civil liability are reviewed to determine when strict liability or negligence might be efficiently employed in risk governance. Further, similar reviews are developed for public and private regulation. A scientific review of the circumstances of offshore methane hydrates finds that the optimal set of rules is a combination of a strict liability paradigm in complementary implementation of public regulations.

The third part examines existing laws and conventions to determine which might be applicable to offshore methane hydrates. The study also reviews if their risk governance strategies are in accordance with the recommendations from the second part of the study. It is found that most of the evaluated laws do follow a similar risk governance strategy of strict liability accompanied by public regulation, but that many of the current laws to address offshore oil and gas hazards would not interface with the particular circumstances of methane hydrates.

In the fourth part of the study, a summary of the three previous parts is presented and recommendations are made as how to update the existing legal frameworks to accommodate the onset of offshore methane hydrate development and production.

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DEDICATION

This dissertation would not be possible, nor would it hold meaning, without the loving support of my Bokhee Kang and of my Benjamin Kang Partain.

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R. A. Partain

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vi. Outer Continental Shelf Lands Act (OCSLA)
vii. Methane Hydrate Research And Development Act (MHRDA)
viii. International Convention Relating To Intervention On The High Seas In Cases Of Oil Pollution Casualties

LIST OF ABBREVIATIONS

$	When otherwise not clarified, one U.S. dollar
AIST	Japan's National Institute of Advanced Industrial Science and Technology
ASEAN	Association of South East Asian Nations
B.C.E.	Before common era; Before Christ
BHP	Benthic Hazard Planning
BP	formerly British Petroleum, now just BP
btu	British Thermal Unit
C	Celsius degrees, when not in the form C_n
C_n	An alkane; *e.gs*. C_1 is methane and C_4 is butane
CAA	Clean Air Act
CCS	Carbon capture systems/sequestration
CDM	Clean Development Mechanism
CH_4	Methane
CLC	Civil Liability Convention of 1992
CO_2	Carbon dioxide
CLC	Civil Liability Convention of 1969
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CRISTAL	Contract Regarding an Interim Supplement to Tanker Liability for Oil Pollution
CWA	Clean Water Act
DARPA	The U.S.'s Defense Advanced Research Projects Agency
DOE	U.S. Department of Energy
EC	European Community
ECO_2	A proper name for an EU project to study offshore CCS injection
EEZ	Exclusive Economic Zone, from UNCLOS
EHR	Enhanced Hydrocarbon Recovery
EIA	Environmental Impact Assessment
EIA	The DOE's Energy Information Administration
ELD	Environmental Liability Directive of the EU
EMSA	European Maritime Safety Agency
ENAA	Japan's Engineering Advancement Association of Japan
EU	European Union
FID	Financial Investment Decision
GHDO	Korea's Gas Hydrate Research and Development Organization
GHG	Greenhouse gas, as defined under the Kyoto Protocol
GTL	Gas-to-Liquids technology
GTS	Gas-to-Solids technology

GWP	Global warming potential
H_2O	Water
H_2SO_4	Hydrogen sulfide
HSZ	Hydrate stability zone
IRCGH	The Indo-Russian Center for Gas Hydrates
ISA	International Seabed Authority
JMHEP	Japan Methane Hydrate Exploitation Program
JOGMEC	Japan's Oil, Gas and Metals National Corporation
KIGAM	Korea Institute of Geosciences and Mineral Resources
kJ	kilo-joule
KNOC	Korea National Oil Company
LNG	Liquified Natural Gas
LSHP	Littoral Surface Hazard Planning
m^3	cubic meter, a volumetric reference
MARPOL	International Convention for the Prevention of Pollution from Ships, from the concept of marine pollution
Mcf	Million cubic feet
MH21	Japanese Research Consortium for Methane Hydrate Resources in Japan
MHHP	Methane Hydrate Hazard Planning
MMBtu	Million British Thermal Units
MOCIE	Korea's Ministry of Commerce, Industry, and Energy
NEPA	The U.S.'s National Environmental Protection Act
NGHP	India's National Gas Hydrate Program
NGL	Natural gas liquids, such as propane and butane
OCSLA	Outer Continental Shelf Lands Act
OPA	The U.S.'s Oil Pollution Act
OPRC	1990 International Convention on Oil Pollution Preparedness, Response and Co-operation
OSPAR	The Convention for the Protection of the marine Environment of the North-East Atlantic (the 'OSPAR Convention')
psia	Pounds per square inch absolute
RCRA	Resource Conservation and Recovery Act
SEA	Strategic Environment Assessment
sH	The most complex hydrate lattice
sI	The simple form of a methane hydrate lattice
sII	A methane hydrate lattice that can hold NGLs
SLP model	Shavell Landes Posner economic model of Tort Law
SUGAR	Submarine Gashydratlagerst_tten: Erkundung, Abbau und Transport
Tcf	Trillion cubic feet
Tcm	Trillion cubic meters
TOVALOP	Tanker Owners Voluntary Agreement Concerning Liability for Oil Pollution
UNCED	United Nations Conference on Environment and Development (1992)

UNCLOS	United Nations Convention on the Law of the Seas
UNFCCC	United Nation's Framework Convention on Climate Change
U.K.	The United Kingdom
U.S.A.	United States of America
USD	United States dollar
USGS	United States Geological Service
VAT	Value added tax
WFD	Water Framework Directive of the EU

Part I

Offshore Methane Hydrates

Chapter 1

INTRODUCTION

> "the economically viable production of gas from hydrates is not a "gold-in-the-ocean" scenario – that is, the prospect of gas hydrates contributing to the world's energy portfolio is not an unreasonable scenario."[1]

1. The dawn of methane hydrates as an energy source

Methane hydrates are a potential source of large amounts of methane that have previously gone undeveloped primarily because of technological shortfalls. However, progress has been made in the last several decades; the successful testing of continuously producing offshore wells was first accomplished in 2013. Given that the basic extraction technologies are now in place, focus in research has shifted to cost reductions and commercial feasibility. Reasonable estimates suggest that offshore methane hydrate installations may be operational in some locations by the year 2020.[2] The commercial development of methane hydrate extraction projects may soon begin.

The benefits of methane hydrate development are particularly of interest to those countries without domestic energy supplies; the development of methane hydrates takes on a strategic role in those cases and might not be as dependent on cost reductions and market forces. The potential benefits of methane hydrates include:

- Methane hydrates are estimated to present at least double the resource base of traditional hydrocarbons.[3]

1 M. R. Walsh et al., *Preliminary Report on the Commercial Viability of Gas Production from Natural Gas Hydrates*, 31 Energy Econ. 815, 815-823 (2009).

2 *See* discussions on the emerging engineering know-how and expected feasibility of offshore methane hydrates in ch. 3.

3 *See* ch. 2, sec. 3.

- Methane hydrates are found in many geographical locations otherwise lacking substantial energy reserves.[4]
- Methane hydrates produce methane, which is often targeted as bridge to more green energy technologies.[5]
- Methane hydrates co-produce fresh water and methane, the two ingredients required for producing hydrogen fuel. [6]
- Fresh water is co-produced alongside the extracted methane; for many coastal communities that water is much needed.[7]
- The extraction of methane hydrates enables the sequestration of carbon dioxide to replace the missing methane molecules; this process can be a form of carbon capture and sequestration (CCS).[8]

Methane hydrates lay off of almost every coast in the world. Reservoirs of methane hydrates are located in many offshore locations around the world, more broadly than conventional oil and gas assets.[9]

These locations represent the potential to reduce the geo-political stress on energy supplies, especially for those countries remote from local energy reserves such as those in East Asia. Stability and surety of delivery will affect the market to reduce energy prices for those countries. Even if methane hydrates are more expensive to develop than conventional natural gas,[10] what might not be economic in the U.S.A. may well be commercially attractive in Japan.[11]

Methane hydrates also present a 'greener' option for fuel; the combustion of methane emits less carbon dioxide than coal and crude oil, and it emits far fewer other hazardous or undesirable substances.[12] Natural gas is a desirable fuel source to replace the dangers, both climatic and health, of coal and crude oil.

4 *See id.*, sec. 5.

5 *See id.*, sec. 2. *See also* the discussion on the role of methane hydrate production to impact on climate change risks, *infra*, at Appendix III.

6 *See id.*. *See also* ch. 3, sec. 5.2.

7 *See id.*, sec. 5.3.

8 *See id.*, sec. 5.1.

9 *See* ch. 2, sec. 5.

10 Early estimates suggest that currently methane hydrates may be 15% to 20% more costly to produce than conventional natural gas fields, but those costs differentials are decreasing. *See* ch. 3, sec. 2.1.

11 Thus, one must be considerate of more than one economic market when considering the potential development of offshore methane hydrates. The price of natural gas is not evenly distributed as a global commodity, unlike oil. *E.g.*, in the last five years, the U.S. has faced domestic natural gas prices under $5 MMBtu, but Japan has faced LNG price floors of $8 MMBtu since before 2007 and since 2011 that price floor has increased to $14 MMBtu. *See* the World LNG Report - 2013 Edition. International Gas Union. Office of the Secretary General. Fornebu, Norway. 2013, p. 14. *Available* at www.igu.org/gas-knowhow/.../igu.../IGU_world_LNG_report_2013.pdf . *See also* Global natural gas prices vary considerably. U.S. Energy Information Agency. *Available* at http://www.eia.gov/todayinenergy/detail.cfm?id=3310 .

12 *See* ch. 3, sec. 1. *See also* the discussion on the role of methane hydrate production to impact on climate change risks, *infra*, at Appendix III.

Thus it should come as no surprise that the governments of Japan, Korea, and China have targeted the commercial development of methane hydrates as national goals to help displace dirty coal and crude oil and to better secure domestic energy supplies; currently Japan and South Korea import over 98% of their energy supplies.[13] These countries see the development of methane hydrates as solution sets to questions of energy supply, fiscal revenue sourcing, and means of air pollution abatement.

For example, Japan relies heavily on natural gas imports. Japan consumes approximately 0.125 Tcm of natural gas annually; almost all of those natural gas volumes were delivered by importing LNG.[14] Japan's geophysical surveys forecast that Japan's offshore Nankai Trough might contain 50.4 Tcm of methane.[15] If Japan consumed that offshore supply of methane hydrates at its current rate of 1/8th Tcm per year, then Japan might possess a domestic multi-century supply of natural gas.[16] Thus, development of the methane hydrate reserves in the Nankai Trough could substantially improve Japan's national energy security and potentially enable its economic expansion.

So, one might reasonably ask, why are methane hydrate resources not already developed and integrated into the broader energy markets? While crude oil and conventional natural gas have been exploited since the 1800s, both the natural abundance of methane hydrates and their potential as an energy resource were only discovered in recent decades.[17] Thus, the whole potential of methane hydrates is novel; but governments and industry are responding quickly.[18] Because the extraction of offshore methane hydrates is very different from methods used for traditional crude oil and natural gas,[19] there were technological challenges that needed to be overcome. However, as the offshore tests of 2013 indicated, these technological challenges are falling rapidly to the wayside.[20] So, methane hydrates were undiscovered, then new but very challenging, and now are almost commercially viable as an energy resource.

13 Y. F. Makogon, S. A. Holditch & T. Y.Makogon, Natural Gas-Hydrates—A Potential Energy Source for the 21st Century, 56 J. Petroleum Sci. & Engineering 14, 15 (2007).

14 Original citation was to 4,387.5 billion cubic feet of natural gas. *See* Japan: Country Analysis. U.S. Energy Information Agency. *Available* at http://www.eia.gov/countries/country-data.cfm?fips=JA||http://www.eia.gov/countries/country-data.cfm?fips=JA .

15 *See* ch. 2, sec. 5, *see also* ch. 3, sec. 4.1.

16 J. Marcelle-De Silva & R. Dawe, Towards Commercial Gas Production from Hydrate Deposits, 4 Energies 215, 223 (2011). The original reference was to 1,800 Tcf, which equates to 50.4 Tcm. That is the energy equivalent of 332.6 billion barrels of oil; contrast that with the estimated oil reserves of Saudi Arabia which are reported by the U.S. Energy Information Administration as 265 billion barrels of oil. *See* EIA Country Analysis Brief: Saudi Arabia. *Available* at http://www.eia.gov/countries/cab.cfm?fips=SA .

17 *See* ch. 2, sec. 1.

18 *See* ch. 3, sec. 4.

19 *See id.*, sec. 3.

20 *See id.*

However, there are substantial environmental and safety risks associated with the development and extraction of offshore methane hydrates.[21] In the less dramatic scenarios, seabed disruptions could result in persistent venting or seeping of methane into the ocean. Such leakages of methane from the hydrate deposit layers cold cause a variety of environmental damages and nuisance damages to both the marine biota and to human communities living nearby.

In more dramatic scenarios, destabilized methane hydrate deposits could shear and cleave off in large cross sections, sending hydrates and sediments sliding across the ocean floor. This type of event could result in subsea landslides, earthquakes, or tsunamis. The damage and injuries from such events could be spread for hundreds of kilometers in radius. Also, should there be an energetic venting of methane, under either type of accident, the methane could reach the atmosphere and burn; one observed event saw flames hundreds of meters high jetting above the ocean's surface.[22] Thus, for all of the potential benefits of offshore methane hydrates, there are substantial risks and hazards to contemplate. For potential entrepreneurs and operators of offshore methane hydrates, there is a present lack of legal certainty to underlay their decision-making and investment decisions.[23]

Ergo, there are legal challenges to address such as the proper provision of risk governance mechanisms for the novel risks and hazards poised by the operation of offshore methane hydrate projects. This study attempts to address some of these concerns. This study primarily focuses on the potential to develop optimal risk governance mechanisms for the risks and hazards from the development of offshore methane hydrate projects. The instruments of civil liability rules, public regulation, and private regulations are examined for their capacity to efficiently set the optimal standards for the development of offshore methane hydrates.

2. Major actors in offshore methane hydrates

The major actors in the international development of methane hydrates are a mixture of technological innovators, resources owners and impacted communities. Additionally, due to the anthropogenic climate change risk posed by released methane and carbon dioxide, the broader global community is affected by the potential hazards.

Most of the technology owners are centralized within a distinct group of nations with substantial national government commitments to the development of the commercial feasibility of methane hydrates. The leading national investors in

21 *See* the discussion on the role of methane hydrate production to impact on climate change risks, *infra*, at Appendix III.

22 See ch. 4, sec. 3.1.

23 "Uncertainty is of course an inherent part of entrepreneurial activity and as such not a bad thing." However, even risk takers have need of legal certainty and have the right to certainty as regards to the legal consequences of those risky activities. Similarly, such actors have expectations of non-retroactivity, the protection of acquired rights (such as licenses), and of legitimate expectations. M. Peeters, & S. Weishaar, *Exploring Uncertainties in the EU ETS: Learning by Doing Continues beyond 2012*, 3 Carbon & Climate L. Rev. 88, at Sec. 1.2. (2009).

methane hydrate technology, as far as can be determined with public documents, are eight countries: Canada, China, India, Japan, Norway, Russia, South Korea, and the United States. The United Kingdom does have some alignment through BP's and Royal Dutch Shell's research activities, but to a lesser extent than one might otherwise expect. Outside of the major Anglo-American oil companies, the overlap of national oil companies and national security interests often results in deeply coordinated behaviors; in the case of companies fully owned by their respective national governments the alignment is so seamless as to suggest that the corporate investment is more properly characterized as governmental investment. This is not to suggest that other countries do not have strategic interests and investments in methane hydrates, but in addition to pure national budgetary support, the publicly available data strongly suggest that the researchers from these countries both publish more often and appear to have more research missions and experimental projects to achieve those goals.

The resource owner list is extensive, and perhaps best described with visual maps.[24] Almost every coastal state and every single arctic state has methane hydrate assets. Practically every coastal member of the European Union is likely to have methane hydrates within their EEZ. Almost the whole eastern and western coastlines of North America have significant methane hydrate deposits. The Caribbean has multiple locations, as does the general Gulf of Mexico.

The list of impacted countries is functionally the same list, plus the few neighboring coastal countries without hydrates. The impacted communities, on the other hand, will primarily be the coastal communities of those resource-owning countries. Those coastal communities will sometimes align with the financial and governmental centers of activities but sometimes they will be functionally distant from central decisions makers.

Many of the categories can overlap, as in Japan. First, as a technology owner, the Japanese government has identified national and industrial security issues in sustainable and locally sourced energy supplies. Japanese corporations have joined with governmental and academic researchers to develop the technologies necessary for the onset of commercial methane hydrate operations.

Second, as a resource owner, once the commercial operations begin, revenues from the sale of the methane will broadly impact both the corporate sector and governmental fiscal abilities. Japanese corporations will enjoy smoother and likely cheaper natural gas cost structures for their industrial needs. The Japanese government should expect to earn royalties and production/severance taxes from the operators; plus whatever income tax and VAT-type taxes may incrementally fall from the new industrial arrangements. Even local communities that provide infrastructural support to the new industrial operations stand to share in revenues, much as Houston or Aberdeen does today, even without revenue sharing arrangements.

Third, as an impacted community, the coastal communities of Japan face potential direct impacts from the environmental hazards posed by commercial

[24] *See* detailed list, *infra*, at ch. 2, sec. 5, and *see* maps in the Appendix I.

methane hydrate operations. The rest of Japan could be indirectly impacted as marine food-stocks become impacted and if tsunami or earthquake events cause industrial slowdowns, as was seen in the Fukushima experience. An identical tale could be told of countries like the United States or Norway.

3. Goals of this study and the research question

The commercial development of offshore methane hydrates promises both great opportunities and dangerous challenges.

This study proposes to focus on offshore methane hydrates because they are likely to come into production prior to onshore supplies, because the global availability of offshore methane hydrates is much greater than onshore, and ultimately, because the known risks of onshore methane hydrates are generally considered more safe than offshore development of methane hydrates.[25]

The potential upside includes abundant energy supplies, a global diversification of energy sources, potential freshwater supplies, potential sequestration of greenhouse gases, and sustainable revenues for many developing nations. The risks include increased greenhouse gas emissions, large-scale combustion events, offshore landslides that could result in tsunamis or earthquakes, and general nuisance to coastal communities. The regulatory and societal challenge is to find an efficient means of balancing those risk and rewards so that communities can rationally chose optimal levels of commercial development of methane hydrates.

The primary research question of this study is how to best facilitate optimal levels of safety in the operations of offshore methane hydrate installations or projects; which legal mechanisms would provide the optimal set of incentives: a civil liability rule of negligence, a civil liability rule of strict liability, public regulations, or private regulations?[26] Are there reasons that complementary implementations of more than one of the potential mechanisms could be preferable to the singular implementation of just one of the mechanisms? And finally, if a set of mechanisms could be chosen, how might the policy maker best develop the necessary mechanisms, given the existing state of laws and conventions?

25 Onshore methane hydrates are found in Arctic permafrost locations. They provide no known risks of tsunamis or earthquakes. They might suffer from similar reservoir disturbances as offshore methane hydrates, *see* ch. 4, that could lead to venting or seepage of methane, but their onshore presence facilitates on-going surveillance and monitoring. Further, once discovered, onshore instability zones could be more readily assessed for damage and potentially remedied. Onshore methane hydrates are also limited to a small number of Arctic countries, primarily Russia, Canada, and the U.S.

26 Following Shavell description for unilateral accidents, optimal social welfare is the balancing of the various marginal costs and benefits to maximize social welfare. "For social welfare to be maximized, an injurer must … choose a level of care that is commensurate with the effect of care in reducing accident losses and with its costs. … the injurer should also select his level of activity appropriately … at the level that appropriately balances the utility he obtains against the additional risks he creates and the costs of care." S. SHAVELL, FOUNDATIONS OF ECONOMIC ANALYSIS, 194 (Belknap Press of Harvard University Press, Cambridge, MA, 2004)

4. Structure of study

This study will proceed in four stages.

In Part I, the study will present an exploration of the science, benefits, and hazards of offshore methane hydrates. A thorough review of the chemistry and physics of methane hydrates is presented. The abundance of methane hydrates will also be discussed. Their abundance as a mineral will be explored as well as their geological and geographical distribution will be presented. Then, the art of extracting and producing offshore methane hydrates will be explored. Thereafter a presentation will be made on the potential harms and hazards that can result from the development of offshore methane hydrates. There are both cataclysmic hazards and non-cataclysmic hazards present with the operation of offshore methane hydrate projects; both types of risk are discussed in depth.

In Part II, a review of theoretical models from Law & Economics is provided to demonstrate the progress made by researchers to broaden and strengthen the utility of their models of accident law and tort law. In particular, a review of the rules of civil liability is made in depth; under which circumstances would strict liability be efficient and under what circumstances would a rule of negligence be efficient. Thereafter, a study is made of public regulation and under what circumstances public regulations might be efficient. A second stage of that analysis examines when public regulations might be operated in complementary implementation to rules of civil liability. Finally, a study of which rules of governance might be best applied to the particular circumstances of offshore methane hydrates is developed. It is found that a rule of strict liability implemented complementarily with public regulations would provide the optimal mix of risk governance for offshore methane hydrates.

In Part III, the study will review existing laws and conventions to determine (i) if those rules would be applicable to offshore methane hydrate project and (ii) if those rules apply the same types of risk governance as suggested in Part II. Four categories of laws and conventions will be examined: (i) UN conventions, (ii) international or regional conventions to protect marine environments, (iii) EU laws, and (iv) federal laws of the U.S.

In Part IV the study will review the discoveries of the first three parts and provide analysis of how to potentially address the gaps between the theoretical models developed in the second part and the existing laws and conventions as discussed in the third part. It will be shown that generally speaking most of the examined existing laws and conventions would offer similar risk governance strategies to those recommended in this study but that those rules rarely match the particular circumstances of offshore methane hydrates. It will be suggested that the existing laws and conventions could be revised or extended to better support the optimal risk governance of offshore methane hydrates. Recommendations on how to best make those changes to the laws are presented in the final chapter. It is advised that the most efficient way to update the laws is to amend those laws already in place and in effect.

A collection of appendices is also provided within the fourth part of the study. The appendices include detailed maps of offshore methane hydrates, notes on the mathematics of the law and economics models presented, and a listing of the references utilized in assembling this study.

The appendices also include an essay on the potential impact on anthropogenic climate change from the development of offshore methane hydrates.

Chapter 2

PRIMER ON METHANE HYDRATES

1. Non-technical introduction to methane hydrates

Methane hydrates are a combination of fresh water and methane that form a solid in both seabeds and permafrost soils. Methane hydrates look like snow or ice, depending on one's perspective. Methane hydrates can be dug up from their deposits with a shovel or extracted from a well if induced to melt and disassociate. The hydrates are an intriguing form of ice, in that they retain their frozen structure at temperatures substantially warmer than purely aqueous ice.

Methane hydrates, as a chemical substance, have been a functional part of chemistry for over two centuries. Methane hydrates were first discovered by Humphrey Davies in 1810.[1] The science of their internal composition was first reported by Michael Faraday in 1823.[2] But it was not until 1934 that Hammerschmidt identified hydrate as the clogging agent in natural gas pipelines that methane hydrates entered into broader research awareness.[3] For their discovery as an energy resource, it was not until 1964 that the first methane hydrate gas field was discovered at Messoyakha, in Siberia.[4] The first initial offshore survey was undertaken in 1970 and the first recovery of offshore methane hydrates occurred in 1981.[5]

1 J. F. Gabitto, & C. Tsouris, *Physical Properties of Gas Hydrates: A Review*, 2010 J. Thermodynamics 1, 1 (2010); C. A. Koh, *Towards a Fundamental Understanding of Natural Gas Hydrates*, 31 Chemical Soc'y Rev. 157, 157 (2002). However, it is suspected that Priestly was the first to observe hydrates. A. Demirbas, *Methane Hydrates as Potential Energy Resource: Part 1–Importance, Resource and Recovery Facilities*, 51 Energy Conversion Mgmt. 1547, 1548 (2010).

2 Koh, *supra* at note 1, at 157; P. Englezos & J. D. Lee, *Gas Hydrates: A Cleaner Source of Energy and Opportunity for Innovative Technologies*, 22 Korean J. Chemical Engineering 671, 672 (2005).

3 Y. F. Makogon, S. A. Holditch & T. Y.Makogon, *Natural Gas-Hydrates—A Potential Energy Source for the 21st Century*, 56 J. Petroleum Sci. & Engineering 14, 16 (2007).

4 Demirbas, *supra* at note 1, at 1548. Makogon was present at Messoyakha and was rewarded for discovering the presence of methane hydrates at Messoyakha. *See* Makogon, Holditch, & Makogon, *supra* at note 3, *en passim*. Makogon was also one of the earliest to scientifically publish on the potential existence of offshore methane hydrates. *See* Makogon 1972.

5 Demirbas, *supra* at note 1, at 1548; Makogon, Holditch, & Makogon, *supra* at note 3, at 16.

Table 1: Recognition of Energy Potential of Methane Hydrates, by first year of government sponsored research and development programs

Year	Nation
1982	U.S.A.
1995	Japan
1996	India
1999	South Korea
2004	China

It was not until the 1990s that methane hydrates were broadly recognized as a potentially feasible energy source and respondent research and development programs initiated; the first international conference on methane hydrate extraction was held in 1991.[6]

The first offshore methane hydrate well was drilled in 1999.[7] The first continuously flowing methane hydrate well was tested only in 2013.[8] Thus, while hydrates are not recent discoveries, it is not until very recent times that their potential as an energy resource was identified.[9]

The development of coal bed methane production technologies took approximately three decades to progress from discovery of potential to commercial feasibility and investment; it has been suggested that the arc of development for methane hydrate production technologies will follow a similar three decade progression.[10] Similarly, due to the strategic needs of countries like Japan and South Korea to obtain local secure energy supplies, researchers in the Global Carbon Project forecast that commercial methane hydrate investments would begin by 2020 and spread to fields globally by 2030.[11] The head of methane hydrate research for the U.S. DOE stated that the production of methane from methane hydrate deposits was already technically feasible by 2005, and that the tailored application of existing off-the-shelf technologies could enable commercial feasibility in the very near term.[12]

The vast majority of hydrates are found offshore coastal shelves around the world; almost every coastal country has methane hydrate assets. Methane hydrates accumulate under mud layers in the seabed; they do not accumulate deeper in the

6 Makogon, Holditch, & Makogon, *supra* at note 3, at 16-18; J. Marcelle-De Silva & R. Dawe, *Towards Commercial Gas Production from Hydrate Deposits*, 4 Energies 215, 216 (2011). *See* Table 2.1. for data on when leading countries initiated their national research and development programs on the commercial feasibility of methane hydrates.

7 Demirbas, *supra* at note 1, at 1548; Makogon, Holditch, & Makogon, *supra* at note 3, at 16.

8 *See* discussion, *infra*, at ch. 3 on extraction technologies.

9 Demirbas, *supra* at note 1, at 1548.

10 Englezos & Lee, *supra* at note 2, at 675 and 677. The time reference is stated as 3 decades at 675 and as 20-25 years at 677.

11 V. Krey et al., *Gas Hydrates: Entrance to a Methane Age or Climate Threat?,* 4 Environmental Research Letters 34007 (2009).

12 R. Boswell, *Resource Potential of Methane Hydrate Coming into Focus*, 56 J. Petroleum Sci. Engineering 9 (2007).

earth under non-permeable rock formations. They can also be found under permafrost areas, wherein biogenic methane has combined with water to form hydrate deposits. Apart from permafrost, they are not generally found onshore but they can be found in certain *talik* lakes in Siberia.[13]

Methane hydrates are dominantly water. The water forms a cage around a single molecule of methane. The cage fits methane just so; almost no other molecule will fit. There are other forms of aqueous hydrates that can hold larger molecules but they are fairly rare in nature. So most of the time, if you find methane hydrates, you have fresh water and sweet gas, no salt and no acids.

This apparent simplicity makes methane hydrates attractive to investors for three simple reasons. Methane is an easy to use fuel that is cleaner than coal or crude oil and methane from hydrates requires almost no chemical treating due to the lack of contaminants; however, methane is commonly listed as a greenhouse gas.[14]

Extraction of methane from hydrates produces a large volume of fresh water that is needed in many locations around the world. Also, the co-production of water and methane enables the production of hydrogen,[15] which is a green fuel source as its combustion leaves only energy and water. There is an extra reason investors might like methane hydrates, it can be used to store other greenhouse gases such as carbon dioxide.[16]

Methane hydrates will disassociate and dissolve in to water and methane under certain conditions: when pressure is reduced sufficiently, when temperatures are raised sufficiently, and when certain chemical means are used to dissolve the hydrates. These technologies can be used in tandem and they can be employed in tandem with carbon sequestration technologies.

Early extraction and production testing is already underway. There are substantial reasons to believe that the technical issues of extraction and production may soon become commercially feasible.

13 *Talik* are those unique spots of ground in permafrost regions that remain unfrozen. They are often accompanied by liquid water accumulations, which result in liquid water lakes year-round.

14 The UNFCCC refers repeatedly to "greenhouse gases" and "carbon dioxide and other greenhouse gases" without explicit reference to methane. Methane is listed as one of the six enumerated greenhouse gas within Annex A of the UNFCCC's Kyoto Protocol. Decision No. 280/2004/EC of the European Parliament and of the Council of 11 February 2004 also lists methane as a greenhouse gas at Art. 3(1)(a). More details on these definitions, *infra*, at ch. 8 and 10.

15 Hydrogen can be produced by exposing methane to steam; methane hydrates would produce methane both as fuel and a feedstock as well as produce freshwater feedstocks. *See* the discussion on the potential to produce hydrogen from methane hydrate resources at ch. 3, sec. 5.2.

16 The hydrate structures can be filled with gases other than methane; carbon dioxide can replace the extracted methane volumes for sequestration purposes. *See* the discussion on the potential to sequester greenhouse gases in methane hydrate deposits at ch. 3, sec. 5.1.

2. Chemistry of methane hydrates

The literature refers to methane hydrates by several names, including natural gas hydrates, clathrates, and gas clathrates.[17] The term clathrate is used for solids that contain one kind of molecule within a crystal lattice of a different molecule.[18]

In the case of methane hydrates, the methane molecule is trapped within a water-ice framework.[19] The overall water-ice structure visually resembles white snow; the methane does not impact the overall appearance of the methane hydrate structure.[20]

Methane hydrates are crystalline solids composed primarily of methane and water.[21] There is some debate if the methane hydrates should be considered crystalline or as a form of thermal glass.[22]

They form as methane is emitted from within the earth but retarded in its seepage by overlaying mud layers in a watery environment.[23] This contact of methane to water under correct pressures and temperatures enables the formation of methane hydrates under that mud layer.[24]

The primary hypothesis is that most of the methane was biogenically created before it accumulated in the methane hydrate deposits.[25] A process of methanogenesis is believed to have been utilized by anaerobic bacteria living below the mud line under the seawaters;[26] the produced methane is a result of the bacterial methogens consuming decayed plant and animal matter in anaerobic conditions.[27] Other by-products of the methanogenesis are carbon dioxide, propane, ethane, and

17 R. A. Dawe & S. Thomas, *A Large Potential Methane Source—Natural Gas Hydrates*, 29 Energy Sources 217, 218 (2007).; Demirbas, *supra* at note 1, at 1550; Z. G. Zhang, et al., *Marine gas hydrates: Future Energy or Environmental Killer?*, 16 Energy Procedia 933, 933 (2012). Natural gas can sometimes include natural gas liquids, common understood to include ethane, propane, butane, pentane, and natural gasoline, so the term natural gas hydrates could suggest a variety of hydrates; for this study the term methane hydrate will be strictly used to indicate those hydrates rich in methane to the exclusion of other hydrocarbons.

18 Dawe & Thomas, *supra* at note 17. Clathrate is derived from the Greek word *khlatron*, which means 'barrier'. *See* I. Chatti *et al*., *Benefits and Drawbacks of Clathrate Hydrates: A Review of Their Areas of Interest*, 46 Energy Conversion Mgmt. 1333 (2005).

19 Dawe & Thomas, *supra* at note 17, at 218. Kurihara refers to hydrates as "in the solid state and hence does not have a flowability." *See* M. Kurihara, M et al., *Gas Production from Methane Hydrate Reservoirs*, *in*: Proceedings of the 7th International Conference on Gas Hydrates (2011).

20 Dawe & Thomas, *supra* at note 17, at 218; Demirbas, *supra* at note 1, at 1550.

21 Dawe & Thomas, *supra* at note 17, at 218; Koh, *supra* at note 1, at 157; G. J. Moridis et al., *Toward Production from Gas Hydrates: Current Status, Assessment Of Resources, and Simulation-Based Evaluation of Technology and Potential*, 12 SPE Reservoir Evaluation & Engineering 745, 1 (2009); Demirbas, *supra* at note 1, at 1550.

22 Gabitto & Tsouris, *supra* at note 1, at 4; A. I. Krivchikov et al., *Thermal Conductivity of Methane-Hydrate*, 139 J. Low Temperature Physics 693, 6-7 (2005).

23 Makogon, Holditch, & Makogon, *supra* at note 3, at 19; Demirbas, *supra* at note 1, at 1548-1549.

24 *Id.*; *id.*

25 Dawe & Thomas, *supra* at note 17, at 219; Koh, *supra* at note 1, at 160; Demirbas, *supra* at note 1, at 1548-49.

26 *Id.*, at 219; *id.*, at 160; *id.*, at 1548-49.

27 Dawe & Thomas, *supra* at note 17, at 219; Demirbas, *supra* at note 1, at 1548-49.

hydrogen sulfide.[28] It is understood that even trace amounts of oxygen are sufficient to kill the methanogenic bacteria.[29] There is evidence of abiogenically sourced methane in some methane hydrate deposits.[30] Thermogenic natural gas is the result of heavier kerogens and oils cooking deeper in the earth followed by the outward migration of the natural gas until it reaches the methane hydrate deposits.[31]

Ice is constructed when water stabilizes into a framework. In the case of methane hydrates, the water forms polyhedral lattices that are stabilized by the inclusion of methane or other molecules.[32] The hydrates do not need to be full in the sense that each cage needs to have a guest molecule; hydrates are stable with less than full cage occupancy.[33]

Methane hydrates carry the general chemical form of $M_n(H_2O)_p$, wherein M represents the inner molecule around which the water lattice forms.[34] The cages themselves can be characterized as X^n, *e.g.* $X^n = 5^{12}$ denotes a twelve-sided dodecahedral cage composed of 5-sided pentagons.[35] The interaction between the methane (guest) and water (host) molecules is mediated by weak Van der Waals forces.[36]

Methane hydrate deposits present a dense form of methane. In terms of energy content, methane hydrates as fully occupied hydrates contain 184,000 btu per cubic foot, in-between conventional natural gas at 1,150 btu per cubic foot and liquefied natural gas (LNG) at 430,000 btu per cubic foot.[37] The disassociation of 1 m^3 of methane hydrates produces 170 m^3 of methane at standard temperature and pressure.[38] In addition, 0.85 m^3 of water is released from the same cubic meter.[39] It has been suggested that methane hydrates present 2 to 5 times greater energy

28 *Id.*, at 219; *id.*, at 1548-49.
29 *Id.*, at 219; *id.*, at 1548-49.
30 *Id.*, at 219; *id.*, at 1548-49.
31 *Id.*, at 219; *id.*, at 1548-49.
32 Englezos & Lee, *supra* at note 2, at 672; Koh, *supra* at note 1, at 157.
33 Gabitto & Tsouris, *supra* at note 1, at 2. Laboratory-created hydrates have been stabilized at 90% occupancy. Koh, *supra* at note 1, at 157.
34 S. Y. Lee & G. D. Holder, *Methane Hydrates Potential as a Future Energy Source*, 71 Fuel Processing Technology 181, 181 (2001); Marcelle-De Silva & Dawe, *supra* at note 6, at 216-217.
35 Koh, *supra* at note 1, at 157-158.
36 Englezos & Lee, *supra* at note 2, at 672; Koh, *supra* at note 1, at 161. Van der Waal forces were defined more as a catch-all term to exclude certain other bonding interactions; Van der Waal forces are not covalent bonds, hydrogen bonds, nor electrostatic bonds between ions. Van der Waal forces are generally defined as a collection of positive and negative forces acting in-between molecules, *e.g.*, Keesom electrostatic forces are one such group of forces. Van der Waal forces are also anisotropic which means that the physical orientation of the molecules to each other affects the potential bonding results.
37 Marcelle-De Silva & Dawe, *supra* at note 6, at 217. In more general terms, *see* Englezos & Lee 2005, p. 673; Demirbas, *supra* at note 1, at 1548.
38 Englezos & Lee, *supra* at note 2, at 673. *See also* Koh, *supra* at note 1, at 160, wherein Koh provides a slightly different presentation of similar data. She compares 90% occupied methane hydrates as equivalent to 156 m^3 of methane under standard conditions.
39 Englezos & Lee, *supra* at note 2, at 673; Demirbas, *supra* at note 1, at 1548.

density than traditional gas reservoirs and 10 times greater density than coal bed methane reservoirs.[40]

The clathrate-nature of methane hydrates requires the inner-molecule to fit within the lattice structure, so hydrates can be formed with methane, ethane, propane, and i-butane but not with n-butane.[41] This is important because it narrows what might be produced from those hydrates; the hydrate lattice acts as a sort of selective filter to prevent various impurities from contaminating the energy resources.

The ice-water lattice itself is commonly found in three forms, called types sI, sII, and sIII or sH.[42] These structures are differentiated by both the number of ice cages to hold trapped molecules and by the sizes of those cages.[43] Types sI provides the smallest cages, capable of holding methane and little else, whereas Type sIII or sH offers the largest cages potentially capable of holding smaller hydrocarbon chains from crude oil.[44] There are other forms, *e.g.* sT, but they are laboratory discoveries not routinely seen in nature.[45]

Types sI and sII were first identified by Von Stackelberg in the late 1940s and early 1950s.[46] Type sH was discovered in the mid-1980s.[47] Type sI and sII are cubic in shape, whereas sIII or H is hexagonal.[48]

Type sI is the form most commonly referenced by the label 'methane hydrate.'[49] Type sI is the most prevalent form of methane hydrate found in nature; it is 99% of the methane hydrates detected offshore.[50] Type sI is composed of 48 water molecules forming into 8 cavities that can each hold one guest gas molecule.[51] Type sI can hold methane, ethane, or carbon dioxide as guest gases.[52] The ratio of guest molecule size to host cell size needs to be precise, at approximately 90% of the cell size.[53] This tight fit for sI and sII is why methane hydrates produce methane cleanly with so few by-products, other than water.[54]

40 Englezos & Lee, *supra* at note 2, at 674; Demirbas, *supra* at note 1, at 1550; Zhang *et al.*, *supra* at note 17, at 934.

41 Dawe & Thomas, *supra* at note 17, at 218; Demirbas, *supra* at note 1, at 1551.

42 Dawe & Thomas, *supra* at note 17, at 218; Koh, *supra* at note 1, at 157; Demirbas, *supra* at note 1, at 1551.

43 Koh, *supra* at note 1, at 157; Demirbas, *supra* at note 1, at 1551.

44 Koh, *supra* at note 1, at 157-159. With specific reference to iso-pentane, *see* Demirbas, *supra* at note 1, at 217. Pentane is larger than butane or propane.

45 Koh, *supra* at note 1, at 159; Englezos & Lee, *supra* at note 2, at 672.

46 Gabitto & Tsouris, *supra* at note 1, at 2; Koh, *supra* at note 1, at 158-159.

47 *Id.*; *id.*, at 159.

48 Englezos & Lee, *supra* at note 2, at 672; Demirbas, *supra* at note 1, at 1551.

49 Dawe & Thomas, *supra* at note 17, at 218; Koh, *supra* at note 1, at 159; Moridis *et al.*, *supra* at note 21, at 1.

50 Marcelle-De Silva & Dawe, *supra* at note 6, at 217.

51 Dawe & Thomas, *supra* at note 17, at 218; Englezos & Lee, *supra* at note 2, at 672.

52 Englezos & Lee, *supra* at note 2, at 672; Demirbas, *supra* at note 1, at 1551.

53 Gabitto & Tsouris, *supra* at note 1, at 3; Demirbas, *supra* at note 1, at 1551. sI can accommodate molecules up to 5.8Å in diameter and sII can accommodate up to 6.9Å in diameter.

54 Gabitto & Tsouris, *supra* at note 1, at 3; Demirbas, *supra* at note 1, at 1551; Zhang *et al.* , *supra* at note 17, at 934.

Type sII is composed of 136 water molecules forming into 24 cavities that can each hold one guest gas molecule.[55] Type sII can contain larger gas molecules and is found to hold propane, argon, krypton, hydrogen sulfide (H_2SO_4), oxygen (O_2), nitrogen (N_2), and i-butane.[56] Type sII is the form of hydrates commonly found in natural gas pipelines as a clogging agent.[57] sII hydrates will form in pipelines when sufficient humidity is present in the pipe and the overall temperature falls within 'room temperature' range.

Type sH is composed of 34 water molecules forming into 3 small cavities, 2 medium cavities, and 1 large cavity for a total of 6 cavities.[58] Due to its large size, over 24 different guest molecules are known to fit in the large cavity.[59].

All three major types, sI, sII, and sH, if fully loaded with methane guest molecules will present their mass as 85% water and 15% methane.[60] However, the overall density of methane hydrates of all three types is statistically the same as regular water ice.[61]

3. Scale of the resource

There are only two sure things known about the global volumes of methane hydrates: there are a lot of methane hydrates and there is a lot of uncertainty about exactly how much; most researchers simply state that the energy stored in methane hydrates is at least as much as double the world's conventional fossil fuels.[62] Estimates range tremendously, lower estimates are several magnitudes smaller than the larger estimates.

There are substantial technical problems in determining the overall resource base. Similar problems exist within traditional oil and gas reservoir

55 Dawe & Thomas, *supra* at note 17, at 218. *Also see* Englezos & Lee, supra at note 2, at 672.
56 Dawe & Thomas, *supra* at note 17, at 218; Koh, *supra* at note 1, at 159.
57 Dawe & Thomas, *supra* at note 17, at 218.
58 Englezos & Lee, *supra* at note 2, at 672; Demirbas, *supra* at note 1, at 1551.
59 Englezos & Lee, *supra* at note 2, at 672.
60 Gabitto & Tsouris, *supra* at note 1, at 2. Makogon places the ratio as 80/20. *See* Makogon, Holditch, & Makogon, *supra* at note 3, at 18.
61 Gabitto & Tsouris, *supra* at note 1, at 3; Demirbas, *supra* at note 1, at 1550.
62 *See* Gabitto & Tsouris, *supra* at note 1, at 1; Moridis *et al.*, *supra* at note 21, at 2; Zhang *et al.* , *supra* at note 17, at 934.

measurements,[63] but the science of methane hydrates is comparatively less developed and the resource itself presents itself less simply in its reservoirs.[64]

The BP Statistical Review of World Energy estimates the current world supply of proved reserves of natural gas, i.e. traditionally supplied methane, at 187.3 Tcm, or 6614.1 Tcf,[65] by the end of 2012.[66] Another current estimate for global (conventional) natural gas supplies places their volumes at 150 Tcm.[67] Englezos and Lee's research suggests a comparable number for traditional natural gas reservoirs at 370 Tcm.[68] At current levels of global production and consumption, this data forecasts 50 plus years of supply from traditional natural gas, *ceteris paribus*.[69] These estimates of global supplies of traditional natural gas provide a baseline against which to measure methane hydrate estimates.

63 While some standardization exists (generally listed as four tiers of reserve certainty, from least certain to most: undiscovered (prospective resources), discovered unrecoverable, discovered sub-commercial (contingent resources) and discovered commercial (reserves)), there remains tremendous variance in both linguistic terminology and terms of probabilistic certainty. Generally speaking, reserves-quality reservoirs are commercially feasible in the present whereas other certainty levels need improvements in technology or increases in market prices to become commercially producible. *See* J. ETHERINGTON, T. POLLEN & L. ZUCCOLO, MAPPING SUBCOMMITTEE, COMPARISON OF SELECTED RESERVES AND RESOURCE CLASSIFICATIONS AND ASSOCIATED DEFINITIONS, (Final Report. December, 2005); *available* athttp://www.spe.org/industry/docs/OGR_Mapping.pdf.

64 Dawe & Thomas, *supra* at note 17, at 221; Moridis *et al.*, *supra* at note 21, at 1-2.

65 Much of the oil and gas industry utilizes Imperial Units instead of metric measures.

1. 1 m^3 of natural gas is generally deemed equivalent to 35 ft^3 for commercial exchanges. *See* Dawe & Thomas, *supra* at note 17, at 221.
2. The BP Statistical Reviews lists the exchange ratio as 1 m^3:35.3 ft^3. *Appendices: Approximate Conversion Factors* in: BP STATISTICAL REVIEW OF WORLD ENERGY JUNE 2013, 44. *Available* at http://www.bp.com/content/dam/bp/pdf/statistical-review/statistical_review_of_world_energy_2013.pdf.

66 *Natural Gas: Proved Reserves*, in: BP STATISTICAL REVIEW OF WORLD ENERGY JUNE 2013, 22. *Available* at http://www.bp.com/content/dam/bp/pdf/statistical-review/statistical_review_of_world_energy_2013.pdf.

67 Moridis *et al.*, *supra* at note 21, at 3.

68 Englezos & Lee, *supra* at note 2, at 674.

69 *Natural Gas: Proved Reserves*, in: BP STATISTICAL REVIEW OF WORLD ENERGY JUNE 2013, *supra* at note 66, at 22. Note the reserves to production ratios. *Also*, these numbers can be contrasted against the annual energy demand budget for the U.S.A., which is 1 Tcm annually. *See* Moridis *et al.*, *supra* at note 21, at 3.

Table 2: Comparative Estimates for Global Methane Hydrates

Scientist(s)	Tcm	Energy Source
BP Statistics	187	Natural Gas
Englezos and Lee	370	Natural Gas
Walsh - Low	2,800	Methane Hydrates
Chatti - Low	3,100	Methane Hydrates
Demirbas[70]	7,104	Methane Hydrates
Collett[71]	9,000	Methane Hydrates
Englezos and Lee - Low	10,000	Methane Hydrates
Englezos and Lee	20,500	Methane Hydrates
Kvenholden and MacDonald[72]	21,000	Methane Hydrates
U.S. Methane Hydrate R&D Act[73]	24,000	Methane Hydrates
Englezos and Lee - High	40,000	Methane Hydrates
Klauda Sandler[74]	120,000	Methane Hydrates
Walsh - High	2,800,000	Methane Hydrates
Chatti - High	7,600,000	Methane Hydrates

Walsh estimated the volume of global methane hydrates at between 100,000 Tcf and 100,000,000 Tcf, or 2,800 Tcm to 2,800,000 Tcm.[75] A consensus view reported by Englezos and Lee is that the global store of methane hydrates holds approximately 20,500 Tcm of methane.[76] They also state that any model that uses a range from 10,000 Tcm to 40,000 Tcm should be considered reasonable.[77] Zhang *et al*. presented an assertion that there is probably enough producible methane hydrate to provide the whole world with sufficient energy supplies to last a millennium.[78] The U.S.'s Methane Hydrate Research and Development Act includes an estimate of the world's methane hydrate reserves that would suggest that the world has over a hundred times more methane hydrates than currently booked natural gas reserves.[79] Englezos and Lee suggested a calculation that if the annual global

70 Estimate was stated as 6.4 Trillion tons of methane. Demirbas, *supra* at note 1, at 1551.

71 Marcelle-De Silva & Dawe, *supra* at note 6, at 221.

72 Referred to as the standard estimate, partially due to their age. MacDonald's numbers date from 1990. Marcelle-De Silva & Dawe, *supra* at note 6, at 219.

73 This number is actually a statutory statement regarding the U.S.'s internal estimate of its own domestic supplies, which it estimates at a quarter of the world's supplies of methane hydrates. It provides an estimate of the domestic volumes at 200,000 Tcf. 800,000 Tcf converts to 24,000 Tcm. *See* 30 USC § 2001(2) and (3).

74 Referred to as the most up-to-date model and likely the most accurate. Marcelle-De Silva & Dawe, *supra* at note 6, at 219.

75 *See* M. R. Walsh et al., *Preliminary Report on the Commercial Viability of Gas Production from Natural Gas Hydrates*, 31 Energy Econ. 815, 815 (2009).

76 Englezos & Lee, *supra* at note 2, at 673.

77 *Id*.

78 Zhang *et al*., *supra* at note 17, at 934; Moridis *et al*., *supra* at note 21, at 2.

79 *See infra* within this section. Compare the U.S. estimate for methane hydrates against the BP estimate for booked natural gas reserves.

consumption of methane is 2.4 Tcm, then the global inventory of methane hydrates could yield a millennium of methane as contrasted against the century's worth of traditional natural gas – it is at least an order of magnitude of difference.[80]

Methane hydrates are primarily an offshore energy strategy. Moridis *et al*. presented a survey of five leading studies on the geographical locations of methane hydrates; the articles consistently found that there was approximately one hundred times more methane hydrates offshore than onshore.[81] The World Wildlife Fund has presented an estimate of 400 gigaton of methane hydrates within Arctic permafrosts and over 10,000 gigaton of methanes hydrates in offshore shelves.[82] Chatti reports that 1.4 Tcm to 34,000 Tcm of methane hydrates may be in found in permafrost areas, and 3,100 Tcm to 7,600,000 Tcm can be found offshore.[83]

Given the abundance of offshore methane hydrates, versus onshore, it is probable that the offshore methane hydrates will be a primary target of both research and eventual commercial investment.[84] Chatti's estimates match the expectations that offshore conditions better provide the phase envelope required for methane hydrate formation.[85] Additionally, the most recent model of methane hydrate depositions, from Klauda and Sandler, forecast 120, 000 Tcm of methane hydrates globally and over 80,000 Tcm of offshore methane hydrates.[86] The Klauda Sandler model has become the standard model very quickly because of its ability to forecast both expected and unexpected real-world methane hydrate discoveries.[87] Partially because of this accuracy, their maps of methane hydrates are the maps most known from popular media on methane hydrate distributions; in particular, they are the basis of the well-known methane hydrate map published in Der Spiegel.[88]

80 Englezos & Lee, *supra* at note 2, at 674.

81 Moridis *et al.*, *supra* at note 21, at 3, *also see* Table 2 at 25. *See also* Marcelle-De Silva & Dawe, *supra* at note 6, at 221. Combining this 100:1 ration of offshore to onshore, and the discussion, supra, of traditional natural gas to methane hydrates as a similar 100:1 ration, the secondary result is that onshore methane hydrates in permafrost areas likely equal the global inventory of traditional natural gas. While this present study is focused on offshore methane hydrate projects, the potential attraction for onshore methane hydrates would only increase once the commercial feasibility of offshore methane hydrates is developed.

82 M. SOMMERKORN & S. J. HASSOL, ARCTIC CLIMATE FEEDBACKS: GLOBAL IMPLICATIONS, 86 (World Wildlife Fund (WWF), 2009).

83 Chatti *et al*., *supra* at note 18, at 1336.

84 Moridis *et al.*, *supra* at note 21, at 2.

85 Chatti *et al*., *supra* at note 18, at 1336.

86 Moridis *et al.*, *supra* at note 21, at 3. *See* J. B. Klauda & S. I. Sandler, *Global Distribution of Methane Hydrate in Ocean Sediment*, 19 Energy & Fuels 459, *en passim* (2005).

87 Moridis *et al.*, *supra* at note 21, at 3. *See* Klauda & Sandler, *supra* at note 86, *en passim*.

88 *See* Appendices I.C. and I.D.

4. Geology of methane hydrates

There is an effective envelop for offshore methane hydrates; low temperatures and high pressures favor their formation.[89] The top of offshore methane hydrate formations are commonly found at approximately 150m to 500m below the seabed, although in equatorial waters that depth has been found lower at 1000m.[90]. The hydrate stability zone (HSZ), *i.e*. the 'sweet spot' for temperature and pressure, is generally 500m to 1000m thick, vertically speaking.[91] The HSZ is generally limited to no deeper than 1500m from the ocean's surface, as ambient temperatures rise with depth.[92]

Table 3: Simple Hydrocarbons by nomenclature

N	Alkane	Formula
C_1	Methane	CH_4
C_2	Ethane	C_2H_6
C_3	Propane	C_3H_8
C_4	Butane	C_4H_{10}
C_5	Pentane	C_5H_{12}

Methane hydrates are found in pressures between 1 to 100 bars, wherein normal atmosphere pressure at sea level is deemed at 1 bar; alternatively, they present between 1500-15 psia.[93] Despite their icy appearance, methane hydrates are present in 'room temperature' temperature ranges from -5 C to +34 C in Nature.[94] Methane hydrate deposits can be characterized by their production profiles. Simple fields contain almost exclusively methane, with less than one percent of C_2 and C_3 and even more faint levels of C_4 and C_5.[95] There are a few complex fields, so far only in the Gulf of Mexico, that display only about 70% methane, with large volumes of C_2 and C_3, and presenting trace amounts of C_4, C_5, carbon dioxide and nitrogen.[96] The

89 Lee & Holder, *supra* at note 34, at 184; Moridis *et al.*, *supra* at note 21, at 1. Demirbas referenced it the other way around, that heat and depressurization leads to hydrate reversion to water and methane. Demirbas, *supra* at note 1, at 1548.

90 Dawe & Thomas, *supra* at note 17, at 223; Makogon, Holditch, & Makogon, *supra* at note 3, at 19.

91 Dawe & Thomas, *supra* at note 17, at 222; Zhang *et al*., *supra* at note 17, at 933.

92 Dawe & Thomas, *supra* at note 17, at 222; Makogon, Holditch, & Makogon, *supra* at note 3, at 19.

93 Dawe & Thomas, *supra* at note 17, at 221.

94 *Id.* Makogon provides laboratory ranges of -200 C to 75 C, with the correspondingly required extreme pressure ranges of 2 GPa to 20 nPa. *See* Makogon, Holditch, & Makogon, *supra* at note 3, at 18.

95 Makogon, Holditch, & Makogon, *supra* at note 3, at 21; Marcelle-De Silva & Dawe, *supra* at note 6, at 218.

96 *Id*., at 21; *id*., at 218.

simple fields appear to be stable at 21 C, whereas the complex fields appear to be stable at a higher 28 C.[97]

While the above description might suggest a smooth layer of methane hydrates in-between mud layers; that is not how methane hydrates are deposited within the HSZ.[98] Methane hydrates have complex geometries with major perturbances due to water flow, pressure and temperature changes, and other factors.[99] In subsea deposits, the most stable methane hydrates are those highest in the reservoir with the most unstable, and gaseous, at the bottom of the reservoir.[100]

It is possible for methane hydrates to form in the open ocean; however the resultant mass is buoyant and would float to the water's surface.[101] As the ocean temperatures rise as the hydrate floats upwards, and as the pressure levels decrease, the hydrate will disassociate. The resultant fizzy ocean waters, awash with gaseous methane, have been described in the literature as a 'fluidized bed' that does not support routine notions of naval buoyancy.[102]

In contrast, in permafrost areas, with the ambient arctic temperatures, methane hydrates are often found near the surface, they can be found within 150m of the land surface; such depths might not require wells for recovery.[103] The stability of methane hydrates in permafrost is less dependent on locational depth, as the low temperatures provide stabilization.[104]

Methane hydrates can be detected by both seismic acoustic imaging, well logs, and via drilling tests.[105] When the methane hydrates are located in not too deep conditions, the difference between the icy structures of the methane hydrates and the heavier viscosity of the collated muds provide strong acoustic signatures.[106]. Methane hydrates have been readily found with seismic detection methods, but they have also been found where no seismic indication suggested they be found, e.g. if no free gas is associated with the methane hydrate reservoir then it might not show in seismic scans, so drilling is often required.[107] There are dangers to testing for methane hydrates by drilling and extraction, in that the methane hydrate can

97 Marcelle-De Silva & Dawe, *supra* at note 6, at 218.

98 Boswell, *supra* at note 12, at 11; Makogon, Holditch, & Makogon, *supra* at note 3, at 19-21.

99 *Id.*, at 11; *id.*, at 19-21.

100 Dawe & Thomas, *supra* at note 17, at p. 223.

101 *Id.*

102 *Id.*, citing R. Corfield, *Close encounters with crystalline gas*, 38(5) Chemistry in Britain 22 (2002).

103 *Id.*; Marcelle-De Silva & Dawe, *supra* at note 6, at 217.

104 Dawe & Thomas, *supra* at note 17, at 223; Marcelle-De Silva & Dawe, *supra* at note 6, at 217.

105 Dawe & Thomas, *supra* at note 17, at 220; Gabitto & Tsouris, *supra* at note 1, at 4; Marcelle-De Silva & Dawe, *supra* at note 6, at 224.

106 Dawe & Thomas, *supra* at note 17, at 220; Marcelle-De Silva & Dawe, *supra* at note 6, at 225. Traditional oil and gas seismic techniques assume deeper assets and harder barriers, *e.g.* salt domes, than are generally present for methane hydrate deposits. Offshore methane hydrate deposits are shallow and covered with mud.

107 Gabitto & Tsouris, *supra* at note 1, at 4; Marcelle-De Silva & Dawe, *supra* at note 6, at 225. Because of such problems, the methane hydrate industry, as such exists, has increased reliance on ocean bottom cables (OBCs) and controlled source electromagnetism (CSEM) to provide more detailed images to identify methane hydrate deposits.

rapidly disassociate into water, sediment and gaseous methane.[108] This potential disassociation both destroys the methane hydrate sample and presents dangers of combustion.

There are several ways that the literature describes the in-situ arrangement of methane hydrates. One approach suggests four distinct morphologies of methane hydrates.[109] They are 'disseminated', 'nodular', 'vein', and 'massive'.[110] Disseminated means that the methane hydrates are formed within the mud matrix of loose coarse sand grains, whereas the other three categories are created by geological or other such disturbances that create trap-like structures to enable the growth of the lattices.[111] Another perspective simplifies this taxonomy to only two morphologies, that of 'pore filling' and of 'grain displacing'.[112] Pore filling is identical in lattice genesis as the previous disseminated morphology, but the idea of grain displacing is that the formation of the lattice itself affects the geological formation and moves it away so that more methane hydrates can be accumulated.[113] Ultimately, the argument over morphology is related to both how and where methane hydrates might have formed and how the methane hydrates might be structurally engaged in their local geology which could have substantial impact on structural stability during extraction and production. In laboratory tests, it appears that the two morphology hypothesis is more readily validated.[114]

Methane hydrate deposits are classified into four different types of deposits based primarily on the complexity required to extract and produce from those deposits; a Class 1 reservoir of methane hydrates is easier to produce commercially whereas a Class 4 reservoir is more challenging to produce commercially.[115]

A "Class 1" deposit occurs when a methane hydrate layer overrides a two-phase water and a traditional natural gas reservoir.[116] Class 1 deposits have been found to function best under depressurization techniques of extraction; depressurization might be the only technology that can produce Class 1 deposits over a long run.[117] Recent Japanese offshore and American onshore research has focused on coarse grained Class 1 deposits.[118]

A "Class 2" deposit is a Class 1 deposit without the traditional natural gas resource in place; a Class 2 deposit merely contains methane hydrates.[119] Depressurization techniques of extraction work well for Class 2 deposits, once some

108 *See infra* at ch. 4 for a more complete discussion.
109 Gabitto & Tsouris, *supra* at note 1, at 5.
110 *Id.*, at 5.
111 *Id.*, at 5.
112 *Id.*, at 5-6.
113 *Id.*, at 6.
114 *Id.*, at 6.
115 Moridis *et al.*, *supra* at note 21, at 12; Walsh *et al.*, *supra* at note 75. There are additional classification issues, such as associated rock or mud layers, and potential mixing of classes within small terrains.
116 Walsh *et al.*, *supra* at note 75.; Marcelle-De Silva & Dawe, *supra* at note 6, at 219.
117 Moridis *et al.*, *supra* at note 21, at 13.
118 Walsh *et al.*, *supra* at note 75..
119 *Id.*; Marcelle-De Silva & Dawe, *supra* at note 6, at 219.

volume of water is extracted, gaseous volumes of methane from the deposit fill the voids and effectively create Class 1 zones within the Class 2 deposit.[120] Additionally, the water zone under a Class 2 deposit can be utilized to facilitate thermal stability or heating, as necessary; thermal techniques can assist in continuity of flow from the production zone at the bottom of the well.[121]

A "Class 3" deposit is a simple methane hydrate deposit without any fluids, neither water nor gas, underneath it.[122] Class 3 deposits lack the free space from which to begin depressurization, unlike Class 1 and Class 2 deposits.[123]

"Class 4" deposits are scattered, as if littorally, on the seafloor in low density clusters.[124] Due to the complexity of both identifying those deposits and of the potential complexity of their development they are not currently seen as foreseeably commercial.[125] Kurihara *et al.* described the Class 4 deposits as "hopeless."[126]

There is an additional potential source of methane hydrates. Chatti mentions that methane hydrates may form at certain depths in the ocean, without overlaying mud barriers.[127] Chatti refers to carbon dioxide rich oceans wherein the hydrates form under pressure and temperature envelopes and then sink towards the sea bottom.[128] It is generally assumed that methane hydrates would be buoyant, but it is possible that some sII or sH might contain both methane and other heavier guest molecules and sink to the ocean floor.

5. Location of methane hydrates

Almost every coastal state in the world is expected to have some amount of offshore methane hydrates. While traditional oil and gas reservoirs have been found in fairly limited areas, methane hydrates have been found on almost every coastline and in most arctic regions.[129] As of 2009, methane hydrates had been drilled and recovered from upwards of two dozen countries in over 77 locations.[130]

Methane hydrates primarily occur in two geological formations, in permafrost and under subsea mud near coastlines.[131] When methane hydrates occur offshore,

120 Moridis *et al.*, *supra* at note 21, at 14.

121 *Id*.

122 Walsh *et al.*, *supra* at note 75.; Marcelle-De Silva & Dawe, *supra* at note 6, at 219.

123 Moridis *et al.*, *supra* at note 21, at 16.

124 Walsh *et al.*, *supra* at note 75.; Marcelle-De Silva & Dawe, *supra* at note 6, at 219.

125 In the U.S government report produced at Lawrence Berkeley National Laboratory, Moridis carefully balanced the techniques and challenges presented to the first three classes of deposits. Class 4 deposits were not discussed at all, other than to dismiss them due to their low densities of methane, (less than 10%), and their lack of confining geologic strata; implying the complete lack of need given a broader awareness of their difficulties. *See* Moridis *et al.*, *supra* at note 21, at 13-17.

126 Kurihara *et al.*, *supra* at note 19. *See also* Marcelle-De Silva & Dawe, *supra* at note 6, at 228.

127 Chatti *et al.*, *supra* at note 18, at 1337; Dawe & Thomas, *supra* at note 17, at 223.

128 Chatti *et al.*, *supra* at note 18, at 1337.

129 *See* maps provided in Appendix I. *See also* Englezos & Lee, *supra* at note 2, at 674.

130 Gabitto & Tsouris, *supra* at note 1, at 2.

131 Dawe & Thomas, *supra* at note 17, at 219.

they often form within 200 km of the coast,[132] placing them generally outside of territorial waters (12 miles) [133] but well within general limits of exclusive economic zones. (200 miles). [134] Thus, the energy resources of offshore methane hydrates would be the exclusive resources of the coastal state but the impact of the development of those resources on living resources within the exclusive economic zone but without the territorial waters would impact upon the legal rights of all other signatory states, under the UNCLOS.[135]

Without intending to overstate the point, the main geographic areas of impact are the following zones:

- The western shelf of Europe, including the EEZs of Spain, Ireland, and the U.K.
- The Mediterranean Ocean, except parts of the Adriatic, Tyrrhenian, and Aegean Seas as noted above. Practically every Mediterranean state is expected to contain methane hydrates within their EEZs.
- The whole west coast of the Americas, from Alaska to Chile.
- The eastern coast of North America. Including almost all of the Caribbean islands.
- The coasts of Argentina, Uruguay and southeastern Brazil.
- The whole coast of Africa in all direction, including the Red Sea and Madagascar.
- Everywhere near the South Asian (India) peninsula, including large zones of the Arabian Sea and the Sea of Bengal.
- Areas offshore of South Korea, Japan, and the Russian islands north of Japan including offshore Kamchatka.
- Almost all of the ASEAN waters, ocean, and seas.
- Offshore of Australia and New Zealand.

When contrasted against the more limited locations of crude oil and traditional natural gas fields, the resource owners of methane hydrates form a much larger proportion of the global community.

Broadly speaking, it is easier to speak of which countries will not likely share in methane hydrate production than to speak the other way around. Given that methane hydrates primarily form either offshore marine areas or in permafrost areas, if a country has neither then it is not likely to have methane hydrates. Almost every country with a coastline will have zones of potential methane hydrates; every area with permafrost is included in the set of countries with coasts.

132 *Id*.

133 The United Nation's Convention on the Law of the Sea. Sec. 2. Art. 3. *Available* at [http://www.un.org/Depts/los/convention_agreements/texts/unclos/part2.htm.

134 The United Nation's Convention on the Law of the Sea. Part V. Art. 57. *Available* at http://www.un.org/Depts/los/convention_agreements/texts/unclos/part5.htm.

135 In particular, *see* UNCLOS Art. 56 and see UNCLOS Arts. 69 and 70. *Available* at http://www.un.org/Depts/los/convention_agreements/texts/unclos/part5.htm. More generally, *see* the discussion on UNCLOS as it relates to the development of methane hydrates, *infra*, at ch. 8.

- Non-Arctic landlocked nations will not generally have gas hydrates.[136]
- The Baltic Sea appears to be poor in methane hydrates; which is rare for coastal states anywhere.[137]
- While the Mediterranean Sea appears to bear extensive methane hydrates deposits, the sub-regional Tyrrhenian Sea and the Adriatic Sea appear to lack substantial methane hydrate deposits. Similarly, much of the Aegean appears to lack methane hydrates.[138]
- A few awkwardly located states, such as Honduras, will have difficulty to connect their EEZ to nearby methane hydrate fields.[139]

Once the two lists are confronted, the resource owners and those not likely-to-be, several immediate observations can be deduced.

The commercial development of methane hydrates will enable many more countries in the world to participate in hydrocarbon extraction and production. The production of methane will become feasible in many locations currently with no local energy supplies. Of the areas lacking methane hydrates, several of them are already in production of crude oil and natural gas, such as Kazakhstan. Many of the new resource owners are developing countries in need of fiscal revenues and affordable energy supplies.

Certain countries are not expected to have any substantial methane hydrate deposits; the clustering is sobering. In South America, Bolivia and Paraguay will not have methane hydrates. In Africa, the states of Botswana, Burkina Faso, Burundi, Chad, Ethiopia, Malawi, Mali, Niger, Rwanda, South Sudan, Uganda, Zambia, and Zimbabwe will be left without methane hydrates. Chad and South Sudan are different from the other states on that list in that they have substantial crude oil reserves. In Asia, several Central Asian states and Mongolia will lack methane hydrates. These countries on the whole are some of the poorest in the world.

This new energy resource might enable many areas to receive new streams of income, and thus affect global price levels on a wide front of commodities, but those countries sans hydrates will not be able to participate in the economy of methane hydrate development. Not only would those countries lack revenues from energy resources, but they would also lack the industrial capacities to benefit from industrial and service industry engagements with the emerging methane hydrate

136 It is worth noting that certain Siberian lakes have had methane hydrates discovered at sufficient depths. It is possible that certain lakes elsewhere may contain the pressure and temperature envelopes required for methane formation. But lakes outside of the main research nations have not been explored, due to the ready abundance of methane hydrates in other locations. It may require local investment to further determine if non-oceanic water bodies contain methane hydrates.

137 Finland does appear to have methane hydrates within its EEZ. Luckily for Denmark, it has extensive territorial waters northwest of its main peninsula wherein tremendous methane hydrates are suspected to exist.

138 That said, Greece and Italy have other areas within their EEZs that do appear to contain methane hydrates, so perhaps it is only the former Yugoslavian areas of the Adriatic that would be substantially impacted by a lack of methane hydrates within their EEZs.

139 Improved surveying will be necessary to help clarify what claims might be attempted.

economies. They are likely to be wholly excluded from the new methane hydrate paradigm without exogenous intervention.

There are many countries within Europe that are not expected to possess any methane hydrate resources. Austria, Belgium, the Czech Republic, Lithuania, Luxembourg, Macedonia, the Netherlands, Poland, Romania, Serbia, Slovakia, and Switzerland will probably not contain any methane hydrates within their main territories. But several of these states do produce methane from other natural gas deposits, such as Poland and the Netherlands. The Netherlands Caribbean territories are likely to hold methane hydrates offshore; France and the U.K. will similarly benefit from Caribbean holdings in addition to their western EEZ reserves. Many of these countries are substantially industrialized and will be able to participate indirectly in the commercialization of methane hydrate via industrial tool making and other services. In addition, many of the countries on this list are among the highest per capita income levels, in contrast to the situation of methane-hydrate-poor states in Africa and South America. Thus, while methane hydrates are not evenly shared across all European countries, a substantial proportion of European countries do have methane hydrate resources, either close to Europe or within overseas territories. And among those European states that do not have methane hydrates, there are both wealthy and less wealthy states, so the impact is neither acute nor imbalanced, as contrasted against the distribution of methane hydrate lacking countries in Africa and South America.

Certain observations are in order:

- First, will the economic diversity of resource owners encourage a race to those with the least regulation?
- Second, the strategic negotiating advantages of the technology owners could perversely incentivate the resource owners to reduce environmental regulatory costs.

First, the diversity of resource owners is stunning. Some of the resource owners have advanced legal systems and stable institutions whereas many other do not. In an almost perfect inverse, the less legally developed locations are generally those with the lowest per capita incomes and thus those most likely to encourage the rapid deployment of methane hydrate production in order to obtain revenues therefrom. Thus, without broader regulatory efforts to divert initial investments into well regulated zones, there might be an initial surge of investment into those areas least capable of regulating for environmental safety.

Second, the contrast of the small size of the methane hydrate technology owners versus the very large size of resource owners means that without regulation the technology owners have their pick of locations and resource owners. It would only be rational, *ceteris paribus*, for those technology owners to seek out the lowest costs locations. Less stringent regulations would generally be expected to be lower cost, as costs of accidents and harms could be externalized from the technology owner.[140]

Perhaps a broader agreement could be reached amongst the technology owners to self-monitor their environmental safety standards even when local conditions and regulation do not otherwise require such measures.

6. Summary and conclusions

Methane hydrates are a newly discovered source of energy supplies, but once extracted provides both water and natural gas. Methane hydrates are a novel energy resource, but the fuel it produces is the long-familiar natural gas methane. Methane hydrates are abundant, their potential supply dwarfs traditional crude oil and conventional natural gas supplies.

The novelty of offshore methane hydrates is clear. Methane hydrates were not geo-physically surveyed until the 1970s and were not recovered in small samples from offshore locations until the 1980s. It wasn't until the 1990s that offshore methane hydrates were identified as a potential energy resource. The first non-continuous well was not drilled until 1999. Only in 2013 was the first successful continuous production well for methane hydrates drilled and operated offshore.

Methane hydrates are a chemical combination of both fresh water and methane. Their combination enables the resulting hydrate to exist as a solid frozen mass at chilly but room temperatures. The hydrates usually form in the ocean under subsea mud layers but above harder ground surfaces. As such, the hydrates form an icy or slushy layer under the mud layers. While frozen and intact, the hydrate structures are very strong but if they are disturbed they can disassociate or cleave and enable massive displacement of the hydrates.

While hydrates could contain other light hydrocarbons, the vast majority of hydrates contain only methane; in fact, the unique size of the hydrate cage structure effectively prevents contamination of the natural gas from many larger molecules so the produced methane is expected to be acid-free. However, carbon dioxide could be injected to replace the methane within the hydrate structures because it would fit within the cages. Thus, methane hydrate deposits could support carbon capture and sequestration (CCS) technologies.[141]

Methane hydrates are endothermic, meaning that it takes an injection of energy to enable the release of the methane from the hydrate. Left alone, methane hydrates are self-stabilizing. Methane hydrates store methane densely; methane hydrate deposits contain 170 cubic meters of conventional natural gas per each cubic meter of methane hydrate deposit. Thus, should energy be introduced into a

140 Such a non-stringent regulation need not be per se predatory on the part of the technology owner. A nation state might offer nationwide indemnification for all methane hydrate liabilities to the technology owners, with counterbalancing promises to provide due process handling of victim claims and rights. The technology owner might then engage in a multi-decade investment only to later discover that the bulk of the promised due process measures never manifested.

141 *See* the discussion on carbon sequestration within methane hydrate deposits at ch. 3, sec. 5.1.

methane hydrate deposit, the potential volumes of emitted methane would be much larger than the volumes of affected hydrates.

Globally, methane hydrates are expected to dwarf the global supplies of traditional crude oil and conventional natural gas. The standard estimate is that the global supply of methane hydrates is about 21,000 Tcm; this volume is three to four magnitudes larger than the global supplies of conventional natural gas. 99% of that global supply is expected to be stored in offshore methane hydrates.

Those offshore volumes are located offshore almost every coastal state in the world. There are also volumes expected in areas of the world's ocean beyond national exclusive economic zones, placing those volumes under the UN's International Seabed Authority's (ISA) control and management. This geographical diversity means that offshore methane hydrates will be located within a variety of legal settings, including both developed and developing countries. The potential of methane hydrates to enable many countries to obtain large supplies of domestic energy is clear; it is equally clear that the development of offshore methane hydrates would occur in a variety of legal settings.

The potential for methane hydrates to provide the world with a large source of methane supplies is countered with the potential for those same volumes of methane to accidentally escape and cause harm and injury.[142] Additionally, methane hydrate deposits can serve as sinks to store carbon dioxide; but that too provides opportunity for risk and harm. As diversely located as offshore methane hydrates are, so too would be the potentially impacted communities around the globe. If methane hydrates were to be developed, the potential risks and hazards of that development would need strategies of risk governance to achieve optimal levels of methane hydrate extraction and of precautionary activities.

142 The potential harms and injuries are discussed at ch. 4.

Chapter 3

METHANE HYDRATES AS AN ENERGY RESOURCE

1. Methane as a green energy source

While the technologies of green and renewable energies develop, the production of methane hydrates could provide an earlier window of opportunity to eliminate coal and crude oil as fuel sources. Natural gas from methane hydrates provides very few pollutants and would yield less carbon emissions than coal or crude oil.

While methane hydrates are not a form of renewable energy, they do open pathways to green energy. While methane is a carbon emitting fossil fuel, methane hydrates provide several methods to achieve near-term green energy supplies while other green and renewable energy supplies advance in technology and feasibility:

- The methane and fresh water extracted from methane hydrates can be used to produce hydrogen fuel. What carbon dioxide is produced in the conversion process can be re-sequestered in the hydrate formation.[1]
- They provide the potential to extract methane, combust that methane to electricity, and to re-sequester the produced carbon dioxide back into the hydrate formation.[2]
- Methane itself provides approximately half the carbon emissions compared against coal for the same amount of produced energy. Methane also produces fewer carbon emissions than crude oil.[3]
- Methane extracted from methane hydrates has practically zero co-produced pollutants, other than carbon, and methane in general

[1] V. Krey et al., *Gas Hydrates: Entrance to a Methane Age or Climate Threat?,* 4 Environmental Research Letters 34007, 4 (2009).

[2] *Id.*

[3] P. Englezos & J. D. Lee, *Gas Hydrates: A Cleaner Source of Energy and Opportunity for Innovative Technologies*, 22 Korean J. Chemical Engineering 671, 671 (2005); S. Y. Lee & G. D. Holder, *Methane Hydrates Potential as a Future Energy Source*, 71 Fuel Processing Technology 181, 183 (2001).

creates much less non-carbon pollution in contrast to the heavy pollutants emitted by coal and crude oil combustion.

Table 1: Carbon Emissions from Energy Sources

Fuel Source	Carbon Emissions[4]
Coal	27 kg/GJ
Crude Oil	21 kg/GJ
Methane	15 kg/GJ

Methane hydrates provide a "kind of clean energy" in that it contains sweet natural gas with no impurities.[5] The overall environmental pollution from the combustion of methane is of a comparatively low degree when compared against the carbon dioxide and other harmful emissions from the combustion of coal, crude oil and less clean forms of natural gas.[6]

Before 1800, plant-based sources, *e.g.* dried wood, provided in excess of 95% of the world's fuel needs. They were essentially carbon neutral fuel sources. The early industrial era was based upon the heat energy from combusted coal; within decades coal had displaced wood as the globe's primary energy resource.[7] By the onset of World War I, coal had reached its peak as an energy resource, providing approximately 75% of the world's energy needs.[8] With the rise of the automobiles after World War I, crude oil and its distillates quickly replaced coal.[9] Crude oil never reached the peaks of energy hegemony that coal had attained, but it reached close to 50% by the 1970s. Coal remained a strong competitor to crude oil, but both generated massive amounts of the greenhouse gas carbon dioxide and other pollutants.

The combustion of coal releases significant pollution beyond greenhouse gases that can cause substantial risk to human health. [10] Coal ash also contains

4 Englezos & Lee, *supra* at note 3, at 671; Lee & Holder, *supra* at note 3, at 183.

5 Z. G. Zhang, et al., *Marine gas hydrates: Future Energy or Environmental Killer?*, 16 Energy Procedia 933, 934 (2012); R. A. Dawe & S. Thomas, *A Large Potential Methane Source – Natural Gas Hydrates*, 29 Energy Sources 217, 217 (2007). *See also* discussion on methane hydrate chemistry, *supra*, at ch. 2, sec. 2.

6 Zhang *et al.*, *supra* at note 5, at 934. The combustion of coal and crude oil, especially as diesel fuel, are known to cause a variety of health and medical injuries to frequently exposed communities. The combustion of coal and crude oil provide the worst sources of fuel-based anthropogenic climate change. In Asia in particular, the health risks can be extreme. The delivery of a geographically diverse abundant supply of methane, or of hydrogen, is an opportunity to save lives and to save the climate.

7 Y. F. Makogon, S. A. Holditch & T. Y.Makogon, *Natural Gas-Hydrates – A Potential Energy Source for the 21st Century*, 56 J. Petroleum Sci. & Engineering 14 (2007).

8 *Id.*

9 *Id.*

10 A typical 600 MWW coal plant might release 14,100 tons of sulfur dioxide (SO_2), 10,300 tons of nitrous oxides (NO_x), 500 tons of small airborne particles, 170 pounds of mercury, and 114 →

surprisingly substantial quantities of radioactive materials, which is carcinogenic.[11] Thus, countries that rely heavily on coal would find the combustion of methane a healthier option.[12]

The alternatives to coal and crude oil, *e.g.*, hydro-electric, geothermal, and nuclear, have never historically exceeded 10% of global demand; current forecasts suggest that they will likely remain under 20% of the world's energy needs.[13]

In the alternative, methane hydrates are forecasted to be able to supply energy volumes beyond the sum of the expected quantities to be provided by alternative forms of energy such as solar, nuclear and hydro-power.[14]

2. Economics of methane hydrates projects

2.1. Economics of methane hydrates

When methane hydrates were first discussed as a potential fuel source in the 1990s it was technologically infeasible to extract methane from methane hydrate deposits.[15] Since those years, the technology and scientific understandings of methane hydrates and their reservoir structures has rapidly developed; it is likely that early adopters will do so for national energy policy and strategic energy supply concerns followed by broader private investment as investment costs drop.[16]

Much of the leading investment in methane hydrates research has been driven by nations with substantial concerns of energy supply security; the research programs have not been driven by private investors — however, the overall goal of

pounds of lead annually. *See* Environmental impacts of coal power: air pollution. Union of Concerned Scientists. *See* at [http://www.ucsusa.org/clean_energy/coalvswind/c02c.html]

11 In a report from the Oak Ridge National Laboratory, UT Battelle for the U.S. Department of Energy, it was estimated that American coal combustion emitted more uranium as ash than America used as nuclear fuel. "According to 1982 figures, 111 American nuclear plants consumed about 540 tons of nuclear fuel, generating almost 1.1 x 10^{12} kWh of electricity. During the same year, about 801 tons of uranium alone was released from American coal-fired plants. Add 1971 tons of thorium, and the release of nuclear components from coal combustion far exceeds the entire U.S. consumption of nuclear fuels. " *See* A. Gabbard, *Coal Combustion, Nuclear Resource or Danger?* (Oak Ridge National Laboratory, UT Battelle for the U.S. Department of Energy, 2008) *Available* at http://web.ornl.gov/info/ornlreview/rev26-34/text/colmain.html.

12 *E.g.*, Greenpeace estimates that current air pollution in China, primarily sourced from coal combustion, may be responsible for a quarter million premature deaths. *See* Ottery, Christine. Interactive Map: Health impact of China's coal plants mapped. Greenpeace UK. *Available* at http://www.greenpeace.org.uk/newsdesk/energy/data/interactive-health-impact-chinas-coal-plants-mapped.

13 Makogon, Holditch, & Makogon, *supra* at note 7.

14 *Id.*

15 As noted earlier, certain fields have been produced that contained both natural gas deposits and methane hydrate deposits; but no 'pure' methane hydrate fields has come online for continuous production as of December 2013.

16 J. Marcelle-De Silva & R. Dawe, *Towards Commercial Gas Production from Hydrate Deposits*, 4 Energies 215, 230 (2011).

these policies have been to provide beneficial economic support to national economies, thus project economics have been inclusive of the supported industrial sectors.[17]

For early investors in methane hydrates projects, there are several concerns. First, the rapid development of methane hydrate technologies has been so fast that one hesitates to make a major investment in caution that better and cheaper technologies are imminent. For those planning eventual investments in methane hydrates, the benefits of waiting have been demonstrated in superior and safer technologies alongside drops in the overall costs of lifting production from the deposits.

Second, the overall science of methane hydrates is stabilizing and coming together, but the transition from scientific laboratories to billion dollar investments will take time. Oil and gas fields have often taken a decade or more in basic exploration and economic modelling before approaching a FID. Methane hydrates will need to transition from scientific research accomplishment to industrial investment and then again from gaining boardroom recognition as a targetable investment to making specific FIDs on specific methane hydrate fields. While corporations can respond to change faster than bureaucracies, they too have paradigmatic drivers that take time to adjust and update.

Third, while the costs of producing methane hydrates have been dropping as the scientific and engineering technologies advance, they remain more expensive to produce than traditional natural gas reservoirs. But how much more expensive is both unclear and subject to details of particular models. Some models compare the costs required to develop, other models compare the market prices required to ensure commercial feasibility. Optimistic estimates suggest that the cost of developing offshore methane hydrate projects should be 15% to 20% more costly than comparably situated conventional natural gas projects.[18] Another forecast stated, based on technologies and costs prior to 2008, the incremental costs of producing from an offshore Class 3 methane hydrate reservoir were $3/Mcf more expensive than production volumes from a conventional offshore natural gas well.[19] A meta-discussion on several economic models from 2005 observed that offshore methane hydrate projects were feasible when the price of natural gas exceeded $7 USD.[20] Another model found that offshore methane hydrate projects would be commercially feasible if crude oil prices were to sustainably remain above $50 USD for the long run.[21]

17 Krey *et al.*, *supra* at note 1, at 4; Marcelle-De Silva & Dawe, *supra* at note 16, at 230.

18 Makogon, Holditch, & Makogon, *supra* at note 7, at 30. In particular, the costs of well drilling are expected to be substantially lower due to the comparable shallowness of methane hydrate deposits and the lack of rock to drill through, as contrasted with conventional natural gas plays. The downside is that methane hydrate projects will likely need more wells to be drilled for comparable volumes to be produced.

19 M. R. Walsh et al., *Preliminary Report on the Commercial Viability of Gas Production from Natural Gas Hydrates*, 31 Energy Econ. 815 (2009).

20 Marcelle-De Silva & Dawe, *supra* at note 16, at 230.

21 Krey *et al.*, *supra* at note 1, at 3.

2.2. *Discount rates and time sensitivity of costs*

Many investors in energy projects develop financial models against an assumed hurdle rate of 15% after a annual discount rate of 10% has been applied.[22]

These assumptions create strong economic incentives for operators to be very responsive to costs and revenues close in time to the FID and less responsive to costs further away from the moment of the FID. When costs and revenues are several decades beyond the FID, then those economic events will be effectively scaled down a magnitude or two in contrast to near term events.

If one assumes the onset of cash costs from the abandoning and sequestration phase to begin three decades after the initial FID, the effect of 30 years of a 10% discount rate renders the effective costs very small in contrast to near term costs and revenues; against the FID date as year zero:

Table 2: Effective Discounts at 10% for Post-FID Stages of Methane Hydrate Projects[23]

Stage	Years	Discount formula	Simple Fraction
Development	1	$costs * \left(1 - {}^{1}/_{10}\right)^{1}$	${}^{9}/_{10}$
	5	$costs * \left(1 - {}^{1}/_{10}\right)^{5}$	${}^{3}/_{5}$
Production	5	$costs * \left(1 - {}^{1}/_{10}\right)^{5}$	${}^{3}/_{5}$
	10	$costs * \left(1 - {}^{1}/_{10}\right)^{10}$	${}^{1}/_{3}$
	20	$costs * \left(1 - {}^{1}/_{10}\right)^{20}$	${}^{1}/_{8}$
Abandonment	30	$costs * \left(1 - {}^{1}/_{10}\right)^{30}$	${}^{1}/_{25}$
	40	$costs * \left(1 - {}^{1}/_{10}\right)^{40}$	${}^{1}/_{70}$
	50	$costs * \left(1 - {}^{1}/_{10}\right)^{50}$	${}^{1}/_{200}$

22 The discount rate for costs is often modeled as $\{\text{costs} \times (1-r)^n\}$; wherein r is the discount rate and n is the number of years from which to discount down. Author's personal industrial experience: When discounting a flow of costs from continuously successive time periods, the formula is usually given as: $\sum_0^n [costs_n \times (1-r)^n]$

23 This table is generated by simply completing the evaluations of specific notable time periods against a traditional compound interest rate calculation. The phrase "discount rate" is used in the oil and gas industry as a reflection of the decreased value of future money versus current money, future revenues need to be 'discounted' for correctly reflecting their current value to an investor. The Catch 22 for risk decision making is that discounted cash flows also apply to future costs, thus, their impact is less than current costs of the same numerical value. Future damages are less costly to a current investor than current damages, *ceteris paribus*.

Risk from the earlier years would be discounted by larger simple fractions, most of the cost impact of the future damages would be retained for the operator's decision making process. But risks from further out would be severely discounted, potentially blunting the cost impact of those future damages in the tortfeasor's decision making. For similar reasons, operators are more sensitive to earlier revenues than later revenues.

The point to be made herein is that the economics of methane hydrate projects will be much more sensitive to early-in-time costs than late-in-time costs. In essence, discount rate analysis over-represents near-term costs and under-represents long-term costs, resulting in a type of bias. Risks and revenues that feature in the first couple decades of project life will be accounted for within FID analysis and risk-decision making while those events and accidents that happen futher out would be disproportionately represented due to the effects of discount rate analysis. The costs of events in the far future might be very large in their own time period but would be included at a substantially smaller size in the discount rate analysis employed to evaluate project risks and costs.

3. Methane hydrate engineering

That methane hydrates is presented as a solid in nature, that the extraction of methane from the hydrate is a resistant endothermic reaction, and that the production of methane hydrates in water actually cools the local environment fostering the reformation of hydrates all make the continuous extraction of methane hydrates much more difficult than the extraction of traditional natural gas.[24]

The technology to produce offshore methane hydrates is advancing rapidly; Japan drilled the first offshore well in 1999 and recently sustained the first successful continuous flow testing from an offshore well in 2013.[25] As of 2008, methane hydrates had been drilled and extracted from 23 locations, 3 in permafrost and 20 from offshore.[26] In the offshore wells, experience has been accumulated in all phases of a methane project's life cycle; wells have been drilled, cemented and made viable, methane has been produced, processed and combusted, and wells have been plugged and abandoned.[27]

24 M. KURIHARA, M *ET AL.*, *Gas Production from Methane Hydrate Reservoirs*, *in*: PROCEEDINGS OF THE 7TH INTERNATIONAL CONFERENCE ON GAS HYDRATES (2011)

25 G. J. Moridis et al., *Toward Production from Gas Hydrates: Current Status, Assessment Of Resources, and Simulation-Based Evaluation of Technology and Potential*, 12 SPE Reservoir Evaluation & Engineering 745, 3 (2009).

26 *Id.,* at 23. *Also see* Koh & Sloan 2007.

27 Moridis *et al.*, *supra* at note 25. *See also* discussion on Japanese efforts in development in both the discussion on hazards from methane projects, *infra* at ch. 4.3, and on their investment in research, *infra* at sec. 4.1.

3.1. *Methods of extraction*

There are three main methods in development to produce and extract methane hydrates. The first is depressurization, the second is thermal stimulation, and the third main method is inhibitor injection.[28]

Depressurization extracts methane from hydrate formation by reducing the pressure level until the phase boundary of the hydrate is breached, causing disassociation of the hydrate.[29] This method found practice at the Siberian field of Messoyhaka for several decades. Most current models assume that depressurization is the most energy efficient means of production because it can be applied using current technologies and be effective in long-run continuous operations; however most models assume a combination of techniques would be required in real-life.[30]

Thermal stimulation directly confronts the endothermic reaction of hydrate decomposition be supplying energy to the hydrates.[31] When the temperature is raised above the equilibrium, this increases the overall pressure within the hydrate; additional pressure returns the hydrate to a stability zone encouraging hydrate formation and thus yields some process control to the operator.[32] Modelling and testing have shown that a 10% energy loss occurs in the overall extraction of methane calories; *e.g.*, it takes 10 kJ of inputted energy to release the volume of methane that could release 100 kJ.[33] On the other hand, the overall cooling of the methane hydrate reservoir system as methane is produced adds the challenge of adding additional energies to continue the extraction process.[34] Overall, the

28 Dawe & Thomas, *supra* at note 5, at 223; Moridis *et al.*, *supra* at note 25, at 2 and 12-17; Marcelle-De Silva & Dawe, *supra* at note 16, at 227.

29 Lee & Holder, *supra* at note 3, at 185; Marcelle-De Silva & Dawe, *supra* at note 16, at 227. This method found practice at the Siberian field of Messoyhaka for several decades.

30 Walsh *et al.* 2009; Moridis *et al.*, *supra* at note 25, at 2 and 12-17; Marcelle-De Silva & Dawe, *supra* at note 16, at 227.

31 Dawe & Thomas, *supra* at note 5, at 223; C. A. Koh, *Towards a Fundamental Understanding of Natural Gas Hydrates*, 31 Chemical Soc'y Rev. 157, 165-166 (2002); Walsh *et al.* 2009; M. J. Castaldi, Y. Zhou & T. M. Yegulalp, *Down-Hole Combustion Method for Gas Production from Methane Hydrates*, 56 J. Petroleum Sci. & Engineering 176 (2007); Englezos & Lee, *supra* at note 3. Endothermic reactions require energy to be added for the reaction to occur. Exothermic reactions release energy as they occur. 50 kJ/mol of energy is required to separate methane from the hydrate formation. Larger molecules require more energy; e.g., propane requires 130 kJ/mol. Lee & Holder, *supra* at note 3, at 185.

32 KURIHARA *ET AL.*, *supra* at note 24. Chatti *et al.* discuss the additional benefits of thermal pressure increases on carbon sequestration techniques. I. Chatti *et al.*, *Benefits and Drawbacks of Clathrate Hydrates: A Review of Their Areas of Interest*, 46 Energy Conversion Mgmt. 1333, 1334 (2005).

33 Lee & Holder, *supra* at note 3, at 185; Marcelle-De Silva & Dawe, *supra* at note 16, at 227. A constant concern in discussions on thermal injection systems is that they will need to consumer substantial portions of the methane produced to provide heat for the injection fluids. This is a costly issue that needs further development if it is to be widely adopted as a primary means of production.

34 KURIHARA *ET AL.*, *supra* at note 24. A variety of means to insert additional energy down-hole to enable the endothermic disassociation to begin have been developed; some of the explored options are heat injection via steam (known in the petroleum industry as "huff-n-puff"), →

injection of hot water or steam into the reservoir is foreseen as causing methane hydrate formation near the well bore and frustrating extraction if there is not sufficient intra-granular room for flow; thus thermal stimulation is advised for secondary recovery after initial methane volumes have been recovered and thus providing circulatory room for hot water or stream fluids.[35]

A supplementary technology for thermal injection technologies is to use horizontal wells, wells that lay parallel to the mineral within its deposit.[36] A dramatic improvement in overall performance has been reported for horizontal wells as compared against traditional vertical wells; Cranganu has suggested that certain combinations of horizontal wells plus injection of oxidized fuel gas into the hydrate layer may reduce overall inefficiencies to less than 2% of produced calories from the hydrate deposits, as compared with earlier models' forecasts of 10% to 20%.[37]

Inhibitor injection disassociates methane gas from the methane hydrate by injecting chemicals known as inhibitors, *e.g*. methanol and glycol, which are known to prevent or inhibit the formation of the icy crystals around the methane.[38] As a primary extraction technology, however, large volumes of injectants would be required which would be both costly to supply and create environmental concerns of such injected volumes; as such, the inhibitor injection method is not expected for Class 1, 2, and 3 deposits.[39]

As hydrates are a common pipeline problem when transporting natural gas in the presence of sufficient water vapor, the extraction of methane from an aqueous environment will have similar challenges.[40] From current experiences with pipeline hydrate solutions, there are four known thermodynamic solutions to that problem: maintaining the temperature of the extraction facility and pipelines at a warmer temperature outside of the phase boundary, down-hole dehydration of the extracted methane, rapid evacuation of the methane to maintain transport pressures below the phase boundary requirements, and to use hydrate inhibitors.[41] Thus, even if inhibitor injection is not part of the disassociation technology strategy, chemical inhibitors may likely be employed to keep both the well and gathering systems

thermal flooding, fire flooding, injection of non-hydrating gases (such as atmospheric volumes), electro-magnetic heating, and the sub-surface placement of nuclear materials. *See* Dawe & Thomas, *supra* at note 5, at 224.

35 KURIHARA *ET AL.*, *supra* at note 24; Marcelle-De Silva & Dawe, *supra* at note 16, at 227.

36 Moridis *et al.*, *supra* at note 25, at 7-12.

37 *Id.,* at 7.; C. Cranganu, *In-situ Thermal Stimulation of Gas Hydrates*, 65 J. Petroleum Sci. & Engineering 76, 79 (2009).

38 Castaldi, Zhou, & Yegulalp, *supra* at note 31; Englezos & Lee, *supra* at note 3; Walsh *et al.* 2009; KURIHARA *ET AL.*, *supra* at note 24; Dawe & Thomas, *supra* at note 5, at 219-220.

39 Marcelle-De Silva & Dawe, *supra* at note 16, at 227.

40 Lee & Holder, *supra* at note 3, at 185; Koh, *supra* at note 31, at 159; Dawe & Thomas, *supra* at note 5, at 219-220.

41 Lee & Holder, *supra* at note 3, at 185; KURIHARA *ET AL.*, *supra* at note 24; Koh, *supra* at note 31, at 159. *See* a much more technical discussion of pipeline inhibition processes at *id.*, at 164-165.

problem free. Additionally, the wells of a methane hydrate deposit will likely need to be heated to prevent accumulation of hydrates within the well structures.[42]

Computer models of methane hydrate wells suggest that there may be long lag times from start-up at the well until full-volume production flow is achieved; unlike traditional methane wells, the methane hydrate wells will increase in produced volumes for a substantial portion of the production profile.[43]

However, not all of the disassociated methane volumes are expected to enter into the well, accumulation would likely occur above the hydrate layer; as such, substantial hazards of venting and seeping would be present unless artificial barriers can be put in place.[44]

3.2. Example typical installation

Once an extraction technology choice is made, the onset of development will probably resemble traditional offshore gas production in many ways. In deep-water offshore production facilities, which 500m to 1000m waters would be, it is now common to rely on floating production platforms. It is common for economies of scale to be leveraged, so often a singular production platform will receive produced natural gas from multiple wells. Due to the depth of the seabeds and the placement of the wellhead structures at the seabed, often the whole christmas tree and associated equipment is placed at the seabed.[45]

Several seabed wellsites may be connected by gathering lines to a single manifold station. Those gathering lines are often lain in the seabed or become settled therein by the movement of subsea currents. Such stations will provide a variety of remote services for the wellsites, including electrical supply and controls, hydraulic supply and control, or chemical injection facilities. The extraction of methane from the hydrate deposit may encourage the use of subsea facilities to separate the lifting of methane and water to the surface to prevent the reformation of hydrates in the gathering and transportation pipes. In that case, the manifolds for methane hydrate fields may also provide first stage separation and treatment facilities; these may include gas/liquid separators and tri-ethylene-glycol towers for dehydration and initial contaminant removal. The manifolds will then connect from the seabed to the production platform via vertically rising pipelines. The manifold would also need to support the recycle and support of its own chemicals and equipment.

Once on the production platform, the extracted methane will be dehydrated and treated again; thereafter the methane is ready for transport, use, or conversion to hydrogen. The produced water will be collected and treated for purification purposes, usually treated with a biocide to prevent accidental contamination

42 Moridis *et al.*, *supra* at note 25, at 14.
43 *Id.*, at 15; Walsh *et al.*, *supra* at note 19. Early models suggested that the lags could run up to eight years.
44 Moridis *et al.*, *supra* at note 25, at 15.
45 A christmas tree is a multiple valve assembly routinely found immediately above the wellhead. A christmas tree is used to control the flow of production.

downstream, and then either transported away or re-injected into a disposal well. The production platform will carry a flare stack for the safe combustion of surplus methane volumes; regulations generally require a certain volume of methane to be continuously flared to ensure the function of the flare in emergency moments. Production platforms also generally have a range of support equipment and facilities, such as hydraulic systems, electrical power systems, crew support cabins and systems, and heli-pads and boat docks. Production platforms normally have export pipelines to transport the natural gas away from the platform and downstream to either marketing or additional processing facilities onshore.

3.3. Recent production tests

The engineering required to model and build safe and reliable methane hydrate extraction technologies has become quite advanced.[46] It is already possible to produce methane from some hydrate fields, the onset of profitable extraction may be soon. This places the timeline of development of methane hydrates between the current commercial development of the new technologies of shale oil and the on-going research and development of carbon capture and sequestration (CCS) technologies. While methane hydrates are not in commercial development, functional wells have been tested both onshore and offshore, one methane hydrate field in Soviet-era Russia was operated for decades. While technology improvements are expected, basic methane hydrate extraction technology is operational today. The commercial development of methane hydrates primarily awaits clarification of the legal environment and commercially feasible pricing structures.

Soviet-era Russian scientists were the first to identify naturally formed methane hydrates in permafrost areas[47] and offshore subsea.[48] Due to those experiences, Class 1 fields are known to be capable of producing safely over long periods, if other conditions are in place.[49] In other words, Class 1 fields are technologically feasible today.

46 Walsh *et al.*, *supra* at note 19.

47 A Class 1 field in Soviet-era Siberia called Messoyahka was the first known methane hydrate field to go into production. It was develop as a conventional natural gas field, and then began to display an unusual yet superior production curve; eventually it was determined that a methane hydrate resource overlay the known natural gas field and that production of the gas was causing the hydrates to disassociate yield methane alongside the conventional natural gas. The produced gas was used for industrial purposes for many years. *See* A. Demirbas, *Methane Hydrates as Potential Energy Resource: Part 1–Importance, Resource and Recovery Facilities*, 51 Energy Conversion Mgmt. 1547 (2010), and *see* Makogon, Holditch, & Makogon, *supra* at note 7.

48 Englezos & Lee, *supra* at note 3, at 672, citing to Y. F. Makogon, *Natural Gases in the Ocean and the Problems of Their Hydrates*, 11 Express-Information 1 (1972).

49 Demirbas, *supra* at note 47.

The Japanese government has set a technological development goal to complete a Phase III of research and development by the close of 2017; 2018 is set to be the year of the onset of Japan's commercial development of methane hydrates.[50]

Early testing of methane hydrates has been underway since the late 1990s. There have been internationally coordinated extraction efforts in onshore Alaska and Canada and offshore Japan. The onshore testing at the Mallik Gas Hydrate Production Research Well in arctic Canada proved that methane hydrates could be reliably and sustainably extracted and produced.[51] Mallik additionally demonstrated that off-the-shelf technology could be employed to extract and produce certain classes of methane hydrates.[52]

Japan's Oil, Gas and Metals National Corporation. (JOGMEC) reported its first successful continuous production from offshore reservoirs in March 2013.[53] The researchers announced that they had successfully produced methane from a deep ocean Class 1 methane hydrates reservoir. The hydrate reservoir was located 300m below the mudline. The Japanese Ministry of Economy, Trade and Industry reported that the research vessel Chikyu had extracted methane from a reserve near the Daini Atsumi Knoll off the coasts of Atsumi and Shima peninsulas in the Nankai Trough, 80 kilometers south of central Honshu.[54]

The method recently employed by the Japanese research team in its offshore continuous production testing employed depressurization to drop the pressure in the reservoir below the equilibrium value at the system temperature.[55] The Japanese team installed a pump at the bottom of the well to remove initial methane volumes; this drop in gas pressure produced a suction that enabled additional the emission of additional methane volumes from the deposits.[56] As methane is removed from the well and pressure continues to be reduced near the well bore, the lower pressure is propagated throughout the production zone. [57]However, this pressure drop also coincides with a reduction in temperature, so not all of the methane will disassociate from the deposit systems.[58] Thus, the operators retain an ability to cease

[50] *See* report from Methane Hydrates 21, *available* at http://www.mh21japan.gr.jp/english/wp/wp-content/uploads/ca434ff85adf34a4022f54b2503d86e92.pdf.

[51] Mallik is an onshore permafrost testing location, located on Richards Island in the Mackenzie Delta of northern Canada. R. Boswell, *Resource Potential of Methane Hydrate Coming into Focus*, 56 J. Petroleum Sci. Engineering 9, 12 (2007).

[52] *Id.*

[53] *See Flow Test From Methane Hydrate Layers Ends*, in: TECHNICAL REPORT (JOGMEC, March 2013); *available* at http://www.jogmec.go.jp/english/news/release/news_01_000005.html?recommend=1

[54] Tabuchi 2013. *See also Gas Production from Methane Hydrate Layers Confirmed,* In: JOGMEC NEWS RELEASES (2013) *Available* at http://www.jogmec.go.jp/english/news/release/release0110.html?recommend=1. *See also* "Japan extracts gas from methane hydrate in world first." BBC News, Business. March 12, 2013. *Available* at http://www.bbc.co.uk/news/business-21752441.

[55] Walsh *et al.* 2009; Castaldi, Zhou, & Yegulalp, *supra* at note 31; Englezos & Lee, *supra* at note 3.

[56] KURIHARA *ET AL.*, *supra* at note 24.

[57] *Id.*

[58] *Id.*; Marcelle-De Silva & Dawe, *supra* at note 16, at 227.

down-hole disassociation processes by observing the ambient downhole temperatures.[59]

This early success in extraction and production follows the investment of hundreds of millions of dollars by Japan into the eventual commercialization of methane hydrate extraction and production.[60] Japan expects to complete its extraction feasibility research and to be ready to begin commercial extraction activities by 2018.[61]

While a variety of hydrocarbons could be found in hydrate formations, historical experience has found methane to by far the most prevalent hydrocarbon present in methane hydrate formations. Tests at Mallik found a range of C_2 through C_5 hydrocarbons, but methane predominated at 98% to 100% of all recovered hydrocarbons from the well over time.[62] Propane and carbon dioxide were the main components of the remaining less-than 2% of the recovered gases.[63]

4. National research programs and agendas

Methane hydrates are targeted by certain countries as both strategic energy policies and as industrial growth targets. Particularly those countries with both extensive methane hydrate resources and sophisticated oil and gas extraction technologies, such as Japan and the United States, are engaged in these methane hydrate feasibility studies. Moridis notes the strategic pattern of government-led investment in lieu of private-led investment; he suspects that this is due to the strategic need for energy supplies trumping profitability concerns.[64] If he is correct, then the timing of technological activation may not wait for traditional notions of commercial feasibility but rather subsidized feasibility.

An immediate observation is the shortness of the list of heavily invested countries. Partially, this is due to the overall centralization of the oil and gas industry.[65] Most of the major oil and gas companies derive from Anglo-American

59 KURIHARA *ET AL.*, *supra* at note 24. The actual heat in a most simple case is from both the over- and under-burden of the deposit. That latent heat and initial gas removal triggers a certain amount of methane disassociation, but the disassociation process it self cools the deposit and returns it to within a stable zone for hydrate formation, ceasing the disassociation process. Additional efforts at pressure reduction is required to facilitate on-going production and extraction.

60 Tabuchi. 2013.

61 *Gas Production from Methane Hydrate Layers Confirmed*, in: JOGMEC NEWS RELEASES. March 12, 2013. *Available* at http://www.jogmec.go.jp/english/news/release/release0110.html?recommend=1.

62 Englezos & Lee, *supra* at note 3, at 672.

63 *Id*.

64 Moridis *et al.*, *supra* at note 25, at 19.

65 This is partially a result of the costs structures of modern oil and gas operations which require extremely large initial investments with relatively small marginal costs of operation. This is the definitional essence of a natural monopoly and it has led to decades of acquisitions, mergers and consolidations across the industry. There is also an interesting pricing dynamic wherein the upstream and downstream sectors of the industry tend to be counter-cyclical which encourages many companies to ensure a balanced portfolio of upstream and →

roots, even when not derived from the Rockefeller/Standard Oil family of companies. The other major private oil companies, of which there are surprisingly few at any substantial scale of size, maintain their primary research and development center near the employable clusters of oil and gas scientists. The vast majority of these research and development centers are near a small number of cities around the world. Thus, while oil and gas operations may be scattered around the world, the technical elite of that industry are not and their research efforts remain clustered.

Next, the technology of methane hydrates is dependent on a few critical bottlenecks. Methane hydrate surveying relies on massive computation capacity, so called "big data" machines. The ocean vessels used for methane hydrate surveying are in short supply. There are few trained scientists who have specialized in this so-far niche of oil and gas research. These bottlenecks and others like them have reduced the opportunity for anyone but the major investors to have access to the necessary technology and researchers.

This small set of knowledge-holders creates a fundamental problem of asymmetrical information, for both the commercial issues and on the environmental safety issues.

Beyond the problem of their limited membership, those parties are additionally reluctant to share scientific data and technology due to both commercial and legal reasons. The first corporations to reduce the cost structures of methane hydrate production stand to earn a lot of revenue, even if they only license the technology to other parties or states. Also, for a variety of intellectual property rights and scientific validation needs, data and technology does not readily become available to non-investing countries and individuals.

The major national investors are Japan, South Korea, the United States, China and India. Norway and Russia appear very motivated in methane hydrate research, but there is very little in public sources to provide financial estimates on their methane hydrate investments.[66] Australia, Canada and the U.K. have been historically engaged in methane hydrates, but their major oil corporations are indistinguishable from their American affiliations, so much of that research shows up hereunder as American research. Germany does have a research agenda into methane hydrates but its research program appears to be primarily focused on the potential to use methane hydrates for carbon sequestration.

downstream assets. And finally, the emergence of the national oil corporations has provided competition for the private oil companies, driving them to gain scale to better match the investment capacity of the national oil companies.

66 The evidence from Russia primarily exists in the form of scientific publications, which were often on co-sponsored cruises with American or Japanese researchers. The data from Norway appears primarily from PowerPoint presentations that have been placed on the internet, albeit apparently without first removing the private and proprietary labels. *See* T. Reichel & J. Husebø, *Gas Hydrate as a Resource – Statoil's Hydrate Initiative* (Technical report, Statoil, Exploration Global New Ventures, 2011), as an example of such a report.

4.1. *Japan*

Japan's severe shortage of domestic energy supplies has driven it to pursue one of the most advanced methane hydrate research programs.[67] Japan's reserves of methane hydrates have been estimated to be able to provide Japan with enough methane to power it for a century.[68] While the United States may defer commercial investment in methane hydrates till the shale boom subsides, Japan does not have shale oil or gas to exploit – Japan will likely march on to commercial development before the United States.[69] Ray Boswell, the technology manager for methane hydrates at the U.S. Department of Energy, has said that he expects Japan to attempt to reach commercial feasibility by 2015.[70]

There are seven major methane hydrates reservoir systems offshore of Japan.

Offshore Shikoku and Honshu:

- The Nankai Trough.[71]
- The Hyuga Nada.[72]

Offshore Hokkaido:

- The Okushiri Basin.[73]
- Offshore of Tokachi-Hikada.[74]
- Offshore of Abashiri.[75]
- The West Tsuguru Basin.[76]
- Offshore, east of the Boso Penisula.[77]

In quest of this abundant and nearby energy supply, Japan began its Japan National Gas Hydrate Program in 1995.[78] Japan has remained committed to reaching

67 J. F. Gabitto & M. Barrufet, *Gas Hydrates Research Programs: An International Review* (Technical report, Prairie View A&M University, 2009).
68 *Id.*
69 N. Jones, *Gas Hydrate Tests to Begin in Alaska*, 1038 Nature News 9758 (2013).
70 *Id.*
71 Gabitto & Barrufet, *supra* at note 67.
72 *Id.*
73 *Id.*
74 *Id.*
75 *Id.*
76 *Id.*
77 *Id.*
78 Makogon, Holditch, & Makogon, *supra* at note 7; COMMITTEE ON ASSESSMENT OF THE DEPARTMENT OF ENERGY'S METHANE HYDRATE RESEARCH AND DEVELOPMENT PROGRAM (NATIONAL RESEARCH COUNCIL (US)), EVALUATING METHANE HYDRATE AS A FUTURE ENERGY RESOURCE. REALIZING THE ENERGY POTENTIAL OF METHANE HYDRATE FOR THE UNITED STATES. (National Academies Press, 2010) (Hereinafter *DOE Methane Hydrate Assessment*).

feasibility of commercial methane hydrate extraction and methane production by 2016.[79]

As early as twenty years ago, the annual research budget for methane hydrates exceeded four million USD. [80] As part of the initial stages of their national methane hydrate research program, Japan had originally budgeted 10 million USD for a 5 year program; those budgets were soon expanded.[81] In 2001, the annual budget was raised to 15 million USD.[82] To better facilitate methane hydrate research, the Japanese Ministry of Economy, Trade and Industry created the Japan Methane Hydrate Exploitation Program (JMHEP) in 2004.[83] Semi-privately, the Japan Oil Gas & Metals National Corporation (JOGMEC) has progressed an integrated methane hydrate research program.[84] It was this same JOGMEC effort that achieved sustained offshore production of methane hydrates in 2013.

Japan is committed to not only the break-throughs required for methane extraction but also the whole of support technologies that industry will need to be able to support in order to build the new methane hydrate production infrastructure. Japan currently coordinates its methane hydrate research through the Japanese Research Consortium for Methane Hydrate Resources in Japan, also known as the MH21 Research Consortium.[85] The MH21 Research Consortium provides private/public alignment on research by coordinating the efforts of JOGMEC, the National Institute of Advanced Industrial Science and Technology (AIST) and the Engineering Advancement Association of Japan (ENAA).[86]

Japan has been actively engaged in international methane hydrate research projects. With American researchers, Japanese scientists have coordinated research into combining Carbon Capture and Sequestration (CCS) technologies with methane hydrate extraction.[87] Japan also coordinated with the U.S.'s National Science Foundation to research methane hydrate deposits in the Nankai Trough. JOGMEC has joined the U.S.'s Chevron-led Joint Industry Project, which focus on researching methane hydrates in the Gulf of Mexico.[88] The ties between Japan's and America's research are coordinated at high levels of diplomacy; on June 6, 2008, U.S. Secretary of Energy Samuel Bodman and the Japanese Minister of Economy, Trade, and Industry concluded a Statement of Intent for cooperation in methane research and development.[89]

With Russian researchers, Japanese researchers explored for methane hydrates under the Okhotsk Sea near Sakhalin Island. Korean, German, and Belgian

79 Englezos & Lee, *supra* at note 3; DOE Methane Hydrate Assessment, *supra* at note 78.

80 Gabitto & Barrufet, *supra* at note 67.

81 Makogon, Holditch, & Makogon, *supra* at note 7.

82 *Id*.

83 Englezos & Lee, *supra* at note 3; DOE Methane Hydrate Assessment, *supra* at note 78.

84 DOE Methane Hydrate Assessment, *supra* at note 78.

85 Gabitto & Barrufet, *supra* at note 67.

86 *Id*.

87 E. ALLISON & R. BOSWELL, DEPT. ENERGY, METHANE HYDRATE, FUTURE ENERGY WITHIN OUR GRASP, AN OVERVIEW, (2007).

88 Gabitto & Barrufet, *supra* at note 67.

89 *Id*.

researchers were also present on that research mission.[90] With French researchers, Japanese scientists worked to improve the seismic data from the Nankai Trough.[91] In Canada, Japan has played a leading financial role in supporting research at the Mallik research facility in northern Canada. JOGMEC has played a leadership role in the developing research at Canada's Mallik Field.[92]

4.2. *South Korea*

Following Japan's lead, in 2000, South Korea initiated the "Korean Gas Hydrate Research and Development Project."[93] South Korea announced a 10-year plan, to cover 2005-2015, to reach commercial feasibility of methane hydrate production. Matching Japan's ambition, South Korea has announced its goals to reach commercial feasibility a year ahead of Japan, in 2015.[94]

Approximately 25M USD annually was budgeted for this research program.[95] That budget follows on the success of a 5-year program that prior to its onset. That previous program was funded at 5M USD annually.[96] Given the contrast against Japan, it would appear that Korea has publicly committed to greater annual expenditures on methane hydrate research; indeed, contrasted with public U.S. data, Korea would appear to be supporting the largest methane hydrate research program in the world. However, the U.S. has much of its investment in alternative energy funnelled through DARPA, obscuring some of its funding, and Japan is not expected to be fully disclosing its private-side investments into methane hydrates.

Estimates suggest that the Ulleung Basin contains over 30 years worth of methane at current Korean levels of consumption.[97] Initial production is scheduled to begin after 2015.[98]

The Gas Hydrate Research and Development Organization (GHDO) manages government coordinated research on methane hydrates; funding is provided by the Korean Ministry of Commerce, Industry, and Energy (MOCIE).[99] The Korea National Oil Co. (KNOC), the Korea Gas Corporation (KOGAS) and the Korea Institute of Geosciences and Mineral Resources (KIGAM) are the leading institutions pursuing research into methane hydrate production.[100]

Early research in the Ulleung Basin was approximately 90 miles east of the coastal city of Pohang and 60 miles south of Ulleung Island.[101] One of the world's

90 *Id.*
91 *Id.*
92 Englezos & Lee, *supra* at note 3; Gabitto & Barrufet, *supra* at note 67; DOE Methane Hydrate Assessment, *supra* at note 78.
93 DOE Methane Hydrate Assessment, *supra* at note 78.
94 DOE Methane Hydrate Assessment, *supra* at note 78.
95 Gabitto & Barrufet, *supra* at note 67.
96 Gabitto & Barrufet, *supra* at note 67; Makogon, Holditch, & Makogon, *supra* at note 7.
97 Gabitto & Barrufet, *supra* at note 67; DOE Methane Hydrate Assessment, *supra* at note 78.
98 Gabitto & Barrufet, *supra* at note 67.
99 *Id.*
100 *Id.*
101 *Id.*

thickest methane hydrate deposit layer was found within the Ulleung Basin deposit, it measured 130m deep. [102]

In its annual report of 2009, KNOC announced its corporate target to become a top fifty oil corporation, with the goals of an annual production volume of 300K BOE/d reserves in excess of 2 billion BOE.[103 ,104]In order to accomplish those targets, KNOC has targeted three technology goals: oil sands, Gas-to-Liquids (GTL) technology and gas hydrates. [105]

Korea surely is matching its methane hydrate commercialization and technology goals against the goalposts of the Japanese government; it remains to be seen which country will succeed first. But it should not be underestimated how critical the development of methane hydrates is to both countries and that the ultimate manifestation of commercial development is likely not constrained by shale gas developments else. Both Japan and Korea need local gas supplies that are both stable in volumes and pricing to become more cost competitive in other industrial areas. Because of these unique factors, Japan and Korea may be the first nations to bring commercial methane hydrate developments forward.

4.3. United States of America and Canada

It is difficult to speak of separate research agendas between the United States and Canada; while the American side is clearly the dominant program they are so interwoven as to be inseparable. The United States possesses onshore permafrost methane hydrates deposits that are very similar to Canada's permafrost deposits. Both countries also have similar Arctic offshore methane hydrate deposits. In these areas, Canada and the United States are closely engaged together.

The United States has warm water hydrates offshore all three coasts, the Pacific, the Atlantic and the Gulf of Mexico. But the United States has primarily focused its extraction and production research on Arctic permafrost locations.

Most of that research that has occurred in Canada has, in fact, been funded, or jointly funded, by U.S. and Japanese interests.[106] Methane hydrate research in Canada has centered on the gas hydrates found offshore Vancouver Island and in the permafrost of the Mackenzie Delta. [107] Because Canada has coordinated with the United States permafrost-based methane hydrate project at Mallik, in the Mackenzie Delta, the Mallik gas hydrates have become probably the most studied gas hydrate deposit in the world. [108]

The United States has several perspectives on methane hydrates. First, its has seen methane hydrates as an alternative source of methane for its military assets.

102 *Id.*
103 *Id.;* Korean National Oil Corporation's 2009 Annual Report, *available* at http://www.knoc.co.kr/ENG/sub04/sub04_4_7.jsp.
104 *Id.*
105 Gabitto & Barrufet, *supra* at note 67.
106 DOE Methane Hydrate Assessment, *supra* at note 78.
107 *Id.*
108 *Id.*

However, due to the lack of utility of methane for both road vehicles and aircraft, methane hydrates have not been a priority target for military fuels needs.

Second, the United States has seen methane hydrates as an exploitable resource in alternative to expensive imports of LNG or crude oil. However, the development of shale oil, tight gas, and shale gas technologies has greatly relieved whatever tightness in energy supplies the United States had expected to encounter. For this reason, the commercialization of methane hydrates has dropped in priority; but research has neither ceased nor slowed down. It appears that the implementation of methane hydrate technologies is being keyed against certain cost structures that reveal that for the United States the commercialization of methane hydrates will need to be self-sustaining on a profitable basis. This is somewhat different from Japan and Korea, in that they face substantially higher LNG prices than domestic natural prices in the United States.

The U.S. was probably the earliest non-Soviet nation to publicly support research into the extraction and production of methane hydrates.[109] While the United States is the oldest and perhaps largest methane hydrate research program, it is also the hardest on which to get solid details. One of the problems with collecting data is the lead role played by both private research interests such as Chevron and ExxonMobil and the role played in American research science of the Defense Advanced Research Projects Agency (DARPA). Both the corporate sponsors and DARPA have extensive reasons for keeping their research agendas and results discrete. So the publicly available data on methane research funding are generally seen as floors, not ceilings, of funding.

As an example of the confusion in the funding of methane hydrate research in the United States, in 2000, Congress approved an annual budget of 33M USD to last five years until 2005.[110] Congress eventually cut the annual budget allotment to just 9M USD.[111] The funding gap was not to last long, by 2005, methane hydrate research was allocated 155M USD.[112] The U.S. national research plan has expected 35.3 Tcf of domestic methane to be commercially booked as reserves from methane hydrates before 2020.[113] A decade plus ago, a lead researcher at the USGS, Timothy Collet, estimated that first commercialization could occur before 2015.[114] Those estimates now appear, with the benefit of time, to speak more to technological capacity than market driven demand.

109 Makogon, Holditch, & Makogon, *supra* at note 7.
110 Gabitto & Barrufet, *supra* at note 67.
111 *Id.*
112 Makogon, Holditch, & Makogon, *supra* at note 7.
113 Englezos & Lee, *supra* at note 3.
114 R. A. Kerr, *Gas Hydrate Resource: Smaller But Sooner*, 303 Science 946 (2004).

4.4. *China.*

China annually increases its energy consumption at a rate approximately equal to France's national energy demand;[115] it currently meets much of that demand with crude oil and coal. It has phenomenal air pollution problems to its reliance on coal for both electrical supplies and industrial heat. When China does import natural gas as LNG, it faces competitive pricing from Japan and South Korea; it often pays substantially higher net gas prices than either Europe or North America. China could address these challenges, in part, by developing its methane hydrate resources.

It is difficult to find accurate numbers on the scale of China's investment in methane hydrates. From the listings of published research articles viewable in online scholarly databases, it is clear that methane hydrate research is extensive within China.

China appears to have begun methane hydrate research in the late 1990s.[116] China created the Guangzhou Center for Gas Hydrate Research in 2004.[117] In 2007, the Guangzhou Center announced that its research mission entitled GMGS-1 had discovered substantial methane hydrate deposit areas in the South China Seas.[118] GMGS-1 was a drilling program, and at least eight sites were drilled, and three of the eight reported thick layers of methane hydrates.[119] Methane hydrates deposits 15m to 20m thick were located within seabed deposits of the South China Seas.[120]

Overall, while the data is not necessarily robust, it appears that many observers suspect minimal annual research budgets of 10M USD for over two decades, demonstrating China's sustained commitment to methane hydrate development. Records suggest that 60M USD was spent on research from 1999 till 2007, averaging 10M USD a year. The Guangzhou Center manages China's methane hydrate research programs. [121] At its establishment, China planned an initial investment of 50M USD.[122] In 2006, China publicly announced that it would provide an annual research budget of 10M USD.[123] These budgets appear to provide a stable research budget of approximately 10M USD per year.

115 G. Traufetter, *China And India Exploit Icy Energy Reserves: Warning Signs on the Ocean Floor* (Der Spiegel, 2007)
116 Makogon, Holditch, & Makogon, *supra* at note 7.
117 DOE Methane Hydrate Assessment, *supra* at note 78.
118 *Id.*
119 *Id.*
120 Traufetter, *supra* at note 115.
121 DOE Methane Hydrate Assessment, *supra* at note 78.
122 Makogon, Holditch, & Makogon, *supra* at note 7.
123 Demirbas, *supra* at note 47; Gabitto & Barrufet, *supra* at note 67.

4.5. India.

India's National Gas Hydrate Program (NGHP) is established under the Indian Directorate General of Hydrocarbons.[124] India has substantial methane hydrate deposits in four key areas.[125]

West Coast - Arabian Sea

- Konkan Basin offshore of Goa.[126]

East Coast - Bay of Bengal

- Krishna-Goad Ayari Basin offshore of Kakinada. [127]
- Mahanadi Basin offshore of Orissa. [128]
- Offshore the Andaman Islands. [129]

India's research budget is very unclear, but the substantial spend is obvious. The NGHP recently commissioned the 104m long Sagar Nidhi, a special purpose methane hydrate research vessel. [130] The NGHP has also commissioned manned research submersibles that can dive to a depth of 6000m. [131]

India began drilling offshore exploratory wells in 2006. [132] The NGHP conducted those well tests with the assistance of the U.S.'s USGS.[133] The NGHP drilled 39 holes at 21 test sites offshore India; methane hydrates were found at most of the test sites.[134] The deposits are rich, *e.g.*, a 128m thick gas hydrate layer was found in one of the test wells. [135] There are no known sustained production tests from those wells,[136] but as Japan demonstrated in 2013, it could soon be feasible in India as well. India has collaborated with Russia on methane hydrate research for decades. [137] As a part of that relationship, India opened the the Indo-Russian Center for Gas Hydrates (IRCGH) in Chennai on March 12, 2004.[138]The IRCGH is a body of the National Institute of Ocean Technology, also located in Chennai. [139]

124 Gabitto & Barrufet, *supra* at note 67.
125 *See* map at Appendix E.
126 Gabitto & Barrufet, *supra* at note 67; Boswell, *supra* at note 51.
127 *Id.*; *id.*
128 *Id.*; *id.*
129 *Id.*; *id.*
130 Gabitto & Barrufet, *supra* at note 67.
131 *Id.*
132 Demirbas, *supra* at note 47.
133 DOE Methane Hydrate Assessment, *supra* at note 78.
134 *Id.*
135 Gabitto & Barrufet, *supra* at note 67.
136 Demirbas, *supra* at note 47.
137 Gabitto & Barrufet, *supra* at note 67.
138 *Id.*
139 *Id.*

5. Other benefits of methane hydrates

5.1. Carbon capture and sequestration (CCS)

The production of methane hydrates enables the potential sequestration of other GHG in the methane-depleted hydrates.[140] Research and testing has begun on the potential to leverage industrial CO_2 emissions in the production of methane hydrates, sequestering one fossil fuel in exchange for another.

Ultimately, the production of methane hydrates could fit hand-in-glove with carbon capture systems/sequestration (CCS) technologies.[141] *E.g.*, the German government's SUGAR Projekt and its ECO_2 project are designed with the goal of storing industrially produced carbon dioxide in methane hydrate deposits; the methane extraction is seen as a cost-recovery feature.[142] In the case of methane reforming, it might be possible for the carbon dioxide by-products to be returned to the reservoir in lieu of the methane.[143]

Research has been undertaken to find ways to optimize the CCS potential of offshore methane hydrates within other energy projects. Hydrogen fuel could be produced from the methane hydrates and the by-product carbon dioxide could be sequestered; methane hydrates would yield a fully green carbon-neutral energy supply.[144] Japanese researchers have investigated the potential to combust the methane from the offshore methane hydrates on site to generate electricity; again the by-product carbon dioxide could be sequestered and enable low-carbon electricity to arrive onshore by wire.[145]

All of the main methods of extraction[146] can be combined with the sequestration of other gases into the hydrate lattice; research has focused on replacing methane with carbon dioxide to covert this fossil fuel extraction process into a carbon neutral or carbon negative activity with attendant benefits against anthropogenic climate change.[147]

140 R. Kikuchi, *Analysis of Availability and Accessibility of Hydrogen Production: An Approach to a Sustainable Energy System Using Methane Hydrate Resources*, 6 Environment, Development & Sustainability 453, 467-468 (2005).

141 Castaldi, Zhou, & Yegulalp, *supra* at note 31.

142 *See* more at the SUGAR website; *available* at http://www.geomar.de/en/research/fb2/fb2-mg/projects/.

143 Kikuchi, *supra* at note 140, at 467-468.

144 W. Rice, *Hydrogen Production from Methane Hydrate With Sequestering of Carbon Dioxide*, 31(14) Int'l J. Hydrogen Energy 1955, 1957 (2006). *See* a similar proposal by Japanese researchers, Kikuchi, *supra* at note 140.

145 S. Maruyama et al., *Proposal for a Low CO_2 Emission Power Generation System Utilizing Oceanic Methane Hydrate*, 47 Energy 340, 342 (2012).

146 *See infra* at sec. 3.4.

147 Englezos & Lee, *supra* at note 3.

5.2. *Production of hydrogen fuel*

Hydrogen has been widely advocated as one of the cleanest fuel sources because its combustion with oxygen yields simply energy and water.[148] Should hydrogen transportation be sufficiently advanced, methane hydrates are likely one of the main feedstock for that future.[149]

Via methane reforming, methane hydrates are a major potential source of a global hydrogen fuel supply.[150] Methane hydrates are unique in their coproduction of fresh water and methane enabling hydrogen to be produced at the point source.[151] Methane reforming requires methane as a fuel and a feedstock along with steam.[152] The chemical reaction is endothermic, requiring an energy input such as heat from combusted methane.[153] The resultant carbon monoxide can be converted to carbon dioxide, suitable for re-injection into the hydrate deposit.[154]

5.3. *Co-production of fresh water*

Methane hydrates are composed primarily of water and methane.[155]. While the primary focus in methane production is the reduction of methane from the methane hydrates, there is a tremendous volume of water involved that can be captured as a by-product. The contrast between traditional gas wells, coal bed methane wells and methane hydrate production is essentially a sequence of magnitudal differences.

Table 3: Comparison of Produced Water Volumes

Type of Well	Bbls per Million scf
Conventional gas well[156]	10
Coal Bed Methane[157]	100
Methane Hydrates[158]	1,000

Walsh presented models of economically viable development plans that required 2 water disposal wells for 5 production wells. [159]Walsh *et al.* also contrasted the

148 Kikuchi, *supra* at note 140, at 454.
149 *Id.*, at 465.
150 *Id.*
151 *Id.*, at 467.
152 The reaction equation is $CH_4 + H_2O \rightarrow CO + 3H_2$; methane and water can produce carbon monoxide and hydrogen. *Id.*, at 456.
153 The reaction equation for combusted methane is generally given as $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$; combusting methane with oxygen yields carbon dioxide and water. *Id.*
154 The reaction equation is $CO + H_2O \rightarrow CO_2 + 3H_2O$; carbon monoxide and water can be combined to yield carbon dioxide and water. *Id.*
155 *E.g.*, type sI methane hydrates are composed of 48 water molecules to 8 gas molecules.
156 Walsh *et al.*, *supra* at note 19.
157 C.A. Rice & V. Nuccio, *Water Produced With Coal-Bed Methane*. In: U.S. GEOLOGICAL SURVEY FACT SHEET FS-156-00 (Washington, D.C., 2000)
158 Walsh *et al.*, *supra* at note 19.

production of methane against the production of water; over time the water volumes rise with methane output and matches the production rate changes of the methane.[160]

To date, almost all of the models have associated the production of water as a disposal cost; increased volumes of water are seen as indicative of delayed payouts on the wells.[161] The voluminous production of water could be problematic, as it would require treating, processing and eventual disposal if handled as modelled.

However, there are two alternative methods for addressing the water volumes without the costs of treating, processing and disposal. First, the water volumes could be treated and processed prior to marketing as fresh water volumes suitable for industrial or consumer uses.

Second, there are technologies that would enable the sequestration of carbon dioxide within hydrates. The extraction of the methane could be coordinated with the injection of the carbon dioxide in such a manner that the methane hydrates are transformed into carbon dioxide hydrates. Those carbon dioxide hydrates could potentially enable cost efficient long-term sequestration of the problematic greenhouse gas. But the key to that accomplishment would be the locking of the carbon dioxide gas into the hydrate structures which would require the on-going presence of the water previously associated with the methane hydrates. Thus, a second usage of the water is to keep it in place to assist in the sequestration of carbon dioxide. As such, there would likely be economic benefits provided by those seeing the sequestration services.

5.4. Replacement of LNG with GTS shipping

Natural gas is a cleaner fuel than crude oil or coal, but its use has been limited by the difficulties and costs of its transportation. The technical understanding of methane hydrate formation and disassociation should enable a new and more energy efficient means of methane storage and transportation. This new form of methane transport has been called "Gas to Solids," or more simply GTS;[162] this is in analog to the name of the technology to convert natural gas to oil called "Gas to Liquids," or GTL.

Based on the emerging GTS technologies, methane hydrate transportation systems can be completely ship-based, requiring no local facilities other than methane feed-in pipes or offloading pipes.[163] The lower investment required for methane off-loading should enable a broader and more efficient market in methane; once extracted from the seabed, methane could be economically transported by hydrate shipping in lieu of subsea pipelines.[164]

159 *Id.*
160 *Id.*
161 *Id.*
162 Englezos & Lee, *supra* at note 3, at 676.
163 *Id.*
164 N. J. Kim *et al.*, *Formation Enhancement of Methane Hydrate for Natural Gas Transport and Storage*, 35 Energy 2717, 2718 (2010); Englezos & Lee, *supra* at note 3, at 676. GTS technology has been →

Mitsui Engineering & Shipbuilding Co., Ltd. built a pilot GTS plant to convert natural gas into hydrate pellets that can be stored at -15 degrees Centigrade and loaded on-board a ship for transport. [165] In addition to the minimal investment in hydrate storage equipment, it is also safer and easier to ship GTS, versus LNG, because they can be kept stable for several weeks at only -10 to -20 C at atmospheric pressures. [166]

A GTS technology was evaluated for shipments from Iran to various ports in East Asia.[167] A cost estimate study found that the comparable costs of shipping by LNG were approximately a magnitude larger than the costs of shipping by GTS.[168] Based on this magnitude order reduction in costs, it was noted that many smaller isolated natural gas fields that not currently in development could be made commercially feasible with this mode of transport.[169]

In August 25, 2010, the U.S. DOE announced a significant breakthrough in GTS technology.[170] The new GTS technology replaces the previous multi-day batch manufacturing method with a rapid and continuous spray technology to produce transportable methane hydrates on board. This new technology would be quicker and cheaper, require less refrigeration and pressure maintenance, and this form of GTS would lose less methane in shipment than LNG.[171] Similar technologies have been developed in South Korea, demonstrating the global interest in high-speed hydrate shipping technologies.[172]

6. Summary and conclusions

Methane hydrates could potentially serve as an abundant source of methane. As seen in Chapter 2, they are broadly distributed around the globe and would likely provide local energy supplies to many nations currently lacking such supplies.

Methane hydrates provide both fresh water and methane when exploited. The extraction of methane hydrates can also be coordinated with carbon capture and sequestration (CCS) in replacing the extracted methane with carbon dioxide.

Methane from methane hydrates is potentially a source of green energy. Methane, when combusted, provides far less greenhouse gas emissions than either coal or crude oil, and clean methane as derived from methane hydrates lacks the uranium ash pollution of coal or the other hazardous substances that can be emitted by combusted coal and crude oil. Methane from methane hydrates can be reformed

reported to be economic in the short and medium distances (less than 5,000 km) and low to medium volumes (less than billion cubic meters) that are not feasible for LNG investments.

165 Englezos & Lee, *supra* at note 3.

166 *Id*.

167 J. Javanmardi *et al., Economic Evaluation of Natural Gas Hydrate as an Alternative for Natural Gas Transportation*, 25 Applied Thermal Engineering 1708, 1718 (2005).

168 *Id*., at 1720.

169 *Id*., at 1721. *See also* Kikuchi, *supra* at note 140, at 468-469.

170 *DOE national laboratory breakthrough could enhance use of domestic natural gas, methane hydrate resource*. In: TECHNICAL REPORT (Department of Energy of the United States, 2010).

171 *Id*.

172 Kim *et al*., *supra* at note 164, at 2722.

with steam from the extracted freshwater to produce hydrogen fuel. The methane could be combusted on platform to generate electricity and the greenhouse gas emissions could be re-injected into the hydrate deposit via CCS technologies. All of these pathways enable a potentially greener and healthier alternative to the volumes of coal and crude oil combusted today.

A key question must arise, if methane hydrates are so potentially useful, why aren't they already more fully developed? As explored previously, the scientific knowledge and awareness of methane hydrates in natural settings is a fairly recent development. Since their discovery in the 1960s and 1970s, it has taken a couple of decades to develop sufficient scientific knowledge to begin engineering studies on offshore methane hydrates.

Recently, the engineering potential to reliably extract offshore methane hydrates in continuous operations has been demonstrated. Field and laboratory experiences have now demonstrated a variety of potential means of extraction. What was once unfeasible has become feasible; engineers are now focused on improving safety and reliability of the extraction systems and on reducing the costs of extraction.

Since the mid 2000s, the costs of producing offshore methane hydrates have been in potential range of commercial demands. While the U.S. benefits from abundant domestic natural gas supplies and sees natural gas prices in the 3 to 6 USD range,[173] Japan and other East Asia countries have paid high premiums for imported LNG, sometimes well over 15 USD for extended periods. As such, the concept of commercially feasible is dependent on the regional market conditions; natural gas does not have as global a price market as crude oil does. Financial studies have demonstrated that certain offshore methane hydrate extraction systems might be within several dollars per kcf of the costs to extract conventional natural gas from offshore locations. Other studies have found that the as of several years ago that the costs difference between producing conventional offshore natural gas and offshore methane hydrates was an increase of approximately 15% to 20%. If the variations in natural gas prices are more divergent than the divergence in the costs of production, then under some circumstances, the extraction of offshore methane hydrates might be already commercially feasible. Key scientists associated with the development of the engineering of such offshore methane hydrate extraction technologies expect the cost structures of offshore methane hydrates to continue dropping so that by the 2020s the costs structures should be competitive at a broader range of natural gas prices and at various offshore methane hydrate locations.

Given the development of science and engineering, the falling costs of methane hydrate extraction, and the potential benefits of methane hydrates, it would appear reasonable that methane hydrate operations would be pursued by a variety of

[173] Since 1998, the price of natural gas at Henry Hub, a major selling point in the U.S., has hovered below 5 USD. There have been short periods above that barrier, *e.g.* in 2008, but not long-term. *See* the data both in chart and in graphics at the EIA. *Available* at http://www.eia.gov/dnav/ng/hist/rngwhhdm.htm. *See* current spot prices at Bloomberg Energy. *Available* at http://www.bloomberg.com/energy/.

actors, both public and private. Such is indeed the fact, as both private energy companies and national governments have coordinated in the development of offshore methane hydrate technologies. This development has not been limited to developed countries nor to traditional private oil corporations. Developing countries, such as China and India, and public/private investment co-operations such as the Korean Oil Company (KNOC) and Korea Gas (KoGas), have expanded the theatre of actors engaged in developing the nascent technology to extract and produce energy from offshore methane hydrates.

So, if methane hydrates are so potentially useful, if they are becoming ever more feasible to commercial extract and produce, and if an array of public and private actors are engaged in those developments, then why aren't there more fully developed commercial plans for the imminent investment in large scale offshore methane hydrate installations?

One of the major reasons is the potential for offshore methane hydrates to present a unique set of risks of hazards that are quite distinct from traditional offshore oil and gas ventures. While the potential harms and damages from major oil spills are too well known, thanks to well-known events such as the 1989 Exxon Valdez and the 2010 BP Macondo incidents, the unique nature of methane hydrates will present novel forms of risk and hazards. Chapter 4 undertakes a review of these risks, but in preview it can be said that unlike in oil spills, methane hydrates will almost exclusively leak, vent or seep methane gas, not crude oil, tars, or other viscous liquids. Additionally, because of the softer structures that methane hydrates form within, the disturbance of those hydrate deposits can lead to sloughing or slippage of wide fields of earth, potentially enabling subsea landslides, earthquakes, and tsunamis. Such methane hydrate events have naturally occurred; subsea scars can be located on both sides of the Atlantic Ocean demonstrating that massive methane hydrate fields have collapsed in geological history. The potential exists for human interaction in offshore methane hydrate fields to unleash both cataclysmic and non-cataclysmic forms of damage.

If the benefits of methane hydrates are to be obtained by both public and private parties, then some legal policy should be developed that can provide an optimal balancing of the obtainable benefits against the potential risks and hazards. The tools of rules of civil liability, public regulation and private regulation can all be explored as a means to set the optimal precautionary standards. By carefully choosing which of those tools to employ, liability or other enforcement consequences can be assigned to those parties best able to attain those optimal levels of methane hydrate operational activities and of precautionary efforts. By clarifying *ex ante* the standards and the actors held responsible, investment decisions can be more clearly and rationally undertaken in offshore methane hydrate installations. Additionally, such clarifications can also provide incentives to invest in the development of superior extraction technologies, precautionary technologies, and in monitoring and remediation technologies; as such capabilities might impact the overall level of expected risks and hazards.

Further, by engaging in this standards setting process prior to the onset of the first offshore methane hydrate installation, there is an opportunity to set standards that can be replicated at subsequent fields around the globe. As many locations of offshore methane hydrates are in areas either new to offshore energy resources or economically or legally developing, it would enable those jurisdictions to have a better chance at sustainably operating their own fields.

Chapter 4 will explore those potential risks and hazards and attempt to provide characterization and categorization of those hazards and harms. Part II of this study will then undertake to examine what kind of legal mechanisms might provide the correct set of precautionary standards and economic incentives to align operators, and other parties if necessary, with those standards. Part III of this study will explore existing laws and conventions for their fit against the conclusions of Part II. Part IV of this study will provide a review of all of the above and suggest how the existing legal paradigms might be best adapted to the circumstances of offshore methane hydrates.

Chapter 4

HAZARDS OF OFFSHORE METHANE HYDRATES

The production of methane from methane hydrates will carry unique risks and hazards to the environment not present with the production of traditional natural gas. As seen in the Japanese environmental assessment, [1] the commercial development of methane hydrates contains a mixture of risks, those common to all offshore mining and those unique to methane hydrates.[2]

What is unique to methane hydrates is the methane hydrate structure itself. The greatest unique environmental problem is the uncontrolled release of methane hydrates. [3] While the science is not yet comprehensive, it appears that from a planning perspective there are two basic scenarios: events that damage the methane hydrate stability so that it seeps methane on a continual but non-cataclysmic basis and those events that cause cataclysmic releases of large volumes of methane.

It is also important to remember that the scientific consensus currently supports the idea that methane hydrate events are geologically current and active, that human interference is not beginning from a neutral position with regards to the hydrates. There is a baseline amount of risk with any in-place hydrates, human activity adds onto that baseline.[4]

Secondary concerns include the risk of seabed subsidence. Methane hydrates lay under essentially plastic mud and sedimentary layers, so as the hydrates are moved and the structural support for the overlaying materials are removed, the seabed is likely to deform and sag. Subsidence can impact the subsea structural systems related to the methane extraction and it can impact the local eco-system. Perhaps the greatest concern on subsidence is that it can become a precursor for landslides, which in turn could result in massive amounts of uncontrolled methane eruptions.

1 *See* Table 2 within sec. 3, *infra*.

2 *See* discussion within sec. 3, *infra*.

3 This would be in contrast to traditional oil spill events, wherein the main hazard source is the spilt crude oil and its associated tars.

4 This makes it substantially different from oil and gas reserves trapped under relatively permanent formations.

1. Impacted communities

Due to offshore location of methane hydrates and the broad continuity of methane hydrate distribution, the communities most likely to be impacted by the harms of methane hydrate development are the self-same states in possession of the methane hydrate reserves.[5] This is not to say that the beneficiaries of methane hydrate development are the same communities as those exposed to risks of harm within those states; in most cases they will be distinct and separate communities despite their common nationalities.

The listing of countries and territories exposed to the risks of environmental harms posed by the commercial development of methane hydrates draws a line under the idea that addressing these environmental challenges is a common and global issue.[6] The variety of nations, the variety of economic development, the variety of legal institutions and institutional stability will all increase the regulatory challenges on balancing the interests of revenue seeking groups versus groups seeking sustainable environmental safety and comfort.

First, there are differences in the economic and industrial capacities of the impacted areas. Many of the areas within East Asia, North America and Europe are technologically competent at advanced oil and gas extraction technologies and are well experienced with operational problems generally. These countries are likely to be able to manufacture their own methane hydrate infrastructure and maintain quality control processes in their implementation. Other areas will not be able to self-provide such manufacturing, servicing, and maintenance of methane hydrate facilities. The potential impact is that one side of the list can self-cure its technology concerns whereas the other side will need to seek external assistance or accept lower quality from local sources. Essentially, one group can see the improvement costs as a "multiplier" type benefit of methane hydrate investment but the other group faces pure economic costs.

Second, there are differences in the stability and reliability of the legal institutions of the impacted areas. Some of the locations provide sound due process and broad protection of rights, other areas have less consistently applied legal institutions.[7]

Third, based upon the variety of legal systems and the quality of their institutions, different forms of optimal regulation may be needed in different locations; the optimal solutions may be dependent on local conditions.

5 The maps in the appendices provide similar information in a more graphical format.

6 *See* Table 1, *supra*.

7 For a more complete discussion on these concerns, *see* M. G. Faure, M. Goodwin & F. Weber, *Bucking the Kuznets Curve: Designing Effective Environmental Regulation in Developing Countries*, 51 Va. J. Int'l L. 95 (2010).

Table 1: Countries with Immediate Exposure to Hazards and Harms from Offshore Methane Hydrate Installations

Region	Nations with Risk Exposure
Africa	Algeria, Angola, Benin, Cameroon, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Egypt, Equatorial Guinea, Eritrea, Gabon, the Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Libya, Madagascar, Mauritania, Morocco (including Western Sahara), Mozambique, Namibia, Nigeria, Sierra Leone, Senegal, Somalia, South Africa, Tanzania, Togo, and Tunisia.
ASEAN	Brunei, Indonesia, Malaysia, the Philippines, and many of the smaller islands and nation states of Micronesia and Polynesia.
South Asia	Bangladesh, Burma, India, and Pakistan.
East Asia	China, Japan, North Korea, Russia,[8] South Korea, Taiwan, and Vietnam.
Europe	Albania, Denmark, Finland, France, Greece, Ireland, Italy, Montenegro, Norway, Portugal, Spain, Turkey, and the U.K.
Middle East	Cyprus, Israel, Iraq, Iran, Kuwait, Lebanon, Oman, Saudi Arabia, Syria, and Yemen.
North America	Canada, Caribbean islands,[9] Costa Rica, El Salvador, Guatemala, Mexico, Nicaragua, Panama, and the United States.
South America	Argentina,[10] Brazil, Chile, Columbia, Ecuador, French Guiana, Guyana, Peru, and Suriname.
ANZAC	Australia, including Tasmania, and New Zealand.

Fourth, it is those communities living most closely to the offshore assets that will be affected,[11] which may not well align with the vested power brokers within their countries; it may be useful to provide non-national forums to provide more balanced negotiations between the communities and the national power brokers. Because of the economics of the actors who can afford to invest in methane hydrate commercialization projects versus the economics of the communities likely to be invested in fishing and other forms of sea-born economies, a substantial inequality presents which could prevent serious or substantial efforts to respond to the concerns of the coastal communities. Additionally, if the nation is dependent on the revenues from methane hydrate development, then what political processes exist to address citizen concerns might be out-balanced by strategic and public policy arguments in otherwise democratic forums.

Fifth, many methane hydrate deposits stretch across multiple national borders and EEZ borders. This will cause several problems. Primarily, it raises the general concerns of waste and unitization to provide for multi-party balanced production

8 The eastern Pacific territories of Russia also have substantial methane hydrate reserves offshore including Sakhalin and Kamchatka around the Sea of Okhotsk.

9 Assuming the Caribbean fits more into this area than other areas, practically every island is assumed to have methane hydrates offshore.

10 The U.K.'s Falklands offshore of Argentina are forecasted to possess methane hydrates.

11 The impact need not be immediate; as discussed, *infra* at sec. 3, such damage could of a persistent nuisance such as the loss of marine life from which incomes and food budgets were derived.

and common regard for environmental safety within the unit of production. *E.g.*, North and South Korea's methane hydrates lay contiguous to each other in the East Sea.[12].

Should North Korea decide to begin production of methane hydrates from near a bordering reservoir, then South Korea might fear accelerated depletion of its own adjacent resources and decide to try to match the extraction activity of the North Koreans.[13] While this type of problem exists in ordinary oil and gas production, in that case it merely leads to overproduction, pressure declines, and resource wastage. With methane hydrates, accelerated extraction and production could lead to structural failure of the methane deposit, resulting in cataclysmic methane venting and potential landslides. Environmental considerations to reduce and abate foreseeable hazards may require *ex ante* diplomatic efforts to result in coordinated extraction protocols if not outright unitizations. A coordinated extraction protocol might be created by regulating how closely methane hydrate wells might be located and how wells close to national territories accommodate revenue sharing or volume tracking and sharing.

Sixth, as it is unlikely that most of the resource owners will become methane hydrate technology owners, and similarly that most of the impacted communities and their states will also likely not become methane hydrate technology owners, the ability to actually build, operate, and sustain commercial operations of methane hydrate fields will likely remain in the hands of a few nations without additional measures. This suggests a strong technological asymmetry of responsibility for the accidents from normal operations. There might be several solutions to this problem. One might be to find a way to enable the resource owners to become joint owners of the technology so that their profit seeking aligns with the operators for sustained safety under agreed to regulations. Another is to separately address some of the environmental safety concerns both within the technologically able parties and separately but in parallel discussions with those parties not able to participate technologically in safety management.

2. Life-cycle risk analysis

2.1. Four discernible stages of risk

The commercial development of offshore methane hydrates will not occur in a legal and historical vacuum; it will inherit traditions and institutions from traditional oil and gas and from the more recently developed CCS technologies. Traditional oil and gas has a recognized life cycle of exploration, development, production and

12 What the Koreas refer to as the East Sea, Japan refers to as the Sea of Japan. It is a matter of substantial diplomatic debate, but herein both names are used interchangeably.

13 Similar problems of split jurisdictions over continuous and singular deposits can be found in many places, because the legal jurisdictions do not well correlate with the natural incidence of hydrate formation. Thus, the U.S. and Mexico might have such concerns, as might South Korea and Japan in the East Sea/Sea of Japan or Angola and Namibia in the South Atlantic Ocean.

marketing, and plugging and abandoning P&A). CCS has a similar multi-stage life cycle, albeit the post-injection and long-term storage period is longer than the P&A period of oil and gas projects because the project objective of storage remains active even though external activities may have greatly reduced. In some ways, the final stages of CCS resemble the late stages of CERCLA/RCRA projects requiring monitoring and surveillance for decades or longer. Many of those procedural stages will be similar to the life cycle of methane hydrate projects.

The commercial development of methane hydrates will encounter basically four stages of activity: (i) exploration, (ii) development, (iii) production, and (iv) abandonment and sequestration. The risk profiles are different in all four stages and require different reviews.

2.1.1. Exploration

Exploration is the geophysical search to identify where methane hydrates lay in the seabed and the determination of the potential of production from those discovered reservoirs. The exploration stage for methane hydrates is practically identical for current oil and gas exploration efforts; methane hydrate exploration activities have been underway for several decades with no significant incidents of harm.

Arguendo, exploration is not well framed temporally, in that it can continue indefinitely until a field begins development activities; some oil and gas fields were explored for decades prior to development activities began. Yet, exploration does not generally occur in a continuum, rather, it occurs on specific voyages and specific sounding missions, thus, the specific instances wherein the seabed would be scientifically or engineeringly engaged would be of fairly brief time periods. Routine exploratory seismic or surveillance missions take no more than weeks or a few months to complete, partially due to the costs involved.[14] Thus the risks and hazards associated with exploration missions can be seen in small discrete temporal batches.

2.1.2. Development

Development focuses on activities undertaken in support of making an investment decision to construct and operate a methane hydrate field. Development is the stage associated with installation and construction of the infrastructure and wells needed to produce methane from the deposits; it is the stage within which EIAs will need to be developed and reviewed. Development includes initial well drilling and testing; production and early safety reports during the development phase are critical to decisions on how and if to go on to the production phase. It is during development that most of the actual hazardous activities will be initially undertaken in the specific field.

Development of methane hydrates fields is novel; as of January 2014 there was not a single offshore methane hydrate field in development or in production. While

14 Longer, more precise data are collected during the development stage.

some data and experiences may be transferable from traditional offshore natural gas development, much of the technology and risk involved will be *terra incognita* (perhaps, *mare incognitum*?) for early developers. It will be difficult to forecast appropriate safety levels or insurance premiums; early developers may be faced with severe concerns about sufficient precaution. Early developers will be likewise hampered by their own lack of historical experience with the resource. Given this overall lack of knowledge and presumed novelty of technologies and risks, development may well be the riskiest stage of the four. However, development is usually the most well defined as to timeframe and duration. So while the risks might be high, at least the time frame of those risks will be bounded.

2.1.3. Production

Production is the stage wherein on-going methane extraction and production activities would be sustained for the commercial life of the methane hydrate field. The production period of oil and gas fields normally lasts decades; methane hydrate fields are similarly expected to potentially produce across multiple decades. While production is expected to last for several decades, it can be difficult to forecast field production life because of on-going improvements in production and extraction technologies.[15]

Production will generally begin after initial safety testing and production flow tests are completed within the development stage. Production will focus on the severing, extraction, and lifting of the methane from the deposits. Once lifted, production will also handle the basic processing and treatment of the production stream and transportation of the production volumes to marketing lines or vessels. Production will generally continue to include new in-field drilling and extensions to the overall installed operational base.

Whereas the hallmark of development is a cascade of activities with novel or initial character, production operates from a paradigm of sustained similar activities. Production operates to provide sustainable and predictable sales volumes of produced methane and other products. Thus, once the initial phase of production is underway, excepting new in-field drilling, one would expect that most risks will be of a similar type and quality for each day of operation. To the extent that seepage or venting could occur, that risk could be equally likely at any point during the time period of production.

Likewise, except for when exogenous tropical storms or earthquakes add stress, there would likely be no reason to expect *ex ante* that such cataclysmic events would occur at any particular time point within the time frame of production. Constant monitoring or surveillance may yield awareness of looming hazardous events, but *ex ante* such events will be extremely difficult to forecast as to timing and extent. Other considerations for the production period will be engagement from

15 There are fields that have operated decades beyond original forecasts. *E.g.*, the Kern Front Oil, the Kern Oil, and the Midway-Sunset Oil fields of southern California have been in operation for over a hundred years.

exogenous sources, such as outside vessels traversing the production field, cable laying or other field disturbing activities, or private actors such as pirates.

2.1.4. Abandonment and sequestration

Abandonment and sequestration are begun only once the final production volumes are lifted and transported. There are essentially two sub-stages to abandonment and sequestration; an early active stage of closing and stabilizing of the field and a subsequent stage of waiting, securing, and monitoring of the field.

Procedures are undertaken to stabilize the deposits and reserves. With methane hydrate deposits, there might also be collateral CCS-style sequestration of other greenhouse gases within the deposit.[16] A variety of stabilizing chemicals may be injected into the deposit level. Thereafter, the wells are processed to plug them and ensure a minimum of communication between the well and wellbore and the surface above the production zones within the deposit. Various seabed recovery and reconstruction efforts might be made to better secure the stability of the remaining in-place hydrates. Subsea facilities such as gathering lines and subsea-manifolds will likely be recovered or otherwise decommissioned as to limit their potential to disturb the seabed. This collection of activities could create risks to the seabed and the deposits, despite their function to prevent long-term risks to the same.

This initial stage of abandonment and sequestration is similar to development in reverse, in that much of the activity is intense and of an initial character for the field. And again similar to development, this early stage of abandonment and sequestration faces a well-defined time frame, in that it would be expected to follow a defined plan of limited years. It is also possible that various wells and sub-sections of the field might have already undergone abandonment and sequestration providing guidance on the closure for the whole field. For this reason, while the risks might be present, the overall risks are confined to a certain time period.

The latter stage of abandonment and sequestration could potentially last decades or centuries; it is yet unclear when it would be possible to declare a depleted hydrate field sufficiently stable and safe as to not require additional care versus those hydrates otherwise present in nature. To the extent that carbon dioxide or other greenhouse gases are stored within the hydrates, as studied under the German Submarine Gas Hydrate Reservoirs project (SUGAR),[17] then the relevant rules on CCS would be invoked and affect the monitoring period of the deposits.

These activities would generally be expected to onset at least several decades after the initial investment decision reached during the development period; the latter stage of abandoning and sequestration could continue for decades or longer

16 *See* discussion at ch. 3, sec. 5.1.

17 As explained on the GEOMAR website, "The German gas hydrate initiative "SUGAR – Submarine Gas Hydrate Reservoirs" is a collaborative R&D project with 20 partners from SMEs, industry and research institutions. The project is coordinated by the Helmholtz Centre for Ocean Research Kiel (GEOMAR)." *Available* at http://www.geomar.de/en/research/fb2/fb2-mg/projects/sugar-2-phase/.

depending on bed stability and if CCS was a co-incidental activity of the methane extraction. Given the role of "time value of money" or discounted cash flow metrics in financial decisions, and the potential decades involved before the actual commencement of the abandoning and sequestration phase, plus the extended period within which those activities would occur, the overall economic impact of these hazards might be expected to be minimized by decision makers at the time of the initial financial investment decision.

2.2. *Other risks and considerations*

2.2.1. Field choice

There is also a matter of field choice, to choose methane hydrate fields that are likely to be stable and safely producible versus choosing those fields more prone to venting, seeping, and landslides. There are several technical means to characterize fields and to differentiate them; the thickness and quality of the mud overlay, the depth and pressures of the deposit, and the general angle of the deposit can all be factors for safety assessments. The choice of field deposit can be applied to each stage of the project's life, as it will separately impact the exploration, development, production and abandonment phases. But generally speaking, one assumes that those fields with more readily foreseeable harms and hazards should come under greater oversight, via liability or regulation, than safer locations.

2.2.2. High ambient risks

A sincere problem could be presented by many of the developing countries that contain methane hydrates within their waters. It is foreseeable that certain countries and resource owners might find that their ambient level of risk and harms exceeds those posed by the development of methane hydrates. *E.g.*, Namibia has faced severe droughts and severe economic underdevelopment; methane hydrates could provide both methane as a revenue and fuel source and volumes of fresh water.[18]

There could be reasonable judgements made that the risks of hydrates for their nation and citizen were less than the risks of not obtaining the revenues and resources obtainable therefrom. *Ergo*, rational actors might opt for greater risk in the future to better provide for those presently suffering; especially those political actors who might not remain in power if short-term problems are not resolved prior to near-term elections.[19]

18 *See* Susan Beukes, "Namibian villagers grapple with the worst drought in three decades", August 7, 2013. In: NEWSLINE (UNICEF, 2013) *available* at http://www.unicef.org/infobycountry/namibia_70107.html.

19 In such cases, the traditional notions of liability and regulation might be insufficient to provide optimal development of methane hydrate resources. *See* the discussion on optimal strategies, *infra*, within ch. 7 and 12. For a broader discussion on the potential coordination problems of transboundary governance of offshore methane hydrates, *see* R. Partain, *Avoiding Epimetheus: Planning Ahead for the Commercial Development of Offshore Methane Hydrates*, 14:2 →

2.2.3. Sovereign immune actors and *de facto* externalized costs

An important exception to the risk analysis of operators and sovereigns is when the two parties are in fact a singular body, when the operator benefits from sovereign immunity. The case can be extended to those cases where a sovereign resource owner might extend its immunity to private actors performing at its behest, or when that sovereign resource owner might offer indemnity or provide minimal safety regulations or liability rules to ensure faster development of its resources.

Such actors may face perverse incentives to produce at risky levels as they may perceive all or some portion of the eventual costs of the hazards as externalities; they would be likely to choose activity levels higher than merited if those external costs were more correctly included in development decisions.

3. Non-cataclysmic hazards

As part of the Japanese team operating offshore production tests from methane hydrate deposits, Yabe *et al.* provided a table of seventeen identified risk factors and likely impacts.[20]

Yabe's chart provides sixteen basic events that could give rise to environmental hazards, but only six basic hazards.[21] The key hazards identified by the Japanese team are impacts to marine life, to fisheries, to aviary ecologies, to benthic ecologies, and the broader scale items of tsunamis[22]and anthropogenic climate change. A few of these items are unique to the production of methane from methane hydrates: seafloor subsidence, submarine landslides, and the combined risks from a cracked methane hydrate deposit bed.

Sustainable Dev. L. & Pol'y (forthcoming December 2014). One of the proposals in that article is the opportunity to provide for methane banking to provide alignment incentives for such resources owners by creating revenue sharing opportunities from fields that could be properly governed in return for forbearance or deferment of production from their own fields.

20 I. Yabe et al., *Environmental Risk Analysis of Methane Hydrate Development*, *in*: 7th International Conference on Gas Hydrates, 4 (2011).

21 The present hazards are somewhat vague and high-level, so it may not be sufficient for more careful enumerations of potential harms.

22 The chart provided by also listed the impact upon telecommunication cables and production pipelines at the bottom of the seabed. In short, subsidence could be the beginning of a very bad sequence of events. They also explain that the landslide case is a more severe case of subsidence. Subsidence might damage seabed gathering systems, but the landslide would obliterate them. Yabe *et al.*, *supra* at note 20.

Table 2: Chart of Risk Factors and Impacts for Offshore Methane Hydrate Development.

Item #	Risk Factor	Impact
1	Greenhouse Gas Emissions	Global Warming
2	Water Quality Change	Impact on Marine Life
3	Lightening	Impact on Marine Life and Birds
4	Interference in Fishery	Impact on Fishery
5	Seafloor Disturbance	Impact on Benthic Community
6	Underwater Noise	Impact on Marine Life
7	[Sediment] Resuspension	Impact on Benthic Community
8	Increase in Turbidity	Impact on Benthic Community
9	Marine Sediment Change	Impact on Benthic Community
10	Seafloor Occupation	Impact on Fishery
11	Seafloor Subsidence	Tsunami
12	Submarine Landsides	Tsunami
13	Cracks in Deposit - Disrupt Methane Entry to Sediment	Impact on Benthic Community
14	Cracks in Deposit - Methane Leakage from Sediment	Global Warming
15	Flaring - Lightening	Impact on Marine Life and Birds
16	Flaring - Greenhouse Gas Discharge	Global Warming

The routine set of subsea mining risks are primarily related to the building and operating of seabed infrastructure. The Yabe *et al.* list of environmental impacts comes from a variety of exploration, development and early production activities.[23] Surface ships will have a variety of emissions and discharges. Mooring lines will need to be installed. Submersible drilling equipment could disrupt the seabeds. Noise and vibration will be frequent and pervasive. Drilling mud and cementing may reach the environment. Gathering lines and their connecting manifolds need to be laid and installed. Drilling operations will require flaring as a safety system, but that implies potentially large flares and venting will be needed on occasion. All of these activities can impact the turbidity of the waters, cause re-suspension of sediments, and create a variety of seabed disturbances. Depending on the depth of the seabed, a variety of eco-systems can be disrupted.

3.1. Venting of methane to the atmosphere

Any discussion on the risks of developing methane hydrates must include a discussion on the role of methane and climate change.[24] Methane is a known

[23] Yabe *et al.*, *supra* at note 20, at 4.

[24] Sec. 4, *infra*, examines certain cataclysmic accidents that might occur from methane hydrate extraction. A separate and reasonable concern is whether such events might impact the thermohaline circulations of deep ocean waters and what might result from such situations? →

greenhouse gas.[25] Methane has a global warming potential index (GWP) 3.7 times stronger than carbon dioxide by mole number and 20 times stronger than carbon dioxide by mass weight.[26] Thus, emissions of methane are generally seen as worse for accelerating anthropogenic climate change than emissions of carbon dioxide. The massive scale of methane hydrate fields and their general presence in almost every coastal country presents a hazard unlike traditional natural gas wells, in that certain accidents in the development of methane hydrates could have global warming impacts far beyond any previous oil or gas disaster.

While some scientists have modelled methane bubble transport and found in simple one-dimensional systems that very little methane should be able to vent from the sub-sea hydrate deposit to the atmosphere,[27] other scientists have made field observations that do document substantial transportation of methane bubbles, and thus gaseous methane, from the seabed to the atmosphere.[28]

When methane is present in free water at low ocean depths, and when there is not a separate mechanism for quick venting, methane can take 100 to 1,000 years to reach the surface.[29] Given that long duration of transit and of the ocean's oxidation

First, it would much depend on where the accident occurred; thermohaline flows engage in both transporting heat to and away from locations thus an accident could shift waters in either direction. Also, if sufficient methane were to reach the atmosphere, then the clathrates gun hypothesis might become central to the question. Yet, the physical models remain substantially in development. Thus it is difficult to venture what impact a major hydrate venting might have; e.g., even if the thermohaline flows were altered, it is unclear without more detail if that would increase or decrease global climate heat and if it might increase risk of a clathrates gun result. For additional background on thermohaline circulation, *see* S. RAHMSTORF, *Thermohaline Ocean Circulation*. In: ENCYCLOPEDIA OF QUATERNARY SCIENCES (Elsevier, Amsterdam 2006). Clearly risks would exist; the question that remains to be answered is how much and of what extremity. At this point in time, given the current state of knowledge, those answers remain unknown. Should that lack of knowledge engage the precautionary principle, should development be prevented until greater certainty of safety can be accrued? Alas, that is probably not an outcome that anyone controls. The existence of those risks and general awareness of them might not be sufficient to prevent the onset of the commercial extraction of offshore methane hydrates as not all technology owners or resource owners would agree on which risks and harms were more relevant. *E.g.*, certain states might be in urgent need of public revenues, energy supplies, and of freshwater to an extent that the other risks of methane hydrate development are seen as relevant only after the first set of worries are addressed. Fear of famine, poverty, and civil disruption might outweigh other risks from their perspective. There thus exists a need to establish governance mechanisms, preferably internationally, prior to the onset of commercial extraction to ensure that all parties are aligned with regards to the goal of setting optimal levels of care and of activity.

25 Z. G. Zhang, et al., *Marine gas hydrates: Future Energy or Environmental Killer?,* 16 Energy Procedia 933, 935 (2012).

26 *Id.*

27 A. Yamamoto, Y. Yamanaka & E. Tajika, *Modeling of Methane Bubbles Released from Large Sea-Floor Area: Condition Required for Methane Emission to the Atmosphere*, 284 Earth & Planetary Sci. Letters 590 (2009).

28 N. Shakhova & I. Semiletov, *Methane Release and Coastal Environment in the East Siberian Arctic Shelf*, 66 J. Marine Systems 227, 235-236 (2007).

29 V. Krey et al., *Gas Hydrates: Entrance to a Methane Age or Climate Threat?,* 4 Environmental Research Letters 34007, 4 (2009).

of the methane while in transit, it is forecast that most methane is converted to carbon dioxide before venting out of the ocean. [30] On the other hand, it has been verified that methane bubbles do not need to exceed a certain saturation level to be able to reach the ocean surface.[31] Ebullition can, and does, transport methane from the seabed to the ocean surface, especially when the depth of the waters does not exceed several hundred meters.

Generally, it is agreed that the amount of methane that will reach the atmosphere from a seabed seepage is dependent upon three factors:[32]

i. the quantity and transfer rate of methane from the sediments to the water column,
ii. the volume of methane which dissolves in the water column, and
iii. the volume of methane which eventually escapes to the atmosphere.

The transfer rate of the methane from the methane hydrate deposit has been identified as the key variable; slow releases appear to be absorbed into the ocean but fast releases do not.[33]

Nature provides ready examples that methane can erupt from ocean depths and reach the atmosphere chemically intact; sometimes methane plumes can make it to the surface and ignite. Offshore Vancouver Island in Canada, it has been discovered that methane hydrates do have localized eruptions that result in gas chimneys to transport the methane to the atmosphere directly.[34] After the eruptions are completed, there are permanent structures left within the hydrate deposit.[35] Similarly, mud volcanoes are often formed with gas hydrates as the methane source.[36] A mud volcano was witnessed in 1958 to suddenly erupt. From approximately 150m below the Caspian Sea's surface, the methane vented out at extremely high speeds and the resulting flame was estimated at a height of 500m.[37] Whether or not the methane erupted from methane hydrates or other sources, as it remains unclear for the Caspian event, it is clear that high speed methane can and does vent to the atmosphere; sometimes dramatically so.

The legacy of ancient chimney structures has been detected in a variety of locations.[38] What were once believed to be smooth surfaces between the mud layers and the methane hydrate deposits are now identified as 'roughness', and are seen as a sign that methane hydrates deposits are not as stable as once thought.[39] Due to this discovery, it is now thought that methane hydrate fields are indeed posed on a

30 *Id.*
31 Shakhova and Semiletov, *supra* at note 28, at 236.
32 J. Marcelle-De Silva & R. Dawe, *Towards Commercial Gas Production from Hydrate Deposits*, 4 Energies 215, 230 (2011).
33 N. L. Bangs *et al.*, *Massive Methane Release Triggered by Seafloor Erosion Offshore Southwestern Japan*, 38 Geology 1019, 1019 (2010).
34 M. HOVLAND, *Gas hydrates*, in: ENCYCLOPEDIA OF GEOLOGY, 261, 266 (Elsevier, Oxford, 2005).
35 *Id.*
36 *Id.*, at 267.
37 *Id.*
38 I. A. Pecher, *Oceanography: Gas hydrates on the Brink*, 420 Nature 622, 622 (2002).
39 *Id.*

careful balance within the gas hydrate stability zone of certain pressures and temperatures.[40] Moreover, these legacy structures might act to collate and collect loose methane within the deposit field.[41] If a commercial operator were to tap into that kind of structure, it could enable a sudden venting of methane.

Without reference to commercial extraction of methane hydrates, there are locations in the world today that cause methane hydrates to disassociate and produce methane flows from the sea bed. West of the island of Spitbergen, in the Svalbard archipelago northwest of Norway, over 250 continuous bubble plumes have been discovered.[42] Observation of the plumes reveal that the methane transports from 200m to 400m below the sea surface to approximately 50m below the surface, by which point the plumes are fully absorbed in the water and no longer traceable.[43]. It is believed that the methane venting has been caused by the increase in local water temperatures by 1 degree centigrade.[44] While the changes in ocean temperature might be anthropogenic, based in carbon emissions from industrial civilization, it remains unclear if that is the case and to which nation or actors blame might be ascribed, so these types of ambient methane hydrate emissions remain beyond the purview of the United Nation's Framework Convention on Climate Change (UNFCCC) and its corresponding Kyoto Accords.[45]

3.2. Damages from methane seepage and ventings

In the minimal case, the disruption of otherwise intact methane hydrates reserves could cause similar effects seen elsewhere in the world today.

"Swamp gas' is the nickname for the biogenic methane created by the anaerobic decay of organic materials underwater.[46] Bubbling and burping up in swamps; it is considered a nuisance due to its distasteful aroma and potential for nuisance flames.

In the African nations of the Democratic Republic of Congo and Rwanda, there are lakes that emit noxious but odourless volumes of methane and carbon dioxide.[47] This type of emission is called *mazuku*; etymologically *mazuku* means "evil winds that travel and kill in the night," in Kiswahili.[48] The emissions come from dissolved

40 *Id.*, at 623.
41 *Id.*
42 M. A. K. Muir, *Challenges and Opportunities for Marine Deposits of Methane Hydrate in the Circumpolar Arctic Polar Region*, 32 Retfaerd Aergang 61, 63 (2009).
43 *Id.*
44 *Id.*
45 *Id.*, at 65. *See* discussion on UNFCCC, *infra*, at ch. 8.
46 A. A. Raghoebarsing et al., *Methanotrophic symbionts provide carbon for photosynthesis in peat bogs*, 436 Nature 1153 (2005).
47 D. Tedesco et al., *January 2002 Volcano-Tectonic Eruption of Nyiragongo Volcano, Democratic Republic of Congo*, 112 J. Geophysical Research B09202, at 5 of 12 (2007). *See also* B. Smets et al., *Dry Gas Vents Mazuku in Goma Region (North-Kivu, Democratic Republic of Congo): Formation and Risk Assessment*, 58 J. Afr. Earth Sci. 787, 788 (2010).
48 Smets *et al.*, *supra* at note 47, at 788.

gases with in the lakes; the deep lakes stratify into three or more levels.[49] In Lake Kivu, *e.g.*, the hypo-limnion or upper-level of the lake waters contains 265 km^3 of carbon dioxide (CO_2) and 54 km^3 of methane (CH_4).[50] That is the equivalent of 54 billion cubic meters of methane or approximately 2 Tcf of methane. The methane is biogenic, sourced from bacterial metabolisms, and the carbon dioxide primarily results from additional bacterial metabolism of the methane and oxidation of the methane.[51] The dissolved gases can be released and then emitted by a variety of mechanisms such as seismic activity or down-swelling cold waters from rain run-offs.[52]

The ambient methane levels have been detected within the necessary concentrations to enable air-borne combustion.[53] These *mazuku* emissions have been known to kill both livestock and humans.[54] Even marine life has been impacted; at the time of the emission from the lakes crawfish and crabs were observed struggling to exit the lake and many fish were found dead soon after.[55] Observational histories detail that the lakes emit these gases with little warning and the *mazuku* fills the valleys that the lakes are situated within.[56] There is essentially no escape for all respirant life forms close to the lakes.[57] Due to these hazards, engineers have installed gas evacuation systems to pump out excessive emissions before they build to dangerous levels; the methane is used to power an electrical plant.[58]

Additionally, there are concerns that a field of leaking methane could cause buoyancy problems for waterborne craft.[59] Indeed, it has been modelled and discussed that certain conditions could lead to a field of methane hydrates disassociating in such a manner that a ship could lose its buoyancy and sink.[60] Non-buoyancy examples also exist. Offshore oil rigs and boats have been lost when methane suddenly erupted from below; the boats became upended by the displaced water pushed by the emerging methane.[61]

49 Wafula *et al.* 2007, at 1.
50 *Id.*
51 *Id.,* at 25.
52 Tedesco *et al.*, *supra* at note 47, *en passim*. *See also* Wafula *et al.* 2007, at 26.
53 Tedesco *et al.*, *supra* at note 47, at 5 of 12.
54 Smets *et al*., *supra* at note 47, at 787.
55 Tedesco *et al.*, *supra* at note 47, at 6 of 12.
56 Smets *et al*., *supra* at note 47, at 789.
57 *Id.*, at 794.
58 *See* the Environmental and Social Impact Assessment summary generated by the African Development Bank for the KivuWatt project. *Available* at http://www.afdb.org/fileadmin/uploads/afdb/Documents/Environmental-and-Social-Assessments/EX%20summary%20ESIA%20KIVUWATT%20may%2026th%202010%20English.pdf.
59 I. S. Leifer et al., *Engineered and Natural Marine Seep, Bubble-Driven Buoyancy Flows*, 39 J. Physical Oceanography 3071 (2009).. *See also* E. A. Keller *et al., Tectonic Geomorphology and Hydrocarbon Induced Topography of the Mid-Channel Anticline, Santa Barbara Basin, California*, 89 Geomorphology 274 (2007)
60 D. Adam, *Methane Hydrates: Fire From Ice*, 418 Nature 913, 914 (2002).
61 *Id.*

Ambient methane is not toxic *per se*, but it is a simple asphyxiant.[62] Methane has no noticeable smell to humans; the smell associated with natural gas in home cooking fuel has a second chemical added, mercaptans,[63] that provide that off-smelling stink to alert home owners to gas leaks. In an industrial accident of unmodified methane, the workers will be challenged to evade an airborne poison that they cannot detect.

Large amounts of methane could become dissolved into the benthic waters and substantially impact sea life.[64] While the resource assets at that depth are well studied, the ecologies of those depths are not.[65] Due to the location of methane hydrates, shallow within the seabed itself, it is expected that the development of methane hydrates will cause "significant impacts on the sediment dwelling fauna."[66] Additionally, the energy levels of the benthic oceans are generally much lower than upper levels of the ocean, preventing effective removal of polluting debris.[67]

When methane seeps are located at 300m below the water's surface, and unless high velocities and large volumes are involved, models suggest that 98% of the seeped methane could be absorbed by bacteria prior to reaching the water's surface, metabolized into carbon dioxide.[68] Glasby provides a broad review of the recent literature and finds that both modellers and field researchers agree that when methane needs to transport through 300m or more of water then the probability of any methane reaching the ocean's surface is very minimal.[69]

When carbon dioxide increases its presence within the water column, several problems are found. First, the acidity of the water column is increased, causing stress to sea fauna.[70]. Second, there is a risk of an affected area becoming a "mortality sink," wherein predators begin to prey off of the dead and dying fauna, further decreasing population sustainability within the zone.[71]

A main exception found in the meta-study is the potential for high speed methane to reach the surface.[72] A second, but perhaps more rare exception, are when the width of the seeps are greater than the depth of the waters; in that case the methane can reach the surface intact.[73] Should a large field under commercial

62 *Available* at http://www.dhs.wisconsin.gov/eh/chemfs/fs/Methane.htm.

63 *Available* at http://www.atsdr.cdc.gov/mhmi/mmg139.pdf .

64 G. P. Glasby, *Potential Impact on Climate of the Exploitation Of Methane Hydrate Deposits Offshore*, 20 Marine and Petroleum Geology 163, 169 (2003).

65 A. G. Glover et al., *The Deep-Sea Floor Ecosystem: Current Status And Prospects Of Anthropogenic Change By The Year 2025*, 30 Envtl. Conservation 219, 220 (2003).

66 *Id.*, at 232.

67 *Id.*, at 220.

68 Glasby, *supra* at note 64; K. A. Kvenvolden, *Potential Effects of Gas Hydrate on Human Welfare*, 96 Proceedings Nat'l Acad. Sci. 3420 (1999).

69 Glasby, *supra* at note 64, at 170.

70 Glover *et al.*, *supra* at note 65, at 225.

71 *Id.*

72 Glasby, *supra* at note 64, at 170.

73 There is an example given of a Gulf of Mexico seep. The seep was over 600m wide and the methane had been seen at the surface 540m above. *See id.*

operation lose some structural integrity and begin to bubble across the field, not collapse but merely simmer as it were, then a large volume of methane might vent to the atmosphere on an on-going basis. Worse, it might become impossible to repair once started.[74]

A separate harm or damage can result from the extraction technologies. When chemicals are injected into the deposit to effect the dissolution of the hydrates, those chemicals are often toxic to those lifeforms living near the hydrates.[75] Not only do micro-fauna such as zooplanktons and micronektons live near methane hydrates, but also macro-fauna such as tubeworms and mussels.[76]

Deepwater organisms already test positive for sea-borne chemical pollutants.[77] The types of chemicals used to aid in hydrate dissolution are generally solvents and not water-soluble. As such, they are the types of chemicals known to significantly affect the zooplanktons and micronektons at the bottom of the food chain.[78] Such chemicals often accumulate; they can become concentrated at magnitudes higher levels within the micro-fauna compared against the ambient water column within which they reside.[79] The problems of toxicity are not limited to the micro-fauna, the food-chain presents toxicity in birds and fish eaten by humans.[80] Those animals can carry toxicity levels higher than health limits for human consumption, making them effective poisonous to human diets.[81]

3.3. Acts that enable seeping and venting of methane

The mechanisms of seeping methane are better understood than cataclysmic releases.

Methane seeps do occur in nature and can be routinely studied. The methane can be absorbed into the water column and begin a process of metabolism that will eventually result in the transmission of carbon dioxide to the atmosphere. The methane can persist as bubbles and present plumes from the seabed to the atmosphere, enabling the venting of slow moving volumes of methane to the atmosphere. Occasionally, even chunks of methane hydrates can break off and rise to the ocean's surface. The impacts of such seepage can be monitored, measured, and studied. Policy makers have the scientific data to estimate the potential impact to marine ecologies and nearby communities caused by artificially created seeps and vents.

74 If repairs were to be made to the field at large, it would likely consist of some sort of entrapment and layering in mud, restoring the pressures necessary for stability.

75 C. R. Smith et al., *The Near Future of Deep Seafloor Ecosystems, in*: Aquatic Ecosystems: Trends and global prospects, 334, at 22 (2008).

76 E. ALLISON & R. BOSWELL, DEPT. ENERGY, METHANE HYDRATE, FUTURE ENERGY WITHIN OUR GRASP, AN OVERVIEW, 9 (2007). *See also* Smith *et al.*, supra at note 75, at 22.

77 *Id.*, at 22.

78 *Id.*

79 *Id.*

80 *Id.*, at 23.

81 *Id.*

The incidence of seeping and venting needs two events. Methane needs to become free from the hydrate structure and a means of transport from the hydrate deposit bed is needed. Policy needs to address both events to be effective.

Experiences in traditional offshore oil and gas well drilling, the testing at Mallik and in the Nankai Trough, and laboratory modeling do provide some insight into the risky behaviors that could artificially cause the methane hydrates to begin seeping methane. It is likely that a methane hydrate field could experience a variety of impacts that could lead to methane seepage and venting without necessarily leading to cataclysmic results. Policy needs to discern what actions could enable methane to become free and available for seeping and what actions could provide the means for the methane to leak out.

3.3.1. Actions that make methane available

Depressurization of the hydrate deposit, increases in the hydrate deposit's temperature, and off-target chemical inhibitors could all artificially cause methane to become free in the methane hydrate deposits.

The production of natural gas from conventional wells and conventional reservoirs has its own risks and hazards; the production of methane from methane hydrate deposits will also include most of those hazards. Drilling and installation of wells is complicated and hazardous. Wells are complicated mechanical systems and can fail. Christmas trees, gathering lines, and other elements of the production system can suffer from ruptures or other break-downs. But the production of methane hydrate will invoke a variety of novel problems and hazards.

Depressurization can occur while drilling into a hydrate layer. Depressurization can occur while extracting methane from a hydrate layer; the removal itself provides empty space in the reservoir and the extraction process likely also effects a hydraulic-type effect on the fluids remaining in the hydrate level and thus decreases the pressure in the area of the evacuation.[82] As seen at Messoyakha,[83] the depressurization of a hydrate deposit can induce additional disassociation of methane from the hydrate layers. But at Messoyakha, the hydrates were under a solid formation unlike the hydrates in most offshore locations.

Depressurization can also occur from accidental evacuation of the hydrates; structural damage to the field could deform the hydrate layer and result in depressurization. *E.g.*, field subsidence might result in deformed hydrate layers that might then disassociated into methane. Cracks in the methane hydrate deposits

82 This particular argument is made without reference to the specific technology used to actively produce the methane from the hydrates; once the methane is intentionally disassociated from the hydrate structure by in-situ heating, chemical agents, or by depressurization systems, the methane needs to be removed. Potentially a lot of the water will also need to be removed. The argument herein is that during these processes additional depressurization can occur from the physical removal of these matters from the production zone.

83 Messoyakha was the first gas hydrate field to be operationally produced. It is located in Siberia. *See* Y. F. Makogon, S. A. Holditch & T. Y.Makogon, *Natural Gas-Hydrates – A Potential Energy Source for the 21st Century*, 56 J. Petroleum Sci. & Engineering 14, *en passim* (2007).

could enable depressurization due to the pressure differential above and below the mud-line.[84]

Increases of the ambient temperatures in the gas hydrate deposit could lead to methane disassociating from the hydrate structure. There are a variety of human activities that could cause those increases to occur.

First, the technology of methane extraction could rely on heat transfer into the methane hydrate deposit.[85] Current models of heat transfer include steam and in situ combustion.[86] These activities may enable some methane to become free without production to the surface. Indeed, Moridis discusses the technical problem of preventing secondary hydrate formation at the well-bore; free methanes are likely to remain in contact with water until the well-bore and the reformation of hydrates at the well will clog the well and prevent removal of the produced and freed methane volumes.[87]

Second, after extraction from the production zone, if the produced methane or water flow through seabed gathering lines, then the warmth of the pipes may provide a local heat source against the mud. With sufficient mud depth, this ought not be a problem, but subsurface currents might raise and relocate the mud at times and gathering lines may become embedded within the mud and become closer to the hydrate deposits. This has been a realistic concern in permafrost areas. The Point Thompson Unit in Alaska, although built onshore, was constructed akin to offshore methods due to concerns that the underlying permafrost would not support the warmth from the field operations.[88]

Chemical stability is primarily a problem resulting from the leakage of injected chemicals into unintended injection zones. Chemical inhibitors are one of the main technologies in testing for the extraction of methane from hydrate deposits. Their original development was for the unclogging of pipelines blocked by methane hydrates formations; they chemically interfere in the lattice structure and enable the escape of methane from the cage structures. The extraction technology assumes that chemical inhibitors can be injected with control of where the inhibitors interact with the methane hydrate. But that will not always be the case. various cracks or fissures within the hydrates could combine with various hydraulic-types forces to transport the inhibitors away from their targeted work site.

84 Cracks could also provide a means of leakage, *see infra* at sec. 3.3.2 for a more complete discussion.

85 Current modeling for these types of technologies assume that as much as 10% of the energy extracted would be needed to heat the hydrate formations. *See* Marcelle-De Silva & Dawe, *supra* at note 32.

86 Overall, the technologies are very similar to the technologies employed in heavy oil and bitumen fields. The petroleum is heated in the reservoir, reducing the viscosity of the bitumen or pitch until it can flow into the well-bore.

87 G. J. Moridis et al., *Toward Production from Gas Hydrates: Current Status, Assessment Of Resources, and Simulation-Based Evaluation of Technology and Potential*, 12 SPE Reservoir Evaluation & Engineering 745, at 14 (2009).

88 Author's personal observations from experience with the Unit.

3.3.2. Actions that provide a means of leakage

Seepage and venting require an opening from the methane gas deposit to the benthic waters. From that opening the methane can transport into the water column. The overall tendency of methane to become free during production processes and to accumulate in sub-mud bubbles has led one researcher to emphasize the need to prioritize hydrate assets with impermeable upper boundaries to prevent accidents.[89]

Three structural problems were identified by Moridis with regards to field stability, all of them derive from problems with field porosity and permeability.[90] The three problems are field subsidence, formation yielding or failure, well-bore stability in the mud and hydrate zone. [91].

Koh explained another critical problem, that the hydrate inhibitors used for extraction work by causing a change in lattice formation, they adsorb onto the surface of the lattice.[92] Once injected, the inhibitors shift the lattice from octahedral crystals to two-dimensional plates or from rhombic dodecahedral crystals to highly branched crystals. [93] In essence, the structural frameworks of the hydrates are disassembled and flattened; they then lose their ability to hold together in all three dimensions, enabling slippage across planar sections of the hydrate fields.[94]

Under both circumstances, the deposit fields could lose substantial structural cohesion. When combined with the porosity and permeability problems of Moridis, wherein the chemicals could use capillary action to flow far beyond the well-bore, the effects could be unpredictable.

Cracks could emerge from faulty construction methods when developing the seabed. The construction activities of well drilling, dredging, and cementing could all provide mechanical energies that might cause fissures or cracks in the mud layers above the hydrates that could enable methane transport. Beyond the development phase of the field, the production period could offer a variety of events that could cause cracks. Cracks could emerge from uneven extraction of methane from the hydrate deposit. Cracks could emerge from uneven in situ burns, excess methane might try exit outside of the control of the well bottom. Evidence has been observed in production testing in Alaska of capillary motives of fluids near the production zone of the well-bore causing "honeycombs of wormhole like disassociation patterns."[95] The creation of such porous pathways could easy lead to cracks either within or above the deposit layers.

89 *Id.*, at 13.
90 *Id.*, at 17.
91 *Id.*
92 C. A. Koh, *Towards a Fundamental Understanding of Natural Gas Hydrates*, 31 Chemical Soc'y Rev. 157, 165-166 (2002).
93 *Id.*
94 Perhaps a suitable, but less technical, analogy would be to begin with a cake that could maintain its vertical integrity and then convert that cake in a stack of pancakes that could slip and slide apart.
95 Moridis *et al.*, *supra* at note 87, at 13.

As a methane hydrate field moves into operational production, there are hazards of methane accumulation away from the well bores. The pressures of built-up methane can provide the means of transport for methane to exit from the hydrate deposit zone; the methane might build up enough force to remove the overlaying mud.[96] Thus, unmonitored methane accumulations might provide their own means of transport out of the deposition zone.

One suspects that mitigating against cataclysmic methane events could support the routine search for such methane accumulations, and if not producible by well, enabling the venting of that methane into the ocean in a safer manner. Seeping and venting may come to be seen as pressure valves against larger risks.[97]

Of course, if one wanted to create seepage or venting, there are direct methods. Once the presence of gas hydrate fields are made public and their potential dangers are more publicized, there are likely some parties who might in certain conditions seek to exploit those hazards.

Given the historical acts of Iraq in Kuwait to destroy the Kuwaiti oil fields in 1990 and 1991, it is not unimaginable that adverse state actors might employ similar military strategies that could result in some actors seeking to intentionally initiate methane transport from the deposits. Additionally, both anti-government terrorists and certain environmentally-focused terrorist groups might seek to intentionally open methane hydrates to transport in the water column.[98]

4. Cataclysmic methane events

There are two basic areas of concern for cataclysmic methane events, the accidental and the strategic. The accidental catastrophe is when routine operations of methane hydrates fields lead to a cataclysmic release of methane. The strategic catastrophe is when an actor decides to intentionally initiate a cataclysmic methane event. One event can be characterized as tortious, but the other might need characterization as criminal or even belligerent under international law.

A cataclysmic event could see a large section of a hydrate field lose its internal structure and shear off, causing the overlying mud layers to fall deep into the ocean. Such an event might be correlated with earthquake-like impacts such as tsunamis. The physical energy of the shear-off would likely enable massive sudden venting of much of the reservoir's methane directly to the atmosphere. That methaneous eruption would also likely induce surface combustion to a broad area so long as the

96 Such events are in the geologic record. *See supra*, sec. 3.1.

97 Perhaps seepage might eventually be sought as a stability maintenance method versus accumulated methane volumes. Such venting is routine at post-clean up industrial dumps. But such 'safety measures' do not eliminate the hazards posed by that calmer transmission of methane into the environment.

98 Given current activities against oil and gas assets, these kind of events are reasonable to occur. The sabotage of Kuwait's oilfields during the Gulf War of George H. W. Bush presidency, the on-going pipeline sabotage in many developing countries, and the Greenpeace boarding of Gazprom's Prirazlomnaya Arctic oil platform are all examples that developers and regulators of methane gas hydrates fields will need to take into consideration.

methane continued to vent from the shaken depths. The impacts to any local community of a tsunami that coincides with ambient combustion would be horrific.

4.1. Sudden massive venting

Methane hydrates are poorly trapped and deposited in great contiguous bulks, these are the key dangerous differences between traditional natural gas and methane hydrates. The gas hydrate stability zones, wherein the deposits accumulate, are fragile on both pressure and temperature vectors, "[a]ny change in temperature and pressure will cause it to decompose ...".[99] A rapid release of substantially large amounts of methane could result in short-scale climate change.[100] This perspective, when combined with an awareness that the expected extraction techniques will focus on warming the hydrates, on depressurizing the hydrates, and injecting chemicals which stimulate the disassociation of the hydrates, leads to the conclusion that the extraction technologies must effect a delicate balancing act to avoid triggering what could become a deposit wide disassociation event and a massive release of methane and freshwater from the hydrate deposits. The extraction of methane from methane hydrate deposits might always remain an extremely hazardous activity even if otherwise desirable.

Methane can vent from the ocean floor and create a column of methane rich gas, analogized to a "super bubble" by Leifer.[101] Such super bubbles have likely occurred in the recent geological past.[102] Alternatively, large chunks of methane hydrates might rise to the surface and sublimate or combust at the ocean's surface. Such an event has been witnessed offshore Vancouver Island at the Hydrate Ridge near the Cascadia Margin.[103] Chunks of methane hydrate, measuring over a cubic meter each, were observed floating in the ocean.[104] Should a methane hydrate become disturbed during commercial operations, and if the field lost stability quickly, then it would be possible for either methane gas to vent directly to the atmosphere or for large chunks of hydrates to break off and float to the surface where they would be potentially explosive.

The resulting behavior of the venting methane is to create a chimney-like structure that connects the hydrate bed to the atmosphere above the ocean water, enabling a direct pipeline of methane ventilation.[105] So long as the buoyancy of the methane bubbles and the pressure from the emitted methane can be maintained, the chimney will be sustained. Thus, once in place, a chimney could provide a manner for a massive methane emission event to occur. All of that methane is potentially combustible at atmospheric conditions, but incomplete combustion is likely to result. Thus some of the methane will be directly absorbed by the atmosphere and

99 Zhang *et al.*, *supra* at note 25, at 935.
100 *Id.*
101 Leifer *et al.*, *supra* at note 59.
102 Keller *et al.*, *supra* at note 59.
103 Glasby, *supra* at note 64, at 170.
104 *Id.*
105 *See supra*, at sec. 3.1.

act as a greenhouse gas while a separate portion of the methane is likely to combust and explode above the ocean's surface.

Additionally, the destabilization of one location is likely to affect the pressure and temperature of nearby deposits, especially if they are in communication.[106] Therefore, the establishment of one chimney would result in substantial depressurization of nearby deposit and potentially enable other chimneys of emission.

Such accidental events have already been witnessed. An accidental chimney was formed on the Pechora shelf; a drilling attempt through a subsea permafrost encountered a hydrate layer.[107] The resulting surge of free methane created a gas-water fountain that rose over a 100m through the waters and shot into the air 10m above the drilling ship. [108]

While the probabilities of sudden massive venting events are difficult to gauge given a lack of historical data, the geological record strongly suggests that cataclysmic venting has occurred in pre-history and earlier periods, there are subsea craters that reflect massive sudden blow-outs of methane.[109] Up to 1 to 5 gigaton of carbon were released in those events, mostly in the form of methane. [110] Additionally, it is believed that massive venting of methane hydrate deposits were instrumental in causing the sudden global warming seen approximately 55.6 millions years ago at the Latest Paleocene Thermal Maximum.[111] During that event, the temperature of the northern hemisphere increased 6 to 12 C.[112]

4.2. Subsea landslides, tsunamis, and earthquakes

Methane hydrate deposits often occur on gentling sloping continental shelf areas; if disassociation occurs and methane and water are released from the deposits, then the overlaying mud and sediments may lose stability and collapse, causing a landslide.[113] This is not an easy condition to induce, because the disassociation of water and methane requires an energy source.[114] The beginning of a disassociation in one location increases the pressure and thus improves the stability of hydrates near the disassociation event. [115]

106 "Communication" occurs when gases, liquids, and kinetic energy are shared or transmitted through the deposit system. The motives can be capillary action, Boyle's Law or Charles's Law. For examples of means in hydrates, *see supra*, at sec. 3.3.2.

107 Shakhova and Semiletov, *supra* at note 28, at 240.

108 *Id.*

109 Krey *et al.*, *supra* at note 29, at 4.

110 *Id.*

111 Zhang *et al.*, *supra* at note 25, at 935.

112 *Id.*, at 935-936.

113 M. F. Nixon & J. L. H. Grozic, *Submarine Slope Failure Due to Gas Hydrate Dissociation: A Preliminary Quantification*, 44 Can. Geotechnical J. 314, 314-315 (2007).

114 *Id.*, at 315.

115 *Id.*

It takes an unusual amount of energy or a unique displacement of the methane hydrate bed to cause landslides; [116] but they do occur. Once they begin to occur, then they can enable positive feed-back loops that enable more methane to be released and more landslides to occur.[117]

There are two known natural triggers, lowering sea levels, which reduce pressure on the hydrates field-wide, and warmer oceans, which heat up the hydrates field-wide. Commercial hydrate development, with field-wide on-going extraction, would potentially offer the types of trigger events necessary for deposit-wide disassociation followed by a landslide.[118]. This is doubly so for those techniques that combine volume extraction with in-situ heating to spur disassociation;[119] a combination of field wide depressurization and field-wide warming.

Methane hydrates often form intermixed with sand and sediment, forming a type of icy cement.[120] Zhang has shown that gas hydrates, *in situ*, can display 10 times greater shear strength than water ice.[121] Studies suggest that the mud or permafrost might actually be structurally dependent on the underlying methane hydrates.[122] If so, then the removal of the methane hydrates could cause the collapse and relocation of the overlaying materials and result in a landslide. Offshore, such a geological event could cause an earthquake or a tsunami.[123]

Generally speaking, offshore methane hydrate deposits lay on inclined slopes, which are overlaid with mud.[124] A positive feedback loop could manifest, wherein one stage of methane and water releases enable others. If the hydrates start to disassociate and the methane is emitted, then there will also be a great release of the previously integrated waters.[125] As the hydrate structures continue to disappear, the shear strength of the deposit will decline, and the structural integrity of the overlaying mud will be lost.[126] Additionally, the released water volumes will both physically lift and assist in the dissolution of the mud bed.[127] The result is that all of the mud and other overlaying materials will begin to fall downwards under the tug of gravity, causing a sub-sea landslide.[128]

116 *Id.*

117 Bangs *et al.*, *supra* at note 33.

118 When oil is raised from the reservoir to the production platform, it is often quite a bit warmer than the adjacent seabed. There are known instances wherein oil platforms ran their production lines through hydrate deposits, which then destabilized as the production line warmed the seabed. Nixon and Grozic, *supra* at note 113, at 315.

119 *See supra*, at ch. 3.

120 Nixon and Grozic, *supra* at note 113, at 316.

121 Marcelle-De Silva & Dawe, *supra* at note 32, at 231.

122 Zhang *et al.*, *supra* at note 25, at 935.

123 I. Chatti *et al.*, *Benefits and Drawbacks of Clathrate Hydrates: A Review of Their Areas of Interest*, 46 Energy Conversion Mgmt. 1333, 1336 (2005), citing Glasby, *supra* at note 64, at 163-175.

124 Zhang *et al.*, *supra* at note 25, at 936.

125 Nixon and Grozic, *supra* at note 113, at 315.

126 Marcelle-De Silva & Dawe, *supra* at note 32, at 231.

127 Zhang *et al.*, *supra* at note 25, at 936.

128 *Id.*

There are certain limiting parameters for operational safety. Early modelling suggests that shallow water hydrates, in waters shallower than 300m, the hydrates will generally lack the conditions to enable a landslide result.[129] Additionally, there is certain depth, below 700m, wherein both temperature and pressure are likely to be safely stable despite changes in ocean temperature or changes of ocean depth. [130]. The deeper the mud layer over the hydrates, the safer the deposit; but the relationship is not linear. A slow improvement in safety is seen as the mud approaches from no mud to 400m in thickness, but then at approximately 400m the safety certainty make a dramatic jump, after which only marginal gains to safety are made.[131]

Thus, there are envelopes of safety, albeit fuzzily described, wherein hydrates could be extracted with high certainty of triggering no landslide events. Some geologies are safer than others; the Beaufort Sea is seen as more likely to offer future landslide under commercial development, whereas the hydrates in the Gulf of Mexico may be more resilient to landslide events.[132] However, even the safest areas were seen as capable of landslides under sufficient conditions.[133]

There are numerous geological signs of earlier events that began as methane hydrate deposit destabilizations that led to landslides, tsunamis and earthquakes. On the United States' Atlantic shelf, over 200 slump scars have been discovered; these are all believed to be methane hydrate events.[134] Additional slump scars have been identified off the west coasts of Africa, in the fjords of British Columbia, and in the Beaufort Sea offshore of Alaska's northern coastline.[135]

The prehistoric landslide of Storegga, offshore Norway, is perhaps one of the best known examples of a landslide caused by a methane hydrate event. It has been measured at over 800km long.[136] The landslide is believed to have carried over 5,500 km3 of earthen material. The tidal waves and tsunamis that resulted are blamed in large part for the submergence of Doggerland. Another similar event occurred in the Kumano Basin, offshore Japan, about 50,000 years ago.[137] While the evidence for events such as Storegga and Kumano are ancient by human standards, geologically they are recent events and the geophysical data suggests that similar processes can occur today.[138] Of particular concern is that the gas hydrates fields offshore Japan routinely experience earthquakes which could trigger or assist in triggering landslides in gas hydrate fields.[139] The Nankai Trough routinely experiences Richter 8 plus scale earthquakes. [140] If a field is already weakened by commercial

129 Nixon and Grozic, *supra* at note 113, at 317.
130 *Id.*
131 *Id.*, at 317 and 319.
132 *Id.*, at 321-322.
133 Nixon and Grozic, *supra* at note 113, at 323-324.
134 Marcelle-De Silva & Dawe, *supra* at note 32, at 231.
135 Nixon and Grozic, *supra* at note 113, at 315.
136 Marcelle-De Silva & Dawe, *supra* at note 32, at 232.
137 Bangs *et al.*, *supra* at note 33, at 1021.
138 *Id.*
139 *Id.*, at 1022.
140 *Id.*

development, an earthquake that might not have originally triggered a landslide might find the depleted field more readily susceptible to collapse.

5. Oil spills and deep ocean eruptions are distinguishable

This section of the study attempts to highlight the differences between traditional oil and gas injuries and the injuries likely to occur from the development of methane hydrates.

The hazards of methane hydrates are different from those of traditional gas wells. In some ways, methane from methane hydrates appears simpler. Methane from methane hydrates is sweet, not sour. It requires less post-production processing and treatment, so it lacks the hazards associated with those activities. Were methane hydrates from a more secure structure, perhaps it would be a simply safer form of natural gas. But it is not from a traditional trap, instead offshore hydrates are under a mud layer and much more dangerous.

But other risks, while present in traditional offshore gas well development, are of a more substantial threat and greater harm when associated with methane hydrates. The potential for methane emissions to accelerate global climate change are much more pronounced with methane hydrates. The potential of a subsea flood of disassociated fresh water to disrupt the eco-system of the benthic communities is again a much greater danger with methane hydrates. The potential to permanently disrupt or lose a local marine eco-system is much more likely with a collapse of a methane hydrate deposit than it would be with a leaking natural gas well.

5.1. Marine oil spills

There is a traditional model for oil spills and it dates back to a period when most spills of concern came from ship-loaded crude oil.[141] The traditional paradigm for oil spills is the "shore-bound surface spill."[142] To better capture the legislative norms associated with "shore bound surface spill" model, this study will refer to these types of harms and hazards as marine oil events.

Although there are a variety of legal institutions available to handle oil spill in the marine oil model, few of them apply to methane hydrates. Even if they did, is doubtful that they would be able to handle the scale and range of the types of hazards brought by the development of methane hydrates. Ultimately, marine oil spills are different events with distinguishable harms and hazards from those presented by methane hydrate projects.

In the United States, there are a variety of laws that address marine oil spills and the laws' domains depend on the method of emission or spill. *E.g.*, the Oil Pollution Act covers tanker spills and oil well spills, but the Clean Water Act governs emissions from run-off waters and from some pipeline spills. The American

141 E. E. Adams et al., *A Tale of Two Spills: Novel Science and Policy Implications of an Emerging New Oil Spill Model*, 62 BioScience 461, 461 (2012).

142 *Id.*

legal institutions are not aligned on the incident of harm but are aligned on the means of the harm and the location of the tortfeasor. This is in part due to the complexity, especially in earlier decades, of sourcing the oil spills to establish legal authority and jurisdiction.[143] Recent advancements in technology, especially remote sensing, have reduced the difficulty in tracking and measuring oil spills at the surface of the ocean and above.[144]

Annually, 1,300,000 tons of crude oil enters the ocean; tanker vessel spills account for less than 8% of the volumes and pipeline spills account for less than 1%.[145] Rain-driven run-off from roads and other surfaces provide approximately 11% of the volumes.[146] Natural seepage is estimated to provide 45% of the total volumes.[147] That leaves a large portion not well accounted for, although intentional ocean vessel discharges are thought to make up a large part of the missing numbers.[148] There are many natural processes that disperse oil and enable other organic processes to break it down;[149] crude oil does not persist naturally if mobile and in an aerobic environment.

The marine oil spill model presumes a spill on the ocean surface as the primary accident; that the oil spill begins at the ocean's surface or quickly rises to it from a shallow depth.[150] Whatever methane is present in the transported crude is quickly evaporated little combustion or interaction with marine waters and marine ecologies.[151] The crude oil and tars then drift from the ocean towards land, coating a variety of marine and estuarial habitats.[152] The life-forms at the ocean surface that bear the brunt of harm; that harm is primarily resultant from the crude oil and tars at the surface.[153] When buried in anoxic sands or embankments, the crude oils can persist for decades without oleophagic bacteria-enabled decomposition.[154] It is to these hazards and harms that marine oil regulation was traditionally targeted.

The marine oil paradigm assumes that the primary hazards result for contamination and inundation from tar and crude oils in the littoral zones of shorelines, marshes, and coastal communities. The crude oil is assumed to degrade

143 Recently, the U.S. Supreme Court has raised similar concerns with regards to connecting tortfeasors to resultant climate change events. For a more complete discussion on the Court's concerns from *Massachusetts* and *Kivalina*, *see* Partain & Lee 2013.

144 *See* I. S. Leifer *et al.*, *State of the Art Satellite and Airborne Marine Oil Spill Remote Sensing: Application to the BP Deepwater Horizon Oil Spill*, 124 Remote Sensing of Environment 185 (2012), wherein a discussion of U-2 mounted avionics is presented. When engaged in such research purposes, the planes might be designated as ER-2 planes (Earth Resources−2).

145 *Id.*, at 187.

146 *Id.*

147 *Id.*

148 *Id.*

149 *Id.*

150 Adams *et al.*, *supra* at note 141, at 461. The key difference was that spilt oil will float and persist in the environment until cleaned-up whereas spilt methane leaves little physical mass after its evaporation or combustion.

151 *Id.*

152 *Id.*

153 *Id.*

154 *Id.*

into thick tars as it is exposed to salt water, solar radiation, and air. Flora and fauna can become entangled and contaminated by the crude oil and tars. This contact can be lethal due to either contact with hydrocarbon solvents or from the tars and oils preventing normal survival behaviours such as flying, hunting and eating. The deteriorating crude and tars accumulate on the shores and sands; where they are likely to remain for decades or more without artificial removal. To the extent that the crude oil and tars float in the ocean, they can come into contact and damage a variety of marine life. Ocean-borne crude oils and tars present an immediate nuisance to fishermen and others dependent on the quality of the epipelagic[155] waters for occupational and recreational purposes. The regulatory goals of planning for marine oil are the prevention of leakage and the provisioning for expedited clean-up and restoration once a leakage event does occur; compensation for what cannot be remedied is often made available as well.

While the crude oil and tars are toxic, they are not likely to add to anthropogenic climate change. Methane gases and other greenhouse gases might be emitted in the course of an oil spill,[156] However, the marine oil paradigm does not generally perceive anthropogenic climate change as a major component of the spill event. The majority of the spilt volumes are viscous in nature and not readily capable of evaporating under normal atmospheric conditions. Thus, the regulatory paradigm for marine oil has not included direct regulation on climate change matters.

In general, boat-based crude oil spills provide no geological concerns. There are no records of tsunamis, earthquakes, nor landslides resulting from boat-based oil spills. Even in the face of marine oil from shallow water oil wells, there are generally no concerns for geologic stability. Indeed, it might be the reverse case, it is the multi-decade operated oil fields that demonstrate subsidence. Louisiana's lower Cajun territory has experienced broad areas of subsidence since the onset of oil production.

5.2. Deep ocean eruptions

There is a developing alternative in the wake of the BP Deepwater Horizon incident, the "deep ocean persistent presence" model.[157] It is important to identify this

[155] Epipelagic waters are generally defined as reaching from the ocean's surface down to about 200m. Crude oil does not normally float at depth, rather it tends to float with a meters of the surface. Such assumptions were eliminated at the Deepwater Horizon event, because chemicals were injected into the oil stream at the wellhead which substantially changed the buoyancy of the resultant hydrocarbon blobs.

[156] Assuming that the spill is not co-incidental with production from a gas well, the main source of greenhouse gases would be either the evaporation of volatile hydrocarbons, such as butane, as the crude is exposed to solar heat and the atmosphere. Ocean-spilled crude oil is often combusted as a means of abatement and that in turn can release a variety of emittants such as carbon dioxide. While noxious, the overall volumes of emissions from both the sublimated/evaporated natural gas liquids and the emitted combustants are globally insignificant in contrast to daily traffic-based combustion.

[157] Adams *et al.*, *supra* at note 141, at 461.

alternative deep ocean hazard paradigm as distinguishable from both the traditional oil spill paradigm and the paradigm of harms from methane hydrates. It is an important area for future legal research but it is outside the scope of this current study.

The Deepwater Horizon event is the paradigmatic deep ocean persistent presence scenario. The spill was not really a spill in as much as it was an eruption of crude oil and natural gas from an out-of-control artificial well-bore into the reservoir.[158] The leak is not at the ocean surface but perhaps a kilometer below at great benthic depths.[159]

The ocean is regarded as having multiple levels; they range from near the sea-surface wherein much light and biotic material exist to deeper levels with little illumination and a scarcity of biotic material. While benthic levels of the ocean are less active, they are critical areas of the ocean from an ecological perspective. The ecology of those depths is especially fragile in contrast with waters closer to the surface.

The crude oils and natural gases emerge at great heat into a cold aqueous environment with great turgidity; the physical energies whirling near the point of eruption also cause great disruption to the general seabed.[160] Odd combinations emerge from this kinetic and thermo-dynamic chaos, chunks of methane hydrates form near the eruption and float off, oil-gas-water emulsions are formed and flow into the turbulence, and sediments mix with all of it to create a variety of substances of varying buoyancy and toxicities.[161]

In contrast to the rapid buoyancy of crude oil spills from the MOP model, the products of the deep ocean eruption do not necessarily move quickly to the surface.[162] A great proportion of the crude oil volume will drift laterally deep within the ocean, as it may lack much buoyancy and be carried away by deep seas currents.[163] Another portion of the erupted hydrocarbons may remain submerged indefinitely, either flotsam or as seabed encrusting.[164] There is evidence that a lot of the post-turbulence sub-sea hydrocarbons can enter marine food chains at the lowest levels;[165] the harms and hazards of the hydrocarbons are passed up the food chain. As with all toxicities in a food chain, the higher in the food chain the greater the resulting accumulated toxicity; deep ocean spill events will reach the human food supplies and cause great risks to human health if not prevented. The damages from a benthic event may not be fully obvious for decades.

There are few, if any, laws properly squared on the "deep ocean persistent presence" model.[166] The majority of existing oil spill laws and regimes are

158 *Id.*, at 462.
159 *Id.*, at 461.
160 *Id.*, at 462.
161 *Id.*
162 *Id.*
163 *Id.*
164 *Id.*
165 *Id.*
166 *See* discussion on EU Offshore Directive, *infra*, at ch. 10.

predicated on the "shore-bound surface spill" model, such as the Oil Pollution Act of the United States. It was drafted in response to the Exxon Valdez spill in Alaska.

There are certain general anti-pollution regulations and ecological preservation regulations that can be brought to bear on deep ocean spills, but again, the events of the BP Deepwater Horizon demonstrated that the ex ante protections for the specific benthic harms were insufficient.[167]

This kind of accident can and needs to be distinguished from the potential harms and hazards of offshore methane hydrate projects.[168] The activities of methane hydrate projects will occur offshore, sometimes hundreds of kilometers offshore. But unlike deep ocean type events, methane hydrate projects will engage in comparatively shallow wells. Methane hydrate projects will obtain resources from below a mud layer unlike the marine oil or deep ocean wells that recover from below a solid rock or salt interface. And the potential injuries from methane hydrate projects will be very distinguishable from MOP or BHP events in that the primary chemical emissions will be gaseous methane and carbon dioxide and not hydrocarbaceous oils and tars.

Thus, while methane hydrate events will clearly not belong within the marine oil paradigm of hazards, it will also not belong to the emerging deep ocean paradigm of hazards, and thus the planning for harms and hazards of methane hydrate projects will need to be included in liability and regulatory frameworks as a novel matter.

6. Summary and conclusions

While the previous chapter established the potential benefits of developing offshore methane hydrate resources, this chapter has established that there is a range of risks and hazards that would accompany that development. Some of the risks might be of a pervasive or non-cataclysmic character while other risks and hazards would be cataclysmic in character.

Non-cataclysmic harms might include continuous or frequent venting or seeping of methane from the deposit beds into the ocean, disruption of the flora and fauna adjacent to the deposit fields, and potential nuisance disruptions to the human communities that routinely interact with the water environments near the deposit fields.[169] These harms would primarily affect those that interact routinely in

[167] It is an interesting observation that in the years since the Deepwater Horizon event, the United States has adopted little in new regulation to address these types of problems. An argument can be made that BP's swift offer to create a large compensation fund, in fear of the American tort system, plus a perception that "the system worked, the problem was fixed," has removed a sense of urgency for reform. It may take a number of years of scientific observation to more firmly determine what damage occurred at benthic depths and what legal remedies may be added before the United States takes more decisive action.

[168] Those harms are detailed, supra, at 4.2 *et seq*.

[169] Following Arcuri's use of Knightian terms, the non-catalcysmic risks hazards posed by offshore methane hydrates are predominately of the *risk* classification, although one would reasonably assume some levels of *uncertain* hazards would remain. *See* A. Arcuri, *The Case for* →

the water immediately adjacent to the hydrate deposit area. In general these localized types of harms would not likely generate transboundary events; although they could become transboundary in character if the zone of the incident were to be sufficiently adjacent to a border.

Cataclysmic harms primarily result from sudden massive methane-release events.[170] As the methane hydrates lay in sheets under mud layers, certain disruptions could cause whole field sections to slough and slide; potentially leading to landslides, earthquakes, and tsunamis. On-going extraction activities could also produce accumulations of free methane under the mud layers that could erupt violently through the mud layers; once initiated, that methane evacuation could cause additional methane volumes to become disassociated and released. If the emissions are released with sufficient energy and volumes, it is feasible that the methane volumes could reach the atmosphere intact and erupt in flame. These harms could result in damages far afield from immediate surroundings of the offshore methane hydrate installation. It is reasonable to believe that such harms might be hundreds of miles or further afield based on evidence from geological records of historical events. Given the far range of cataclysmic injuries, it is very likely that the accident and its harms would be transboundary in character.

Both categories of harms release greenhouse gases into the atmosphere, facilitating anthropogenic climate change. Methane and carbon dioxide are listed as greenhouse gases under the UNFCCC and its Kyoto Protocol.[171] Methane can be released from the seabed via cracks in the mud layers, via persistent venting or seeping, or by massive emission events. Carbon dioxide can result from the methane being metabolized by sea-borne biota. When methane is vented at low energy levels and at sufficient depths in the ocean then it has been modelled that almost all of the emitted methane would be converted to carbon dioxide prior to the gases reaching the ocean's surface. Either way, the emissions of methane from methane hydrate deposits would result in the eventual transfer of greenhouse gases to the atmosphere, increasing the risks and likelihood of anthropogenic climate change. That is a harm presented to current and future generations, globally.

These events, cataclysmic harms, non-cataclysmic harms, and climate change harms, do happen in nature. The geological evidence is clear that both massive sloughing and landslides have occurred around the world; there are tsunami run-up scars in the soil beds of Scotland and Norway from the Storegga events of 8,000 years ago. At the non-cataclysmic level, methane hydrate chunks routinely dislodge and float to the surface of the sea. Ocean warming events such as hurricanes can

a Procedural Version of the Precautionary Principle Erring on the Side of Environmental Preservation, 11-12 (Global Law Working Paper No. 09/04, 2007).

170 For the cataclysmic hazards, the potential outcomes are known and the probabilities are coming into focus. But perhaps it is yet premature to suggest that the risks are Knightian *risks*. They will likely remain in the range of *uncertainty* for near-term policy makers. *See id*. Due to the undesirability of learning from historical accidents or large-scale experiments, the advancement of computer simulations will likely be at the forefront of that shift from *uncertainty* to *risk*.

171 See discussion on UNFCCC, *infra*, at ch. 8, sec. 4.

warm seabed deposits of methane hydrates and induce temporary seeping from the sea beds. In some parts of the world, venting methane, called *mazuku*, has flowed out of lakes and asphyxiated villages. The nuisance odour of swamp gas is a smell familiar to many people who live close to swamps. It is expected that with offshore methane hydrates, anthropogenic disturbances to the methane hydrate beds will be additive to the pre-existing natural risks.

The affected communities from offshore methane hydrate development are potentially of a very wide character. Because almost every single coastal country in the world is expected to either possess its own offshore methane hydrates or be adjacent to such deposits, the whole range of developing and developed economies could be impacted. Similarly divergent, some methane hydrates sit offshore high-density urban areas while other deposits lay offshore of uninhabited areas.

Adjacency is not the only vector of concern. Some hydrates lay on fairly flat fields while other lay on steep slopes; the greater the incline the higher the risks of landslide or tsunami. Some hydrates lay in cold waters, others in warmer waters; the warmer the waters the greater the ambient chances of disassociation. There is also great diversity in the way that methane beds can be formed with regards to forming cements with gravels and grains of sand; firmer hydrate deposits would be safer than others.

But that said, most readers would have been largely unaware of the risks posed by offshore methane hydrates. That is because methane hydrates are endothermic; it takes something ‘extra’ to get an accident from methane hydrates. Once hydrates are formed, it takes energy from outside to raise the potential for the hydrates to disassociate. Thus, when hydrates are under pressure and within cool temperatures, they are very unlikely to destabilize and vent or seep. The harms from methane hydrates in nature are usually predicated by exogenous sources of energy, *e.g.*, such as earthquakes or warm ocean currents. Sometimes, slow processes accumulate for a suddenly appearing emission; but again the energy source was usually found to be exogenous. Thus, offshore methane hydrates are inherently stable once formed and lying in deposits, but they can be disturbed.

The development, production, and even certain stages of the abandonment and sequestration phases of an offshore hydrate installation all offer potential sources of exogenous energy that could induce hydrate structures to disassociate and enable various harms to result. The various risk explored by Yabe *et al.* detailed the many standard operation activities that could lead to energy-adding disturbances that could lead to increased levels of methane hydrate accidents. Because methane hydrates do not readily disassociate, the very act of producing methane hydrates would require the introduction of exogenous energy into the deposit bed to enable the disassociation that could then lead to the extraction of the disassociated methane volumes; the very act of production requires the destabilization of the hydrate. The range of extraction technologies reviewed in Chapter 3 were effective techniques because of their means of adding energy to the deposit beds; depressurization, thermal stimulation, and inhibitor injection all serve to destabilize the hydrate beds. The enterprise of extracting methane from methane hydrate beds is a balancing act of sufficient energy injection to loosen and remove methane gases without injecting so much energy as to destabilize the bed and result in harms.

Safe offshore extraction of methane hydrates, even continuous and flowing extraction, has been achieved in practice; it is possible to extract safely. The risks can be managed, so long as reasonably stable methane hydrate beds are chosen at the beginning. The ability to categorize the risks of disassociation and their vectors of causation gives rise to hope, in that hydrate risks are characterizable and hydrate disturbances can be measured, thus the sources of the risks, hazards, and harms can be assayed and monitored for potential impact on the deposits of offshore methane hydrates.

This is where standards of safety and precaution become necessary to ensure that the whole collection of operators and investors, of local citizens living within the zones of potential harm, and of nations further afield concerned with anthropogenic climate change can all become assured that optimal levels of offshore methane hydrate development and precautions are met.

The key to that management of risks from offshore methane hydrate development and production is the subject of the next section of this study, Part II. Therein the study of rules of civil liability, public regulation and private regulation will be explored to determine the optimal means of standards settings and of efficient achievement of those standards. Optimal governance mechanisms for offshore methane hydrates will be identified. Part III will follow to compare existing laws and conventions for their match and fit against the recommendations presented in Chapter 7 or Part II. Part IV will provide a summary of the whole study and present final conclusions.

Chapter 4

Part II

Governance of Accidental Risk

Chapter 5

RULES OF CIVIL LIABILITY

This Part II of the study provides three chapters. The overall focus of these three chapters is to identify which means of risk governance might optimally provide for the efficient governance of the risks and potential harms from the development of offshore methane hydrates. This effort in Part II is theoretical in character, comparing the unique circumstances of offshore methane hydrates to the rules of civil liability and to both public and private regulation.

Chapter 5 reviews the civil liability rules of strict liability and negligence. It attempts to provide a survey of when each rule might be optimally or efficiently employed; introductory comments on the potential application of each rule to offshore methane hydrates are provided.

Chapter 6 addresses the theory of regulation and when regulations might be optimally or efficiently employed. Additionally, that chapter addresses the potential for regulations and rules of civil liability to be complementarily engaged to efficiently govern.

Finally, Chapter 7 will provide an integration of the first two chapters and apply them to the question of what mix of civil liability rules and regulations might optimally govern the risks and hazards from offshore methane hydrate installations. It is within Chapter 7 that the theoretical recommendations for a mechanism of risk governance will be presented.

Part III of this study will provide a comparison of the results of this Part II, the risk governance mechanism presented in Chapter 7, with the existing laws and conventions that might be applicable to the development of offshore methane hydrates. Part III will examine the conventions of the UN, international maritime and oil spill conventions, laws of the EU, and the federal laws of the U.S. Particular attention will be paid to both the general applicability of the various laws and conventions to offshore methane hydrates and to the general fit and match of the existing laws to the recommendations from Chapter 7.

Part IV of this study presents a summary and final conclusions for the whole of the study. Part IV also includes various appendices, including maps, mathematical notes, and a reference section.

1. Rules of civil liability to govern accidental harms

Liability rules stem from the legal traditions first enunciated under the Roman *lex Aquilia*,[1] that tortfeasors[2] should be held responsible for the damages they cause to another person's property. Traditionally, liability arose from an idea of social obligations; it is the flip-side of contractual or volitional obligations, in that liability arises from non-consensually derived damages.[3]

Law and Economics provides a framework for evaluating the strategic consequences of incentives from public actors onto the decisions and economic activities of private actors. Rational actors are assumed to exist, the actors face choices and prices, and can make optimizing decisions.[4] When the markets provide actors with a complete data set, *i.e*. when the costs faced by the actor include all of the potential costs derived from the consumption of a given product, then the actor could make efficient decisions. But what if informational problems arise, *e.g*., what if a product's costs to the actor did not include the costs of damage to others beyond the actor *cum* consumer, would efficient consumption decisions still be attained? Externalities are the economic phenomena that are transferred from a first actor to a second actor without economic consideration; the recipient is thus unable to provide cost or pricing information data back to the first actor.[5]

Pigou suggested that negative externalities could be efficiently addressed by taxing an economic activity that creates externalities within the jurisdictional zone of a sovereign; thus economic information could be provided to the first actor.[6]

1 G. D. DARI MATTIACCI, *Economic Analysis of Law: A European Perspective, in*: TORT LAW AND ECONOMICS, 2 2006.

2 A note on the vocabulary choices of this chapter. This chapter will primarily employ the Anglo-American common law term *tortfeasor* as indicative of the lead actor in an activity that gives rise to a tortious injury to a second or third party person. Much of the economic literature employs the word *injurer*, certain quotes herein retain that original word choice. There is not an effective difference in meaning. Etymologically in English, tortfeasor derives from the Anglo-Norman legal term *tort fasieur*, the tort-doer; and *tort* itself derives from Latin *tortus*, to twist and thus to hurt, *e.g., see* torture. This phrasing is perhaps more active in voice than the term *delict*, which derives from the Latin *de linquo,* to depart from or to be missing, *i.e.*, to evade one's duties. Injurer derives from the Anglo-Norman borrowing from Latin of *iniuria*, or the lack of a legal right. Both injurer and tortfeasor indicate an actor who violates another's lawful rights or who invades another's legally protected interests. Interestingly, the etymology of the word *victim* derives from the Latin word for a sacrificial animal, implying that the victim played a passive role in their resultant injury. If so, then perhaps there is a linguistic bias to be careful to take note of, that *victim* in the law and economics literature does not suggest unilateral nor bilateral nature of an accident but merely the party counterpart to the tortfeasor.

3 Mattiacci, *supra* at note 1, at 2.

4 *See* A. PACCES & L. T. VISSCHER, *Methodology of Law and Economics*, *in*: LAW AND METHOD: INTERDISCIPLINARY RESEARCH INTO LAW, 85, #-# (Tübingen: Möhr Siebeck, 2011).

5 *See id*. *See also* R. Van den Bergh & L. T. Visscher, *Optimal Enforcement of Safety Law, in*: MITIGATING RISK IN THE CONTEXT OF SAFETY AND SECURITY. HOW RELEVANT IS A RATIONAL APPROACH?, 29 (R.V. de Mulder, ed., Rotterdam: Erasmus University Rotterdam 2008), for an applied discussion on optimal enforcement policies to address existing externalities.

6 A. C. PIGOU, THE ECONOMICS OF WELFARE (1924).

Pigou suggested that by setting the marginal additional tax rate for an externality equal to the marginal costs caused by the same externality, the economic producer of the externality would be driven to efficiently balance the utility of the externality against its welfare costs to the broader community.[7]

Coase established his revolution on the idea that in the absence of transaction costs, such an effort would be unneeded because the parties on both sides of the externality would be able to efficiently negotiate the conflict to resolution.[8] Coase demonstrated that externalities are essentially a conflict of overlapping property rights.[9] Coase used the existence of the conflicts, and their demonstrable inefficiency, to demonstrate both that transaction costs were important considerations and of how those costs impacted the need for legal rules to assign certain initial conditions to better improve market efficiencies.[10]

1.1. Prioritizing accident reduction over compensation

Lawyers, both Civil and Common, have seen liability rules as a system that provides compensation for victim of tortious acts.[11] There are valid critiques of this perspective, that using liability as a source of compensation is substantially less efficient that other means such as insurance.[12] The *polluter pays principle* is a principle of environmental tort law that reflects the fundamental paradigmatic focus, who pays what to the victim as a means of justice and compensation.[13]

In the last fifty years, a new school of thought has developed on the proper role of liability rules.[14] Economists began to see liability rules as a system of incentives to prevent unwanted behaviors and outcomes.[15] Whereas the older notion was that tort law serves to administer justice to those injured, the newer model evidenced that tort law could serve to guide tortfeasors to optimal levels of risky behavior. The contrast of these two paradigms can be suggested as the *ex post* compensation for damages versus the *ex ante* prevention of harm.[16] These two ideas, although espousing different teleological ends, can be broadly compatible with each other.[17] Micro-economic analyses suggest that incentives can be created or

7 *Id.*
8 R. H. Coase, *Problem of Social Cost*, 3 J. L. & Econ. 1 (1960).
9 *Id.*
10 *Id.*
11 Mattiacci, *supra* at note 1, at 3; M. G. Faure, *Environmental liability*, *in* Tort Law And Economics, 247, 249 (Edward Elgar, 2009).
12 *Id.*, at 3; *Also see* S. SHAVELL, ECONOMIC ANALYSIS OF ACCIDENT LAW, 263 (Harvard University Press, 1987).
13 Faure, *supra* at note 11, at 249.
14 *Id.*
15 *Id.*
16 M. G. Faure, *Liability and Compensation for Damage Resulting from CO_2 Storage Sites*, 26 (2013) (unpublished manuscript) (on file with author).
17 Policy makers should be advised that if the liability rules are tasked with both creating incentives to avoid inefficient levels of accidents and providing the means to compensate →

utilized that will push the actors to reach efficient levels of activity and risk; and thus minimize accident costs.[18]

In an economic view of liability rules, liability rules provide incentives to the decision maker in current time to consider the potential costs of future harms and hazards.[19] Taking those costs into account, the actor can then optimally choose the efficient level of care for a given activity. "An ounce of prevention is worth a pound of cure,"[20] could be an apt summation of the theoretical perspective.

Calabresi stated that the objective of tort law is to minimize the social costs of a tort defined as the sum of the of total accident costs, administrative costs, costs of properly allocating accident losses by means of insurance, and accident prevention costs of both the tortfeasor and the victim.[21] Finsinger and Pauly have added that normatively, the net social welfare of any risky activity should be positive in value.[22]

> "The main goal of tort law is to internalise the externalities in order to enhance optimal decisions on the level of precaution."[23]

The goals of liability rules are to induce the involved parties to attain efficient levels of activity and efficient levels of care or precaution.[24] Liability rules can be used to control the behavior of one or of both parties.[25] Liability rules can also directly

accident victims, then the overall effectiveness to accomplish either goal could be substantially diminished. Faure, *supra* at note 16, at 32. *See also* Faure, *supra* at note 11, at 249, citing G. T. Schwartz, *Mixed Theories of Tort Law: Affirming Both Deterrence and Corrective Justice*, 75 Tex. L. Rev. 1801 (1997).

18 M. GLACHANT, *The Use of Regulatory Mechanism Design in Environmental Policy: A Theoretical Critique*, *in*: SUSTAINABILITY AND FIRMS: TECHNOLOGICAL CHANGE AND THE CHANGING REGULATORY ENVIRONMENT, 179, 181 (Edward Elgar, Cheltenham, 1998).

19 The concern is that certain events create costs or impacts that are not recognized by the actor; economists call these costs "externalities". By using liability rules, the legal system is able to redirect the costs of torts back to those who society has decided should bear those external costs, usually the original tortfeasor. For those individuals who are profit-seeking, such as corporations or investors in energy projects, the legal assignment for ex post costs of damages can thus become expected costs of operational hazards and become included in ex ante decision making on the project. Since the costs of the damages can be reduced by expenditures for safety and caution, the operator/investor is able to efficiently gauge the correct duty of care and ensure an efficient use of economic resources.

20 Benjamin Franklin. February 4, 1735 issue of The Pennsylvania Gazette; as paraphrased by Faure, *supra* at note 16, at 27.

21 H. B. SCHÄFER & A. SCHÖNENBERGER, *Strict Liability versus Negligence, in*: ENCYCLOPEDIA OF LAW AND ECONOMICS, 598 (Edward Elgar, 2000). They cite to G. CALABRESI, THE COSTS OF ACCIDENTS: A LEGAL AND ECONOMIC ANALYSIS (Yale University Press, New Haven, Conn., 1970).

22 *Id.*, at 602. They cite to J. Finsinger, & M. Pauly, *The Double Liability Rule*, 15 Geneva Papers on Risk Ins. 159 (1990).

23 G. D. DARI MATTIACCI, *Economic Analysis of Law: A European Perspective, in*: TORT LAW AND ECONOMICS, 4 (2006).

24 *Id.*

25 *Id.*

impact or ignore activity levels.[26] Liability rules are generally employed where transaction costs appear to be barriers to Coasean negotiations to clarify contrasting assertions of rights.[27]

Liability rules are effective because they force actors to consider *ex post* requirements to pay damages and compensation in *ex ante* decisions.[28] Including those impacts in the *ex ante* decisions processes should affect both care level and overall activity level decisions.[29] This mixed paradigm has been in place for a longtime, and as such is generally seen as uncontroversial.[30]

1.2. Choice of instrument: strict liability versus negligence

Shavell was one of the first economists to develop models of liability rules that enabled policy makers to evaluate the efficiency of a particular liability rule to achieve the optimal level of accident avoidance.[31] Given the intent of his models, it is clear that Shavell examined liability rules from the perspective that liability rules are tools to provide *ex ante* incentives to avoid accidents. [32] He demonstrated that both strict liability and negligence could, under the right circumstances, provide efficient results to optimally manage the potential harms and hazards from accidents.[33]

A standard economic model of tort law emerged several decades ago and has been considerably refined.[34] The standard model broadly supports the finding that a rule of strict liability would be preferable, or more efficient, to a negligence rule in most situations. There are several theoretical models that extend support to the

26 *Id.*, at 4-5. *See also*, S. Shavell, *Strict Liability versus Negligence*, 9 J. Legal Stud. 1 (1980), *en passim*.

27 *See infra* at ch. 6.

28 Mattiacci, *supra* at note 23, at 3.

29 *Id.*; Faure, *supra* at note 11, at 251.

30 Glachant, *supra* at note 18, at 181. *See also* G. Calabresi, *Some Thoughts on Risk Distribution and the Law of Torts*, 70 Yale L. J. 499 (1961); R. A. Posner, *A Theory of Negligence*, 1(1) J. Legal Stud. 29 (1972); Shavell, *supra* at note 26; and H. B. SCHÄFER & F. MÜLLER-LANGER, 'Strict liability versus negligence' *in*: TORT LAW AND ECONOMICS (2009).

31 *See* S. Shavell, *On Moral Hazard and Insurance*, 93 Q. J. Econ. 541 (1979); Shavell, *supra* at note 30; and Shavell, *supra* at note 12.

32 In this, Shavell set the theoretical stage to focus on how to efficiently reduce the incidence of accidents and away from the question of how efficiently or justly those rules might provide compensation to victims. "The aim of this article is to compare strict liability and negligence rules on the basis of the incentives they provide to "appropriately" reduce accident losses. ... In particular, there will be no concern ... with distributional equity—for the welfare criterion will be taken to be the following aggregate: the benefits derived by parties from engaging in activities less total accident losses less total accident prevention costs." Shavell, *supra* at note 26, at 1.

33 *Id.*

34 J. Nussim & A. D. Tabbach, *A Revised Model of Unilateral Accidents*, 29 Int'l Rev. L. & Econ. 169, 169 (2009). *See also* at footnote 2, same page. *See also* Calabresi, *supra* at note 21; Shavell, *supra* at note 26; W. M. Landes & R. A. Posner, *The positive economic theory of tort law*, 15 Ga. L. Rev. 851 (1980); Schäfer & Schönenberger, *supra* at note 21; Schäfer & Müller-Langer, *supra* at note 30.

application of negligence rules under certain circumstances.[35] The theoretical impacts of *ex post* avoidance strategies,[36] of risk allocation,[37] of the (a)symmetries of externalized costs and benefits,[38] and of general informational shortages[39] all lead to specific logics for the use of negligence rules.

The choice of strict liability versus negligence comes down to two main tests; (i) which system provides more efficient incentives for people to undertake safer activities and (ii) which system provides more efficient incentives for people to make given activities safer?[40] Thus the policy maker is faced with determining which rule set is more likely to be efficient in light of the circumstances surrounding the activity to be regulated or influenced.

It will be central to this study to determine if the operations and the risks of offshore methane hydrate installations fit within the standard model or whether they merit the rule of negligence from other specific needs. First a review of the arguments for when strict liability could be efficiently implemented is provided. Second, a similar review of like arguments for when a rule of negligence might be efficient applied is developed. A discussion of certain concerns regarding the application of both rules is presented thereafter. Following those reviews, a summation of the potential arguments for the application of the arguments to the conditions and circumstances of offshore methane hydrates is presented. A conclusion is reached that strict liability would be more efficient than a rule of negligence for the nascent offshore methane hydrate industry.

2. When strict liability is preferable

There are several types of activities wherein strict liability has been modeled to be more efficient at determining the optimal levels of activity and precaution.

> First, when the underlying harms and hazards are best described as unilateral in nature, that the majority of the information needed to determine the probability and severity of the accident is determined by the injurer, then strict liability has been found to be optimal over negligence.[41]

35 *See* K. N. Hylton, A Positive Theory of Strict Liability. 4(1) Review of Law & Economics 153 (2008) (Due to licensing limits where the present study was undertaken, its research relied on the working paper version of Hylton's article; as such, all point citations are to that source material. *See* K. N. Hylton, *A Positive Theory of Strict Liability.* (Boston University School of Law Working Paper No. 06-35, *available* at SSRN: http://ssrn.com/abstract=932600); Nussim & Tabbach, *supra* at note 34; *See also* T. Friehe, *Precaution v. Avoidance: A Comparison of Liability Rules,* 105 Econ. Letters 214 (2009).

36 Friehe, *supra* at note 35.

37 M. Nell & A. Richter, *The Design of Liability Rules for Highly Risky Activities - Is Strict Liability Superior When Risk Allocation Matters?,* 23 Int'l Rev. 31 (2003).

38 Hylton, *supra* at note 35.

39 Nussim & Tabbach, *supra* at note 34.

40 Schäfer & Schönenberger, *supra* at note 21, at 598.

41 *See* discussion, *infra*, at 2.1 Unilateral accidents ‑ strict liability efficiently sets both precaution and activity levels

> Second, when activities are described as abnormally hazardous activities, or activities wherein the externalized costs far outweigh the externalized benefits to society, then strict liability has been found to be optimal over negligence.[42]
>
> Third, when decentralization is a policy goal, strict liability is preferable.[43]
>
> Fourth, when the activities themselves are innovative and present novel and uncertain risks and hazards, then strict liability has been found to be optimal over negligence.[44]
>
> Fifth, when the transaction costs presented to the judicial systems are matters of concern for the policy makers, then strict liability has been found to be optimal over negligence.[45]

The commercial development of offshore methane hydrates is well characterized by these five scenarios. The commercial development of offshore methane hydrates will primarily present risks and hazards best characterized as unilateral in nature. Due to the severity of the potential harms and hazards from cataclysmic methane hydrate events, the operation of offshore methane hydrate projects could be characterized as abnormally dangerous.[46] As no offshore methane hydrate projects have ever been commercially developed, and as offshore methane hydrate deposits have never been produced for yearlong periods, the activities of such offshore projects could be characterized as innovative and presenting novel and uncertain risks and hazards. Finally, as the geography of the known offshore methane deposits lay offshore of jurisdictions with limited judicial resources, it is likely for many of those jurisdictions that transaction cost management will be of importance to their policy makers. For these reasons, strict liability is likely to be more efficient for the management of the harms and hazards from offshore methane hydrate projects.[47]

2.1. *Unilateral accidents – strict liability efficiently sets both precaution and activity levels*

Broadly speaking, the rule of strict liability has been found to be efficient more often than the rule of negligence in unilateral situations. Both strict liability and negligence achieve efficiency with regards to preventative measures within unilateral accident models.[48] Strict liability is superior to negligence in that strict

42 *See* discussion, *infra*, at 2.2 Abnormally hazardous activities
43 *See* discussion, *infra*, at 2.3 Strict liability enables decentralization
44 *See* discussion, *infra*, at 2.4 In the face of uncertainties
45 *See* discussion, *infra*, at 2.5 When transaction costs of justice are critical
46 *See* the discussion and definitions of 'abnormally dangerous', *infra*, at sec. 2.2.
47 *See* discussion, *infra*, at Ch. 7.
48 While Schäfer & Müller-Langer, *supra* at note 30, offer perhaps the most recent demonstration of this result, their paper follows a history of similar findings, including the seminal models of Shavell and the Landes-Posner systems; likewise, Schäfer has published similar demonstrations with other authors. *See* Schäfer & Müller-Langer, *supra* at note 30, at 25.

liability efficiently obtains optimal levels of tortfeasor activity but negligence often cannot.[49]

Shavell proposed that accidents could be categorized into two sets of models, unilateral accidents and bilateral accidents. Unilateral accidents are those in which only the tortfeasor's actions affect the probability and severity of the accident.[50] Bilateral accidents are those accidents that enable the actions of both the tortfeasor and the victim to affect the probability and severity of the accident.

Under a rule of strict liability,[51] the tortfeasor is able to optimize his utility as impacted by the costs he would bear in accidents. The tortfeasor's optimand is the same as the social welfare function, thus strict liability is efficient.[52] Shavell found that in the stranger-stranger unilateral tort, that strict liability achieved efficiency by requiring the tortfeasor to include the full costs of the accident in his overall welfare function.[53] Schäfer and Müller-Langer also demonstrated that only strict liability provides for both efficient setting of precaution and activity levels. Strict liability enables control of activity levels and correctly sets an efficient level of activity.[54]

Under a negligence rule, the assumption is that a rational tortfeasor would choose a level of care equal to the duty of care, *i.e.*, that the care level selected is the efficient care level. [55] Then the tortfeasor under a negligence rule is tasked with optimizing its utility function given the tortfeasor's choice of activity level and the assumed duty of care.[56] The tortfeasor will select a higher level of activity than the welfare efficient level of activity, given the due care level; because the tortfeasor does not bear the costs of injuries incurred whilst operating at due care levels. [57] Thus in stranger-stranger unilateral contexts, the negligence rule would yield results of due care but at excessive levels of activity, resulting in higher than efficient levels of accidents with the victims being required to bear the costs of those accidents. [58] This results in the tortfeasor engaging in an excess of activity, excessive accidents result, and negligence is seen as inefficient. [59] Negligence does not require the tortfeasor to consider certain costs so long as the prescribed duty of care is met, thus the tortfeasor's activity level is too high and thus inefficient.[60]

Under a 'no liability' rule, the tortfeasor exercises no duty of care and bears no costs of the accidents so the activity level of the tortfeasor is guided solely by his

49 *Id.*

50 Unilateral accident models are those models that investigate the consequences of a single actor's decisions on activity choice, activity level, and precaution level.

51 In Shavell's unilateral formulation, the tortfeasor has a care or precaution level and an activity level. Social welfare was defined as the sum of income equivalent of the utility of the tortfeasor, less the costs of the activity at activity level.

52 Shavell, *supra* at note 26, at 11.

53 *Id.*at 11-12. *See* Equation (2).

54 Schäfer & Müller-Langer, *supra* at note 30, at 25.

55 Shavell, *supra* at note 26, at 11.

56 *Id.*, at 12.

57 *Id.*

58 *Id.*

59 *Id.*

60 Schäfer & Müller-Langer, *supra* at note 30, at 25.

personal utility, as affected by his selections of precaution and activity levels,[61] and again the tortfeasor would over-engage in tortious conduct. Shavell ranks the cumulative results as Proposition 1:

> *"PROPOSITION 1. Suppose that injurers and victims are strangers. Then strict liability is efficient and is superior to the negligence rule, which is superior to having no liability at all."* [62]

In effect, strict liability forced the tortfeasor to internalize and adopt Kaldor-Hicks-type welfare efficiency.[63] The same scenario under negligence requires only that the tortfeasor maintains a duty of care but no additional costs from whatever accidents occur, so long as the duty was met.[64] Thus, when activities can be described as unilateral in character, the common consensus is that a rule of strict liability is strongly preferable to the rule of negligence. [65]

2.2. *Abnormally hazardous activities*

Usually the first introduction a young law student has to strict liability is in relation to 'abnormally hazardous activities;'[66] as such, abnormally hazardous activities are often the paradigmatic example of when the rule strict liability should be employed. The main logic is that when certain actors choose to engage in abnormally dangerous activities that other actors, not conjoining or consenting to such adventurism, should not be expected to suffer for resulting harms of those dangerous activities. [67]

61 Shavell, *supra* at note 26, at 11.

62 *Id.*, at 12. Note that Hylton's Positive Theory of Strict Liability model can be shown to replicate the basic tenet of the Shavell-Landes-Posner model, that under unilateral accidents both strict liability and negligence are efficient. *See* Hylton, *supra* at note 35, at 6. An identical result is reached for Shavell's seller-stranger scenario. *See* Shavell, *supra* at note 26, at 14.

63 *Id.*, at 11-12. *See* Equation (2).

64 *Id.*, at 11-12.

65 Hylton provided a caveat to this result. Despite the potential equality of the efficiencies offered under strict liability and negligence under certain conditions, when the potential harms and benefits are small, actors might be more sensitive to their own harms than other due to the differences in transaction costs to identify both sets of data; in such environments, Hylton found that negligence might be more robust than strict liability. *See* Hylton, *supra* at note 35, at 23.

66 *See* United States' Restatement (2[nd]) Tort §520. Hylton listed the definitional elements, "In determining whether an activity is abnormally dangerous, the following factors are to be considered:

(a) existence of a high degree of risk of some harm to the person, land or chattels of others;
(b) likelihood that the harm that results from it will be great;
(c) inability to eliminate the risk by the exercise of reasonable care;
(d) extent to which the activity is not a matter of common usage;
(e) inappropriateness of the activity to the place where it is carried on and;
(f) extent to which its value to the community is outweighed by its dangerous attributes."

Id., at 18-19.

67 Expressed another way, strict liability operates similar to a finding of a breach of duty of care, regardless of whatever precautionary efforts were taken, whenever a tortfeasor caused injury →

2.2.1. Controlling tortfeasor with strict liability in bilateral accidents

When Shavell examines bilateral accidents, those accidents wherein both parties have control over actions that lead to accidents, he finds that the critical issue is "which party do we want to control, the tortfeasor or the victim?" The focus of control was on the activity levels of the parties. This is an extension of Calabresi's earlier cheapest cost avoider rule, that the person who could have prevented the accident with the least cost of taking care should be the person held liable for the accident.[68]

Shavell suggested that ultra-hazardous activities have two characteristics which especially merit the application of strict liability rules.[69]

First, the activities are
(i) uniquely identifiable and
(ii) impose non-negligible risks on non-participant victims which "make[s] the activity worthwhile controlling."[70]

Second, the victim's engagement with the risky activity is entirely routine in normal life, thus "activity that cannot and ought not be controlled."[71]

Shavell's definition focuses on the rights of the non-participant victims to remain undisturbed in their routine activities; this has ready application to industrial activities that could be characterized as ultra-hazardous but occurring near populated areas. [72]

Shavell then stated that given those descriptions of ultra-hazardous activities that the application of strict liability to such dangerous activities falls within his Propositions 4 and 6 from his model of bilateral accidents between strangers.[73]

> "*PROPOSITION 4. Suppose that the tortfeasor and victim are strangers. Then none of the normal liability rules is efficient. Strict liability with a defense of contributory negligence is superior to the negligence rule if it is sufficiently important to lower tortfeasor activity levels. Strict liability*

via an abnormally dangerous activity. *See* "Concluding Comments. #4. Shavell, *supra* at note 26, at 24.

68 Schäfer & Müller-Langer, *supra* at note 30, at 10. *See* Calabresi, *supra* at note 21.

69 Shavell examines the ultra-hazardous from a bilateral perspective in part because a unilateral accident was already established to be more efficiently addressed with strict liability, even those ultra-hazardous in nature.

70 *See* "Concluding Comments. #4. Shavell, *supra* at note 26, at 24.

71 *Id.*

72 Shavell's definition did not require much more than the imposition of "non-neglible" costs of harm onto the victims so what might reasonably be characterized as ultra-hazardous remained open ended. *See id.*

73 In so doing, he implicitly assumes that the ultra-hazardous scenarios involve victims *cum* strangers, and that a rule of contributory negligence is in effect. *Id.*

without the defense and no liability are each inferior to whichever rule is better: either strict liability with the defense or the negligence rule."[74]

"PROPOSITION 6. Suppose that injurers are sellers and that victims are strangers. Then the results are as given in Propositions 4 and 5."[75]

As such, the goal becomes to efficiently incentivize the tortfeasor to control his activity level and leave the victim unaffected in his activity level;[76] this is best achieved by the rule of strict liability with defense of contributory negligence.

In the stranger-stranger scenario, he found that strict liability with a defense of contributory negligence, efficiency could not be achieved because the victims would bear no costs for accidents and would have no incentive to reduce their activity levels.[77] The negligence rule in this scenario reflects the reverse, that the tortfeasor will face no costs to reduce activity levels and thus the negligence rule is inefficient.[78] Further, no liability rule and strict liability without contributory negligence are rated as inferior to either of the two previous results.[79] Thus, in bilateral stranger encounters, the policy choice is inefficient but does enable the policy maker to reduce either tortfeasor activity levels under strict liability with contributory negligence or to reduce victim's activity levels with the negligence rules.[80]

Indeed, Shavell proves that in stranger-stranger encounters, no simple liability rule can be efficient.[81] Table 1, *infra*, provides the results of Shavell research; that while other bilateral situations could be efficiently governed b rules of civil liability that no cases involving strangers were found to be so. These results are identical when the seller-stranger scenario is modelled; it is more efficient to use strict liability if the target is to reduce tortfeasor activity levels and more efficient to use negligence if the target is to reduce victim activity levels.[82]

74 Shavell, *supra* at note 26, at 19. Hylton found that that the private liability rules provide different controls and that they do not necessarily provide the same result as the social welfare optimand. Under strict liability, the actor responds to the cost consequences of his own acts; under negligence the actor responds to the cost consequences of the acts of other actors. This finding aligns well with Shavell's bilateral accident model, but Hylton's model herein is a unilateral accident model. *See* Hylton, *supra* at note 35, at 7 and 10. *See* also Shavell, *supra* at note 26, *en passim*.

75 *Id.*, at 20.

76 *See* "Concluding Comments. #4. *Id.*, at 24.

77 *Id.*, at 19. Specifically, Shavell targets the condition of $s = \bar{s} = s^*$ as the cause.

78 *Id.*

79 *Id.*

80 *Id.*

81 *Id.*, at 19-20. *See* Proposition 5. While not exclusively for this finding, but inclusive thereof, *see* the discussion, *infra*, on the complementary implementation of public and private regulations with rules of civil liability in Ch. 6, Sec. 4, and see Ch. 7, Sec. 3.3, and also see Ch. 12, Sec. 2.3.

82 Shavell, *supra* at note 26, at 20. *See* Proposition 6.

Table 1: Shavell's Bilateral Accidents: Are Liability Rules Efficient?

Encounter	Strict[83]	Strict[84]	Negligence	No Liability
Stranger-Stranger	No*[85]	No***[86]	No**[87]	No***
Seller-Stranger	No*	No***	No**	No***
Seller-Customer[88]	No	No	Yes	Yes
Durable Goods	No	No	Yes	No
	No	No	No	No
Seller-Customer[89]	Yes	No	Yes	Yes
Non-Durable Goods	Yes	No	Yes	No
	Yes	No	No	No

Shavell's conclusions on bilateral accidents are much more complex than for the unilateral accidents. Because the results are substantially different, it highlights the importance of correctly identifying events as unilateral or bilateral events. Unlike the unilateral results, no rule was found to be consistently efficient.[90] But, if the least cost avoider can be identified *ex ante*,[91] then the application of that principle to determine which actor should be governed can be combined with the appropriate choice of regime to obtain first best results.[92] If the tortfeasor were the least cost avoider, *e.g.*, an offshore methane hydrate installation operator, then the rule of strict liability would be the robust choice.

Schäfer, *et al.*, extended Shavell's unilateral accident model to establish an additional argument for the application of strict liability to abnormally hazardous activities. They demonstrated that under a negligence rule, the actor will over-engage in risky activity, whereas under a strict liability rule the actor might under-engage in a risky but socially beneficial activity.[93]

83 Strict Liability <u>with</u> Defense of Contributory Negligence.

84 Strict Liability <u>without</u> Defense of Contributory Negligence.

85 One asterisk, *, indicates that the rule limits the tortfeasor's behavior.

86 Three asterisks, ***, indicates inferiority to other inefficient results.

87 Two asterisks, **, indicates that the rule limits the victim's behavior.

88 Entries to the right reflect three orders of knowledge. Top row, the customer knows the risk of each seller. Middle row, the sellers' average risk. The bottom row, uncertain knowledge or misperception.

89 Entries to the right reflect three orders of knowledge. Top row, the customer knows the risk of each seller. Middle row, the sellers' average risk. The bottom row, uncertain knowledge or misperception.

90 However, there may be theoretical reasons to find negligence to be more robust than strict liability when this model's assumptions are relaxed. That was the result when Schäfer, *et al.*, extended this section of Shavell's research. They found that when the identity of the lowest costs avoider was determined *ex post*, and not *ex ante*, then both parties face a probabilistic distribution as to potential judgment and damages. *See* Schäfer & Müller-Langer, *supra* at note 30, at 11.

91 And might not the operator of the offshore methane hydrate project be that foreseeable least cost avoider of most if not all of the harms and hazards from its own operations?

92 Schäfer & Müller-Langer, *supra* at note 30, at 11.

93 Schäfer & Schönenberger, *supra* at note 21, at 606. For the case of:

→

As such, strict liability tends to require net positive social welfare results whereas negligence rules tend to enable net negative social welfare results.[94] If an activity is abnormally hazardous and has the potential to expose victims to very expensive injuries, then strict liability provides a mechanism that can ensure that such activities are undertaken only when the net costs and benefits of that activity are net positive for both the tortfeasor and society at large. The negligence rule would enable excessive amounts of that abnormally hazardous activity. Thus, under Schäfer's, *et al.*, arguments strict liability is a superior rule to ensure net positive results for the broader community from the abnormally hazardous activity.

2.2.2. Landes Posner strict liability conditions

Landes and Posner provided an approach was similar to Shavell's analysis of stranger-stranger bilateral accidents.[95] Their approach also reflects Shavell's observation that while strict liability or negligence may fail to be fully efficient under bilateral conditions, that strict liability would be more effective at altering tortfeasor behavior.[96]

Landes and Posner's conditions of strict liability provided guidance as to both the character of abnormally hazardous activities and the tortfeasor's behaviors.[97] They state that an abnormally hazardous activity poses high expected costs in injury and that additional levels of care will be ineffective in reducing the probability of risk. They also focus the effort to alter the tortfeasor's behaviors while assuming that the potential victims' activities either cannot be changed or should not be changed.

Landes and Posner advised the rule of strict liability in scenarios that presented the combination of expensive injuries, inability to reduce risk through additional care, the impossibility to control the activities of potential victims and the primary goal to limit dangers by efficiently controlling the overall level of the tortfeasor's engagement in the abnormally hazardous activity.[98]

i. Over-engagement under a negligence rule, they cite to A. M. Polinsky, *Strict liability versus negligence in a market setting* (National Bureau of Economic Research, Inc., No. 0420, 1980)
ii. Under-engagement under a strict liability rule, they cite to Shavell, *supra* at note 26.

94 Strict liability requires the tortfeasor to bear all of the costs, so tortfeasors have stronger incentives to ensure the net positive worth of their activities. Under negligence, the tortfeasor will escape some of the consequences and costs of his actions so long as he meets his duty of care. Schäfer & Schönenberger, *supra* at note 21, at 606.

95 Shavell, *supra* at note 26, at 18

96 See Proposition 4, that "strict liability is superior to the negligence rule if it is sufficiently important to lower tortfeasor activity levels." Shavell, *supra* at note 26, at 19.

97 Faure, *supra* at note 16, at 37, citing to Landes and Posner, *supra* at note 34.

98 *Id.,* citing to Landes and Posner, *supra* at note 34.The listed items were:
i. high expected accident costs,
ii. the impossibility that more care by the tortfeasor would reduce accident risk,
iii. the impracticability to constrain the victim's activity in flavor of the tortfeasor, and
iv. the desirability to reduce the risk by an activity level change of the tortfeasor.

2.2.3. Disproportionate risks to benefits

Expanding upon the ratio of externalized costs and benefits to the victims, Hylton's model provided a strong basis for the application of strict liability if the underlying activity displayed disproportionate externalized risks of harm without counter-balancing externalized benefits to the community. [99] Abnormally hazardous activities, by their very definition, are likely to qualify to be governed by strict liability.

Hylton took his observations on the cross effects of externalized costs and benefits to provide a comparative risk analysis that forecasts when which civil liability rules would be efficiently applied or at least more robust.[100] Noting that more risk reduces the optimal levels of an activity but that the reverse is true for externalized benefits, Hylton observed the rule paradigms of strict liability and negligence provided offsetting and balancing results.[101]

Under strict liability, the more externalized risk there is, the more damages will be assigned to the actor based upon his own activity level. [102] But under negligence, the actor will have an incentive to reduce his activity in response to the risks externalized by other actors. [103]

This led Hylton to propose the following two propositions: [104]

> *Proposition 1:*
>
> *"If $q_A > q_B$, holding A strictly liable is preferable to using the negligence rule in regulating the activity level of A. If, however, $q_A \leq q_B$, strict liability is not preferable to negligence. In simpler terms, if A externalizes more risk to others than they externalize to him, strict liability is preferable to negligence. However, if there is a reciprocal exchange of risk between A and B, or if B externalizes more risk than does A, holding A strictly liable is not preferable, as a method of regulating A's activity level choice, to the negligence rule."*[105] *(Underscoring added.)*
>
> *Proposition 2:*

99 Hylton differed from the above analysis in the case where external benefits from the abnormally hazardous activity coincided with abnormally large benefits to the potential victims; in that case he suggested that application of a negligence rule might be more efficient. *See* Hylton, *supra* at note 35, at 18-20.

100 *See* footnote, *supra* at sec. 2.2.1., in discussion on Shavell's fourth proposition.

101 *Id.*, at 10.

102 *Id.*

103 *Id.*

104 Hylton did not thusly label the propositions, so this labeling follows the sequence in which they were presented in the article. Also, for a more complete presentation of the models referred to in the quote from Hylton, *see* the discussion summarizing Hylton's models, *infra*, at Appendix II.C.

105 *Id.*, at 11.

> *"If there is reciprocal exchange of risk between A and* $(q_A = q_B)$*, strict liability and negligence provide the same incentives for care and for activity level choices."* [106]

These results provide simple guidance, that strict liability should be used when the risk asymmetry is substantial; otherwise the negligence rule is at least equally efficient and potentially preferable. [107] Hylton summarized these results:

> "Where there is asymmetry in risk externalization, negligence causes high risk-externalizers to increase their activity levels while low risk-externalizers decrease their activity levels." [108]

A negligence rule faced with asymmetrical externalization of risks results in more extreme behavior from the actors than comparatively under a rule of strict liability. The risky actors engage in higher levels of activity, the less risky actors engage in lower levels of activity.

2.3. Strict liability enables decentralization

Decentralization occurs when each tortfeasor can determine his level of preventative activities based on his unique costs; tortfeasors are not identical in that they might face different technology and cost choices.[109] Decentralization enables each tortfeasor to separately and uniquely optimize their due care and activity level decisions based on their own unique circumstances, thus this enables each tortfeasor to set their own standards to achieve the optimal levels of precaution and activity level.

The availability of decentralization is certain under strict liability but under negligence decentralization only becomes available under certain additional rules. Strict liability places the full risk of the precautionary level decision with the tortfeasor with no outside determined imposition of precaution costs. Thus, the tortfeasor can coordinate his costs to his precautionary activities and thus achieve decentralization.[110]

Negligence requires the tortfeasor to meet a certain minimal level of care, the reasonable man standard, regardless of a tortfeasor's unique costs to achieve that

106 *Id.*

107 When the tortfeasor is singular but the victims many, the choice of civil liability rule may have a second criteria of risk-neutrality versus risk aversion. Nell and Richter provided a demonstration that risk neutrality provides equivalent choice-of-rule results for both abstract singular victim and multiple-count victims but models with risk aversion have distinguishable results for singular victim versus multiple-count victims. They provided a proof that the optimal level of care increases, in risk aversion models, as the number of potential victims is increased in total head-count. *See* Nell & Richter, *supra* at note 37, at 35.

108 Hylton, *supra* at note 35, at 12.

109 Tortfeasors likely face different costs of care; decentralization is the policy goal to enable each actor to set their own individualized efficient levels of activity and precaution versus requiring them to meet community-wide standardized levels.

110 Schäfer & Müller-Langer, *supra* at note 30, at 18.

level of care.[111] *V*ariations to the standard negligence rule can provide for decentralization.[112] The application of both partial liability and a "highest degree of care" standard can effectively provide full self-selection of tortfeasors to enable decentralization.[113] Kahan demonstrated that partial liability or use of the difference principle can provide decentralization under negligence; especially when the tortfeasor faces high per unit costs of care.[114] In response to Kahan, Miceli proposed to establish due care levels at the efficient due care level of the least cost of care tortfeasor, holding each tortfeasor to the "highest degree of vigilance, care and precaution."[115]

2.4. In the face of uncertainties

2.4.1. Uncertain *ex ante* duty of care

When certain activities are new and they present novel risks, it can be difficult to ascertain the potential harms and hazards and to accurately determine *ex ante* the efficient duty of care or means of precautions. In that uncertainty, Schäfer, *et al.*, stated that strict liability would remain as efficient as it was with well-established activities, as the rule of strict liability never required a duty of care for its efficient operation.[116]

Schäfer, *et al.*, contrasted the efficiency of strict liability under uncertainty against the difficulty faced by the rule of negligence in similar circumstances. Negligence, in requiring a probabilistic interpretation of the duty of care, could drive tortfeasors to inefficiently over- or under-comply against the unknown duty of care.[117]

2.4.2. Incentives for safety innovation

Additionally, with novel activities and uncertain risks, policy makers might want to consider which rule better provides incentives to reduce the likelihood of future

111 Negligence posits a reasonable man standard, but the results of that standard need be identical for all potential tortfeasors. Thus, negligence inherently makes it more difficult to obtain decentralization.

112 *See* D. L. Rubinfeld, *The Efficiency of Comparative Negligence*, 16 J. Legal Stud. 375 (1987); O. Bar-Gill & O. Ben-Shahar, *The Uneasy Case for Comparative Negligence*, 5 Am. L & Econ. Rev. 433 (2005); and T. J. Miceli, *On Negligence Rules and Self-Selection*, 2 Rev. L. & Econ. 349 (2006).

113 *See* Schäfer & Müller-Langer, *supra* at note 30, at 17-18; and *see* R. COOTER & T. ULEN, LAW AND ECONOMICS, 388 (Pearson Addison Wesley, 2004).

114 *See* Schäfer & Müller-Langer, *supra* at note 30, at 17.

115 *See id.*, at 18. Citing to Miceli, supra at note 112, who in turn was citing to M. Kahan, *Causation and Incentives to Take Care Under the Negligence Rule*, J. of Legal Stud. 427 (1989).

116 Schäfer & Müller-Langer, *supra* at note 30, at 26.

117 That said, Schäfer, *et al.*, did caveat that efficiency might be obtained under a negligence rule, just unreliably so. *See id.*

injuries. Under a rule of strict liability, because the tortfeasor has to bear all of the costs of harm, the search costs for safer alternatives fall to the tortfeasor.[118]

The rule of negligence is less effective in providing incentives for safety innovation as the tortfeasor is only incentivized to reduce the costs of reaching the established due care levels.[119] Negligence provides a safety net for the tortfeasor, in that as long as certain established historical norms are met,[120] then no additional damages from harms can be assessed against the tortfeasor.

2.4.3. Complex interactions of precaution and activity levels

Nussim and Tabbach noted that the activity level might affect marginal expected harm in non-linear ways; the marginal expected harm could be either increased or decreased with additional levels of activity.[121] A rule of strict liability places the calculus of trade-offs solely with the tortfeasor but a negligence rule requires a public manifestation of a duty of care, which might be complicated and prohibitively costly for legislators and judges. Nussim and Tabbach provided an analysis that suggested that application of a negligence rule would result in a duty of care in excess of the actually optimal duty of care, creating inefficient results.

In their model, the social objective is the sum of the utility less the costs of precaution and less the costs of harms and injuries to victims. The model posits a condition that marginal investment in precaution is met by the marginal reduction in accident costs. Also, the marginal costs of increasing the activity level equal the marginal social costs of additional activity. These are impacted by their interdependency.[122]

Certain behavioral options can be identified within this framework. First, consider the case of specialization, wherein exposure to a risky activity decreases the marginal costs of precaution.[123] The result is that precaution and activity are

118 Schäfer & Schönenberger, *supra* at note 21, at 605. Especially relevant for the case of complicated or exotic industrial technologies, strict liability imposes the research costs upon the party mostly likely to find the answer, and to find that answer at the lowest costs.

119 Coasian transaction costs have been noted as blocking negligence from operating better with this particular problem. See J. R. Chelius, *Liability for industrial accidents: a comparison of negligence and strict liability systems*, 5 J. Legal Stud. 293, 296-297 (1976).

120 The very employment of historical norms has also been cited as one of the downfalls of the negligence rule in its underperformance to provide proper incentives for innovations. See G. Parchomovsky & A. Stein, *Torts and Innovation*, 107 Michigan Law Review 285, 303-306 (2008).

121 Nussim & Tabbach, *supra* at note 34, at 170.

122 In their model, the cross effects are described as: $\frac{\partial^2 J(x,z)}{\partial x \partial z} = -c_{xz}(x,z) - h_{xz}(x,z)$. This relationship can be contrasted with the Shavell and Landes Posner models' assumption that $\frac{\delta^2 J(x,z)}{\delta x \delta z} = 0$. *See* Nussim & Tabbach, *supra* at note 34, at 171.

123 As formulated: $c_{xz}(x,z) < 0$. *Id. See also* the discussion on "fatigue or wear and tear" in Appendix II.D. It appears that Nussim and Tabbach examine the concept that higher levels of activity could fatigue either the humans or the machinery involved in the higher activity level and thus the costs of care might increase along with the increased level of activity. It is also important to note the tentative 'could' in the phrase, as they state in their conclusion; "The →

complements. Second, fatigue could cause the costs of precaution to increase with activity levels; thus increases in either activity level or in precaution increase the costs of precaution. [124] When the fatigue effect is strong, then precaution and activity levels become substitutes. [125]

Nussim and Tabbach found that for the negligence rule, this complexity provides an unexpected result; when faced with high costs of ascertaining the effects of interdependency on resultant activity level and undertaken precautions, legislators and judges should set the value of due care higher than the otherwise established efficient level of care.[126] Legislators and judges cannot simply determine the activity level by setting a simple due care level, in that interdependency effects will require a simultaneous solution to both activity level and level of care.[127]

In some sense, this is captured by the idea of jointly permitting certain activity levels and safety standards within an environmental regulatory setting; as such, to the extent that regulatory means can better combine these two targets than civil liability might, regulatory means would be preferable. But much of the information needed to make such determinations is hidden or costly.

2.5. *When transaction costs of justice are critical*

In an extension of the logic but not the result of Shavell's earlier arguments, Schäfer *et al.* demonstrated that strict liability would likely present fewer cases to the courts than negligence would. Further, once in court, the costs of litigating under a rule of strict liability are expected to be less than the costs of litigating under a rule of negligence. Thus, when the transaction costs of preserving rights afforded under the rules of civil liability are of concern, the rule of strict liability is preferable to a rule of negligence.

Shavell had argued that under a rule of negligence, the tortfeasor would be likely to meet his duty of care and thus not be held liable and *ergo* no suits would be brought by the victim; also, because it was less costly to litigate under strict liability more claims would be brought forward; that negligence increased the transaction costs of litigating and thus provided an incentive to avoid litigation, whereas strict liability with its lack of a duty of care rule would be less costly and provide an incentive to litigate anytime the expected payoff from litigation was higher than the costs of filing. [128] Additionally, strict liability requires less information to be

costs of care are not necessarily proportionate to the activity level; it may be increasing with increasing or decreasing rates or be independent. " Underscoring added.

124 As formulated: $c_{xz}(x,z) > 0$. *Id.*

125 The input of either reduces the other, *ceteris paribus*: $\frac{\delta^2 J(x,z)}{\delta x \delta z} < 0$

126 At some $x > x^*$. *Id.*, at 173.

127 *Id.*, at 172. In some sense, this is captured by the idea of jointly permitting certain activity levels and safety standards within an environmental regulatory setting; as such, to the extent that regulatory means can better combine these two targets than civil liability might, regulatory means would be preferable.

128 S. Shavell, *A Model of the Optimal Use of Liability and Safety Regulation*, 15 Rand J. Econ. 271 (1984). Schäfer & Schönenberger, *supra* at note 21, at 604; wherein they cite to Shavell, *supra* at note 12, at 264.

presented to the court than a rule of negligence would require, because strict liability does not require a finding of both the existence or setting level of a prescribed duty of care and whether that duty was in fact met by the tortfeasor.[129]

Schäfer *et al.* suggested that the overall simplicity of the strict liability rule, which drove the lower costs identified by Shavell, should actually encourage tortfeasors to settle out of court if the facts of harm are readily apparent.[130] Additionally, when litigation costs are considered, because errant courts will bear substantial transaction costs, the optimal rule may not necessarily be foreseeable *ex ante* but a strict liability rule is expected to be less costly.[131]

There are three impact factors. First, because victims bear more costs to litigate under a negligence rule, as they have more to establish in court, they will initiate less litigation that those victims facing a strict liability rule.[132] Second, because the law of strict liability is both simpler, in that no causation need be developed nor any level of care be established, the legal consequences are more readily foreseeable.[133] Third, this foreseeability will lead to more pre-trial settlements, enabling low cost transference of wealth from tortfeasor to victim.[134]

If lawsuits based in rules of civil liability were to reach adjudication, the costs presented by litigation under a rule of strict liability will be less than those costs posed by litigation under a rule of negligence. Courts will have fewer tasks to accomplish in adjudication under strict liability because they will only need to determine the scale of the harms.[135] Under negligence, courts need to prove negligence by establishing both a duty of care rule and then an evidentiary hearing on whether that duty was met, such a process can face high transaction costs.[136] Thus, the overall costs of resolving conflicts under a negligence rule would be expected to run higher than under a strict liability system.[137]

129 *See* M. G. FAURE, 'Regulatory Strategies in Environmental Liability', *in* THE REGULATORY FUNCTION OF EUROPEAN PRIVATE LAW, 129, 137 (F. Cafaggi, F., Watt, H. Muir, eds., Cheltenham, Edward Elgar, 2011). *See also* M. G. Faure, *Designing Incentives Regulation for the Environment*, 17 (Maastricht Faculty of Law Working Paper 2008-7, 2008).

130 *I.e.*, if it is cheaper because it is obvious, then rational litigators would also expect the courts to render foreseeable judgments and thus preempt the need for actual litigation, leading to pre-trial settlements. As a result, those cases brought to court under strict liability are most likely to be cases wherein the parties has divergent views as to the extent or scale of the harms received by the victim. *See* Schäfer & Schönenberger, *supra* at note 21, at 604.

131 Schäfer & Müller-Langer, *supra* at note 30, at 16.

132 *Id.*

133 *Id.*

134 *Id.*

135 Clearly both forms of adjudication would also require several findings, such as causation, but as those matters would be common to both they would not provide for substantial cost differences, even if the nuances of the issues were distinguishable between the two rules. *E.g.*, establishment of causation might be somewhat different under strict liability and under negligence, but the similarity of the task overweighs the potential differences.

136 Schäfer & Schönenberger, *supra* at note 21, at 604.

137 *Id.*

3. When negligence is preferable

As noted in the first section of this chapter, there are a large number of arguments in favor of the application of strict liability. As stated by Schäfer and Müller-Langer, "the strict liability rule, therefore, seems to dominate the negligence rule in terms of giving the right incentives." [138]

Yet, Schäfer and Müller-Langer also noted that most of the legal traditions in the world display a preference for negligence rules over strict liability.[139] Civil law nations have negligence as the general rule and common law countries assume a default of negligence for any risky activities unless previously assigned to strict liability or other specific torts. [140] Civil law nations provide specific enactments for when strict liability is to be applied and common law countries generally reserve strict liability for abnormally dangerous activities. [141]

This divergence between theoretical expectations of strict liability and real-world application of negligence rules has led researchers to find rational models of when negligence would be rationally preferable. Many of these results are obtained by the weakening of the simplifications of the standard models. It broadly appears that judicial error, transactions costs, information searches, and ultimately the desire to not prevent those risky activities with broad welfare benefits from over-deterrence lead policy makers to apply negligence rules.

First, the standard model follows the normal economic assumptions of rationality and financial capacity to respond to economic events. Once the problems of risk aversion, risk allocation or incomplete insurance are added to the standard model, the negligence rule becomes more robust than strict liability. Similar results avail if the tortfeasor would be unable to pay or unwilling to pay the due damages by means of insolvency or avoidance strategies.[142]

Second, the standard model assumed that the courts were able, under both strict liability and negligence rules, to return accurate judgments and damages. When that assumption is relaxed, that judgments and damages might be errant, then negligence has been found to be more robust than strict liability.[143]

Third, both the actors to the risky activity and the courts called to judge on the resultant harms need access to complete and accurate information. The standard model assumes as much. When critical information is missing, negligence has been suggested as more fit to provide that data than strict liability.[144]

Fourth, even though an activity might display high risks and costly externalized hazards, if those risks and hazards are symmetrical to their

138 Schäfer & Müller-Langer, *supra* at note 30, at 18.

139 *Id.*

140 *Id.*

141 *Id. See also* the United States Restatement (2[nd]) on Torts for a demonstration of the limited historical application of strict liability. The Restatement is currently in process to the 3[rd] edition.

142 *See* discussion, *infra*, at 3.1 Imperfect tortfeasors.

143 *See* discussion, *infra*, at 3.2 Imperfect or inaccurate damages.

144 *See* discussion, *infra*, at 3.3 Need for data transparency.

externalized benefits to public welfare, then it might be in the interest of the community to support a higher level of activity to obtain those externalized benefits. As seen in earlier discussions of bilateral accidents, a negligence rule would better enable higher levels of activity at a due level of care than a rule of strict liability would enable.[145]

While the character of offshore methane hydrate operations might include certain aspects of these conditions, it is not clear that these circumstances would make a compelling argument to reverse the strength of the previous arguments for the application of strict liability for that industry. While more complete arguments are to be found, *infra*,[146] a short discussion is presented here. Risk aversion is not the same behavior as risk recognition; while longtime operators in oil and gas ventures surely have recognized the potential hazards of their industries they do for the most part remain engaged in those hazardous activities.[147] Thus, it would be difficult to make a prima facie case that the likely operators of offshore methane hydrate installations would be rationally hindered by risk aversion or like concerns.

The chance of court error is more likely than the previous concern. The potential harms and hazards of offshore methane hydrate accidents would likely be both complicated and widespread; the technological issues would also be plentiful. However, courts have responded reasonably to other large environmental accidents; if there were to be unique problems due to the character of cataclysmic methane hydrate accidents those problems might in turn be more properly addressed by regulation than civil liability.[148]

Would there be sufficient information on the risks, precaution costs, and potential hazards both *ex ante* to make correct decisions and *ex post* to sustain accurate judgments; one assumes that there could always be more information. However, much of the evolving science and engineering preceding the commercial development of offshore methane hydrates has in fact been conducted conjointly with multiple national governmental agencies or otherwise published through peer-reviewed scientific and engineering journals. While surely some amount of private in-house technology and operation procedures could be reasonably assumed, there is little or no reason to expect a significant enough data failure to prevent civil rules from functioning properly, for either negligence or strict liability.

Finally, the onset of commercial development of offshore methane hydrates will surely externalize accidental risks, but will it externalize potential public welfare benefits? While the benefits of offshore methane hydrates were enumerated in Chapter 3, one would likely assume that those benefits would not be received without some form of economic payment. *E.g.*, it unlikely that one might obtain

145 *See* discussion, *infra*, at 3.4 Balancing of externalized costs and benefits.
146 *See* discussion, *infra*, in ch. 7.
147 Indeed, a *res ipsa loquitur* argument might well be made that if those oil and gas operators are aware of the hazards and have remained engaged, then likely they have found solutions to those risks such as insurance, self-insurance, safety planning and a variety of other means. Indeed, one of the earliest messages sent by BP in the wake of the Macondo incident was to reassure their investors of their intent to recover and continue in the industry.
148 This avenue of accident governance is directly addressed in the next chapter, *see* ch. 6.

electrical power or methane fuel without paying for it. Likewise, while CCS storage within the hydrate deposit might not have a direct billing to the local community, it is likely that either their taxes or their electrical bills might contain the costs of that service. Thus, it is not clear that these types of benefits would qualify as formal externalities.[149] A demonstrated lack of externalized benefits but a clear presence of risks is traditional grounds for a rule of strict liability; all of the major models reviewed in this study would concur. Thus, if a rule of negligence were to be applied, it would be in want of proof of externalized public benefits.

But even if such externalized public benefits were to be established, a strong argument can be made that the accidents likely to result from methane hydrate operations are more properly characterized as unilateral and thus better governed with strict liability. And in the alternative, while the commercial and energy supply benefits might be readily demonstrated, just as surely some members of the public might be concerned about potential climate change impacts or cataclysmic accidents to an extent that they would advocate that the potential externalized risks might outweigh the externalized benefits, and thus deem the ratio of risks to benefits more in line with the application of a rule of strict liability.

3.1. Imperfect tortfeasors

3.1.1. Actors with risk aversion or incomplete insurance

The standard models of accident risk governance assumed risk neutrality; this assumption is critical to the efficiency of strict liability within the standard models.[150] Risk aversion was not generally included in earlier accident models, such as in Shavell's unilateral and bilateral models. [151]

Nell and Richter suggested that risk aversion could be added to the standard models.[152] They provided a demonstration that the application of risk aversion to unilateral accident models would break the standard symmetry of both strict

149 I. Gilead, *Tort Law and Internalization: The Gap Between Private Loss and Social Cost*, 17 Int'l Rev. L. & Econ. 589 (1997).

150 For a discussion on the connection between risk neutrality and the standard models, *see* Faure 2001. *See also* Endres & Schwarze 1992.

151 Nell & Richter, *supra* at note 37, at 33.

152 Nell and Richter provide a list of reasons that corporate entities might be risk averse: (i) corporate notions of risk aversion operate only for well-financed diversified portfolio holders which is contrary to many investors both private and public, (ii) even for such parties as qualify as well-diversified portfolio holders, they can only achieve genuine risk neutrality if there is no system risk component which might not be true for certain highly risky (investment) activities, (iii) there is much evidence of structural imperfections in the capital market which could frustrate efforts to diversify risk, (iv) transaction costs tend to prevent portfolios from being sufficiently diversified, (v) entrepreneurial decisions within firms are made by risk averse humans who are guided by careful strategies to remain in employment and are often rewarded for conservative stewardship of capital, and (vi) those same human managers will have the potential to display risk aversion or pessimism against the risk of large losses. *Id.*

liability rules and negligence rules to efficiently set precaution levels.[153] They provided two levels of analysis, the first focused immediately on the risk adverse parties and second on the role insurance might play in such settings.

Nell and Richter found that for risk adverse actors, negligence was more robust than strict liability.[154] In a simple model, the results were completely divergent, with negligence being increasingly preferred as the number of potential victims increases.

In contrast, strict liability was found to be preferable only when parties are risk neutral or when insurance is readily available, which in turn appears to require risk neutral insurance providers.[155] When the ideal terms for strict liability are not present, then strict liability leads to insufficient activity levels.[156] They found that when the number of victims is sufficiently large, risk aversion can drive strict liability to prevent otherwise socially beneficial activity from occurring.[157]

They then modelled how the provision and impact of insurance affected the parties risk allocation strategies. If insurance markets were perfect, then tortfeasors and victims could both eliminate their risks in exchange for purchasing insurance policies; but in the real world liability insurance limits coverage to leave some risks with the purchasers.[158] The optimal amount of liability for the tortfeasor increases as the amount of insurance becomes available; the intuition herein is that if the tortfeasor can purchase insurance efficiently then it is more efficient for social welfare for the risk to be moved from victim to tortfeasor and onto the insurer, *i.e.* from the most risk averse towards less risk averse parties.[159] But there is a limit, in that tortfeasors would not purchase a full amount of insurance so long as the costs of the insurance include non-trivial loading fees, so coverage will remain shy of the total exposure and the tortfeasor will continue to bear less than full risk.[160]

The efficiency of loading is critical; as the loading fee becomes trivial in cost, strict liability becomes more robust and as the loading fee become more expensive then negligence becomes more robust.[161] *Ergo*, the more costly it is to provide insurance, the more negligence is preferable and the less costly insurance is the more strict liability is preferable.

Given the result that insurance companies will charge for claims and for loading fees, and that customer *cum* tortfeasors would not pay for full coverage,

153 *Id.*
154 *Id.*, at 31.
155 *Id.*, at 42.
156 *Id.*
157 *Id.*, at 43.
158 *Id.*, at 40.
159 *Id.*, at 41.
160 In the modelling terms presented by Nell and Richter: But there is a limit, in that tortfeasors won't buy full insurance so long as there is a positive loading fee, $m > 0$, so the level of coverage, d, will remain $d < 1$, and the of risk allocated to the tortfeasor, q^*, will not reach 1.
161 In the modelling terms presented by Nell and Richter: The efficiency of loading is critical, as $m \to 0$, strict liability becomes more robust and as m, diverges from zero negligence becomes more robust. *Id.*, at 42.

neither strict liability nor negligence approximate the optimal solution.[162] However, there is simply no convergence to the negligence rule as was seen above.[163] Yet, at sufficiently high levels of victims, the maximum level of care becomes optimal.[164] Thus, negligence was found to be more robust than strict liability for risk averse tortfeasors with incomplete insurance options when the number of victims is large or when the insurers themselves are risk averse.[165]

Nell and Richter found that when insurance is imperfectly provided then negligence is a superior rule.[166] When insurance is costly to purchase, as compared to expected pay-outs in claims, then negligence is more robust. This is especially true when the cost of the insurance is driven by the risk aversion of the insurer.[167]

Friehe found a similar result when the number of potential victims is large and insurance is provided.[168]

3.1.2. Insolvency

Shavell demonstrated that under insolvency constraints, strict liability was likely to provide incentives to the tortfeasor to undertake insufficient precaution and over-engage in activity; thus, negligence would be preferable.[169]

When Nussim and Tabbach's 'durable precaution' model is extended to the insolvency problem, it develops a three-tier analysis, (i) when the assets exceed the expected costs of damages, (ii) when they equal them, and (iii) when the assets are less than the expected costs of damages.

When the assets exceed the expected costs of damages, then there are no effective constraints preventing the tortfeasor from choosing optimal levels of activity and precaution.[170] However, if the marginal utility to the tortfeasor of additional activity does not decline, as in diminishing returns, then the tortfeasor is likely to pursue maximum activity levels.[171]

When the assets are less than or equal to the expected costs of damages,[172] then the tortfeasor would face declining marginal costs of damages as the activity level increases; those costs are said to "plummet to zero."[173] This drop in costs encourages the tortfeasor to engage in the maximum level of activity. This has a

162 *Id.*
163 *Id.*, at 41.
164 *Id.*, at 42.
165 *Id.*
166 *Id.*
167 *Id.*
168 *Id.*
169 Nussim & Tabbach, *supra* at note 34, at 175; citing to S. Shavell, *The Judgment Proof Problem*, 6 Int'l Rev. L. & Econ. 43 (1986).
170 "Assets exceed the expected costs of damages." *Id.*, at 176.
171 *Id.*
172 "Assets are less than or equal to the expected costs of damages,[172]" as formulated: $A \leq z^{*}h$. *Id.*, at 175.
173 *Id.*

secondary effect on the precautionary level, which drops below the prescriptive level of care, $\tilde{x} \leq x^*$.[174]

These results are roughly in alignment with Shavell's analysis on insolvency, but they diverge from the incorrect estimation analyses and thus clarify that the choice of civil liability rules need to take these matters into separate account.

3.1.3. Strategic avoidance plus precaution

When tortfeasors can invest in both precaution and avoidance, negligence will outperform strict liability in unilateral accidents.[175] Once tortfeasors exercise avoidance strategies, strict liability becomes notably weaker than negligence.

When avoidance is highly effective, both strict liability and negligence yield similar results, which is that both rules produce precaution levels less than the socially optimal level.[176] Negligence achieves first-best performance in all ranges of the avoidance parameters, but strict liability can only do so in limited settings.[177] As negligence is socially less costly than strict liability, it is preferable when avoidance is exercised.[178]

If the courts were to set their prescriptive due care level to the levels that the avoidance-seeking tortfeasors self-selected, *per* the argument above, then the resultant overall social costs would become lower than if the courts had pursued the naive[179] notion of optimal due care.[180] This is a complex result that would require the summation of the additional risks, and thus social costs, undertaken by the avoidance-seeking tortfeasors and the social cost reductions enabled by the lowered prescriptive duty of care; the net impact may be unforeseeable.

3.1.4. Defects of optimism and pessimism

Behavioral economics affects the results of the liability rule models; negligence provides a more robust response in achieving efficiency under these changes to the basic models.[181] Negligence appears to be preferable primarily because it separates the decision processes of the tortfeasor from the determination of the appropriate

174 *Id.*

175 Friehe, *supra* at note 35, at 216. Avoidance is defined as the efforts made to reduce the likelihood of being held responsible, not the avoidance of an accident itself. *E.g.*, when a tortfeasor seeks legal advice to minimize consequences after the accident occurs, that is an instance of avoidance. It is a wholly separate notion from precaution, which is the avoidance of liability before the occurrence of an accident.

176 *Id.*, at 215. At Lemmas 1 and 2.

177 *Id.*, at 215.

178 *Id.*. At Proposition 1.

179 Here *naive* refers to the model's level of due care as if no avoidance were undertaken by the tortfeasors.

180 *Id.*. At Proposition 2.

181 Schäfer & Müller-Langer, *supra* at note 30, at 24. Behavioral economics posits, among other issues, that humans tend to deviate from rationality in predictable ways, thus rational models can be built from non-rational logic systems.

level of precaution whereas strict liability would leave that determination with the tortfeasor who would be suffering from certain cognitive biases.[182]

Schäfer *et al*. posited that once certain emotional ambiguities of optimism and pessimism are introduced that negligence leads to better results than a rule of strict liability.[183] Humans tend to be overly optimistic about avoiding accidents or about environmental risks.[184] In such optimism, the tortfeasor underestimates their expected harms to victims and thus enacts a lower level of precaution.[185] Under a strict liability rule, this would see the tortfeasor misestimate the potential impacts on victims and thus set a level of care below the efficient level; on the other hand, a negligence rule would remain unaffected and remain efficient as the standard of care is not set by the tortfeasor's estimate of harms and damages and the tortfeasor's behavior is unchanged by the optimism.[186]

Humans tend to be excessively pessimistic about catastrophic accidents such as earthquakes;[187] excessive care will result. Excessive care will result in certain inefficiency under strict liability,[188] whereas negligence might be efficient in this setting.[189] Again, the negligence rule might be preferable because the determination of precaution is set exogenous to the tortfeasor by the prescribed duty of care.

3.2. Imperfect or inaccurate damages

When inaccuracy of judgments in producing accurate sanctions is introduced to the costs to be borne by the tortfeasor, the results on efficiency are markedly impacted. Negligence will not need the sanction to equal the harms caused,[190] but strict liability will need the sanctions to equal the harms imposed in order to yield an

182 Arguendo, it appears to be presumed that the court retains a higher level of freedom from the affects of behavioral economics in this understanding. Clearly, that assumption might be poorly grounded.

183 Schäfer & Müller-Langer, *supra* at note 30, at 25. They cite to J. C. Teitelbaum, *A Unilateral Accident Model Under Ambiguity*, 36 J. Legal Stud. 431 (2007), with special reference for pessimism models.

184 *Id*., at 24., citing to A. Guppy, *Subjective Probability of Accident and Apprehension in Relation to Self-Other Bias, Age, and Reported Behaviour*, 25 Accident Analysis Prevention 375 (1993); C. R. Sunstein, *Behavioral Analysis of Law*, 64 U. Chi. L. Rev. 1175 (1998); and N. D. Weinstein, *Optimistic Biases About Personal Risks*, 246 Science 1232 (1989).

185 *Id*.

186 *Id*.

187 *Id*. , citing to G. GIGERENZER, *The Law and Economics of Irrational Behavior, in:* IS THE MIND IRRATIONAL OR ECOLOGICALLY RATIONAL? 37 (Stanford, Stanford University Press, 2005) and C. Jolls, , C. Sunstein & R. Thaler, *A Behavioural Approach to Law and Economics*, 50 Stan. L. Rev. 1471 (1998).

188 *Id*.

189 Negligence has been observed to be inefficient, in the general case, because the tortfeasor does not take into account the costs of damages when he meets the prescribed duty of care. By setting his standard of care higher than the prescribed rule, he might actually achieve an efficient result. *See* similar modeling effects within Nussim and Tabbach's analysis of costly legislation, *infra*, at Appendix II.D..

190 Schäfer & Schönenberger, *supra* at note 21, at 605.

optimal result.[191] Strict liability loses its efficiency in the face of inaccurate damages.[192]

Court errors are likely to frustrate efficient governance of accident risks.[193] The incorrect estimation of damages affects both the strict liability rule set and the negligence rule set. The incorrect estimation of damages is believed to be a wide spread problem in the real world.[194] A variety of transaction costs problems could frustrate efforts to set correct damages.[195] Punitive damages attempt to correct for some of those issues, but they are likewise frustrated by transaction costs problems.[196]

E.g., in the case of a tortfeasor choosing to increase their care level and to thus over-comply,[197] the mechanical results are that the costs of care are increased, the expected damages are decreased, and the probability of being held liable for negligence also decreases.[198] Given this mix of directions in costs changes, it is difficult to forecast what the tortfeasor would choose to do without the specific costs being detailed; but it is most likely that either way the tortfeasor is not likely to land on an efficient result.[199]

3.2.1. Complexity and strict liability

Strict liability did not provide sufficient incentives under imperfect damages. Strict liability was found to be frustrated by interdependencies between the activity level and the level of precaution undertaken; only under certain rare conditions did the

191 *Id.*

192 R. Cooter, *Prices and Sanctions*, 84 Colum. L. Rev. 1523 (1984).. *See also* L. T. VISSCHER, *Tort Damages, in*: TORT LAW AND ECONOMICS, ENCYCLOPEDIA OF LAW AND ECONOMICS, 153, *en passim* (Vol. 1, 2nd Ed., M. G. Faure ed., Cheltenham, UK: Edward Elgar, 2009).

193 Court errors do occur and must be taken into account. There are three primary listed sources for court errors: (i) error in determinations in the level of efficient care, (ii) error in the assessments of an tortfeasor's actual rendered level of care, and (iii) the parties own inabilities to monitor and render specific levels of care continuously. Schäfer & Müller-Schäfer & Müller-Langer, *supra* at note 30, at 8.

194 Nussim & Tabbach, *supra* at note 34, at 173.

195 *Id.*

196 *Id.*, at 174.

197 The three sources of court errors have two effects on the efficiency of liability rules; to over-comply or to under-comply. Over-compliance better ensures that whatever the actually imposed level of care turns out to be that the tortfeasor met that hurdle and will not bear the potentially larger costs of the harms rendered. Under-compliance results from an awareness that errant courts might sometimes render no judgment for damages despite the tortfeasor failing to meet the sanctioned level of due care, thus it becomes irrational to always pay the costs for meeting the sanctioned level of due care. Schäfer & Müller-Langer, *supra* at note 30, at 8.

198 The mechanics of the decision process are determined by three factors; (i) the impact on the costs of care, (ii) the expected damages, and (iii) the resultant impact on being held liable for negligence. Schäfer & Müller-Langer, *supra* at note 30, at 9.

199 *Id.*

rule provide any certainty as to effect and under no certain case was efficiency found by Nussim and Tabbach.[200]

When the judgment damages are expected to be too high, the tortfeasor would enact over-precaution and become inefficient. Symmetrically, when the expected judgment damages are too low, the tortfeasor will behave with under-precaution and cause excessive accidents and harms.[201]

A rule of strict liability is not very robust when presented with incorrectly estimated damages and interdependent activity and precaution decisions. Within these requirements, stable forecasts of policy setting for tortfeasors under rules of strict liability can be achieved only within two narrow results.[202] Due to the complicated interdependency effects, the remaining situations had mixed results. Thus, the direct and indirect results of a specific policy may well be in conflict with each other, creating a lack of clear effect.

There is no efficient outcome under a strict liability rule, only inefficient over- or under-compliance.[203] This is a rational, albeit inefficient, result of responding to errant court judgments.

3.2.2. Complexity and negligence

When the potential of the court system to render errant damages is considered, the negligence rule can be more robust and retain its efficiency in contrast to a less reliable strict liability rule.[204]

Multiple studies found that for a tortfeasor under a negligence rule, there are several foreseeable results.[205] Under systematic overestimation of damages, the tortfeasors would operate at the prescribed duty of care level and at their maximum levels of activity.[206] Under systematic underestimation of damages, the tortfeasors would face strategic choices.[207] If the estimate error is small, then the tortfeasor will exercise due care, x*, and operate at maximum levels of activity.[208] The major exception to that finding was when extreme underestimation of damages set the

200 Nussim & Tabbach, *supra* at note 34, at 174-175.

201 Schäfer & Müller-Langer, *supra* at note 30, at 26.

202 If damages are overestimated, then both care and activity level will be increased if and only if the elasticity of the probability of accidents given a level of precaution exceeds the elasticity of the first derivative of the same. On the other hand, overestimated damages will decrease both activity and precautions if and only if the elasticity of the first derivative of the utility function is less than unity. Nussim & Tabbach, *supra* at note 34, at 174. *See also* the mathematical discussion at Appendix II-D.

203 $m > 1$ always leads to over-deterrence and $m < 1$ always leads to under-deterrence. Schäfer & Müller-Langer, *supra* at note 30, at 9.

204 *Id.*

205 Schäfer & Müller-Langer, *supra* at note 30, at 26. *See also* mathematical discussion at Appendix II-B. *See also* Nussim & Tabbach, *supra* at note 34, at 174-175. *See also* mathematical discussion at Appendix II-D.

206 *Id.*, at 174. An overestimate of damages costs reinforces the calculus to avoid damages by operating at the due care level.

207 *Id.*

208 *Id.*, at 174-175.

costs of liability below the costs of due care, wherein the tortfeasor was expected to operate at below the level of due care and at levels of activity lower than the maximum – in effect, the tortfeasor would operate under a *de facto* rule of strict liability as they would always be found liable because their duty of care was unmet.[209]

But even a negligence rule can become sufficiently complex as to match strict liability's loss of efficiency. Schäfer and Müller-Langer found that a negligence rule would function inefficiently when the error rate becomes extreme; either at very low or very high error rates.[210] Similarly, Nussim and Tabbach found that if the error were significant enough, then the tortfeasor would exercise a lesser level of care, *i.e.*, below the prescribed duty of care, and operate below maximum levels of activity.[211]

3.3. *Need for data transparency*

Negligence bears higher transaction costs, but those costs may come with informational benefits. The Janus-nature of the aforementioned transaction costs of negligence is that those transactions provide information to the public to better inform them and the courts on the efficient, and hence appropriate, duty of care.[212]

Strict liability enables a tortfeasor to make a private decision with regards to precautionary efforts.[213] The event of harm does not require any disclosure of information other than the detailing of the harms rendered to the victim and a sufficient argument that it was the tortfeasor's activity that resulted in the harm. Thus the findings of a strict liability process will provide little information to the public with regards to potential precautionary efforts or to missed opportunities for more clear standards.

Negligence requires the detailing of causation and of the precautionary options and actions of the tortfeasor, in addition to the evidences of harms to the victim.[214] Additionally, this information will be made public in court, both in testimony and in rendered decisions, so that the general public can be engaged in the decision processes to establish appropriate activity levels and precautionary efforts.[215] Furthermore, this information can be transmitted to other potential tortfeasors to

209 *Id.*

210 The error rate is defined as ms$\{0 < m < \omega\}$; wherein "zero error" would be m = 1 and ω is a very large positive real number. *See* Schäfer & Müller-Langer, *supra* at note 30, at 9.

211 Nussim & Tabbach, *supra* at note 34, at 174-175.

212 Schäfer & Müller-Langer, *supra* at note 30, at 18.

213 *Id.*

214 *Id.*

215 The argument here is not that strict liability cases do not result in lawsuits with publicly available information; rather, that strict liability likely leads to a higher percentage of pre-court settlements that would remain private if not also privileged and thus result in fewer cases making it to court. Additionally, those cases that did reach court would provide less information than analogous negligence cases. *See* discussion, *supra*, at 2.5 When transaction costs of justice are critical. *See also* Schäfer & Müller-Langer, *supra* at note 30, at 18.

both improve the costs efficiency of precautionary measures and to measure their own levels of care vis-à-vis the now-effective ex ante prescribed duty of care.[216].

Nussim and Tabbach have provided an argument that a negligence rule could provide a means of efficiently bootstrapping the appropriate prescription of the optimal duty of care. [217] When legislators and judiciary officials would face high transaction costs in determining the correct level of due care, it would be more robust if they were to choose a negligence rule and preemptively set the level of due care higher than the otherwise efficient level might have been; future discovery in future trials could then enable a lowering of the duty of care to optimal levels.[218]

3.4. Balancing of externalized costs and benefits

Hylton demonstrated that strict liability could be overburdening and threatening to important positive externalities; he argued for the restriction of strict liability to those cases of substantially asymmetrical risk externalization not offset by counterbalancing externalized benefits.[219]

Given the interconnections of externalized costs and benefits, he found that negligence, strict liability, and no liability rules all have their respective zones of efficiency. [220] Negligence was robust when the externalized risks and the externalized benefits were well paired.[221] Strict liability won out as more robust when risk asymmetry, *i.e.*, that the tortfeasor externalizes more risks than the collective community of victims, is present and the risks increase in relative scale to the wealth of the victims. [222]

Hylton provided a review of four cases; the results are thus ambiguous at first glance, but they do clearly emerge from an analysis of two relationships;[223] (i) the ratios of externalized probabilistic risks between tortfeasor and victim(s), $(q_A\colon q_B)$, and (ii) the ratios of externalized probabilistic benefits between tortfeasor and victim(s), $(w_A\colon w_B)$.[224]

216 *Id.*, at 19.

217 Nussim & Tabbach, *supra* at note 34, at 173. Similarly, if the legal institutions or if the technical complexity of the risky behavior create conditions that prevent clear ex ante determinations of judgment damages, then negligence may provide a more robust means of achieving socially efficient outcomes. Schäfer & Müller-Langer, *supra* at note 30, at 9.

218 Nussim & Tabbach, *supra* at note 34, at 173. *See* the mathematical discussion at Appendix II-D.

219 *See* the mathematical discussion at Appendix II-C.

220 Hylton, *supra* at note 35, at 15. For no liability rules, Hylton supported the idea of subsidization when the net welfare results were positive. *See* Quadrant III in Table 2, *infra*.

221 *Id.*, at 15, 22.

222 *Id.*, at 23.

223 In Hylton's model, there are two parties, tortfeasor A and victim(s) B.

224 *Id.*, at 14.

Table 2: Liability Rule Expectations based on Externalized Benefits and Risks

		Externalized Benefits	
		$w_A > w_B$	$w_A \leq w_B$
Externalized Risks	$q_A > q_B$	I. Negligence (probably)	II. Strict Liability
	$q_A \leq q_B$	III. Subsidy (no liability)	IV. Negligence

He developed a quadrant mapping of the results, *supra* at Table 2:

I. $(q_A > q_B)$ and $(w_A > w_B)$. A provides exceptional externalized risks and benefits. A externalizes both more risks, q_A, and more benefits, w_A, than his average community of actors externalize to the community.[225]

II. $(q_A > q_B)$ and $(w_A \leq w_B)$. A is risky but of average benefits. A externalizes more risks, q_A, than the norm, but A provides the same or fewer externalized benefits, w_A, compared to the norm in his community of actors. [226]

III. $(q_A \leq q_B)$ and $(w_A > w_B)$. A provides exceptional benefits at normal risks. A provides the same or fewer externalized risks, q_A, than the norm, but externalizes more externalized benefits, w_A, against the norm in his community of actors. [227]

IV. $(q_A \leq q_B)$ and $(w_A \leq w_B)$. A is normal in externalized risk and benefits. A provides the same or fewer externalized risks and benefits as compared against the norms in his community. [228]

Hylton proposed that negligence is likely to be most effective or efficient when the risks ratios are symmetrical or when the externalized risks and benefits are well-balanced with each other because "communities are likely to form around activities that cross-externalize similar risks."[229] As a result, negligence was recommend in two out of four scenarios, making it Hylton's preferred result.

Strict liability is most likely to be of benefit to policy makers when $(q_A > q_B)$ and $(w_A \leq w_B)$, *i.e.*, when A displays extraordinary risks without sufficient offsetting benefits to the community. Negligence would see A undertake excessive activity,

225 *Id.*

226 *Id.*

227 *Id.*

228 *Id.*

229 *See* Quadrant I and IV of Table 9.5. Quadrant I is the high risk/high benefit case that probably merits negligence to ensure sufficient production of externalized benefits. Quadrant IV is the routine case wherein most ordinary activities with balanced risks and benefits fit. *See id.*, at 15.

causing inefficiently high numbers of accidents to B, who would reduce his own activity to minimize his damages.[230]

In the opposite direction is when A displays extra-ordinary benefits to the community with average risk; such a situation might be given a no liability rule or a subsidy, effectively the same, to encourage A to undertake more of this beneficial activity.[231]

Similarly, Nell and Richter found that as the number of potential victims increases, and the tortfeasor is exercising a maximum feasible level of due care,[232] the correct assignment of risk allocation should shift from the tortfeasor to the victims at large.[233] Negligence with a due care level set at the maximum level of care is the optimal rule, whereas strict liability is equally not optimal. [234]

4. Summary and conclusions

This chapter has reviewed the rules of civil liability, strict liability and negligence. Both rules of civil liability, strict liability and negligence, can be efficient within their own clusters of fitting circumstances. When determining which rule would be more effective, it is to the circumstances of the activity that we should look.

Strict liability is more robust than negligence in unilateral accidents or for bilateral accidents wherein the tortfeasor controls most of the incidents of risk. The operators and owners of offshore methane hydrates development projects would likely be such potential tortfeasors. Strict liability is also preferable when addressing the risks of abnormally hazardous activities; public welfare might benefit from the activity itself but the management of the risk is difficult or perhaps infeasible by any party other that the undertaker, *i.e.*, the potential tortfeasor. It has been well established in Chapter 4 that the extraction of offshore methane hydrates may well be considered as abnormally hazardous, especially in certain locations. Strict liability enables the complete set of costs and benefits, including those externalized, to be addressed by a single decision maker; that focus of information and control enables the efficiency of strict liability for the above situations. Also, because the determinations on optimal precaution and activity levels are made by the tortfeasor,

230 *See* Quadrant II of Table 9.5. *See id.*

231 *See* Quadrant III of Table 9.5. *See id.*

232 Maximal level of due care as x_{max}. Nell & Richter, *supra* at note 37, at 37.

233 The risk aversions coefficients for the tortfeasor and the victim are denoted as α and β, respectively; where $\alpha > 0$ and $\beta > 0$. *Id.* The tortfeasor's share of liability is $q \in (0 \leq q \leq 1)$; the victim's share of risk is similarly $(1-q)$. *Id.*, at 39. The optimal liability for the tortfeasor, meeting due care x_{max} , is found to be:

$$q^* = \frac{\boldsymbol{\beta}}{n\alpha + \beta}$$

234 This matches the results of the negligence rule; the negligence rule emerges from this argument as $q^* \to 0$ as $n \to \infty$. Strict liability provides the opposite result, in$q^* \to 1$ as $n \to \infty$, and assigns all of the risk to the tortfeasor. However, one ponders if this result is real-world applicable when the victims face a unilateral model wherein they can take no or few steps to avoid harm but the tortfeasor has readily avoidable means to avoid risk, as in an offshore methane hydrate project accident.

they can correctly integrate local marginal costs and benefits and thus gain access to decentralization. It appears that for a variety of uncertainties, strict liability can be more robust than negligence. [235]

The rule of negligence has its own domains of efficiency. The more likely it becomes that victims have a role to play in averting harm, the more likely negligence is efficient to govern the combined risks of the tortfeasor and the victim. But with methane hydrates, neither the inhabitants of the eco-system nor the impacted coastal communities would be expected to have such roles. The more likely that the tortfeasor's risk neutrality is replaced with risk aversion, the more likely negligence will be more robust.[236] But the development of offshore methane hydrates is expected to be primarily carried out by corporations or other institutional arrangements with limited senses of risk aversion. Similarly, the presence of insolvency, strategies of liability avoidance, incorrectly estimated judicial damages, or the effects of behavioral economics can all present circumstances to support negligence as a more robust rule than strict liability. Again, depending on the circumstances of the accident, a rule of negligence might be efficient to govern the risks and hazards of that activity. However, as will be explored in Chapter 6, such problems might be also addressed, perhaps more efficiently, by regulation.

This chapter has provided an initial foray into when either rule might be optimal for offshore methane hydrates. The more complete resolution of that research is to be found in Chapter 7, wherein a joint discussion of the rules of civil liability and of regulations as applied to offshore methane hydrates operations will be entertained. But it beckons from the exploratory comments made within this chapter to reveal that Chapter 7 will support the application of strict liability to govern the risks and hazards of offshore methane hydrates.

[235] *See* a similar conclusion on the potentially more robust application of strict liability to environmental pollution, M. G. FAURE, AND S. E. WEISHAAR, *The Role of Environmental Taxation: Economics and the Law, In*: HANDBOOK OF RESEARCH ON ENVIRONMENTAL TAXATION, 399, 403 (Cheltenham, Edward Elgar, 2012).

[236] *See* the discussion on Nell & Richter's risk allocation models, *infra*, at Appendix II.E.

Chapter 6

PUBLIC AND PRIVATE REGULATION

This chapter examines the potential role of public and private regulation to govern the risks and hazards of offshore methane hydrates. It could be said that the primary goal of both civil liability rules and both types of regulations is to set standards to enable the attainment of optimal activity and due care levels.

The previous chapter, the first of Part II, explored the various circumstances that private parties could efficiently set those standards and ensure the attainment of those standards under rules of civil liability. It explored the circumstances wherein a rule of strict liability might be efficient and those circumstances wherein a rule of negligence might be efficient. It previewed a preliminary finding that a rule of strict liability might be more robust for the circumstances of offshore methane hydrates.

In this present chapter, the second of Part II, a discussion is presented on the role of public and private regulations, how standards might be set through the tool set of regulations. Second, the reasons for and advantages of public regulation to govern the risks of accidents are presented. Third, a discussion reviews the potential interactions of public regulation and private rules of civil liability. Fourth, the potential for private parties to advance private regulation to set standards and provide self-governance is examined. Finally, a discussion on the potential application of both public and private regulation to offshore methane hydrates is presented. A preliminary finding is presented that the circumstances of offshore methane hydrates would benefit from both public and private regulation.

The following chapter, the third within Part II, will integrate the conclusions of the chapter on civil liability rules and this chapter on public and private regulation with the unique circumstances of offshore methane hydrates as developed within Part I of this study. Specific recommendations are made in that chapter as to the optimal portfolio selection of civil liability rules, public regulation and private regulation. In brief preview, the third chapter of Part II will present an argument for the complementary implementation of public regulations alongside a rule of strict liability; it also presents an argument that private regulation could be additionally integrated alongside these two previous recommended mechanisms.

1. On regulation

Regulations, both public and private, formulate and set standards so that actors can avail themselves of these standards *ex ante* to their decisions to undertake certain activities.

Both public and private regulations can enable incentives to affect the actor's conduct prior to incident of accident or injury.[1] Regulations can define and include behavioral norms as part of their *ex ante* standard setting process. While rules of civil liability respond to injury and damages, regulations can respond to both injury and to risky behaviors without resultant injury. For those activities wherein potential hazards might be extreme or irreversible, regulations can respond to faulty behaviors prior to the incidence of an accident whereas rules of civil liability would be limited to injunction-type remedies.[2] Because regulations can be applied where civil liability rules might fail to be applicable or functional, some scholars have labeled "the public law approach as 'the preferred approach.'"[3] Yet, the general approach developed by Shavell provides an analytic structure to evaluate when public regulations might be more robust than rules of civil liability.[4]

Regulations generally offer a degree of due and deliberative processes that are placed before the public *ex ante*, not only before the engagement in a potentially risky act but also potentially before the standards themselves are determined.[5] Civil liability offers, in contrast, rulemaking of an *ex post* type and generally by a small sub-section of the populace; to the general public the decisions of a court may appear *deus ex machina*.

Public regulations are argued to be effective because the standards can be based upon more information than might have been available to only the tortfeasor, victims, or courts; that the central regulatory body would have the resources and purview to make a more complete gathering of information.

1 *See* R. Van den Bergh & L. T. Visscher, *Optimal Enforcement of Safety Law, in*: MITIGATING RISK IN THE CONTEXT OF SAFETY AND SECURITY. HOW RELEVANT IS A RATIONAL APPROACH?, 29 (R.V. de Mulder, ed., Rotterdam: Erasmus University Rotterdam 2008). " … fines can be attached to norm breaking behaviour, irrespective of whether losses have occurred, and/or harmful behaviour." *Id.*

2 Van den Bergh & Visscher set out a temporally framed set of enforcement measures; (i) preclusionary measures, (ii) act-based sanctions, and (iii) harm-based sanctions. They demonstrated that regulations could provide policy tools at each temporal stage while rules of civil liability would be primarily limited to harm-based sanctions with some access to preclusionary measures *via* inunction type petitions. Van den Bergh & Visscher, *supra* at note 1.

3 M. G. FAURE, AND S. E. WEISHAAR, *The Role of Environmental Taxation: Economics and the Law, In*: HANDBOOK OF RESEARCH ON ENVIRONMENTAL TAXATION, 399, 404 (Cheltenham, Edward Elgar, 2012), citing to L. BERGKAMP, LIABILITY AND ENVIRONMENT (Kluwer Law International, The Hague, Netherlands, 2001).

4 *Id.*, at 404-406.

5 Generally, most modern public states develop regulations within democratic or at least publicly deliberative processes, so that the nature and character of the regulations is coordinated with social awareness.

Private regulations are argued to be effective due to the specialized knowledge that certain actors might have with regards to a certain activity; private regulations might arise from a group of actors directly engaged in undertaking the regulated activity or they could arise from other private groups engaged in observing and monitoring the regulated activity.[6]

Historically, another aspect that influenced the general adoption of regulations by governments is the capacity to enforce the regulations. Most modern states contain the means of enforcement, at least the means to find culpability, to extract fees or taxes from those who fail to abide by the regulations, and potentially to incarcerate those offenders.

The set of reasons generally provided from a theoretical perspective on why regulations should be employed by a society are predicated in terms of the alternatives; "public enforcement appears attractive whenever the probability of punishment under a private regime appears to be low,"[7] particularly if one allows the notion of 'punishment' to mean enforcement of damages to provide *ex ante* incentives.

The overall body of literature on environmental torts, or more broadly stated industrial torts that have broad and diffuse impacts on nature and social settings, supports the role of *ex ante* regulations to determine standards and to provide incentives to operators to efficiently balance risk and welfare by relying on those standards. Liability rules do offer one means of clarifying initial conditions for improvement of Coasian negotiations. However, regulations have long provided an alternative to liability in that they provide specific and more comprehensive allocations of rights and of duties than liability rules could offer.

Regulatory standards are also developed within the public sphere in a manner that is more subject to public review than the judicial decisions of appointed judges or the thought processes of tortfeasors under strict liability. Statutes enacted by legislatures are explicitly under the operation of electoral representation and thus democratic in function. By extension, when legislative bodies appoint regulatory authorities to provide more detailed review and persistent oversight of the enacted legislation and detailed regulations, those activities remain within the governance of democratic organs. Much existing legislation contains explicit requirements of public participation of various forms in the drafting of legislation, plans, and proposals. Some environmental rules provide for public engagement in the regulatory review of private projects. Thus regulations provide an alternative mechanism for collecting information across otherwise asymmetrical sources and

6 *See* N. Gunningham, M. Phillipson & P. Grabosky, *Harnessing Third Parties as Surrogate Regulators, Achieving Environmental Outcomes by Alternative Means*, 8 Bus. Strategy Environment 211, *en passim* (Australian Centre for Environmental Law, 1999).

7 K. N. Hylton, *When Should We Prefer Tort Law to Environmental Regulation?*, 41 Washburn L.J. 515 (2001). (Due to licensing limits where the present study was undertaken, its research relied on the working paper version of Hylton's article; as such, all point citations are to that source material. *See* K. N. Hylton, *When Should We Prefer Tort Law to Environmental Regulation?*, 4 (Boston University School of Law Working Paper No. 01-11, *available* at SSRN: http://ssrn.com/abstract=285264).

enabling a democratic process to evaluate and value the various positive and negative externalities in setting standards for optimal behavior with regards for the regulated activity.[8]

2. Benefits of positive regulations

Civil liability rule systems are at their root merely systems and all systems have weaknesses and dependencies. Liability rules are no exception and require systemic stress analyses to understand where they may encounter difficulties in operation.

It has been argued that there is a fundamental shift in focus between the rules of civil liability and regulations.[9] Under the rules of civil liability, the tortfeasor retains the privilege to make an independent assessment of how to optimally prevent harm.[10] Strict liability rules provide incentives to avoid the incidence of harm; negligence rules provide incentives to optimize the amount of damages to be paid to the victims of the tortfeasor's risky activity.[11] In a sense the rules of civil liability motivate the tortfeasor to consider *ex ante* the future *ex post* costs of their activity decisions, but those costs are predicated on *ex post* determinations of causation and for negligence rules of preventative due care efforts. On the other hand, regulation appears to enable a regulatory body to determine *ex ante* specific standards of behavior for particular risky activities.[12]

Shavell found three criteria that suggested when liability rules might not be effective despite otherwise sound reasons for employing rules of civil liability.[13] The three reasons were:

i. Information asymmetry: Parties lack sufficient knowledge,
ii. Insolvency risk, and
iii. Effective Absence of Lawsuit Threat.

8 No argument is made herein that such regulatory drafting processes are theoretically efficient, *e.g.* Kenneth Arrow demonstrated the difficulties of assembling a public utility function from diverse individual utility functions, nor is there any argument presented that such processes are free of lobbying and other regulatory capture strategies. The argument is simple put that at least more voices might be heard and that some form of public audit of the regulations can occur prior to their adoption, unlike the tort liability rules developed by judicial decisions. It is an argument to distinguish procedural aspects, not quality nor efficiency.

9 M. G. FAURE, 'Regulatory Strategies in Environmental Liability', *in* THE REGULATORY FUNCTION OF EUROPEAN PRIVATE LAW, 129 (F. Cafaggi, F., Watt, H. Muir, eds., Cheltenham, Edward Elgar, 2011). *See also* M. G. Faure, *Designing Incentives Regulation for the Environment*, (Maastricht Faculty of Law Working Paper 2008-7, 2008).

10 *Id.*, at 140. *See also id.,* at 20-21.

11 *Id.*, *id.*

12 *Id.*, *id.*

13 *See* S. Shavell, *Liability for Harm versus Regulation of Safety*, 13 J. Legal Stud. 357 (1984). *See also* S. Shavell, *A Model of the Optimal Use of Liability and Safety Regulation*, 15 Rand J. Econ. 271 (1984), *and see* S. SHAVELL, ECONOMIC ANALYSIS OF ACCIDENT LAW (Harvard University Press, 1987).

Additionally, there are concerns on the institutional capacity of certain jurisdictions to efficiently and effectively govern via rules of civil liability.

Effective enforcement of civil liability is predicated on three issues: [14] (i) the probability of the violation's detection, (ii) once detected, the probability of prosecution, and (iii) the probability of punishment once prosecuted.[15] Problems at any one of more of these stages can cause civil liability regimes to be frustrated; public regulations are seen as potentially able to address those problems.[16]

2.1. *Information asymmetry*

The concept of information asymmetry is that liability rules work as designed when the affected actors have sufficient knowledge to make accurate and rational decisions to achieve efficient levels of accidents. However, there are situations that lack that characteristic; the tortfeasor might not be informed of the existence of his victims or lack awareness of the extent of the damages caused by his accidents. The standard model suggested a two-step problem:[17]

i. A market failure results from incomplete supply of information.
ii. A market failure could be corrected by regulation based upon a more complete set of information not present in the marketplace.

There are multiple ways in which externalities could cause informational asymmetry. Transaction costs to resolve the externalities may be too large. In such cases, liability rule are likely to falter and may need the reinforcement of regulation by an agency that can better integrate the disparate sources of information and integrate them for socially efficient policy decisions. The public burse is assumed, in general theoretical models, to be sufficiently larger than most private budgets that it can afford to gather a larger amount of relevant information to facilitate proper enforcement of a legal norm.[18] Such a result might occur due to dispersed victims or due to each victim's injury being too marginal to justify investigatory costs. [19] Also, the central sovereign is generally seen as having better and more complete access to the whole set of related parties and the relevant data that they might bring to the administration of the legal norm. [20]

Shavell proposed a rule to determine when a regulatory framework would be more efficient than rules of civil liability. [21] Rules of civil liability should be

[14] Hylton, *supra* at note 7, at 12.
[15] *Id.*, at 4.
[16] *Id.*
[17] *See* G. J. Stigler, *The Economics of Information*, 69 J. Pol. Econ. 213 (1961). *See also* A. Schwartz & L. L. Wilde, *Intervening in Markets on the Basis of Imperfect Information: A Legal And Economic Analysis*, 75 U. Pa. L. Rev. 630 (1978). And *see also* E. Mackaay, *Economics of Information And Law*, (Groupe de recherche en consommation, 1980).
[18] Hylton, *supra* at note 7, at 3.
[19] *Id.*
[20] *Id.*
[21] Shavell, *supra* at note 13; with reference to 13 J. Legal Stud. 357 (1984). *See* Faure, *supra* at note 9, at 140. *See also See* Faure, *supra* at note 9, at 21.

employed when the pairing of tortfeasor and victim have more information on the impacts of the risky activity, but regulation should be employed when a regulatory body might have a more complete set of information about those impacts.[22]

This regulatory body need not be a governmental agency, a private agency might be able to collect the complete data set and share the data as needed, but the functional role of government does provide it access to a broader set of data and participants than most other potential agencies.

2.2. *Information revealing mechanisms*

There is a developing area of mechanism design, that of truth revealing mechanisms.[23] Truth revealing mechanisms are designed to create incentives that encourage the revelation of information between the regulator and the regulated actor.[24]

Glachant offers a critical appraisal of the Shavell analysis; informational asymmetry may present an intractable problem for policy makers in the choice of civil liability, regulation, or nothing at all.[25]

At the root of Glachant's concerns is that Coase may have suggested a deeper paradigmatic shift than accounted for by Shavell. Glachant's concern is that the costs of information searches are themselves a form of transaction costs and if they are included in the overall cost analysis then the informational clarity to pursue regulatory guidance in the face of informational uncertainty or asymmetry might be incomplete.[26] In fact, Glachant argued, it may be impossible to discern when civil rules, regulations or no policy at all might be preferable if the sum of the overall set of transaction costs is not readily resolvable.[27]

In such models, it is assumed that the regulator is less informed than the actor; the actor is closer to the facts or technologies that affect the safety levels.[28] But in turn, the actor is less informed about the potential harms and hazards, particularly as they impact third parties beyond the actor.[29] Due to the state of incomplete or imperfect data, economic tools are employed instead of direct quota systems, to

22 Shavell, *supra* at note 13; with reference to 13 J. Legal Stud. 357 (1984). *See also* Van den Bergh & Visscher, *supra* at note 1, wherein an argument is further developed that even when private parties might have informational advantages, if the private parties' private interests and broader social interests were to not align, then private parties might lack incentives to take advantage of the civil liability mechanisms to recover damages. Thus, the informational concerns need to consider not merely the sum of data but also the strategic outcomes of the data possessed by a party; public actors might act where private actors might fail to act.

23 M. GLACHANT, *The Use of Regulatory Mechanism Design in Environmental Policy: A Theoretical Critique*, *in*: SUSTAINABILITY AND FIRMS: TECHNOLOGICAL CHANGE AND THE CHANGING REGULATORY ENVIRONMENT, 179, 2 (Edward Elgar, Cheltenham, 1998).

24 *Id.*, at 3.

25 *Id.*

26 *Id.*, at 9-10.

27 *Id.*

28 *Id.*, at 3.

29 *Id.*

enable the actor to integrate sufficient data to determine an efficient level of activity and of care. [30] A tax may be used to transfer information to the actor. [31]

If the regulator were to ask the actor for his estimated impact costs of pollution abatement, the actor would be tempted to over-report his costs in order to minimize the policy decision's impact on his operations. [32] As Glachant stated the problem:

> "[C]ommunication between agents is subject to strategic manipulation if (i) the objectives sought by the emitter and the receptor differ and (ii) the receptor's decision influence emitter's gains." [33]

The regulator searches for a collection of methods, F, to transform the receipt of the messages into a functional policy A that holds true for two conditions:

i. that the regulator's method can yield a specific policy for each unique set of messages:,[34] and
ii. that for all combinations of private pollution abatement costs there will exist some set of messages from the n actors that will establish an equilibrium of the game. [35]

Glachant states that indeed there is a menu of such methods to transform the messages from the actors into specific policies that will reveal the necessary information to the regulator.[36]

It is the dynamic of the messages on the likely policy results that drive this potential to reveal information and balance the earlier recognized asymmetry. [37] However, there are several concerns that this analysis reveals.

First, an assumption of budgetary neutrality cannot be maintained, *i.e.*, there will always be an effective capital flow from the regulator to the actors; subsidies will be provided for the information received. [38]

Second, because of the aforementioned capital leakage, the system is second best optimal. The results can be improved, but examples in the literature suggest that the mapping of the administrative communications with emitters that can result in actionable policies might actually require drafting of unique policy instruments for each actor. [39]

As such, Glachant projects, in a Coasean manner, that the overall problem with routine mechanism design is that it assumes too readily zero-cost transaction

30 *Id.*
31 *Id.*
32 *Id.*
33 *Id.*
34 *Id.*, at 5.
35 *Id.*
36 *Id.*, at 5-6.
37 *Id.*, at 6.
38 *Id.*
39 *Id.*

costs to obtain information relevant for policy design. [40] As he states, "we are especially suspicious towards the zero administrative costs assumption." [41]

He documents several problematic areas that are likely to not be zero-costs in the collecting or processing of information:

i. The design of the menu options by the regulator. This is an exercise in scientific, engineering, and economic analysis of $(n+1)$ participants.[42]
ii. The means of communicating the menu to the n actors. [43]
iii. The strategic calculations undertaken by each actor to determine their message m_i back to the regulator. [44]. Frankly, the interlinearity of actors responding to each other's anticipatory strategies could be computationally vexing in a way that would require next-best approximations.
iv. The messages need to be correctly and timely collected and sorted by the regulator. [45]
v. The mapping of the received messages into a coherent and workable policy, especially if the policies need to be actor-specific, could be especially cost intensive. [46]

The results of Glachant's study are that informational strategies do exist to rectify the observed informational asymmetries, but they will likely be costly. Thus, regulations might not be appropriately seen as more efficient than lawsuits in civil liability when informational asymmetry is too costly.

This is not to suggest that no form of rules or regulations could ever be efficient, not at all. But it does highlight the centrality of obtaining sufficiently accurate information for the regulatory body to be able to efficiently set optimal standards. And underlying that challenge is the quest to obtain that information in the closest verisimilitude to perfect cost-less information as possible.

When certain assumptions of perfect information are met, indeed one can forecast which rules or regulations might efficiently set optimal standards. But when faced with uncertainty it becomes more complex to ensure those efficient results. When information needs to be obtained from private actors, transaction costs will be incurred; these costs could affect which sets of standards are optimal given the inclusion of the costs of this information against the *ceteris paribus* of zero-cost information. Second, regulators seeking to improve the mapping of policy to individual information sets on cost would likely need to produce a result that

40 *Id.*, at 7.
41 *Id.*
42 *Id.* And here is a latent assumption of a singular policy challenge; imagine the complexity facing real administrators facing numerous industrial settings.
43 *Id.*
44 *Id.*
45 *Id.*
46 *Id.*

appears rather similar to the idea of decentralization. But the tailoring of policy to each actor would likely bear its own set of transaction costs. In summary, if regulatory bodies face costly information acquisition problems, the results of which could be differing sets of standards shy of the optimal standards that might have been obtained *if* information had been cost-less.

Thus, regulatory bodies are in need of cost-efficient means of obtaining critical information for standard setting. As a consequence, Glachant's model establishes a predicate for arguments raised in Section 4, *infra*, that public regulations can be complementary to the function of rules of civil liability. As such, the application of a regulatory process can suss out information that once acquired might aid either regulators or petitioners in addressing their Coasean negotiations or lawsuits. Additionally, Glachant's concerns could be addressed by the development of standards by private regulation. While the public regulations and private regulations might not result in identical standards, the development of private regulations and the promulgation thereof does reveal information that might otherwise by difficult for the regulatory body to efficiently obtain.

2.3. Insolvency risk

Liability rules depend on the consequences of being financially responsible for the damages caused by an accident being included in rational decision making procedures. To the extent that a party is unable or unwilling to be financially responsible,[47] liability rules will not work as designed. Shavell demonstrated that the rule of strict liability loses its efficiency in the face of insolvency whereas a rule of negligence more robustly retained its functionality.[48] Shavell also proposed that regulations would be more efficient than rules of civil liability when the expected costs from judgment damages were expected to exceed the wealth or capitalization of the tortfeasor.[49]

Insolvency is the problem that even if the tortfeasors could be detected, prosecuted and punishments levied, the tortfeasor would still avoid consequences simply because they have insufficient capital to bear the fines imposed; it is a legal

47 Such cases could be insolvency from routine bad luck or poor financial planning to strategically undercapitalized corporations.

48 *See* S. Shavell, *The Judgment Proof Problem*, 6 Int'l Rev. L. & Econ. 43 (1986).

49 On the contrary, when the tortfeasor's wealth or capitalization is expected to be in excess of the expected damages, then rules of civil liability would retain their efficiency; of course this is a statement that civil liability works efficiently when no insolvency is present. *See* Shavell, *supra* at note 13; with reference to 13 J. Legal Stud. 357 (1984).

null.[50] As such, those insolvent tortfeasors have no economic incentives to avoid the accidents, or, to achieve reasonable or efficient levels of precaution.[51]

There are several conditions to consider:

i. when the actor has no funds, when they are insolvent,
ii. when the actor has some funds, but some of his liabilities would exceed that amount of funding, and
iii. when the actor takes legal steps to avoid liability judgments.

To the extent that an actor is genuinely insolvent or unfunded, case (i), they will rationally not include the consequences of financial liabilities, as those liabilities will be undeliverable. The actor would behave as if the liability rule were not in place.

To the extent that the actor is incompletely funded *vis-a-vis* his potential liabilities, case (ii), he will only respond to liability rules as far as his funding supports. Once the potential liability extends beyond that budgetary boundary, the liability rule will cease to be effective. This could occur either by a limit on funds on hand, or in the case of a corporation be limited to the capital reserves prior to a bankruptcy or act of dissolution.

The third issue is raised when actors take on legal forms of organization to limit their exposure to liability risks; this is part of the avoidance strategy concept discussed in Chapter 5.[52] Limited liability for certain forms of business associations can frustrate the functional purposes of liability rules. [53] One of the defining aspects of legal incorporation is to provide limited liability; in essence, all corporations pose a type of insolvency risk.

50 Hylton, *supra* at note 7, at 12. While one might argue that tortfeasors might be provided incentives by addressing their future post-insolvency incomes, the operators of large resource projects would likely be legal personages, such as corporations, that might not have future income pending a major accident. The elimination of such entities is often even tax rewarded, as in the American tax code's deduction allowance for "worthless stocks, " under 26 U.S.C. 165 and 26 C.F.R. 1.165-1. Thus, strategic avoidance remains a substantial concern.

51 *Id.*, at 12.

52 A famous example is the structures that O.J. Simpson had in place prior to the litigation for his civil lawsuit on the murder of his wife and Ron Goldman. While Mr. Simpson lost the case and was found civilly liable for their murders, he has transferred his assets out of his personal accounts to trust funds and similar vehicles. He has paid only a portion of the financial judgments entered against him, although he was able to sustain a comfortable lifestyle post-judgment.

53 *E.g.*, Many oil and gas operators specifically provide that each well is included within its own corporation to both limit liability from the holding company and also to enable certain financial and tax planning measures called "worthless stock deductions" in the case of a bad well or early life accident. Thus, otherwise well-funded operators might employ corporate entities to limit and de-aggregate risks in a common production project. In such cases were legal structure can be used to prevent or limit assessments of financial liabilities, liability rules will not function as designed.

Given that insolvency is a problem of insufficient capital for economic incentives to be effective,[54] it is important to recognize that the regulatory body would need enforcement measures beyond cost-driven measures.[55] Laws that operate to reduce avoidance capacity, laws that criminalize or otherwise penalize the tortfeasors, or laws that remove access to the underlying activity itself might be instances of such measures.

2.4. Underdeterrence: the effective absence of lawsuit threat

Rules of civil liability function to set standards of optimal behavior. Those standards will work effectively as incentives *ex ante* if there is an expectation on the part of the tortfeasor that some real and expectable *ex post* damages will be assessed when harm or injury results from the tortfeasor's activity. When the fundamental element of the lawsuit to obtain those damages fails to be pursued, then a core mechanism of civil liability fails to operate. Regulations can address these problems by (i) directly providing standards *ex ante* to potentially tortious activities, and (ii) provide information to the public to better facilitate the implementation of civil liability rules.

The effective absence of lawsuits seeking redress for injuries prevents the mechanism that transits *ex post* damages into *ex ante* incentives. That lack of *ex ante* incentives frustrates the efficient avoidance of accidents; an alternative mechanism is needed to provide the incentives to obtain the standards. In such events wherein lawsuits fail to be filed, Shavell demonstrated that regulations could be more efficient than rules of civil liability.[56] Regulations can directly provide the necessary standards; this setting of standards can be done *ex ante* to the onset of activity and thus provide the necessary *ex ante* incentives for the tortfeasor's decision making process.

While it might seem odd that regulations could function to facilitate the implementation of civil liability rules, an argument could be made that sometimes transaction costs could prevent or frustrate the proper litigation that would enable civil liability rules to function as designed; the activity of creating standards via a regulatory process and the gathering of necessary information by the regulatory body could alleviate the problems frustrating the implementation of civil liability rules.[57] The missing information could be made public and therefore reduce the transaction costs of litigation for rules of civil liability. By facilitating the transaction costs or by fixing missing markets, regulations can either provide for the

54 Every corporation has a limited account of capital against which its liabilities are limited. Considering that most of the operators that would eventually develop offshore methane hydrates would likely be incorporated, this concern of insolvency is relevant to the choice of governing mechanism.

55 S. Shavell, *Uncertainty over Causation and the Determination of Civil Liability*, 28 J. L. & Econ. 587 (1985).

56 Shavell, *supra* at note 13; with reference to 13 J. Legal Stud. 357 (1984).

57 Hylton, *supra* at note 7, at 3.

subsequent prosecution of private litigation or provide public enforcement to the same ends.[58]

The central notion to liability rules is that they provide a plea for bringing an injury to court for resolution; if that process is unlikely to occur then the effectiveness of the liability rule is much diminished.[59] To the extent that such a problem is foreseeable, the liability rule will provide little to no incentive to achieve an efficient level of accidents. If the liability rule is inefficient, then regulations or other means may be called for to ensure a socially optimal level of safety and accidents is ensured.

Shavell identified three major sources of underdeterrence:[60]

i. Disparate Plaintiffs: When injuries are spread across too many plaintiffs, then their individual injuries and expected awarded judgments might be too small to justify the individual transaction costs of litigation.[61] This 'rational apathy' result is adverse to the community, wherein the sum of the injuries would have justified the transaction costs of litigation as a single case.

ii. Lack of Evidence: The passage of time can enable the loss or lack of evidence to prevent bringing a case to trial.

iii. Missing Parties: The passage of time can enable the loss or lack of either the tortfeasor or the victim; this could be by death, disappearance, or dissolution in the case of a corporate tortfeasor.

Another well documented economic logic, examined by both Landes and Posner and then by Kunreuther and Freeman,[62] for why cases might fail to be brought forward was that the establishment of a causal linkage between risky activity, tortfeasor and victim, and the specific injury suffered may well be difficult to establish, especially for many environmental injuries.

Injuries might be related to chemicals dispersed into the environment, such as toxins or greenhouse gases. The potential role for the chemicals to have a direct effect and cause specific harm may also be well understood by science, but the evidentiary demonstration that a particular source of the chemical emission was

58 *Id.*

59 *See* Shavell, *supra* at note 13; at 363; and *see* W. M. Landes & R. A. Posner, *Tort Law as a Regulatory Regime for Catastrophic Personal Injuries*, 13 J. Legal Stud. 417, 417 (1984).

60 Shavell, *supra* at note 13; with reference to 13 J. Legal Stud. 357 (1984).

61 Environmental and industrial injuries to individuals are often spread across a wide area and may only provide marginal injuries to the individual but cause community level harms. After the victims realize that they are injured, it might not be readily apparent that other parties are also similarly injured. Assuming that any litigation would bear at least a *de minimis* cost burden, many potential plaintiffs might evaluate their particular injury in isolation and decide to forego litigation due to the expected benefits of litigation being less than the costs. In that case, they might also decide to forego additional search costs to identify other co-victims who might could have shared the costs of litigation.

62 *See* Landes & Posner, *supra* at note 59. *See also* H. C. KUNREUTHER & P. K. FREEMAN, *Insurability, Environmental Risks and the Law, in*: THE LAW AND ECONOMICS OF THE ENVIRONMENT, 302 (2001).

causally connected to a specific injury may be difficult to establish.[63] *E.g.*, a chemical factory might release a known toxin that can cause cancer, and it might be clearly documented that said factory did indeed emit such a toxin, but it may be difficult to clearly demonstrate that a specific instance of cancer was specifically caused by the emitted volumes of that toxin as the cancer may have arisen from exposure to other toxins or dangers in the victim's environment. Additionally, injuries may require time to develop or may not be noticed until a time later than the act causing the injury to result. In such a case, the tortfeasor might no longer be present either in the jurisdiction or more seriously might no longer exist either by death, insolvency, or dissolution. Such issues could both raise standing problems and transaction costs problems for bringing forth liability litigation.

Schäfer and Schönenberger observe that not all parties will bring litigation when standing would otherwise exist.[64] In that event, the tortfeasors under both rules, negligence and strict liability, would not expect to pay for all of the damages that their rules expect them to suffer. [65] Thus, the tortfeasors could adopt a higher risk profile with the assumption that only a percentage of the harms would translate to actual judgments against them. In such a case, they argue that punitive damages can serve to "fill the gap" of missing litigation and ensure that tortfeasors regain the full extent of the tort rules damages. [66]

A potential reason for certain plaintiffs to bring suits for judgment to recover damages is that their injuries might be non-pecuniary in character. Non-pecuniary injuries are those injuries that do not have immediate market valuations from which to give rise to pleadings; this clearly leads to difficulties in utilizing economic incentives as predicated within the standard civil liability models. One can lose a car or economic usages and provide specific damages in the plaint, yet one may have difficulty pleading the value of an injury based in loss of companionship or enjoyment of undisturbed nature. Some non-pecuniary injuries may even be difficult to articulate or to render into specific grounds that are supported in the law. These difficulties increase the transaction costs of litigation for all parties, as the plaintiff needs to expend more to discover a proper avenue of pleading, the respondent needs to find a way to address such a plaint, and then the court would need engage in a search for a proper means of compensation or remedy for the non-pecuniary injury which may well be novel. (Non-novel non-pecuniary injuries may have precedential models to rely on.)

63 *E.g.,* the U.S. Supreme Court has decided to avoid all climate change related tort cases on precisely such grounds, *see Native Village of Kivalina v. Exxon Mobil Corporation*, 133 S. Ct. 2390, 185 L. Ed. 2d 1116 (2013). *See also* the lower appellate decision that was affirmed by the Supreme Court's decision to deny writ of certiorari, at *Native Village of Kivalina v. Exxon Mobil Corp.*, 696 F.3d 849 (9th Cir. 2012). *See* a discussion of these cases at R. A. Partain & S. H. Lee, *Article 20 Obligations Under the KORUS FTA: The Deteriorating Environment for Climate Change Legislation in the U.S.,* 24 Stud. Am. Const. 439 (2013).

64 H. B. SCHÄFER & A. SCHÖNENBERGER, *Strict Liability versus Negligence, in*: ENCYCLOPEDIA OF LAW AND ECONOMICS, 605 (Edward Elgar, 2000).

65 *Id.*

66 *Id.*

2.5. *Institutional capacity*

Improved capacity to detect, prosecute, and provide for the punishment of tortfeasors are seen as key advantages of the regulatory rules over the civil liability rules.[67] The overall liability system needs to accurately be able to both identify the externalities and determine their quantitative impacts prior to being able to assign damage to a party. The public government is generally assumed, in theoretical discussions, to be financially and human-resources-wise capable in contrast to situations wherein private actors might not be sufficiently capitalized or otherwise supported.[68]

The underlying damages need to be addressable in pecuniary or similar metric terms to function within both overt social reassignment and enable replacement or compensation in proportion to the damages.

The concept of a judicially determined liability system requires the judges to have access to adequate levels of information as to the costs and benefits of the event and its externalities. If that information is not delivered to the judges, then several problems can result. First, if the tortfeasor is expected to take into account the actual costs of damages when liable under either strict liability or a negligence rule, then inaccurate damage judgments from judges will, to the extent that problem is foreseeable by the tortfeasor, cause the tortfeasor to make a rational decision to choose an inefficient level of activity or of caution. In a strict liability framework, underestimation of the costs of damages will result in excessive engagement in the hazardous activity or an insufficient level of caution.[69]

3. Problems of regulation

While regulations can provide many solutions and can work in complementarity with rules of civil liability, they also contain problems of their own. First, a short review of the basic functional problems of regulations is provided. Next, the problems of utilizing the defense of regulatory compliance within a rule of civil liability setting are discussed.

None of these problems are "show stoppers," rather they are concerns that suggest that the use of regulation must be tempered with realistic expectations of their performance and they also reinforce the need for complementary implementation with civil liability regulation.

3.1. *Why efficiency may be lacking*

There are several scenarios when the efficiency of regulation is lacking.

67 Hylton, *supra* at note 7, at 12.

68 *Id.*, at 4.

69 R. Cooter, *Prices and Sanctions*, 84 Colum. L. Rev. 1523 (1984). *See also* M. G. FAURE, *Environmental liability*, *in* TORT LAW AND ECONOMICS, 247, 252 (Edward Elgar, 2009).

First, regulations have historically tended to over focus on the prevention of 'bad acts' instead of focusing on the attainment of targeted conditions.[70] This is somewhat to be expected, in that it was often the problem of emissions or spilling by the tortfeasor that would have gotten regulatory notice, not the idea of a more perfect environment; especially if the regulatory design was to improve on the function of a tort system whose underlying roles included both compensation for damages and punishment for tortious acts.[71]

Second, the actual operations of regulations, when applied to large populations, requires major capital expenditures;[72] funds must be spent to gather reconnaissance on activities, to monitor potential tortious conduct, to evaluate potential injuries, to integrate that collection of data into enforcement decisions, and the costs of that enforcement. Tietenberg and Lewis presented a balancing problem; policy effectiveness must be counterbalanced against the costs of the policy.[73] If the regulatory goals were too tightly defined, then the social costs of enforcement would run too costly; but, if the regulatory goals were too loosely defined, then the social costs of the damage from failed policies would be too costly.[74] It is implied that the social planner needs to minimize the combination of the costs to establish efficient regulations; but that in itself recognizes that regulations are not likely to ever become completely successful, in that they would face ever higher costs as the policy goals grew stricter.

Third, for a variety of reasons from agency capture to the Tietenberg and Lewis costs balancing, regulatory standards often fall short of the level of rigor needed to provide the full set of corrective incentives that could optimally reduce accident risk and hazards.[75] In such cases, full regulatory compliance would still leave an excess of risk in the community, reducing net welfare.

Fourth, regulations provide a jurisdiction-wide standard. That standardization is part and parcel of their appeal. However, that same standard setting prevents the attainment of decentralization and thus prevents the individual tortfeasor from efficiently reacting to their own/private marginal costs of precaution.[76]

Fifth, following the third argument from above, regulations set low standards; enabling innovation to become static. Regulations work by requiring parties to comply with the standards, but rarely are there incentives to perform higher than mere compliance. To profit-maximizers, such as corporations, over-compliance with a regulatory framework would be costly and wasteful. Thus, a condition results wherein insufficient incentives fail to motivate tortfeasors to modify their activities

70 *See* M. G. Faure, & S. Ubachs, *Comparative Benefits and Optimal Use of Environmental Taxes*, 1 Critical Issues in Envtl. Taxation 29, (2003).

71 Also, this follows a pattern from criminal law, in that the regulatory body focused on the prevention of acts that hurt the public welfare instead of focusing on how to improve it.

72 T. H. TIETENBERG & L. LEWIS, ENVIRONMENTAL AND NATURAL RESOURCE ECONOMICS (Reading, MA: Addison-Wesley, 2000).

73 *Id.*

74 *Id.*

75 *See* Faure, *supra* at note 9, at 26-27.

76 *Id.*, at 27.

to optimal precaution and activity levels.[77] Thus, an excess of accidents would be likely to result.

Finally, the drafting and creation of regulations is burdened with complex transaction costs. The problems-to-be-regulated must be identified, they must be studied, and various interest groups must be brought together in order to result in a final set of regulations. Once that investment is made, it is not likely to be repeated. Thus, regulations become sticky,[78] drafted infrequently and long-lasting. But underlying technological development might continue and the problems facing the victims might be changing. Rules of civil liability, and the rule of strict liability in particular, are more efficient at adjusting to 'state of the art' preventative means and of efficient activity level determinations. Further, there does appear to be a risk of path-dependence,[79] that once a regulation sets a certain form of precaution as a standard, that what innovation does thereafter would occur from around this accepted standard, whereas rules of civil liability might better retain the possibility of more diverse pathways of innovation.

3.2. *Regulatory compliance as a defense from liability*

There is no fundamental requirement that the duty of care from a negligence rule is in any way connected to compliance with a regulatory regime; a court could simply find two disjoint systems. Some courts have found that the failure to comply with regulatory norms becomes a form of *per se* negligence; that the regulatory rules support some *de minimis* norm of duty, of a necessary but perhaps insufficient level of care. On the other hand, some courts have found regulatory compliance to function as sufficient indicia of a met duty of care; this is called a "defense of regulatory compliance."[80]

The concept of regulatory compliance as a defense to liability is less positively viewed by the literature. It has been rejected by many legal systems.[81] There are several reasons. Regulatory standards are often set as minima, neither as ideal levels

77 *Id.*

78 Shavell addressed the theoretical origins of stickiness in a discussion on insurance contracts over long time periods, *see* Shavell 1976. Stickiness is related to a variety of phenomena, primarily the complex interactions of various transaction costs that prevent more continuous adjustments to pricing/cost data over time. In this study, regulations are discussed as a form of technology and the choice to adopt up-to-date technologies is affected so that the choice of technology becomes sticky, the regulations are not frequently updated.

79 For a seminal paper on path dependency on effects of technological choice, *see* W. B. Arthur, *Competing Technologies, Increasing Returns, and Lock-In by Historical Events,* 99 Econ. J. 116 (1989).

80 Shavell, *supra* at note 13, at 365; M. G. Faure & R. Van den Bergh, *Negligence, Strict Liability and Regulation of Safety Under Belgian Law: An Introductory Economic Analysis,* 12:43 Geneva papers on Risk and Insurance 95, 110 (1987); C. D. Kolstad, T. S. Ulen & G. V. Johnson, *Ex Post Liability for Harm vs. Ex Ante Safety Regulation: Substitutes or Complements?,* 80 Am. Econ. Rev. 888, 888-901 (1990); and P. Burrows, *Combining Regulation and Legal Liability for the Control of External Costs*, 19(2) Int'l Rev. L. & Econ. 227 (1999)

81 *See* Faure & Ruegg 1994, at 55-56.

nor as targeted levels of activity; therefore the enabling of a regulatory compliance defense resets the liability rule from strict liability to a negligence rule with a regulatorily defined level of care.[82]

Effective removal of incentives to achieve more efficient levels of activity and care eliminates the effectiveness of both strict liability rules and negligence rules, as the regulatorily defined level of care is likely to omit many potential events which an otherwise undefined duty of care standard could have been taken into account at trial.[83]

It has been formally proven that rational actors should respond to regulatory compliance defense rules by limiting their precautions to those required by the regulations even if more efficient levels of accidents lay beyond those requirements.[84] If such actors did receive benefit of a regulatory compliance defense and if their legal environment were to lack counterbalancing rules of civil liability, then inefficient decisions on preventative care levels would likely result.

The regulatory compliance defense rule also presents a hazard of regulatory capture wherein the operator has an incentive to limit both the completeness of the regulations and the enforcement levels of those regulations.[85] This in turn presents a *quis custodiet ipsos custodes* concern, in that additional measures might be required to monitor the civil servants impacted by such efforts.

Tort law, especially as developed under the common law system, acted as a gap-filler for the limitations of regulatory efforts.[86] No regulatory system is ever complete or perfect, and some device is needed to maintain both adaption to change and justice under new circumstances. The application of a regulatory compliance defense rule would eliminate that role for tort law and leave the overall system more friable.

4. Coordination of liability rules and regulations

The interactions of regulatory guidelines on the interpretation of tort law responsibilities have long been recognized as non-simple. But there are many reasons to suspect that the two systems of accident management could be used in a complementary manner.[87] Indeed, Gunningham and Sinclair have stated that

[82] Shavell, *supra* at note 13, at 365. *See also* Faure & Van den Bergh, *supra* at note 80, at 110; FAURE, *supra* at note 69, at 254.

[83] Burrows, *supra* at note 80.

[84] Kolstad, Ulen & Johnson, *supra* at note 80, at 888-901; Burrows, *supra* at note 80.

[85] M. G. Faure, I. M. Koopmans & J. C. Oudijk, *Imposing Criminal Liability on Government Officials under Environmental Law: A Legal and Economic Analysis*, 18 Loy. LA Int'l & Comp. LJ 529 (1995).

[86] S. ROSE-ACKERMAN, *Environmental Liability Law*, *in*: INNOVATION IN ENVIRONMENTAL POLICY, ECONOMIC AND LEGAL ASPECTS OF RECENT DEVELOPMENTS IN ENVIRONMENTAL ENFORCEMENT AND LIABILITY, 223, 123 (1992).

[87] *See* Kolstad, Ulen & Johnson, *supra* at note 80. *See also* ROSE-ACKERMAN, *supra* at note 86, and *see* S. Rose-Ackerman, *Public Law versus Private Law in Environmental Regulation: European Union Proposals in the Light of United States Experience*, 4(4) Rev. Eur. Commun. & Int'l Envtl L. 312 (1995). *See also* Faure & Ruegg 1994. And *see also* Burrows, *supra* at note 80. And *see* A. →

"'single instrument' or 'single strategy' approaches are misguided," but that "in the large majority of circumstances (though certainly not all), a mix of instruments is required, tailored to specific policy goals"[88] There is a broad understanding within the literature that for environmental hazards, the coordinated implementation of civil liability rules and regulations could be more robust than the singular application of either.[89]

Several main arguments have been raised.

The effectiveness of the regulations depends greatly upon the underlying effectiveness of the regulatory body to enforce the regulations. In certain situations, it might be desirable to "belt and suspenders" by using the complementary private aspect of civil liability rules to ensure that risky activities remained monitored when regulatory bodies face enforcement challenges.[90]

Regulatory bodies, and the regulators inside them, face targeted efforts to lobby them and capture their agenda; this effort to refocus regulatory control is known as agency capture. Employment of civil liability rules reduces the effectiveness of agency capture. [91]

There are other logical reasons for a complementary implementation of both civil liabilities and regulations. A regulatory body can work to collect and then publicize the missing information that prevented civil liability rules from being effective; *i.e.*, the regulatory body can assist in fixing Shavell's missing market or market failure. Or, rules of civil liability might be useful in mitigating the Nyborg & Telle problem of 'regulatory loss of control'; the parallel existence of private enforcement from civil liability claims could reduce the tortfeasor's expectation of evasion.[92]

The development of regulations can also be used as a sort of *de minimis* duty of care; the ability to spot the tortfeasor's failure to attain the regulatory-set minimums could provide courts with a lower cost method to identify when negligence occurs. This use of regulations is referred to as negligence *per se*. The reverse of this logic would be to suggest that attainment of regulatory standards could act as a proof that the prescriptive duty of care was met; this argument has not found broad support among economists.

Regulations, especially those traditionally labeled 'command and control,' are systems that contain both benefits and flaws. The singular application of a public regulatory framework has been modeled as potentially adverse to the morale of the public.[93] This is in part because the uniformity of the adopted regulations removes

Arcuri, *Controlling Environmental Risk in Europe: the Complementary Role of an EC Environmental Liability Regime*, 15(2) Tijdschrift voor Milieuaansprakelijkheid 39 (2001). *See also* Faure, *supra* at note 9, at 143 *and see* Faure, *supra* at note 9, at 24.

88 N. Gunningham & D. Sinclair, *Regulatory Pluralism: Designing Policy Mixes for Environmental Protection*, 21 L & Pol'y 49, 50 (1999).

89 Faure & Weishaar, *supra* at note 3, at 405-406.

90 Faure, *supra* at note 9, at 143. *See also See* Faure, *supra* at note 9, at 24.

91 *Id.*; *id.*

92 *See* Van den Bergh & Visscher, *supra* at note 1, for a discussion of the Nyborg & Telle problem within their discussion of compliance strategies as an alternative to deterrence strategies.

93 B. S. Frey, *Morality and Rationality in Environmental Policy*, 22(4) J. Consumer Pol'y 395 (1999).

the choice making from the tortfeasor and victim and places it elsewhere; [94] the active 'decider' has become the process that drafts and enacts regulations.[95]

Regulations may be expensive to operate,[96] may be poorly focused on activity instead of results, may be insufficiently written to achieve optimal targets, may prevent decentralization, and they may effectively reduce incentives for tortfeasors to achieve optimal levels of precaution and activity level setting.[97] Many of these flaws are inherent in the benefits; *e.g.*, the expenses of operating a regulatory framework are often due to the costs of collecting information about the various tortfeasors and the character of their activities – this is the very collection of data that was valued as a reason to implement regulations.

As such, where regulations are weak is often well aligned with where civil liability rules are efficient; thus the argument for the complementary implementation of civil liability rules and regulations is well founded.

4.1. Civil Liabilities defend against agency costs and lobby capture

A central problem to the effective exercise of positive regulation is that it needs to be administered by human agents who may not always be properly aligned with the aims of the regulation itself; "public enforcement agents do not always have the right incentives."[98] Actors within the regulatory body may thus set regulatory standards that deviate from the optimal set of standards, *vis-à-vis* what they would have done unimpeded.

First, there are a couple of reasons for that problem that regulatory bodies can become inefficient without external distractions. Internal bureaucratic processes, such as who gets promoted, may be at odds (perhaps innocently due to simple complexity) with the broader regulatory targets. [99] Also, there are substantial agency costs in the administration of public regulations. [100] Agency costs are a term developed to describe the various transaction costs of administering public regulations, but the term is primarily focused on the concept of lobby capture and other means in which the regulator receives incentives contrary to original design of the regulations.[101]

94 *Id.*

95 As Frey stated, even the movement towards market based incentives to reinforce regulatory frameworks is very much akin to selling indulgences, it provides the wrong message that environmental error can be washed clean with cash when in fact much of that damage cannot. *Id.*

96 Rules of civil liability are generally seen as a "relatively cheap instrument" in contrast to the "higher system costs" of regulation. The formulation of detailed *ex ante* norms, the coordination costs of aligning inconsistent policies across divergent bureaucracies, and the costs of monitoring can all lead to regulations being more costly than rules of civil liability. *See* Van den Bergh & Visscher, *supra* at note 1.

97 *See* Faure, *supra* at note 9, at 26.

98 Hylton, *supra* at note 7, at 5.

99 *Id.*

100 *Id.*

101 *Id.*

Second, Hylton proposed that the specificity of regulations themselves encourages the tortfeasor to lobby to engage in the drafting and determination of those rules in ways that are unavailable within the framework of private litigation. [102] He added that concentrated interest groups would be able to bring such lobbying efforts forwards, whereas private citizens would be blocked by the transaction costs of integration and representation. [103]. Hylton argued that such resultant regulations might look harsh at first glance but would actually be friendly (*i.e.* sub-optimal from a general welfare perspective) to the industry that brought the lobbying effort to the regulatory body.[104]

By the provision of a rule of civil liability alongside standards set by regulation, it becomes less cost-effective for industry groups to lobby solely regulatory bodies as those bodies no longer offer "one-stop shopping" for regulatory relief. Especially as regulatory compliance is generally not accepted as a defense in most jurisdictions, *see supra* Section 3.2, those actors who would have sought to gain regulatory shielding would find themselves still exposed where rules of civil liability enabled victims to pursue damages in court.

4.2. Revelation of hidden information

Private litigation, especially negligence lawsuits, produces *ex post* information to the public.[105] This production of ex post information can be transformed into informed ex ante rules.

The victim is an expert on injuries suffered, the tortfeasor is an expert on the activity and precaution options, the attorneys can bring forth various other experts into the courtroom; all of these testimonies are further focused by the actual incident of a specific and historical harming.[106] This is advantageous, cost-wise, over the ex ante parliamentary or administrative discussions prior to the drafting of regulations which need address a wider range of potential harms and hazards over a wider range of potential parties. The benefits of litigating ripe cases with present injuries provides a much richer data set than otherwise obtainable:

"A public regulatory scheme could not hope to match the negligence system in terms of its scope, detail, and encapsulation of private information. To do so would require public agents to discover ex ante how much a potential victim would be hurt by a specific injury, and how much it would cost a potential injurer to avoid the injury." [107]

102 *Id.*, at 7.

103 *Id.*, at 7-8. *But see also* M. Olson, *The Logic of Collective Action: Public Goods and the Theory of Groups* (Harvard Economic Studies, 1971).

104 Hylton, *supra* at note 7, at 7-8. Given the modern development of private interest lobbying groups from all sectors of life, perhaps this argument is not as strong as it might once have been.

105 *Id.*, at 8.

106 *Id.*

107 *Id.*

As tort cases are resolved, conduct norms emerge, predicated on real-life events and data.[108] As additional courts continue to process the conduct norms in civil liability litigation, there is the potential for stable expectations to develop on likely outcomes; these expectations form the basis of *ex ante* rules for all future accidents and risk planning. [109]

4.3. Regulatory noncompliance as negligence per se

While the idea of negligence *per se* is not a necessary logical result, it does provide the benefit of reinforcing the regulatory regime with the power of the tort system if the regulatory system itself lacks the ability to ensure compliance or effective policing. Additionally, the idea of *per se* negligence also reduces certain transaction costs for courts attempting to find clear means of defining a minimal duty level of care as the regulations can provide clear structure where the common law may yet be vague and undefined.

The drafting of regulations also usually provides a certain due process and openness to community voices so that the regulations may suggest and include concerns that might not otherwise be readily apparent in an adversarial courtroom setting. The engagement of the concept of *per se* negligence does provide a certain marriage of tort liability and regulatory command and control; the use of tort law to reinforce a regulatory system and the use of a regulation to assist the process of tort law liability would appear to provide some resilience to both sides.[110].

Yet, Shavell demonstrated that negligence *per se* might lead certain actors to become overcautious because their efficient care level would have been the level set by the regulations. [111]

4.4. Coordinated use of civil liability and regulations

On the other hand, there can be useful applications of regulatory frameworks to liability rule systems. While most papers debate the comparative efficiencies, as if only one could be applied to the exclusion of the other, a growing trend of research in law and economics' suggests that the joint-implementation of civil liabilities and regulations may be incrementally beneficial beyond the singular implementation of either.[112]

108 *Id.*

109 *Id.*

110 ROSE-ACKERMAN, *supra* at note 86. *See also* FAURE, *supra* at note 69.

111 Shavell, *supra* at note 13; with reference to 13 J. Legal Stud. 357 (1984). *See also* FAURE, *supra* at note 69.

112 Schmitz listed Kolstad, Ulen & Johnson, *supra* at note 80, and Shavell, *supra* at note 13; with reference to 15 Rand J. Econ. 271 (1984), as the only two such articles that pre-dated his article from 2000. P. W. Schmitz, *On The Joint Use of Liability and Safety Regulation*, 20 Int'l Rev. L. Econ. 371, 2 (2000). Since then, there have been many more such studies. *E.g.*, these are some of the most cited such articles, according to Google Scholar:

i. M. Boyer & D. Porrini, *Modelling the choice between regulation and liability in terms of social welfare*, 37(3) Can. J. Econ. /Revue Canadienne d'économique 590 (2004).

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As was shown by Shavell, the application of civil liability rules are frustrated by informational uncertainty.[113] More recently, Kolstad, Ulen and Johnson demonstrated that regulatory frameworks, with their *ex ante* clarifications on appropriate levels of care, can be implemented to correct the inefficiencies of negligence rules facing informational uncertainties.[114]

Schmitz extended the same family of Shavell-Landes-Posner models in the development of his system.[115] Schmitz finds that when tortfeasors face different budgetary assumptions, then civil liabilities and regulations can be complementary and optimal.[116] The Schmitz model relies on a strict liability rule as its modeled civil liability rule within an unilateral accident model from Shavell.[117]

When the regulatory optimand is developed without reliance on a civil liability rule, and if injurers are heterogeneous with regards to wealth, then the complementary use of regulations and civil liability rules may lead to reduced social cost; this is contract to when only regulatory rules or only civil liability rules would be enforced exclusively.[118] That scenario has two extreme forms.

i. When the population of tortfeasors is poor then regulations would be more socially cost efficient.[119]
ii. When all of the tortfeasors are wealthy, then civil liability is more efficient.[120]

It is demonstrated by the model that when civil liability is employed alongside of regulatory frameworks, that the regulatory standard should be set lower than it would have been if the regulatory framework was designed without a corresponding civil liability rule.[121]

ii. P. Calcott & S. Hutton, *The choice of a liability regime when there is a regulatory gatekeeper*, 51(2) J. Envtl. Econ. Mgmt. 153 (2006).
iii. G. De Geest & G. Dari-Mattiacci, *Soft Regulators, Tough Judges*, 15(1) Supreme Ct. Econ. Rev. 119 (2007).
iv. R. Innes, *Enforcement costs, optimal sanctions, and the choice between ex-post liability and ex-ante regulation*, 24(1) Int'l Rev. L. Econ. 29 (2004).
v. J. G. Zivin, R. E. Just, & D. Zilberman, *Risk Aversion, Liability Rules, and Safety*. 25(4) Int'l Rev. L. Econ. 604 (2005).

113 Shavell 1980.
114 Kolstad, Ulen & Johnson, *supra* at note 80.
115 Schmitz, *supra* at note 112, at 3. He also makes reference to an earlier survey by Schäfer & Ott, which is in turn coordinated with the more recent Schäfer models presented in Chapter 5, *supra*. C. Ott & H. B. Schäfer, *Negligence as Untaken Precaution, Limited Information, and Efficient Standard Formation in The Civil Liability System*, 17 Int'l Rev. L. & Econ. 15 (1997).
116 Schmitz, *supra* at note 112, at 3.
117 *Id.*, at 11.
118 *Id.*, at 9.
119 *Id.*
120 *Id.*, at 10.
121 *Id.*, at 3-4, and at 10.

4.5. Grounds for deference to rules of civil liability

Private tort litigation, relying on rules of civil liability, enables private actors to bypass those problems by simply eliminating the middle-man problem.[122] As described, supra in Chapter 5, the economic models of civil liability demonstrate that private litigation can bring damages to the tortfeasor sufficient to provide incentives to the tortfeasor to alter his behavior to achieve reasonably efficient care. Private actors can achieve efficient behaviors from tortfeasors without the agency costs of the central bureaucrats, at least theoretically.[123]

There is also an institutional arrangements argument to be made, that common law civil liability rules, and to a certain extent civil law's judicial mandates within civil liability as well, provide a "flexible, undefined structure" with which to solve tortious disputes.[124] Tort law provides that injuries can be redressed in court without too much in the way of specifics delineating which injuries are permitted redress or not.[125] The regulatory structure is the opposite, it "has more structure and definition" and offers detailed rules.[126]

It can be argued that private litigation provides a better defense to over-zealous use of resources to achieve enforcement of the legal norms, in contrast to the risks posed by the central bureaucrats.[127]. Private litigators need produce their own capital resources for litigation and thus must limit their activity to the expected outcomes of the litigation; this is a key concept within the theoretical models of civil liability.[128] Research literature has demonstrated that government agencies can become trapped in political rhetoric or in zealous pursuit of compliance and expend disproportionate sums on lesser problems, economically speaking.[129]

While not explicitly stated in Hylton's argument, it appears in contrast to his argument on private litigators that he finds regulators bound by neither capital budgets of enforcement nor by the effective costs of their imposed sanctions; the regulators are argued to operate beyond economic feedbacks to match the sanctions to the harm in proper alignment as suggested by theoretical economic models of

122 Hylton, *supra* at note 7, at 6.

123 *Id*. *See also* Hylton's model to see his argument on the resilience of various civil liability rules to achieve those ends. *Infra,* at Appendix II C.

124 *Id*., at 7.

125 *Id*. Hylton remains squarely within reference to common law, but there does not appear to be any substantial contrast with the civil code notions of routine tort and their support of redress by civil liability. Perhaps his argument could have been made more broadly.

126 *Id*.

127 *Id*., at 6.

128 *Id*.

129 Hylton refers to the research of Viscusi and Hamilton, which has revealed economic problems with the execution of various hazardous waste clean-up sites in the United States. They demonstrated that regulators often required million dollar solutions to problems posing harms of magnitudes less. *See id*., citing to W. K. Viscusi & J. T. Hamilton, *Are Risk Regulators Rational? Evidence from Hazardous Waste Cleanup Decisions*, 89 Am. Econ. Rev. 1010, (1999).

civil liability.[130] Essentially, the private litigation system presents an effective equivalent to the "public with prices" model of public regulations.[131]

4.6. Potential symmetries of policy effects

Hylton provided a taxonomy of public and private civil liability and regulations.[132] The means of law enforcement are bifurcated into two major camps, that of public law and that of private law.[133] Then public law is divided into rule compliance or sanctions-driven law and into taxes and fees or prices-driven law. The first grouping is labeled public law with controls and the latter grouping as public law with prices.[134] Private law is divided into private with strict liability and private with conduct norms, negligence and nuisance fall into the latter category.[135] The environmental regulatory structure in the U.S. is described as public law with controls system; the U.S. is described as very short on implementations of public laws with prices. [136]

Hylton stated that the public law with prices system should be equal in function and efficiency to private law with a strict liability system. [137]

But traditional common law in the U.S. has not had such a pure system of private with strict liability, so that abstract system of economically driven mechanisms remains largely untested within the U.S. for environmental torts. [138] What the U.S. has traditionally had is a large system of private with conduct norms. [139] A list of such rules is given: (i) trespass, (ii) nuisance, (iii) *Ryland*-based strict liability for abnormally dangerous activities.[140]

130 A "Bleak House" argument is made therein that bureaucracies are likely to see the enforcement of regulations as a "full employment program" that has little regard for the actual regulatory ends. It is unclear to the present author that American rules on financing tort trials are any less subject to abuse and thus limits this argument from Hylton as potentially rhetorical and not scientific. *See* Hylton, *supra* at note 7, at 6. Dicken's arguments were indeed against private litigators. *See* Charles Dickens, *Bleak House*, 1853.

131 Hylton, *supra* at note 7, at 7.

132 *Id.*, at 1-2.

133 *Id.*

134 *Id.*

135 *Id.*

136 *Id.*, at 2.

137 *Id.*

138 *Id.*

139 *Id.*

140 Hylton states that while the Ryland standard is a form of strict liability, it is quite distinct from the standard form developed with law and economics literature. The common law version under Ryland requires an analysis of the defendant's conduct, his state of mind about the activity and ultimately the general activities of the local community. These are all softeners that cause Ryland liability to approach the functional description of negligence with a very high duty of care. *Id.*, at 2.

5. Private regulations

5.1. Standard setting by private groups

A key difference between rules of civil liability and public regulations is who sets the standards; in private regulations, a set of private actors who are expected to be uniquely well-informed as to the technologies, benefits, and potential injuries of a specific activity are the standard setters. These standards might arise as industrial norms,[141] as official rules of professional associations,[142] or as standards of recommended practices from industrial associations.[143] Such standards reflect the expertise of the practitioners within their relevant industries or technological specialties.

When it comes to regulating risks and hazards from industrial activities, a reasonable question to ask is who might have the best information on the actual risks and potential acts of precautions; one might expect that those most engaged in the activity would be well versed in such knowledge.[144] Private regulation works on the assumption that the collective group of actors engaged in those types of activities would be well informed to determine best available practices and be able to respond to the most recent of innovations. Private regulation also relies on the idea that the collective group of actors is self-interested to optimize the balance of their private profits and their duties to pay damages – but by combining knowledge sets beyond the individual tortfeasor the collective group might be able to discover more optimal solutions.[145]

However, private regulations need not be a collection of the tortfeasors, it could be based on another group of parties similar deeply engaged in the issues of the activity but a group distinct from the tortfeasors.[146] Such groups have been referred to as surrogate regulators.[147] They could be drawn from public interest

141 *E.g.*, the Institute of Electrical and Electronics Engineers Standards Association (IEEE-SA) provides a wide variety of industrial standards across many sections of the economy. *Available* at http://standards.ieee.org .

142 *E.g.*, *see* the ethical rules adopted by the American Medical Association. *Available* at http://www.ama-assn.org/ama/pub/physician-resources/medical-ethics/code-medical-ethics.page .

143 *E.g.*, the American Petroleum Institute (API) maintains an "inventory of over 600 standards and recommended practices." *See* 'Publications, Standards, and Statistics Overview', at API. *Available* at http://www.api.org/publications-standards-and-statistics .

144 The argument is not made here that such parties would be the *best* informed, but rather, only that such parties ought to reasonably knowledgeable about such concerns. Due to the potential advancement of technology and related matters, and their likely involved role in that development, they might also be in possession of relevant information in advance of other parties such as regulators.

145 In this sense, it is not unlike the logic of strict liability, but it does impose the consensus result of the private regulation; that requirement to meet such a regulatory obligation could undo several advantages of strict liability such as decentralization.

146 Gunningham, Phillipson, & Grabosky, *supra* at note 6.

147 *Id.*, at 212.

groups,[148] from commercial third parties such as green consumers or financial investors,[149]insurance institutions,[150] or environmental consultants.[151] When this form of private regulation is co-integrated with public regulatory efforts then the approach has been called "integrated regulatory design."[152]

Private regulation might be effective for methane hydrate projects and operators. The operator would face a private need to address its investors and shareholders to validate that it responsibly engaged in methane hydrate operations as a capital project to earn revenues and profits with an appropriate level of risk.[153] Currently in offshore oil and gas operations, it is common for a group of energy companies to invest together in a common project and have one of those companies act as operator. The joint-venturers retain rights to inspect and audit the management and oversight of the offshore projects. As such, it is efficient for the energy companies to have common standards across similar projects to enable both consistent training for attaining those standards and to facilitate audits as standards would be consistent at each project.[154] Or, perhaps private regulation arises in an integrated regulatory design, wherein a collection of private but engaged groups could assist in the development and oversight of private regulations for offshore methane hydrates operations.

5.2. Nimbleness and flexibility of private regulation

Miller stated that private enterprise is more flexible than bureaucratic organs at adapting to change.[155] This would be critical in an industry undergoing rapid technological innovation and development, especially if the expertise to follow such advancements required years of study and experience that would be difficult for new entrants to achieve. Bureaucratic organs are also challenged by requirements of due process and public deliberation to which private enterprises are not subjected, thus private enterprises can process new information and reach decisions quicker.

One of the problems to be faced in any nascent industry with innovative technologies is the speed at which lessons learned can be transformed into guidance

148 *Id.*

149 *Id.*, at 214 and 216.

150 *Id.*, at 217.

151 *Id.*, at 218.

152 *Id.*, at 220.

153 It would be reasonable to assume that the operator and its board would have created internal incentives to better obtain such results. As such, it is reasonable to work with a rational model of a profit-seeking operator that would be responsive to economic incentives provided by the rules of civil liability or by either public or private regulations.

154 Therein lies the basis of the 600-odd "standards and recommended practices" maintained by the API. *See* the prior footnote, *supra*. Offshore contracts are thus able to refer to standards by their serial numbers enabling the ready inclusion of the standards without new negotiations at each project.

155 J. C. Miller III, *The FTC and Voluntary Standards: Maximizing the Net Benefits of Self-Regulation*, 4 Cato J. 897 (1984); and *see* A. I. Ogus, *Rethinking Self-Regulation*, 15 Oxford J. Legal Stud. 97, 98 (1995).

and normative rule setting. Bureaucracies might be poorly staffed to respond to rapidly advancing technologies or they may lack funding or opportunities to investigate rapidly advancing technologies. Even executive branches of government that are more responsive to daily and short-term needs experience difficulty obtaining sufficient information to develop regulations without extensive support from those parties actively engaged in the development of the new technologies and their industrial uses. One should expect no difference with regards to methane hydrate projects.

5.3. Informational advantages of private regulation

The operator should already be aware of the costs and technologies involved in achieving the efficient level of accidents and could therefore develop the new necessary standards more cheaply than bureaucrats due to that informational advantage. [156] Additionally, the operator would need to bear its own costs of operations and maintain a profit-seeking optimand from its investors and shareholders, so the operator will be bound to achieve both an efficient level of accidents and safety and an efficient usage of its capital resources.

It is likely that the operators will have better information than governmental actors on the technologies and best practices for efficiently operating methane hydrate projects.[157] In that case, it would be simpler, cheaper and more efficient for the operator to develop the necessary guidance to achieve the efficient level of accidents, once that level is determined.

Additionally, to the extent that a grouping of operators could develop the procedures, some form of industry organization, there would be potential for private standards to evolve and become privately enforced. *E.g.*, many oil and gas projects are joint venture projects with joint investment by several operators but managed and operated by a single specific operator. In an example wherein the operators *ex ante* agreed to certain standards and norms of operational procedures for a methane hydrate project, then those other non-operating investors would want the rights and permissions to audit that the operator was indeed enforcing the agreed to standards and norms and that their investments were soundly within planning guidelines. So long as the private regulations were acceptable to both governmental and other agencies, the costs of enforcement and policing would be born by those profiting from the on-going operations of the methane hydrate project. This method of private regulation could be a potentially large welfare effect for the operator/investors, the government *cum* regulator, and the public-at-large.

[156] *Id.*; and *id.*

[157] See A. I. Ogus, *Rethinking Self-Regulation*, 15 Oxford J. Legal Stud. 97 (1995); and *see* A. I. OGUS, *Self-Regulation* in: ENCYCLOPEDIA OF LAW AND ECONOMICS (Cheltenham, Edward Elgar, 2000)

5.4. *Perceived caveats on private regulation*

There are concerns on the capability of private regulation to provide fair and efficient regulation of risky activities:[158]

i. Industry needs to earn public trust,
ii. Danger of weak enforcement,
iii. Self-serving regulation, not necessarily in public interest,
iv. Creation of barriers to entry,
v. Uncertain legitimacy within democratic and open societies, and
vi. Governmental limits and "conditional self-regulation."

It has been often held that industry, and the rise of the industrial revolution, was responsible for the need for stronger tort law systems.[159] However, what may have been more central to the rise of tort law in the 1800s may have been the increasing cases of stranger to stranger encounters which were facilitated by the changes in industry, transportation, and urban living that were contemporaneous to the industrial era.[160]

When industries are allowed to provide private regulation for themselves, they need to be able to provide strict compliance and enforcement of those regulations. When the structure of joint ventures is taken into account, that common groups of investing corporations divide operational roles across different projects but that all of the corporations are on both sides of the fence, it becomes clear that perverse incentives could arise to allow slack enforcement at one location to receive counterbalancing slack enforcement at another location. Without a party external to this *daisy-chain* of enforcement, the "buck is passed" along the chain without certainty of enforcement. When combined with the dangers of weak enforcement, private regulation can become ineffective.

Additionally, traditional joint venturers rely heavily on contractors and other parties to provide critical services and support roles; yet, those contractors are in need of good relationships with their clients to ensure and secure access to future work assignments. This tension between operational roles and service relationships creates an atmosphere wherein the contractors are potentially reluctant to speak out although they might actually be the actor best able to confirm or audit the maintenance of the agreed to private regulations.

Private regulation has been doubted to take into account as many voices as might be heard by a bureaucratic organ more concerned with due process and transparency; the source of the efficiency of the private regulation is ultimately also a problem spot for private regulation. What the industrial groups decide to target as

158 A. J. Campbell, *Self-regulation and the Media*, 51 Fed. Comm. L. J. 711, 717 (1998); T. W. Reader, *Is Self-Regulation the Best Option for the Advertising Industry in the European Union--An Argument for the Harmonization of Advertising Laws through the Continued Use of Directives*, 16(1) U. Penn. J. Int'l L., 181 (1995), at 182 and 210.

159 G. W. White, Tort Law in America: An Intellectual History, 16 (Oxford University Press, New York, 2003)

160 *Id.*

efficient levels of accidents may not align with other parties exposed to the risk. *E.g.*, an operator of a methane hydrate project might have lower regards or lower levels of knowledge for benthic micro-fauna than other interested individuals. Or, *e.g.*, an operator might have a high regard for the integrity of its well field but low regards for the pre-existing recreational utility of that sea surface that long time community members may have previously enjoyed. As such, private regulation could potentially emerge as incomplete and in need of public adjustment or correction. For methane hydrate projects, there will likely be many voices and many concerns that would need to be integrated into a broader more cohesive set of standards and regulations in order to garner broad public support prior to the early onset of development and production activities. Private industry could muster an effort to coordinate such an engagement, but it is probably more efficient for all parties to rely on those political processes already present within open democracies to handle the development of new regulations.[161]

There is a concern that private regulation could be used by those already in the industry to prevent the entry of additional market participants. The industrial insiders, as it were, could conspire to set standards too high or in a manner too difficult to comply with for those new to the industry. Also, to the extent that the enforcement was left in the hands of the same private actors, there could be concerns that the overall enforcement could be applied unevenly to benefit the original members of the collective. It is unclear just how many "new entrants" there might be to the methane hydrate industry as it does not yet even exist.[162] This particular problem is probably not sufficiently ripe for consideration in the regulation over methane hydrate projects.

Democracies promote the ideal that laws are publicly drafted through transparent procedures, vetted by the public via various forms of openness including privately held media, and ultimately approved of and legislated into law or regulation by democratic elected proxies or representatives. Even those systems that provide broad powers to judges to enact effective legislation provide ample recourse to judicial reversal and constitutional cassation of those decisions. The development of private regulation, putatively behind closed doors by private interests, could readily appear to be the opposite of a democratic process. To the effect that the private regulations are developed in lieu of public regulations, it could further appear that the process could potentially be a by-pass of the role of the democratic government to determine public policy and to provide for the public welfare. Arguments could also clearly be made that even public laws are often drafted in rooms with few attendants and that private regulations can be drafted

161 Once those regulations are settled and agreed upon, perhaps those regulations could be implemented privately. In that sense, this discussion anticipates the issues of conditional self-regulation, discussed *infra.*

162 Silicon Valley provides many ready examples of well-entrenched firms that suddenly found themselves sharing their market space with new and very competitive entrants; *e.g.* Boeing and Elon Musks's SpaceX. While barriers might be created that required previous experience with oil or gas, it might be equally reasonable that whoever met survive vetting at the public licensing stage might well be able to address such private regulatory barriers as well.

with inputs from multiple community voices. Nevertheless, it would appear that private regulation does bear the burden of demonstrating the resultant regulations and guidelines are at least as good and as balanced as what might have emerged from a more democratic process if the private regulations are to gather public support for their usage in lieu of those public regulations.

All in all, the above conclusions lead to the development of conditional private regulation, that private regulation works best if coordinated and monitored to some extent by public authorities. Governments can limit the application of private regulation to certain aspects of operations or require the inclusion of a wider range of voices in the development of the regulations. The government can impact either the development of the regulations, the means of enforcing the regulations, or both. In this manner, it is hoped that some of the efficiencies of the private enterprise can be dove-tailed with the open transparency and inclusive character of public legislation. Certainly, for novel industries such as methane hydrate production it will be important to get as broad a consensus as possible in the development and acceptance of any form of private regulation.

6. Conclusion – Regulations in harmony with rules of civil liability

> "Given the fact that (for a variety of reasons) all policy instruments seem to have particular advantages, but also suffer from particular weaknesses, it may be optimal to use the strengths of particular policy instruments in an optimal way in combination with other instruments."[163]

This chapter has established the place of public and private regulations to set standards for optimal levels of activity and precaution. It has found that public regulations can function alongside private regulation in integrated regulatory mechanisms.

It has also found that rules of civil liability, and strict liability in particular, and regulations could be complementarily implemented. In the next chapter, where the circumstances of offshore methane hydrates are reviewed in light of the findings of this and the previous chapter, the recommendation will be made that a rule of strict liability should be implemented alongside an integrated regulatory mechanism with both public and private regulations.

Several reasons to adopt and employ regulations were presented in this chapter. Regulations can rebalance information asymmetries and restore full function to weak instances for rules of civil liability. Regulations can pursue tortfeasors where civil liability rules falter, such as when avoidance schemes or insolvency are present in tortfeasors. Regulation can assist when lawsuits are unlikely to be filed; regulatory bodies can unify disparate victims, can persist over time, and could have the capital, human, and technological resources that many victims might not. Additionally, regulatory bodies might be able to process claims

163 *See* Faure, *supra* at note 9, at 40.

in their own manners, *e.g.* administrative courts, to provide a sense of due process that might otherwise be missing institutionally in some locales.

It appears that often where one paradigm is weak, the other is more robust. In that sense, there is an opportunity to apply regulations in complementary fashion alongside of civil liability rules; it need not be an exclusive choice. To provide the tortfeasors with incentives from both the regulatory paradigm and the civil liability paradigm would provide the tortfeasors with a more complete portfolio of incentives to better ascertain efficient management of accidental risks in contrast to the limited basket of incentives provided by mere regulatory guidance.[164]

But it is really in the complementary aspect that regulations gain their best effect. The power of the regulatory body to correct the market will attract those to 'correct' the regulatory body; the coordinated implementation of civil liability rules would limit the potential distortion and recursively make the original attack on the regulatory body less attractive in the first place. Regulations help civil liabilities to function better, civil liabilities help the regulatory body to function better.

In closing, neither paradigm is perfect, but in complementary implementation regulations and rules of civil liabilities can function closer to optimal than either would alone. Thus, it would be preferable to see joint implementation of regulations alongside a rule of civil liability for the governance of methane hydrates.

164 *See id.*, at 41.

Chapter 7

GOVERNING WITH STRICT LIABILITY AND REGULATIONS

The commercial development of offshore methane hydrates will necessitate planning for accidental risk. Due to the unique risks and hazards associated with the development of offshore methane hydrates, it is unlikely that their development would be capable of beginning without some form of *ex ante* risk governance mechanism such as civil liability or regulations.

The commercial development of offshore methane hydrates will potentially provide both benefits and risks to the general public. If they are to be sustainably and safely developed, then the correct legal policy choices will need to be made. Should the risks and hazards be governed by rules of civil liability or by regulations; and if by civil liability, by strict liability or negligence?

The present chapter is the third chapter within Part II, it serves to integrate the civil liability and regulation analysis of the previous two chapters with the unique circumstances of offshore methane hydrates as developed in Part I.

The previous two chapters provided a review of under which circumstances a rule of strict liability might be efficiently employed and when a rule of negligence might be efficiently employed. They discussed the role of regulations, both public and private, to set standards. The previous chapter explored the potential for complementary implementation of multiple mechanisms to more completely address the risks and hazards of a targeted activity.

The present chapter provides a review of the unique and distinguishing circumstances of offshore methane hydrates. It reviews the fundamental science of offshore methane hydrates. It provides a review of the benefits that the development of offshore methane hydrates might afford. It also discusses the risks and hazards posed by that same development. The present chapter then goes to demonstrate that a strict liability rule would be more robust than a rule of negligence for the unique circumstances of offshore methane hydrates. Then the chapter discusses the potential benefits of implementing both a rule of strict liability and public regulations. This present chapter will argue that the combination of strict liability and regulations, when implemented in a complementary fashion, would provide for optimal governance of the risks and hazards from offshore methane hydrate installations. The potential to complement both of those systems with private regulations is also addressed.

Following this present chapter is Part III, which will provide a review of existing laws and conventions for their match and fit with the recommendations of this present chapter. Chapters in sequence will review conventions of the UN, international maritime and oil spill conventions, EU laws, and the federal laws of the U.S. Thereafter, Part IV will provide a summary and exposition of conclusions. Part IV also contains appendices of maps, mathematical notes, and reference listings.

1. The character of offshore methane hydrate accidents

The accidental risks of offshore methane hydrate projects are novel, as of 2014 no such fields were yet in commercial or even in sustained noncommercial development. There are engineering models from previous decades of experience in developing and producing offshore natural gas and crude oil reservoir systems, but there will remain much novelty to be integrated into the knowledge bases that will provide for the decision processes in implementing both strict liability-based and negligence-based safety planning.

The risks of cataclysmic accidents are unique to the specific operations of offshore methane hydrate fields; routine and ordinary human activities at sea are not known to have ever triggered these events. Sudden massive venting of methane, subsea landslides, tsunamis and earthquakes do not traditionally result from the types of activities undertaken by the communities located adjacent to the methane hydrate deposits. As far as knowledge exists, while cataclysmic methane hydrate events have occurred in the geological past, they have never been triggered by any human activities prior to the onset of methane hydrate exploitation.

The major harms and hazards of methane hydrate projects are reasonably described as unilateral in nature. The harms would result from activities primarily occurring in or near the production zone from which the methane hydrates are extracted. It is unlikely that anyone other than the operators and its affiliates and contractors would have access or normal reasons to be in adjacency to those areas of risk; thus, it is unlikely for bilateral accidents to occur. It is not impossible for bilateral accidents to occur,[1] but the types of events would require such clearly unique actions that they are probably not justifiable as reasons to characterize methane hydrate risks as bilateral.[2]

1 To the extent that third party causation needs to be considered, they do not necessarily require the use of bilateral accident models. *E.g*s:
(a) Commercial fishermen or mineral prospectors might engage in dangerous dredging or seismic operations that could trigger harms; but one assumes that basic permitting and responsibility for protecting the methane hydrate deposits properly belongs with the operator, thus even these intrusions are in some sense due to the failure of the operator and thus the accidents fit the unilateral characterization.
(b) Energy pirates attempting to steal access to hydrates or terrorists simply intent on havoc are another potential source of harm, and such risks exist today in the energy industry, but are generally seen as intervening sources of causation and thus outside of the realm of civil liability and more in the domain of criminal law and its enforcement.

2 *Arguendo*, in a sense, it takes two for a house to fall, the homeowner with a house unprepared for tsunamis and an actor that sets off tsunamis. However, it is unclear if a house can truly be →

2. Governing offshore methane hydrates with strict liability

2.1. Arguments for applying strict liability to offshore methane hydrates

2.1.1. The unilateral character of offshore methane hydrate projects

As stated in section 4.1, immediately *supra*, the major harms and hazards of methane hydrate projects are reasonably described as unilateral in nature.

Offshore methane hydrates would be generally located at sea removed from direct or normal interactions with onshore communities. The few potential interactions for potential victims to interact with the operational or hazardous areas of the hydrate fields would primarily be limited to surface craft crossing the field at water level. The vast majority of offshore methane hydrate fields lay beyond routine shoreline tourist activities and deep below routine skin or scuba diving activities. The main opportunity for accidental overlap and contributory risky acts from victims might be either commercial fishing that dredges nets too close to the mud layers or interferes with gathering lines or subsea mining operations; but those risks are routinely addressed within existing offshore installations and are not known to have created any major accidental events.[3]

The primary risks are technologically, geologically, and operationally under the primary and likely sole control of the operator and its joint venturers and subcontractors; the opportunity for bilateral accidents is fairly limited.[4] As such, the commercial development of offshore methane hydrate primarily presents accidents and hazards of a unilateral character. The rule of strict liability has repeatedly been found to be superior to the rule of negligence in governing unilateral accidents, thus strict liability should be applied to the governance of offshore methane hydrate installations and operations.

2.1.2. Governing abnormally hazardous activities

There are reasonable arguments that the development and operation of methane hydrate extraction installations could be seen as abnormally hazardous activities.

prepared for the tsunamis it might face, at least within the routine budgets of ordinary homeowners. If homeowners cannot afford sufficient protection, ceteris paribus, it would appear that they are essentially unable to avoid damage and thus the accident would remain primarily unilateral in character.

3 But both of those activities can be reasonably engaged with by the operator to alert those actors to the potential risks that they would be entering into should they draw too near. Indeed, one might readily assume that the operator would bear a certain responsibility under either rule of civil liability to ensure that trespassers are safely intercepted prior to any potential to disrupt safe operations.

4 This particular analysis excludes events such as warfare or terrorism wherein the act against the safety and stability of the hydrate field is intentional and deliberate.

First, a review of Shavell's Ultra-Hazardous Strict Liability Rule is developed,[5] followed by a review of the Landes-Posner conditions for strict liability.[6]

Shavell found that strict liability should be chosen as the rule of civil liability if (i) the underlying activities are uniquely identifiable, (ii) if the activity is worth controlling due to its imposition of non-negligible risks upon non-participant victims, and (iii) if the victim's engagement with the risky activity is entirely normal and thus "activity that cannot and should not be controlled."[7]

Methane hydrate installations are clearly uniquely identifiable from other activities; they will be distinctive from both other forms of hydrocarbon extraction and of other offshore activities. Methane hydrates projects would pose non-negligible risks onto non-participants; thus such activity is potentially worth controlling.[8] Most victims would have no awareness of their interaction with the activities of the methane hydrate project other than that it exists and operates, the victims essentially do none other than maintain the lives they enjoyed prior to the onset of methane hydrate extraction activities. Thus elements (i) and (iii) are clearly met, but element (ii) is only partially met. Shavell's model requires clarification on the issue of when does an activity merit control and when should that control be in the form of civil liability rules. However, one can reasonably infer that Shavell would have seen the potential for methane venting and subsea landslides as items worth controlling. Thus, all three elements would likely be seen as met, and Shavell's ultra-hazardous rule would advocate for strict liability for offshore methane hydrate projects.

The Landes-Posner conditions for strict liability require the satisfaction of four elements; strict liability should govern the activity:

i. if the expected accidents costs are large,
ii. if it is impossible for the risk of the accident to be reduced by additional precaution by the tortfeasor,
iii. if it is impractical to alter the behavior of the victim in favor of the tortfeasor, and
iv. if it is desirable to reduce risk by affecting the activity level of the tortfeasor.[9]

The potential harms from subsea landslides, offshore tsunamis, and potential environmental harms from methane and other emissions could certainly be costly. Both non-cataclysmic and cataclysmic accidents could pose massive discomforts and loss of livelihoods, loss of property, and potential injuries or deaths to humans,

5 *See* discussion on point, *supra*, at ch. 5, sec. 2.2.

6 Hylton's related asymmetrical conditions for strict liability are addressed within appendices, *infra*, at Appendix II-C.

7 *See supra*, at ch. 5, sec. 2.2.

8 Somewhat adverse to Shavell's position, it is not a logical requirement that such spill-over risk mandates the imposition of social controls; Hylton's model provides a richer discussion on point. *See* the discussion on Hylton balancing of externalized social costs and benefits, *infra* at Appendix II-C.

9 *See* discussion, *supra*, ch. 5, sec. 2.1.

fauna, and flora. The first aspect of the Landes-Posner conditions would likely be met in offshore methane hydrate accidents.

It is not as clear that additional precautions would not affect the overall risk levels; given technological developments and on-going refinements to operational standards, one might assume that risks could be reduced. However, safety planners have to be responsive to the technologies and realities presented to them within their window of operational control, which be quarterly or annually measured. They will face fixed points of technology, budgets, and human and capital resources from which to optimize their accident management plans. As such, it is arguable that additional precautions would not be feasible once the initial plans are developed; while safety improvements might become available in future time periods they would be irrelevant for the prevention of accidents within the decision maker's timeframe. Thus, *arguendo*, the second aspect of the Landes-Posner conditions would be met in offshore methane hydrate accidents.

As argued in the previous paragraph, the victims have next to no interaction with the installations thus a certain policy goal would be to protect the daily lives and routines of the potential victims as much as possible. The third aspect of the Landes-Posner conditions would likely be met in offshore methane hydrate accidents.

Finally, it is not clear that merely reducing the activity levels of the methane hydrate operator is a socially beneficial agenda; the commercial operation of methane hydrate fields could be potentially of much social value. However, the commercial operation of methane hydrate fields could also come with great harm and damage, those costs must be balanced against the previous opportunities for social welfare gains. Thus, there are many potential vectors within which the activity levels of certain parties or at certain locations should be curtailed by economic incentives. *E.g.*, certain fields would present higher levels of risks than other fields; incentives should be provided to encourage operators to prefer the safer methane hydrate deposits. *E.g.*, certain operators would be more technically, scientifically, and financially capable of safely managing offshore methane hydrate operations; incentives should be motivated to prevent incompetent operators from engaging in this industry. As such, while the commercial development of offshore methane hydrate might avail of broad benefits to the general public, many vectors of its implementation could be severely adverse to the general public and thus public policy would likely want to govern the activity level in those sectors of the industry. As such, the fourth aspect of the Landes-Posner conditions would likely be met in offshore methane hydrate accidents. Given that all four conditions of the Landes-Posner test have been readily met, strict liability would be advised for the development of offshore methane hydrates.

2.1.3. Achieving decentralization

The ability to achieve decentralization is a key concern; as discussed, *supra*,[10] strict liability efficiently enables decentralization. Decentralization is the ability of each tortfeasor to make their own unique determination of how to attain the optimal levels of activity and precaution whilst observing their own private costs to attain those goals. Decentralization enables each tortfeasor to coordinate their private costs efficiently without the need to match an exogenously determined standard. Multiple researchers have presented models that suggest a rule of negligence often fails to obtain decentralization whereas a rule of strict liability more robustly does obtain it.[11]

Decentralization has been demonstrated to be obtainable under certain versions of negligence. Miceli demonstrated that by carefully setting the duty of care to a high level, to that of the least cost of care tortfeasor,[12] then the highest degree of "vigilance, care and precaution" could be attained alongside decentralization. Similar requirements could be set for rules applicable to methane hydrate extraction operations. Miceli's methods also address the concerns that only under strict liability would a tortfeasor spend an efficient amount in search of precautionary technologies.[13] Thus, the choice for a rule of negligence need not prevent the attainment of decentralization in governing accidents resultant from methane hydrate accidents.

However, Miceli's requirements to set the standard duty of care at the level of that "least cost of care tortfeasor" would likely require knowledge not available *ex ante to* initial accidents and litigation or prior to the development of an information obtaining regulatory framework. Making no argument here that such a regulatory framework is not also a public good; it suffices to say that strict liability would efficiently obtain decentralization prior to those collections of data by regulatory fiat.

The onset of offshore methane hydrate operations will arrive with a host of new technologies and expertises that will for the most part be managed as intellectual property and as operational trade secrets based on in-house experiences. Each methane hydrate operator would likely face substantially different safety functions and decentralization would be a valuable policy attainment. As strict liability is widely held as more robust in supporting decentralization, it should be preferable to negligence. Considering that decentralization is readily and efficiently

10 *See* discussion, *supra*, at ch. 5, sec. 2.3.

11 *See* discussion, *supra,* at ch. 5, sec. 2.3.

12 By setting the due care level with regard to that of the tortfeasor with lowest costs of precaution, Miceli has accomplished two items. First, he has created a market for operators to seek cost efficiencies in precaution, making more precaution more affordable. One assumes that the party with the lowest costs of precaution must, ceteris paribus, be in possession of the most efficient precaution technology, and thus, Miceli's rule provides for the least waste in achieving the duty of care.

13 *See* discussion, *supra* at ch. 5, sec. 2.4.2. *See also* H. B. SCHÄFER & A. SCHÖNENBERGER, *Strict Liability versus Negligence, in*: ENCYCLOPEDIA OF LAW AND ECONOMICS, 605 (Edward Elgar, 2000).

attained under strict liability, variants of negligence should not be preferred to it without additional reasons to avoid strict liability being noted.

2.1.4. Handling uncertain *ex ante* duty of care

Schäfer *et al*. suggested that a rule of strict liability would be preferable to a rule of negligence when the duty of care is not *ex ante* clearly observable by the tortfeasor;[14] if the values are hidden then they cannot be accurately included in decision-making.

In the case of a nascent industry such as methane hydrates, it is likely that barring extra measures the eventual duty of care could be obscure *ex ante*.[15] As such, the logical conclusion is that strict liability might be preferable to negligence at least until a consensus developed to establish a clear determination of what duty of care would be employed by a negligence rule and thus make a clear *ex ante* duty feasible.

However, one finds it unlikely that an industry such as methane hydrate exploitation would be capable of reaching development without some form of regulation. A longer discussion of the expected application of regulation to offshore methane hydrates is found, *infra*, at Section 3.

Offshore methane hydrates will be found in government owned or administrated waters and as national assets the hydrates would likely face some form of regulation with regards to waste prevention and safe extraction. Most countries would likely require some form of permit process to produce those hydrates from their jurisdictional waters and this licensing process would itself likely be subject to regulation; *e.g.,* such regulations often require filing of EIAs and contingent emergency plans by the prospective operators. There are many reasons to expect that the extraction of most hydrates would come under several forms of regulation. Given the variety of regulations that offshore methane hydrates would likely engage,[16] and the need of various regulatory bodies to respond to the circumstances of offshore methane hydrates, that it is unlikely that offshore methane hydrates could move into development without *ex ante* standards being regulatorily established ahead of initial licensing and development activities.

In conclusion, while the theoretical advantage is probably given to the choice of strict liability, the underlying problem of an uncertain *ex ante* duty of care is not likely to be a substantial problem due to the coincidental development of regulations as the onset of methane hydrate exploitation approached.

14 *See* discussion, *supra* at ch. 5, sec. 2.4.1.

15 However, the duty of care could be clarified and established *ex ante* by several means. The most direct means would be to buttress the application of negligence with regulations that provide guidance as to required duties of care and precaution. Industrial groups could agree to certain industry wide standards of care. *See* the discussion on regulation and private regulation, *infra,* at ch. 6.

16 For a more complete discussion, *see* the four chapters within Part III. However, the mere onset of acquiring licenses to begin development of offshore methane hydrate would spark regulatory reviews in the U.S. under OCSLA and the CWA and under similar regulatory frameworks in the EU and its Member States. *See* Chapters 10 and 11, *infra*, in Part III.

2.1.5. Provide incentives for safety innovations

There is an established argument that strict liability provides better incentives to the tortfeasor to develop safety and precautionary technology because the rule places all of the costs of harm at the tortfeasor's feet.[17]

In the case of methane hydrates this is doubly likely to be effective, as few parties beyond the operators would have access to the relevant technologies, to the fields and activities in question, and to the operation awareness of encountered risks. Those operators will also have pre-existing financial capacities to develop such technologies in advance of development and production and would also be recipient of the revenues from methane sales from the installations to provide future funding of safety and precautionary technologies. While coordination with universities, government institutes, and local communities should be fostered, the effective development of the required safety and precautionary technologies will likely need the leadership and cooperation of the operators.

Thus both from a practical and a theoretical perspective, it is quite advisable to employ a rule of strict liability to best create the incentives that would result in the most sure development of safety and precautionary technologies.

2.1.6. Preventing victim coordination problems

Schäfer *et al*. raised a concern that when there are too many plaintiff victims, that interactive due care between the victims leads to problems of victims raising each other's risk levels; by choosing a rule of strict liability such a problem can be prevented.[18]

In the case of methane hydrate projects, the scale of "too many victims" reaches another level of analysis, that of the potential efficiency of public regulations over the basic efficiency of any rule of civil liability due to the larger potential number of victims.[19] However, as will be argued *infra*, [20] the preferred solution would be a combination of a rule of strict liability alongside public regulations.

2.1.7. Minimizing the costs of justice

Civil liability rules need to be enforced by courts, but such efforts incur substantial transaction costs. Due process, discovery, and the costs of trial are all non-trivial, even in the best of circumstances. Models demonstrate that strict liability is more

17 *See* discussion, *supra*, at ch. 5, sec. 2.1.

18 *See* discussion, *supra* at ch. 5, sec. 2.4. *Also*, arguendo, while the case of unilateral accidents is driven by the behavior of the tortfeasor to create damage unilaterally to the victim, the any rule of civil liability depends on the damage being brought to court for adjudication in order to provide the incentives to the tortfeasor. Without that potential litigation and resultant judgment for damages, the incentive would be voided of impact.

19 *See* discussion, *supra* at ch. 6, sec. 2.4.

20 *See* discussion, *infra*, at sec. 3.3.

robust than negligence because it is foreseeable that strict liability could result in a higher percentage of pre-trial settlements and also that the rule of strict liability present simpler cases to litigate. Thus, strict liability is preferable if the transaction costs of the administration of justice are of material concern.

For offshore methane hydrate projects operating in developed countries, this may not present as large a concern as it might to those projects located offshore of countries with weak or developing legal institutions. Thus, those jurisdictions might well benefit from the application of strict liability.

But even in developed settings, the ability of community representatives to obtain justice might be challenged if they need compete against the resources of large methane hydrate operators. In those countries with weak or developing legal institutions, both the operators and various community representatives might find the legal institutions poorly suited to the litigious needs of major methane hydrate accidents. Especially for that scenario, the goal should be to facilitate the reliability and stability of access to justice for all parties. Because the standard models demonstrate that a rule of strict liability places less stress, or transaction costs, on the local justice system, strict liability should be applied in those conditions.[21]

2.2. *Arguments for applying negligence to offshore methane hydrates*

2.2.1. Lack of risk-averse actors in offshore methane hydrate development

Under an analysis of risk aversion and risk allocation, the rule of negligence was found to be more robust.[22] Perhaps most importantly, if risk aversion does manifest in the invest decision, and a strict liability rule is in place, it has been modeled that such a situation could prevent socially beneficial activity from occurring at all. If the development of methane hydrate does in fact offer the benefits that it is expected to bear, then the rule of strict liability could prevent the receipt of those benefits.

However, it is unlikely that the operators of offshore methane hydrate projects would suffer from material levels of risk aversion. *Prima facie*, the investment itself is a risky enterprise, and thus investors with substantial risk aversion would likely shy from such project. Second, the type of operators expected to enter into the development of offshore methane hydrates would likely have engaged in decades of previous risky offshore oil and gas projects; if they had once had substantial risk aversion problems, financial or otherwise, they have likely found tools to address those concerns in the interim. Indeed, most of the expected operators have large capital holding and routinely self-insure on their larger projects.

Thus, it is unlikely that substantially risk-averse actors would be engaged in offshore methane hydrate operations. Even if some elements of risk aversive behaviors survived into the nascent industry, the existing offshore oil and gas operators would be expected to be able to transfer know-how and means to address those concerns without affecting their ability to rationally address their risks

21 *See* the mathematical notes to Shavell, in Appendix II-A.

22 *See* discussion, *supra* at ch. 5, sec. 3.1.1.

management strategies. As such, there is no particularly strong reason to promote a rule of negligence merely to address risk-averse actors.

2.2.2. Insolvency of operators

The problem of potentially insolvent tortfeasors is more robustly addressed with a rule of negligence.[23] While one hopes that investors in methane hydrate projects would not be *ex ante* expected to be insolvent, all companies face the risk of insolvency.

Many corporate structures are designed to limit overall risk and liability by limiting the amount invested within the corporate entity, so insolvency remains an issue for daughter affiliates of an otherwise solvent corporation. Additionally, it is routine in the oil and gas industry to place each well or lease within its own corporate entity to enable certain financial and tax planning opportunities,[24] so capitalization for the corporate entities in possession of the well may well be insolvent against major accidents.

Insolvency of offshore methane hydrate operators is a concern to be addressed; and as negligence is generally found more robust for conditions facing insolvency, negligence should be preferred for offshore methane hydrates, at least on this issue. However, insolvency can be addressed within a regulatory framework as well, to better ensure that sufficient capital stocks and insurance policies are instituted to minimize the potential of operators to become insolvent while licensed to operate offshore methane hydrate installations.[25] *E.g.*, mandates could be required to ensure that the corporations holding offshore methane hydrate installations remain solvent or retain certain levels of capital funding to prevent insolvency from becoming a functional problem.[26]

Thus there is a finding that insolvency would potentially remain a risk for the development of offshore methane hydrate operators, but that a rule of negligence is neither the exclusive means nor necessarily the optimal means with which to address the problem.

23 *See* discussion, *supra* at ch. 5, sec. 3.1.2.

24 One such strategy is known as "worthless stock deduction" planning, which enables pass-through of dry-hole losses to tax accounts while receiving uplift on producing wells via tax credits.

25 *See* discussion, *supra* at ch. 6, sec. 2.3.

26 *E.g.*, many licensing and permitting regulations require certain financial proofs of sufficient financial reserves to operate such offshore installations. Additionally, many corporate acts enable look-through or veil-piercing rules when corporate behavior is financially tortious, as such might well be the case in certain avoidance strategies following major industrial accidents. *See* the discussions, *infra*, both in ch. 6 Regulations and the latter chapters of addressing particular existing laws in Part III.

2.2.3. Strategic operators: avoidance and precaution

The traditional operators of offshore oil and gas installations are financially sophisticated; they routinely have very large-scale investments in offshore projects in multiple jurisdictions around the globe.[27] It is to be expected that these investors would be fully aware of functional means of avoidance and of precaution and that their legal counsel would be engaged in ensuring that those corporations bore no legally unnecessary levels of liabilities. But that is not the same as to suggest that these parties have incentives to strategically avoid their liabilities.

However, there are always certain risks that certain corporate structures, intended for other financial or tax planning purposes, might effectively create similar results to avoidance stratagems. It is not unusual for the financial operations of an offshore investment to operate primary beyond the local jurisdiction of a wellsite or project.[28] Similarly, operational control might be structured in a manner that the operational joint venture sits beyond the local jurisdiction.[29] And of course, there will always be reference to such corporate characters as Enron, who left many in the public wary of the *bona fides* of major corporations. Thus, although this present author would expect few direct bad faith avoidance strategies, it is reasonable to expect that other good faith measures might create *de facto* results too similar to ignore.

But there are many existing regulations in place to reduce the overall risk to be addressed by the choice of civil liability rules. Thus, while the opportunity for avoidance strategies could be present during the development and operation of offshore methane hydrate operations, and while a rule of negligence might be more robust for this particular concern, regulations, particularly pre-existing regulations, might functionally pre-empt the advantages provided by a rule of negligence.

2.2.4. Behavioural operators of offshore methane hydrate projects

To the extent that modeling has been undertaken on the role of behavioral economics and law, it emerges that negligence is more robust at dealing with the

27 Just the list of ExxonMobil, RD Shell, Chevron, and BP conjure the very idea of sophisticated international corporations. But it is not only these major independent oil corporations (IOCs) that investors, as there are a wide variety of major national oil corporations (NOCs) that often dwarf these IOCs in financial capacity and access to markets. It has been reported that NOCs now control over 90% of the world's conventional oil and gas reserves, are currently exceeding IOC investments in R&D by 20% *p.a.*, and generally receive more favorable terms in the financial markets when raising capital. *See* J. Leis, J. McCreery & J. C. Gay, *National Oil Companies Reshape the Playing Field*, Bain Brief, 1, 1-2 (2012).

28 Such planning could be required for various corporate law compliance requirements or to efficiently structure dividend and tax obligations.

29 *E.g.*, the joint venturers might hold the project in a partnership in country A, which then holds the project within a corporation within country B. Operational decisions could be executed from within jurisdiction A since the corporation located in B would be wholly owned and operated by the parental partnership.

routine errors identified by behavioral economists.[30] Humans are generally observed underestimating the chances that they can avoid environmental accidents.[31] At the same time, they are overly pessimistic about catastrophic accidents. Both types of events are potentially part of a methane hydrate event, and thus these behavioral impacts are important to consider.

However, the types of corporations and other investment bodies likely to engage in the development and commercialization of offshore methane hydrate assets are not likely to suffer from these behavioral defects. First, their financial decision processes are far removed from singular decision makers; the teams of managers, engineers, lawyers, and investors required to execute a successful methane hydrate project would require operational procedures of control that would do much to offset any behavioral economic issues such as might be found in natural humans.

This is not to suggest that those decision-making procedures would not contain the potential for error, just that the behavioral concerns of optimism and pessimism would be expected to be mitigated by corporate controls procedures. As such, behavioral economics is not likely to be a prevailing concern of governing methane hydrate accident risk. *Ergo*, behavioral economics will not present sufficient argument for the application of a rule of negligence for offshore methane hydrate projects.

2.2.5. Insurance markets and the operators of offshore methane hydrate projects

A rule of negligence is more robust than a rule of strict liability when insurance markets are imperfect.[32] The insurance market for methane hydrate accidents will need to be responsive to the novel harms of offshore methane hydrates. It is unclear at this time how that might be done, thus, functionally it is unclear what kinds of insurance products would be available to investors in offshore methane hydrate installations.

30 *See* discussion, *supra* at ch. 5, sec. 3.1.4.

31 It is important to underscore the role of actual humans in the study of behavioral economics. The field is focused on the errors made by humans, not by other entities such as corporations. Corporations clearly can make errant decision processes, but the discussion of such problems would not be included within this area. To a sub-argument that corporations are still governed by groups of humans and therefore might display behavioral economics, the very fabric of corporate law is the study of the principle/agent dynamic at many contrasting levels; *e.g.*, shareholders *vs*. executives *vs*. employees. In that matrix of opposing forces, cognitive decisions errors do occur, but they are generally of another character. *See* H. A. SIMON, ADMINISTRATIVE BEHAVIOR. (New York: Free Press, 1965), as an early seminal study on such corporate decision making processes. Similarly, Oliver Williamson's body of research on "bounded rationality" was centered on the cognitive functions of corporate bodies; *see* O. E. Williamson, *The Economics of Organization: The Transaction Cost Approach*, 87(3) Am. J. Sociology 548 (1981).

32 *See* discussion, *supra* at ch. 5, sec. 3.1.5.

The industry of methane hydrates is novel and the risks are to some extent unknowable until a certain amount of operational experience accrues. The potential costs of harms from the more extreme cases could need to respond to tsunami and landslide impacts on coastal communities, to respond to certain economic losses from those injuries and potentially respond to mass loss of lives; such a risk would be extremely expensive. Not to say that there are not means available, but the more financially demanding a market is, the more likely it is to reach problems.

Given the particular risks of the novel industry,[33] a rule of negligence may be more efficient for methane hydrate accidents. However, the expected operators of offshore methane hydrate installations, as discussed *supra* at section 2.2.1 with regards to risk aversion, have likely addressed similar concerns before and have the financial sophistication to address these types of concerns. The major existing operators have deep financial capacity to self-insure and to purchase insurance.[34] As such, there is not a pressing need to employ a rule of negligence to remedy the potential problems posed by a lack of insurance.[35]

2.2.6. Addressing imperfect or inaccurate sanctions against methane hydrate accidents

If the expected judgments do not match the actual harms,[36] or if there is systematic slack in the assignment of judgments,[37] negligence has been found more robust at achieving proper levels of precaution. To the extent that real world conditions following a methane hydrate accident may mismatch, and one certainly might think it possible, the choice of rule should be for negligence.

But the types of accidents that might befall an offshore methane hydrate operation are not likely to result in precision injuries or damages. Both the non-cataclysmic and cataclysmic injuries would be expected to either be limited

33 Calabresi and Klevorick have argued that strict liability might present incentives to acquire new information more robustly than a rule of negliegence; but, they found that the choice of rule was complex and they did not find a definite result.*See* G. Calabresi & A. K. Klevorick, *Four Tests for Liability in Torts*, 14 J. Legal Stud. 585, 621 and at 626 (1985).

34 *E.g.*, as was seen at the BP Macondo incident, BP was able to immediately produce $20 billion to establish the Gulf Coast Claims Facility, a type of settlement fund, prior to the onset of tort litigation. It is generally understood that the funding came solely from BP's own capital and current revenues. It is not unlikely that this particular industry would be unable to provide its own insurance if the market was otherwise unable to support such a need.

35 One might ask how climate change harms impacts this analytical result. It would appear that the scope of harms from accelerated climate change, induced by a methane hydrate accident, could be so severe as to dwarf the impact of both rules from civil liability; it might not make any difference which rule as in application as the sum of the damages might well exceed the capital of the operator and thus prevent the impact of either rule's incentive mechanisms. In such cases, regulation would be more robust, and potentially, there might be need to hold certain acts that increase such risks as criminal or bellicose in character. Thus, the application of strict liability remains more robust for those situations wherein civil liability would be effective; regulations or other non-civil liability means would be needed in other situations.

36 *See* discussion, *supra* at ch. 5, sec. 3.2.

37 *See* discussion, *supra* at ch. 5, sec. 3.2.

primarily to the wellsite, and thus bypass this concern, or affect a larger onshore community of residents. Should the accident affect an onshore community, damages will be at best approximations.[38] But the critical question to ask is whether the difference in damages would be sufficient for an actor under strict liability to reduce their level of precaution. In the case of offshore methane hydrates, it would appear that the tortfeasor would stand to lose on their own personal account, in terms of loss of revenue, property, and personnel, that one reasonably wonders if additional incentives would be necessary to motivate efficient levels of precaution.

2.2.7. Need for data transparency

Negligence offers an opportunity to present more evidence and arguments at trial than strict liability would require. Thus it has been argued that perhaps a rule of negligence can be usefully employed to provide information to the courts and to the public that could enable efficient determinations of appropriate precaution and activity levels.[39]

The commercial development of methane hydrates faces perhaps a somewhat unique situation in that its basic science and engineering have been primarily developed under the subsidies and guidance of national governments. As such, a large body of information on the risk and hazards of that same technology will be publicly available prior to the first applications for commercial development. Further, many nations require EIAs to be completed prior to the approval or licensing for new projects, improving the likelihood that offshore methane hydrate projects would not be developed without public awareness of its risks and hazards. Thus the risk of insufficient data for public determination of appropriate precaution and activity levels is relatively lighter for offshore methane hydrates than many other new industrial processes that were developed without such *ex ante* public involvement. As such, there is little to no need to apply the rule of negligence to offshore methane hydrate projects based on this concern.

2.2.8. Balancing of externalized benefits and risks

Gilead and Hylton, separately, have both provided an analysis of determining rules of civil liability based on the ratios of externalized social benefits and social costs.[40]

38 If an onshore community is impacted by a methane hydrate accident, one would expect a large number of claims on a wide variety of matters. Also, in certain cases, particularly after more severe accidents, records or evidences might be damaged or lost in the cataclysms following. Therefore, precise determinations of injuries might not be efficiently or even feasibly rendered for such cases.

39 *See* discussion, *supra*, at ch. 5, sec. 3.3.

40 *See* I. Gilead, *Tort Law and Internalization: The Gap Between Private Loss and Social Cost*, 17 Int'l Rev. L. & Econ. 589 (1997). *See also* K. N. Hylton, A Positive Theory of Strict Liability. 4(1) Review of Law & Economics 153 (2008) (Due to licensing limits where the present study was undertaken, its research relied on the working paper version of Hylton's article; as such, all point citations are to that source material. *See* K. N. Hylton, *A Positive Theory of Strict Liability.*
→

Each determination must first resolve the ratios of externalized risks and of externalized benefits. A case could be made that the benefits of offshore methane hydrate projects would match or exceed their risks; but it is also not unforeseeable that some stakeholders might envision lower potential benefits of additional methane exploitation.

According to Hylton's quadrant analysis of comparative externalized risks and benefits,[41] the rule of strict liability should be applied if and when the tortfeasor's externalized risks exceed those posed by the victim and when the tortfeasor's externalized benefits are the same or less than those posed by the victim. Methane hydrate projects will externalize a substantial amount of risk, certainly in excess of the externalized risks from the potential victims. However the ratio of externalized benefits is not as clear for methane hydrates; thus, it is unclear if the externalized risk/benefit ratios of a methane hydrate project would support the application of strict liability.

The externalized risks of methane hydrates are more readily foreseeable but one could reasonably expect some divergence of opinion amongst policy makers on the externalized benefits. For this reason, Hylton's four-quadrant model of civil liability rules might not render a clear determination which quadrant offshore methane hydrate might sit within; as such, Hylton's method is indeterminate for offshore methane hydrate projects.

Gilead's model of the "Gap" provides additional insight into the complexities caused by not only the symmetries or asymmetries of externalized costs and benefits but also to the impact on rule choice when those asymmetries are compounded by a "Gap" in estimating the privately assessed damages versus the actual public negative externality.[42] Gilead provided insight into when strict liability might be more robust than negligence in such conditions, and that is when the internalized "Gap" is small.[43] Additionally, Gilead advised that strict liability should be applied when externalized costs are high and only limited welfare benefits are generated for third parties;[44] in this he and Hylton were in theoretical agreement.

2.3. Complexity in implemention

One of the problems of implementing rules of civil liability is the complexity of it; there are many several manners in which the rules can be frustrated if not correctly implemented or if the circumstances are not sufficiently compatible. Hereunder a quick survey of several concern areas is developed. Particular attention is spent to both the impact on selection of strict liability versus negligence and on the impact of the circumstances of offshore methane hydrate operations.

(Boston University School of Law Working Paper No. 06-35, *available* at SSRN: http://ssrn.com/abstract=932600).

41 *See* discussion, *infra*, at sec. 3.4, and see also Table 3 in Appendix II.C.

42 Gilead, *supra* at note 40, *en passim*.

43 *Id.*, at 607.

44 *Id.*, at 608.

2.3.1. Joint and several liability

The concept of joint and several liability primarily appears to operate from a compensatory purpose;[45] however, one might want to evaluate if joint and several liability were to be applied, would it affect the choice of liability rule? The answer is that joint and several liability does two things; (i) it solves insolvency problems in enabling a victim to switch from insolvent actors to solvent actors, and (ii) it forces the tortfeasors to monitor each other, potentially providing them with incentives to set private standards of acceptable precautionary and activity levels.

Tietenberg stated that the group of comingled tortfeasors would have an incentive to monitor each other; that monitoring could both reduce the overall likelihood of a tort event and also enable the tortfeasors to provide information to the plaintiffs and court in discovery.[46] Similarly, Feess and Hege have proposed an alternate rule for determining the shares of damages for scenarios wherein a group of co-tortfeasors would be made responsible for monitoring the risks and procedures for an activity.[47]

If one assumed that joint and several liability did result in enhanced cross-tortfeasor observation and data collection, and if a main advantage of negligence was its ability to force the collection of similar data, then the presence of a joint and several liability rule might reduce the benefits of a negligence rule for that effect. Also, forcing the potential co-venturers of a risky project, such as offshore methane hydrates, to *ex ante* recognize their joint and several liabilities might well provide incentives for them to privately negotiate amongst themselves to reduce the risk of strategic avoidance or insolvency as such events would directly burden the other co-venturers. Thus, the implementation of a joint and several liability rule might mitigate some of the advantages ascribed to the rule of negligence, *supra*.[48]

The traditional commercial operations of oil and gas operators might also illuminate this issue. Traditionally, multiple co-venturers split ownership of the offshore energy investment and designate one of the co-venturers as the operator. But each of the co-venturers is generally a peer of the operator, of similar size, technical acuity, and of capital and financial resources; indeed, it is likely that the same group has other joint ventures in common and each might be operator at the different projects. Thus, in this environment the group of co-investors *cum* co-tortfeasors could establish a potentially responsible peer-arrangement with functions akin to auditors. They would be able to have access to private data

45 An attempt to use joint and severable liability rules as a compensation system instead of an incentive system would dilute the incentives to efficiently avoid accidents; that result should be avoided in general if the primary goal is to manage the levels of accidental harms.

46 M. G. Faure, Liability and Compensation for Damage Resulting from CO_2 Storage Sites, 59 (2013) (unpublished manuscript) (on file with author); citing to T. H. Tietenberg, Indivisible Toxic Torts: The Economics of Joint and Several Liability, 65 Land Econ. 305 (1989).

47 M. G. FAURE, *Environmental liability*, *in* TORT LAW AND ECONOMICS, 247, 259 (Edward Elgar, 2009); citing to E. Feess & U. Hege, *Safety Regulation and Monitor Liability*, 7 Rev. Econ. Design 173 (2002).

48 *See* the discussions, *supra*, at sec. 3.1 and 3.3 within this chapter.

usually difficult to obtain by outsiders or regulators and yet they would have good cause to maintain a state of vigilance because a lapse of safety could lead to shared damages and liabilities; it becomes a commercial necessity to meet the local rule of civil liability because the operator would likely face private liability to his co-venturers for his own failures to maintain agreed to standards of precaution. Thus, joint and several liability would likely be of substantial benefit for offshore methane hydrate installations and thus also provide a greater likelihood of overall accident avoidance.[49]

2.3.2. Causality: threshold or proportionate

Causality is required for the judicial finding of a tort; some actor needs to be found causing the sequence of events that resulted in the injury to the victim. While the causation of a simple tort may be readily apparent, *e.g.,* who hit whom, the facts and events of a chemical emission may be much more difficult to causally connect to an injury.[50]

Difficulties may include multiple sources and background risks:[51]

i. Multiple potential sources of the specific chemical, *e.g.,* there were multiple sources of industrial emissions,
ii. The chemical in question is also found in the ambient natural environment to some degree, so a question might arise as to what degree the industrially emitted chemical is causally connected to the injury versus those exposures to the chemical from natural settings.
iii. Multiple ambient sources of risks, of which only one is the industrially emitted chemical.

For such events, uncertainty is an unavoidable issue in the decision of causality. Traditionally, many courts have relied on the threshold rule of "more likely than not," which is usually interpreted as meaning a greater than 50% chance of

49 Given that such investors in offshore methane hydrates would likely be engaged in multiple projects in multiple locations, as do oil and gas operators today, one might expect that at least the private arrangements and private regulations suggested here could become standardized across jurisdictions for transaction cost efficiencies. Further, it has been argued that even those states with appropriate legal institutions, sufficiently safe hydrate deposits, and with access to state-of-the-art prevention technologies would want to provide for a broader global management of methane hydrate resources to preserve the potential to exploit their own hydrates without the collateral of accidents and harms from those resource owners less well situated. *See* R. A. Partain, *Avoiding Epimetheus: Planning Ahead for the Commercial Development of Offshore Methane Hydrates*, 14:2 Sustainable Dev. L. & Pol'y (December 2014 Forthcoming).

50 There is no reason to limit the following discussion to emitted chemical other than to provide ready and comparable references to the different models evaluated. The actual torts involved are too numerous to list, but it is hoped a common semantic makes the discussion easier to follow.

51 Faure, *supra* at note 46, at 59; citing to J. Trauberman, *Statutory Reform of Toxic Torts: Relieving Legal, Scientific, and Economic Burdens on the Chemical Victim*, 7 Harv. Envtl L. Rev. 177 (1983), and S. D. Estep, *Radiation Injuries and Statistics: The Need for a New Approach to Injury Litigation*, 59 Mich. L. Rev. 259 (1960).

likelihood to be the cause of the injury.[52] Yet this method presents risks of erroneous determinations; actors might face 100% judgments for the costs of damages when their role in the harm was less than 100% — actors would face incorrect high costs, which could cause over-deterrence in the type of activity.[53]

A more recent development is the proportionate liability role, which avoids the threshold issue by determining what extent of the injury was causally related to the emitted chemical.[54] Instead of focusing on liability for the whole injury, the rule of proportionate liability refocuses the liability trial to a determination of how much of the injury was caused by the acts of the disputed tortfeasor.[55] This has benefits for both sides; the plaintiffs need only to establish some amount of non-zero causality to enable a finding of liability and the respondent will likely face a smaller overall liability judgment. Transaction costs and certainty are both more efficiently achieved under the proportionate liability rule; if in practice the correct determination could be made by the courts then the result would be efficient.[56]

However, theory and practice are expected to diverge in real life settings. There are substantial concerns that science is limited in its ability to reconstruct events of causation and thus a certain amount of error is likely to be present in the courtroom.[57] As such, scholars have warned that reliance on even proportionate systems of causality is likely to remain inefficient.[58]

Methane hydrate accidents, especially those of cataclysmic character, may develop from a complex combination of events and from multiple incremental activities over a long period of time.[59] Or, they might occur suddenly from singular

52 *See* Faure, *supra* at note 47, at 258; citing to C. Miller, *Causation in Personal Injury: Legal or Epidemiological Common Sense?*, 26 Legal Stud. 545 (2006).

53 Id., at 257; citing to S. Shavell, Uncertainty over Causation and the Determination of Civil Liability, 28 J. L. & Econ. 587 (1985), and H. Kerkmeester, De betekenis van het waarschijnlijkheidsbegrip voor de aansprakelijkheid uit onrechtmatige daad: Meijers geactualiseerd (The Meaning of the Concept Probability from Tort Law: Meijers Actualized), 6111 Weekblad voor Privaatrecht 767 (1993).

54 *Id.*, at 258; citing to L. BERGKAMP, LIABILITY AND ENVIRONMENT (Kluwer Law International, The Hague, Netherlands, 2001).

55 Id., at 257; citing to D. Rosenberg, The Casual Connection in Mass Exposure Cases: A Public Law Vision of the Tort System, 97 Harv. L. Rev. 849 (1983); D. Kaye, The Limits of the Preponderance of the Evidence Standard: Justifiably Naked Statistical Evidence and Multiple Causation, 7 L. & Soc. Inquiry 487 (1982); M. J. Rizzo & F. S. Arnold, Causal Apportionment in the Law of Torts, 80 Colum. L. Rev. 1399 (1980); and M. J. Rizzo & F. S. Arnold, Causal Apportionment: A Reply to the Critics, 15 J. Legal Stud. 219 (1986).

56 *Id.*, at 258; citing to W. M. Landes & R. A. Posner, *Tort Law as a Regulatory Regime for Catastrophic Personal Injuries*, 13 J. Legal Stud. 417 (1984); G. O. Robinson, *Probabilistic Causation And Compensation For Tortious Risk*, 14 J. Legal Stud. 779 (1985); and J. Makdisi, *Proportional Liability: A Comprehensive Rule to Apportion Tort Damages Based on Probability*, 67 N.C. L. Rev. 1063 (1988).

57 *Id.*, at 258.

58 *Id.*; citing to Estep, *supra* at note 51, and L. H. Tribe, *Trial by mathematics: Precision and ritual in the legal process*, 84 Harv. L. Rev. 1329 (1971).

59 *E.g.*, cracking the mudlayer above the hydrate reservoir could accumulate from vibrations, fluid injections, and even from local weather phenomena. The cumulative effect could take a long period to suffice before the field erupted.

acts of singular actors.[60] The types of risks associated with methane hydrate fields are basically the type of events associated with triggering equilibria or tipping point; a certain amount of activity can occur and build up until finally a sudden release or event could occur that results in the particular harm and damage. In such conditions, causality may be quite difficult to determine; especially after a cataclysmic event the necessary physical or eyewitness evidence may be eliminated coincidently with the accident itself. In such lights, a rule of strict liability might be more robust, in that its evidentiary burden is a lighter one than the burden under a rule of negligence as no duty of care needs review. In the type of accidents that methane hydrate fields are likely to have, especially on the severe end, strict liability might be more likely to be implementable after an accident in contrast to a rule of negligence.

2.3.3. Difficulties of long-term liability issues.

From the dateline of the FID[61] for a methane hydrate project, the development period might last 5 to 10 years and the production period several decades beyond that to potentially much longer. The abandonment and sequestration phase of a methane hydrate project could last decades to much, much longer, especially if the methane hydrate project engaged in carbon sequestration alongside the methane production. The time frame of risk, from FID to the final risky event, could be a century or more in length.

The decision at FID is to initiate this very long sequence of risky events; how can the operator make that decision if actors might become liable after the decision, or if duties of precaution change after behaviors are undertaken, or if future liabilities even matter given sufficient passage of time? These are problems of time frame management; the next three sections of this chapter are focused on these issues. This first section discusses the challenges of *ex post facto* determinations of liability. The next two sections discuss *ex post* changes in the expected levels of precaution and time frame management.

When an activity that was previously not a source of liability later becomes a source of liability, an *ex post facto* determination of liability, then the operator would not have received the incentive it needed to operate efficiently. Thus, it would appear to have no validity as a tool to reduce the incidence of accidents.[62] On the other hand, if operators could reasonably forecast that additional future liabilities

60 *E.g.*, horizontal drilling and resistance within the mudlayer could cause sufficient mechanism stress and vibration that it might suddenly cause a section of the mudlayer to fail.

61 FID stands for "Financial Investment Decision." FID can refer both to the decision and to the date of the decision to initiate the development, production and marketing phases of a hydrocarbon field. It is commonplace for FID models to anticipate cost structures and potential revenue forecasts from FID till abandonment. FID models attempt to determine the overall profitability of a given project over the whole lifetime of the project to create a metric that can enable projects to compete for limited capital resources within the operator's assets. *See* discussion, *supra*, at ch. 3, sec. 2 on the "Economics of Methane Hydrates."

62 Faure, *supra* at note 47, at 261.

might be determined *ex post*, then they could decide to include those expected damages into their decision making process. Having received an incentive to reduce their overall precautions;[63] it becomes effectively the same math as operating with an expectation that one might be find liable regardless of behavior, so the care level is reduced.

Another way in which incentives can become muddled is when the judicially enforced duty of care is changed as time goes by and becomes a new liability rule *ex post facto* for events from the past. One could make a reasonable assumption that in most cases that duty of care level change would result in a higher level of care. Indeed, the foreseeability of such a reasonable assumption was studied by Shavell; it is reasonable in some cases for an operator to assume that duty of care levels would increase over time so that they should take such foreseeable adjustments into account *ex ante*.[64]

But is this ultimately efficient, to require an operator to forecast both technological advancements and social responses to that new knowledge; indeed, "is it even feasible?" one might ask. Indeed, there are substantial dangers to this approach in that it might lead to over-deterrence in the regulated activity and cause a decrease in overall welfare.[65]

The development of methane hydrate projects is likely to spur rapid advancement in both the underlying associated technologies and in the public's awareness and understanding of the risks and benefits of methane hydrate projects. To that extent, if operators needed to take any and all foreseeable or possible *ex post* changes to liability into account, it would likely have the effect of setting a higher bar to entry than the inclusion of *ex ante* liability rules. That higher standards would evolve over time is of course a most reasonable thing.[66] American common law has a tool called prospective overruling, that enables a judge to rule on a specific case that for the immediate defendant that the older duty of care applied but prospective and future cases would be held under a new standard of care.[67]

While operators are to be held liable, it is foreseeable that methane hydrate projects that span decades of operation might outlast the initial operators or even outlast the regulatory body that originally licensed and permitted the project. The decisions to be made by the initial operator at the time of the development and production phases will have an impact on overall safety and reliability over the whole time-frame yet the foreseeability that the operator may not be solvent or in operations that far into the future plus the toll that discount rates will have on the

63 *Id.*; citing to J. Boyd & H. Kunreuther, *Retroactive Liability or the Public Purse?*, 11 J. Regulatory Econ. 79 (1997).

64 *Id.*, at 262; citing to S. Shavell, *Liability and the Incentive to Obtain Information About Risk*, 21 J. Legal Stud. 259 (1992).

65 *Id.*

66 *Id.*, at 263; citing to C. Ott & H. B. Schäfer, *Negligence as Untaken Precaution, Limited Information, and Efficient Standard Formation in The Civil Liability System*, 17 Int'l Rev. L. & Econ. 15 (1997); and A. Endres & R. Bertram, *The Development of Care Technology Under Liability Law*, 26 Int'l Rev. L. & Econ. 503 (2006).

67 *See* J. Boyd & H. Kunreuther, *Retroactive Liability or the Public Purse?*, 11 J. Regulatory Econ. 79 (1997). *See also* the discussion at Faure, *supra* at note 47, at 263.

economic decisions related to the project will strongly limit the serous and due consideration of some of the risks of the project.[68] For this reason, it should be considered that liability rules might not be completely efficient at mitigating all of the risks of methane hydrate projects.

However, there are several reasons to hold that most of the decisions made for the long-term risks actually are identical to decisions to be made for more near-in-time risks for which the operators are indeed likely to take liability rules into consideration. Thus, while the long-term long tail risks are present within methane hydrate projects, it is unlikely to cause unique or specific risks otherwise unaccounted for by the already suggested combination of regulation and liability rules.

First, the risks for offshore methane hydrates are likely to be front loaded, in that technology and practical experience will build over time making precautionary planning more accurate and thus more efficient. Accidents are reasonably more likely to happen in the early years as the learning curve builds. Thus a potential majority of the risks for the initial operator are in the early decades.

Second, the discount rate on financial accounting will also create a focus for near term safety, as interruptions to operations in early years could be substantial impediments to the overall return-on-investment for the project.

Third, and perhaps unique to offshore methane hydrates, the need to replace wells and continue with in-field development over time means that while the field itself might remain in operation for scores of years, localized wellsites will rotate in and out of production more frequently so that the whole life cycle of production and abandonment might be encountered at some sties within the first several decades of production. The types of activities to be seen at the end of the field will actually be seen at some of the earlier wellsites within decades of the field's start-up.

Finally, the sequestration and abandonment of methane hydrate fields is expected to be endothermic and thus self-stabilizing or self-cementing, somewhat unlike the re-injection of natural gas (CH_4) or carbon dioxide (CO_2) into conventional depleted reservoirs. Thus, one might reasonably conclude that the project operators will focus on the near-term risks in alignment with long-term risks; albeit short-term here might reference to a period of several decades.

To the extent that carbon sequestration is a co-factor of the abandoning and sequestration of the methane hydrate field, the rules and regulations addressing CCS should be applied;[69] CCS within and without methane hydrate projects should face a common regulatory structure.

68 *See* the discussion on financial planning and the impact of discount rate, *supra*, in ch. 3.

69 There is much interest in replacing the extracted methane volumes with carbon dioxide volumes. Indeed, both Germany and Japan have actively invested in this potential means of obtaining carbon-neutral methane volumes. *See* the discussion, *supra*, in ch. 3.

2.3.4. Real world overlap in implementations of strict liability and negligence

There are a variety of ways in which the theoretical versions of strict liability and negligence differ from their implementations in the real world. In particular, as various defenses and different precautionary standards are coordinated with either rule, the functional results tend to blend or merge into a continuum. For example, the OPA provides for a rule of strict liability to be imposed on those who spill oil into a marine environment;[70] but it also determines the provision, or lack thereof, of liability caps based on whether grossly negligent behavior was involved in causing the oil spill. So the OPA is a rule of strict liability that still calls for an examination of the level of precaution undertaken at the time of the accident.

Traditional nuisance also functions in-between strict liability and negligence.[71] Nuisance functions akin to negligence in its determination of a violation of a conduct norm; as such, if a tort could be properly classified as a nuisance then it would be properly governed by a rule of strict liability.[72] Nuisance law holds a tortfeasor liable only if he has "unreasonably interfered" with the use and enjoyment of another's land; this unreasonable interference tests the balancing of externalized benefits and externalized costs[73]. *E.g.*, when the courts find reasonable exchange benefits and harms, the courts will find no occurrence of nuisance.[74]

Hylton has argued that it lays closer to strict liability. Hylton's model of strict liability suggested that nuisance is a situation wherein typically the risks caused by the activity are unreciprocated by other actors or activities, so a state of excessive externalized risks prevails in a nuisance.[75] It is not explicitly stated, but the analysis implicitly assumes that the nuisance provides insufficient externalized welfare benefits conditions, in that no substantial externalized social benefits accrue from the nuisance generating activity.[76] As such, the model presented integrates nuisance alongside strict liability in alignment with his model's externalized risk versus benefit analysis.[77]

70 See ch. 11, sec. 4, for a more complete treatment on OPA.

71 G. C. Keating, *Nuisance as a Strict Liability Wrong*, 4 J. Tort L. 11 (2012).

72 *See* K. N. Hylton, *When Should We Prefer Tort Law to Environmental Regulation?*, 41 Washburn L.J. 515 (2001)(Due to licensing limits where the present study was undertaken, its research relied on the working paper version of Hylton's article; as such, all point citations are to that source material. *See* K. N. Hylton, *When Should We Prefer Tort Law to Environmental Regulation?* (Boston University School of Law Working Paper No. 01-11, *available* at SSRN: http://ssrn.com/abstract=285264), at 9-12; and *see* Hylton *supra* at note 40,, *en passim*.

73 *Id.*, at 9.

74 *Id.*

75 In the mathematical phrasing of his model, $q_A > q_B$. Hylton, *supra* at note 40, at 21-22. *See also* description of the model, *supra*, at Appendix II-C.

76 In the mathematical phrasing of his model, $wA \leq wB$. *Id.*, at 21.

77 *Id.*, at 15, 21-22. Hylton stated that nuisance could also be identified by the six-part test for abnormally dangerous activities from the RS (2[nd]) Torts. For a more complete discussion on Hylton's quadrants of negligence, strict liability and subsidization, *see* the discussion, *infra*, at Appendix II C.

Thus, in conclusion, while a modeler might propose the adoption of strict liability or negligence, the policy maker must be aware that combining that rule with additional defenses or standards of precautions could lead to unanticipated results vis-à-vis the efficient governance of risk from accidents. Likewise, modelers should take care to advise with awareness of the existing institutional preferences and biases within each jurisdiction to ensure that the functional result is obtained, even if the name on the civil rule is other than that advised in the model.

2.4. Conclusions – apply strict liability

This chapter has attempted to provide a study of which rule of civil liability would be preferable for the commercial development of offshore methane hydrates. The fundamental advantages of both rules were evaluated in turn.

Strict liability was found to be preferable for a variety of circumstances likely to match the circumstances of offshore methane hydrate operations. Included among those circumstances were two of the most important considerations for implementing a rule of strict liability: Unilateral accidents and abnormally hazardous activities. Both of those sets of circumstances were found to be reasonable descriptions of offshore methane hydrate operations and related accidents.

> "Environmental pollution can in most cases certainly be considered a unilateral accident … Since the victim cannot influence the accident risk, strict liability seems to be the first best solution to give the potential polluter optimal incentives for accident reduction in those cases."[78]

Further, because strict liability places all of the costs of harm with a single actor, the tortfeasor, a variety of informational challenges can be overcome efficiently. [79] Even when the accident was of a bilateral nature, if the tortfeasor was the least cost avoider of the accident, then a rule of strict liability was found to be the preferred rule.[80]

Negligence was found preferable for a variety of deviations from the standard unilateral and bilateral models. While all of those issues are real world concerns, the unique circumstances of methane hydrate operations did not substantially require the cures offered by negligence for these issues.

78 M. G. Faure, *Designing Incentives Regulation for the Environment*, 16 (Maastricht Faculty of Law Working Paper 2008-7, 2008). *See also* a similar summation of this idea at M. G. FAURE, 'Regulatory Strategies in Environmental Liability', *in* THE REGULATORY FUNCTION OF EUROPEAN PRIVATE LAW, 129, 136 (F. Cafaggi, F., Watt, H. Muir, eds., Cheltenham, Edward Elgar, 2011).

79 This result is predicated upon the tortfeasor having reasonably accurate forecasts of accurately rendered damages. *See* discussion, *supra*, at sec. 3.2

80 As demonstrated, *supra*, the operators of methane hydrate projects would indeed be the likely lowest cost avoider of methane hydrate accidents.

It may well be that in the modern world that the lines between strict liability and negligence have blurred in practice. Almost nowhere do strict liability and negligence exist in the pure state employed by the theoretical models. And almost nowhere do the rules operate with no regulatory framework somehow addressing safety and responsibility of one form or another. But no foundation was discovered within those concerns for switching from a recommendation of strict liability for methane hydrate projects.

In conclusions, it is recognized that no theoretical rule of civil liability would ever perfectly fit a real world activity and that in the modern world it is very more certain that an activity like methane hydrate exploitation would face some complex circumstances. Nevertheless, the conclusion is affirmed by a review of the advantages of strict liability, of negligence, and of the complexities of implementation that the rule of strict liability is the more preferable of the two rules for application to the development of offshore methane hydrates. This is in alignment with the broader trends of evolving environmental law, as strict liability is increasingly viewed as the default preference for environmental torts.[81]

3. Governing offshore methane hydrates with regulations

3.1. Regulations for offshore methane hydrates

As developed in Chapter 6, the primary role of public regulations is to set optimal standards when rules of civil liability would be inefficient to determine those standards. Shavell provided three primary circumstances wherein civil liability rules would either become inefficient or dysfunctional:[82]

i. Information asymmetry
ii. Insolvency risk
iii. Underdeterrence

The following sub-section will demonstrate that the Shavell conditions would be realistic concerns for the commercial development of offshore methane hydrate installations. A regulatory body could be robust in addressing these concerns and be able to develop appropriate standards for the development of offshore methane hydrates.

An argument is also presented that the regulations could and should be implemented complementary to the implementation of civil liability rules. Further, following the earlier analysis that strict liability would likely be preferable to a rule of negligence for offshore methane hydrate projects, it is recommended that a rule of strict liability be implemented alongside of regulations to provide optimal levels

81 *See* a discussion on the passage of strict liability rules within European states and the European Union at Faure, *supra* at note 78, at 138. *See also* the discussion on existing laws within Part III of this current study.

82 *See* the discussion in ch. 6, sec. 2.

of safety for the operational and post-operational activities of offshore methane hydrates.

Additionally, exploration of the potential for private regulation or integrated regulatory design to assist in setting standards for the development of offshore methane hydrates.

3.1.1. Information asymmetry

Shavell stated that if the tortfeasor and victim were to have more information, that the risk would be more efficiently managed by civil liabilities, but if a regulatory body would be better informed, then regulations would be preferable.

An argument is presented that a regulatory body could avail to itself certain economies of scale that victims, or even certain operators, might not obtain, that certain risks and hazards would be better investigated by a singular regulatory body than by the general public or operators in the case of offshore methane hydrate activity. As such, there is a clearly defined role for a regulatory body to relieve certain informational asymmetries that are likely to exist for offshore methane hydrate facilities. An argument is not being made herein that a regulatory body would be better informed on all the risks and hazards, merely that it might be more efficient at transforming a more balanced set of information regarding all of the parties and thus be more efficient at developing the necessary standards.

As the fundamental task of regulations is to set standards, sufficient information must be possessed to determine what standards should be set and to what specifications.

The question of information asymmetry engages two questions;

i. Is there an incomplete supply of information that could prevent proper function of civil liability rules, and
ii. Could a regulatory body provide a cure for that problem?[83]

With application to methane hydrates, there would likely be a potential information-processing problem for the potential victims. The first problem is that many victims might not even self-identify as victim prior to an accident, as the actual radius of harm might be only vaguely determinable prior to an actual event. As such, they would be unlikely to appropriately invest in learning about offshore methane hydrates or its risks. Also, some victims may not be able to process the scientific content or the voluminous data that might be required to develop functional understandings of the potential risks. Thus, even if information about the risks and hazards of offshore methane hydrates were publicly available, there are potential concerns that such information might not induce the efficient operation of civil liability rules to generate optimal standards. A regulatory body might be needed to possess and process that data in order to better provide the necessary standards.

83 See the discussion in ch. 6, sec. 2.1.

As a second line of concern, while it had been earlier argued that much of the current research and development has been fostered by public investment and thus information would be more available than had the technologies been developed privately, there remain several other forms of potential informational asymmetries.

As to be expected, the majority of offshore methane hydrate extraction activities would happen not only offshore but also near or in the seabed. On-going operations would not be observable by the general public, thus potential victims would not have adequate access to monitor and be aware of critical developments that could impact the risk levels from that extraction activity. But, it would also not be desirable to enable local observation by numerous visitors, because that type of activity could place the hydrate bed at risk, frustrating the very purpose that the observations were meant to cure. A regulatory body could both collect relevant data and provide various means of publication of that data without adding material levels of marginal activity levels to the hydrate beds.

The on-going development of offshore methane hydrates will generate a lot of scientific data, which again, would likely be in need of publication and a regulatory body could both act to ensure the quality and reliability of that data and to ensure its ready collection and distribution. But data is not directly useful for the routine potential victim without some additional layer of translation. A regulatory body could ensure that the public was informed of relevant and material updates to the status of field conditions and of potential dates of risk or precaution.

So, while certain informational elements would already be public knowledge, on-going operations will continue to create new events of risk and on-going needs of awareness and assurance for the general public. It would be very inefficient and highly risky to permit the general public to privately engage in monitoring, thus the role for a regulatory body is readily confirmed.

3.1.2. Insolvency risk

As discussed in the previous chapters, insolvency frustrates rules of civil liability because insolvency limits the impact of negative financial incentives; a firm would not pay a judgment in damages if it is insolvent and thus its behaviour would not be modified from its *a priori* disposition.[84] To affect activity decisions *ex ante*, the actor or firm would need to expect in advance of its risky activities that it would be insolvent *ex post* of the activities and thus be rendered immune to damages. Regulations can play several roles in addressing insolvency problems with offshore methane hydrate projects.

Regulations can set standards to both prevent insolvency in offshore operators and to set standards to address those scenarios wherein offshore operators are insolvent. First, they can require certain financial standards be met by prospective operators. Operators might need to establish certain financial bona fides,

84 *See* a more complete discussion on the concerns regarding insolvency and the potential interfaces with both civil liability rules and regulation at ch. 5, sec. 3.1.2. and at ch. 6, sec. 2.3.

demonstrating their history of being financially responsible to both investors and to recipients of legal judgments against the operators.

Second, regulations could provide standards to facilitate on-going financial disclosures and audits to better monitor and prevent the situation of the methane hydrate field being operated by a likely insolvent operator. Parameters could be included to enable the regulatory body to replace foreseeably insolvent operators with more financially secure operators.

Third, regulations could require various financial and insurance tools be employed so that even unforeseeable events that might otherwise render the tortfeasor suddenly insolvent could provide sufficient financial means to prevent operational insolvency results. If the insolvency is not curable, perhaps such a regulation could delay the insolvency problem long enough to replace the operator as described above.

3.1.3. Under-deterrence

It is perhaps with under-deterrence that regulations could be of the most assistance to ensuring the optimal levels of safety over the long life of an offshore methane hydrate installation. To the extent that rules of civil liabilities become underutilized, they would likely fail to optimally set standards. Regulations can be used to set standards for those scenarios wherein rules of civil liabilities would falter.

Shavell listed three primary sources of under-deterrence:[85]

i. Disparate plaintiffs.
ii. Lack of evidence.
iii. Missing parties.

Methane hydrate accidents are not likely to impact just one or two parties; they are likely to affect broad areas of ocean and then impact large numbers of victims. While the potential for injury to certain victims might be sufficiently large to merit private and individual recovery, the costs of litigation against a very large operator might be prohibitive. A regulatory body could assist to level the playing field and better facilitate unified litigation where feasible or to directly represent the victims, in lieu of individual lawsuits, when coordinated litigation becomes too complex to be effective. Additionally, the costs of investigation after a methane hydrate accident would not be efficiently pursued by individuals; a regulatory body might have the means to more efficiently inquire into the important questions that would need revelation prior to litigation.

Another problem with evidence is that courts have found it difficult with current scientific models to provide sufficient connections between the acts leading to climate change and the results and damage that result from that climate change. The U.S. Supreme Court has wrestled with this issue in several cases and has resisted climate change damages due to the technical problems of associating a

85 *See* the discussion in ch. 6, sec. 2.4.

specific tortfeasor to the specific damage rendered to a specific victim.[86] Add to the inability of connecting the tortfeasor to the victim to the complexity of methane's interactions in both the water column and then in the atmosphere and one becomes appreciative of the potential evidence problems that might limit victims from effectively bringing their cases to trial.

Methane hydrates are combinations of water and methane trapped in seabed layers of mud, they are about as ephemeral an energy supply as one might imagine. After a seabed eruption or landslide, there may very well be little left in direct evidence at the site of the origins of the harmful events. Further, were methane volumes to erupt, they are explosive and could severely damage local installation facilities. Should tsunamis or similar large-scale disturbances take place, large areas of nearby recording keeping facilities might also be lost. And this assumes that the cascade of events is within a short time frame; it might be that the chain of causal events were decades slow to unzip and that much of the evidence might have been obscure for years prior to the harmful events. As discussed at section 3.1.1, there is much that that a regulatory body could do to collect and ensure the retention of relevant data from the field and its occupants. Thus there is a clear role for a regulatory body to prevent and ameliorate the problem of lacking evidence.

Further, it is quite possible that after certain cataclysmic accidents, that a number of victims may simply become untrackable or lost. Much as can occur in any tsunami, seaside villages might be swept away. But there is the more banal issue that the fields are likely to be operated for multiple decades and that the post-operational plugging and abandonment phase might need much longer periods of observation and monitoring. Few of the operators are likely to remain in place for that long, field assets are routinely bought and sold; likewise operators themselves are subject to the same market forces as all other major corporations in that they are acquired, merged, and spun off over their lifetimes. Victims as well should be expected to move in and out of the potential impact zones as the years go by.

Thus, it can be readily seen that Shavell's conditions are both likely to be present in the operational and post-operational years of an offshore methane hydrate installation. Under-deterrence is likely to be a realistic problem that regulations could address more robustly than singular application of civil liability rules.

Offshore methane hydrate installations might be operational for many decades. Potential onshore victims would move in and out of the zone of hazard over those years. Acts in early years might accumulate over time with other acts in later years to create hazards and harms not readily detected at either time period. The risky activities of today might not impact victims until many years later; those present at the event of the risky act might not be the victims present at the time of the injury. Thus, there are substantial coordination problems that might need to be addressed as offshore methane hydrates are developed and produced.

86 For an in-depth discussion on the difficulties the U.S Supreme Court has faced with climate change cases and the problem of climate-tort evidence, *see* R. A. Partain & S. H. Lee, *Article 20 Obligations Under the KORUS FTA: The Deteriorating Environment for Climate Change Legislation in the U.S.,* 24 Stud. on Am. Const. 439 (2013).

Furthermore, as Schäfer and Schönenberger stated,[87] there if there were to be a risk that some victims would fail to bring lawsuits, then the tortfeasors would logically assume more risk. In that case, regulations could act to fill the gap to provide standards that would have otherwise been provided under rules of civil liabilities. With offshore methane hydrates, the scale difference between the financial and technological capacities of the operators and the potential transaction costs faced by routine victims might cause the victims to hesitate in their pursuit of litigation. In that face of non-cataclysmic accidents, *e.g.* a fisherman loses a traditional area of fishing due to methane venting from the seabed, that fisherman might need the assistance of a regulatory body that could better match the operator in court. Also, due to the scientific complexity of a variety of the potential interactions, many of the potential non-cataclysmic accidents and harms might escape direct notice by the victims; again, a regulatory body might be better resourced to both detect and pursue remedy with the operators.

3.2. *A role for private regulation or integrated regulatory design*

As explored in Chapter 6, Section 5, there might be reasons to include private regulation or integrated regulatory designs alongside of public regulation. Private regulations enable those possessing specialized knowledge on the risk activity to develop standards.

The ability of certain interested private actors to remain avant-garde is especially relevant when risky activities are highly novel and in a state of rapid innovation, because public regulations might not be able to keep abreast of the optimal standards as precautionary technologies and scientific understandings of the risks and hazards progress.[88] Also, where legal institutions are less likely to be able to process the technological or scientific challenges of the risky activity,[89] then it might be beneficial to address those risks with the assistance of private regulations.

For offshore methane hydrates, it is likely that both of the above conditions would be present in many of the locations that such hydrates would be located. The technology and scientific understanding of both the means of production and of the potential risk and harms are likely to continue to advance quickly. It would be useful for the technology stakeholders to participate in developing the appropriate standards, if not exclusively through private regulation then through mediated integrated regulatory mechanisms alongside of public regulations.[90] The participation of parties beyond the operator might also be advantageous in setting

87 *See* ch. 6, sec. 2.4.

88 See ch. 6, sec. 3.1 on regulatory stickiness.

89 *See* M. G. Faure, M. Goodwin & F. Weber, *Bucking the Kuznets Curve: Designing Effective Environmental Regulation in Developing Countries*, 51 Va. J. Int'l L. 95 (2010).

90 *See* N. Gunningham & D. Sinclair, *Regulatory Pluralism: Designing Policy Mixes for Environmental Protection*, 21 L & Pol'y 49 (1999).

standards; much the leading expertise on offshore methane hydrates currently sits with university researchers and environmental observers.[91]

The second utility of private regulations would occur when offshore methane hydrates are developed in regions lacking historical experience in regulating offshore resources or lack experience in administrating regulations on high-tech but high-risk activities. In such scenarios, the operators might possess strategic advantages in the ability to both set optimal standards and to ensure the exercise of those standards vis-à-vis the local governments.[92] If industry had been engaged by governments in a developed jurisdiction in integrated regulatory mechanisms, then it is also possible that developing areas would indirectly benefit from the private standards set in the developed areas.

Thus for the development of offshore methane hydrates, given its likely trajectory of innovation and its geographic diversity, private regulations could be implemented in parallel to public regulations. Not only operators but also other private groups could become engaged in a strategy of integrated regulatory mechanisms with a central regulatory body.[93] The privilege to institute private regulations, however, should be counterbalanced with requirements of disclosure, transparency, and of public access and audit. Further, diverse and potential adverse groups should be included within the private regulatory process; that might provide both policy balance and watchfulness. Private regulations can work effectively, but they should remain within the spirit of democracy and not run work to effect escape from other legal norms and requirements.

3.3. Complementing strict liability with regulations

As established, *supra*, at Chapter 6, Section 3, it is generally advisable to coordinate rules of civil liability with complementary regulations. And both public and private regulations can be implemented in a coordinated integrated regulatory mechanism. Rules of civil liability, of public regulation, and of private regulation could all play roles in setting the optimal standards for the development of offshore methane hydrates.

If regulations are not efficient in all circumstance, then there might be opportunity to implement rules of civil liability alongside those regulations as a buttress. Regulations may fall short of efficiency or optimality under several circumstances.[94] And likewise, rules of civil liabilities have certain circumstances within which they are less robust and provide poor incentives to achieve optimal levels of precaution and activity; but those circumstances can be improved upon in some case by regulations.

91 *See* N. Gunningham, M. Phillipson & P. Grabosky, *Harnessing Third Parties as Surrogate Regulators, Achieving Environmental Outcomes by Alternative Means*, 8 Bus. Strategy Environment 211 (Australian Centre for Environmental Law, 1999).

92 See the discussion at ch. 6, sec. 5.1.

93 *See* Gunningham, Phillipson, & Grabosky, *supra* at note 91.

94 For a more complete discussion discussing the circumstance within which regulations are likely to become inefficient, *see ch.* 6, sec. 4, *supra*.

It has already been demonstrated, *supra* at Section 2, that the more robust rule of civil liability for offshore methane hydrates would be a rule of strict liability. Rules of strict liability provide optimally for the accident risks of unilateral accidents, certain bilateral accidents, and abnormally hazardous accidents, among others.[95] But rules of strict liability cannot efficiently provide incentives for certain circumstances; complementary regulations could assist to remedy those circumstances.[96]

Given the demonstrations, supra, that both strict liability and regulations could effectively govern certain circumstances of the development of offshore methane hydrates and yet that both approaches provide for distinguishable circumstances, then it would reasonably be prudent to ensure that both strict liability and regulations were complementarily implemented to provide for a more comprehensive portfolio of incentives to optimally govern the commercial development of offshore methane hydrate installations.

4. Conclusion – governing with strict liability and regulations

This chapter has provided a review of the arguments on how to best govern the risks and hazards from the commercial development of offshore methane hydrates. This chapter presented the recommendations that strict liability should be applied in coordination with both public and private regulations.[97]

The present chapter has assayed the arguments for both strict liability and negligence and found that the application of strict liability to the circumstances of offshore methane hydrates was more likely to provide for robust and optimal governance of their risks and hazards. The character of offshore methane hydrate accidents are expected to be primarily unilateral in nature, strict liability is efficient for that case. Even when bilateral types of accidents could occur it was found that the primary ability to prevent or manage those accidents would remain dominantly in the operator's control thus strict liability would be more efficient to govern the operator.

The character of the expected development, production, and abandonment and sequestration activities would likely qualify as abnormally hazardous activities and thus merit governance under a rule of strict liability. To the extent that certain *ex ante* standards of care or precaution are unclear or remain in formation, and one would reasonably expect such standards to be in evolution given the novelty of offshore methane hydrate operations, strict liability would be a more robust

95 *See* discussions, *supra*, in ch. 5 and within this chapter at sec. 2.

96 *See* discussions, *supra*, in ch. 5, sec. 3, on when strict liability is less robust than negligence.

97 Since Plato, and likely before him, the question of how to obtain good governance, of how to ensure that governance institutions are well used and not abused, has been a topic of much debate. It would appear from recent history that the processes of democracy and transparency are central to ensuring that those institutions that we choose to govern ourselves by remain functional and optimal; it would appear no less so for the enactment and enforcement of the suggested governance mechanisms for offshore methane hydrates as proposed within this Chapter.

mechanism than a rule of negligence. A rule of strict liability provides no indemnification for meeting a duty of care and thus provides a more clear incentive to the potential operators to innovate in matters of safety and precaution. Given the diversity of risks and hazards of offshore methane hydrates and the emergent need to address those risks with technological solutions, strict liability's capacity to provide those aforementioned incentives for safety and precautionary innovations would be preferred over the weaker incentives provided by a rule of negligence.

Additionally, the literature supported findings that a rule of strict liability could be more efficient in addressing the transaction costs of justice. A rule of strict liability might ultimately prevent problems of complex interaction between the victims. Further, the implementation of a rule of strict liability would enable the attainment of decentralization; decentralization would enable each operator to achieve optimal levels of offshore methane hydrate activities with optimal levels of safety and precaution as based on upon their own unique technology sets and cost functions.

The potential application of a rule of negligence was reviewed; the results supported the choice of strict liability. The circumstances of offshore methane hydrate activities were investigated to determine if various issues known to be more robustly addressed by a rule of negligence would be present. Risk averse operators, insolvent operators, operators demonstrating strategic avoidance of liabilities, operators facing imperfect insurance markets, and operators facing mis-estimated damages were all reviewed; it was generally found that the circumstances of offshore methane hydrates did not present these risks in a manner that supported the application of a rule of negligence.

The chapter has also provided an analysis whether regulations might provide efficient governance of the risk s and hazards of offshore methane hydrates; it was found that regulations could so provide. A fundamental issue is that public regulations would be able to set standards prior to the development of offshore methane hydrates development and production activities. A regulatory body would be capable of addressing certain informational asymmetries that might be present in the development and operation of offshore methane hydrates. Regulations could provide direct standards to prevent insolvency and to provide non-financial incentives to those operators that do become insolvent. A regulatory body could act when rules of civil liabilities would be challenged by problems of under-deterrence.

Arguments have been presented that private regulations, particularly when part of smart regulation or integrated regulatory mechanisms, could improve standard setting and improve on the benefits of public regulation. Such a mechanism could thus benefit from the participation of regulatory bodies, of operators and investors, of university researchers and scientists, and of informed observers such as environmental groups. Because the technology of offshore methane hydrate operations would be expected to be rapidly advancing, the private actors engaged in that technological development could bring their knowledge to the design of the standards and ensure that the standards remain "best available" and up-to-date to avoid regulatory stickiness. As a separate concern, offshore methane hydrate can be found in many locations where local governments might lack historical experiences governing the risks of offshore resources or might be institutionally challenged to address the technological complexity of the hydrate operations. In such settings, private regulations could facilitate the local governments' efforts to govern the risks and hazards; the role of integrated regulatory mechanisms can in part be shared from areas with offshore experience to areas lacking those experiences.

The final conclusion and recommendation of this chapter is that strict liability, public regulation, and private regulation should be complementarily implemented to govern the risks and hazards of offshore methane hydrates. One observation was made that there are multiple risks and hazards, that civil liability and regulations possess strengths in different areas, and that the integrated implementation of both would provide a portfolio of incentives to govern a wider collection of risks and hazards. Another observation was that the operations of civil liability rules can function to protect and enhance the operations of regulatory efforts and *vice versa* that regulatory efforts could provide information and other transaction cost reliefs that could enhance the operation and efficiency of rules of civil liability.

In conclusion, this chapter supports the joint application of strict liability, public regulations, and private regulations in complementary implementation. The chapter finds that both public and private regulations could be engaged in an integrated regulatory mechanism. Combining the civil liability rule of strict liability together with an integrated regulatory mechanism could enable reinforcing feedback, enhancing and improving the function of both sides.

These recommendations for the joint implementation of strict liability, public regulations, and private regulations will be applied in analysis to existing laws and conventions in the following four chapters of Part III. Part IV of this study will present an integration and summary of the findings on the circumstances of offshore methane hydrates from Part I, of the analysis herein on rules of civil liability and regulations from Part II, and of the state of existing laws and conventions from Part III.

Part III

Review of Existing Laws

Governing with Strict Liability and Regulations

Chapter 8

CONVENTIONS OF THE UNITED NATIONS

Part III presents a collection of analyses on existing laws and conventions that potentially apply to the development of offshore methane hydrates. The laws, conventions, and legal instruments reviewed in each chapter were chosen for their *prima facie* potential to be applied to the development of offshore methane hydrates. As the overall set of laws that might apply would be too numerous to include for the purposes of this study, major or representative laws and conventions were chosen.

There are two primary focuses of the analyses. One focus is to review the laws or conventions to determine if they would in fact apply to offshore methane hydrates. A second focus is to determine if the laws or conventions match the recommendations from Chapter 7 to complementarily implement strict liability, public regulations, and private regulations.

Chapter 8 focuses on the international conventions of the United Nations. Chapter 9 addresses both international maritime conventions and international oil spill conventions. Chapter 10 reviews the legal instruments of the EU. Chapter 11 provides analysis on federal laws of the U.S. A summary of these results and integration with the broader results of Parts I and II are provided in Chapter 12 within Part IV.

1. Introduction

The international legal community has taken dramatic steps in the last several decades towards clarifying a common perspective on international environmental law. While much work remains to develop complete and comprehensive international regulations, a set of Kelsian norms have at long last been established.

The overall results of these efforts are the common recognition of the importance of the environment and of the need for international comity to prospectively protect and preserve the global environment. The balancing of state sovereignty rights and the recognition of the common human heritage to the environment is a key focus of the new paradigm. Acts of war and hegemonic authority are discouraged, to be replaced by a united effort to achieve global sustainable development.

2. Convention on the Law of the Sea (UNCLOS)

The 1982 United Nations Convention on the Law of the Sea, (UNCLOS),[1] is one of the most comprehensive international law conventions functioning in environmental law.[2] Originally drafted in 1982, it did not enter into formal operation until 1994. UNCLOS governs many aspects of activities that occur within coastal, marine, and oceanic locations.

The United Nations Convention on the Law of the Seas and the Rio Declaration on Environment and Development provide the modern paradigm of sustainable development within the oceans and seas. If methane hydrates are to become commercially developed in any country outside of Peru, Syria, Turkey, the United States, and Venezuela, then the coastal states engaged in that development effort will be regulated by UNCLOS and guided by the Rio Declaration.

The guidance from UNCLOS and the Rio Declaration will guide methane hydrate resource owners to engage in the development of rules and regulations to guide the development activities to provide for the protection of the environment. That protected environment is both the areas under the coastal state's jurisdiction and those ecologies further afield. Additionally, UNCLOS provides that the International Seabed Authority can also develop similar rules and regulations for those hydrates within the high seas Area. Both UNCLOS and the Rio Declaration call for the provision of clear regulations to provide recovery and compensation for all environmental harms that would be caused by the development of methane hydrates.

2.1. Rules on mineral exploitation

UNCLOS establishes the oceanic boundary lines for coastal states. The "Zone" is defined as that area of the oceans and seas that is beyond national jurisdiction.[3] It is the idea of the Zone and of the usages of the Zone that are the subject of UNCLOS. The territorial limits of coastal states are set at 12 miles offshore, as measured against the baseline of its coastal geography.[4] For the 12 miles beyond the territorial waters, coastal states are given rights to their contiguous zones, which are intended to enable them to enforce their territorial waters.[5] Within these areas, the coastal states retain comprehensive sovereignty.

1 1982 United Nations Convention on the Law of the Sea, December 10, 1982, Montego Bay, Jamaica. 1833 UNTS 3, 21 ILM 1261 [hereinafter UNCLOS].

2 C. H. Allen, Protecting the Oceanic Gardens of Eden: International Law Issues in Deep-Sea Vent Resource Conservation and Management, 13 Geo. Int'l Envtl. L. Rev. 563, 586 (2000).

3 UNCLOS art. 1.1(1)

4 *Id.*, art. 3

5 *Id.*, art. 33

For the exploitation of minerals, coastal states enjoy Exclusive Economic Zones (EEZ) that extend far beyond their territorial waters. The EEZ are limited to stretch no further than 200 nautical miles beyond the baseline that determines their territorial waters.[6] Additional details are provided on the definition of the continental shelf, which is similarly defined at 200 nautical miles beyond the baselines, in the base case, but there are more concerns about the actual underlying geography and geology and may enable a coastal country to claim up to 350 nautical miles beyond its baseline.[7]

Coastal states enjoy full sovereignty over the minerals contained in the sea, seabed, and its subsoil in both the EEZ and the continental shelf areas. Coastal states retain their:

> " sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living, of the waters superjacent to the seabed and of the seabed and its subsoil, and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents and winds[.]"[8]

And coastal states exercise:

> "... exercises over the continental shelf sovereign rights for the purpose of exploring it and exploiting its natural resources. ... The natural resources referred to in this Part consist of the mineral and other non-living resources of the seabed and subsoil together ..."[9]

Coastal have the exclusive right to authorize and regulate drilling on the continental shelf, and thus within their EEZs, for all purposes.[10]

There are economic differences though. For minerals extracted from within the EEZs' 200 nautical mile limits, the coastal states retain all of the economic benefits of produced minerals. The coastal states are required to make payments, or payments in kind, to the International Seabed Authority (ISA) against the net value of minerals with mineral extraction that occurs beyond the 200 nautical miles.[11]

i. The first five years are free of payments;
ii. Then in year 6, a 1% payment is required;
iii. Every thereafter increases the toll by 1%, until the toll rate equals 7%;
iv. All subsequent years pay a toll rate of 7%.

The ISA is to redistribute those funds "to States Parties to this Convention, on the basis of equitable sharing criteria, taking into account the interests and needs of

6 *Id.*, art. 57
7 *Id.*, art. 76
8 *Id.*, art. 56.1(a),
9 *Id.*, art. 77
10 *Id.*, art. 82
11 *Id.*, art. 82.2.

developing States, particularly the least developed and the land-locked among them."[12]

2.2. *Protection of the environment*

In addition, the coastal states retain the jurisdiction and duty to handle "protection and preservation of the marine environment."[13]

While UNCLOS provides guidance as to where coastal states retain certain aspects of sovereignty at different points in the ocean, UNCLOS does that to define and delimit the Zone, that area of the oceans beyond any national jurisdiction. Within that zone, all minerals and resources, living and non-living, as said to "belong to the common heritage of all mankind."[14] Resources include methane hydrates, as resources are defined as "all solid, liquid" or gaseous mineral resources in situ in the Area at or beneath the seabed."[15] So, within the Area, all methane hydrates belong to all of mankind; their development and exploitation will be administered by the ISA.[16]

UNCLOS takes a very clear line that environmental concerns should remain front and center with all activities taking place in the Area. The operational behavior of the member states in the Area are controlled by UNCLOS. State parties are liable for the damages, including environmental damages, caused on their behalf within the Area.

Within all three locations, the EEZ, the continental shelf, and within the Area, "States have the obligation to protect and preserve the marine environment."[17] Within the areas under their sovereignty, States have the "right to exploit their natural resources" but only if "pursuant to their environmental policies and in accordance with their duty to protect and preserve the marine environment."[18]

There are several requirements set out to establish the manner in which the ocean and its associated ecologies must be protected.[19] Those subsections most relevant to the commercial development of methane hydrates are listed hereunder:

i. "States shall take ... all measures consistent with this Convention that are necessary to prevent, reduce and control pollution of the marine environment from any source, using for this purpose the best practicable means at their disposal"[20]

ii. "States shall take all measures necessary to ensure that activities under their jurisdiction or control are so conducted as not to cause damage by

12 *Id.*, art. 82.4.
13 *Id.*, art. 56.1(b)(iii),
14 *Id.*, art. 136
15 *Id.*, art. 133
16 *Id.*, art. 151.1(a).
17 *Id.*, art. 192
18 *Id.*, art. 193.
19 *Id.*, art. 194,
20 *Id.*, art. 194.1

pollution to other States and their environment, and that pollution arising from incidents or activities under their jurisdiction or control does not spread beyond the areas where they exercise sovereign rights"[21]

iii. "These measures shall include, *inter alia*, those designed to minimize to the fullest possible extent: (c) pollution from installations and devices used in exploration or exploitation of the natural resources of the seabed and subsoil, in particular measures for preventing accidents and dealing with emergencies, ensuring the safety of operations at sea, and regulating the design, construction, equipment, operation and manning of such installations or devices"[22]

Within the Area wherein states lack sovereignty or jurisdiction, state parties are liable for their own behavior as well as "state enterprises or natural or juridical persons which possess the nationality of States Parties or are effectively controlled by them or their nationals."[23]

The Area shall only be used for the "benefit of mankind as a whole."[24]

> "(a) the prevention, reduction and control of pollution and other hazards to the marine environment, including the coastline, and of interference with the ecological balance of the marine environment, particular attention being paid to the need for protection from harmful effects of such activities as drilling, dredging, excavation, disposal of waste, construction and operation or maintenance of installations, pipelines and other devices related to such activities;"[25] (Underscoring added.)

Art. 145 further clarifies the environmental duty of care:

> "(b) the protection and conservation of the natural resources of the Area and the prevention of damage to the flora and fauna of the marine environment."[26]

As operational details of how environmental safety should be guarded and preserved with preventative behaviors are to be provided by UNCLOS,[27] Annex III provides a full set of operation guidelines for the ISA to manage the exploitation of minerals within the Area. Key among the concerns enumerated:

21 *Id.*, art. 194.2
22 *Id.*, art. 194.3(c)
23 *Id.*, art. 139.1.
24 *Id.*, art. 140
25 *Id.*, art. 145(a).
26 *Id.*, art. 145(b).
27 *Id.*, art. 147

i. Given that the extraction and production of methane hydrates are regulated by UNCLOS, the selection of qualified operators is to be determined by the rules, regulations, and procedures of the ISA.[28]

ii. To be qualified, the Annex requires both financial and technical competence to be established.[29] (Underscoring added.)

iii. Additionally, the applicant operator must be sponsored by a Member State and the Member State must be able to demonstrate that they have the capacity to "ensure, within their legal system" that the applicant operator will be required to operate to the environmental protection standards of the ISA.

That said, if the Member State has sufficient regulations and institutions to "reasonably appropriate for securing compliance" from the applicant operator, and that operator later fails its duties under the Member State's laws, then the Member State itself will not be liable for any harms caused by the sponsored operator. Thus, in the event that extraction from methane hydrates becomes operationally commercial in nature, then Member States have a strong incentive to provide sound regulatory regimes and institutions to better defend themselves under UNCLOS.

2.3. Risk governance under UNCLOS

UNCLOS requires the development of regulatory systems prior to the commercial development of methane hydrates. "Rules, regulations and procedures shall be drawn up in order to secure effective protection of the marine environment from harmful effects directly resulting from activities in the Area" if undertaken with regards to the exploitation of minerals, such as methane hydrates.[30]

Should an operator cause harm, they will be liable for the actual amount of damage; but if the damage was caused by a failure of the ISA to operate correctly under UNCLOS and thus to manage the operator's behavior, then the ISA shall be liable for the actual amount of damages.[31] The operative term for responsibility is the act of a "wrongful act" by either the operator or the ISA.[32] It does not appear that "wrongful act" is explicitly defined within UNCLOS; albeit there are behavioral requirements for environmental stewardship set out at Part XII that might be applicable in illuminating the phrase.

While there are requirements for the operators to demonstrate their financial capacity to respond to the harms they might create, nowhere in UNCLOS is it explained where the ISA or the UN more broadly might receive sufficient revenues to handle the burdens of a major methane hydrate catastrophe. But the requirement

28 *Id.*, Annex III, art. 4.1.
29 *Id.*, Annex III, art. 4.2.
30 *Id.*, Annex III, art. 17.2(f)
31 *Id.*, Annex III, art. 22
32 *Id.*

for a regulatory body to address insolvency is reassuringly close to the model of governance suggested, *supra*, at Chapter 7.

Also intriguing under UNCLOS is the idea that all technology developed to operate within the Area should be shared and distributed as part of the "common heritage" paradigm of UNCLOS.[33] The data from activities in the Area is required to be shared and transferred inter-members.[34] This type of arrangement would normally assume a regulatory body to be involved; perhaps the ISA would coordinate but it is not clear if other regulatory bodies could lead or if the ISA and the UN could coordinate a "methane hydrate data clearinghouse registry."

In conclusion, UNCLOS has sufficient ambit to regulate the development of the methane hydrates. If the extraction of methane hydrates happened within the Area, then the environmental regulations would apply and there would need to be a new set of regulations and rules to establish proper safety practices and methods of handling environmental damages. Such rules and regulations do not currently exist.

3. Convention on the Transboundary Effects of Industrial Accidents

The United Nations Convention on the Transboundary Effects of Industrial Accidents (UNCTEIA) will not likely apply to the development of offshore methane hydrate projects.[35] But the convention might apply to the onshore facilities related to the processing and marketing of natural gas and hydrogen. If it did apply, it appears that it would favor a civil liability rule of negligence over that of strict liability.

3.1. Exclusion of certain hydrocarbon accidents

The Convention is to be applied to "the prevention of, prepared for, and response to industrial accidents capable of causing transboundary effects, including the effects of such accidents caused by natural disasters."[36] However, the Convention provides a nine-point list of exceptions to the Convention.[37] Within that list, accidents that occur in the marine environment, including seabed exploration and exploitation, are excluded from the Convention.[38] Similarly, leakages into the sea, such as oil or other harmful substances, are excluded from Convention coverage.[39] Thus, any accidents related to the seeping, leakage, or venting of methane from an offshore methane hydrate project is excluded from the coverage of the Convention.

33 *Id.*, Annex III, art. 5.
34 *Id.*, Annex III, art. 14
35 United Nations Convention on the Transboundary Effects of Industrial Accidents, March 17, 1992, 2105 U.N.T.S. 457 [hereinafter UNCTEIA]
36 UNCTEIA art. 2, sec. 1.
37 *Id.*, art. 2, sec. 2.
38 *Id.*, art. 2, sec. 2(f).
39 *Id.*, art. 2, sec. 2(g).

3.2. Application to onshore facilities of offshore installations

If the project had onshore facilities, otherwise related to the offshore activities, but an accident arose onshore from those associated onshore facilities, without direct causation from the offshore activities, then the Convention might apply. Such events might be the leakage of a gas transportation pipeline or the rupture and conflagration of an onshore methane storage facility. It is not likely that such events would become transboundary in the general sense of the term, but a quick review of the potential implications is developed, *infra*.

The Convention provides that industrial accidents result from the loss of control during hazardous activities over hazardous substances; either during the processing or storing within an installation or when such hazardous substances are in transport.[40] Hazardous activities are those activities that engage in hazardous substances and which are capable of transboundary effects.[41] Transboundary effects are those serious effects that occur within one jurisdiction as a result of industrial accidents in other jurisdictions, so long as both jurisdictions are under the sovereignty of signatories to the Convention.[42] Also, the industrial accident needs to qualify as such and also not be listed as an exception to the Convention; *e.g.*, onshore methane processing, storage, and transportation are not per se excluded.[43]

Methane and hydrogen gases are reasonably characterized as hazardous substances under the Convention. A substance is a hazardous substance if it is listed under Annex I, either as a named substance or as a chemical that needs certain minimum quantities.[44] Methane, as natural gas, is a listed as a named substance under Annex I; either as regular gaseous methane or as a cryogenic liquid such as LNG.[45] To the extent that hydrogen is extracted,[46] or otherwise associated with the onshore activities, it would also be named substance under Annex I.[47]

3.3. Risk governance under UNCTEIA

Once the character of a hazardous activity has been identified, such as an onshore methane processing facility or a hydrogen generation facility, then the obligations of the Convention are binding upon the parties.[48] Foremost among the obligations is "to protect human beings and the environment against industrial accidents by preventing accidents *as far as possible*," by reducing the frequency and severity of

40 *Id.*, art. 1(a)(i) and (ii).
41 *Id.*, art. 1(b).
42 *Id.*, art. 1(d) and (f).
43 *Id.*, art. 2. sec. 1 and 2.
44 *Id.*, Annex I. pt. I and II.
45 Minimum quantity of 200 metric tons, a functionally tiny amount of methane for a methane producing facility. *Id.*, Annex I. pt. II. sec. 11.
46 *See* discussion on producing hydrogen from methane hydrates at Chapter 3, Section 5.2.
47 Minimum amount required is 50 metric tons. If daily production of hydrogen is assumed, to provide a green fuel stock, then this volume would be readily met. UNCTEIA. Annex I. pt. II. sec. 5.
48 *Id.*, art. 3, generally.

those accidents that do occur and by mitigating the effects of the accidents that do occur.[49]

The Convention thus establishes a very high duty of care, to prevent accidents "as far as possible";[50] but it does not appear to be an unlimited demand but rather the highest reasonable levels of due care implying a balancing of social benefits and costs. The Parties are to "take appropriate measures for the prevention of accidents,"[51] the Parties are to "take appropriate measures to establish and maintain adequate emergency preparedness...,"[52] and "the Parties shall support appropriate international efforts to elaborate rues, criteria, and procedures in the field of responsibility and liability."[53]

Is the requirement for "as far as possible" efforts a strict liability rule or a rule of negligence? It is likely that the drafter had a strict liability rule in mind, but left sufficient flexibility for a narrow version of a negligence rule to be implemented by some states; the Convention itself does not clearly set a negligence rule, leaving the details of such to the further efforts of the Parties.[54] The overall semantic character of the Convention reasonably appears to support and suggest the development of a rule of strict liability, or a unique form of a negligence rule with the duties of care set at the highest feasible levels.

Indeed, one might be able to comply with a combination of regulations and civil liability rules. *E.g.*, the Convention highlights the type of minimal goals of safety that should be addressed by the implementing state; Annex IV provides a non-binding non-obligatory listing of methods to prevent industrial accidents.[55] Yet, precisely because of this non-binding non-obligatory character of these rules, no particular duty level is prescribed therein. Thus, there is little evidence for the duty of care needed for a rule of negligence; yet, the means to attain decentralization under a rule of strict liability has been left unblocked by the regulatory suggestions. Thus, a combined regulatory and strict liability framework would coordinate with the Convention.

That the Convention engaged in such discussions with regards to sufficient or fitting levels of precaution, suggests the drafter expectations that a regulatory approach would be taken by many and as such would benefit from some sort of template to facilitate later coordination intra-parties.

49 Emphasis added. *Id.*, art. 3, sec. 1.
50 *Id.*, art. 3, sec. 1.
51 *Id.*, art. 6, sec. 1.
52 *Id.*, art. 8, sec. 1.
53 *Id.*, art. 13.
54 *Id.*, art. 13.
55 See "Such measures may include, but are not limited to ...," (emphasis added), at UNCTEIA. art. 6. sec. 1.; and "the following measures may be carried out ...," (emphasis added), at *Id.*, Annex IV. Preamble.

4. Framework Convention on Climate Change

The 1992 United Nations Framework Convention on Climate Change, (UNFCCC),[56] addresses the problems posed by anthropogenic climate change; it is particularly focused on the issues related to the emissions of greenhouse gases.[57] Additional details necessary for the effective administration of the UNFCCC were developed and adopted as the 1997 Kyoto Protocol to the UN Framework Convention on Climate Change (Kyoto Protocol.)[58]

4.1. Governance of anthropogenic climate change

The UNFCCC defines greenhouse gases in a scientific frame, "gaseous constituents of the atmosphere, both natural and anthropogenic that absorb and re-emit infrared radiation."[59] The Kyoto Protocol provides an enumerated list of greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorcarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).[60] Thus methane and methane hydrates are potentially regulated by the UNFCCC.

The UNFCCC recognizes two determinants of anthropogenic greenhouse gases, emissions and sinks. Emissions are the release of greenhouse gases into the atmosphere.[61] Emissions arise from a source of greenhouse gases; a source is any process or activity that releases greenhouse gases or their precursors to the atmosphere.[62] Sinks are those processes, activities, or methods that remove greenhouse gases or their precursors from the atmosphere.[63]

The anthropogenic venting and seeping of methane to the atmosphere from offshore methane hydrate installations qualify as emissions under the UNFCCC because methane is a listed greenhouse gas and the transmission to the atmosphere would qualify as an emission. Likewise, there is a reasonable argument to be made that the release of carbon dioxide from interactions of vented or seeped methane volumes could also qualify as emissions, however there is an intermediate role played by Nature in converting that methane into carbon dioxide thus the emission is indirectly anthropogenic in character.

The absorption of carbon dioxide back into the hydrate beds in replacement of the extracted methane volumes would likely qualify as a sink under the UNFCCC.[64]

56 92 United Nations Framework Convention on Climate Change, May 9, 1992, New York, USA. 1771 U.N.T.S. 107, 31 ILM 849 [hereinafter UNFCCC].

57 UNFCCC. Preamble.

58 1997 Kyoto Protocol to the UN Framework Convention on Climate Change (UNFCCC). December 11, 1997, 2303 U.N.T.S. 148, 37 ILM 22 [hereinafter Kyoto Protocol].

59 UNFCCC. art. 1. sec. 5.

60 Kyoto Protocol. Annex A. Greenhouse Gases.

61 UNFCCC. art. 1. sec. 4.

62 *Id.*, art. 1. sec. 9.

63 *Id.*, art. 1. sec. 8.

64 *E.g.,* Japan has expressed interest in a plan that would extract the methane to fuel offshore electrical generation coordinated with re-injection of the exhaust carbon dioxide volumes back into the hydrate reservoirs. *Also*, Germany has a research interest in offshore CCS that →

Many of the promoted means of developing offshore methane hydrate installations have included the option of CCS alongside methane production in part to facilitate minimizing the net impact of offshore methane hydrate installations under the UNFCCC. Thus offshore methane hydrate installations might qualify as both emitters and sinks and need netting under the UNFCCC accounting procedures.

4.2. Governance of regulatory character

The UNFCCC requires its Contracting Parties to employ the *precautionary principle,* that they should "take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects."[65] However, the UNFCCC takes a measured approach to which strategies should be undertaken, in that requires the "measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost."[66]

Additionally, the UNFCCC is sensitive that each country or culture may face different determinants of cost-effectiveness and that each country is enabled to take its unique circumstances into account.[67] Thus, the potential for methane hydrate projects to both emit and sink greenhouse gases needs to be integrated within the framework of the precautionary principle.[68] However, the UNFCCC does not particularly determine how a particular country might utilize its methane hydrate resources, that depends on the unique "socio-economic contexts" of each Contracting Party. Thus, the UNFCCC has preserved to its Contracting Parties the

coordinates with methane hydrate reservoirs; Projekt SUGAR and Eco2 lead those efforts. *See* a more complete discussion, *supra*, in Chapter 3, Section 5.1.

65 UNFCCC. art. 3. sec. 3. The precautionary principle has been difficult to convert into practical procedural terms under the UNFCCC; for a broader discussion on the application of the precautionary principle in international and EU law, *see* Arcuri 2007.

66 *Id.*, art. 3. sec. 3. Arcuri described cost effective assessments (CEAs) as an aspect of the *precautionary principle*. A. Arcuri, *The Case for a Procedural Version of the Precautionary Principle Erring on the Side of Environmental Preservation*, (Global Law Working Paper No. 09/04, 2007). It remains unclear how exactly the precautionary principle is to offset against the cost/benefits models prescribed by the prevention and proportionality principles from law and economics; however, it appears that the CBM approach might be more robust for cases of risk whereas the precautionary principle might be intended to apply to situations of uncertainty. *Id.*, at 16-17, relying on Frank Knight's terms of risk as opposed to uncertainty, *see id.*, at 11-12.

67 *Id.*, art. 3. sec. 3.

68 There are a variety of potential schemes that might be utilized to either prevent riskier fields from coming into development or to control access to the key technologies. However, many states possessing offshore methane hydrates would have strong incentives to resist those schemes; public welfare needs or private greed could overtake preventative efforts. A proposal has been suggested for methane hydrate banking; unsafe fields could defer development in exchange for revenues from safer fields in production. If those riskier fields become safe due to later improvements in legal institutions or technological advances, those fields could go into development and repay those field owners that shared revenues in the earlier time period. This idea is introduced in R. A. Partain, *Avoiding Epimetheus: Planning Ahead for the Commercial Development of Offshore Methane*, 14:2 Sustainable Dev. L. & Pol'y (December 2014 Forthcoming).

decisions of regulations or rules of civil liability. The burden is imposed at the state-level and not lower.

While all of the Contracting Parties are obligated to undertake broad responsibilities to ameliorate and reduce the threat of anthropogenic climate change,[69] the UNFCCC distinguishes between Annex I Parties and Annex II Parties. Annex I Parties are developed countries, and as such are expected to lead the UNFCCC's Parties by establishing national policies and measures to limit anthropogenic emissions of greenhouse gases and to protect and enhance greenhouse gas sinks and reservoirs.[70] The Annex I Parties are obligated to provide measurements and metrics on their progress in achieving those goals.[71] The Kyoto Protocol took the next step to make those requirements functional.[72] The Protocol set an aspirational goal to limit anthropogenic emissions of greenhouse gases.[73] There is a new list of Parties so committed at Annex B to the Protocol. [74] The goals, as drafted within the Protocol, are percentage targets against an estimated level of emissions from the year 1990; *e.g.* the United States committed to reduce its emissions to 93% of its 1990 emission levels.[75] The overall changes to emissions are reduced by increases to sinks and reservoirs;[76] thus the use of methane hydrate deposits as both energy resource and as CCS facility could be tallied on both sides of the emissions target.

Groupings of Annex I Parties can agree to achieve their targets as an aggregate; [77] this could assist methane hydrate projects by including a transboundary perspective on the combined emissions and sink planning related to the project. Additionally, Parties may volitionally transfer or acquire emission reduction units by engaging in projects that reduce anthropogenic emissions or enhancing their removal by sinks.[78] The Protocol also provides for a Clean Development Mechanism, (CDM), which enables Parties outside of Annex I to engage in sustainable development in line with the UNFCCC.[79] The CDM enables developed countries to sponsor efforts within the developing countries that would assist the attainment of UNFCCC targets by enabling the Annex I Parties to receive some emission reduction units for their own accounts.[80] Also, more broadly the Annex II Parties and other developed Parties are obligated to provide new financing mechanisms to support the attainment of the UNFCCC targets by assisting in the financing of projects that would limit emissions and enhance sinks.[81] Thus, there are

69 *Id.*, art. 4. sec. 1(a) through (j).
70 *Id.*, art. 4. sec. 2(a)
71 *Id.*, art. 4. sec. 2(b) and (c).
72 Kyoto Protocol. art. 2. See art. 2., sec. 1(a) for a list of specific obligations.
73 *Id.*, art. 3.
74 *Id.*, art. 3. art. 1. and at Annex B.
75 *Id.*, art. 3. art. 1, 2, and 3. and at Annex B.
76 *Id.*, art. 3. art. 3. and at Annex A.
77 *Id.*, art. 4.
78 *Id.*, art. 6.
79 *Id.*, art. 12. sec. 2.
80 *Id.*, art. 12. sec. 3(a) and (b).
81 *Id.*, art. 11.

several means for the financing and development of methane hydrate projects if they are characterized as green energy projects that reduce emissions and enhance sinks.

Annex II countries undertook additional financial, technological and burden-sharing obligations to assist developing countries to reduce and mitigate their own anthropogenic emissions.[82] The Developed Parties have special obligations to assist those countries particularly vulnerable to be impacted by the effects of climate change due to anthropogenic emissions.[83] There are particular concerns raised for a limited number of critical situations:

" (a) Small island countries;
(b) Countries with low-lying coastal areas;
(c) Countries with arid and semi-arid areas, forested areas and areas liable to forest decay;
(d) Countries with areas prone to natural disasters;
(e) Countries with areas liable to drought and desertification;
(f) Countries with areas of high urban atmospheric pollution;
(g) Countries with areas with fragile ecosystems, including mountainous ecosystems;
(h) Countries whose economies are highly dependent on income generated from the production, processing and export, and/or on consumption of fossil fuels and associated energy-intensive products; and …"[84]

Subsections (a), (b), (d), and (g) could be adversely affected by the potential harms and hazards of methane hydrate projects. Subsections (c), (e), and (f) might benefit from the potential freshwater reserves associated with methane hydrates or the pollution abatement that methane hydrates might offer over existing energy resources. Finally, subsection (h) raises a query on the potential impact on those countries highly dependent on other non-methane hydrate but fossil fuel industries from the development of methane hydrate technologies. For if methane hydrates are developed as a form of green energy under the UNFCCC, then surely it would affect the revenues of those countries previously benefiting from coal and crude oil industries.

4.3. Risk governance under the UNFCCC

The approach to risk governance taken under the UNFCCC is best described as regulatory in nature. What discipline that exists is to coordinate at the state level of international law and not below to lesser actors, thus rules of civil liability are not engaged in directly by the UNFCCC. The previous paragraphs, *supra* Section 4.2, demonstrated a variety of requirements that could only be properly be undertaken by regulatory bodies at both the UNFCCC level and within its party states.

82 UNFCCC. art. 4. sec. 3.
83 *Id.*, art. 4. sec. 4.
84 *Id.*, art. 4., sec. 8.

To the extent that ratifying states opt to facilitate their own domestic obligations under the UNFCCC by enacting domestic regulation or civil liabilities to limit the risks of unplanned emission accidents is not explicitly addressed within the UNFCCC or the Kyoto Protocol. Some countries have taken stricter discipline into account,[85] but others countries have not.[86]

Thus, the main impacts of the UNFCCC on methane hydrate projects would be two-fold. First, for those countries having undertaken discipline to achieve their UNFCCC emission targets, methane hydrate venting or seeping of methane or carbon dioxide could bring regional discipline against the country permitting the project but not any particular notion of civil liability.

Second, there are means to share emission reduction units via several mechanisms that could provide financial support to methane hydrate projects if the projects were sufficiently green in focus.

In conclusion, the UNFCCC does support a regulatory body's oversight of the data and operations of offshore methane hydrate installations. To the extent that a Contracting Party needs to monitor its overall levels of emissions and sinks, the offshore installations could fit within that regulatory rubric. To the extent that such observation data overlaps with similar data needs for accident awareness and prevention, that regulatory framework could both directly improve preventative efforts and could also provide secondary support to reducing the various transaction costs of implementing a strict liability regime.

5. Espoo EIA Convention

The Convention on Environmental Impact Assessment in a Transboundary Context functions as the UN's equivalent to the EU's EIA Directive.[87] When a proposed activity emerges that would be likely to cause a significant adverse transboundary impact, then the Contracting Parties have a duty to notify those other Contracting Parties that would be affected by the activity.[88]

Appendix I provides a list of activities that are likely to have transboundary effects.[89] Offshore hydrocarbon production is a listed activity under the Appendix; it is defined to include the extraction of natural gas if the installation extracts more

85 *See* discussion on EU efforts to limit greenhouse gases, *infra*, at Chapter 10, Section 7, which established fiscal discipline for Member States falling short of their commitments.

86 Several key developed countries, and thus significant emitters, have not ratified the Kyoto Protocol despite their ratification of the underlying UNFCCC; *e.g.* the United States.

87 The Convention on Environmental Impact Assessment in a Transboundary Context, February 25, 1991, 1989 U.N.T.S. 309 [hereinafter Espoo EIA Convention].

88 Espoo EIA Convention. art. 3. sec. 1.

89 *Id.*, art. 3. sec. 1. and Appendix I

than 500,000 cubic meters of methane a day.[90] However, as of January 2014, the Appendix I was not in effect as not enough Contracting Parties had ratified it.[91]

The commercial development of a methane hydrate project would have the potential to make an impact on "on the environment including human health and safety, flora, fauna, soil, air, water, climate, landscape and historical monuments or other physical structures or the interaction among these factors;" there is no requirement for adverse effects.[92] To the extent that such impacts could cross from one jurisdiction to another jurisdiction, such an impact would qualify as a transboundary impact.[93] In that sense, the awareness of an impending methane hydrate project that would have a transboundary impact would raise the requirement to provide notification to the other impacted Contracting Parties.

This system of notifications would be primarily a regulatory action that collects information but provides for no judicial damages; thus the Convention provides no explicit form of *ex ante* anticipation of *ex post* costs to provide incentives in the manner that civil liability systems provide. But the convention would clearly be an information clearing house that would complement a strict liability system.

6. Rio Declaration on Environment and Development

United Nations Conference on Environment and Development (UNCED) was held in 1992; it has been described as one of the most ambitious international environmental conferences of the twentieth century.[94] Both binding conventions, such as the Convention on Biological Diversity and the United Nations Framework Convention on Climate Change (UNFCCC), and soft law documents, such as the Rio Declaration of Principles, were accomplished at that conference.[95] The conference effectively shifted international customary law towards a paradigm of precautionary law and a broader notion of protecting whole eco-systems, as contrasted against earlier paradigms of limited numbers of specifically targeted species.

The Rio Declaration is akin the Universal Declaration of Human Rights, in that it is aspirational in character. Unlike the previous discussed matters, supra in Section 2, 3, 4, and 5, the Rio Declaration is not binding law. It might reflect developing *opinio juris*, but it is a relatively source of soft law.

90 *Id.*, Appendix I. sec. 15. "Offshore hydrocarbon production. Extraction of petroleum and natural gas for commercial purposes where the amount extracted exceeds 500 metric tons/day in the case of petroleum and 500 000 cubic metres/day in the case of gas."

91 Only 21 Parties had ratified the Appendix as part of the second amendments as of January 26, 2014. The underlying Convention has 45 Parties, so a total of 34 Parties need to ratify the Appendix; *i.e.* 13 more Parties. *Available* at https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-4-c&chapter=27&lang=en

92 Espoo EIA Convention. art. 1. sec. (vii).

93 *Id.*, art. 1. sec. (viii).

94 Allen, *supra* at note 2, at 599.

95 *Id.*, at 599-600.

The document lists twenty-seven specific principles and guidelines for future efforts to better coordinate economic growth and ecological conservation.[96] Several of those principles have direct application to the development of methane hydrates.

Principle 2: States maintain their sovereign rights to exploit their own resources pursuant to their own environmental and developmental policies, but they have a corresponding duty under international law to ensure that activities within their jurisdiction or control do not cause damage to the environment of other of areas beyond the limits of their national jurisdictions.

Principle 4: Requires that planning and actions to mitigate potential environmental harms are included within all efforts of development and growth.

Principle 7: Calls for the global community to act in comity to conserve, protect, and restore the health and integrity of the Earth's ecosystem.

Principle 10: Calls for all states to engage their citizens in the due and deliberative processes of engagement and decision making on matters that could affect the environment. Information sharing and awareness building are also called for.

Principle 11: Calls, amongst other targets, for a recognition that different states have different legal institutions and stages of economic development, and as such the regulatory standards applied by some countries may be inappropriate and of unwarranted economic and social cost to other countries.

Principle 13: Calls for the development of national laws regarding liability and compensation for the victims of pollution and other environmental damage. States should also cooperate to develop international law regarding liability and compensation for adverse effects of environmental damage caused by activities within their jurisdiction or control to areas beyond their jurisdiction.

Principle 15: Calls for states to protect the environment by widely adopting the use of the *precautionary approach*, limited only according to their capabilities.

96 Rio Declaration. Principles 1 to 27. The whole Declaration can be found within the UN's archives; *available* at http://www.unep.org/Documents.Multilingual/Default.asp?documentid=78&articleid=1163.

Principle 16: Calls for the international adoption of the *polluter pays* principle into domestic and international laws.

Principle 17: Calls for Environmental impact assessments to become a standard activity for all activities which might endanger or harm the environment.

The Rio Declaration does establish more clear norms of comportment with regards to prospective acts of commercialization and the aspirational goals of the international legal community for the prospective protection of the environment.

6.1. Risk governance under Rio Declaration

Perhaps the most important risk governance issues with the Declarations are the recognition of (i) the necessity to establish liability systems to address environmental protection concerns, (ii) that both regulatory and civil liability systems could be engaged, and (iii) that different countries and cultures might need different manners of liability and regulations implementations, (iv) that precautionary principles should be applied and (v) that the polluter pays principle should be applied.

The general call for liability rules reflects a growing recognition that polluters or tortfeasors need to know *ex ante* that they will be held accountable for their decisions. It is probably true that the flexibility of the Declaration reflects an inability to have agreed to greater specifity; but for the present study it enables the retention of legal flexibility, particularly for jointly and complementarily implementing civil liability rules and regulations as circumstances fit. The precautionary principle sets a Coasian right to the general public, that they have a right to retain their current enjoyment of Nature and to their way of life; it places the burden on the tortfeasor to prevent harm even if it is unclear that harm would result. The polluter pays principle, without additional clarification, lacks a mechanism to recognize a prophylactic duty of care for the tortfeasor, if you pollute then you will need to pay the damages. Put together, it would appear that the Declaration on the whole is more closely aligned with a strict liability perspective or a very stringent regulatory system and not with a rule of negligence or permissive regulatory framework.

In the case of methane hydrates, prior to the onset of commercial development, there would need to be a serious and substantial effort to develop effective and clear rules and regulations to ensure the safe and proper operation of the methane hydrate projects, to preserve both the local and afar ecologies. The rules and regulations should be established not unilaterally but in international comity, to yet to recognize the differences in legal institutions of different states. There should scientific undertakings to provide environment assessment reports to the impacted communities. And finally, the international community should establish, by consensus, a clear regime regarding liability and compensation for the victims of pollution and other environmental damage from the development of methane hydrates.

7. Conclusion

The conclusions of this review of United Nations conventions is that while their applicability to individual or corporate level actors might be limited, the conventions do support using liability rules and regulations to govern risk from accidents, particularly environmental accidents.

While the various conventions address liability for offshore accidents, it would appear that hydrocarbons have been excluded in certain arrangements, perhaps due in part to the parallel functions of the regional marine pacts and oil pollution pacts discussed in the next chapter.

Nevertheless, the UN conventions do appear to prefer the application, or at least the spirit, of a strict liability rule or its parallel in regulatory matters. In that vein, the conventions align with the recommendation of a complementary strict liability and regulation framework as developed in Chapter 7. It is also correct that the UN conventions do not address methane hydrates directly, but they do address many aspects of the development and operation circumstances of offshore methane hydrates.

Chapter 8

Chapter 9

INTERNATIONAL MARITIME CONVENTIONS AND OIL SPILL CONVENTIONS

The rise of oceanic transportation of fuel and other potentially hazardous materials gave cause to the development of a group of regional marine pacts and international oil spill pacts. The two groups of conventions are somewhat interwoven, as they both address the potential leakage of hazardous elements into the ocean.

Both of these legal paradigms provide the development of a risk governance scheme with historical perspective and insight. While the oil spill pacts are predicated solely on responding to the risks and hazards of crude oil shipments, the regional pacts also contain substantial language addressing hydrocarbon incidents. Overall, the international maritime conventions and oil spill conventions provide rubrics of strict liability and of effective incentives to seek optimal levels of preventative caution whilst also fostering the commercial benefits of marine transport and of energy supplies.

Yet, it will be seen that both sets of conventions are likely to apply only indirectly to the potential risks and hazards of offshore methane hydrates. As will be explored, *infra*, some of that disconnection stems from the ocean going vessel paradigm underlying the conventions and some of the disconnection arises from linguistic word choices that leave methane and related concerns out of the domain of the conventions.

1. Regional marine conventions

There are a collection of regional conventions that address the protection and sustainable exploitation of particular oceans, seas, and surrounding environments. Some of the regional marine conventions are explicitly focused on the potential harms and hazards of hydrocarbons while others are more general in scope.

Herein is provided a review of four of the major regional marine conventions:

i. the OSPAR Convention (North East Atlantic Ocean),[1]
ii. the Barcelona Convention (Mediterranean Sea),[2]
iii. the Bonn Agreement (North Sea),[3] and
iv. the Helsinki Convention (Baltic Sea).[4]

Please also find the table of Contracting States to each agreement or convention, *infra*, following the conclusion.[5]

1.1. OSPAR Convention (North East Atlantic Ocean)

OSPAR stands for Oslo and Paris and the acronym refers to the documentary history of the Convention in that it conjoined the Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft, "Oslo Convention (1972)," against at-sea dumping of wastes with the Convention for the Prevention of Marine Pollution from Land-Based Sources, "Paris Convention (1974)," against land-based sea pollution and oil pollution.[6] OSPAR was founded under Art. 197 of UNCLOS for global and regional cooperation.[7]

OSPAR requires the Contacting Parties to take all possible steps to prevent and eliminate pollution to protect the maritime area.[8] OSPAR requires the Contracting States to adopt programs and measures and to cross-harmonize their policies.[9] OSPAR states that nothing in OSPAR is to be taken to prevent Contracting States from undertaking more stringent measures than that required within OSPAR, both substantively and procedurally, to protect the maritime area.[10] OSPAR requires application of both the *polluter pays principle*[11] and the *precautionary principle*[12] in the design of the program and measures to be adopted by the Contacting Parties.

1 *See* discussion, *infra*, at Section 1.1.

2 *See* discussion, *infra*, at Section 1.3.

3 See discussion, infra, at Section 1.2.

4 *See* discussion, *infra*, at Section 1.4.

5 Table 1 can be located after Section 3.

6 The Convention for the Protection of the Marine Environment of the North-East Atlantic, September 22, 1992, 2354 UNTS 67, 32 ILM 1069 [hereinafter OSPAR]. *available* at http://www.ospar.org/html_documents/ospar/html/OSPAR_Convention_e_updated_text_2007.pdf. *See also* OPSAR. Preamble and art. 1.(q) and (r). See also "History." About OSPAR. OSPAR Commission Website; *available* at http://www.ospar.org/content/content.asp?menu=00350108080000_000000_000000 .

7 OSPAR. Preamble. *See* discussion on UNCLOS, *supra*, at Chapter 8, Section 2.

8 *Id.*, art. 2. sec. 1(a).

9 *Id.*, art. 2. sec. 1(b).

10 *Id.*, art. 2. sec. 5.

11 *Id.*, art. 2. sec. 2(b)

12 *Id.*, art. 2. sec. 2(a)

OSPAR mandates the best available techniques and the best environmental practices.[13] The term 'best available techniques' requires the use of the latest stage of development or state of the art of processes or methods of operation.[14] Economic feasibility is to be taken in account when determining the best available technique.[15] The best available technique should be based on those recently successful comparable processes or methods of operation and up-to-date technological advances and changes in scientific knowledge and understanding.[16] Given the inputs of economic feasibility, advancing science and newly successful comparable processes and methods, the best available techniques should be expected to change over time.[17]

The phrase of 'best environmental practices' means the application of the most appropriate combination of controls and strategies.[18] In developing the combination of measures, seven key factors are to be taken into consideration.[19] The environmental hazard of the product and its production is to be considered.[20] The social and economic implications of the measures should be integrated with the analysis.[21] The potential for substitution and the scale of use should both be considered, as well as the potential environmental benefit or penalty of substitute.[22] Advances in scientific knowledge and understanding should be taken into account.[23] And finally, the time limits for implementation of the measures should be considered.[24]

The Contracting Parties are required to undertake all possible steps to prevent and eliminate pollution from offshore sources, as guided by the OSPAR's Annex III.[25] Offshore sources is defined in include both offshore installations and offshore pipelines.[26] An offshore installation is any "man-made structure, plant or vessel or parts thereof, whether floating or fixed to the seabed, placed within the maritime area for the purpose of offshore activities.[27] Pollution is defined as "introduction by man, directly or indirectly, of substances or energy into the maritime area which results, or is likely to result, in hazards to human health, harm to living resources

13 *Id.*, art. 2. sec. 3(b)(i). *See also* the explicit requirements for offshore sources. *Id.*, Annex III. art. 2(a) and (b).

14 *Id.*, Appendix I. sec. 2.

15 *Id.*, Appendix I. sec. 2(c).

16 *Id.*, Appendix I. sec. 2(a) and (b).

17 *Id.*, Appendix I. sec. 3.

18 *Id.*, Appendix I. sec. 6.

19 *Id.*, Appendix I. sec. 7(a) through (g).

20 *Id.*, Appendix I. sec. 7(a).

21 *Id.*, Appendix I. sec. 7(g).

22 *Id.*, Appendix I. sec. 7(b), (c) and (d).

23 *Id.*, Appendix I. sec. 7(e).

24 *Id.*, Appendix I. sec. 7(f).

25 *Id.*, art. 5.

26 *Id.*, art. 1(k).

27 *Id.*, art. 1(l).

and marine ecosystems, damage to amenities or interference with other legitimate uses of the sea."[28] However, vessels and aircrafts, and wastes therefrom, are exempt from inclusion under offshore sources.[29] Vessels include any water-borne crafts, including "air-cushion craft, floating craft whether self-propelled or not, and other man-made structures in the maritime area," but excludes offshore installations.[30] The critical definition is that of offshore activities, which are those activities undertaken for "exploration, appraisal or exploitation of liquid and gaseous hydrocarbons."[31]

All potential discharges or emissions from the offshore installations and activities must be authorized and regulated by competent authorities of the Contacting Parties.[32] Accidental venting or seeping of methane would not be considered dumping, as dumping requires the deliberate act of disposal.[33] Thus, accidental venting and seeping of methane would not be regulated under Annex III's Art. 3.[34] Thus, the exclusion of weather and other cause based force majeure does not apply to accidental venting and seeping, unless so granted under domestic laws of the Contracting State.[35]

OSPAR Annex III has already addressed the offshore sequestration of carbon dioxide, in that such carbon dioxide is not considered a dumping of waste for OSPAR.[36] So, offshore sources of pollution basically arise from offshore installations, vessels, and pipelines associated with the exploration, appraisal or exploitation of liquid and gaseous hydrocarbons, such as methane from offshore methane hydrate deposits. If the development of methane hydrate projects offers risks of harm and hazards from offshore installations that may potentially emit pollution, then OSPAR's Contracting Parties would be obligated to prevent and eliminate hazards to human health, harm to living resources and marine ecosystems from those potential methane hydrate projects.

1.2. Bonn Agreement (North Sea)

The Bonn Agreement covers the North Sea and attempts to protect it from pollution by oil and other harmful substances.[37] The Agreement is fairly brief and leaves out much in the way of detail, as opposed to the details seen in OSPAR or in the

28 *Id.*, art. 1(d).

29 *Id.*, Annex III. art. 1 (a) and (b).

30 *Id.*, art. 1(n).

31 *Id.*, art. 1(j).

32 *Id.*, Annex III. art. 4.1.

33 *Id.*, art. 1(f)(i) and (f)(ii)

34 Compare OSPAR's Annex III. art. 3.2. with Annex III. art. 4.1.

35 OSPAR. Annex III. art. 4.2. and Annex III. art. 6.

36 *Id.*, Annex III. art. 3.3(a), (b), (c), and (d).

37 Agreement for cooperation in dealing with pollution of the North Seas by oil and other harmful substances. O.J. (L 188), 9 [hereinafter Bonn Agreement].

Barcelona Convention.[38] The Agreement serves primarily to coordinate national level efforts to respond to specific pollution events.[39] Additionally, the Bonn Agreement coordinates within the OSPAR Convention's shadow.

The Agreement is to be invoked whenever a Contracting Party is presented with either the actual presence or the prospective presence of oil or other harmful substances.[40] The phrases "oil" and "harmful substances" are not defined nor detailed within the Agreement.

The Agreement was not intended to alter in any form the underlying laws or civil liability rules that affect the prevention and combat of marine pollution.[41] While the Agreement itself coordinates international action and facilitates cost-recovery between the Contracting Parties,[42] nothing in the Agreement limits further pursuit by the Contracting Parties against third-parties.[43]

Where the Bonn Agreement lacks substantive details, its affiliated Manual provides some details.[44] The chapter addressing oil pollution clearly is focused on persistent crude oils and liquid petroleums.[45] Natural gas and methane are addressed as flammable and exploding gases within the chapter on hazardous materials; however the operatic paradigm is vessel transported gases.[46] Hazardous chemicals are sorted into four classes; evaporators, floaters, dissolvers, and sinkers.[47] Evaporators are sub-sorted into three response modes: toxic gas cloud, toxic and explosive gas cloud, and explosive gas cloud.[48]

Methane is listed as being both a health risk gas, for distances within 200m of the gas cloud, and as an explosion risk for distances within 200m of the gas cloud.[49]

It is perhaps noteworthy that the development of offshore windmill farms has been included within the coverage of the Bonn Agreement.[50] The installations

38 *See* the discussion on the Barcelona Convention, *infra*.

39 Bonn Agreement. *En passim*.

40 *Id.*, art. 1.

41 *Id.*, art. 8. sec. 1.

42 *Id.*, Arts. 9 and 10.

43 *Id.*, art. 11.

44 Bonn Agreement Counter Pollution Manual. As of 15 January 2014. *Available* at http://www.bonnagreement.org/eng/html/counter-pollution_manual/welcome.html.

45 *See* the frequency and dominant use of the phrase "oil slick" to describe oil pollution, *en passim*, at "Policy Strategy of Oil Pollution Combating." *Available* at http://www.bonnagreement.org/eng/html/counter-pollution_manual/Chapter22_Policy%20strategy%20oil%20pollution%20combating.htm .

46 *See* the discussion on how harmful substances leak from vessels. Bonn Agreement Counter Pollution Manual, Chap. 26. sec. 1. "Categorisation of hazardous substances."

47 *Id.*, Subsec. 4.

48 *Id.*, Subsec. 8.

49 Bonn Agreement Counter Pollution Manual. Addendum 1: "Intervention on gases and evaporators, card number F1.1, F1.2, F1.3". p. 2. It is important to recall that the risk states therein is related to leaks of methane from LNG-type containers at sea, not methane vented or leaked from the ocean at any low or high rate.

50 *See id.*, ch. 8: Offshore Windfarms.

associated with offshore windfarms are seen as novel risks for shipping and the installations could also complicate oil pollution recovery and abatement efforts.[51] To the extent that methane hydrate projects are foreseen in the North Sea area, it would probably be reasonable to assume that a similar chapter might be drafted to take the particular harms and hazards of subsea methane extraction into the greater Bonn Agreement framework.

1.3. Barcelona Convention (Mediterranean Sea)

The Barcelona Convention and its associated documents are designed to provide protection to the Mediterranean both within and without the EU.[52] It applied general concepts of transboundary coordination and of monitoring.[53]

Pollution is defined as the introduction by man, both directly and indirectly, of substances or energy into the marine environment that could cause a variety of harms to both the marine environment and human use and enjoyment thereof.[54]

The Barcelona Convention implements several key environmental law policies. It requires the application of the *precautionary principle*; a lack of full scientific certainty should not be used as a reason for postponing cost-effective measures.[55] All appropriate means should be undertaken to preserve biological diversity.[56] This implementation of the precautionary principle balances the prevention of environmental degradation against the costs-effectiveness of such measures.[57] The best available techniques and the best environmental practices are called for within the Convention;[58] this clarifies the precautionary principle but also requires data sharing among both competent authorities and operators. Finally, the means to be undertaken are to reflect the reality of the social, economic, and technological conditions of the signatories.[59]

While the Convention calls for early implementation of potentially effective measures, it constrains it call to cost effective socially balanced measures; it does not call for any and all measures at all costs.

The Convention applies the *polluter pays* principle.[60] The costs of pollution are to be borne by those individuals that introduce the pollution to the environment.[61]

51 *Id.*,

52 Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean and its Protocols, February 16, 1976, 1102 U.N.T.S. 27 [hereinafter Barcelona Convention].

53 See Barcelona Convention. Arts. 9, 11, and 12.

54 *Id.*, art. 2(a).

55 *Id.*, art. 4. sec. 3(a).

56 *Id.*, art. 10.

57 *Id.*, art. 4. sec. 3(a).

58 *Id.*, art. 4. sec. 4(b).

59 *Id.*, art. 4. sec. 4(b).

60 *Id.*, art. 4. sec. 3(b).

61 *Id.*, art. 4. sec. 3(b).

The Convention calls for the contracting parties to formulate and adopt appropriate rules and procedures for the determination of liability and compensation resulting from harms to the Mediterranean region.[62]

The Convention requires the signatories to take all appropriate measures to eliminate and remediate pollution from the exploration and exploitation of the continental shelf, the seabed, and its subsoil.[63] These requirements make no reference to hydrocarbons, instead they apply to any and all minerals, including hydrocarbons and potentially methane hydrates.

The Convention expands the concepts from the EU's EIA Directive to the broader Mediterranean region.[64] Functionally, the Convention supports the development and adoption of Protocols to expand and details the objectives of the Convention.[65] For the purposes of this study, the most important protocol to the Convention is the "Offshore Protocol."[66]

The stated goal of the Protocol is that:

> "[t]he Parties shall take, individually or through bilateral or multilateral cooperation, all appropriate measures to prevent, abate, combat and control pollution in the Protocol Area resulting from activities, inter alia, by ensuring that the best available techniques, environmentally effective and economically appropriate, are used for this purpose."[67]

The Protocol does not designate a rule of civil liability, but requires that such be employed by the signatories to ensure that the polluter pays, *i.e.* the operator, and that the polluter pays prompt and adequate compensation.[68] Also, the Protocol requires each signatory to ensure sanctions exist to punish violators; the character of the requirements appear to be more regulatory than civil liability in design:

> "[e]ach Party shall prescribe sanctions to be imposed for breach of obligations arising out of this Protocol, or for non-observance of the national laws or regulations implementing this Protocol, or for non-fulfilment of the specific conditions attached to the authorisation."[69]

Additionally, the Protocol requires the operators to maintain insurance or other financial securities to ensure that the problems of insolvency do not arise at the time

62 *Id.*, art. 16.

63 *Id.*, art. 7.

64 *Id.*, art. 4. sec. 3(c).

65 *Id.*, Arts. 21 and 22.

66 Protocol for the Protection of the Mediterranean Sea against Pollution Resulting from Exploration and Exploitation of the Continental Shelf and the Seabed and its Subsoil. O.J. (L 4), 15 [hereinafter Offshore Protocol].

67 Offshore Protocol. art. 3. sec. 1.

68 *Id.*, art. 27. sec. 1 and 2(a).

69 *Id.*, art. 7.

of compensation.[70] The Protocol provides for certain limited applications of force majeure and certain public welfare justifications.[71] But those exceptions are terminated if "intent to cause damage or recklessly and with knowledge that damage will probably result."[72]

Methane hydrate projects broadly appear to qualify to be regulated under the Offshore Protocol. 'Activities' is defined to include scientific activities, exploration activities, and exploitation activities that would include development and production stages of a methane hydrate project but apparently not the abandonment and sequestration period.[73] Removal of Installations, otherwise known as sequestration and abandonment within oil and gas, are defined and addressed within the Protocol;[74] similar EIA and authorizations requirements are found.[75] Installations are defined as floating, mobile, or fixed; they include drilling units, production units, storage units, and loading and transporting units.[76] Operators include both those authorized or licensed to operate offshore facilities or those in *de facto* control of such facilities.[77] Article 6 of the Protocol essentially requires the performance of an EIA, and strictly does so for EU waters.[78]

The Offshore Protocol does not list methane or natural gas as 'oil.'[79] Oil is defined as "petroleum in any form including crude oil, fuel oil, oily sludge, oil refuse and refined products."[80] Crude oils, and various refinery products, are listed as harmful or noxious substances.[81] But the Protocol integrates the definition of pollution from the Convention, so methane or natural gas might qualify as a form of a substance that could be deleterious to the environment.[82] Additionally, the venting or seeping of methane into the water column may be seen as adding energy and thus qualify as pollution in that sense.[83]

70 *Id.*, art. 27. sec. 2(b).

71 *Id.*, art. 14. sec. 1(a).

72 *Id.*, art. 14. sec. 2.

73 *Id.*, art. 1(d).

74 *Id.*, art. 20.

75 *Id.*, art. 20. sec. 1 and 2.

76 *Id.*, art. 1(f)(i) through (v).

77 *Id.*, art. 1(g)(i) and (ii). A literal reading suggests that even non-normal personnel might be included within this scope; *e.g.* a pirate or terrorist of an offshore facility might be classified as a *de facto* operator.

78 *Id.*, art. 6. sec. 1, 2, and 3.

79 *Id.*, art. 1(l). *See* Annex V and the Appendix. But the Appendix title carries a footnote that states, "the list of oils should not necessarily be considered as exhaustive." Nevertheless, nothing in the list, nor the nomenclature of oil and refining, suggests that methane should be included within the category of oil under the Protocol.

80 *Id.*, art. 1(l)

81 *Id.*, Annex I. pt. A. sec. 6.

82 *Id.*, art. 1(e)

83 *Id.*, art. 1(e)

The Protocol addresses both support of developing countries within the region and the support of transboundary concerns.[84]

1.4. *Helsinki Convention (Baltic Sea)*

The Helsinki Convention serves a similar role as OSPAR and the Barcelona Convention, to protect a marine region from environmental harms.[85] Overall, the Helsinki Convention is drafted similarly to other regional marine conventions.

It carries the same definition of pollution as seen in other regional marine documents, supra, the "introduction by man, directly or indirectly, of substances or energy into the sea … which are liable to create hazards to human health, to harm living resources and marine ecosystems … ."[86] The Convention has an identical definition to dumping as OSPAR.[87] Oil is narrowly defined as oils, refinery products, or sludge;[88] definitely exclusive of natural gas or methane. Harmful substance is defined as any substance that could cause marine pollution.[89]

The Helsinki Convention mandates that the Contracting Parties take all appropriate legislative, administrative, or other relevant measures to prevent and eliminate pollution in the region.[90] The Convention requires the application of the *precautionary principle*.[91] It requires the application of the best available technology[92] and of the best environmental practice.[93] The Contacting parties are required to apply the *polluter pays principle*.[94] The Convention requires the prevention of the introduction of harmful substances[95] and pollution from ships,[96] including waste dumping.[97] The Convention requires the Contracting Parties to take all appropriate action to conserve natural habitats and biological diversity and to protect ecological processes.[98] Broadly speaking, the Helsinki Convention is well aligned with both other regional marine conventions and UN environmental policies.

The exploration and exploitation of the seabed and its subsoil require both the prevention of pollution and the preventative preparations to ensure adequate

84 *Id.*, art. 24 and 26.

85 Convention on the Protection of the Marine Environment of the Baltic Sea Area, April 9, 1992, 1507 U.N.T.S. 167, 1994 OJ (L 73) 20, 13 ILM 546 (1974) [hereinafter Helsinki Convention].

86 Helsinki Convention. art. 2. sec. 1.

87 *Id.*, art. 2. sec. 4.

88 *Id.*, art. 2. sec. 6.

89 *Id.*, art. 2. sec. 7. Methane, hydrogen or even potentially freshwater or mud might qualify.

90 *Id.*, art. 3. sec. 1.

91 *Id.*, art. 3. sec. 2.

92 *Id.*, art. 3. sec. 3.

93 *Id.*, art. 3. sec. 3.

94 *Id.*, art. 3. sec. 4.

95 *Id.*, art. 5.

96 *Id.*, art. 8.

97 *Id.*, art. 11.

98 *Id.*, art. 15.

preparedness is maintain in order to provide immediate action to respond to accidental pollution when it occurs.[99] Annex VI to the Convention provides additional guidelines for offshore oil and gas activities.[100] Offshore activity is defined to be any exploration or exploitation of oil and gas by either fixed or floating installations.[101] An offshore unit is any particular installation engaged in oil or gas exploration, exploitation or production activities, including transportation.[102] EIAs are required before any licensing can occur within the marine region.[103] Among the items to be investigated during the EIA assessment should be included a compositional analysis of the deposit zone, of its sediments, hydrocarbon content, and of potentially hazardous substances or hazards.[104] On-going and subsequent studies should be made on the deposit zone to ensure the prevention of pollution and the emission of harmful substances.[105] Finally, each offshore unit should have a pollution emergency plan to ensure quick and appropriate responses to accidents.[106]

1.5. Risk governance under the regional marine conventions

The regional marine conventions are very similar in design with regards to risk governance. While they are all high level international agreements that leave specific implementation to the signatory states, the conventions provide clear guidance on the types of governance needed to both attain the policy goals and to enable coordination across parties.

They all call for the contracting states to implement liability rules that function in harmony with the polluter pays principle. The polluter pays principle does not provide for a duty of care that would indemnify tortfeasors as a rule of negligence would. The polluter pays principle at its core would be opposed to the idea that victims of environmental pollution would need to bear the costs of damage simply because the tortfeasor operated reasonably; the quintessence of the polluter pays principle is that the polluter always pays; this is the spirit of the rule of strict liability. The polluter pays principle could be implemented in regulations, but the overall spirit that the victims are not to blame and not to pay would remain the same.

There is clearly support within the conventions for the use of regulations to govern risk. There many items to be achieved and confirmed and it would be very inefficient to allow private civil liability claims to pursue that level of investigation; additionally, no rule of civil liability would be able to enforce or perform those investigations until an actionable cause arose, thus, the purpose and function to

99 *Id.*, art. 12. 1.

100 *Id.*, Annex VI.

101 *Id.*, Annex VI. Reg. 1. sec. 1.

102 *Id.*, Annex VI. Reg. 1. sec. 2.

103 *Id.*, Annex VI. Reg. 3. sec. 1.

104 *Id.*, Annex VI. Reg. 3. sec. 2(d).

105 *Id.*, Annex VI. Reg. 3. sec. 3 and 4.

106 *Id.*, Annex VI. Reg. 7.

provide on-going safety monitoring would be defeated. A regulatory body would be far better suited to the needs of on-going monitoring and procedural assurances.

Another aspect is that the conventions require active steps be undertaken to prevent and eliminate pollution; again, a regulatory body could act daily and currently without need of actionable causes so long as the regulations receive a sufficient delegation of power to act.

Further, in the conventions there is much discussion of permits and licensing, this remains the exclusive territory of regulatory bodies.

There is also much scientific and other specialized knowledge sets required to implement the obligations of the conventions. It would be more efficient to train and maintain a dedicated pool of experts instead of the stop and start of civil liability lawsuits.

In conclusion, the conventions set high standards and provide a framework for contracting states to base their domestic enactments upon. Both regulations and rules of civil liability are encouraged, but it would appear that more attention has been given the development of the regulatory framework. If a rule of civil liability is employed by a contracting state, it would likely need to be a rule of strict liability. As such, the regional marine conventions align with the recommendations of Chapter 7 to implement regulations alongside of strict liability rules.

2. International oil spill conventions

2.1. A brief history of marine oil spill conventions

The current oil spill regimes were developed primarily as a reaction to several significant spills, all from seagoing vessels. The paradigm of oil spills as currently understood by existing oil spill regimes is the broken tanker or leaking well in shallow waters paradigm.

That the laws and conventions responding to catastrophic oil spills respond primarily to this paradigm made practical sense. Historically, this type of oil spillage in shallow waters has been the most common type of offshore-based oil spill, as documented in governmental records.[107] In a recent Congressional Research

107 This is not to say that offshore well-based leaks were unknown; however these well-based catastrophes were "the exceptions that proved the rule" until recently. Two well-known examples are the Union Oil event offshore Santa Barbara, CA, and the Ixtoc event offshore the Yucatan Peninsula in Mexico. Both of these events pre-date the 1990 Oil Pollution Act and the International Convention of 1992. The Santa Barbara offshore blowout and seeps began on January 28, 1969. It was the third largest oil leak in U.S. history, ranked behind only the BP Macondo explosion and the Exxon Valdez shipwreck. It was however in only 57m of water, so the effects were largely similar to a vessel leak. The Ixtoc was an offshore drilling catastrophe that began on June 3, 1979. It too was in 50m of water, so its leak while massive and long lasting functionally resembled a massive vessel leak in many ways.

Service report, it was documented that only approximately 1% of all oil spill incidents were from extraction activities.[108]

The marine oil spill paradigm assumes that crude oil is spilled near or at the ocean surface, for the oil to collect at the surface or very near the surface, and that the oil is likely to spilled sufficiently close to shore to quickly threaten the shoreline and coastal areas with persistent crude oil contamination. The paradigm assumes that only certain heavy crudes will yield persistent crude contamination removing lighter fuels such as gasoline or natural gas from substantial focus of the damages.

The original spill of concern was the Torrey Canyon spill of 1967,[109] which contaminated 80 km of French coastlines and 190 km of Cornish shorelines in the United Kingdom. This spill leaked 119,000 tons of crude oil into the sea.[110] That spill resulted in several legal regimes and conventions: the Civil Liability Convention of 1969,[111] the Fund Convention,[112] TOVALOP,[113] and CRISTAL.[114]

These four conventions were revealed for their weaknesses under the Amoco Cadiz spill of 1978. The Amoco Cadiz spilled 223,000 tons of crude oil onto the shores of Brittany, France, nearly double the amount spilled in the earlier Torrey Canyon spill. That accident led to updates to the CLC and the Fund Convention. The updates were entitled the "Protocols." The two protocols were the Protocol of 1984 to amend the International Convention on Civil Liability for Pollution Damage 1969 and the Protocol of 1984 to amend the International Convention on the Establishment of an International Fund for Compensation of Oil Pollution Damage.[115]

108 J. L. RAMSEUR, CONG. RESEARCH SERV., RL33705, OIL SPILLS IN US COASTAL WATERS: BACKGROUND, GOVERNANCE, AND ISSUES FOR CONGRESS, 3 (2010).

109 M. G. Faure, & H. Wang, *The International Regimes for the Compensation of Oil-Pollution Damage: Are They Effective?*, 12 Rev. Eur. Commun. & Int'l Envtl. L. 242, 242 (2003).

110 International Tanker Owners Pollution Federation, Ltd. ITOPF. Oil Tanker Spill Statistics 2011. 2012. At p. 7; *available* at http://www.itopf.com/information-services/data-and-statistics/statistics.

111 International Convention on Civil Liability for Oil Pollution Damage, November 29, 1969, 973 U.N.T.S 3; 9 ILM 45 [hereinafter CLC]. The CLC is still in force as updated by the CLC of 1992. ; *available* at http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-on-Civil-Liability-for-Oil-Pollution-Damage-(CLC).aspx

112 International Convention for the Establishment of an International Fund for Compensation for Oil Pollution Damage (Brussels, December 18, 2012)

113 The Tanker Owners' Voluntary Agreement concerning Liability for Oil Pollution, (TOVALOP), was originally intended as a stop-gap measure by the owners and operators of oil-transporting vessels until the adoption of the CLC in 1975. No longer operational as an industrial convention since February 20, 1997; *available* at http://www.itopf.com/about/history/ .

114 The Contract Regarding an Interim Supplement to Tanker Liability for Oil Pollution, (CRISTAL), was originally intended as a stop-gap measure by the producers and refiners of petroleum until the adoption of the Fund Convention in 1975. No longer operational as an industrial convention since February 20, 1997; *available* at http://www.itopf.com/about/history/ .

115 Faure & Wang, *supra* at note 109, at 245.

Despite the public support for the international conventions, the U.S. failed to sign on as a signatory to any of the conventions. After the Exxon Valdez spill of 1989, again a large sea-going vessel leak,[116] the U.S. finally responded with the enactment of the Oil Pollution Act of 1990 (OPA).[117] In responding to the Exxon Valdez incident, OPA primarily targeted the shipment of oil in tankers and the types of harm caused by those spills. Global awareness to the Exxon Valdez spill resulted in additional updates to the CLC and Fund Convention, they are known as the 1992 Conventions.[118] The OPA does apply to offshore oil and gas facilities, and thus would now apply in some contexts to offshore methane hydrate facilities; the lessee is the deemed tortfeasor and the liability for offshore facilities is distinct from other sources of oil pollution. [119] The OPA also provides a limited liability version of strict liability due to certain caps placed on the maximum amount of assessable damages.[120]

However, OPA is substantively different from several important sections of the CLC and Fund Convention, so the legal responses to oil spills are significantly distinguishable from each other.[121]

There are doubts on the ability of the MOP regimes to address major spills from deep sea wells, such as the BP Deepwater Horizon, or potentially, methane hydrate extraction projects. Houck called for more detailed and reviewed "worst case planning" by the EPA under NEPA; he details how three major worst case studies were ignored prior to the BP spill.[122] A recent extensive review and critique of the overall liability system of U.S. oil spill law has been provided by Faure and Wang.[123]

2.2. *Civil Liability Convention of 1969/1992*

The Civil Liability Convention of 1969/1992, (CLC), derives from an earlier sequence of agreements originally designed to respond to crude oil spills from

116 Interestingly, the Exxon Valdez spill only released 37,000 tons of crude oil, much less than the earlier volumes that drove enactments in Europe.

117 For more information on OPA, *see infra*, at Chapter 11, Section 4.

118 *See* discussion on CLC, *infra*, at Section 2.2.

119 *See* the definition of "responsible party" at 40 U.S.C. §2701(32)(C). See also the limitations on liability for "offshore facility" at 40 U.S.C. §2704(a)(2).

120 OPA provides for routine strict liability up to certain maximum limits; below those limits there are no duty of care protections for the tortfeasor. *See* at 40 U.S.C. §2702(a). The types of damages are limited to certain categories of damages. *See* at 40 U.S.C. §2702(b)(2). And there are defense of cause majeure, *see* 40 U.S.C. §2703(a) and limited defenses of contributory gross negligence on the part of the victims, *see* 40 U.S.C. §2703(b).

121 *See* relevant discussions, *infra*, at Section 2.2., and at Chapter 11, Section 4.

122 *See* Houck 2010, p. 11035, 11037-11039.

123 M. G. Faure, & H. Wang, *Civil Liability and Compensation for Marine Pollution - Lessons to Be Learned for Offshore Oil Spills*, 8 Oil, Gas, Energy L. Intelligence 29 (2010).

vessels and boats and were later extended to include other hazardous substances.[124] It would not likely apply to damages resultant from methane hydrate harms, but it is guiding in its approach to liability management.

The CLC defines oil as "any persistent hydrocarbon," and provides examples of crude oil, fuel oil, diesel oil, and lubricating oil;[125] however, nothing in this definition appears to include methane or any of the lighter alkanes that might be found in methane hydrate deposits. The definition of pollution damage as "loss or damage outside the chip by contamination resulting from the escape or discharge of oil form the ship…,"[126] and while the definition provides extensions of damage to include the environment, it does not appear to include any pollution caused by forces or substances other than oil. As the CLC provides exclusively with regards to pollution damage within the territories of the Contracting States,[127] it would be difficult to connect the hazards and harms of methane hydrates to the CLC.

The owner of a ship is to be held liable for any pollution damage caused or associated with that ship.[128] Owner's liability is extinguished if (i) damage resulted from war or hostilities,[129] (ii) damage resulted from exceptional, inevitable, and irresistible natural phenomena,[130] (iii) wholly caused by undertaking by a third party's act or omission,[131] (iv) caused by Governmental negligence or wrongful act,[132] and if in partial or whole causation by the victim of the pollution damage.[133] As such, the rule employed is essentially a rule of strict liability.

Liability is limited to a fixed amount determined by the tonnage of the ship; the maximum amount of liability was set at 89,770,000 accounting units, today the

124 International Convention on Civil Liability for Oil Pollution Damage, November 29, 1969, 973 U.N.T.S 3; 9 ILM 45 [hereinafter CLC]. The CLC is still in force as updated by the CLC of 1992. *Available* at http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-on-Civil-Liability-for-Oil-Pollution-Damage-(CLC).aspx.

125 CLC art. I., sec. 5. *See* the additional language defining crude oil and fuel oil found within the International Convention on the Establishment of an International Fund for the Compensation for Oil Pollution Damage, 1992 at art. 1., sec. 3(a) and (b). Crude oils are defined as liquid hydrocarbons, apparently in distinguishing them from gases, and fuel oils are heavy distillates or residues. Neither definitional refinement appears to include any light alkanes, especially not methane.

126 *Id.*, art. I., sec. 6(a).

127 *Id.*, art. II., (a).

128 *Id.*, art. III., sec. 1. See also art. IV., wherein that liability is extended to joint and severable liability if multiple ships are involved in joint causation of pollution damage.

129 *Id.*, art. III., sec. 2(a).

130 *Id.*, art. III., sec. 2(a).

131 *Id.*, art. III., sec. 2(b).

132 *Id.*, art. III., sec. 2(c).

133 *Id.*, art. III., sec. 2(d). If the victim is wholly and solely responsible for the acts of causation, then no liability attaches to the owner; if the victim is partially at cause, then the owner's liability is limited to that extent covered by the victim.

equivalent of 134,655,000 USD.[134] However, that limit to liability is not preserved if the act that resulted pollution was committed with intent to cause such damage, or recklessly and with knowledge of probably resultant pollution damage.[135] The availability of the limited liability is predicated on the establishment of a fund capable of making such payments in presentation to the court before which liabilities are established.[136] Expenses undertaken by the owner to prevent or remediate the pollution damage are equally ranked for recompense under the fund with other pollution damage claims.[137]

It is a reasonable statement that the assignment of liability under the CLC appears to display liability channeling to the owner, a form of strict liability in that no excuse of reasonable care is provided, multiple defenses to the strict liability rendering it close to a functional negligence rule, and that the idea of strict liability must be tempered with the recognition of limited liability.

As the primary focus of the "Civil Liability Convention" is on civil liability, its text is primarily focused on establishing strict liability as the agreed to rule and the means of coordinating civil liability across affected jurisdictions. There is not ample material to draw conclusions on regulations.

2.3. International Convention for the Prevention of Pollution from Ships (MARPOL)

The International Convention for the Prevention of Pollution from Ships, (MARPOL),[138] was designed to address marine pollution and contamination from crude oil and noxious liquids. Because exploitation of subsea minerals is exempt from MARPOL, because methane is excluded from consideration as an oil, and because methane is not a defined liquid or noxious liquid, MARPOL would not likely apply to methane hydrate projects. MARPOL follows the CLC in establishing strict liability for accidental emissions.

MARPOL's definition of harmful substances is very broad; if the substance might harm human life, marine life or the local ecology, then it is a harmful

134 *Id.*, art. V., sec. 1. That accounting unit is defined to be the Special Drawing Rights unit of the International Monetary Fund. *See* CLC art. V., sec. 9(a). See also the converter tables at International Monetary Fund, "SDRs per Currency unit and Currency units per SDR last five days," *available* at http://www.imf.org/external/np/fin/data/rms_five.aspx

135 *Id.*, art. V., sec. 2.

136 *Id.*, art. V., sec. 3. *See* International Fund for the Compensation for Oil Pollution Damage, 1992 for the details of the fund and its stewardship. It is because of the advancements in the funding under this Convention that other earlier funds such as CRISTAL (Contract Regarding an Interim Supplement to Tanker Liability for Oil Pollution) and TOVALOP (Tanker Owners' Voluntary Agreement concerning Liability for Oil Pollution) have since been abandoned or folded into the International Fund. *See* W. TETLEY, INTERNATIONAL MARITIME AND ADMIRALTY LAW, 454 (Editions Yvon Blais, Thomson Company, 2002).

137 *Id.*, art. V., sec. 8.

138 International Convention for the Prevention of Pollution from Ships, November 2, 1973, 34 UST 3407;1340 UNTS 184 [hereinafter MARPOL].

substance.[139] MARPOL's definition of ships includes all sea-going vessels and platforms that might be related to an offshore methane hydrate installation.[140] A discharge would be the release by any cause of harmful substances from a ship into the oceanic environment,[141] however, events arising from the "exploration, exploitation and associated offshore processing of sea-bed mineral resources," are exempted from the definition of discharge.[142] Thus to the extent that methane hydrates or methane were held to be harmful substances, if they were released, *e.g.* vented or seeped, from activities associated with a methane hydrate project, then that situation would not be a discharge and not a reportable incident of a discharge of harmful substances.[143]

Annex I of MARPOL 73/78,[144] hereafter simply Annex I, provides extensive rules on the handling, disposal and leaking of oil from ships and platforms. However, it would not apply to methane hydrate accidents.

It defines oil as "petroleum in any form including crude oil, fuel oil, sludge, oil refuse and refined products … and, without limiting the generality of the foregoing, includes the substances listed in appendix I to this Annex."[145] The listed chemicals at Appendix I include the classes of Asphalt solutions, Gasoline blending stocks, Gasolines, Oils, Jet Fuels, Distillates, Naphthas, and Gas oils, but nowhere in the listings are light alkanes nor methane products.[146] Thus, Annex I would not apply to the types of harms and hazards contemplated by this study.

MARPOL could apply to offshore facilities. Oil tanker is defined as a ship that primarily carries oil;[147] similarly, a combination carrier is a ship designed to carry a combination of oil and solid freight.[148] Furthermore, the regulation primarily applies to ships;[149] but offshore structures engaged in the "exploration, exploitation and associated offshore processing of sea-bed mineral resources," whether floating or fixed, will be treated as legally equivalent to ships of 400 tons gross tonnage.[150]

139 MARPOL 1973. art. 2(2). "Harmful substance means any substance which, if introduced into the sea, is liable to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea, and includes any substance subject to control by the present Convention."

140 *Id.*, art. 2(4). "Ship means a vessel of any type whatsoever operating in the marine environment and includes hydrofoil boats, air-cushion vehicles, submersibles, floating craft and fixed or floating platforms."

141 *Id.*, art. 2(3)(a)

142 *Id.*, art. 2(3)(b)(ii).

143 *Id.*, art. 2(6).

144 Annex I of MARPOL 73/78, Regulations for the Prevention of Pollution by Oil. See at [http://library.arcticportal.org/1699/1/marpol.pdf]

145 MARPOL. Annex I. Reg. 1(1).

146 *Id.*, Annex I. Appendix I.

147 *Id.*, Annex I. Reg. 1(4).

148 *Id.*, Annex I. Reg. 1(5).

149 *Id.*, Annex I. Reg. 2(1).

150 *Id.*, Annex I. Reg. 19.

Annex II responds to noxious liquids other than oils.[151] Methane will not likely present as a liquid in Nature, nor is it technically a liquid within hydrate structures;[152] it would also not qualify under the Annex II definition of liquid.[153] Thus, the concerns on noxious liquids do not relate to the harms and hazards of methane hydrate projects.

2.4. International Convention on Oil Pollution Preparedness, Response, and Cooperation (OPRC)

The 1990 International Convention on Oil Pollution Preparedness, Response and Co-operation focuses on the actual events and incidents of oil pollution.[154] The focus, though, is tightly on oil. Oil is defined as "petroleum in any form including crude oil, fuel oil, sludge, oil refuse and refined products;" thus methane hydrates and methane are excluded from the category of oil.[155] Oil pollution incidents are defined as situations wherein oil is discharged,[156] thus methane hydrate events would not normally lead to an oil pollution incident.

However, methane hydrate project installations might qualify as offshore units, which are defined to include offshore natural gas installations.[157] And, the 2000 Protocol[158]adopted the term hazardous and noxious substances which could include methane and methane hydrates.[159] Thus it is feasible that the OPRC would apply to pollution incidents from methane hydrate projects under the 2000 Protocol whereas it would not have found an oil pollution incident under the original OPRC.

[151] Annex II of MARPOL 73/78, Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk. *Available* at http://library.arcticportal.org/1699/1/marpol.pdf.

[152] *See* the discussion on the chemistry of methane hydrates, supra, in Chapter 2.

[153] MARPOL. Annex II. Reg. 1(5). "Liquid substances are those having a vapour pressure not exceeding 2.8 kp/cm^3 at a temperature of 37.88C."

[154] OPRC. art. 1. sec. 1. "Parties undertake, individually or jointly, to take all appropriate measures in accordance with the provisions of this Convention and the Annex thereto to prepare for and respond to an oil pollution incident." 1990 International Convention on Oil Pollution Preparedness, Response and Co-operation, November 30, 1990, 1891 UNTS 51, 30 ILM 733 [hereinafter OPRC]. *Available* at http://cil.nus.edu.sg/1990/1990-international-convention-on-oil-pollution-preparedness-response-and-co-operation/ .

[155] OPRC. art. 2. sec. 1.

[156] *Id.*, art. 2. sec. 2.

[157] *Id.*, art. 2. sec. 4. "Offshore unit means any fixed or floating offshore installation or structure engaged in gas or oil exploration, exploitation or production activities."

[158] 2000 Protocol on Preparedness, Response and Co-operation to Pollution Incidents by Hazardous and Noxious Substances. (2000 Protocol.) 14 Mar 2000, London. *See* at [http://cil.nus.edu.sg/2000/2000-protocol-on-preparedness-response-and-co-operation-to-pollution-incidents-by-hazardous-and-noxious-substances/]

[159] OPRC. 2000 Protocol, art. 2., sec. 2. "Hazardous and noxious substances means any substance other than oil which, if introduced into the marine environment is likely to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea."

Should methane hydrates qualify as hazardous and noxious substances, then the OPRC would require every nation engaged in methane hydrate activities to establish a national system for responding promptly and effectively to pollution incidents.[160] The 2000 Protocol requires extensive pre-planning and preparation for potential pollution incidents, and strongly encourages the cooperation of the Contracting Parties to coordinate where possible on response capability and research into preventative technologies and strategies.[161] But for most countries in Europe and North America, the requirements are in parallel to other similar commitments.[162]

2.5. *Risk governance under international oil spill conventions*

Of the international oil spill conventions that address liability, they all called for the implementation of strict liability regimes with limited defences of force majeure-type events and limited defences from grossly or recklessly negligent victims. The conventions also assume that many procedural aspects of oil pollution prevention, detection, and remediation can be coordinated internationally; it is hard to imagine how that might be coordinated without manifestations tantamount to regulations. Indeed, several of these conventions are overseen by a common regulatory body, the International Maritime Organization under the United Nations. Thus, the international oil spill conventions are in alignment with the recommendations of Chapter 7.[163]

3. Summary and conclusions

The regional marine conventions and the international oil spill conventions are all problem-solving oriented; they are primarily aimed at preventing and limiting pollution of the marine environment from petroleum and hazardous substances.

At large, the international maritime conventions and oil spill conventions are in alignment with the recommendations from Chapter 7. They all either explicitly or implicitly called for the implementation of strict liability; not a single convention in the collection advocated or supported a rule of negligence. None of them disavowed the useful role of regulation and most provided frameworks of the regulations that they expected to be put into place to both provide a certain standard of sufficient breadth and coverage of contracting states' resultant

160 *Id.*, art. 4., sec. 1.

161 *Id.*, *en passim.*

162 The OPRC does not explicitly discuss liability beyond the recovery of costs of the parties; liability is assumed to be dealt within in separate proceedings beyond this convention.

163 There will always be concerns that the limited liability aspects of certain regimes are not in complete alignment with theoretical models; however, perhaps these limits reflect more completely on the impact of Coasian negotiations, that transaction costs to achieve liability rules limited the ultimate result. In that case, the rules in place might align well with a more detailed model of liability in consideration of the transaction costs to enact and enforce the rules, and thus, might reflect well on optimal incentives.

regulations and to provide for better intercommunication and cooperation on the eventual need to work together to address transboundary problems associated with oil spills and other marine pollutants.

However much alignment might exist between the international maritime conventions and the oil spill conventions and the recommendations of Chapter 7, there remains a fundamental disconnect in that most of the aforementioned conventions would barely be applicable to the risks and hazards of offshore methane hydrates. Not that the conventions are in any form structurally opposed to such, but rather that it appears that need for such coverage was not imaginable at the time the conventions were drafted and implemented. Indeed, much of the language and vocabulary of the conventions could readily be extended to coordinate with the particular circumstances of offshore methane hydrates. Because the existing international maritime and oil spill conventions do reflect both a history of diplomatic draftings and accumulated practical experiences, it might be wise to build upon their foundations in addressing the risks and hazards of offshore methane hydrates.

The employment of standards such as requirements to maintain "best available techniques" and "best environmental practices" are clearly relevant in providing the standards for offshore methane hydrates. Many of the functional definitions from these conventions, such as "offshore activities" and "offshore installations" can readily be extended to cover similar or identical concepts related to offshore methane hydrates. Other definitions, *e.g.*, such as "pollution" within OSPAR, already might be interpretable as applicable to methane hydrates, as it includes all "substances or energy" that could result in hazard to human health or the marine ecosystem. However, more clear standards could be set by provision of explicit terms that make clear that emissions, seeps, and ventings from methane hydrates should be included within that definition when introduced by human activities.

The international maritime and oil spill conventions have histories of textual evolution. *E.g.*, OSPAR has an Annex III that addresses novel concerns related to CCS events. *E.g.*, the Barcelona Convention has an Offshore Protocol to address offshore exploitation events more directly. Thus, it is a reasonable option to consider that the existing international maritime and oil spill conventions might be amendable to include the circumstances related to the events of offshore methane hydrates that could lead to risk and harms of the oceanic domains that those conventions currently protect.

Table 1: Signatories to Major Regional Marine Conventions near major European water bodies.

	Regional Marine Conventions				
	OSPAR	**Helsinki**	**Bonn**	**Barcelona**	**B. Offshore**
Albania				yes	yes
Algeria				yes	
Belgium	yes		yes		
Croatia				yes	
Cyprus				yes	yes
Denmark	yes	yes	yes		
Egypt			yes		
Estonia		yes			
EU	yes	yes	yes	yes	
Finland	yes	yes			
France	yes		yes	yes	
Germany	yes	yes	yes		
Greece				yes	
Iceland	yes				
Ireland	yes		yes		
Israel				yes	
Italy				yes	
Latvia		yes			
Lebanon				yes	
Lithuania		yes			
Libya				yes	yes
Luxembourg	yes				
Malta				yes	
Monaco				yes	
Montenegro				yes	
Morocco				yes	yes
Netherlands	yes				
Norway	yes		yes		
Poland		yes			
Portugal	yes				
Russia		yes			
Slovenia				yes	
Spain	yes				
Sweden	yes	yes	yes		
Switzerland	yes				
Syria				yes	yes
Tunisia				yes	yes
Turkey				yes	
U. K.	yes				

Chapter 10

EUROPEAN UNION LAWS

The European Union has a wide variety of legal instruments that address environmental protections and related industrial torts; thus the selection of materials to be reviewed herein is necessarily quite limited. An effort has been made to select those directives or frameworks more likely to be engaged in the governance of risks and hazards from offshore methane hydrate installations.

The Environmental Impact Assessment (EIA) and Strategic Environment Assessment (SEA Directives) have been chosen for their broad role with regards to both the approval of projects and the review of programs and plans.[1] They both serve to increase the awareness level of policy makers as to the specific environmental risks and hazards posed by various projects or programs; as such, they aid in standards-setting decision processes. (A review of the EIA and SEA Directives also provides some perspective on the similarly drafted NEPA within the U.S.)

Several directives have been selected because they touch on the regulation and liabilities attending to industrial accidents. The Environmental Liability Directive (ELD) was selected due to its role in providing oversight of the legal issues related to environmental damages.[2] The ELD extends legal protection to aspects of nature that might not otherwise be protected under more traditional rules of injury. The Seveso III Directive provides for the prevention and control of events surrounding industrial accidents.[3]

The Offshore Directive was selected because it is perhaps the closest legal instrument that the EU currently has to address the extraction of natural gas from offshore methane hydrate deposits.[4] Many aspects of traditional offshore oil and gas operations would be similar to the eventual operations of offshore methane hydrate installations.

1 *See* at sec. 1 and 2.
2 *See* at sec. 3.1.
3 *See* at sec. 3.2.
4 *See* at sec. 4.

The Carbon Capture and Sequestration (CCS) Directive is included due to the major overlap between the two endeavors of carbon dioxide sequestration and methane hydrate extraction;[5] indeed, as explored in Chapter 3, many offshore methane hydrate development plans foresee both activities running concurrently in offshore methane hydrate installations. In some ways, it is not unreasonable to imagine that a hypothetical Offshore Methane Hydrate Directive would be an amalgam of the Offshore Directive and the CCS Directive.

The EU coordinates extensive governance of its waterways and oceans; the Marine and Water Frameworks are reviewed for the potential impacts the development of offshore methane hydrate might pose.[6]

Finally, the EU is fully engaged with the goals and obligations of the United Nations' UNFCCC. As such, it has developed a Greenhouse Gas Mechanism to enable it and its Member States to set and coordinate greenhouse gas emissions targets.[7] The methane that could directly be emitted and the resultant carbon dioxide from metabolized or combusted methane are both listed as greenhouse gases within the Kyoto Protocol and are thus governed within the Greenhouse Gas Mechanism.

1. The EIA Directive

The laws and regulations on environmental harms and hazards are guided by two central directives; the Environmental Impact Assessment (EIA)[8] Directive and the Strategic Environmental Assessment (SEA)[9] Directive. These two directives require the *ex ante* review of projects, programs and plans that might in some manner have an impact on the environment.

The EIA and SEA Directives are elements that are invoked in a wide array of EU laws; they are used to ensure that consistent review and forethought are applied to environmental issues across the EU and its member states. In addition to their role as positive law within the EU matrix, the EIA and SEA provide foundational

5 *See* at sec. 5.

6 *See* at sec. 6.

7 *See* at sec. 7.

8 Directive 2011/92/EU Of The European Parliament And Of The Council Of 13 December 2011 On The Assessment Of The Effects Of Certain Public And Private Projects On The Environment. O.J. (L. 26) [hereinafter EIA Directive 2011/92/EU]. The EIA Directive, reflects the codification of the original Council Directive 85/337/EEC and its subsequent amendments Directives 97/11/EC, 2003/35/EC, and 2009/31/EC. The Directive is currently undergoing review for amendment to provide streamlining to the procedures and to improve cross member state consistency. *See* "Review of the Environmental Impact Assessment (EIA) Directive;" *available* at http://ec.europa.eu/environment/eia/review.htm. *See also* "Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment," *available* at http://ec.europa.eu/environment/eia/pdf/COM-2012-628.pdf.

9 Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment. O.J. (L 197), 30 [hereinafter SEA Directive].

legal norms for similar review efforts within both EU member states and for countries and associations beyond the EU. As such, their influence is often guiding on activities at the earliest stage of drafting and development.

The EIA Directive applies to any project, public or private in nature, prior to the issuance of a permit for the onset of the project's development.[10] A project includes the execution of construction projects (including installations) and other interventions in the natural surroundings and landscape including extractive efforts such as mineral resources.[11] The person held responsible for the drafting of the EIA report is the developer, the applicant who initiates a project by requesting authorization, or development consent, for the project.[12] Member states may elect to apply the EIA to projects related to their national defense, on a case-by-case basis.[13] The EIA Directive allows projects that are designed through legislative processes and adopted by specific acts of national legislation to be exempt from the EIA Directive; the Directive holds out that similar due diligence reviews are assumed of the legislatures as guided by the EIA Directive.[14] Member states are required to integrate the designs of the EIA Directive into their national laws to ensure that prior to consent for development all projects likely to have significant effects are properly assessed.[15]

1.1. Offshore methane hydrates qualified under Annex I

Methane hydrates projects would require the completion of an EIA review. The EIA Directive provides two manners of determining when a project should be reviewed under this Directive. There is a specific list of project types that must complete an EIA review at Annex I; these reviews are not optional.[16] There is a secondary list of activities at Annex II that may need review; member states can either review those projects on a case-by-case basis or provide *ex ante* threshold guidelines.[17]

Annex I has multiple activities that would characterize offshore methane hydrate projects. It is almost certain that a methane hydrate project would qualify as an Annex I project, as it *per se* qualifies under several listed categories and arguably could be included under several other Annex I categories. Or, depending on how the process of project development was managed and how the member state(s) in question decide how to handle such a review process, there are potentially several different aspects of a methane hydrate project that might need their own EIA review procedures.

10 EIA Directive, *supra* at note 8, art. 1, sec. 1.
11 *Id.*, art. 1, sec. 2(a).
12 *Id.*, art. 1, sec. 2(b) and (c)
13 *Id.*, art. 1, sec. 3.
14 *Id.*, art. 1, sec. 4.
15 *Id.*, art. 2.
16 *Id.*, art. 4, sec. 1.
17 *Id.*, art. 4, sec. 2(a) and (b).

So long as the methane hydrate project is designed to produce in excess of 500,000 m^3 of methane daily,[18] then the project would certainly qualify as an Art. 4(1) - Annex I project requiring a full EIA process.[19] The methane extracted from methane hydrates is the same chemical as the term natural gas, thus methane extraction is *per se* natural gas extraction.[20] It is fairly unlikely that methane hydrate reservoirs contain substantial quantities of petroleum as distinct from natural gas; to the extent that any hydrocarbon liquids are recovered it is very reasonable to assume that they would fall below the "500 tonnes/day" minimum requirement.[21]

Several ancillary aspects of methane hydrate projects would also likely qualify under Annex I. To the extent that CCS technologies are engaged to offset the extract volumes of methane with carbon dioxide, then the project would be a storage site pursuant to Directive 2009/31/EC ("The CCS Directive").[22] Depending on the location of the methane hydrate project and the gathering and transportation needs to move the methane and relate fluids from the wellsites to the platforms to onshore facilities, the project may qualify as a pipeline.[23] Assuming that methane qualifies as natural gas and if the pipelines involved in its transport were wider than 80 cm and longer than 40 km, then the pipelines of the project would qualify.[24] If similar pipelines were utilized to transport carbon dioxide to the wellsites for sequestration then those pipelines would also qualify under Annex I.[25]

Methane hydrate projects could be characterized as an integrated chemical installation for the production of basic organic chemicals.[26] Methane is an organic chemical; its extraction involves "chemical conversion processes" to convert methane hydrates to methane and other components.[27] One would reasonably assume that the scale of investment required to construct methane hydrate projects presumes chemical product volumes sufficient to qualify as "on an industrial scale."[28] To the extent that the project is engaged in the conversion of the methane and water volumes into steam and hydrogen, the project might qualify as in the "production of basic inorganic chemicals."[29] In that case, the chemical processes to convert methane to hydrogen would like better satisfy the "chemical conversion processes" requirement.[30]

18 The equivalent of 17,600 kcf/d. *See* natural gas calculator at the U.S. Dept. of Energy; *available* at http://www.netl.doe.gov/energy-analyses/energy-calc.html .
19 EIA Directive, *supra* at note 8, Annex I, Sec. 14.
20 *See* chemistry of methane hydrates, *supra*, ch. 2, sec. 2.
21 EIA Directive, *supra* at note 8, Annex I, Sec. 14. *See* chemistry of methane hydrates, *supra*, ch. 2, sec. 2.
22 *Id.*, Annex I, Sec. 22. *See* CCS and methane hydrates, *supra,* ch. 3
23 *Id.*, Annex I, Sec. 16.
24 *Id.*, Annex I, Sec. 16(a).
25 *Id.*, Annex I, Sec. 16(b).
26 *Id.*, Annex I, Sec. 6(a).
27 *Id.*, Annex I, Sec. 6 and 6(a). For details on the chemical processes involved, *see supra*, Chapters 2 and 3.
28 *Id.*, Annex I, Sec. 6.
29 *Id.*, Annex I, Sec. 6(b).
30 *Id.*, Annex I, Sec. 6.

Methane hydrate projects might could be characterized as groundwater abstraction schemes to the extent that the water volumes associated with the methane in the hydrate formations is produced alongside the methane.[31]

It is possible that methane hydrate projects could be characterized as "trading ports, piers for loading and unloading," if the offshore structures are built in such a manner to facilitate transport of produced methane, water, or hydrogen volumes.[32]

Methane hydrate projects should not be characterized as crude-oil refineries nor as gasification/liquefaction installations of coal or bituminous shales.[33] Methane hydrate projects would lift negligible amounts of crude oil, if at all, and no volumes of coal or shale would be extracted nor processed. To the extent that any hydrocarbon liquids would be produced coincidentally at a methane hydrate project, it would be very unlikely for those chemicals to be processed or refined onsite; more likely they would be relocated to a regular refinery location for disposition.

1.2. Offshore methane hydrates qualified under Annex II

Even though the EIA procedures will almost certainly be invoked by the Annex I analyses, it is remains worthwhile to review the Annex II categories because there are several additional categories of activities that are not present in the Annex I list that might also merit review under a methane hydrate project.

Under the category of Energy Industry, there are several subcategories that might be involved as support systems to a methane hydrate project. Industrial installations for carrying gas, steam or water may be involved in both offshore efforts to extract the methane or as part of onshore support systems.[34] To the extent that the methane hydrate project is producing substantial volumes of natural gas that will need translation into an onshore distribution network, it is likely that the facilities will need storage facilities to provide safe and reliable delivery of the natural gas into the distribution pipelines. As such, the methane hydrate project may include the sub-categories of surface storage of natural gas, underground storage of combustible gases, and surface storage of fossil fuels.[35]

As the methane hydrates are in a solid form prior to removal from the deposit, it would be reasonable to describe their extraction as an extractive industry category. First, the surface industrial installations for the extraction of natural gas that will be associated with a methane hydrate project would likely independently qualify as an Annex II category project.[36] As the hydrates are underground, they potentially involve underground mining.[37] While not immediately foreseeable, it is not impossible to imagine that marine or fluvial dredging may be involved in either

31 *Id.*, Annex I, Sec. 11. *See* chemistry of methane hydrates, *supra*, ch. 2, sec. 2.
32 *Id.*, Annex I, Sec. 8(b).
33 *Id.*, Annex I, Sec. 1.
34 *Id.*, Annex II, Sec. 3(b).
35 *Id.*, Annex II, Sec. 3(c), (d), and (e).
36 *Id.*, Annex II, Sec. 2(e)
37 *Id.*, Annex II, Sec. 2(b).

the direct extraction of methane hydrates or utilized as a means of facilitating the removal of methane hydrates.[38] While the phrasing of deep drilling is left unclarified in Annex II, it is conceivable that fresh water can be produced from the hydrate deposits and then positioned as potable water for human or livestock consumption.[39]

Certain aspects, or sub-projects, of a methane hydrate project are likely to fit within several of the sub-categories of Infrastructure Projects. Depending on the overall footprint of the project and its associated co-projects, *e.g.* electrical power generation, it might be engaged in the development of an industrial estate project.[40] To the extent that carbon dioxide sequestration is involved in the methane hydrate project, it would likely involve gas pipeline installations and pipelines for the transport of the to-be-injected carbon dioxide.[41] And without regard to the use of hydrate waters as potable waters, if the project plans to remove those waters from the deposit then the project could be seen as engaged in the abstraction of groundwater.[42]

It is not likely that the products from a methane hydrate project would qualify as petroleum, petrochemicals, or as chemical products.[43] Nor is it likely that a methane hydrate project or its products would be considered as part of a chemical industry category.[44] Nor would the methane hydrate project fit any of the categories under Annex II's Mineral Industry, as the listed items are fairly specific and exclude any of the materials involved in a methane hydrate project.[45]

Qualification under Annex II requires a determination from the relevant member state on whether the project needs an EIA assessment.[46] The requirements for the determination are detailed at Annex III;[47] they are broad and detailed in scope. Annex III requires the detailing of the project's characteristics; of note are the use of natural resource, the production of waste, the associated pollution and nuisances, and the risks of accident with particular regard to the substances or technologies involved in the project.[48] The location of the project is critical, especially with regards to the existing use of the area, the regenerative capacity of the project's surroundings, the impacts on wetland and coastal zones, and nature reserves and parks.[49] Finally the characteristics of the potential impact must be detailed.[50] All of the issues previously addressed in Annex III must also be addressed with regards to extent of the impact on populations and the geographical

38 *Id.*, Annex II, Sec. 2(c).
39 *Id.*, Annex II, Sec. 2(d)(iii).
40 *Id.*, Annex II, Sec. 10(a).
41 *Id.*, Annex II, Sec. 10(i).
42 *Id.*, Annex II, Sec. 10(l).
43 *Id.*, Annex II, Sec. 6(c)
44 *Id.*, Annex II, Sec. 6
45 *Id.*, Annex II, Sec. 5.
46 *Id.*, art. 4, sec. 2.
47 *Id.*, art. 4, sec. 3.
48 *Id.*, Annex III, sec. 1(c), (d), (e), and (f).
49 *Id.*, Annex III, sec. 2(a), (b), and (c)(i)(ii) and (iv).
50 *Id.*, Annex III, sec. 3.

area, on the trans-frontier nature of the project, the magnitude and complexity of the impact from the project, the probability of the impact, and of the duration, frequency, and reversibility of the impact.[51]

1.3. Risk governance within the EIA Directive

Of focused interest to efficient governance of the risks and harms from methane hydrate projects is the collection of data provided at this early stage of pre-development. The risks of the project need to be clearly enumerated and stated,[52] the probability of the impact needs to be forecasted,[53] and the duration, frequency of potential accidents needs to be squarely addressed.[54] The actual nature of the impact, of the potential harms and hazards, needs to be surveyed; the potential for reversibility also needs to be evaluated.[55]

There is value to this Annex II & III process, even if the member state decides to exempt the project from an EIA review. All of this data is collected prior to the onset of the EIA assessment itself and then provided to the public.[56] Additionally, the public (which one assumes would include both the impacted communities and specialized public interest groups) has opportunity to engage in the determination process, enabling it to request information and explanations that the competent authorities might not have requested.[57]

Once a project qualifies for assessment,[58] the EIA Directive requires application of §5 through §10 in the completion of the assessment.[59] Article 5 requires that the assessment includes all of the information as directed under Annex IV.[60] Additionally, the developer may request from the specific competent authority from the relevant member state for clarification on what types of information are to be included in the assessment.[61] At a minimum, the developer should submit to the competent authorities:

"(a) a description of the project comprising information on the site, design and size of the project;"[62]

"(b) a description of the measures envisaged in order to avoid, reduce and, if possible, remedy significant adverse effects;"[63]

51 *Id.*, Annex III, sec. 3.
52 *Id.*, Annex III, sec. 1(f)
53 *Id.*, Annex III, sec. 3(d).
54 *Id.*, Annex III, sec. 3(e).
55 *Id.*, Annex III, *En passim, see*, sec. 2(c), 3(a) and 3(e).
56 *Id.*, art. 4., sec. 3 and 4.
57 *Id.*, art. 6, sec. 2. and especially at 2(g). This form of public interaction is of course in parallel to more discrete means of engagement, such as privately lobbying the competent authorities and other branches of the member state's regulatory administration.
58 Directly under *id.*, art. 4, sec. 1. with Reference to Annex I, or, in the alternative under *id.*, art. 4, sec. 2 and 3.
59 *Id.*, art. 4, sec. 1 (for Annex I projects) and 2 (for Annex II projects).
60 *Id.*, art. 5, sec. 1.
61 *Id.*, art. 5, sec. 2.
62 *Id.*, art. 5, sec. 3(a)

"(c) the data required to identify and assess the main effects which the project is likely to have on the environment;"[64]

"(d) an outline of the main alternatives studied by the developer and an indication of the main reasons for his choice, taking into account the environmental effects;"[65]

"(e) a non-technical summary of the information referred to in points (a) to (d)."[66]

All five issues should address both their direct and indirect effects on (i) human beings, fauna and flora, (ii) soil, water, air, climate and the landscape, (iii) material assets and cultural heritage, and (iv) the interaction between all of these factors.[67] The Annex IV requirements are stated simply but they require both broad and detailed reports. The description of the project would need to explain both the production processes of the methane hydrate project and estimates of the expected residues and emissions which would include all forms of pollution.[68] The breadth of the emissions definition, which includes such phenomena as vibrations, light and heat, might include disturbances such as earthquakes or tsunamis in the case of a methane hydrate project.[69] A review of the alternatives is required to be submitted; clearly such information provides documentary proof of both options acknowledged to be known and tacit admissions of technologies unknown to the developer, if they cannot list them as an alternative one assumes that they are unaware.[70] The developers are also responsible for explaining the choices made by the developers while taking into account the effects of those choices on the environment.[71] In Annex IV, Art. 3, there is a repetition of the requirements found within the EIA Directive itself to report on the impacts on life, cultural assets and the environment.[72] Then, Annex IV requires a study of the impacts, including potential harms, of the project's simple existence in the environment, of its use of natural resources, and of the potential of the project to emit pollution, create nuisances, and to eliminate, meaning discharge, waste products.[73] Once the various impacts and potential harms and hazards have been itemized, potential means of prevention, reduction and offsetting measures should be provided in the

63 *Id.*, art. 5, sec. 3(b)

64 *Id.*, art. 5, sec. 3(c)

65 *Id.*, art. 5, sec. 3(d)

66 *Id.*, art. 5, sec. 3(e)

67 *Id.*, art. 3(a), (b), (c), and (d).

68 *Id.*, Annex IV, art. 1. "A description of the project, including in particular: (a) a description of the physical characteristics of the whole project and the land-use requirements during the construction and operational phases; (b) a description of the main characteristics of the production processes, for instance, the nature and quantity of the materials used; (c) an estimate, by type and quantity, of expected residues and emissions (water, air and soil pollution, noise, vibration, light, heat, radiation, etc.) resulting from the operation of the proposed project." Underscoring added.

69 *Id.*, Annex IV, art. 1(c).

70 *Id.*, Annex IV, art. 2.

71 *Id.*, Annex IV, art. 2.

72 *Id.*, art. 3(a), (b), (c), and (d).

73 *Id.*, Annex IV, art. 4.

assessment.[74] To the extent that the developer can identify where shortfalls in knowledge or technology exist that would improve the assessment itself, they should ensure that such is provided in the report.[75] An explanation of the scientific methods and techniques used to develop the above forecasts is to be included in this assessment of potential impacts.[76] Finally, there is a requirement to provide a non-technical version of the above reports within the assessment.[77]

While that assessment is in drafting and undergoing review, there are several opportunities for non-developer parties to engage in the process. Member states are to ensure that all of the relevant authorities are given opportunities to express their expertise on the assessment.[78] The general public has extensive rights reserved within the EIA Directive.[79] Most importantly, the public is to be informed when and where the information gathered for the assessment will be made public and when the public can participate in the assessment review.[80] The EIA Directive itself does not explicitly provide means of control, approval or veto, to the public, but the Directive would allow each member state to so grant to its own citizens under its own statutes.[81] However, the public has a right reserved to it that either it does receive a sufficient interest in the review and development of the assessment or to have access to due process before a court of law or other independent and impartial body to challenge the decision, acts, or omissions on substantive or procedural grounds.[82]

The EIA Directive requires that the assessment review engages other member states should they be discovered to be at transboundary risk.[83] Similarly, the transboundary-affected member state, once engaged, shall provide to its authorities and the public the same access to the information as was afforded to the parties in the original member state.[84]

Critically important is the conclusion of the assessment process, at which time the member state(s) need to release the reasons for the decision (and any attached conditional requirements), an explanation of the impact of the public's participation on the decision process, and a description of the main measures necessary to avoid, reduce, and offset the major adverse effects of the approved project.[85]

Because the rules provide for both the technical and non-technical provision of the information, the public and other parties will face lower transaction costs in reviewing the materials. This would affect both the potential *ex post* litigation

74 *Id.*, Annex IV, art. 6.
75 *Id.*, Annex IV, art. 8.
76 *Id.*, Annex IV, art. 5.
77 *Id.*, Annex IV, art. 8.
78 *Id.*, art. 6, sec. 1.
79 *Id.*, art. 6, sec. 2(a) through (g).
80 *Id.*, art. 6, sec. 2(f) and (g).
81 *Id.*, art. 2. Of course, EU constitutional concerns apply to all such drafting efforts.
82 *Id.*, art. 11, sec. 1., as limited by, sec. 2 and 3.
83 *Id.*, art. 7.
84 *Id., art.* 7, sec. 3(a) and (b).
85 *Id.*, art. 9, sec. 1(a), (b), and (c).

decisions made after an impact event, *e.g.*, a harmful accident, or to better facilitate the *ex ante* drafting of necessary regulations.

2. The SEA Directive

Whereas the EIA Directive applied to projects, the Strategic Environment Assessment ("SEA") Directive is targeted at plans and programs.[86] Plans or programs related to methane hydrate projects would most likely qualify under the categories of energy and industry, and potentially under the waste and water management categories.

Plans and programs, broadly speaking, are those plans and programs that are undertaken by authorities within member states at local, regional or national levels and are subject to legislative procedures by Parliament or Government.[87] The overall character of the Directive is procedural in nature, not substantive.[88]

The preamble of the SEA Directive explains that the precautionary principle was a central goal of the Directive, to preserve, protect and improve the quality of the environment, the protection of human health, and the prudent and rational utilization of natural resources.[89]

A SEA is required for every plan or program that is likely to have significant environmental effects.[90] There are specific explicit requirements for SEAs to be drawn for any plan or program prepared for energy, industry, transport, waste management and water management, among others, if those plans or programs would set the framework for future development of those areas of interest listed within Annex I and II of the EIA Directive.[91]

Additionally, member states should identify if other plans or projects would have significant environmental effect beyond those identified, *supra*; if review is undertaken and a SEA is found unwarranted then the authorities need to make that analysis public.[92] These SEAs are to be accomplished and completed prior to the submission or adoption of the plans or programs by a legislative process.[93]

Due to the nature of the plans and programs being essentially of a political and legislative nature, there is inherently a certain amount of due process and democratic political process within the EU to support an assumption that public ultimately does have a say on these plans and programs. However, the SEA Directive highlights the need and mandates the active participation of the public, and other authorities beyond the drafters of a SEA, to ensure that they have a

86 SEA Directive, *supra* at note 9.
87 *Id.*, art. 2, sec. (a).
88 *Id.*, Preamble Sec. 9.
89 *Id.*, Preamble Sec. 1.
90 *Id.*, art. 3, sec. 1.
91 *Id.*, art. 3, sec. 2(a).
92 *Id.*, art. 3, sec. 4 and 5 and then at 6, respectively.
93 *Id.*, art. 4, sec. 1.

chance to review the findings of the SEA and to consult on the SEA.[94] Furthermore, in the event of transboundary considerations, the SEA Directive has functionally similar mechanisms to the EIA Directive.[95]

The information to be reviewed under a SEA assessment is detailed in Annex I to the SEA Directive.[96] In an effort to be as inclusive as possible of relevant information, the Annex advises to include all information from its immediate implications as well as its "secondary, cumulative, synergistic, short, medium, and long-term permanent and temporary, positive and negative effects."[97] It is clear that the assessment is to be drafted from as broad and inclusive a perspective as possibly feasible; if there are any harms affects due to the plans or programs evaluated, however vague, they should identified, quantified, and probabilistically modeled for both benefits and costs.[98]

The notion of plans and programs are distinct from that of projects, they reflect potential legislation or policy enactments, and as such merit slightly different considerations than those listed under Annex IV of the EIA Directive.[99] It should include an outline of the contents and main objectives of the plans or programs as well as any interconnection(s) with other plans or programs.[100] It should describe the current state of the target environmental settings and how they might evolve without the plans or programs.[101] The assessment should make clear what characteristics are likely to be impacted by the plans or programs and how the plans or programs are expected to protect those areas or characteristics.[102]

The SEA Directive's Annex I repeats the mantra of life from the EIA directive;[103] it also requests specification of the measures envisaged to prevent, reduce, and offset any significant adverse effects of the plans or programs on such ecological and social concerns; this should include technical description of the various monitoring methods necessary to achieve these goals.[104] It also calls for a listing of the reasons why the particular plans or programs were selected, which options were eliminated and the reason for their elimination, and what limits in knowledge frustrated or limited a more complete review of the options.[105] Finally, a non-technical version of the above discussions is required.[106]

94 *Id.*, art. 6, sec. 1, 2, and with regards to NGOs Sec. 4. *See also* SEA Directive, 2001/42/EC. Preamble Sec. 15.
95 *Id.*, art. 7.
96 *Id.*, Annex I,
97 *Id.*, Annex I, sec. 1.
98 *Id.*, Annex I, sec. 1.
99 The following description can be contrasted with that from the EIA discussion, *supra*, at sec. 1.
100 *Id.*, Annex I, (a).
101 *Id.*, Annex I, (b).
102 *Id.*, Annex I, (c) and (d).
103 "... human beings, fauna and flora, soil, water, air …" *et seq. See* EIA Directive, *supra* at note 8, art. 3, *en toto*, *see also id.*, Annex IV, art. 3.
104 SEA Directive, *supra* at note 9, Annex I, (f), (g) and (i).
105 *Id.*, Annex I, (h).
106 *Id.*, Annex I, (j).

3. Environmental Liability and Seveso III Directives

The EU has provided two legal instruments to address the commercial and industrial activities that could result in environmental and social harms, the Environmental Liability Directive ("ELD")[107] and the Seveso III Directive ("Seveso III").[108] These establish doctrines that then have broader applications in other areas of environmental regulation, such as the Birds and Habitats Directives,[109] the Marine Strategy Framework Directive,[110] and the Water Framework Directive.[111] The ELD is not likely to apply to the development of offshore methane hydrate projects, *infra*; the Seveso III is *per se* not applicable to the offshore development of hydrocarbons such as methane hydrates, also *infra*.

Beyond those, the Directive on Natural Habitats governs the impacts on special environment ecologies and on certain protected species.

3.1. Environmental Liability Directive

3.1.1. Unsure applicability to methane hydrates

The ELD was intended to address environmental harms and hazards generally. The Offshore Directive and the CCS Directive have also applied the ELD to address the liabilities from environmental harms from offshore activities and carbon sequestration activities.[112] But there are several reasons why the ELD is not likely to address the events associated with methane hydrate projects.

3.1.1.1. Limited scope of environmental damages

The ELD governs environmental damages caused by occupational activities;[113] its focus is squarely on damages to Nature.[114] However, the ELD does not apply to all

107 Directive 2004/35/CE Of The European Parliament And Of The Council Of 21 April 2004 On Environmental Liability With Regard To The Prevention And Remedying Of Environmental Damage. O.J. (L 143), 56. [hereinafter ELD.]

108 Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC Text with EEA relevance. Official Journal of the European Union - Legislative. Vol. 197., 24 July 2012, Pp. 1–37.

109 Directive 2009/147/EC of the European Parliament and of the Council on the conservation of wild birds. (Birds Directive) Official Journal of the European Union - Legislative. Vol. 20., 26 January 2010, pp. 7-25., and see the Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (Habitats Directive) Official Journal of the European Union - Legislative. Vol. 206., 22 July 1992, Pp. 7-50, respectively.

110 Marine Strategy Framework Directive, *supra* at note 178.

111 *See* Directive 2000/60/EC as an example of one of the major directives within that framework.

112 It would at first appear that the ELD limits to itself to waters closer to the shoreline than where methane hydrates are deposited. However, the adoption of the ELD methods by the Offshore and CCS Directives would extend this zone of application. *See* ELD, *supra* at note 107.

113 ELD, *supra* at note 107, art. 3.1(a).

sources of environmental hazards.[115] It declares that it addresses only those causes of harm that arise from a diffuse character wherein a causal link still functions to connect tortfeasor and accident.[116] It also excepts various acts of God and force majeure that result in accidents otherwise covered within the ELD.[117] The damage can be perfected in nature or of imminent threat to occur;[118] an imminent threat requires a sufficient likelihood of the threat.[119]

Environmental damage is defined as measurable adverse change in a natural resource which worsens the environment against a baseline, unless permitted by relevant authorities from the member states: [120]

> "damage to protected species and natural habitats, which is any damage that has significant adverse effects on reaching or maintaining the favourable conservation status of such habitats or species. The significance of such effects is to be assessed with reference to the baseline condition, taking account of the criteria set out in Annex I"[121]

> "Damage to protected species and natural habitats does not include previously identified adverse effects which result from an act by an operator which was expressly authorised by the relevant authorities"[122]

Thus, the scope of damages under the ELD is primarily centered on those 'parties' that would not otherwise be able to bring their own plaints to trial. This limits the potential applicability of the ELD to the various potential

114 *Id.*, art. 2.1(a), (b), and (c). The Preamble suggests, *see* at Sec. 8, that the ELD should be applied to wherevers occupational activities present risks for human health. Of course, environmental harm can impact humans and human health in many ways, but the ELD handles the human-related issues indirectly. There is a limit role of land damage to include those contaminations that might impact human health. *See id.*, art. 2.1 (c).

115 ELD, *supra* at note 107, art. 4.

116 *Id.*, art. 4, sec. 5.

117 *Id.*, art. 4, sec. 1(a) and (b). *See also* art. 4, sec. 6. for activities related to war or natural disasters.

118 *Id.*, art. 3, sec. 1(a) and (b).

119 *Id.*, art. 3, sec. 9.

120 *Id.*, art. 2, sec. 2. Clearly this raises an immediate issue of metrics and measurement, of observation and detection. These are not necessarily readily reduced to low cost technologies in many cases and thus might be seen as preventing recognition of certain damages less readily reduced to measurement or lack clear *ex ante* base lines against which to draw contrasts over time. Certain damages may have occurred in a location that *ex ante* to detection was not assumed to be a likely site of damage and so went unobserved at the beginning of the operations that ultimately led to the harm. Yet, this might also serve as an incentive to both protect the courts from the nuisance of unserviceable pleas in court and to encourage the development of baseline metrics by those interested in protecting their surroundings. Those best able to observe, suggests the ELD, have a duty to themselves to observe and take measurements.

121 *Id.*, art. 2, sec. 1. *See also id.*, art. 2, sec. 3(a) and (b). The idea of protected species and natural habitats is detailed at Directive 79/409/EEC. art. 4(2) and at Directive 92/43/EEC Annexes II and IV.

122 ELD, *supra* at note 107, art. 2, sec. 1(a).

injuries and harms that might result from offshore methane hydrate accidents.

3.1.1.2. Lack of applicable Annex III activities

The listed activities under Annex III do not appear to overlap with the general nature of methane hydrate projects. Annex III activities do not include activities that substantially related to methane hydrate project related activities.[123] Issues of waste management, water disposal management, and water abstraction might be relevant to a methane hydrate project, but it is not clear that the intent of the Annex III listings had such an offshore purpose in mind.[124] It is also not clear that the operations at an offshore methane hydrate project would be seen as in the manufacture, use, storage, etc., of dangerous chemicals.[125]

3.1.1.3. Potential non-Annex III activities

Given the lack of applicable activities under Annex III and the lack of clearly excludable conventions under Art. 4, unless the environmental risks of methane hydrates are included within the scope of Annex III, those harms would likely only be found applicable under the at fault or negligence rule of Art. 3, Sec. 1(b). Thus, some focus needs to be put on those non-Annex III occupational activities that could damage protected species and natural habitats.

While one might expect to find broad definitions of water damages as provided within the U.S.'s Clean Water Act, such is not available under the ELD. Water damage, another form of environmental damage, includes any damage that impacts "adversely affects the ecological, chemical and/or quantitative status and/or ecological potential" of the waters addressed within the River Basin Water Directive.[126] This is partially due to separate EU actions on the EU related seas and oceans.[127] However, this nuanced definition would appear to prevent the application of the ELD to the waters under which the vast bulk of methane hydrates are expected to lay, as methane hydrates lay offshore the coasts beyond the reach of the River Basin Frameworks.[128]

123 *Id.*, Annex III art. 1 to 12.

124 *Id.*, Annex III art. 2, 3, 4, and 6.

125 *Id.*, Annex III art. 7.

126 *Id.*, art. 2, sec. 1(b). See also Directive 2000/60/EC, art. 2, sec. 1., infra, for surface water definitions relied on by this ELD. See also "waters" at ELD, *supra* at note 107, art. 2, sec. 5., which nominally limits waters to just that of the River Basin Frameworks. See the River Basin Frameworks at Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy. Official Journal of the European Union - Legislative. Vol. 327., 22 December 2000, p. 1-72.

127 *See* the discussion, *infra*, sec. 6.1 and 6.3, on the various water protection frameworks within the EU.

128 *See* discussions on methane hydrate geology and geography, *supra*, at Chapters 2 and 3. *See also* footnote 116, *supra*, on potential extension of ELD into offshore waters if the Offshore Directive, *infra* at note 169, were applicable to methane hydrates.

It is also difficult to connect the onshore harms of cataclysmic methane hydrate accidents to application under the ELD. Land damage is defined in a fairly limited sense to impacts on human health; "significant risk of human health being adversely affected as a result of the direct or indirect introduction, in, on or under land, of substances, preparations, organisms or micro-organisms." [129] Perhaps sudden inundation by water would qualify as an 'introduction of a substance that could adversely affect human health,' but it reads beyond the intent of the ELD.

There is a potential argument to boot-strapping the ELD into regulating the development of methane hydrate projects, in that *arguendo* methane hydrates are *themselves* a natural resource deserving protection under Art. 2.[130] The definition of damage includes reference to adverse change to a natural resource; to the extent that a methane hydrate project did damage the hydrate deposits, the impairment of use and production for future generations, then the notion of environmental damage might reasonably apply.[131] However, natural resource is a defined term within the ELD and appears to exclude natural resources such as methane hydrates, as they are not generally considered to be "protected species and natural habitats, water and land," especially as land damage is previously defined at that which causes adverse risks to human health by the introduction of substances, preparations, organisms or micro-organisms.[132]

Finally, there may be some protected species and natural habitats in the vicinity of methane hydrate projects; but it is most likely that if protection of the species and habitats near methane hydrates are to be protected that they will need to be more explicitly detailed as target under the relevant frameworks. Protected habitats could include methane hydrates, as "1180 Submarine structures made by leaking gas" is a designated habitat under the Habitats Directive,[133] but 1180 is not currently listed as a priority habitat and thus is not protected under the ELD.[134] It is also not clear that the structures itemized at 1180 are methane hydrate deposits versus other sources of subsea methane such as a volcanic vent.[135] The 1180 is

129 ELD, *supra* at note 107, art. 2, sec. 1(c).
130 *Id.*, art. 2, sec. 2.
131 *Id.*, art. 2, sec. 2.
132 *See id.*, art. 2, sec. 1(c) and 12.
133 Directive 92/43/EEC's Annex I, See also Interpretation Manual of European Union Habitats. European Commission. EUR 28. DG Environment. Habitats Committee. April 2013, at 16-17. *available* at http://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int_Manual_EU28.pdf.
134 Interpretation Manual of European Union Habitats. European Commission. EUR 28. DG Environment. Habitats Committee. April 2013. Pp. 16. *available* at http://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int_Manual_EU28.pdf.
135 Interpretation Manual of European Union Habitats. European Commission. EUR 28. DG Environment. Habitats Committee. April 2013, at 16. *Available* at http://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int_Manual_EU28.pdf. The Manual describes structures of carbonate cement and is less focused on the underlying reservoirs from whence the methane originates; the manual is focused on the

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neither a special habitat nor is it occupied by specially protected species, so it is not an area currently protected by the Habitat's Directive. As a result, it is not likely that the ELD's damage to natural resources clause would apply to methane hydrates unless amended or clarified.

3.1.1.4. Exclusion of international conventions on civil liability

The ELD excludes a list of pre-existing conventions that are of a more specialized nature and thus deemed better suited to the particular harms addressed within those conventions.[136] Of the conventions listed at Annex IV, four of the five listed address oil pollution:

i. "International Convention of 27 November 1992 on Civil Liability for Oil Pollution Damage;"[137]
ii. "International Convention of 27 November 1992 on the Establishment of an International Fund for Compensation for Oil Pollution Damage;"[138]
iii. "International Convention of 23 March 2001 on Civil Liability for Bunker Oil Pollution Damage;"[139]
iv. "International Convention of 3 May 1996 on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea;"[140]

Given this extensive exclusion of the oil spill paradigm from the ELD, one wonders to what extent events from a methane hydrate project might be likewise become excluded from the ELD. A careful reading of the excluded conventions reveal that damages discussed in those conventions are unlikely to be co-incident with a methane hydrate accident. Thus, the result is inconclusive.

3.1.2. Governance of risk within the ELD

The ELD provides that the prevention and remedying of environmental damages should be developed through the *polluter pays principle*.[141] Thus, operators of activities that create environmental damages should be required to be financially liable for those damages; this is explicitly intended to provide economic incentives

locus of plants and animals near these structures. Usually, no plants but a large diversity of invertebrates are found in these areas.

136 ELD, *supra* at note 107, art. 4. sec.2, with reference to Annex IV, and Sec. 3, with reference to certain maritime related conventions.

137 *Id.*, Annex IV, sec. (a).

138 *Id.*, Annex IV, sec. (b).

139 *Id.*, Annex IV, sec. (c).

140 *Id.*, Annex IV, sec. (d).

141 *Id.*, Preamble Sec. 2. *See also* Preamble Sec. 18 and *see* art. 1.

to motivate the operators to optimize the risks of such accidents to manage their liability exposure.[142]

The ELD presents a mixed strategy with regards to liability; the ELD distinguishes between Annex III activities and non-Annex III activities.[143] The ELD applies to environmental damages caused by activities listed at Annex III and to any damage to protected species and natural habitats caused by occupation activities not on Annex III.[144] Annex III activities are to be governed by a rule of strict liability.[145] Non-Annex III activities are to be governed by "at fault" or negligence rules.[146]

Should a competent authority find an operator nonresponsive and thus decide to undertake such measures by themselves, the competent authority is able to recover those expenditures from the operators.[147] To avoid a pass-through tax burden to tax payers, competent authorities may charge the operators fees for the transaction costs of addressing the environmental hazards and harms.[148]

The ELD is limited to addressing environmental damage, and *per se*, the ELD is categorically denied application to matters of personal injury, private property damages, and forms of economic loss.[149] It also excludes several international conventions on civil liability.[150] Additionally, the ELD yields no rights to private parties to make economic recoveries for damage to such protected species or habitats; its application remains on the public welfare.[151]

3.2. Seveso III Directive

Seveso III applies to the prevention and control of major accidents that introduce dangerous substances to the environment; is it further stated *inter materia* that the accidents are generally industrial in nature.[152] In that regard, it is similar to the perspective of the United Nations Convention on the Transboundary Effects of Industrial Accidents and indeed Seveso III is the implementation of that Convention within the EU.[153]

Seveso appears to take stronger language than the UN Convention on the Transboundary Effects of Industrial Accidents. In contrast to the Convention's repeated use of "appropriate," Seveso repeatedly relies on the phrase "all necessary measures." "Operators should have a general obligation to take all necessary

142 *Id.*, Preamble Sec. 2.
143 The ELD explicitly avoids engagement with rights of compensation for traditional damage under international agreements on civil liability. *See* ELD, *supra* at note 107, Preamble, sec. 11.
144 *Id.*, art. 3, sec. 1(a) and (b).
145 *Id.*, art. 3.1(a)
146 *Id.*, art. 3.1(b). *See also* the Preamble at sec. 9.
147 *Id.*, Preamble sec. 18.
148 *Id.*, Preamble sec. 18.
149 *Id.*, Preamble sec. 14.
150 *Id.*, Preamble sec. 11.
151 *Id.*, art. 3, sec. 3.
152 Directive 2012/18/EU. art. 1. For full citation, *see* discussion, *supra*.
153 *Id.*, Preamble at, sec. 1, 2, 3, and 5.

measures to prevent major accidents,"[154] "the operator is obliged to take all necessary measures to prevent,"[155] the Member States must inspect to ensure that "the operator has taken all necessary measures,"[156] and the discussion of the duties of a Member State after an accident uses the "necessary" phrasing thrice.[157]

3.2.1. Inapplicability of Seveso III to offshore methane hydrates

Seveso III provides the rules for the prevention of major accidents involving dangerous substances.[158] And Seveso III does include both hydrogen and natural gas as dangerous substances.[159]

However, Seveso III does not apply to the offshore exploration and exploitation of hydrocarbons such as methane hydrates.[160] Seveso III does not apply to the exploration, exploitation, extraction, and processing of minerals from boreholes such as methane hydrates.[161]

Seveso III does not apply to the underground storage of natural gas in conjunction with the exploration and exploitation of hydrocarbon such as methane hydrates.[162] And finally, Seveso III would not apply to the pipeline transport of methane, hydrogen, or other dangerous substances.[163]

As such, there is very little potential for the development of methane hydrate projects to be regulated by Seveso III.

3.2.2. Risk governance within Seveso III

Seveso III lacks a specific discussion on liability, other than of the obligations of the Member States to ensure that operators undertake all necessary measures.[164] However, the preamble makes clear that operator failed compliance should be met with penalties that should be effective, proportionate, and dissuasive.[165]

Given the mandate to provide for penalties for compliance failures and the repeated phrasings of "all necessary measures," there is a combined semantic sense of a duty that can be failed and that incentives should be provided to ensure that those duties are met. However, there is no discussion of what should occur if that duty is met and accidents still occur.

154 *Id.*, Preamble, sec. 12
155 *Id.*, art. 5, sec. 1.
156 *Id.*, art. 5, sec. 2.
157 *Id.*, art. 17.
158 *Id.*, 1.
159 *Id.*, Annex I, pt. 2, sec. 15 "Hydrogen" and 18 "Liquefied flammable gases" but not at Sec. 34 "Petroleum Products".
160 *Id.*, art. 2, sec. 2(f).
161 *Id.*, art. 2, sec. 2(e).
162 *Id.*, art. 2, sec. 2(g).
163 *Id.*, art. 2, sec. 2(d).
164 *Id.*, *en passim*.
165 *Id.*, Preamble, sec. 29.

Is a strict liability rule suggested in the requirement for the operator to undertake all measures necessary to "limit their consequences,"[166] to the mandate that the "operator takes any necessary remedial actions?"[167] It is difficult to ascertain because there is a paucity of financial responsibility clarifications with Seveso III;[168] presumably the details rest within each Member State's individualized implementation. It is perhaps more reasonable that Seveso III expects domestic regulations to be drafted and implemented as part of a command and control regulatory framework.

4. Offshore Directive

As currently enacted, the Offshore Directive[169] would likely apply to the exploration, development and production of methane hydrates from offshore operations.[170] However, it will be shown that the Offshore Directive remains focused on viscous oil spill damage and could be in need of amending to better address the potential hazards of offshore methane hydrate operations.[171]

166 *Id.*, art. 5, sec. 1.

167 *Id.*, art. 17(c).

168 Neither Annex II nor Annex IV provide explicit requirement to detail whence financing is sourced for the remediation and compensation budgets. Annex II Sec. 5(c) does refer to "mobilizable resources."

169 DIRECTIVE 2013/30/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 12 June 2013 on safety of offshore oil and gas operations and amending Directive 2004/35/EC. O.J. (L 178), 66 [hereinafter Offshore Directive].

170 Exploration and production are defined terms of the Offshore Directive, at Offshore Directive, art. 2(15) and (16) respectively. The definition of exploration includes "drilling into a prospect and all related offshore oil and gas operations necessary prior to production-related operations". *Id.*, art. 2(15). However, traditional oil and gas parlance distinguishes between "exploration," the project phase focused on finding and identifying producible oil and gas volumes, and "development," the project phase that occurs after the financial investment decision and includes all the construction, drilling and preparations prior to the onset of production activities.

171 The Offshore Directive was adopted in response to the events of April 20, 2010 when an oil and gas well broke near the christmas tree close to the seabed/ocean interface. The resulting accident brought awareness to the dangers of deep sea oil and gas exploration and production, as contrasted with the hazards of boat-based oil spills such as the Exxon Valdez of 1989. *See* Offshore Directive, Preamble at (5), see "Accidents relating to offshore oil and gas operations, in particular the accident in the Gulf of Mexico in 2010, have raised public awareness of the risks involved in offshore oil and gas operations and have prompted a review of policies aimed at ensuring the safety of such operations."

4.1. *Applicability to offshore methane hydrates*

The subject and scope of the Offshore Directive is to ensure the provision of "minimum requirements for preventing major accidents in offshore oil and gas operations and limiting the consequences of such accidents."[172]

Major accidents are defined as incidents associated with installations that involve "explosion, fire, loss of well control, or release of oil, gas or dangerous substances" and could result in substantial human injuries.[173] Other forms of major accidents include those that involve serious damage to the installation that also involve substantial human injuries,[174] events that lead to the serious injury of five or more humans,[175] or those events that could result in major environmental damages.[176] Those major accidents need to occur offshore, which is defined as those areas within the territorial seas, exclusive economic zones, or continental shelves of member states.[177] The definition of offshore parallels the zones of "marine waters" for the Marine Strategy Framework Directive, thus the applicability of those regulations on the avoidance of environmental damages applies to offshore operations.[178] Finally, offshore oil and gas operations include most regular aspects of oil and gas exploration, development and production except for trans-coastal transportation of oil and gas.[179]

As methane is natural gas, and assuming methane hydrate operations would require an installation or infrastructure, then the Offshore Directive applies to the exploration, development and production of methane hydrates from offshore waters of the Member States of the EU.[180] Events resulting from the release of methane from methane hydrate fields would be considered major accidents if they also resulted in "significant potential to cause, fatalities or serious personal injury" or if the methane ventings or seepages resulted in "any major environmental incident."[181] The additional cases of major accident also apply, those involving damages to the installation with corresponding human injuries or other incidents that result in substantial injuries to five or more persons.[182]

172 Offshore Directive, *supra* at note 169, art. 1.1.
173 *Id.*, art. 2(1)(a).
174 *Id.*, art. 2(1)(b).
175 *Id.*, art. 2(1)(c).
176 *Id.*, art. 2(1)(d).
177 *Id.*, art. 2(2).
178 Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy O.J. (L 164), 19 [hereinafter Marine Strategy Framework Directive]. *See* Marine Strategy Framework Directive, art. 3.1(a) and (b). This is also noted in Offshore Directive, Preamble at (58), which provides guidance that the "definition of water damage in Directive 2004/35/EC should be amended to ensure that the liability of licensees under that Directive applies to marine waters of Member States as defined in Directive 2008/56/EC."
179 Offshore Directive, art. 2(3).
180 *Id.*, art. 2(3).
181 *Id.*, art. 2(1)(a) and (1)(d).
182 *Id.*, art. 2(1)(b) and (1)(c).

4.2. Risk governance within the Offshore Directive

Member States are required to ensure that operators undertake all "suitable measures" of prevention, to provide that operators remain liable for the acts of their sub-contractors, and that operators undertake all "suitable measures" to limit consequences for human health and the environment.[183] The Directive requires that the Member States ensure that operators and licensees comply with the Directive.[184] The Member States are to provide penalties within their own legal systems for noncompliance. [185] The penalties should "effective, proportionate, and dissuasive."[186]

Environmental damage and harm caused by offshore activities are to be regulated under the Environmental Liability Directive. [187] The definition of environmental damage is inherited from the Environmental Liability Directive.[188] Member states do a have an affirmative duty under the Offshore Directive to ensure that licensed operators are financially liable for both prevention and remediation of environmental harms from offshore activities; this is to be accomplished by domestic legislation.[189] The phrasing suggests a rule in comport with the operations of a strict liability rule, but the requirement does not particularly require a rule of civil liability, regulatory guidance would appear to suffice.[190]

While the Preamble refers to a particular standard of care, that of "where the costs of further risk reduction would be grossly disproportionate to the benefits of such reduction,"[191] it does not appear that a rule of negligence was suggested; rather, the whole of the Directive appears to reflect the polluter pays principle and thus the rule of strict liability. [192] The licensee, as determined by Directive 94/22/EC,[193] is to be held financially liable for both the prevention and remediation of major accidents and their consequences.[194]

183 *Id.*, art. 3, sec. 1, 2, and 3.
184 *Id.*, art. 34.
185 *Id.*, art. 34.
186 *Id.*, art. 34.
187 *Id.*, art. 7.
188 *Id.*, art. 7. For a more complete discussion on the limitations of the ELD with regards to offshore methane hydrates, please see the discussion on the ELD, *infra*, at sec. 6.1.
189 *Id.*, art. 7.
190 Under the ELD, Annex III activities are *per se* under a strict liability rule, non-Annex III activities are under a "fault-based" rule. *See* discussion, *supra*, at sec. 3.1.
191 Offshore Directive, *supra* at note 169, Preamble, sec. 14.
192 All European Union environmental laws need to be read with the guidance of art. 191(2) TFEU, that the polluter pays principle is fundamental to all EU legislations. "Union policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Union. It shall be based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay."
193 Directive 94/22/EC of the European Parliament and of the Council of 30 May 1994 on the conditions for granting and using authorizations for the prospection, exploration and production of hydrocarbons. [1994] OJ L 164.
194 Offshore Directive, *supra* at note 169, art. 7.

Additionally, the Offshore Directive is subordinated to the rules under the EIA Directive, SEA Directive, and 94/22/EC.[195]

4.2.1. Call for a regulatory body

Overall, the Offshore Directive provides for a deliberate and cautious review of offshore oil and gas projects prior to their licensing and through-out their operational periods. The Member States are required to ensure the public of their participation during the review process.[196] Prior to the issuance of a license for offshore oil and gas operations, the Member States must ensure that the applicant is technically and financially capable of meeting their responsibilities under the Offshore Directive.[197] The Member States shall also ensure that the there are sustainable financial instruments made available to better provide for the financial needs of major accidents and their risk management.[198]

Competent authorities are to be established by the Member States to be responsible for overseeing the study, evaluation, regulatory compliance and monitoring of major hazards.[199] Additional requirements set out at Annex III. The competent authority is to remain independent and objective; it should not be involved in the revenue or economic development discussions related to the offshore projects it oversees.[200]

The European Maritime Safety Agency (EMSA) shall provide technical and scientific expertise to the Member States and the Commission, with special regards to the detection and monitoring of transboundary oil or gas spills.[201] EMSA may also assist in the drafting and development of the Member States' external emergency response plans; it may also develop a catalog of available emergency equipment and services.[202] EMSA may also assist the Commission in reviewing the external emergency response plans of Member States to ensure that the plans are in compliance with the Offshore Directive.[203] EMSA can also run review exercises to test the designed emergency mechanisms for major accidents.[204] EMSA has a potentially major role to play in ensuring consistent safety levels are maintained Union-wide.

195 *Id.*, art. 1, sec. 3.
196 *Id.*, art. 5.
197 *Id.*, art. 4.1. and 2.
198 *Id.*, art. 4.3.
199 *Id.*, art. 8.1(a) through (f).
200 *Id.*, art. 8.2., 8.3., and 9(a).
201 *Id.*, art. 10.1 and 10.2(a).
202 *Id.*, art. 10.2(b) and (c).
203 *Id.*, art. 10.3(a).
204 *Id.*, art. 10.3(b)

4.2.2. Regulatory actions

Member States are to require that all suitable measures are undertaken to prevent major accidents.[205] Suitable is defined to mean "right or fully appropriate", in consideration of "proportionate effort and cost, for a given requirement or situation."[206]

The Member States are also to require offshore oil and gas operations to be managed on the basis of systematic risk management so that whatever risks or hazards that cannot be eliminated are acceptable.[207] Acceptable is defined as a level of risk that the costs or efforts to further reduce its expected harms would be grossly disproportionate to the benefits received for such an effort.[208] This is not a statement that once marginal benefits exceeds marginal costs to halt efforts at risk reduction, but a defense that not all technologically feasible measures need be undertaken if, on the whole, those resources might be put to better purposes for the impacted communities.

In this process of review, the operator/licensee is to submit a variety of plans and procedural documents:

i. a corporate major accident prevention policy,[209] detailed at Annex I-8,
ii. a safety and environmental management system applicable to the installation,[210] detailed at Annex I-9 and Annex IV,
iii. a design notification for a production installation,[211] detailed at Annex I-1,
iv. a scheme of independent verification,[212] detailed at Annex I-5 and Annex V,
v. a report on major hazards for a production installation or a non-production installation,[213] detailed at Annex I-2 and Annex I-3, respectively,
vi. an amended report on major hazards in the event of a material change or dismantling of an installation,[214] detailed at Annex I-6,
vii. an internal emergency response plan,[215] detailed at Annex I-10,
viii. a notification of well operation and information on that well operation,[216] detailed at Annex I-4 and Annex II,
ix. a notification of combined operations,[217] detailed at Annex I-7,

205 *Id.*, art. 3.1.
206 *Id.*, art. 2(6).
207 *Id.*, art. 3.4.
208 *Id.*, art. 2(8).
209 *Id.*, art. 11.1(a).
210 *Id.*, art. 11.1(b).
211 *Id.*, art. 11.1(c).
212 *Id.*, art. 11.1(d).
213 *Id.*, art. 11.1(e).
214 *Id.*, art. 11.1(f).
215 *Id.*, art. 11.1(g).
216 *Id.*, art. 11.1(h).

x. a relocation notification,[218] detailed at Annex I-1,

The application of these guidelines to methane hydrates is straightforward. They require the operator to demonstrate that the major hazards and potential accidents are well understood.

i. Each and every potential major hazards resulting from the exploration and production of methane hydrates needs to be identified and cataloged. Not only surface-related hazards but also those subsea- and seabed-related should be thus identified.
ii. The potential environmental harms from venting or seeping methane and resultant metabolites such as carbon dioxide needs to be inventoried. If additional chemicals are involved in the production of methane hydrates, such as injected carbon dioxide or in-situ fuels and oxidizers, then their potential environmental harms also need to be included in that study.
iii. The interactive effects of multiple wells into a common deposit, the effects of various production stimulation efforts, the impacts of field deterioration, all of the combination events that might impact major hazards or major accidents should be analyzed. With regards to methane hydrates, particular attention needs to be placed on subsea and seabed activities.
iv. The likelihood and consequences of all of the major hazards of methane hydrate exploration and production need to be determined. Environmental, meteorological and seabed limitations on safe operations need to be evaluated from the perspective of methane hydrate fields and not from traditional oil and gas well stability perspectives. Similarly, the environmental conditions for methane hydrates may need to include consequences from landslides, tsunamis, and oxygen-deprived atmospheres near the major accident sites.
v. A list of operations and expected correlated major hazards will need to be drawn up for methane hydrate exploration and production. While an operator would need to report on the number of persons adjacent to the installation per the Offshore Directive, it might not suffice to stop there. Operators should probably advise on the number of people who while not involved in the operations of the installation may still be impacted as a "first wave" of injuries or deaths. Due to the tsunami, landslides, and atmospheric fire risks, those persons might be some distance from the installation.

217 *Id.*, art. 11.1(i).
218 *Id.*, art. 11.1(j).

The Member States will need to prepare their own SEAs as they develop their "plans and programs" in response to the Offshore Directive and each prospective operator will be expected to complete their own EIAs as they bring projects forward for licensing and approvals; licensing authorities are required to consult with competent authorities.[219]

Prior to the onset of well operations and the commencement of offshore exploration and production, the Member States are required to ensure that the operators have in place internal emergency response plans.[220] The Member States are to ensure the operator retains and maintains appropriate expertise and equipment to perform its internal emergency response plans without delay whenever major hazards should emerge.[221] The Member States are also required to bring forward their own external emergency response plans and acts of emergency preparedness.[222] Annex VII and Annex VIII provides guidelines for the drafting of the external emergency response plans together with the operators;[223] once drafted the plans should be shared with the Commission and the general public for feed-back.[224]

Once operations commence, the Member States have the duty to require that the operator is taking all reasonable steps, in light of the definition of suitable, to carry out its functions and duties under the Offshore Directive.[225] If a Member State ascertains that an operator no longer has the capacity to meet the relevant requirements, it should remove that operator and replace the operator with a new qualified operator.[226] Amidst all of the EIA and similar risk and hazard studies that need to be presented, reviewed and enforced, the Member States need to enforce a variety of other measures as well. The Member States must ensure that only properly licensed parties are operators of installations within their jurisdictions.[227] Member States are required to enforce safety zones around the approved and permitted installations.[228] The Member States need to ensure that independent verification of the various risk and hazard studies is performed prior to the completion of design for production installations or prior to the onset of operations for non-production installations; the Member States must provide that the feedback from independent verifiers must be taken into consideration by the operators.[229] The Member States are to ensure that both the plans and the equipment necessary to address major hazards or major accidents is constantly kept ready and in place by

219 *Id.*, Preamble at (16) and Offshore Directive, *supra* at note 169, art. 4.2. and 5.1.
220 *Id.*, art. 28.1.
221 *Id.*, art. 28.2.
222 *Id.*, art. 29.1.
223 *Id.*, Annex VI.
224 *Id.*, art. 29.2 and 3.
225 *Id.*, art. 6.1., 2., 3.
226 *Id.*, art. 6.4.
227 *Id.*, art. 6.1. and 6.2.
228 *Id.*, art. 6.7.
229 *Id.*, art. 17.

the operators.[230] Member States are also required to investigate into major accidents outside of the EU if the operator is also registered within their jurisdiction.[231]

The Offshore Directive does provide for extensive research and investigation into the potential causes and concerns related to major hazards and major accidents. Note the constellation of required documents focused on safe operation of offshore operations: the report on major hazards, a safety and environmental management system, a corporate major accident prevention policy, and the combination of internal and external emergency response plans.[232] When combined, they present a host of obligations on the part of potential operators of offshore methane hydrate operations.

The report on major hazards, for either production installations or non-production installations, is be developed by the operator in conjunction with its workers' representatives.[233] In addition to data on the companies and employees involved in the proposed installation, the report should include a complete description of the proposed installation.[234]

5. Carbon Capture and Sequestration Directive

Directive 2009/31/EC, the "CCS Directive,"[235] provides for the regulation of geological storage of carbon dioxide.

5.1. Applicability to offshore methane hydrates

While the CCS Directive is intended to apply to the sequestration of carbon dioxide, as discussed in Chapter 3, many suggested plans for offshore methane hydrate projects include carbon dioxide injection and sequestration in to the depleted methane hydrate reservoirs. In those cases, the CCS Directive would apply directly to those types of offshore methane hydrate projects. Also, the concerns with gas leakage from subsurface reservoirs have parallels within the risks of offshore methane hydrate production stage and abandonment and sequestration stage.

The geological storage of carbon dioxide for the purposes of the CCS Directive is defined to be the injection of carbon dioxide streams into underground geological formations.[236] The CCS Directive applies to all geological storage of carbon dioxide within the territory of the Member States, including within their Exclusive

230 *Id.*, art. 19. Also additional requirements enumerated at Offshore Directive, Annex IV.
231 *Id.*, art. 20.
232 *Id.*, art. 11.
233 *Id.*, art. 12.1 and 2.
234 *Id.*, Annex I-2(1), (2), and (4).
235 Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006, O.J. (L.140), 114 [hereinafter CCS Directive].
236 *Id.*, Art. 3.1.

Economic Zones and on their continental shelves per UNCLOS.[237] If the methane hydrates from those offshore zones were developed in conjoined re-injection of carbon dioxide into the hydrate deposits, then the CCS Directive would apply to the methane hydrate project. The storage of carbon dioxide within the water column is prohibited.[238]

5.2. *Risk governance within the CCS Directive*

The preamble to the CCS Directive indicated that the liability matters related to the operations of CCS facilities is to be broken up by the underlying character of the damages. Environmental harms and damages are to be governed by the ELD[239] and climate change harms and damages by the Directive 2003/87/EC.[240]

As was discussed, *supra* at Section 3.1, the ELD itself provides little foundation for governing the risks associated with offshore methane hydrates; so to the extent that environmental harms would result, the Offshore Directive would likely not provide sufficient incentives to the operators to employ optimal levels of due care or activity. It is also unclear, due to the bifurcated liability rules of the ELD, if methane hydrate accidents would be governed under its strict liability rule for Annex III activities or under its Art. 3.1(b) 'at fault' or negligence rules.

Directive 2003/87/EC, as amended, provides for penalties in the case of unpermitted or excessive greenhouse gas emissions.[241] Violators are required to purchase and submit sufficient allowances or to make payment of an excess emissions penalty.[242] There is no provision for civil liability; the effort to govern greenhouse gases is solely regulatory in nature. This directive would apply to vented or seeped methane from offshore methane hydrate projects as methane is one of the listed greenhouse gases under Annex II of the Directive.[243]

237 *Id.*, 2.1. S*ee also* art. 2.2 that excludes certain research and testing projects from regulation under the Directive.

238 Art 2.4. This is parallel to the regulations in the Marine Framework, which do regulate the emission of carbon dioxide and methane gases into the water column. See, *infra,* at sec. 4. While when methane is released at depth into the water column with insufficient velocity that methane is likely to become metabolized by local biota into carbon dioxide, it is not reasonable that such transport of methane into the water column should be interpreted as water-storage of carbon dioxide.

239 For a discussion of risk governance under the ELD, please see the discussion, *supra*, at sec. 3.1.

240 CSS Directive, Preamble, sec. 30. Directive 2003/87/EC is the directive that established the greenhouse gas emission trading systems within the EU. *See* Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC (Text with EEA relevance). Official Journal of the European Union – Legislative. 275, 25/10/2003, p. 32–46.

241 Directive 2003/87/EC, art. 16.

242 *Id.*, art. 16, sec. 2 and 3.

243 The list of chemicals denoted as greenhouse gases by Annex II are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs) , perfluorocarbons (PFCs), sulphur hexafluoride (SF_6). Directive 2003/87/EC. Annex II.

Member states are required to enact penalties for regulatory noncompliance within domestic law that are "effective, proportionate, and dissuasive."[244]

5.2.1. Assignments of Liability

In the event of a "significant irregularity," the competent authority is to require that the operator take the necessary corrective measures.[245] Should the operator fail to do so, then the competent authority is required to assume control and undertake the necessary corrective measures itself with the operator remaining liable for the costs of such efforts.[246] While the original version of Directive 2003/87/EC provided that greenhouse gas emissions related to force majeure events would be potentially excludable from penalty, the current enactment no longer contains that provision.[247]

At closing of the facility, the operator is to remain liable for the potential accidents from the storage facility until it has been deemed that the carbon dioxide will have been completely and permanently contained.[248] After that point in time, the liabilities for the storage facility would be transferred to a competent authority.[249]

5.2.2. Regulatory actions

When the CCS Directive is applicable, the operators will be required to complete EIAs. The selection of storage sites,[250] the permitting of exploration permits,[251] and the permitting of storage,[252] are likely to be seen as part of a "private project ... likely to have significant effects on the environment" and "involving the extraction of mineral resources" and thus require the completion of an EIA.[253]

If an EIA is required, then the CCS Directive provides clear guidance on safety planning with regards to overall geological stability and risk assessment.[254] These

244 CCS Directive, *supra* at note 235, art. 28. *See also* Preamble, sec. 42.
245 *Id.*, art. 16, sec. 1 and 2.
246 *Id.*, art. 16, sec. 4 and 5.
247 Directive 2003/87/EC. Formerly at art. 29.
248 *Id.*, art. 18.
249 *Id.*, art. 18.
250 CCS Directive, *supra* at note 235, art. 4
251 *Id.*, art. 5
252 *Id.*, art. 6.
253 *Id.*, art. 1.1 and 1.2.
254 Art. 7 details the informational requirements for storage permits. An assessment of the expected reliability of the storage facility is required at art. 7.3, the engineering details of expected field operations are required at art. 7.4., and a description of the preventative measures on significant irregularities is required at art. 7.5, art. 13 requires an extensive monitoring capability prior to permitting. Ongoing comparisons between modeling expectations and observed data are required at art. 13.1(a), the detection of significant irregularities is required at art. 13.1(b), the detection of migrating gas volumes is required at art. 13.1(c), the detection of leaking gas volumes is required at art. 13.1(d), the detection of significant adverse effects to the environment is required at art. 13.1.(e), the assessment of the →

safety regulations are also a strong model for regulating the field safety of methane hydrate projects. In many places, one could replace “storage complex” with “methane hydrate deposit” and have a good first approximation of draft methane hydrate regulations.

Annex I to the CCS Directive provides detailed guidance on what data and analyses should be provided in evaluating the safety of the storage complex of the CCS project and its surrounding area.[255] First, a wide array of scientific and engineering data must be collected.[256] Then, a variety of models must be produced to research potential future risks and hazards.[257]

The CCS Directive provides a detailed method for conducing risk assessments. There are three main components of that assessment, the exposure assessment, the effects assessment, and the risk characterization.[258] The exposure assessment focuses on the “environment and the distribution and activities of the human population above the storage complex, and the potential behavior and fate of leaking CO2 from potential pathways.”[259] This assessment demonstrates the nexus of the communities at risk versus the potential location of hazardous ventings and seepages. The effects assessment examines the particular risks and hazards of the venting and seeping gas on the various biota in the impacted communities, including on humans.[260] The risk characterization is a combination of several reports on the short-term and long-term expected safety, or lack thereof, from the proposed conditions of field usage.[261] The risk characterization should also include analysis and modeling of worst case scenarios.[262]

effectiveness of corrective measures is required at art. 13.1.(f), and the continual assessment of the overall safety and stability of the storage complex is required at art. 13.1.(g).

255 *Id.*, Annex I, Steps 1, 2, and 3.

256 *Id.*, Annex I, Steps 1. Steps 1(a) through (g) requires the collection of a wide variety of data types, including geology and geophysics, hydro-geology, reservoir engineering, geochemistry, geo-mechanics, and seismicity and surveillance on natural and man-made pathways that could provide leakage pathways. Steps 1(h) through (l) require the collation of potential interactions with local flora, fauna, and habitats.

257 *Id.*, Annex I, Steps 2 and 3. Step 2 requires the building of a complicated three-dimensional geological earth model that can be used to forecast and understand likely stability and danger scenarios. Step 3 requires that the model developed in Step 2 be used to perform dynamic behavior models of the CCS activities.

258 *Id.*, Annex I, Step 3.3.2., 3.3.3, and 3.3.4.

259 *Id.*, Annex I, Step 3.3.2.

260 *Id.*, Annex I, Step 3.3.3

261 *Id.*, Annex I, Step 3.3.4.

262 *Id.*, Annex I, Step 3.3.4.

6. The Marine Framework

6.1. Marine Strategy Framework Directive

The MSF Directive requires that Member States develop strategies to ensure the present health and future viability of EU marine ecosystems and that such plans are developed and in place by the year 2020.[263]

To the extent that the "programs of measures" called for under the Directive qualify as "plans and programs" under the SEA Directive, then they should be coordinated with the requirements of the SEA Directive; as such, there are opportunities for the public to engage in the drafting of the MSF Directive's "programs of measure".[264]

The Member States are obligated under the Directive to implement marine strategies to:

> "(a) protect and preserve the marine environment, prevent its deterioration or, where practicable, restore marine ecosystems in areas where they have been adversely affected;"[265]
>
> "(b) prevent and reduce inputs in the marine environment, with a view to phasing out pollution … so as to ensure that there are no significant impacts on or risks to marine biodiversity, marine ecosystems, human health or legitimate uses of the sea."[266]

The reference to "no significant impacts" clearly requires some rationalization of which harms are significant and which impacts are not; ergo, it recognizes that some impacts are indeed tolerable and acceptable. The applied marine strategies are to take an ecosystem level perspective, this also suggests a net-sum perspective and the legislative permission to make trade-offs for the greater social welfare as the same section calls for the sustainable use of marine resources for future generations of human beings.[267]

The MSF Directive has a broad definition of marine waters, they are defined as including the "waters, seabed and subsoil on the seaward side of the baseline" extending as far out as its Member States exercise jurisdiction under UNCLOS, to the EEZ or coastal shelf claims.[268] Marine waters also include coastal waters, to the extent not already addressed by other EU Directives or legislation.[269] Also to be

263 Marine Strategy Framework Directive, *supra* at note 178, art. 1, sec. 1.
264 *See supra*, sec. 2.
265 Marine Strategy Framework Directive, *supra* at note 178, art. 1, sec. 2(a)
266 *Id.*, art. 1, sec. 2(b)
267 *Id.*, art. 1, sec. 3.
268 *Id.*, art. 3, sec. 1(a). *See also* discussion on UNCLOS, the EEZ and other marine jurisdictions, *supra* at ch. 8, sec. 2.
269 *Id.*, art. 3, sec. 1(b).

included within the scope of the MSF Directive's purview are the major marine areas already covered by separate conventions.[270]

Good environmental status is positively defined with the upbeat markers of ecological diversity, of clean, healthy and productive oceans, and of sustainability for the future generations.[271] The physiographic, geographic, geologic, climatic, hydro-morphological, physical, and chemical properties and characteristics of the ecosystems are to be protected and preserved.[272] Pollution is defined as the direct or indirect introduction into the marine waters of items that could cause harm to those marine water ecosystems.[273] Sources of pollution can include human activity, substances, energy, and anthropogenic noise.[274]

6.1.1. Applicability to offshore methane hydrates

The Marine Strategy Framework Directive, (MSF Directive),[275] would likely apply to the development of methane hydrate projects.

The regulation of methane hydrate projects could be effected via the development of specific components of marine strategies applied to areas containing methane hydrate deposits. The MSF Directive requires its implementation in all of the marine areas of the EU and its Member States dependencies,[276] thus it covers the areas that contain methane hydrates.[277]

Each area containing methane hydrate deposits will need to address them within a program of measures to achieve and maintain good environmental status.[278] When the hydrates overlay transboundary marine ecosystems, then a regional cooperative effort is called for by the directive.[279] If pre-existing regional conventions are already in place, then those conventions are called on to extend to adopt these measures and strategies.[280]

The marine strategies would need to adopt a survey position on the targeted good environmental status, the strategies are to be developed in alignment with the descriptor elements in the Directive's Annex I and the scientific factors at Annex

270 *Id.*, art. 4. Sections. 1 and 2. For examples of pre-existing conventions, see the Barcelona Convention on the Mediterranean Sea, the Bonn Agreement on the North Seas, or the Helsinki Convention on the Baltic Sea.

271 *Id.*, art. 3, sec. 5.

272 *Id.*, art. 3, sec. 5(a) and (b).

273 *Id.*, art. 3, sec. 8.

274 *Id.*, Thus the activities of the development and operation of a methane hydrate project would conceivably engage in multiple potential sources of pollution beyond just methane leakages and venting; they could introduce a variety of noises or energy sources into the marine waters. Additionally, there is potentially argument to be made that the energy released into the ocean by methane hydrate related landslides or tsunamis could be seen as energy releases from the project and thus be listed as a source of pollution under this Directive.

275 Marine Strategy Framework Directive, *supra* at note 178.

276 *Id.*, art. 4, sec. 1 and 2.

277 *See* discussion on methane hydrate geography, *supra* at ch. 2, sec. 3 and 4.

278 Marine Strategy Framework Directive, *supra* at note 178, art. 5, sec. 2(b)(i).

279 *Id.*, art. 6, sec. 1 and 2.

280 *Id.*,. 6.

III.[281] The programs should itemize what actions need to be undertaken to ensure the achievement or maintenance of good environmental statuses for the targeted marine environments.[282] The programs should establish a set of indicators and tests that can provide on-going metrics for the observation of the programs once in place.[283] It is required that the programs of measures are cost-effective and technically feasible and that cost-benefit analyses are undertaken to affirm those requirements prior to the placement of those measures into service.[284] The costs of the development of the plans and their placement into service are to be supported by EU funding due to the priority of the agenda to sustainably preserve the marine environment.[285]

It is at that pre-activation stage of planning that methane hydrates and the potential for harms and hazards from the development of methane hydrates projects could be included within these marine strategies. Particular attention could be brought to the potential to affect sea-floor integrity,[286] as seen with anthropogenic stressors leading to additional methane venting or seeping with its potential for subsea landslides. Similarly, the various activities and effects of methane hydrate exploration and extraction could lead to various introductions of noise and energy that could adversely affect the marine environment, these potential sources of pollution need to be discussed under the Directive.[287]The potential for the effects of vented or seeped methane to create eutrophication in the waters and its potential adverse effects on marine biota could be another point of concern under the Directive.[288] The observation of metrics on these concerns should be supported under the program of measures; effective monitoring programs should be put in place if the above concerns are found to be covered by the Directive.[289]

The Commission issued its Methodological Standards Decision to further implement the MSF Directive.[290] The Decision provided an annex with greater depth on the environmental factors to consider when implementing the MSF Directive.[291] There are substantial concerns raised on the overall chemical effects of emissions into the water columns, such as nutrient levels, nutrient enrichment, and the effects on oxygen levels; all of which could be impacted by the methane venting

281 *Id.*, art. 3, sec. 5. *See also id.*, art. 8, sec. 1(a).
282 *Id.*, art. 13, sec. 1.
283 *Id.*, art. 10, sec. 1.
284 *Id.*, art. 13, sec. 3.
285 *Id.*, art. 22, sec. 1 and 2.
286 *Id.*, Annex I, sec.6.
287 *Id.*, Annex I, sec.11.
288 *Id.*, Annex I, sec.5.
289 *Id.*, Annex V. *See also* art. 11, sec. 1. and art. 24.
290 2010/477/EU: Commission Decision of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters. O.J. (L 232), 14 [hereinafter Methodological Standards Decision].
291 *Id.*, Annex. *En passim.*

and seeping.[292] Also, potential physical damages to the seabed and subsurface are detailed;

> "The main concern for management purposes is the magnitude of impacts of human activities on seafloor substrates structuring the benthic habitats. Among the substrate types, biogenic substrates, which are the most sensitive to physical disturbance, provide a range of functions that support benthic habitats and communities."[293]

Similarly at Descriptor 7, there are concerns on the geological and hydrographical impacts from marine activities:

> "Permanent alterations of the hydrographical conditions by human activities may consist for instance of changes in the tidal regime, sediment and freshwater transport, current or wave action, leading to modifications of the physical and chemicals characteristics set out in Table 1 of Annex III to Directive 2008/56/EC." [294]

> "Such changes may be particularly relevant whenever they have the potential to affect marine ecosystems at a broader scale and their assessment may provide an early warning of possible impacts on the ecosystem."[295]

The concerns within Descriptor 7 certainly fit the character of methane hydrate projects.[296] The overall extraction of methane from the hydrate deposits will be substantially an exercise in sediment and freshwater transport. The potential for landslides or tsunamis from cascade events from methane venting or seeping could impact currents and wave action. These issues could certainly have the potential to affect marine ecosystems at a broader scale. Thus, methane hydrate projects would likely be regulated under this Decision, if they are regulated under the MSF Directive.

6.1.2. Risk governance within the MSF Directive

Broadly speaking the MSF Directive is not liability focused but rather focused on the development of regulatory structures to ensure the maintenance of good marine environments; nowhere within the directive does it provide for liability rules or regulatory punishments.[297] The Directive does not interface with the behavior of

[292] *Id.*, Annex. pt. B, sec. 5.1, 5.2, and 5.3. *See also* discussion on methane in water column, *supra* at ch. 4, sec. 3.

[293] *Id.*, Annex. pt. B, sec. 6.1 and 6.2.

[294] *Id.*, Annex. pt. B. Descriptor 7.

[295] *Id.*, Annex. pt. B. Descriptor 7.

[296] *See* discussion on methane hydrate hazards, *supra* at ch. 4, sec. 3 and 4.

[297] The only sense of enforcement of the MSF Directive would be in the sense that any Directive is enforceable within general EU mechanisms, but as the MSF Directive is aimed at Member State action and not private parties, civil liability rules would not be applicable for failure to develop policy and plans.

private parties except indirectly through the implementation of the marine strategies.

While not a system of civil liability, it does assign both a duty to Member States to retain and maintain certain good environmental statuses within their marine waters and it clarifies that they are to do so with cost-effective and technically feasible means.[298] A broad sense of cost/benefit analysis is found throughout the Directive.

6.2. Dangerous Substances Directive

The Dangerous Substances Directive will not apply to the development of methane hydrate projects because it has been phased out and superseded by the MSF Directive.[299] However, much of its guidance will survive within other sources incorporated into the corpus of material surrounding the MSF Directive, so it a brief review is warranted.[300]

The Directive provides that Member States are to take the appropriate steps to eliminate pollution.[301] Pollution is similarly defined as within the MSF Directive.[302] States are required to develop and implement programs to address discharges into the waters; if the substances are listed in Annex I's List II, then the substances need to be given prior authorization by the competent authorities.[303] Technically, this suggests that such emissions would be permitted and thus exempted from the ELD as permitted activities.[304]

Of particular interest is the potential lack of methane from the listed substances under Annex I. List I of Annex I presents "persistent mineral oils and hydrocarbons of petroleum origin,"[305] but methane is not a persistent hydrocarbon as it evaporates and dissipates rapidly if not explosively. List I also provides a listing for those substances that are carcinogenic, but methane is not generally thought to be carcinogenic.[306] List II includes "non-persistent mineral oils and

298 Marine Strategy Framework Directive, *supra* at note 178, art. 1, sec. 2(a) and (b) and then at art. 13, sec. 3, respectively.

299 Directive 2006/11/EC of the European Parliament and of the Council of 15 February 2006 on pollution caused by certain dangerous substances discharged into the aquatic environment of the community. Official Journal of the European Union - Legislative. O.J. (L 64), 15 [hereinafter Dangerous Substances Directive.]

300 The argument here is that it is reasonable that no lessening of environmental protections was intended by the adoption of the MSF Directive, and to the extent that the Dangerous Substances Directive provides ecological safety standards one could reasonably assume that such guidelines, for the most part, remain persuasive and effective.

301 Dangerous Substances Directive, art. 3. With reference to Annex I's List I Substances and List II Substances.

302 *Id.*, art. 2, sec. (e).

303 *Id.*, art. 6, sec. 2.

304 See discussion on the Environmental Liability Directive, *supra* at sec. 3.1.

305 Dangerous Substances Directive, Annex I, List I, sec. 7.

306 *Id.*, Annex I, List I, sec. 4. For non-carcinogenic character of methane, see the health advisory on methane provided by the New Jersey Department of Health. *Available* at http://nj.gov/health/eoh/rtkweb/documents/fs/1202.pdf.

hydrocarbons of petroleum origin," but it is not clear from the combined usage of oils and petroleum, (*i.e.*, literally "oil from rocks"), that gaseous methane would be included whereas gasoline would surely be included.[307] Also, List II includes substances that could affect the taste or smell of products derived from the waters for human consumption.[308] It is unclear if vented or seeping methane in the water column would affect the taste or smell of seafood or other such products. Ergo, methane hydrate projects might have been regulated under List II of Annex I, but it is uncertain.

6.3. Water Framework Directive

The Water Framework Directive (WFD) is very similar in intent and operations to the Marine Strategy Framework Directive.[309] Instead of a focus on marine and oceanic waters, the WFD places its focus on what might called a river basin perspective; it focuses on inland waters, coastal waters, lakes and rivers.[310] Where rivers flow into coastal areas and have confluence with saline marine waters, those transitional waters are covered by the WFD.[311] Due to this focus on waters inland and very near the coast, it is unlikely that methane hydrate deposits would be found in those waters and thus it is unlikely that methane hydrate projects would be directly regulated by the WFD.[312]

The WFD has a very similar definition of pollution to the one found in the MSF Directive.[313] Similar goals of healthy aquatic ecosystems, as found within the MSF Directive, can be found within the WFD's good ecological status, good ecological potential, quantitative status, and good quantitative status terms.[314] The Member States are required to develop programs of measures that can achieve the ecological and environmental goals set out within the WFD.[315] These programs are thus also covered by the SEA Directive, similar to the interface found within the MSF Directive.[316] The WFD also requires coordination with other environmental oriented directives, including the EIA Directive.[317]

307 *Id.*, Annex I, List II, sec. 6.
308 *Id.*, Annex I, List II, sec. 3.
309 Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. O.J. (L 327) 1 [hereinafter Water Framework Directive].
310 *Id.*, art. 2, sec. 13; art. 3, sec. 1; and art. 4, sec. 1. See also art. 2, sec. 1, 4, 5 and 6.
311 *Id.*, art. 2, sec. 1 and 6.
312 The caveat here is that the onshore facilities of a methane hydrate project, and those appurtenances in proximity to those installations in coastal waters, might be regulated under the WFD.
313 *Id.*, art. 2, sec. 33.
314 *Id.*, art. 2, sec. 21, 22, 26 and 28.
315 *Id.*, *See* art. 11, 16, and 17 on the requirement to develop programs of measures, and *see* art. 4. on the overall environmental objectives of the WFD.
316 *See* discussion on SEA Directive, *supra* at sec. 2.
317 Water Frameworks Directive, Annex VI, pt. A. *See* Sec. (v) for reference to the EIA Directive, *supra* at note 8.

7. Greenhouse Gas Mechanism

The EU has implemented the UNFCCC and its Kyoto Protocol.[318] Once a year, the Commission is to compile an EU greenhouse gas inventory.[319] This inventory will account for each Member State's greenhouse gas emissions and sinks.[320] To assist in coordination, the Community and its Member States are to establish registries to ensure accurate accounting, tracking, and accrual of records and credits.[321]

Decision 280/2004/EC provides for the monitoring mechanisms required under those agreements.[322] The targeted levels of emissions were finally set in 2010 by Commission Decision 2010/778/EU.[323] These two GHG Decisions effectively coordinate the EU's compliance efforts under the UNFCCC and the Kyoto Protocol.

7.1. *Applicability to offshore methane hydrates*

The development of methane hydrate projects potentially put at risk large reserves of methane, a listed greenhouse gas.[324] Accidents, minor or major, could be considered as greenhouse gas emission events.

The Kyoto Protocol called for the monitoring of all anthropogenic greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).[325]

Decision 280/2004/EC set a mechanism to monitor all anthropogenic emissions of greenhouse gases by sources and sinks.[326] Decision 280/2004/EC

318 For adoption of the UNFCCC, *see* 94/69/EC: Council Decision of 15 December 1993 concerning the conclusion of the United Nations Framework Convention on Climate Change. O.J. (L 33), 11. For adoption of the Kyoto Protocol, *see* 2002/358/EC: Council Decision of 25 April 2002 concerning the approval, on behalf of the European Community, of the Kyoto Protocol to the United Nations Framework Convention on Climate Change and the joint fulfilment of commitments thereunder. O.J. (L 130), 1. *See also* Decision No 280/2004/EC of the European Parliament and of the Council of 11 February 2004 concerning a mechanism for monitoring Community greenhouse gas emissions and for implementing the Kyoto Protocol. O.J. (L 49). 1. [hereinafter Decision No 280/2004/EC]

319 Decision No 280/2004/EC of the European Parliament and of the Council of 11 February 2004 concerning a mechanism for monitoring Community greenhouse gas emissions and for implementing the Kyoto Protocol. O.J. (L 49). 1. [hereinafter Decision No 280/2004/EC]

320 *Id.*, art. 4, sec. 2.

321 *Id.*, art. 6, sec. 1.

322 *Id.*

323 2010/778/EU Commission Decision of 15 December 2010 amending Decision 2006/944/EC determining the respective emission levels allocated to the Community and each of its Member States under the Kyoto Protocol pursuant to Council Decision 2002/358/EC (notified under document C(2010) 9009). O.J. (L 332), 41.

324 Decision 280/2004/EC, art. 3, sec. 1(a). *See also* discussion on UNFCCC and the Kyoto Protocol, *supra* at ch. 8, sec. 4.

325 *Id.*, art. 3, sec. 1(a). *See also* discussion on UNFCCC and the Kyoto Protocol, *supra* at ch. 8, sec. 4.

326 *Id.*, art. 1(a).

provides an accounting for both the outward emission of GHGs and an accounting of the capture and/or sequestration of GHGs to provide a net number emitted.[327] Carbon dioxide (CO_2) and methane (CH_4) are both listed as greenhouse gases to be monitored under the program.[328]

7.2. *Governing risk within the Greenhouse gas mechanism*

The Greenhouse gas mechanism is regulatory and nature and does not contemplate civil liability matters. There are financial mechanisms to dissuade Member States from exceeding their obligatory emission limits. Routine emissions of methane or carbon dioxide would need to be contained within the emission targets; methane hydrate projects would need strategies that balanced emission permits for routine emissions, emission credits for sinking activities on-site, and potential penalties for unpermitted emissions.[329] There does not appear to be a regulatory plan for cataclysmic levels of methane gas emissions.

The EU has committed itself and its Member States to reducing their emissions of greenhouse gases.[330] Member States are committed to specific reductions of their greenhouse gases.[331] Decisions 2002/358/EC, 280/2004/EC and 2010/778/EU require that each Member State and the EU as a community achieve targeted emissions level maximums, as listed and detailed in Decision 2010/778/EU.[332]

Table 1: EU Greenhouse Gas Emission Standards

Member	Allocation[333]	2020 Target
Belgium	673995528	–15 %
Bulgaria	610045827	20 %
Czech Republic	893541801	9 %
Denmark	273827177	- 20 %
Germany	4868096694	-14 %
Estonia	196062637	11 %
Ireland	314184272	-20 %
Greece	668669806	-4 %
Spain	1666195929	-10 %
France	2819626640	-14 %
Italy	2416277898	-13 %

327 *Id.*, art. 3, sec. 1.

328 *Id.*, art. 3, sec. 1(a). *See also* Decision No 406/2009/EC, art. 2, sec. 1., discussed *infra.*

329 With regards to potential penalties, *see* Directive 2003/87/EC, art. 16. This Directive was discussed, *supra*, within sec. 5.2.

330 Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020. O.J. (L 140), 136

331 *Id.*, art. 3, sec. 1.

332 Decision 280/2004/EC, art. 7, sec. 1.

333 Decision 2010/778/EU. Annex.

Cyprus	n/a	-5 %
Latvia	119182130	17 %
Lithuania	227306177	15 %
Luxembourg	47402996	-20 %
Hungary	542366600	10 %
Malta	n/a	5 %
Netherlands	1001262141	–16 %
Austria	343866009	–16 %
Poland	2648181038	14 %
Portugal	381937527	1 %
Romania	1279835099	19 %
Slovenia	93628593	4 %
Slovakia	331433516	13 %
Finland	355017545	–16 %
Sweden	375188561	–17 %
United Kingdom	3396475254	–16 %

The Decision provides that Member State emission need to remain within a specified range; they can remain within a three-year moving average and they can offset by 5% by borrowing from other year's allotments.[334] Member States can also consume Certified Emission Reductions (CERs) and Emission Reduction Units (ERUs) to account for reductions in their overall emissions.[335]

The EU provided financial incentives to remain on target for greenhouse gas emissions reductions. First, the EU can sanction a Member State by reducing their next year's allotment by the amount overused in the current year, as multiplied by 1.08.[336] Next, the Member State can be required to develop a corrective action plan within three month's of notification of default.[337] Finally, the Member States ability to plan, trade, and coordinate with other states can be curtailed until the emission targets are met.[338]

It would appear that the GHG Mechanism would extend to all emissions within the sovereign waters of EU Member States. To the extent that methane hydrates were explored and exploited within the EEZ or coastal waters of those Member States, the GHG Mechanism and its emissions tracking, regulating, and enforcement powers should be applicable to emissions from those offshore methane hydrate projects. Thus, the development of offshore methane hydrates would need to be included in national emission budgets and planning.

334 Decision No 406/2009/EC, art. 3.

335 *Id.*, art. 5, sec. 1. The Certified Emission Reductions (CERs) and Emission Reduction Units (ERUs) are established under Directive 2003/87/EC.

336 *Id.*, art. 37, sec. 1(a).

337 *Id.*, art. 37, sec. 1(b) and Sec. 2.

338 *Id.*, art. 37, sec. 1(c).

Further, cataclysmic failure at a methane hydrate field could frustrate efforts to achieve GHG emission controls via the GHG Mechanism.[339] A massive offshore emission could require substantial and immediate curtailment of onshore emissions to remain within the Mechanism targets; such a reduction would likely impact both domestic industry and public enjoyment of transportation and general energy related utilities.

8. Summary and Conclusions

The EU presents a wide array of legal instruments to govern and control risky activities, particularly those with environmental impacts.[340] They demonstrate broad support for public regulations to lead in setting preventative standards.

The EIA and SEA Directives support the general collection of information on potential environmental risk factors as related to pending reviews of both new projects and new programs or policies. It is clear that both the EIA and the SEA would be applicable to offshore methane hydrate projects and programs, respectively. In the case of methane hydrates, these collected data sets can then be employed by public authorities to ensure that sufficient standards have been set in place to address the set of risks posed by an activity under review. Additionally, that gathered set of information can also thereafter be shared with both the general public and the private parties operating the offshore methane hydrate installations. Thus the EIA and SEA serve to potentially improve standard setting measures and also to facilitate the operations of both rules of civil liability and of private regulations.

339 Perhaps the purchasing of carbon credits could somewhat facilitate a response to a major methane release event, but one suspects that the carbon credit markets would already by functioning and clearing; thus, a dramatic and unexpected need for credits would both increase prices for credits upwards and potentially still fail to provide a sufficient quantity to cover the emission target requirements. However, to the extent that such need might be foreseeable, that potential demand could be reflected in current carbon credit prices and thus enable carbon emission reductions at other non-methane hydrate facilities.

340 While the discussion has focused on achieving optimal incentives, there are clearly issues regarding the feasibility of that within the context of the EU regulatory scheme. The EU has committed itself to the precautionary principle; it has taken a policy stance that its citizens would prefer to gamble that 'no change' is safer than 'change' when knowledge is yet uncertain. To the extent that such is predicated on actual democratic voices, then rules might remain functionally optimal; but, if on the other hand, such a precautionary requirement is overcautious policy, then that principle might indeed be a form of over-deterrence. For now, this study assumes that the precautionary principle does reflect in some form the preferences of the citizens, albeit more GARP than actual preferences, as most citizens apparently prefer to protest over other matters more frequently than the precautionary principle. Nevertheless, the concerns on anthropogenic climate change and the potential incidence of cataclysmic harms such as tsunamis make the requirements of the precautionary principle less distant from ideal settings than might be the case with other less risky activities.

While many aspects of the Offshore Directive and the CCS Directive would appear applicable to offshore methane hydrate installations, both of these directives rely on the ELD and the GGM to govern environmental and climate change risks and hazards. This creates a problem, in that the ELD appears to have limited governance of the specific circumstances associated with methane hydrate accidents. This could be addressed by expanding on the protected waters under the Marine Framework and the wildlife species and protected habitats guarded by the Habitats Directive. Likewise, the GGM does not appear to explicitly provide for the type of methane or carbon dioxide emissions that might result from offshore methane hydrate projects. While the overall emission impacts could be included within national accounts, due to certain force majeure type exclusions it is not clear that the accidental emissions would be included. Also, it is not clear that those emissions that were included in national accounts would actually lead to the emitter being financially sanctioned; a lack of a readily transparent connection between emissions and economic damages could prevent the incentive mechanisms from operating efficiently.

The EU could address these concerns by a combination of actions. Prior to drafting new instruments or determining the optimal standards of preventative and operational levels, the EIA and SEA could be invoked to support early research into establishing the potential harms and hazards facing diverse EU communities. Thereafter, first, the EU could expand the range of protected habitats and protected species to protect specific areas adjacent to the methane hydrate fields. Second, methane and carbon dioxide gas emissions from seeps or venting events at offshore methane hydrate operations could become more clearly connected to the accounts of the operators. Third, the EU could update the Offshore Directive to become inclusive of concerns related to the development of offshore methane hydrates and to provide for the overlapping operations of CCS technologies and storage within those offshore sites.

Following the conclusion delivered in the previous chapter on international maritime and oil spill conventions, the legal instruments of the EU already function in much alignment with the recommendations of Chapter 7 but lack explicit language to ensure that the circumstances of offshore methane hydrates are included within that risk governance. While fresh instruments could be drafted and developed to address the circumstances of offshore methane hydrates, it appears reasonable to build upon the previously establish instruments and expand them to address offshore methane hydrates.

Chapter 10

Chapter 11

FEDERAL LAWS OF THE UNITED STATES

The United States has a sophisticated array of environmental regulations and was often an early adopter of such regulations; its National Environmental Protection Act, Clean Water Act and Clean Air Act were adopted years earlier than in many other jurisdictions.

Not unlike the results of the studies in the previous chapters on international maritime and oil spill conventions and on EU laws, U.S. federal laws on oil and gas governance remain focused on the terms of crude oil; its accident laws and environmental laws more so. The U.S. would be in need of regulatory updating to better govern the risks from the development of offshore methane hydrates. It will be demonstrated that the federal laws might be readily expandable to include the circumstances of offshore methane hydrates.

1. Introduction

The United States has a variety of legal strategies to address environmental harms caused by hydrocarbon spills and similar events. The federal regulatory system provides federal statutes and regulations on several forms of environmental damage. The U.S. federal regulatory regime includes several major planks that might address harms from methane hydrate hazards.[1] They include:

- the National Environmental Protection Act (NEPA)[2]
- the Outer Continental Shelf Lands Act (OCSLA),[3]
- the Oil Pollution Act (OPA),[4]
- the Clean Water Act (CWA),[5]

1 J. L. RAMSEUR, CONG. RESEARCH SERV., RL33705, OIL SPILLS IN US COASTAL WATERS: BACKGROUND, GOVERNANCE, AND ISSUES FOR CONGRESS, 10-12 (2010).

2 P.L. 91-190, as amended. The National Environmental Policy Act is codified at 42 U.S.C. §4321 *et seq.*

3 P.L. 95-372, as amended, codified at 43 U.S.C. §1801 *et seq.*

4 P.L. 101-380, as amended, codified at 33 U.S.C. §2701 *et seq.*

5 P.L. 92-500, as amended, codified at 33 U.S.C. §1251 *et seq.*

- the U.S.'s adoption of the International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties, 1969,[6]
- National Oil and Hazardous Substances Pollution Contingency Plan,[7]
- the Clean Air Act (CAA),[8] and
- the Methane Hydrate Research and Development Act (MHRDA).[9]

An observer is left with an interesting result. Oil spills and their environmental harms are squarely and well addressed by OPA, the CWA, and other regulatory acts. However, the concern over natural gas, *i.e.* methane, is comparatively understated for environmental harms.[10]

Nevertheless, these federal laws as a whole comport well with the recommendations of Chapter 7, for a complementary implementation of both strict liability and public regulations. Additionally, the particular semantic structure of the federal laws might facilitate the adaption of those rules more readily than might be the case in other jurisdictions. Given that combination, it could be reasonably argued that the U.S. federal laws might be expanded to include the circumstances of offshore methane hydrates. Additionally, most of the federal laws have been in place for multiple decades and offer a sense of establishment and reliability that could be built upon.

2. National Environmental Protection Act (NEPA)

Broadly stated, the National Environmental Protection Act (NEPA) provides a wide base of authority to the Environmental Protection Agency to enable deliberative efforts to be made to protect the environment of the United States.[11]

NEPA contains neither direct provisions to civil liabilities nor regulatory penalties; it much resembles the afore-discussed EU EIA Directive in that manner.[12] But its overall impact is to provide public information, which could very much impact on both the development of regulations and on the implementation of civil liability rules.

NEPA directs the EPA to handle a variety of executive and regulatory matters related to environmental legislation. One of its key duties under NEPA is the creation and administration of environmental reviews for bills of legislation.[13] Such

6 Codified at 33 U.S.C. §1471 *et seq*.

7 Codified at 40 CFR Part 300.

8 Codified at 42 U.S.C. §7401.

9 P.L. 106-193, as amended and codified at 30 USC § 2001 *et seq*.

10 This concern need not wait for the onset of offshore methane hydrates. There are numerous offshore natural gas wells that could have accidental releases of methane at levels dangerous for marine biota, human health, and climate change concerns.

11 P.L. 91-190, as amended. The National Environmental Policy Act is codified at 42 U.S.C. §4321 *et seq*.

12 *See* a discussion on the EU EIA Directive, *supra*, in Chapter 10.

13 K. ALEXANDER, CONG. RESEARCH SERV., RS20621, OVERVIEW OF NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) REQUIREMENTS, 2(2008).

bills would include the laws on leasing methane hydrate resources, laws on the regulated operations of federally held methane hydrates, and whatever environmental and tort laws would be enacted to protect the environment in the wake of methane hydrate development.

Environmental reviews are not generally drafted within the EPA but rather within the specific Department or other governmental body proposing a particular piece of legislation or path of action. NEPA requires that the environmental reviews of the bills begin concurrently with the onset of the bill's drafting and not after the bill has already been drafted. These prospective reviews are to encourage the integration of environmental considerations throughout the drafting process. Environmental reviews can take one of three forms: a categorical exclusion, (CE), an environmental assessment, (EA), or an environmental impact statement, (EIS).[14]. A CE is employed when the draft bill is expected to present no calculable environmental impact.[15] An EA is undertaken if the draft bill presents potential environmental concerns; a positive finding under an EA leads to an exhaustive EIS.[16] Finally, an EIS is a comprehensive report to address all of the identified environmental concerns once the EA has identified them.[17]. In general, federal agencies have institutionally been encouraged to tilt towards CEs and away from EAs, because they are cheaper to execute; this leaves many environmental aspects of draft bills often unexplored.[18] While the NEPA statute does not overtly require public access or participation to the review process, the associated regulations do provide those rights to the general public.[19]

Should methane hydrates approach commercial development, the NEPA will require both the drafting of rules and regulations to manage the overall impact to the American environment and NEPA will require a process that is open to the general public. NEPA also clarifies that the drafting of such bills of law will not occur within the EPA but within the departments or agencies previously appointed to oversee such areas of regulations.

3. Outer Continental Shelf Lands Act (OCSLA)

The Outer Continental Shelf Lands Act (OCSLA) would regulate those methane hydrates within U.S. territorial waters. The OCSLA provides for the recognition of the mineral assets of the United States offshore in its territorial and EEZ waters. It also provides the regulatory framework to lease those minerals.

The onset of methane hydrate development is also limited by previous efforts to prevent offshore development of oil and gas within the U.S. A variety of specific statutes banning offshore developments, *e.g.* the North Carolina Outer Banks Protection Act, and presidential executive moratoria have either directly prevented

14 *Id.*, at 3.
15 *Id.*, at 3.
16 *Id.*, at 3-4.
17 *Id.*, at 4.
18 *Id.*
19 *Id.*, at 5.

the leasing of areas offshore both the West and East Coasts or have prevented budget allocations from supporting the administrative costs of that licensing. Today only the areas offshore Alabama, Louisiana, and Texas are active in development activities.[20]

3.1. Applicability to offshore methane hydrates

OCSLA defines minerals to include both oil and gas,[21] and thus methane hydrates.[22] Likewise, OCSLA includes minerals, and thus methane hydrates, within its definitions of "lease",[23] "exploration,"[24], "development,"[25], "production,"[26] and "fair market value."[27] As such, OCSLA provides the legal foundations for leasing and economically managing methane hydrates within the U.S.'s EEZ.

What might not be expected, though, is that OCSLA provides to the Secretary of Commerce, not the Department of the Interior or the Environmental Protection Agency, the duties to perform environmental assessments on prospective and on-going methane hydrate leases and operations.[28] NEPA remains in application, nevertheless, as it applies to all federal agencies.[29]

3.2. Risk governance under the OCSLA

OCSLA calls for the implementation of a regulatory framework and an overseeing regulatory body. The Commerce Secretary is required to monitor the human,

20 *See* maps of some of the moratoria areas; *available* at http://www.boem.gov/Oil-and-Gas-Energy-Program/Leasing/Areas-Under-Moratoria.aspx .

21 OSCLA provides the legal definitions of oil and gas separately. *See* "gas means natural gas as defined by the Federal Energy Regulatory Commission," *and see* "oil means a mixture of hydrocarbons that exists in a liquid or gaseous phase in an underground reservoir and which remains or becomes liquid at atmospheric pressure after passing through surface separating facilities, including condensate recovered by means other than a manufacturing process." 30 CFR §559.002. (Underscoring added.)

22 43 USC § 1331(q) "The term "minerals" includes oil, gas, sulphur, geopressured-geothermal and associated resources, and all other minerals which are authorized by an Act of Congress to be produced from "public lands" as defined in section 1702 of this title."

23 43 USC § 1331(c) "The term "lease" means any form of authorization which is issued under section 1337 of this title or maintained under section 1335 of this title and which authorizes exploration for, and development and production of, minerals."

24 43 USC § 1331(k) "The term "exploration" means the process of searching for minerals … "

25 43 USC § 1331(l) "The term "development" means those activities which take place following discovery of minerals in paying quantities, including geophysical activity, drilling, platform construction, and operation of all onshore support facilities, and which are for the purpose of ultimately producing the minerals discovered."

26 43 USC § 1331(m) "The term "production" means those activities which take place after the successful completion of any means for the removal of minerals, including such removal, field operations, transfer of minerals to shore, operation monitoring, maintenance, and work-over drilling."

27 43 USC § 1331(o).

28 43 USC § 1346(a)(1) and (b).

29 *See* discussion on NEPA, *supra*, at Section 1.

marine, and coastal environments of the outer Continental Shelf and the coastal areas impacted by the development and production of methane hydrates.[30] The Commerce Secretary, alongside the Coast Guard, is to "require, on all new drilling and production operations and, wherever practicable, on existing operations, the use of the best available and safest technologies which the Secretary determines to be economically feasible, wherever failure of equipment would have a significant effect on safety, health, or the environment[.]"[31]

The Secretary is required to study any area included in an oil and gas lease sale in order to determine what information would be needed for the assessment and management of the environmental impacts on the human, marine, and coastal environments of the outer Continental Shelf and of the coastal areas which may be affected by oil and gas or other mineral development.[32] The collection of that data should lead to regulations to protect the human, marine, and coastal environments; thereafter the Secretary, the Coast Guard, and the U.S. Army are required to enforce those safety and environmental regulations.[33] The Act provides for both civil and criminal penalties and punishments for violations of those regulations.

OCSLA does provide for both civil and criminal penalties,[34] and it allows citizen suits against both private and public parties,[35] but generally under the Chevron doctrine the Secretary of Commerce is given broad authority to interpret the statute and regulate accordingly. OCSLA provides no specific liability, remedy or punishment for environmental harms caused by the operation of the mineral leases assigned under its authority.

4. Oil Pollution Act (OPA)

The OPA is the major federal act of addressing hydrocarbon spills within the jurisdictional waters of the United States;[36] thus it extends beyond state waters into federal jurisdictions offshore.

30 43 USC § 1346(a)(1).
31 43 USC § 1347(b).
32 43 U.S. Code § 1346(a).
33 43 U.S. Code § 1348(a).
34 43 USC § 1350.
35 43 USC § 1349.
36 While the U.S. has taken notice of UNCLOS, it has not ratified it. Its own notions of jurisdictional waters take note of the vocabulary of UNCLOS but are enacted separately under federal law. Thus, OPA applies to the EEZ of the U.S., but the legal basis is not the international standard, *per se*. *See* 33 U.S.C. § 2701 (8) "exclusive economic zone" means the zone established by Presidential Proclamation Numbered 5030, dated March 10, 1983, including the ocean waters of the areas referred to as "eastern special areas" in Article 3(1) of the Agreement between the United States of America and the Union of Soviet Socialist Republics on the Maritime Boundary, signed June 1, 1990." The U.S. EEZ extends "200 nautical miles from the baseline from which the breadth of the territorial sea is measured." *See* Presidential Proclamation Numbered 5030, archived at the UN; *available* at http://www.un.org/Depts/los/LEGISLATIONANDTREATIES/PDFFILES/USA_1983_Proclamation.pdf.

It was designed to consolidate federal regulatory authority and to clarify the liabilities attending oil spills in the wake of the Exxon Valdez incident in Alaska.[37]

4.1. Inapplicability to offshore methane hydrates

OPA applies to oil and to hazardous substances that are released in an unpermitted manner into water; but it does not apply to certain hazardous chemicals as defined under other statutes. [38] So while methane emissions might be regulated elsewhere under federal law as a hazardous substance, it is not so for OPA.

While technically methane could be included under petroleum, it would not appear to be so contemplated within OPA. [39] There is not a singular reference to natural gas or methane within OPA. §2701(2) provides a standard definition for a volume measure of a barrel of crude oil, but nowhere in OPA is there a comparable definition of volume or mass for natural gas or methane, nor are there any conversion factors provided to convert them into barrels equivalent. On the whole, accidents primarily motivated by natural gas or methane events would appear to fall outside of the scope of OPA's liability scheme.

It is clear that the drafters of OPA were concerned with the particular ecological and community damages of the Exxon Valdez crude oil incident and focused on the impact of crude oil; the exclusion of natural gas and methane may have resulted from a lack of historical accidents that would have enabled popular political action.

37 RAMSEUR, *supra* at note 1, at 12.

38 *See* the discussions, *infra*, at Section 5 on the CWA for the list of hazardous substances that apply to water. Methane is not currently listed under these laws; *e.g.*, methane is sometimes regulated under the CAA, but as an air pollutant and not as a hazardous air pollutant, which is what was carved out under OPA. For the purposes of OPA, oil "does not include any substance which is specifically listed or designated as a hazardous substance under subparagraphs (A) through (F) of section 101(14) of the Comprehensive Environmental Response, Compensation, and Liability Act [42 U.S.C. §9601] and which is subject to the provisions of that Act [42 U.S.C. §9601 et seq.][.]" That subsequent definition refers to listings of hazardous substances under the Federal Water Pollution Control Act, 33 U.S.C. §1317(a) and §1321(b)(2)(A), the Solid Waste Disposal Act, 42 U.S.C. §6921, the Clean Air Act, 42 U.S.C. §7412, and the Toxic Substances Control Act, 15 U.S.C. §2606.

39 Oil is defined as any kind of oil but it is not explicitly stated that methane or methane hydrates would be included within that term; a reasonably reading suggests that natural gas and methane would be excluded from the definition of oil. *See* 33 U.S.C. §2701 (23) "oil" means oil of any kind or in any form, including petroleum, fuel oil, sludge, oil refuse, and oil mixed with wastes other than dredged spoil, but does not include any substance which is specifically listed or designated as a hazardous substance under subparagraphs (A) through (F) of section 101(14) of the Comprehensive Environmental Response, Compensation, and Liability Act (42 U.S.C. § 9601) and which is subject to the provisions of that Act."

4.2. *Risk governance under the OPA*

OPA provides that the tortfeasor is to be held strictly liable for all public and private clean-up costs.[40] It does not displace neither state-level jurisdiction nor state-level rules of civil liability nor state regulations to the extent that such rules exist and to the extent that certain federalism issues such as pre-emption are not in conflict; thus liability for oil spills in general might fall concurrently under both federal and state laws, including OPA.[41]

There are limits to the liability imposed by OPA. Liabilities are 'capped,' or limited by the type of vessel from which the hydrocarbon escaped.[42] The listings include vessels, ports, and rigs;[43] (i) tank vessels,[44] (ii) vessels,[45] generally, (iii) onshore facilities and deepwater ports,[46] (iv) offshore facilities (excluding deepwater ports),[47] and (v) mobile offshore drilling units.[48] These five categories have limits imposed by tonnage, hulling, and character of activity.[49]

Those liability limits are set aside when the hydrocarbon spill results from acts of gross negligence or willful misconduct.[50] Thus, while OPA functions with strict liability, it is important to note that the overall liability is determined under a variant of a 'duty of care' rule. Operators that avoid gross negligence or willful misconduct are effectively sheltered from catastrophic liabilities which in turn facilitates investment in the energy sector by responsible operators. Those operators that do display gross negligence or willful misconduct lose those protections and become liable.

Additionally, it should be noted that OPA provides liability in complement to liabilities and penalty fines provided by other sources of law within the U.S., thus, it would be misleading to suggest that the complete set of damages to be faced by a

40 Nichols 2010, p. 1; RAMSEUR, *supra* at note 1, at 12. *See* 33 U.S.C § 2701(32).

41 33 U.S.C. §§ 2718(a) and (c).

42 RAMSEUR, *supra* at note 1, at 13.

43 Listings, *infra*, derive from the liability limiting rules found within 33 U.S.C. § 2704.

44 33 U.S.C. § 2704(a)(1).

45 33 U.S.C. § 2704(a)(2). *See also* 33 U.S.C. § 2701(37) "vessel" means every description of watercraft or other artificial contrivance used, or capable of being used, as a means of transportation on water, other than a public vessel."

46 33 U.S.C. § 2704(a)(3). *See also* 33 U.S.C. § 2701 (24) "onshore facility" means any facility (including, but not limited to, motor vehicles and rolling stock) of any kind located in, on, or under, any land within the United States other than submerged land." And *see also* 33 U.S.C. § 2701(6) "deepwater port" is a facility licensed under the Deepwater Port Act of 1974 (33 U.S.C. § 1501-1524)." *E.g.*, such as the crude oil offloading LOOP facility offshore Louisiana

47 33 U.S.C. § 2704(a)(4). *See also* 33 U.S.C. § 2701 (22) "offshore facility" means any facility of any kind located in, on, or under any of the navigable waters of the United States, and any facility of any kind which is subject to the jurisdiction of the United States and is located in, on, or under any other waters, other than a vessel or a public vessel."

48 33 U.S.C. § 2704(b)(1) and (2). *See also* 33 U.S.C. § 2701 (18) "mobile offshore drilling unit" means a vessel (other than a self-elevating lift vessel) capable of use as an offshore facility."

49 33 U.S.C. § 2704.

50 RAMSEUR, *supra* at note 1, at 13.

tortfeasant operator would be strictly limited to these particular limits; they are merely the liability limits under OPA.

The statue refers to both "removal costs" and "damages," reflecting that the statute pursues both the immediate and indirect notions of damages.[51] Those costs may include injury to natural resources, loss of personal property and resultant economic losses, loss of subsistence use of resources, lost revenues resulting from injuries to property or natural resources, lost profits and earnings from injuries to property or natural resources, and the costs of providing additional public services during or after the hydrocarbon spill incident.[52]

Certain damages are only recoverable by units of the federal or state government.[53] In particular are certain environmental damages and wasting acts that impact governmental revenues.[54]

5. Clean Water Act (CWA)

The Clean Water Act (CWA) would likely govern neither methane hydrates nor their potential association with environmental harms. Methane has not been included within the more general oil spill and hazardous substances discharge rules.

5.1. Inapplicability to offshore methane hydrates

Oil is defined as a viscous liquid and not as a gaseous substance.[55] As such, methane and other natural gases would not qualify as oil. Similarly, there is a volumetric measure for crude oil, at "barrel," but no such legal definition is provided for emitted gas within the CWA.[56]

Methane from methane hydrates is not likely to qualify as chemical wastes, nor is it likely to fit any of the other enumerated items. It could be defined to become included under the term hazardous substances, but such would require explicit

51 *See* an example of such phrasing at 33 U.S.C. § 2702(a). *See also* § 2701 (5) "damages" means damages specified in section 1002(b) of this Act [33 U.S.C. § 2702(b)], and includes the cost of assessing these damages." And *see also* § 2701 (30) "remove" or "removal" means containment and removal of oil or a hazardous substance from water and shorelines or the taking of other actions as may be necessary to minimize or mitigate damage to the public health or welfare, including, but not limited to, fish, shellfish, wildlife, and public and private property, shorelines, and beaches."' And *see also* § 2701 (31) "removal costs" means the costs of removal that are incurred after a discharge of oil has occurred or, in any case in which there is a substantial threat of a discharge of oil, the costs to prevent, minimize, or mitigate oil pollution from such an incident."

52 RAMSEUR, *supra* at note 1, at 12-13.

53 33 U.S.C. § 2702(b)(2)(D).

54 33 U.S.C. § 2702(b)(2)(D).

55 33 USC § 1321(a)(1) "oil" means oil of any kind or in any form, including, but not limited to, petroleum, fuel oil, sludge, oil refuse, and oil mixed with wastes other than dredged spoil;

56 33 USC § 1321(a)((13) "barrel" means 42 United States gallons at 60 degrees Fahrenheit.

listing within the associated regulations.[57] The current listing of hazardous substances includes no mention of natural gas, methane, ethane, or butane.[58] Thus as methane is neither an oil nor a listed hazardous substances, its emissions into the water *sans* co-produced oil are not covered by the CWA.

Furthermore, oil and gas operations are specifically spoken of within this section; it excludes certain materials associated with oil and gas production.[59] The CWA excludes "water, gas, or other material which is injected into a well to facilitate production of oil or gas, or water derived in association with oil or gas production" from inclusion within the definition of pollutants.[60] Thus, potential injectants into the hydrate deposits, such as carbon dioxide, would be exempt from the CWA; *caveat*, such injectants would need their own permitting as part of the operator's licensing arrangement.

5.2. Risk governance under the CWA

The CWA is a very broad grant of regulatory power that supports much of the EPA's activity base. As such, it supports a regulatory body.

The CWA does provide for both regulatory penalties and civil liabilities for oil spills and hazardous substances discharges. The regulatory penalties provide for an administrative hearing process and are limited to $125,000.[61]

Should the Secretary opt to forego the administrative route for judicially enforced civil liabilities, the judgment can get much larger.[62] The civil liabilities are based on both the volumes of oil spill and a determination of the character of causations. Polluters of spilt volumes are to be held liability under a rule of strict liability.[63]

Spilling events not derivative of grossly negligent behavior face liabilities *cum* civil penalties in an amount up to $ 25,000 per day of violation or an amount up to $ 1,000 per barrel of oil or unit of reportable quantity.[64] If the accident follows from grossly negligent behavior, then the liabilities *cum* civil penalties increase to not less

57 *See* 33 USC § 1321(a)(14), directing the definition of hazardous substances to the rule of (b)(2) and *see also* 33 USC § 1321(b)(2)(A) The Administrator shall develop, promulgate, and revise as may be appropriate, regulations designating as hazardous substances, other than oil as defined in this section, such elements and compounds which, when discharged in any quantity into or upon the navigable waters of the United States or adjoining shorelines or the waters of the contiguous zone or in connection with activities under the Outer Continental Shelf Lands Act or the Deepwater Port Act of 1974, or which may affect natural resources belonging to, appertaining to, or under the exclusive management authority of the United States (including resources under the Magnuson-Stevens Fishery Conservation and Management Act of 1976), present an imminent and substantial danger to the public health or welfare, including, but not limited to, fish, shellfish, wildlife, shorelines, and beaches.

58 40 CFR 117.3

59 33 USC § 1362(6)(B).

60 33 USC § 1362(6)(B).

61 33 USC § 1321(b)(6).

62 33 USC § 1321(b)(7)(F).

63 33 USC § 1321(b)(7).

64 33 USC § 1321(b)(7)(A).

than $ 100,000, and not more than $ 3,000 per barrel of oil or unit of reportable quantity.[65]

6. Intervention on the High Seas in Cases of Oil Pollution Casualties

Under the U.S.'s adoption of the International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties, 1969, [66] offshore methane hydrates operations would not likely be regulated

Oil is defined as 'convention oil', *i.e.*, "crude oil, fuel oil, diesel oil, and lubricating oil."[67] Non-liquid gaseous volumes such natural gas or methane would not be seen as included within convention oil. Similarly, "a substance other than convention oil" is defined to mean those oils, noxious substances, liquefied gases, and radioactive substances specifically listed within the protocol or determined to be a hazard to human health, to harm living resources, to damage amenities, or to interfere with other legitimate uses of the sea.[68]

Natural gas or methane is only listed if included within "liquified gases" or as a harm to living resources as an interference with legitimate usages of the sea. Methane as extracted from offshore deposits would not manifest as a liquefied gas until substantially downstream of the extraction process. Methane is rendered into LNG only when prepared for oceanic transport via boat; should the methane be transported onshore for processing and marketing no LNG would likely be produced.

Similarly, methane does not generally find itself included within noxious gases and it generally has no affinity with radioactivity, thus, it would likely fail to be included under the listings of those "oils, noxious substances, liquefied gases, and radioactive substances … determined to be a hazard to human health," as methane would likely be qualified as one of the four categories.

7. National Oil and Hazardous Substances Pollution Contingency Plan

For similar reason as seen in the U.S.'s Intervention on the High Seas in Cases of Oil Pollution Casualties, the National Oil and Hazardous Substances Pollution Contingency Plan has not been applied to methane environmental hazard planning. Natural gas is usually not considered to be either oil or a hazardous substance . Also, most emergency response planners have not foreseen a need for "methane clean-up" in the same way that they need to plan for crude oil clean up operations.

65 33 USC § 1321(b)(7)(D).
66 Codified at 33 U.S.C. §1471 *et seq.*
67 33 U.S.C. §1471(3)
68 33 U.S.C. §1471(1) and at (1)(B) in reference to 33 U.S.C. §1473(a).

8. Clean Air Act (CAA)

The Clean Air Act (CAA) could regulate methane emissions from crude oil and natural gas production operations, but so far methane has not been included. In a letter sent by New York Attorney General Eric T. Schneiderman to Lisa P. Jackson, the Administrator of the Environmental Protection Agency, he announced that the state of New York intended to sue the EPA to bring about changes in the CAA to include the regulation of methane emissions from oil and gas operations.[69] New York was joined in the letter by the states of Connecticut, Delaware, Maryland, Massachusetts, Rhode Island, and Vermont. The letter explains that while the EPA issued preliminary regulations on methane emissions from oil and gas operations in 1985, those regulations were never made effective, contrary to the requirements of 42 U.S.C. § 7411(b)(1)(B). The states argue that the EPA needs to regulate methane emissions from existing sources of methane emissions, as well as from new and modified facilities, under 42 U.S.C. § 7411(d)(1)(A). This case has not yet been brought to court and it will be several years at least before a final decision is rendered. But it is clear from the substantial efforts of these many states that the CAA is not currently regulating methane emissions and thus the CAA is not currently applicable to potential methane hydrate events or accidents.

9. Methane Hydrate Research and Development Act (MHRDA)

The Methane Hydrate Research and Development Act[70] (MHRDA) provided for the financing of research to develop technologies that could reduce the incidence and impact of damages from methane hydrate development, from methane "degassing" and from events related to drilling into methane hydrate deposits. But the MHRDA makes no provisions for the development or use of regulations on environmental hazards from methane hydrate development.

The MHRDA was originally passed in 2000 and amended in 2005. Its design is to support the funding for research and development in methane hydrates; all of the research and development activities are to be coordinated by the Department of Energy.[71] It provides for no civil liabilities and provides for little in the way of regulations beyond standard NEPA requirements. It does provide a research budget to ascertain if those items might become necessary.

Intriguingly, nowhere in the act are methane hydrates or gas hydrates defined; the only functional reference to their character is a statement that methane hydrates can offset the decline in America's domestic natural gas assets.[72]

69 Letter from New York Attorney General Eric T. Schneiderman to EPA Administrator Lisa P. Jackson. Available at the website of the New York Attorney General,http://www.ag.ny.gov/pdfs/ltr_NSPS_Methane_Notice.pdf .

70 P.L. 106-193, as amended and codified at 30 USC § 2001 *et seq*.

71 30 USC § 2003(a)(3).

72 The quote: "methane hydrate may have the potential to alleviate the projected shortfall in the natural gas supply." 30 USC §2001(5).

9.1. *Risk governance under the MHRDA*

While there is a requirement for the investment in projects that:

"(D) assist in developing technologies required for efficient and environmentally sound development of methane hydrate resources;"[73]

"(F) conduct basic and applied research to assess and mitigate the environmental impact of hydrate degassing (including both natural degassing and degassing associated with commercial development);"[74]

"(G) develop technologies to reduce the risks of drilling through methane hydrates; and ... ,"[75]

there is no regulatory language requiring the drafting or planning for the use of those technologies nor for the drafting or development of regulations that would respond to the incident of environmental damages from methane hydrate development.

But at least there is official recognition that there is a technological problem that certain environmental harms could result and technologies to mitigate those harms should be invested in. The listed hazards to the environment are (i) the development of methane hydrates generally, (ii) methane hydrate venting (therein referenced as "degassing"), and (iii) the risks associated with drilling into methane hydrate deposits.

MHRDA does require the assembly of a "Methane Hydrates Advisory Committee" that should include members from environmental organizations alongside other members from industrial enterprises, institutions of higher education, oceanographic institutions, and state agencies.[76] However, none of the listed reports from that committee and the associated research has focused on the environmental hazards and their mitigating technologies.[77]

The Secretary of the Department of Energy is also directed to ensure that the "data and information developed through the program are accessible and widely disseminated as needed and appropriate."[78]

Perhaps most interestingly, the MHRDA requires the Secretary to ensure that to "maximum extent practicable, greater participation by the Department of Energy in international cooperative efforts."[79] It is unclear to what extent that request is

73 30 USC § 2003(b)(1)(D).
74 30 USC § 2003(b)(1)(F).
75 30 USC § 2003(b)(1)(G).
76 30 USC § 2003(c)(1).
77 *See* the list of reports as listed by the Department of Energy's website. *Available* at http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/MH_ReferenceShelf/RefShelf.html and at http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/pdf/MHBibliography.pdf .
78 30 USC § 2003(e)(3).
79 30 USC § 2003(e)(6).

aimed strictly at research and technology or to what extent it can be responsive to the aspirations of the Methane Hydrates Advisory Committee.

10. Summary and Conclusions

The federal laws of the U.S. provide extensive legal foundations to address the challenges of offshore oil spills; but they lack a paradigm perspective for natural gas accidents. This could be readily remedied by extending current liability and regulatory frameworks to include natural gas within the existing laws.

OCSLA currently provides for the leasing of methane hydrates as minerals offshore the U.S. but within its jurisdictional waters. OCSLA has regulated offshore leasing for over sixty years, and thus has a body of relevant definitions and regulations to draw upon. OCSLA calls for public regulations to ensure safety standards are established and maintained; OCSLA requires the application of the "best available and safest technologies," in all offshore operations. To that end, the Commerce Secretary is tasked with ensuring that appropriate research is undertaken to protect human, marine, and coastal environments. Additionally, OCSLA provides for certain civil and criminal penalties to be applied when it or its derivative regulations are violated. OCSLA might be readily implemented as-is for offshore methane hydrates, although it would probably be beneficial to include more explicit language on the inclusion of offshore methane hydrates to better ensure the smooth operation of key terms of OCSLA.

OPA provides for strict liability to be applied to petroleum spills; it requires the application of strict liability. OPA is designed to operate alongside other rules of civil liability, especially state level civil liability systems. It is also designed to operate in parallel to the regulatory systems under OCSLA; thus OPA and OCSLA provide a mirror to the recommendations of Chapter 7. OPA explicitly includes offshore extraction facilities as well as mobile offshore drilling units; thus it clearly anticipates offshore developments. But it appears that methane leakages, ventings, seepings, or other emissions are beyond the current scope of OPA; even conventional gas appears beyond the scope of OPA. OPA would need to add terms to define natural gas and methane hydrates, it would need to provide volumetric standards for methane the way it defines barrels for crude oil. With a few simple changes, OPA could be ready for offshore methane hydrates.

The third major piece of the U.S. federal response to petroleum accidents is the CWA. The CWA enables a regulatory body to pursue either civil liability claims in court or to impose civil penalties as a matter of administrative power. The CWA enables penalties to be established based upon the volumes released by the petroleum accident. The penalties are set magnitudes higher than the market value of the spilt volumes, strict liability applies at $1,000 a barrel and increases to $3,000 a barrel when the accident resulted from grossly negligent behavior; the economic incentive to prevent spills could be made more clearly to the tortfeasor. However, the CWA does not currently apply to methane volumes in the water, only to liquid lipids and oils or other listed hazardous substances. But again, as in OPA's case, minor word-smithing might extend the application of the CWA to include water-borne methane either in its own character or as a listed hazardous substance. Similarly, the penalty provisions could be readily extended to include specific volumes of methane for the same penalty levels as is currently provided for barrels of oil or for other volumes of hazardous substances.

Likewise, the U.S.'s federal implementation of the International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties, 1969, could be extended as discussed for other similar international oil spill conventions within Chapter 9.

The political complexity of amending the CAA to include methane emissions prevents ready analysis of how it might be extended to cover offshore methane hydrates.[80]

Finally, the MHRDA provides, in anticipation of the needs of the OCSLA, for the research and development in efficient and safe technologies for the production of methane hydrates (both onshore and offshore), in environmental protection with special regards to methane venting and seeping (both natural and anthropogenic), and in risk reducing technologies for methane hydrate drilling. MHRDA also calls for the publication of the collection data and research results, which could then be used in standards setting, in civil litigation, and in public awareness building.

The U.S. federal laws on petroleum accidents are in substantial alignment with the recommendations of Chapter 7, but they are in need of extension to include the circumstances of offshore methane hydrates. Due to the directness and simple penalty structures of the federal laws, such changes might be readily implemented.

80 *See* R. A. Partain & S. H. Lee, *Article 20 Obligations Under the KORUS FTA: The Deteriorating Environment for Climate Change Legislation in the U.S.,* 24 Stud. Am. Const. 439 (2013), for a more complete discussion of the issues involved, especially with regards to the Supreme Court's resistance to hold that the CAA already grants such regulatory powers to the EPA.

Chapter 11

Part IV:

Conclusion and Appendices

Chapter 12

SUMMARY AND CONCLUSIONS

1. The potential impact of offshore methane hydrates

The most important facts about methane hydrates can be summarized quickly. Offshore methane hydrates offer abundant energy and fresh water supplies to practically every coastal state in the world; both developed and developing economies could be substantially impacted by the commercial development of offshore methane hydrates. Offshore methane hydrates also offer the means to provide those benefits while also serving as substantial sinks for climate change policy makers. It is a policy trio of substantial benefits: water policy, energy policy, and climate change policy. But the downside is that the commercial development of offshore methane hydrates could unleash both cataclysmic and non-cataclysmic risks and harms.

1.1. Benefits of offshore methane hydrates

Methane hydrates are a potential source of both methane and fresh water.[1] After the methane volumes are extracted, the methane can be converted expeditiously into routine natural gas for use as both industrial and residential energy supplies;[2] extracted water could be used for both consumer and agricultural purposes. As the methane volumes are extracted from the hydrate deposits, streams of carbon dioxide can be injected into the same hydrate structures to provide CCS storage.[3] It also appears that the costs of extracting and producing offshore methane hydrates are dropping and may become price competitive with other energy sources in the near future; it may already be price competitive with certain LNG prices.[4]

1 *See supra*, at ch. 2, sec. 2.

2 *See supra*, at ch. 3, sec. 3.

3 *See supra*, at ch. 3, sec. 5.1.

4 *See supra*, at ch. 3, sec. 2. The LNG comparison here is to spot prices seen in the recent decade in northeast Asia.

In the alternative, the methane can be combusted on-site to generate electricity and the exhaust therefrom can be re-injected into the hydrate deposits for CCS storage. Or, the methane can be reformed with steam (created with extracted fresh water and heated with methane) to create hydrogen fuel.[5] From methane fuels, to carbon-neutral electricity, to hydrogen fuel options, the commercial development of offshore methane hydrates could enable a wide array of green and greener energy options.[6] In an era concerned with anthropogenic climate change, these are potentially exciting options.

Methane hydrates exist abundantly in many locations; almost every coastal country is expected to possess methane hydrate reserves.[7] Methane hydrates can be found onshore in arctic permafrost, but those countries containing onshore methane hydrates also possess offshore methane hydrates.[8] Developed countries, such as Japan and South Korea, that do not currently possess strategic volumes of domestic energy supplies do possess substantial offshore methane hydrate supplies.[9] Many developing countries with no domestic energy supplies are expected to possess substantial offshore methane hydrate reserves; many of those countries might also be interested in the fresh water co-produced with the methane hydrates to assist in their agricultural development and consumer fresh water needs.

The world has faced critical energy supply shortages since the dawn of the fossil fuel era of industrialization. While not a perfect cure to that problem, the commercial development of offshore methane hydrates could enable local access to energy supplies and level the geo-political playing field of energy markets. The potential benefit to both lower energy costs and potential stability of supplies could assist global economic development.

1.2. Hazards of offshore methane hydrates

But the extraction of offshore methane hydrates is a "new thing under the sun."[10] To extract energy supplies from under subsea mud layers will require innovative technologies and engage in new risks here-to-fore unbreached in offshore energy extraction.[11] Previously, offshore operators feared methane hydrates as one of the most dangerous aspects of offshore drilling and in gas-pipeline transportation. There will be a lot of unlearning to accomplish as methane hydrates are increasingly seen as valuable energy resources.

Methane hydrates collect under mud layers in the ocean.[12] The icy crystals are endothermically stable, in that they need extra energy to be added to their reservoir

5 *See supra*, at ch. 3, sec. 5.2.

6 *See supra*, at ch. 3, sec. 1.

7 *See supra*, at ch. 4, sec. 2.

8 *See supra*, at ch. 2, sec. 5.

9 *See supra*, at ch. 3, sec. s 4.1. and 4.2.

10 With obvious apologies to the author of Ecclesiastes 1:9.

11 *See supra*, at ch. 3, sec. 3.

12 *See supra*, at ch. 2, sec. 4.

system before they will begin to disassociate and release the methane volumes from the hydrate structures.[13] Left alone, they are and have been stable for geologically long time frames.

But scientists have found evidence that ancient earthquakes or landslides have added that necessary energy to ancient hydrate deposits.[14] When that happened, earthquakes and tsunamis occurred; those events resulted in massive impacts on coastal flora and fauna.[15] *E.g.*, the Mesolithic-era Storegga event sent tsunami waves 40m high directly into the coasts of Iceland and Norway; such an event in modern times might kill millions of coastal dwellers and severely impact a broader radius of coastal communities.[16]

Without tsunamis, major disruptions of the mudlayer and of the underlying hydrate deposits could enable massive and sudden disassociation of methane.[17] Given a sufficient release of methane, the methane can create a funnel, or chimney, which can enable the methane to be directly released into the atmosphere without first transmitting through the water column.[18] Such a large emission of methane into the atmosphere could cause several problems. Methane itself is combustible and explosive; such an event would create a radius of danger preventing emergency crews from gaining immediate access to the damage area. Such volumes could also potentially asphyxiate first responders. Finally, the emission of methane into the atmosphere would be a grave accident in climate change consequences, as methane is considered substantially more dangerous than carbon dioxide for inducing climate change.

Are cataclysmic events likely? Probably not; however, until more learning is acquired from more completely developed offshore extraction projects, the risk might remain difficult to ascertain. However, given that methane hydrates are endothermic and given the potential to measure the amounts of energy injected or placed into the hydrate deposits, it should be feasible to substantially limit black swan type events by setting standards to ensure that cautious energy budgets are enforced to prevent overstimulation of the hydrate deposits. Yet, given the complexity of the hydrate structures, given the limits of sub-mud-line surveillance, and given the complex marine interactions that will continue to exist from natural processes, it would likely remain impossible to prevent all likelihoods of cataclysmic events at offshore methane hydrate installations. Thus whatever result standards emerge to address the risks and hazards of offshore hydrate accidents, there will remain a need to ensure that those standards contemplate how to address cataclysmic accidents.

Gentler events also could make substantial impacts to the adjacent coastal communities and to the flora and fauna of the oceans wherein the offshore methane

13 *See supra*, at ch. 2, sec. 2.

14 *See supra*, at ch. 4, sec. 5.2.

15 *See supra*, at ch. 4, sec. 5.2.

16 *See supra*, at ch. 4, sec. 5.2.

17 *See supra*, at ch. 4, sec. 5.1.

18 *See supra*, at ch. 4, sec. 5.1.

hydrate projects enable methane venting or seepage to occur.[19] The preparation of fields for production involves a variety of drilling and vibration inducing activities. Extraction may well include various heating injections and flooding techniques.[20] The depletion of the methane or water volumes could cause hydrate bed collapses that in turn could lead to structural problems.[21] Both the development and on-going operation of offshore methane hydrates could lead to non-cataclysmic methane accidents. Given the many modes in which the hydrate deposit could become disturbed and begin to emit methane, the chance of non-cataclysmic venting and seepage would not be expected to be slight; rather, one might reasonable conclude that minor events could reasonably occur in most fields. But it would also be more likely than not that such event would lose their energy source or be detected and addressed and thus be events of limited duration and of limited impact.

Methane itself is a greenhouse gas and its constant seepage and emission could enable additional anthropogenic climate change to occur.[22] Methane is also interactive with the biota of the ocean, both as a food stock for certain micro-biota and as a displacer of oxygen.[23] Methane can be digested and converted metabolically into carbon dioxide, which is another critical greenhouse gas.[24] The nuisance of emitted methane and carbon dioxide gas volumes, the potential interference into marine economies such as fishing and tourism, and the general anxiety that living near to a field of risk could all be considered part of the harms and hazards of living near offshore methane hydrate projects.[25]

The commercial development of offshore methane hydrate technologies would offer both risks and rewards. The needs of certain countries to achieve domestic energy supplies, to sustain economic development, and to potentially address parallel issues of fresh water supplies and of effective climate change policies could encourage an earlier timeframe of development. On the other hand, there are substantial risks and hazards that challenge both the communities local to methane hydrate accidents and global communities impacted by climate change events. The risks and benefits need to be balanced; efficient means of obtaining the optimal levels of safety and extraction activity are needed.

19 *See supra*, at ch. 4, sec. 4.1.

20 *See supra*, at ch. 4, sec. 4.3.

21 *See supra*, at ch. 4, sec. 4.3.

22 *See* the discussion, *infra*, at Appendix III.

23 *See supra*, at ch. 4, sec. 4.2.

24 Some marine biota can metabolize methane. There are also non-biotic chemical processes in the water column that can enable the decomposition of methane into carbon dioxide. *See supra*, at ch. 4, sec. 4.2.

25 *See supra*, at ch. 4, sec. 4.2.

2. Model governance of the risks from offshore methane hydrates

The primary tools available for the governance of accidental risk are rules of civil liability and regulations, both public and private.

This study has investigated the overall circumstances of offshore methane hydrates and found that they would be best governed under a rule of strict liability.[26] However, there would remain certain circumstances that might frustrate a rule of strict liability, in those cases public regulations were found to be efficient means of risk governance for offshore methane hydrates.[27]Additionally, it has been recognized that private regulation can be integrated into a regulatory mechanism with public regulation.[28]

Ergo, it is be the recommendation of this study that a rule of strict liability be employed alongside public and private regulations for the optimal set of incentives to efficiently set the correct standards for safety and precaution and the correct levels of operational activity at the offshore methane hydrate installations.[29]

2.1. A rule of strict liability should apply.

In the last fifty-plus years since Calabresi's first foray in the law and economics of accident law,[30] much advancement has been made. There is now a substantial body of literature to draw from and a strong consensus has emerged on when certain rules of civil liability could be efficiently applied and under what circumstances other rules might be efficiently applied.[31] Of course there remains much theoretical activity and not all models agree, but there is a workable standard model that can be utilized for the present study.

When accidents are primarily or exclusively under the control of a single actor, theory suggests that a rule of strict liability would be more efficient than a rule of negligence.[32] When accidents are a result of both the tortfeasor's and the victim's actions, but the tortfeasor's acts are more critical to containing the risk of harm, again, theory suggests that a rule of strict liability would be more efficient.[33] When the underlying activity creating the harm is abnormally hazardous, theory suggests that a rule of strict liability would be more efficient.[34] When particular uncertainties are to be encountered, theory suggests that a rule of strict liability would be more efficient.[35] And when it is important to prevent stress to a judicial system, theory

26 *See* ch. 7, sec. 2.4.

27 *See* ch. 7, sec. 3.3.

28 *See* ch. 7, sec. 3.2.

29 *See* ch. 7, sec. 4.

30 G. Calabresi, *Some Thoughts on Risk Distribution and the Law of Torts*, 70 Yale L. J. 499 (1961).

31 *See supra*, ch. 5, sec. 1.2.

32 *See supra*, ch. 5, sec. 2.1.

33 *See supra*, ch. 5, sec. 2.2.1.

34 *See supra*, ch. 5, sec. 2.2.2.

35 *See supra*, ch. 5, sec. 2.2.4.

suggests that a rule of strict liability would present fewer transaction costs on the path to justice.[36]

The development of offshore methane hydrates contains the circumstances that advocate for a rule of strict liability.[37] Offshore methane hydrates projects would primarily be of a unilateral nature of activity and risk; the operator would be the primary if not sole determiner of which risky acts would be undertaken, of when they would be undertaken, and how they would be undertaken; thus a rule of strict liability would be the efficient policy choice.[38] Even if there were a nexus of both the operator and local community members in that acts leading to methane hydrate accidents, i.e., a bilateral accident model, the determinants of risk would still primarily sit with the operator and thus a rule of strict liability would be the efficient policy choice.[39] When the potential risks of cataclysmic events are considered, the development of offshore methane hydrates could reasonably be characterized as abnormally hazardous.[40] But one need not rely on the risks of tsunamis and earthquakes, the damages from non-cataclysmic accidents could also be characterized as abnormally hazardous in that the combined risks both local and global are neither normal nor safe; thus a rule of strict liability would be the efficient policy choice.[41] Given the novelty of the nascent industry, many uncertainties are to be encountered, such as indeterminate *ex ante* duty of care, uncertainty of future harms, and complex interactions of precaution and activity levels; a rule of strict liability would be the efficient policy choice.[42] And given that many of the countries wherein methane hydrate deposits lay have developing legal institutions and may not be able to bear the full brunt of transaction costs from a major methane hydrate accident, a rule of strict liability would again be the efficient policy choice.[43]

A rule of negligence cannot be excluded from consideration,[44] but the circumstances of offshore methane hydrates strongly fall on the side of those favoring a rule of strict liability.[45] However, if only a rule of strict liability were to be employed, there would likely be a number of circumstances that would fail to provide the correct incentives to optimally set precautionary levels and activity levels. To correct for these potential events, public regulations should be employed in a complementary manner to the rule of strict liability.[46]

36 *See supra*, ch. 5, sec. 2.5.
37 *See supra*, ch. 7, sec. 2.1.
38 *See supra*, ch. 7, sec. 2.1.1.
39 *See supra*, ch. 7, sec. 2.1.2.
40 *See supra*, ch. 7, sec. 2.1.2.
41 *See supra*, ch. 7, sec. 2.1.2.
42 *See supra*, ch. 7, sec. s 2.1.5 and 2.1.6.
43 *See supra*, ch. 7, sec. 2.1.7.
44 *See supra*, ch. 7, sec. 2.2.
45 *See supra*, ch. 7, sec. 2.4.
46 *See supra*, ch. 7, sec. 3.2.

2.2. *Public and private regulations should be engaged.*

Public regulations can directly set standards *ex ante* of a tortfeasor's engagement in a risky activity; as such, public regulations can enable the tortfeasor to make strategic decisions on activity levels and on care levels in alignment with the standards set by the regulatory body. This could facilitate the development of offshore methane hydrates by both setting optimal standards before financial investment decisions would need to be made. Clear *ex ante* regulations could also communicate to the engineers and developers of the offshore hydrate installation to what standards and tolerances for safety their designs and plans should achieve. The establishment of optimal standards, under the deliberative process requirements as set out under the EIA and SEA Directives and under NEPA,[47] would also disclose to the public critical information about the risky activities to be undertaken at the installations and enable many groups to engage in the development of those standards.

Public regulations can be usefully applied to cure certain circumstances so that routine economic decisions can be properly performed; regulations can cure or at least ameliorate missing markets or market failures.[48] The consensus view holds that regulations could be efficient at achieving optimal levels of precaution and activity levels when civil liability rules are stymied by (i) informational asymmetries, (ii) insolvency, (iii) problems of underdeterrence, and (iv) of institutional juridical capacity.[49]

The development of offshore methane hydrates demonstrates aspects from each of the above concerns. Informational symmetries would likely be a concern as offshore methane hydrates projects are developed and operated.[50] *E.g.*, while the development of the technologies and science related to offshore methane hydrate operations has been greatly fostered by public investments, the ability to continually monitor on-going events would be dangerous and prohibitive if extended to all of the potential victims. Thus, there is an efficient role for a regulatory body to play to enable both a quality collection of data to be obtained and made publicly available while limiting the overall impact to the safe operations of the hydrate fields. Public regulations could be the efficient policy choice for methane hydrates to address informational asymmetries.

While one would hope that the revenues from the sales associated with commercially operated offshore methane hydrates projects would ensure solvency, there a variety of reasons that policy vigilance should be maintained to ensure that potential insolvency of operators does not diminish the effectiveness of public safety planning.[51] Whereas a strict liability rules begins to falter when the operator becomes insulated from the informational incentives of potential damages,

47 *See supra*, ch. 10, sec. 1 and 2, and *see* ch. 11, sec. 2.

48 *See supra*, ch. 6, sec. 2.

49 *See supra*, ch. 6, sec. 2.1, 2.3, 2.4, and 2.5.

50 *See supra*, ch. 7, sec. 3.1.1.

51 *See supra*, ch. 7, sec. 3.1.2.

regulations can provide policy tools to incentivize the operator to both stay solvent and to provide non-monetary behavioral incentives. Public regulations could be the efficient policy choice for methane hydrates to address insolvency.

Underdeterrence results when various plaintiffs fail to plead their injuries and receive judicially determined damages. In the event of offshore methane hydrate accidents, there are a variety of means in which victims might fail to plead their injuries.[52] *E.g.*, in non-cataclysmic methane leakages and venting, plaintiffs might not have sufficient evidence of the leakage events, or they might not be able to directly connect their injury to the leakage event, or their incidental harm might not cost-justify litigation on an individual basis. In such scenarios, a regulatory body might be able to collect a superior set of evidence, be able to connect more points of causation, and be able to integrate many injury claims into a cost-justifiable set. In other considerations, potential victims may be missing; it might be due to the long timeframes of some injuries or the results of a cataclysmic accident that swept victims away. Public regulations could be the efficient policy choice for methane hydrates to address underdeterrence.

Private regulations enable those closest to the activity and its risks to develop the optimal standards.[53] Because the technology of developing and operating offshore methane hydrate fields is likely to continue to advance and because the risks and hazards will become better understood as more experience is gained, it would be advantageous to have those parties closest to those learning engaged in setting the optimal standards.[54] Additionally, it has been demonstrated that private regulations can be developed to function alongside of public regulation; such a mechanism is called an integrated regulatory mechanism.[55] It was the recommendation of this study that private regulation be developed in harmony with public regulation to ensure that all of the advantageously informed parties could participate in standards setting efforts.[56]

Finally, in consideration of certain legal systems, not all jurisdictions have court systems that can support the litigious demands that a major methane hydrate accident event might entail.[57] A regulatory or administrative body might be more efficient to gather and handle legal claims than a singular litigant with a rule of strict liability. The presence of private regulations could also assist with these concerns.

52 *See supra*, ch. 7, sec. 3.1.3.

53 *See supra*, ch. 6, sec. 5.

54 *See supra*, ch. 7, sec. 3.2.

55 *See supra*, ch. 6, sec. 5.1.

56 *See supra*, ch. 6, sec. 5.1, and *see* ch. 7, sec. 3.2. It goes without saying that a private regulation system should remain within public scrutiny and the requirements of democracy; this study would not support unmonitored private regulation, rather it calls for coordinated co-implementation of private *and* public regulations.

57 *See supra*, ch. 7, sec. 3.1, and *see* ch. 4.2.

2.3. *Application of civil liability, public regulations, and private regulations.*

Thus, public regulations and private regulations would be efficient in certain circumstances. But so was the rule of strict liability. Might they well be implemented in complementary fashion? Yes, they would.[58]

Rules of civil liability can help to protect the effectiveness of public regulations when such regulations or regulatory bodies would be affected by agency costs and lobby capture.[59] Regulations can help to provide critical information to lower transaction costs and to better ensure the function of a strict liability rule in court.[60] When it is difficult to determine *ex ante* safety standards, regulations can serve as a floor beneath which potential tortfeasors are incentivized to stay above.[61] In the study, other reasons for complementary implementation were reviewed and few reasons were found to support a contrary result.[62]

Thus, this study supports the combined approach of both public regulation and rules of civil liability. This study further supports the choice of a rule of strict liability for the civil liability system.

3. State of existing governance for offshore methane hydrate risks

There are wide arrays of international, regional, and national legal frameworks that address situations analogous to offshore methane hydrate operations. Some of the governance directly addresses oil spills and related emissions into the ocean; others address various environmental liabilities or climate change concerns. Some of these legal systems appear to apply as currently enacted to offshore methane hydrates, but few properly provide sufficient attention to the particular needs of offshore methane hydrate accidents. It would appear that a lack of historical examples has prevented more complete drafting of the existing laws; this is not a critique, as laws need not regulate what is not yet in existence.

3.1. *Laws of the UN*

Within the UN's umbra, there are several conventions that would likely govern or coordinate with domestic governance of offshore methane hydrates. First, UNCLOS would provide the jurisdiction over the waters and subsea lands that contain methane hydrates.[63] While UNCLOS does not apply to every country in the world, its paradigm of EEZ does appear globally recognized, either by ratification of the Convention, by functioning *opinio juris*, or as with the U.S. by presidential declaration. UNCLOS calls for comprehensive "rules, regulations and procedures"

58 *See supra*, ch. 7, sec. 3.2.

59 *See supra*, ch. 6, sec. 3.1.

60 *See supra*, ch. 6, sec. 3.2.

61 *See supra*, ch. 6, sec. 3.3.

62 *See supra*, ch. 3, sec. 3.

63 *See supra*, ch. 8, sec. 2.

to protect the ocean and its environment. Also, to the extent that methane hydrates were to found further offshore than the EEZ, then UNCLOS provides that the ISA would become the regulatory body to both establish the relevant regulations and to provide for the leasing of such methane hydrates.

The Convention on the Transboundary Effects of Industrial Accidents (UNCTEIA) provides a *per se* exclusion to offshore hydrocarbon accidents with the understanding that oil pollution has been dealt with by separate international efforts;[64] many conventions make similar provisions and assumptions. However, the UNCTEIA does establish what is likely an expectation for ratifying states to adopt strict liability type rules in their civil liability or regulatory systems. When states do develop those regulations, they are "to protect human beings and the environment against industrial accidents by preventing accidents *as far as possible*," by reducing the frequency and severity of those accidents that do occur and by mitigating the effects of the accidents that do occur.[65] Further, UNCTEIA does list methane and hydrogen as hazardous substances that might be within its ambit of regulation were it not otherwise specifically excluded for offshore oil and gas operations. So while UNCTEIA would not directly apply to the development of offshore methane hydrates, it does strongly suggest an approach to take in governing such risks.

The United Nations Framework Convention on Climate Change, (UNFCCC) and its Kyoto Protocol do not provide a liability framework for accidental greenhouse gas emissions, but they do set absolute limits on emissions for a certain sub-class of signatories.[66] Those countries that have assumed obligation emission limits are required to enforce those obligations with domestic law; the EU, its Member States, and Japan are such parties but the U.S. and Canada are not. The EU has a sophisticated mechanism to ensure compliance, *see infra* at Section 3.3, but many other countries with methane hydrate assets have not assumed emissions obligations. As such, the UNFCCC will be challenged by the development of offshore methane hydrates and further developments would be needed.

3.2. Regional marine and other oil spill conventions

The challenges of responding to oil spills resulted in multiple international conventions. The problems of transboundary oil spills, particularly in the waters off of Europe, led to a collection of regional marine pacts.

The regional marine pacts, taken as a group, call for the adoption of two key legal principles: (i) the *polluter pays principle*, and (ii) the *precautionary principle*.[67] As such, the fundamental tone of the regional marine pacts is to support rules of strict liability.[68] The regional marine pacts also call for the implementation of certain

64 *See supra*, ch. 8, sec. 3.

65 UNCTEIA Art. 3. Sec. 1. *See supra* at ch. 8, sec. 3.

66 *See supra*, ch. 8, sec. 4.

67 *See supra*, ch. 9, sec. 1.

68 *See supra*, ch. 9, sec. 1.3.

measures to ensure high safety standards are maintained; it is most likely that such measures would be carried out as public regulations.[69] These measures should include those measures that could eliminate and remediate pollution from the exploration and exploitation of the continental shelf, the seabed, and its subsoil; such measures would be applicable to offshore methane hydrates and any potential methane venting or seepage. Several of the pacts, such as the Barcelona Convention, have additional protocols to specifically address the risks associated with the operations of offshore facilities, such as would be needed to extract methane hydrates.[70]

The international conventions to address marine oil pollution have been extended to address other hazardous substances, but methane does not appear to be considered as hazardous for these purposes.[71] They generally set rules of strict liability with limited exceptions for the behaviors of third parties. Some, such as the CLC, cap the liability limits of owners; those caps are revoked when the accident is a result of gross negligence on the part of the tortfeasor.[72]

Thus, a variety of efforts to address oil spills have advanced transboundary coordination and promoted the concept of strict liability for environmental damages. However, in their focus on oil they have not provided substantive language to directly address harms resultant from methane-based accidents.

3.3. Laws of the EU

The laws of the EU are more recently drafted, on the whole, than their counterparts in the U.S.; as such, many of them reflect more recent trends in legal theory. Generally speaking, the EU directives support the application of strict liability; this is in part due to the direct enactment of the *polluter pays principle* into the TFEU. The most relevant directives are the EIA & SEA Directives, the Offshore Directive, the CCS Directive, and the Marine Framework collection of directives.

The EIA Directive and the SEA Directive provide for the cautious and public review of upcoming projects and plans that might substantially impact the environment.[73] They call for exhaustive studies to be completed in advance of the granting of approvals or licenses, so that specific causes of harms or hazards could be addressed in full prior to the acceptance of such risks.[74] While not providing specific requirements on how to implement civil liability or regulatory governance beyond the collection and review of environmental precautionary data, by the very collection of that data they do provide for many cures that would otherwise befall both rules of civil liability and public regulation of offshore methane hydrate

69 *See supra*, ch. 9, sec. 1.5.

70 *See supra*, ch. 9, sec. 1.3.

71 *See supra*, ch. 9, sec. 2.2 and 2.4.

72 *See supra*, ch. 9, sec. 2.2.

73 *See supra*, ch. 10, sec. 1 and 2.

74 *See supra*, ch. 10, sec. 1. *See also, supra*, ch. 10,sec. 3.

projects and of the policies and plans to facilitate their development. As such, they function as meta-rules on the rules applicable to offshore methane hydrates.

The Offshore Directive provides for the regulation of offshore oil and gas installations.[75] As such, to the extent that offshore methane hydrate installations would be viewed as a type of unconventional natural gas projects, the Offshore Directive would apply to their development and operations. The Offshore Directive provides both broad and deep requirements on precautionary planning related to offshore hydrocarbon operations. But a review of the Directive found that it was primarily focused on historical modes of offshore accidents and did not include provisions that would better address the needs of an offshore methane hydrate industry.

The CCS Directive reflects the other half of the coin from the Offshore Directive, as it could regulate the injection of carbon dioxide into offshore reservoirs.[76] As has been discussed, offshore methane hydrates can be extracted in conjunction with CCS injection activity; in fact, due to the economic uplifts from facilitating methane extraction and Kyoto Protocol concerns, most suggested commercialization studies have included some form of CCS-type injections in the extraction process. Similar ideas have been floated within the EU, Germany's SUGAR Projekt would seek to inject carbon dioxide into offshore methane hydrate reserves. As such, it is likely that within EU waters that the development of offshore methane hydrates would be regulated by the CCS Directive. But the CCS Directive, even if applicable, would address only a slice of the operations related to the development, production, and abandonment and sequestration of the methane hydrates. The CCS Directive would probably be most important and most centrally applied during the abandonment and sequestration phases, as it might govern long-term liability and post-production ownership of the methane hydrate fields.

The Water and Marine Frameworks draw in a large number of marine, coastal, and riparian protecting directives, decisions, and regulations.[77] They function in coordination to protect the biota and human communities that need their ecosystems and environments to continue to be healthy and vibrant.[78] All marine projects, while still in the planning and pre-development stages, need to provide programs of measures to achieve and maintain good environmental status and when the hydrates overlay transboundary marine ecosystems, then plans for regional cooperation must also be provided. The various international regional marine conventions are called on by the Frameworks to extend this planning and cooperation. The Frameworks track a variety of hazardous activities, including chemicals transported through the water columns, to prevent accidental damages to those ecosystems. The Frameworks present a selection of known fragile environmental areas and endangered biota to specifically protect; while the presence of methane is known to affect marine biota in several substantial

75 *See supra*, ch. 10, sec. 4.

76 *See supra*, ch. 10, sec. 5.

77 *See supra*, ch. 10, sec. 6.

78 *See supra*, ch. 10, sec. 6.1. and 6.3.

pathways, the marine locations and biota adjacent to those areas do not currently appear to be specifically protected under the Frameworks.

3.4. *Laws of the U.S.*

The laws of the U.S. read like a spoonful of alphabet soup; NEPA, OSCLA, OPA, and the CWA would be the primary federal laws applicable to the development of offshore methane hydrates in American jurisdictional waters.[79] It remains important to note that while the U.S. does not belong to UNCLOS, it does generally recognize similar legal notions as developed within UNCLOS; thus the U.S. does claim an EEZ beyond its traditional coastal waters.[80] Also, while some methane hydrates might be found within state jurisdictional waters, the majority of the methane hydrate deposits are expected to be located in federal waters. And finally, while the methane hydrates might lay offshore in federal waters, onshore damages might be spread across multiple state jurisdictions with distinguishable common law traditions on tortious damages and differing state codes on liabilities. Thus, the U.S. model would be more complicated than surveyed herein.

NEPA supports the function of the EPA, the U.S. *de facto* environmental ministry.[81] All existing and future acts of legislation and substantially related regulations need review by the EPA under NEPA. After enactment, the EPA would steward the overall management and enforcement of those environmental rules.[82] Most importantly, the EPA would likely steward enforcement litigation in the case of environmental damages. Thus, the EPA is granted wide and substantive authority to determine the scope and requirements of future regulatory efforts related to offshore methane hydrates.

The OSCLA provides the underlying access to licensing of the offshore federally administered minerals.[83] Critically important, OSCLA splits responsibility for specifically mineral-related planning from the EPA to the Commerce Department. To the extent that precautionary regulations or standards as related to the offshore methane hydrates themselves would need to be developed or approved, it would fall to the Secretary of Commerce to approve them. Thus, the environmental damages would be bifurcated into those directly related to the offshore methane hydrate operations and those only indirectly so damaged; one set of regulations would be developed primarily from a commerce perspective and the other from a primarily environmental perspective. In this result, the U.S. demonstrates that its approach to offshore methane hydrate planning would likely be commercially centered. Once the Commerce Dept. issues its safety regulations to protect the human, marine, and coastal environments; the Secretary, the Coast

[79] *See supra*, ch. 11, sec. 1.

[80] *See supra*, ch. 11, sec. 3.

[81] *See supra*, ch. 11, sec. 2.

[82] *See supra*, ch. 11, sec. 2.

[83] *See supra*, ch. 11, sec. 3.

Guard, and the U.S. Army are required to enforce those safety and environmental regulations.[84]

The OPA applies to incidents of crude oil spills into the marine environment.[85] It has a very sophisticated strict liability rule alongside a system of liability assignment and of algorithmic liability caps based on tonnages, vessel types, and activities.[86] It also provides two modes of liability caps for those operators acting non-grossly negligent and those acting grossly negligent. Yet, as it primarily addresses crude oil, if the methane hydrates accident does not co-produce oil into the ocean, then the OPA likely would not apply.[87]

The CWA suffers from the same oil-focus as the OPA. As such, it would likely not apply to offshore methane hydrate accidents.[88] However, again like the OPA, it provides a well-developed regulatory system of negative incentives to punitively encourage operators to not spill oil.[89] Daily fees or per-barrels-spilt fees can be imposed and the powers to bring tortfeasors to court are also provided under the CWA. It was these powers that first brought attention to the question of how many barrels were spilled at the BP Macondo incident, because the disparity in spillage estimates created billions of dollars in penalty differences. But again, while the CWA has a long and useful history of addressing crude oil and other hazardous substances in the ocean and other waterways, it does not currently have the ambit to cover oceanic methane emissions.

4. Recommendations

4.1. Emergent need for standards

There is an emergent need to provide rules of civil liability and regulations for the development of offshore methane hydrates. Tremendous economic benefits are challenged by substantial accidental risks and hazards. The time to begin the studies for those rules and regulations should be soon, as the industry is likely to develop within the coming decade. The argument is that it is more likely than not that some investors or nations might begin the development of offshore methane hydrates in the very near future; as such, it would be advisable to develop the necessary standards in advance of those programs and projects.[90]

84 *See supra*, ch. 11, sec. 3.2.

85 *See supra*, ch. 11, sec. 4.

86 *See supra*, ch. 11, sec. 4.2.

87 *See supra*, ch. 11, sec. 4.1.

88 *See supra*, ch. 11, sec. 5.1.

89 *See supra*, ch. 11, sec. 5.2.

90 To be clear, the argument presented is not an argument to stimulate investment to ensure earlier adoption of offshore methane hydrates. The argument is predicated on the recognition of several nations' stated national agendas to begin the extraction of offshore methane hydrates and in recognition of the imminent technological feasibility of those agendas. Should any of those or other actors actually move forward with plans to develop offshore →

Offshore methane hydrates could provide new sources of natural gas and fresh water supplies. Importantly for the timing of its development, many countries that currently lack access to domestic energy supplies are expected to possess reserves of offshore methane hydrates. For some countries, that access to local energy supplies within their political control could provide strategic stability and continuity of energy supplies critical for economic growth and development. Such policy concerns could motivate some countries to begin offshore methane hydrate production before it was commercially competitive with more conventional energy supplies.

However, the engineering technology of offshore methane hydrates is rapidly advancing and the costs of its extraction and production are dropping. It is a common view of methane hydrate researchers that offshore methane hydrates may become commercially viable within the next ten years. Japan and South Korea have both established national research programs to obtain that commercial capability by 2020.

If it becomes the case that the technologies and cost structures of offshore methane hydrates reach commercial or politically sufficient levels of advancement, it would be beneficial for both energy investors and for the general public to have already determined optimal standards. Once the economic motives of methane hydrate projects become more evident, it might become more difficult to negotiate the development of the necessary standards.

At the present moment, the development of offshore methane hydrates finds a fairly united community of researchers supported by both private investment and government support. Once projects would become commercial in nature, one might expect certain adversarial positions to be taken.[91] It might be best to attempt to find common ground on standards and on optimal precautions and optimal levels of offshore hydrate development before that competitive aspect of eventual development opens up.

4.2. General recommendations

What the future of offshore methane hydrates needs is a clear and operational set of guidelines and incentives to ensure both for the private operators and the general public that such offshore operations will achieve the socially optimal safety level, so that both private profits and general welfare can be best obtained. The recommendations of this study are that a combined rule of strict liability for damages resultant and the development of effective public regulations would best provide for that optimal level of safety.

methane hydrates, it would be constructive to have the necessary standards in place ahead of those development efforts.

91 *E.g.*, different energy corporations might try to gain proprietary advantages in technology by hiring key researchers. *Also, e.g.*, governments might have alternative goals for national resources than commercial operators might have.

In summary of Section 3, *supra*, there are various laws that would be applicable as written but many would need adjusting to fit the circumstances of offshore methane hydrates.

Those laws such as the EIA & SEA Directives and the NEPA, but also those like OSCLA, that require environmental assessments to be completed prior to the licensing and permitting of offshore activities are most complete and less in need of revision or updating, Those specific laws focused on hydrocarbon accidents and similar industrial accidents are generally poorly suited to the specific circumstances of offshore methane hydrates as currently enacted.

The EU has two directives that are so close to the nature and character of offshore methane hydrate operations that one wonders if it might be feasible to adjust those existing directives.

First, the Offshore Directive reflects careful drafting to be inclusive of both known historical oil spill accidents and other potential types of offshore accidents; the generic phrases "major accident," "major hazard," and "environmental impact" are oft used in lieu of more specific forms of accidents. However, the historical bias of well-known oil spill events does lurk within the legal paradigm of the Offshore Directive. The Preamble connects the Offshore Directive to oil spills caused by ships. [92] Additional language could be added to emphasize the potential for both crude oil and natural gas accidents within offshore extraction operations. Specific mention of the unique circumstances of methane hydrate accidents could buttress the application of the Offshore Directive to such events.

In discussing the importance of the preservation of the Arctic's environment, focus is put on Arctic marine oil pollution with no discussion of the harms of natural gas emissions, venting or seepage.[93] The definitions section of the Offshore Directive includes an "oil spill response effectiveness" term, but no analog for methane hazards.[94] Such could be readily remedied by either providing parallel definitions and concerns for methane related events or by expanding the current terms to be more inclusive and more clear. *E.g.*, the EMSA is charged with the duty monitor the extent of an "oil <u>or</u> gas spill" (underscoring added); but gases do not spill as such, the word choice reflects historical expectations of an "oil <u>and</u> gas spill" event, alike the 2010 Gulf of Mexico incident, wherein crude oil has been the dominant semantic concern.[95] *E.g.*, in the discussion on "Internal emergency response plans," there is a requirement for an analysis of the oil spill response effectiveness of the proposed plans.[96] The internal emergency response plan is required to include a list of necessary equipment including those for capping a spill; no requirement or analog terms are made for dealing with gaseous venting or seepages.[97] *E.g.*, there is a requirement for environmental factors to be considered

92 Offshore Directive. Preamble 49.
93 Offshore Directive. Preamble 52.
94 Offshore Directive. Art. 2(32).
95 Offshore Directive. Art. 10.2(a).
96 Offshore Directive. Art. 14.1.
97 Offshore Directive. Annex I, 10(5).

in the estimate of the oil spill response effectiveness metric, but no symmetrical analysis is suggested for gaseous accident response plans.[98]

Further, reference is made to dispersants, which only find use against crude oils.[99] The external emergency response plan is required to address "oiled animals" that might reach the coast in advance of the "actual spill."[100] Similarly, when well operations are to be undertaken, a similar requirement exists for an analysis of the oil spill response effectiveness of the proposed plans.[101] Neither requires an analysis for response effectiveness to methane accidents. The same asymmetry is found in the requirements for the report on major hazards for operation of a production installation[102] and for the report on major hazards for a non-production installation.[103]

So while the Offshore Directive can be read to include planning for major accidents and major hazards of the exploration and production of methane hydrates, the Offshore Directive retains a semantic bias for crude oil spills. By broadening its existing terms or by providing parallel details for events related to both conventional and methane hydrate related accidents, the Offshore Directive could be extended to better cover the circumstances of offshore methane hydrates.

As discussed earlier, the CCS Directive is a perfect fit for those aspects of offshore methane hydrate projects that do elect to engage in co-productive carbon dioxide injections back into the hydrate deposits. To that extent, the CCS Directive is well drafted for application to offshore methane hydrate projects. However, because of certain similarities between the CCS technologies and hydrate extraction technologies, they can be viewed as the reverse of each other, some of the terms developed within the CCS Directive might be employable within a future Offshore Methane Hydrate Directive or as terms to assist in the redrafting of the current Offshore Directive. "Leakage" is defined at Art. 3.5. to include any release of carbon dioxide from the storage complex, and "storage complex" is defined at Art. 3.6. to include the storage site and the surrounding geological domain. The definition of "significant irregularity" at Art. 3.17. parallels the concerns of deteriorating stability of methane hydrate fields; "significant irregularity means any irregularity in the injection or storage operations or in the condition of the storage complex itself, which implies the risk of a leakage or risk to the environment or human health." Any efforts undertaken to correct significant irregularities or leakages are defined as "corrective measures" at Art. 3.19.

If these types of suggestions were implemented, then the conjoint application of strict liability with sophisticated public regulations could be readily effected within the European Union and its Member States.

[98] Offshore Directive. Annex I, 10(8).

[99] Offshore Directive. Annex I, 10(12).

[100] Offshore Directive. Annex VII at (h).

[101] Offshore Directive. Art. 15.1.

[102] Offshore Directive. Annex I, 2(5).

[103] Offshore Directive. Annex I, 3(5).

The general trend of U.S. federal laws related to oil spills has focused on assignment of liability based on rules of strict liability, on liability caps, and on penalties for lost volumes. As such, the American federal laws could also be readily amended if their current character were to be retained. Once that were accomplished, existing safety regulations could be updated; as the American petroleum industry provides the bulk of such regulation privately within the API, one assumes that those materials could and would be updated as offshore methane hydrate projects approached early development.

OCSLA primarily addresses the leasing of minerals and was found to be effectively applicable to offshore methane hydrates in its current form. OCSLA could be expanded with substantially minor edits to bring attention to the need to provide oversight for methane safety in addition to the existing language on crude oil and on minerals in general. OCSLA already provides grant of administrative powers to the Commerce Secretary to provide regulatory guidance to ensure the best available practices and safest technologies; these regulatory powers could be used to support development of the appropriate standards and rules for the development of offshore methane hydrates.

OPA at large has a strict liability rule that could be readily adjusted to include methane hydrate accidents. OPA could have accidents and operators redefined to include the circumstances related to offshore methane hydrate accidents. Specifically, OPA could be amended to explicitly provide for the inclusion of marine-based methane emission accidents to parallel its current definition for oil spills. OPA could also include volumetric standards for methane to parallel with its crude oil barrel standards. OPA currently provides a taxonomy of vessel and facilities in defining the liability caps for oil spills; methane hydrates operations might deserve a similar but separate listing of facility types if liability caps were to be retained for methane hydrate operations.[104] To better address particular concerns related uniquely to offshore methane hydrate accidents, there might be several enumerations of particular acts or omissions that would substantiate gross negligence for offshore methane hydrate operators.

The CWA enables fines and penalties for marine pollution. The CWA could be amended more simply than would be required for OPA by including methane as a marine pollutant for the purposes of the CWA. Once included as a marine pollutant, volumetric standards for emitted, seeped, or vented methane should also developed and included in parallel to the existing volumetric measures provided for barrels of crude oil. Finally, the penalty areas of the CWA could be amended to include both barrels of crude oil leaked or volumes of methane emitted.

In speaking of private regulations, there are existing organizations in place that could assist with the development of those private regulations for offshore methane hydrates. *E.g.*, as mentioned *supra*[105], the API provides over 600 standards

104 *E.g.,* offshore methane hydrate extraction facilities might be onboard a drilling and producing vessel or they might attached to moored or connected structure.

105 *See* ch. 6, sec. 5.1, Footnote 148.

for the oil and gas industry. Additionally, there are other research groups and environmental groups that maintain research related to the development of offshore methane hydrates. These groups could be encouraged to begin drafting of suggested private regulations. Those draft regulations could also serve to inform public regulatory bodies in the development of their own regulations or in the coordinated development of integrated regulatory mechanisms.

5. Final conclusions

Offshore methane hydrates provide a cornucopia of potential benefits and hazards. Because the effects of these benefits and hazards would engage far beyond a private cluster of individuals, a public law response is needed.

This study has also found that the technological hurdles are being reduced, that the costs of extracting and producing offshore methane hydrate are dropping, and that several nations have explicitly stated that they intend to produce offshore methane hydrates within this decade. As such, the timing to develop the necessary rules of civil liability and regulations is pressing.

The theory of law and economics has provided a means of evaluating alternative rules of civil liabilities and of alternate public regulations. It is the result of this study that a rule of strict liability should be implemented in a complementary fashion with public and private regulations. That combination would provide a more complete set of precautionary incentives to the relevant actors, a more complete set of information to all parties, and the combination would reinforce the effectiveness of both systems of risk governance.

It was found that there are existing and functional rules to address hydrocarbon accidents. The basic paradigm for spilt crude oil is broadly in alignment with the recommendations of this study. The rules generally display a preference for the rule of strict liability. The rules often call for extensive amounts of public regulations in parallel to the assignment of strict liability.

Where problems were found it was found that they were usually a result of the simple problem that accidents predicated upon methane leakages were not explicitly included in the drafting of oil spill laws and conventions. Even when broader terms of hazardous substances were included within such frameworks, it appeared that water-borne methane was not included. Thus, water-born methane has fallen between the cracks, so to speak, of otherwise sound and useful laws and regulations.

It is the conclusion of this study that such oversight could and should be readily remedied. The fundamental frameworks that already exist could and should be extended to include the potential for the commercial development of offshore methane hydrates. Such efforts could be dove-tailed into existing regulatory frameworks and case law histories by amending the existing laws to be more inclusive.

Such a process, although perhaps the efficient choice from a transaction costs perspective, would still require extensive discussion and commentary. Changes to EU Directives would likely engage mechanisms under the EIA and SEA Directives, changes to U.S. federal laws would require both administrative and public processes under NEPA. These procedural reviews would not be quick and should not be unsafely expedited; to provide sufficient time to ensure safety and public support, these reviews should be started sooner not later.

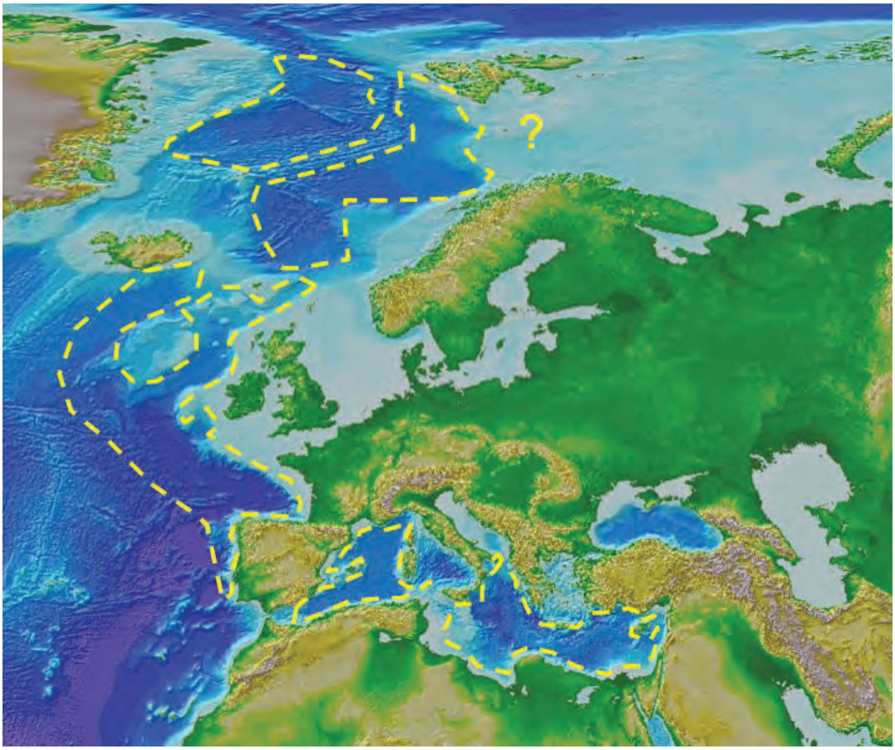
Chapter 12

Appendix I

MAPS OF METHANE HYDRATES

Appendix I. A.

Map: Statoil's map of methane hydrates near European waters. Reichel 2011.



Maps of methane hydrates

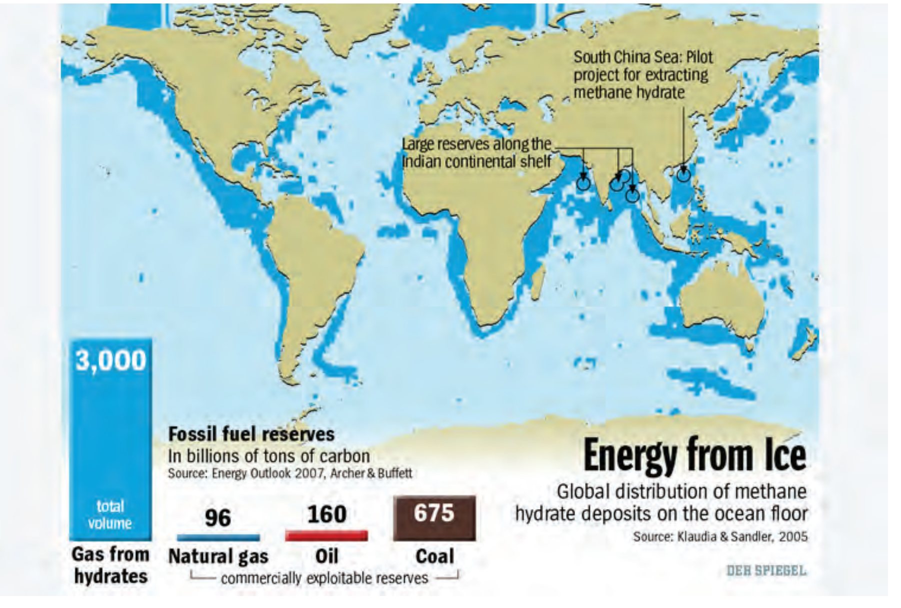
Appendix I. B.

Map: Mother Jones/The Atlantic global map of methane hydrate locations

Global map of methane hydrates, as co-published by Mother Jones and The Atlantic. The yellow squares indicate where methane hydrates have been extracted; the blue push-pins show where methane hydrates are expected to be found.
(Image by Alice Cho.)

Appendix I. C.

Map: Der Spiegel's global map of methane hydrates, based on the Klauda Sandler map

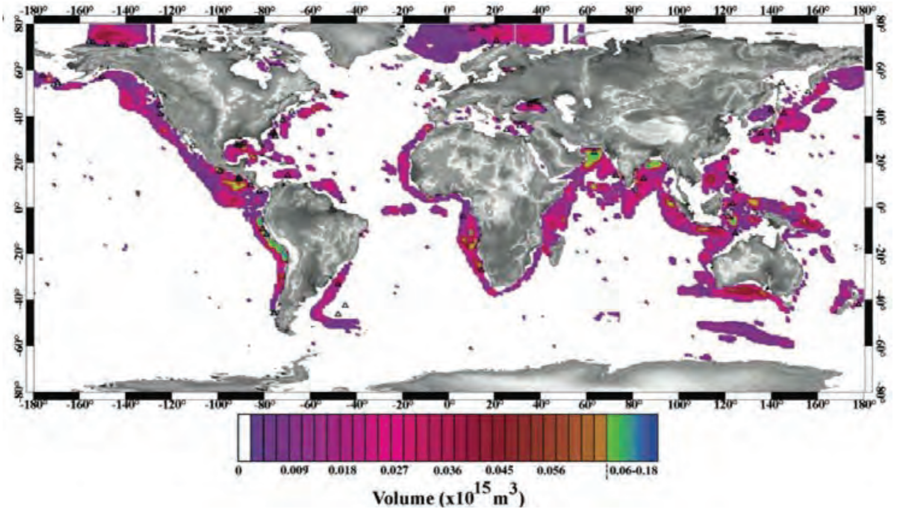


Der Spiegel presented an article on methane hydrates, this image became famous due to the overlapping topic in the novel "The Swarm".

Contrast this map with the image in Appendix I. D., which is the original map from Klauda & Sandler 2005.

Appendix I. D.

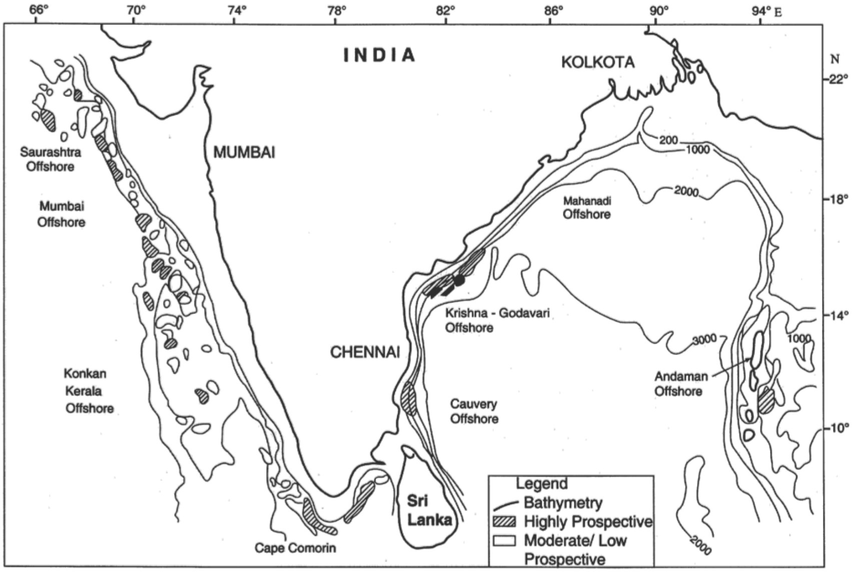
Map: Klauda and Sandler's global map of methane hydrate distribution. Klauda & Sandler 2005.



This mapping of offshore methane hydrates is their original image. Most of the current maps found in popular media are derived from this mapping of the potential methane hydrates.

Appendix I. E.

Map: Map of likely methane hydrate deposits near India. Ramana 2006.



Appendix II A

SHAVELL'S ECONOMIC MODELS OF ACCIDENTS

Shavell was one of the first to develop a model of liability rules that enabled policy makers to evaluate the efficiency of a particular liability rule to achieve the optimal level of accident avoidance.[1] Given the intent of the model,[2] it is clear that Shavell examined liability rules from the perspective that liability rules are tools to provide *ex ante* incentives to avoid accidents and not from the perspective of how efficiently or justly those rules might provide compensation to victims.

Shavell's model of liability rules provides for both unilateral and bilateral tort events.[3] A unilateral tort event is an event where only one party controls the actions that lead to an accident.[4] A bilateral tort event is an event wherein both parties control actions that can lead to an accident between them.[5] Shavell established a second dimension of analysis based on the relationships of the parties; (i) mutual strangers, (ii) sellers and non-customers, and (iii) sellers and customers or employees.[6] He tested the liability rules of strict liability, of negligence, and of no legal recognized liability.[7] Shavell found that in unilateral torts that strict liability was efficient in all of the cases, negligence in limited cases, and no liability rule in only one case.[8]

1 *See* S. Shavell, *On Moral Hazard and Insurance*, 93 Q. J. Econ. 541 (1979); S. Shavell, *Strict Liability versus Negligence*, 9 J. Legal Stud. 1 (1980); and S. SHAVELL, ECONOMIC ANALYSIS OF ACCIDENT LAW (Harvard University Press, 1987).

2 "The aim of this article is to compare strict liability and negligence rules on the basis of the incentives they provide to "appropriately" reduce accident losses. ... In particular, there will be no concern ... with distributional equity—for the welfare criterion will be taken to be the following aggregate: the benefits derived by parties from engaging in activities less total accident losses less total accident prevention costs." Shavell, *supra* at note 1, at 1.

3 *Id.*, *en passim.*

4 *Id.*, at 2 and 10.

5 *Id.*, at 6 and 17.

6 *See id.*, at 2-6 for the unilateral models and at 6-9 for the bilateral models.

7 *See* an example of the rules in contrast at Tables 1, 2, and 3 at *id.*, at 17, 21, and 22.

8 *See* Table 1, p. 17, for tabular data on the results from Proposition 3 on seller-customer unilateral torts. *Id.*

In preview, Shavell suggested a theoretical preference for strict liability. Shavell found that strict liability was efficient in all of the examined cases for unilateral accidents, unlike negligence or no liability.[9] For bilateral accidents, he found that the results were more complicated, in that none of the simple rules yielded efficient results.[10] In bilateral accident prevention, the civil liability rule choice depended on which actor(s) the community wishes to target to bear the burdens of accident avoidance.[11] Finally, Shavell found that certain ultra-hazardous activities merit the application of strict liability.[12]

1. Shavell on unilateral accidents

Shavell found that in the stranger-stranger unilateral tort, that strict liability achieved efficiency by requiring the injurer to include the full costs of the accident in his overall welfare function.[13]

In effect, strict liability forced the injurer to internalize adopt Kaldor-Hicks welfare efficiency.[14] The same scenario under negligence requires only that the injurer maintain a duty of care but no additional costs from whatever accidents occur, so long as the duty was met.[15]

Table 1: Elements of Shavell's Unilateral Accident Model

Term	Explanation	
x	The tortfeasor's care or precaution level	
	$x \geqq 0$	Precautionary level is greater or equal to zero/
	$\bar{x}$	Duty of care level of precaution
y	The tortfeasor's activity level	
	$y \geqq 0$	Activity level is greater or equal to zero/
$l(x)$	Expected accident losses per unit of tortfeasor activity level	
$a(\bar{x}, y)$	Income equivalent of the utility to tortfeasor from engaging in activity at level y while exercising care level x	
$W(x, y)$	Social welfare	

9 *See infra*, Table 2.
10 *See infra*, Table 3.
11 *See infra*, at Section 2.
12 *See infra*, at Section 3.
13 Shavell, *supra* at note 1, at 11-12. *See* Equation (2).
14 *Id.*, at 11-12. *See* Equation (2).
15 *Id.*, at 11-12.

In Shavell's formulation, the injurer has a care or precaution level, $x \geqq 0$, and and activity level, $y \geqq 0$. Social welfare, $W(x, y)$, was defined as the sum of income equivalent of the utility of the injurer, $a(\bar{x}, y)$, less the costs $l(x)$ of the activity at activity level y, $-yl(x)$.[16]

$$W(x, y) = a(x, y) - yl(x) \tag{1}$$

Under strict liability, the injurer is able to optimize his utility as impacted by the costs he would bear in accidents. His optimand is the same as the social welfare function, thus strict liability is efficient.[17]

$$a(x, y) - yl(x) \tag{2}$$

Under negligence, assume that the injurer chooses an $x = \bar{x}$, that the care level selected is the efficient care level.[18] Then the injurer under a negligence rule is tasked with optimizing $a(\bar{x}, y)$ given the injurer's choice in y.[19] The injurer will select $y(\bar{x}) > y^*(\bar{x})$, wherein $y^*(\bar{x})$ denotes the welfare efficient level of activity given the due care level.[20] Thus in stranger-stranger unilateral contexts, the negligence rule would yield results of due care but at excessive levels of activity, resulting in higher than efficient levels of accidents with the victims being liable for the costs of those accidents.[21] This results in the injurer engaging in an excess of activity, excessive accidents result, and negligence is seen as inefficient.[22]

Under a "no liability" rule, the injurer exercises no duty of care and bears no costs of the accidents so the activity level of the injurer is guided solely by his personal utility, $a(x, y)$,[23] and over engages in tortious conduct.

Shavell ranks the results as Proposition 1:

> *"PROPOSITION 1. Suppose that injurers and victims are strangers. Then strict liability is efficient and is superior to the negligence rule, which is superior to having no liability at all."*[24]

An identical result is reached for the seller-stranger scenario.[25]

Under the seller-customer, or seller-employee, scenario, the results for strict liability are almost identical to the two previous analyses; strict liability is found efficient.[26] However, analysis of negligence in this scenario leads to new results.[27]

16 *Id.*, at 10-11.
17 *Id.*, at 11.
18 *Id.*
19 *Id.*, at 12.
20 *Id.*
21 *Id.*
22 *Id.*
23 *Id.*, at 11.
24 *Id.*, at 12.
25 *Id.*, at 14.
26 *Id.*, at 15.
27 *Id.*

Negligence is found to be efficient if the customers or employees are aware expected accident losses of either each seller or of the overall average of the sellers.[28] But if the customers or employees were faced with uncertainty as to the expected accident losses of the sellers, then negligence became inefficient.[29] When no liability rule is applied, only the case of knowledge of each seller's duty of care level can result in efficiency; knowledge of average care levels or uncertainty about the safety levels results in inefficiency, although the former is more efficient than the latter.[30]

In summary, Shavell found that in unilateral accidents that strict liability was efficient in every examined scenario but negligence was inefficient except when the victim is accurately aware of the care level of the tortfeasor. But that is tempered with the counterpoint that with sufficiently accurate information the results of a negligence regime are similar to no liability rules at all. Shavell thus demonstrated that for unilateral accidents strict liability is superior to both negligence and a lack of liability rules, yet negligence more efficient than a lack of liability rules.

Table 2: Unilateral Accidents: Are Liability Rules Efficient?

Encounter	Strict Liability	Negligence	No Liability
stranger-stranger	Yes	No	No, worse
seller-stranger	Yes	No	No, worse
seller-customer[31]	Yes	Yes	Yes
	Yes	Yes	No
	Yes	No	No

2. Shavell on bilateral accidents

When Shavell examines bilateral accidents, those accidents wherein both parties have control over actions that lead to accidents, he finds that the critical issue is "which party do we want to control, the injurer or the victim?" This is an extension of Calabresi's earlier cheapest cost avoider rule, that the person who could have prevented the accident with the least cost of taking care should be the person held liable for the accident.[32]

28 *Id*.
29 *Id.*, at 16.
30 *Id., at* 16.
31 Entries to the right reflect three orders of knowledge. Top row, the customer knows the risk of each seller. Middle row, the sellers' average risk. The bottom row, uncertain knowledge or misperception.
32 H. B. SCHÄFER & F. MÜLLER-LANGER, 'Strict liability versus negligence' *in*: TORT LAW AND ECONOMICS, 10 (2009). *See* G. CALABRESI, THE COSTS OF ACCIDENTS: A LEGAL AND ECONOMIC ANALYSIS (Yale University Press, New Haven, Conn., 1970).

In the stranger-stranger scenario, he finds that strict liability with defense of contributory negligence, efficiency cannot be achieved because the victims will bear no costs for accidents and will have no incentive to reduce their activity levels.[33] The negligence rule in this scenario reflects the reverse, that the injurer will face no costs to reduce activity levels and thus the negligence rule is inefficient.[34] Further, no liability rule and strict liability without contributory negligence are rated as inferior to either of the two previous results. [35]. Thus, in bilateral stranger encounters, the policy choice is inefficient but does enable the policy maker to reduce either injurer activity levels under strict liability with contributory negligence or to reduce victim's activity levels with the negligence rules.[36]

Table 3: Bilateral Accidents: Are Liability Rules Efficient?

Encounter	Strict[37]	Strict[38]	Negligence	No Liability
Stranger-Stranger	No*[39]	No***[40]	No**[41]	No***
Seller-Stranger	No*	No***	No**	No***
Seller-Customer[42]	No	No	Yes	Yes
Durable Goods	No	No	Yes	No
	No	No	No	No
Seller-Customer[43]	Yes	No	Yes	Yes
Non-Durable Goods	Yes	No	Yes	No
	Yes	No	No	No

Indeed, Shavell proves that in stranger-stranger encounters, no simple liability rule can be efficient.[44] These results are identical when the seller-stranger scenario is modelled; it is more efficient to use strict liability if the target is to reduce injurer activity levels and more efficient to use negligence if the target is to reduce victim activity levels.[45]

33 Shavell, *supra* at note 1, at 19. Specifically, Shavell targets the condition of $s = \bar{s} = s^*$ as the cause.
34 *Id., at* 19.
35 *Id.*
36 *Id.*
37 Strict Liability <u>with</u> Defense of Contributory Negligence
38 Strict Liability <u>without</u> Defense of Contributory Negligence
39 *Limits Injurer's Behavior
40 ***Inferior to other inefficient results
41 **Limits Victim's Behavior
42 Entries to the right reflect three orders of knowledge. Top row, the customer knows the risk of each seller. Middle row, the sellers' average risk. The bottom row, uncertain knowledge or misperception.
43 Entries to the right reflect three orders of knowledge. Top row, the customer knows the risk of each seller. Middle row, the sellers' average risk. The bottom row, uncertain knowledge or misperception.
44 *Id., at* 19-20. *See* Proposition 5.
45 *Id., at* 20. *See* Proposition 6.

The seller-customer model is overall similar to the results seen in the unilateral case if the goods sold are non-durables;[46] strict liability with defense of contributory negligence is efficient at all levels of customer knowledge, negligence is efficient with certain knowledge about the sellers but not against uncertain knowledge, and no liability is efficient only when presented with certain knowledge about each specific seller.[47] An interesting plot twist is that the rule of strict liability without a defense is inefficient in every case of knowledge. But when the product is a durable good, then strict liability becomes inefficient both with and without defense at all levels of knowledge; this is primarily because the customer has no incentive to limit his activity level.[48]

When the parties were seller-customer and the customer had accurate information about the safety levels of the seller, then both strict liability (with defense of contributory negligence) and negligence were efficient. In the same case, strict liability was efficient without knowledge but negligence was inefficient without information. But in the 'simpler' case of stranger-stranger encounters, neither strict liability (of both types) nor negligence were efficient; they both failed to provide for efficient levels of care. However, the strict liability rule provided optimal behavior from the tortfeasor and the negligence rule provided optimal behavior from the victim – in bilateral events between parties with no market interaction, the liability rules can be used to control the party most able to cause hazard or harm but not both at the same time, a priority decision must be made.

Shavell's conclusions on bilateral accidents are much more complex than for the unilateral accidents. Because the results are substantially different, it highlights the importance of correctly identifying events as unilateral or bilateral events. Unlike the unilateral results, no rule was found to be consistently efficient.[49] But, if the least cost avoider can be identified ex ante, then the application of that principle to determine which actor should be regulated can be combined with the appropriate choice of regime to obtain first best results.[50]

46 *Id., en passim*. Non-durables are defined by Shavell to be those goods that created the event where the activity level of both the seller and the customer are identical. He provides the example of a restaurant meal; the restaurant prepares and serves one meal, the customer eats one meal. *Id.,* at 8; *see also* Table 2.

47 *Id., at* 21. *See* Table 2.

48 *Id., at* 8. *See also* Table 3.

49 However, there may be theoretical reasons to find negligence to be more robust than strict liability when this model's assumptions are relaxed. That was the result when Schäfer, et al., extended this section of Shavell's research. They found that when the identity of the lowest costs avoider was determined ex post, and not ex ante, then both parties face a probabilistic distribution as to potential judgment and damages. This result creates a problem of uncertainty, and that in turns results in the Uncertain Legal Standards model discussed, *infra*, at Appendix II-B, Section 1.4. *See also* SCHÄFER & MÜLLER-LANGER, *supra* at note 32, at 11.

50 SCHÄFER & MÜLLER-LANGER, *supra* at note 32, at 11.

3. Shavell's Ultra-Hazardous Strict Liability Rule

Beginning courses in Tort Law often suggest that strict liability is employed for cases wherein abnormally hazardous activities are engaged in, to ensure that those parties that engage in that type of activity are responsible for any damages resulting from their decisions to undertake risky activities.[51]

Shavell suggests that ultra-hazardous activities have two characteristics which especially merit the application of strict liability rules. First, the activities are (i) uniquely identifiable and (ii) impose non-negligible risks on non-participant victims which "make[s] the activity worthwhile controlling."[52] Second, the victim's engagement with the risky activity is entirely routine in normal life, thus "activity that cannot and ought not be controlled."[53]

Shavell then states that given those descriptions of ultra-hazardous activities, that it falls within his Propositions 4 and 6 from his model of bilateral accidents between strangers.[54] In so doing, he implicitly assumes that the ultra-hazardous scenarios involve victims *cum* strangers, and that a rule of contributory negligence is in effect.

> *"PROPOSITION 4. Suppose that the injurer and victim are strangers. Then none of the normal liability rules is efficient. Strict liability with a defense of contributory negligence is superior to the negligence rule if it is sufficiently important to lower injurer activity levels. Strict liability without the defense and no liability are each inferior to whichever rule is better: either strict liability with the defense or the negligence rule."*[55]

> *"PROPOSITION 6. Suppose that injurers are sellers and that victims are strangers. Then the results are as given in Propositions 4 and 5."*[56]

As such, the goal is to efficiently incentivize the tortfeasor to control his activity level and leave the victim unaffected in his activity level;[57] this is best achieved by the rule of strict liability with defense of contributory negligence.

51 *See* Shavell, *supra* at note 1, at 24, "Concluding Comments. #4."
52 *Id.*
53 *Id.*
54 *See* "Concluding Comments. #4. Shavell 1980, p. 24.
55 Shavell 1980, p. 19.
56 Shavell 1980, p. 20.
57 *See* "Concluding Comments. #4. Shavell 1980, p. 24.

Appendix II B

SCHÄFER, OTT, SCHÖNENBERGER AND MÜLLER-LANGER

The Shavell model has been updated and explored by Schäfer and Ott, Schäfer and Schönenberger and by Schäfer and Müller-Langer,[1] and that model is presented hereunder.[2]

The model starts as a unilateral case wherein the victim has no role to play in the incidence of the harmful event. Schäfer *et alia* have presented a simplification wherein the activity level is given, to better focus on the duty of care, x. The optimand becomes:[3]

$$\min \; c(x) + d(x) \tag{1}$$

and if the first derivatives are set equal to each other, [4]

$$c'(x) = -d'(x) \tag{2}$$

1.1. Rule of No Liability

Under a rule of no liability, the term $d(x)$ is not included in the tortfeasor's decision process and thus only his own costs, $c(x)$, are included into his considerations.[5] This

1 Schäfer co-authored earlier versions of this model with Ott in 1995 and separately with Schönenberger in 1999; those articles were updated most recently in 2009 with co-author Müller-Langer. While the mathematic models are not completely identical, they are clearly closely related and thus are here presented as a joint-product. *See:*
   i. C. Ott & H. B. Schäfer, *Negligence as Untaken Precaution, Limited Information, and Efficient Standard Formation in The Civil Liability System*, 17 Int'l Rev. L. & Econ. 15 (1997).;
   ii. H. B. SCHÄFER & A. SCHÖNENBERGER, *Strict Liability versus Negligence, in*: ENCYCLOPEDIA OF LAW AND ECONOMICS (Edward Elgar, 2000); and
   iii. H. B. SCHÄFER & F. MÜLLER-LANGER, 'Strict liability versus negligence' *in*: TORT LAW AND ECONOMICS (2009).

2 Schäfer & Schönenberger, *supra* at note 1, at 599-604.

3 *Id.*, at 599.

4 Schäfer & Schönenberger, *supra* at note 1, at 599. Schäfer & Müller-Langer, *supra* at note 1, at 5.

5 Schäfer & Schönenberger, *supra* at note 1, at 600. Schäfer & Müller-Langer, *supra* at note 1, at 5.

absence of the victim's external costs will lead to a result that the tortfeasor will seek to optimize at the inflection point, where:

$$c'(x) < 0, and\ c''(x) = 0 \tag{3}$$

Table 1: Schäfer, Ott, Schönenberger, and Müller-Lange Models of Civil Liability Rules

Term	Explanation	
x	Level of care or precaution[6]	
	x^*	Socially optimal level of care
	x^{**}	Any level of care below the optimal level of care
$c(x)$	Accident prevention costs borne by the tortfeasor, given a certain level of care[7]	
$d(x)$	total expected damages based on level of care; costs borne by victim [8]	
a	Activity level of the tortfeasor[9]	
$u(a)$	Utility of tortfeasor given activity level	
m	Judgment error rate[10]	
	md	Resultant judgment damages[11]

and thus the tortfeasor is expected to choose a lowest level of care. One could reasonably assume that lower costs of care imply higher accident costs, so the no liability rule case is expected to (i) not be efficient and (ii) "clearly not socially desirable."[12]

1.2. *Unilateral negligence rule*

The negligence rule can be established as:[13]

$$B < PL \tag{4}$$

which is Judge Hand's formulation that an actor is negligent if the born burden of care, B, was found to be less than the probable, P, losses, L, from the harmful event.

6 Schäfer & Schönenberger, *supra* at note 1, at 599.
7 *Id.*
8 *Id.*
9 Schäfer & Müller-Langer, *supra* at note 1, at 5. *See* Equation 4 therein.
10 Schäfer & Müller-Langer, *supra* at note 1, at 9. Explained in the discussions prior to Equation 19.
11 *Id.*
12 Schäfer & Schönenberger, *supra* at note 1, at 600.
13 *Id.*

Assuming that the appropriate level of care is x^*, then the tortfeasor faces a choice, to either act under care and pay no accident costs or to not take due care, x^{**}, and pay accidents costs:

$$c(x^*) \leq c(x^{**}) + d(x^{**}) \tag{5}$$

Since insufficient care is tantamount to low costs of care, the implied result is that the costs of total expected damages to the victim will be higher.[14] As the definition of the appropriate level of care, x^*assumes that less care results in more net costs, the tortfeasor should choose to follow the guided appropriate level of care; negligence is efficient for a unilateral case. [15]

Interestingly, if the amount of precaution costs required by the courts exceed the socially optimal level of care, efficiently minded actors will discard the negligence rule's duty of care for the more efficient socially optimal level of care and simply bare what excess costs over their duty of care requires, as that would be cheaper than the court imposed duty of care.[16] On the other hand, if the costs of due care are less than the imposed damages, then the imposed damages can also be less than the actual harms and the negligence rule will remain efficient.[17] This is because it will remain rational to expend the lesser costs of due care than the more costly damages. [18]

It can be very difficult for judicial and legislative authorities to correctly determine the socially efficient duty of care.[19] Schäfer *et al.* present the argument that it is far more flexible and computable to determine the cheapest alternative method that would have prevented the accident; the delta of the costs of the care assumed and the costs of the next alternative can be compared against the costs of the harms for an application of Hand's Rule, *supra* at Eq. 4. [20]

Schäfer *et al.* provided a unilateral model that accommodates a variable for the activity level, a.[21] Given the utility function of the actor cum tortfeasor, u,

$$\max \ u(a) - ax - ad(x) \tag{6}$$

The optimal level of activity, a, can be found by the first determinants,

$$u'(a) = x^* + d(x^*) \tag{7}$$

The result is that the tortfeasor should increase his activity level, assuming a predetermined level of care, until his marginal utility from additional activity

14 *Id.*

15 *Id.*

16 *Id.*, at 601.

17 Schäfer & Müller-Langer, *supra* at note 1, at 5.

18 *Id.*

19 This is an argument to consider against both statutorily determined duty of care levels and of certain regulatory controls. Schäfer & Schönenberger, *supra* at note 1, at 602.

20 *Id.*

21 Schäfer & Schönenberger, *supra* at note 1, at 603.

exceeds the marginal costs, both his own and the external costs, caused by increased activity level. [22]

1.3. *Unilateral strict liability rule*

Under an unilateral strict liability rule, the tortfeasor has no required duty of care but he does face the total costs of the activity, both his own and the external costs.[23]

$$c(x) + d(x) \tag{8}$$

As such, the social costs equal the private costs borne by the tortfeasor, so the private minimization of costs will have the same result. [24] Strict liability achieves a socially optimal level of care. [25]

1.4. *Uncertain Legal Standards*

Court errors do occur and must be taken into account.[26] There are three primary listed sources for court errors:

(i) Error in determinations in the level of efficient care, [27]
(ii) Error in the assessments of an injurer's actual rendered level of care, [28] and
(iii) The parties own inabilities to monitor and render specific levels of care continuously. [29]

These three problems have two effects on the efficiency of liability rules; to over-comply or to under-comply. [30] Over-compliance better ensures that whatever the actually imposed level of care turns out to be that the injurer met that hurdle and will not bear the potentially larger costs of the harms rendered. [31] Under-compliance results from an awareness that errant courts might sometimes render no judgment for damages despite the injurer failing to meet the sanctioned level of due care, thus it becomes irrational to always pay the costs for meeting the sanctioned level of due care. [32]

The mechanics of the decision process are determined by three factors;

(i) the impact on the costs of care,[33]

22 *Id.*
23 Schäfer & Schönenberger, *supra* at note 1, at.
24 *Id.*
25 *Id.*
26 Schäfer & Müller-Langer, *supra* at note 1, at 8.
27 *Id.*
28 *Id.*
29 *Id.*
30 *Id.*
31 *Id.*
32 *Id.*
33 *Id.*, at 9.

(ii) the expected damages, [34] and
(iii) the resultant impact on being held liable for negligence. [35]

In the case of an injurer choosing to increase their care level and to thus over-comply, the mechanical results are that the costs of care are increased, the expected damages are decreased, and the probability of being held liable for negligence also decreases. [36] Given this mix of directions in costs changes, it is difficult to forecast what the injurer would choose to do without the specific costs being detailed; but it is most likely that either way the injurer is not likely to land on an efficient result. [37]

Under a negligence rule, it has already been demonstrated that under-compensation can still result in an efficient level of due care.[38] It is only when the error rate, m, approaches the limits of zero or of very large numbers,[39] that the negligence rule would function inefficiently.[40]

Under a strict liability rule, there is no resultant efficient outcome only inefficient over- or under-compliance. [41]. $m > 1$ always leads to over-deterrence and $m < 1$ always leads to under-deterrence.

Thus when the error potential of the court system is considered, the negligence rule can be more robust and retain its efficiency in contrast to a less reliable strict liability rule. [42]

Additionally, when litigation costs are considered, because errant courts will bear substantial transaction costs, the optimal rule may not necessarily be foreseeable *ex ante* but a strict liability rule is expected to be less costly.[43] There are three impact factors. First, because victims bear more costs to litigate under a negligence rule, as they have more to establish in court, they will initiate less litigation that those victims facing a strict liability rule. [44] Second, because the law of strict liability is both simpler, in that no causation need be developed nor any level of care be established, the legal consequences are more readily foreseeable. [45] Third, this foreseeability will lead to more pre-trial settlements, enabling lost cost transference of wealth from tortfeasor to victim. [46]

34 *Id.*
35 *Id.*
36 *Id.*
37 *Id.*
38 *See supra* in discussion on Schäfer's *et al.* unilateral negligence model, at Section 2.
39 The error rate is defined as m ∈ $\{0 < m < \omega\}$; wherein "zero error" would be m = 1 and ω is a very large positive real number.
40 *Id.*
41 *Id.*
42 *Id.*
43 *Id.*, at 16.
44 *Id.*
45 *Id.*
46 *Id.*

Appendix II C

HYLTON'S POSITIVE THEORY OF STRICT LIABILITY

Hylton extended the "Shavell-Landes-Posner"[1] model of civil liability to provide a theoretical foundation for the widespread application of negligence as opposed to strict liability. He extends the Shavell-Landes-Posner model by including three additional concerns.

i. The model addressed the cross externalization of risk between the parties involved in an accident.
ii. The model added more detail on the causal considerations central to tort law.
iii. The model provided a treatment to explicitly handle the effects of benefits externalization. In so doing, the Calabresian lowest cost avoider is shown to be incomplete or inefficient.

1. Alignment with Shavell's Unilateral Models

The model assumes unilateral causation and unilateral risk.[2] It assumes that all actors are risk neutral.[3] It assumes that reasonable care reduces accidents but is costly to effect.[4] The model assumes error-less litigation and that the costs of litigation are zero.[5] It assumes that all victims receive what the law provides under the modeled civil liability rule, thus all victims win at court.[6] It then assumes that

1 K. N. Hylton, A Positive Theory of Strict Liability. 4(1) Review of Law & Economics 153 (2008) (Due to licensing limits where the present study was undertaken, its research relied on the working paper version of Hylton's article; as such, all point citations are to that source material. *See* K. N. Hylton, *A Positive Theory of Strict Liability,* 4 (Boston University School of Law Working Paper No. 06-35, *available* at SSRN: http://ssrn.com/abstract=932600)
2 *Id.*, at 5.
3 *Id.*, at 4.
4 *Id.*
5 *Id.*, at 5.
6 *Id.*

the actors are rational in that they will choose reasonable care, x_r, if the incremental costs of damages are greater than the costs of reasonable care. [7]

Table 1: Elements of Hylton's Positive Theory of Strict Liability Model

Term	Explanation	
i and j	actors in the model, *e.g.*, A and B	
q_i	The likelihood that actor i will cause harm to actor j while actor i exercises care x_r	
	$(1 - q_i)$	The likelihood that actor i will ***not*** cause harm to actor j while actor i exercises care x_r.
p_i	The likelihood that actor i will cause harm to actor j while actor i exercises care $x_\emptyset$.	
	$(1 - p_i)$	The likelihood that actor i will ***not*** cause harm to actor j while actor i exercises care $x_\emptyset$.
	$p_i > q_i > 0$	The likelihood of risk with no care is higher than the risk with care, which is non-negative.
v	Costs or loss due from an accident, per the unit of activity undertaken	
x	Care, both the level and the cost of care. Care is available at two discrete levels:	
	$x = x_\emptyset = 0$	No-care carries zero costs and zero level of precaution
	$x = x_r$	Care exercised at reasonable level, $x_r > 0$
	$x_r + q_i v < p_i v$	Reasonable care is rational, both privately and socially; equivalently stated as $[x_r < (p_i - q_i)v]$
y	Activity level	
$C(y)$	Cost of activity level, at a unit of activity	
	$C_{soc}(y)$	Social costs of activity y
	$C_{priv}(y)$	Private costs of activity y
$B(y)$	Benefits of activity level y, at a unit of activity	
	$B_{soc}(y)$	Social benefits of activity y
$\delta(y)$	depreciation or capital exhaustion from y	
w	probability of conferring benefits/welfare on others	
z	Benefit per unit of activity	

The duty of care is modeled through the choice of q_i versus p_i. The probabilistic causation of injury is predicated on the assumption of care, those risks of causation based on no care are reflected by p_i and those including reasonable care are reflected by q_i. Consider a situation with two actors A and B. Hylton stated that

[7] *Id.*

given a state of care, *e.g.* both of them take reasonable care, there are three ways an accident can occur; (i) they both cause an accident, (ii) A causes an accident, and (iii) B causes an accident.[8] If they both took care and both caused an accident, then the likelihood of injury to both actors is $q_A q_B$. [9] Similarly, if A and B both exercise reasonable care but only A causes an accident, then the likelihood of injury is $q_A(1-q_B)$. [10]

Changing course, if A displayed reasonable care but B did not, and if A caused an accident and B did not, then the likelihood of harm would be $q_A(1-p_B)$.[11] The functional observation is that the level of duty of care or the lack thereof is indicated by the choice of q_A or p_A, respectively, and the act of causation is demonstrated by the simple probability q_A or p_A, and the lack of causation by the additive inverse of $(1-q_A)$ or $(1-p_A)$. It is dense but functional notation.

Table 2: Hylton's Completed Likelihoods of Harm from A's Perspective.

Reasonable care by Actor *i*	Causation by Actor *i*: ***A***	***B***	***A ∧ B***	***Ø***
A	$q_A(1-p_B)$	$(1-q_A)p_B$	$q_A p_B$	$(1-q_A)(1-p_B)$
B	$p_A(1-q_B)$	$(1-p_A)q_B$	$p_A q_B$	$(1-p_A)(1-q_B)$
A ∧ B	$q_A(1-q_B)$	$(1-q_A)q_B$	$q_A q_B$	$(1-q_A)(1-q_B)$
Ø	$p_A(1-p_B)$	$(1-p_A)p_B$	$p_A p_B$	$(1-p_A)(1-p_B)$

The model can be shown to replicate the basic tenet of the Shavell-Landes-Posner model, that under unilateral accidents both strict liability and negligence are efficient.[12] Thereafter, the model can be extended to include other features and demonstrate the correlation between the model and real-world tort law institutions.

Assuming B takes care and A does not, then A's expected costs are represented thusly under a strict liability rule: [13].

$$\begin{aligned}\{p_A q_B[(v-v)+v]\} + \{p_A(1-q_B)[0+v]\} \\ + \{(1-p_A)q_B[(v-v)+0]\} \\ + \{(1-p_A)(1-q_B)[0+0]\}\end{aligned} \tag{1}$$

8 Hylton states that there are 12 causal pathways to consider, but his analysis suggested 16; he explicitly ignored the case of neither party causing an accident. Yet, he did include that case in his analytical equation enumerated (1) in his article. I have completed the implied set of sixteen at Table 2. *See id.*, at 5-6.

9 *Id.*, at 5.

10 *Id.*

11 *See* the completed table on the likelihood of harms at Table 2.

12 *Id.*, at 6.

13 *Id.*

Taken in pieces, the four stages of the function are the four events of (i) both parties cause harm to each other, (ii) A causes harm to B but B does not cause harm to A, (iii) A does not cause harm to B but B causes harm to A, and (iv) neither party causes harm.[14]

First, $p_A q_B[(v - v) + v_B]$ demonstrates that B exercised care x_r thus the use of q_B. A did not exercise reasonable care, thus the use of p_A. They both caused harm to each other, thus the causal form $p_A q_B$. A suffered a loss v, but he paid for that, thus $(v - v)$. Finally, B suffered a loss v, which A paid.

Second, $p_A(1 - q_B)[0 + v]$ demonstrates that B caused no injury while being within reasonable care. A was both without precaution and caused an injury to B. A received no injury, $v = 0$, but B was injured, so A paid $v \in (v > 0)$ to B.

Third, $(1 - p_A)q_B[(v - v) + 0]$ demonstrates that A caused no injury, $(1 - p_A)$, to B even with A's state of no precautions. B did cause an injury to A, q_B. A's injury was paid by A, thus $(v - v)$. And B was not injured, so A did not pay B.

And finally, the fourth section $(1 - p_A)(1 - q_B)[0 + 0]$ demonstrated that neither A nor B caused an accident, although an accident may have occurred. As it is clear that Hylton intended to work with definitions of strict liability and negligence that require the establishment of causation prior to the potential assessment of judgmental damages, neither party is in a position to have damages made liable against them, thus the term $[0 + 0]$.

When these sections are summed and simplified, they yield $p_A v$.[15] As $x_r + q_i v < p_i v$ was provided as an assumption underlying the model, then $x_r + q_A v < p_A v$ clearly requires a rational A to choose reasonable care as it is cheaper than $p_A v$, demonstrating that strict liability could lead to efficient results.

Similar expansions can be modeled against when both A and B take care and that obtains A's expected costs of $q_A v$.[16] Assuming A took reasonable care necessitates x_r which is then added to $q_A v$; $x_r + q_A v < p_A v$, demonstrating that again strict liability could lead to efficient results. Or, when neither A nor B take reasonable care, then A's expected costs will be found to be $(pA - qA)v$, which is per se the rational behavior assumption of $x_r + q_A v < p_A v$ restated as $x_r < (p_A - q_A)v$.[17] So, yet again, the effort demonstrates that strict liability could lead to efficient results. We have seen when B takes care, when A and B take care, and when neither A nor B takes care. Given this exhaustion, strict liability is shown to be efficient.[18]

It can readily shown, with strict liability demonstrated, that negligence is also efficient.[19] The incremental liability for failing to take care under negligence is

14 This is the list of scenarios from the second row of Table 9.3. *Id.*

15 *Id.*

16 *Id.*

17 *Id.*

18 Hylton did not discuss the case when only A takes care, for in that case it is assumed that A has exercised care x_r and that doing so reduced the overall accidents and v, and thus performed no worse than under the other three cases already presented. *Id.*

19 *Id.*

$p_A v$.[20] And $p_A v$ is *per se* more costly than reasonable care, , *per* $x_r + q_A v < p_A v$.[21] Thus, negligence will be efficient.

2. Externalized Costs and Benefits

The model can be expanded to accommodate considerations of externalized costs and benefits.[22] The model assumed that activities are such that both the costs and benefits are shared across both the actor preforming the activity and other actors; *e.g.*, increased activity by A could increase the risks or costs to $\boldsymbol{B}$.[23]

The total benefits of undertaking an activity y are denoted as (y) .[24] Hylton argued that the potential origins of benefits are too diverse to model, unlike his approach with costs.[25] Recalling the parameters w as the probability of actor i conferring a benefit on actor j and of z denoting the benefit per unit of activity y, the social benefits of y have the following formula:[26]

$$yB_{soc}(y) = y(b(y) + w_A z + w_B z) \tag{2}$$

The socially optimal level of activity y is determined by the equating of marginal social costs of y to the marginal social benefits of y. Including the results from the demonstration of $C_{soc}(y)$, infra, we can obtain the required formula for optimal social engagement in y, when y^* denotes the socially optimal level of y:[27]

$$x_r + \delta(y^*) + q_A v + q_B v + y^* \delta\ '(y) = b(y^*) + w_A z + w_B z + yb\ '(y^*) \tag{3}$$

The cross effects of risk are seen within $q_A v + q_B v = (q_A + q_B)v$ and the cross effects of externalized benefits are seen within $w_A z + w_B z = (w_A + w_B)z$.[28]

Two observations follow:

i. Positive increases to $(q_A + q_B)v$ decrease the optimal amount of activity y.
ii. Positive increases to $(w_A + w_B)z$ increase the optimal amount of activity y.

The private cost of an activity y to A are denoted as $C_{priv}(y)$ and the social or externalized costs are denoted as $C_{soc}(y)$.[29] $C_{soc}(y)$ will include several parts:

20 *Id.*
21 *See* Table 2, *supra*.
22 *Id.*
23 *Id.*, at 7.
24 *Id.*
25 *Id.*
26 b is well-behaved with regard to y with the standard assumptions of diminishing returns; $b(y) > 0, b'(y) < 0,$ and $b''(y) \geq 0$.
27 *Id.*, at 8.
28 *Id.*
29 *Id.*, at 7.

i. the cost of taking reasonable care x_r,
ii. the depreciation, $\delta(y)$, to capital assets by engagement in y, and
iii. the costs of accidents, v. [30]

The model resumes the prior result that A and B will both take reasonable care under either strict liability or negligence, so the model assumes that both A and B did in fact take reasonable care.[31] However, even with reasonable care accidents may happen. [32] The social cost of the accidents that occur under the reasonable care of A and B is the following formula: [33]

$$yC_{soc}(y) = y(x_r + \delta(y) + q_A(1 - q_B)v + (1 - q_A)q_B v + 2q_A q_B) \tag{4}$$

$$yC_{soc}(y) = y(x_r + \delta(y) + q_A v + q_B v) \tag{5}$$

The private costs under a strict liability rule are the following formula: [34]

$$\begin{aligned} yC_{priv}(y) = y(x_r + \delta(y) + q_A(1 - q_B)v \\ + (1 - q_A)q_B(v - v) + q_A q_B[(v - v) + v]) \end{aligned} \tag{6}$$

$$yC_{priv}(y) = y(x_r + \delta(y) + q_A v) \tag{7}$$

And similar logic supports the private costs formula under a negligence rule, presented here in the reduced form: [35]

$$yC_{priv}(y) = y(x_r + \delta(y) + q_B v) \tag{8}$$

The most immediate observation is that the private costs formulae under strict liability and negligence are identical but for one term, that of $q_A v$ versus $q_B v$, respectively, and the social cost formula includes the effects from both.[36] This reflects that the private liability rules provide different controls and that they do not necessarily provide the same result as the social welfare optimand. Under strict liability, the actor responds to the cost consequences of his own acts; under negligence the actor responds to the cost consequences of the acts of other actors.[37]

Hylton took these observations on the cross effects of costs and benefits to provide a comparative risk analysis that forecasts when which civil liability rules

30 *Id.*
31 *Id.*
32 *Id.*
33 *Id.*
34 *Id.*, at 10.
35 *Id.*
36 *Id.*, at 7 and 10. It is also potentially useful to observe that $\left(C_{priv}(y) + C_{soc}(y)\right) > C(y)$; that the total costs of an accident are less than the sum of the private and public costs because the private and public accounts overlap; thus their sum includes double-counting.
37 *Id.* This finding aligns well with the Shavell's bilateral accident model, but the model herein is a unilateral accident model. *Supra*, Appendix II-A.

would be efficiently applied or at least more robust. Noting that more risk reduce the optimal levels of an activity but that the reverse is true for externalized benefits, Hylton observed the rule paradigms of strict liability and negligence provided offsetting and balancing results. [38] Under strict liability, the more externalized risk there is, the more damages will be assigned to the actor based upon his own activity level. [39]

But under negligence, the actor will have an incentive to reduce his activity in response to the risks externalized by other actors. [40] This led Hylton to propose the following two propositions:

> *Proposition 1:*[41]
> *"If $q_A > q_B$, holding A strictly liable is preferable to using the negligence rule in regulating the activity level of A. If, however, $q_A \leq q_B$, strict liability is not preferable to negligence. In simpler terms, if A externalizes more risk to others than they externalize to him, strict liability is preferable to negligence. However, if there is a reciprocal exchange of risk between A and B, or if B externalizes more risk than does A, holding A strictly liable is not preferable, as a method of regulating A's activity level choice, to the negligence rule."*[42] (Underscoring added.)
>
> *Proposition 2:*
> *"If there is reciprocal exchange of risk between A and $(q_A = q_B)$, strict liability and negligence provide the same incentives for care and for activity level choices."* [43]

These results provide simple guidance, that strict liability should be used when the risk asymmetry is substantial, otherwise the negligence rule is at least equally efficient and potentially preferable.

The results can be explained simply, the only functional difference in the private costs functions under strict liability and negligence are in the assignments of risk:

i. the likelihood that A will cause injury to B while A undertakes reasonable care, q_A, and
ii. the corresponding risk from B, q_B. [44]

Under Proposition 2, if the risks are identical, then the results of the legal liability rules will be identical; the rules become simply $yC_{priv}(y) = y(x_r + \delta(y) + qv)$ without reference to any particular actor. [45]

38 *Id.*, at 10.
39 *Id.*
40 *Id.*
41 Hylton did not thusly label the propositions, so this labeling follows the sequence in which they were presented in the article.
42 *Id.*, at 11.
43 *Id.*
44 *Id.*

The optimal level of activity, $\bar{y}_s$, for A under strict liability can be modeled by equating A's marginal private benefits and marginal private costs: [46]

$$x_r + \delta(\bar{y}_s) + q_A v + \bar{y}_s \delta'(\bar{y}_s) = b(\bar{y}_s) + w_B z + \bar{y}_s b'(\bar{y}_s) \quad (9)$$

The left side of the equation is the marginal private costs to A, the right side the marginal benefits to A.[47]
Similarly, the optimal level of activity, $\bar{y}_n$, for A under negligence can be shown:[48]

$$x_r + \delta(\bar{y}_n) + q_B v + \bar{y}_n \delta'(\bar{y}_n) = b(\bar{y}_n) + w_B z + \bar{y}_n b'(\bar{y}_n) \quad (10)$$

Comparing these two optimality equations, one can readily observe the role of q_A and q_B; the relative risks determine the optimal activity levels:

i) A will chose the same private activity level under both strict liability and negligence rules if $q_A = q_B$.[49]
ii) If a negligence rule is imposed, and if A poses a higher external risk than B, $q_A > q_B$,
   (a) then A will chose a higher level of activity than the strict liability rule would determine for A, [50]
   (b) but B would be incentivized to select a lower level of activity than he would under strict liability. [51]

Hylton summarized these results:

> "Where there is asymmetry in risk externalization, negligence causes high risk-externalizers to increase their activity levels while low risk-externalizers decrease their activity levels." [52]

3. Hylton's Quadrant of Negligence, Strict Liability and Subsidy/No Liability

A negligence rule in the faced with asymmetrical externalization of risks results in more extreme behavior from the actors than under a rule of strict liability. The risky actors act more, the less risky act less.

45 *Id.*
46 *Id.*
47 A will only receive the benefits provided by B, A would not model the benefits conferred to B or other actors. *Id.*
48 *Id.*
49 *Id.*, at 12.
50 *Id.*
51 *Id.*
52 *Id.*

Furthermore, taking into account the previously issues with strict liability's potential to detriment externalized social benefits, there should probably be a bias for employing negligence when such a condition exists.

Under a strict liability rule, the marginal social costs curve would set lower values of y than the private marginal cost curve.[53] This is because the actor discounts the self-imposed harms and is only reactive to the harms posed externally to other actors.[54] Yet, the social to private analysis lies in the reverse direction for the marginal social and private benefit costs curves. The cost curves suggest the private actor would select more activity than the social community and the benefits curves suggest that the private actor would choose less than the social community would choose.[55]

The results are thus ambiguous at first glance, but they do clearly emerge from an analysis of two relationships; (i) the ratios of externalized probabilistic risks $(q_A{:}\,q_B)$, and the ratios of externalized probabilistic benefits $(w_A{:}\,w_B)$.[56]

Hylton provided a review of four cases:

1. $(q_A > q_B)$ and $(w_A > w_B)$. A provides exceptional externalized risks and benefits. A externalizes both more risks, q_A, and more benefits, w_A, than his average community of actors externalize to the community.[57]
2. $(q_A > q_B)$ and $(w_A \leq w_B)$. A is risky but of average benefits. A externalizes more risks, q_A, than the norm, but A provides the same or fewer externalized benefits, w_A, compared to the norm in his community of actors.[58]
3. $(q_A \leq q_B)$ and $(w_A > w_B)$. A provides exceptional benefits at normal risks. A provides the same or fewer externalized risks, q_A, than the norm, but externalizes more externalized benefits, w_A, against the norm in his community of actors.[59]
4. $(q_A \leq q_B)$ and $(w_A \leq w_B)$. A is normal in externalized risk and benefits. A provides the same or fewer externalized risks and benefits as compared against the norms in his community.[60]

53 *Id.*, at 14.
54 *Id.*
55 *Id.*
56 *Id.*
57 *Id.*
58 *Id.*
59 *Id.*
60 *Id.*

Table 3: Liability Rule Expectations based on Externalized Benefits and Risks

		External Benefits	
		$w_A > w_B$	$w_A \leq w_B$
External Risks	$q_A > q_B$	I. Negligence (probably)	II. Strict Liability
	$q_A \leq q_B$	III. Subsidy (no liability)	IV. Negligence

Given that the models are probabilistic and that the goal of legal policy is to obtain results in the greater good, policy directions can be developed from these observations. This analysis provides an answer to those calling for rules of civil liability to provide a more explicit and positive model to address both the positive and negative externalities of the effects of those rules.[61]

Strict liability is most likely to be of benefit to policy makers when ($q_A > q_B$) and ($w_A \leq w_B$), *i.e.*, when A displays extraordinary risks without sufficient offsetting benefits to the community. Negligence would see A undertake excessive activity, causing inefficiently high numbers of accidents to B, who would reduce his own activity to minimize his damages.[62]

In the opposite direction is when A displays extra-ordinary benefits to the community with average risk; such a situation might be given a no liability rule or a subsidy, effectively the same, to encourage A to undertake more of this beneficial activity.[63]

Hylton proposed that negligence is likely to be most effective or efficient when the risks ratios are symmetrical or when the externalized risks and benefits are well-balanced with each other because "communities are likely to form around activities that cross-externalize similar risks."[64]

Hylton applies the model to explain the common law approach of strict liability for dangerous activities. In reference to the United States' Restatement Tort 2nd § 520, he develops an argument that the six-part definition therein of abnormally dangerous activities matches well the second quadrant of Table 9.5.[65]

Those six elements of the definition are listed:

> "In determining whether an activity is abnormally dangerous, the following factors are to be considered: (a) existence of a high degree of risk of some harm to the person, land or chattels of others; (b)

61 M. G. Faure, *Liability and Compensation for Damage Resulting from CO_2 Storage Sites*, 52 (2013) (unpublished manuscript)(on file with author). *See also* I. Gilead, *Tort Law and Internalization: The Gap Between Private Loss and Social Cost*, 17 Int'l Rev. L. & Econ. 589 (1997).

62 *See* Quadrant II of Table 3. Hylton, *supra* at note 1, at 15.

63 *See* Quadrant III of Table 3. *Id.*

64 *See* Quadrant I and IV of Table 3. Quadrant I is the high risk/high benefit case that probably merits negligence to ensure sufficient production of externalized benefits. Quadrant IV is the routine case wherein most ordinary activities with balanced risks and benefits fit. *Id.*

65 *Id.*, at 18-19.

> likelihood that the harm that results from it will be great; (c) inability to eliminate the risk by the exercise of reasonable care; (d) extent to which the activity is not a matter of common usage; (e) inappropriateness of the activity to the place where it is carried on and; (f) extent to which its value to the community is outweighed by its dangerous attributes." [66]

The argument is quickly made: (a), (b), and (c) are the queries to inquire if the risk externalized by A, even under reasonable care, is excessive to the norm, *i.e.* $q_A > q_B$ — if so then strict liability should be applied; (d) is an inquiry to determine reciprocity, within this model Hylton states it is equivalent to testing for "if $qA \neq q_B$ then apply strict liability;" (e) is a similar inquiry to reciprocity but based on locality norm basis, within this non-geographical model that concept models essentially the same as for (d); and (f) appears to be a ranking of asymmetrical risk versus asymmetrical benefits, if externalized risks to harm outweigh externalized benefits then strict liability should be applied.[67]

In conclusion, Hylton's Positive Theory of Strict Liability provided a discourse on which to evaluate the externalized risks of harm and the externalized social benefits of a given risky activity. The model provides broader support for the application of negligence rules without frustrating the original Shavell-Landes-Posner models.

Ultimately, the model suggests that strict liability is correctly limited in efficient applications when externalized benefits are more fully accounted for within a framework. More specifically, strict liability should be reserved for those cases when the activity poses extensive social costs without counter-balancing social benefits. In other cases, some version of negligence rules should be employed. There is a minor case wherein externalized social benefits are obtained with little to no externalized social costs; for these cases no-liability rules or even subsidies should be provided.

[66] *Id.*
[67] *Id.*, at 19-20.

Appendix II D

NUSSIM AND TABBACH ON DURABLE PRECAUTIONS AND INTERACTIVE DECISIONS

Nussim and Tabbach suggest that the standard model makes several assumptions that merit revisiting.[1] They call their extension of the standard model a "durable precaution" model.[2]

First, they question if the assumption that precaution costs are proportionate to activity levels; in particular, their model contrasts the roles of durable precautions as opposed to the general model's non-durable or consumable precautions.[3] Durable precautions are said to be buy once, use multiple times; non-durable precautions are bought once, used once.[4] Further, the costs of durable precautions may be wholly uncorrelated with the activity level.[5] A lit exit sign in a movie theater is such a durable precaution as would be safety and training education.[6] It can be difficult to model the costs of durable precautions, because "the marginal effectiveness of care may fall due to fatigue or wear and tear, increase under specialization, or remain unchanged if the means of care is perfectly durable."[7]

Second, they note that activity level may affect marginal expected harm in non-linear ways; the marginal expected harm could be both increased or decreased with additional levels of activity.[8]

Third, they note that care and activity levels are interdependent; the marginal effects of one aspect impact the marginal behavior of the other.[9] Due to this interdependency, the socially optimal behavior of tortfeasors cannot be determined

1 J. Nussim & A. D. Tabbach, *A Revised Model of Unilateral Accidents*, 29 Int'l Rev. L. & Econ. 169, 169 (2009).
2 *Id.*, at 170.
3 *Id.*, at 169.
4 *Id.*, at 169-170.
5 *Id.*, at 170.
6 *Id.*
7 *Id.*, at footnote No. 6
8 *Id.*
9 *Id.*

in a two-step process but rather requires that the level of care and of activity be solved simultaneously. [10]

Fourth, the impact of the previous two notes drives a change in the analyses of mis-estimated damages for strict liability and negligence. [11] *E.g.*, the standard model suggested that if damages were consistently set lower than actual harms then under a strict liability rule the tortfeasor would take insufficient precaution and engage in excessive activity level; but that analysis ignores the interdependency effect between activity level and precaution. [12]

Fifth, the model suggests that the issues of insolvent tortfeasors and of underestimation of damages are more distinct than observed under the standard model. [13] The effects of interdependency go in different directions for these two issues. [14]

Overall, the model presented is a model of unilateral accidents. [15] No contractual relationships are assumed between the tortfeasor and the victim, they are assumed to be strangers to each other. [16] Both activity level and levels of precaution are determinants of risk. [17] Victims play no role in the determination of risk, risk remains within the control of the tortfeasors. [18]

10 *Id.*
11 *Id.*
12 *Id.*
13 *Id.*
14 *Id.*
15 *Id.*, at 171.
16 *Id.*
17 *Id.*
18 *Id.*

Table 1: Elements of the Durable Precaution Model

Term	Explanation	
z	Tortfeasor's activity level	
	z_{max}	Upper boundary limit to z
x	Tortfeasor's precautionary level	
$u(z)$	Tortfeasor's utility, based on activity level z	
	$u'(z) > 0$	utility increases with more care
	$u''(z) < 0$	diminishing marginal returns
$c(x, z)$	Cost of precautionary level.[19]	
$h(x, z)$	Expected level of harm, based on activity level, z, and precautionary level, x.[20]	
$p(x, z)$	probability of accidents given a specific level of care and of activity.	
	$p'(x) < 0$	increased precaution reduces probability of accidents
	$p''(x) > 0$	increasing marginal returns

The social objective is the sum of the utility less the costs of precaution and less the costs of harms and injuries to victims.

$$J(x, z) = u(z) - c(x, z) - h(x, z) \quad (1)$$

With the attendant requirements for an interior solution:

$$-h_x(x, z) = c_x(x, z) \quad (2)$$

$$u_z = c_z(x, z) + h_z(x, z) \quad (3)$$

The rational condition that marginal investment in precaution is met by the marginal reduction in accident costs is set. Also, the marginal costs of increasing the activity level equal the marginal social costs of additional activity. These are impacted by their interdependency:[21]

$$\frac{\partial^2 J(x, z)}{\partial x \partial z} = -c_{xz}(x, z) - h_{xz}(x, z) \quad (4)$$

Certain behavioral options can be identified within this framework. First, consider the case of specialization, wherein exposure to a risky activity decreases the

19 Not necessarily Shavell's $c(x, z) = xz$, but potentially many other function types as well. *See id. Also see* footnote No. 18.

20 This model does not assume $h_{xz}(x, z) = 0$, in that the relationship is potentially nonlinear. *See id. Also at* footnotes No. 19 and 20.

21 This can be contrasted with the standard model's assumption that $\frac{\delta^2 J(x,z)}{\delta x \delta z} = 0$. *Id.*

marginal costs of precaution; $c_{xz}(x,z) < 0$.[22] The result is that precaution and activity are complements. Second, fatigue could cause the costs of precaution to increase with activity levels; thus increases in either activity level or in precaution increase the costs of precaution: $c_{xz}(x,z) > 0$.[23] When the fatigue effect is strong, then precaution and activity levels become substitutes.[24]

Retaining the behavioral assumption that the likelihood of harm is linearly related to the activity level of the tortfeasor, given a certain level of precaution, the model posits harm:[25]

$$h(x,z) = p(x)zh \tag{5}$$

If the precautionary measures are durable precautions, then they can be characterized as $c(x,z) = x$.[26] The resultant socially optimal results are simpler than the broader model,[27] *supra*:

$$J(x,z) = u(z) - x - zp(x)h \tag{6}$$

$$-zp'(x)h = 1 \tag{7}$$

$$u'(z) = p(x)h \tag{8}$$

The optimal choices driven by this variation of the model are denoted as x^* and z^*. Precaution and activity are complements.[28] *E.g.*, increasing precautions decreases the marginal expected costs of activity, in terms of generating expected harms, and thereby provides an incentive for higher levels of activity.[29]

For the negligence rule, this provides an unexpected result; when faced with high costs of ascertaining the effects of interdependency on resultant activity level and undertaken precautions, legislators and judges should set the value of due care higher than the otherwise established efficient level of care, at some $x > x^*$.[30] Legislators and judges cannot simply determine the activity level by setting a simple due care level, in that interdependency effects will require a simultaneous solution to both activity level and level of care.[31] In some sense, this is captured by the idea of jointly permitting certain activity levels and safety standards within an

22 *Id.*
23 *Id.*
24 The input of either reduces the other, *ceteris paribus*: $\frac{\delta^2 J(x,z)}{\delta x \delta z} < 0$
25 *Id.*
26 *Id.*, at 172.
27 *Id.*
28 *Id.*
29 *Id.*
30 *Id.*, at 173.
31 *Id.*, at 172. In some sense, this is captured by the idea of jointly permitting certain activity levels and safety standards within an environmental regulatory setting; as such, to the extent that regulatory means can better combine these two targets than civil liability might, regulatory means would be preferable.

environmental regulatory setting; as such, to the extent that regulatory means can better combine these two targets than civil liability might, regulatory means would be preferable.

But much of the information needed to make such determinations is hidden or costly. Also, the durable aspects of precautions disconnect the costs of care from the activity level. So, the ideal rate to set the due care level at a level that solves $-zp'_{max}(x)h = 1$, [32] which is the optimand from above under durable precautions but set at the maximum level of safety available. This policy does not have a design intent to reduce activity by setting due care levels high, but instead is designed to match higher levels of activity with higher levels of precaution. [33] It is tantamount to observing that the costs of precaution are, on a unit basis, cheaper as the activity level increases.

Thus, when it is difficult for the policy maker to determine the impact of their due care or activity level prescriptions, and when negligence allows a setting for due care levels but not activity levels, then the policy maker should set due care levels at a level higher than the otherwise socially optimal level. [34]

The mis-estimation of damages affects both the strict liability rule set and the negligence rule set. The mis-estimation of damages is believed to be a wide spread problem in the real world. [35] There are a variety of transaction costs problems that frustrate correct damage setting. [36] Punitive damages attempt top correct for some of those issues, but they are likewise frustrated by transaction costs problems. [37] The model is extended to include a function for the mis-estimation of damages; $h(\gamma) = h\gamma$, wherein γ is a representation of the error rate.[38] This leads to the following reinterpretations of the basic optimands: [39]

$$J(x, z) = u(z) - x - zp(x)h\gamma \quad (9)$$

$$-zp'(x)h\gamma = 1 \quad (10)$$

$$u'(z) = p(x)h\gamma \quad (11)$$

Within these requirements, stable forecasts of policy setting for tortfeasors under rules of strict liability can be achieved only within two results. If damages are overestimated, then both care and activity level will be increased if and only if the elasticity of the probability of accidents given a level of precaution exceeds the

32 *Id.*, at 173.
33 *Id.*
34 *Id.*
35 *Id.*
36 *Id.*
37 *Id.*, at 174.
38 *Id.* In this model γ = 1 represents no error, γ > 1 represents overestimation of error, and 0 < γ < 1 represents underestimation of error.
39 *Id.*.

elasticity of the first derivative of the same.[40] On the other hand, overestimated damages will decrease both activity and precautions if and only if the elasticity of the first derivative of the utility function is less than unity.[41] All other results are left a mix of up in one aspect and down in the other, making results mixed, all due to the interdependency effects. The direct and indirect results of a specific policy may well be in conflict, creating a lack of clear effect. A rule of strict liability is not very robust when presented with mis-estimated damages and interdependent activity and precaution decisions.

For a tortfeasor under a negligence rule, there are several results. First, under systematic overestimation of damages, $\gamma > 1$, the tortfeasors would operate at the prescribed level of care, x^*, and at maximum levels of activity, z_{max}.[42] Second, under systematic underestimation of damages, $0 < \gamma < 1$, the tortfeasors would face strategic choices.[43] If the estimate error is small, then the tortfeasor will exercise due care, x*, and operate at maximum levels of activity, z_{max}.[44] However, if the error is significant enough, then the tortfeasor will exercise a lesser level of care, $\tilde{x} < x^*$, and operate below maximum levels of activity, $\tilde{z} < z_{max}$.[45] Thus, only when the underestimation is substantial will the negligence rule not achieve due care.[46] However, even in that case, a solution such as provided for uncertain legislators, supra, can be employed to counterbalance this result.

Thus, in the face of mis-estimated damages and interdependent activity and precaution decisions negligence is more robust than strict liability.

Shavell demonstrated that under insolvency constraints, the strict liability rules were likely to provide incentives to the tortfeasor to undertake insufficient precaution and over-engage in activity.[47] When the durable precaution model is extended to the insolvency problem, it becomes a three tier analysis, when the assets exceed the expected costs of damages, when they equal them, and when the assets are less than the expected costs of damages. When the assets exceed the expected costs of damages, $A > z^*h$, then there are no effective constraints preventing the tortfeasor from choosing optimal levels of activity and precaution, $x^*$and z^*.[48]

However, if the marginal utility to the tortfeasor of additional activity do not decline, as in diminishing returns, then the tortfeasor is likely to pursue maximum activity levels, z_{max}.[49] When the assets are less than or equal to the expected costs of damages, $A \leq z^*h$, then the tortfeasor faces declining marginal costs of damages as

40 *Id. See* $-\left(\frac{p'(x)}{p(x)}\right)x > -\left(\frac{p''(x)}{p'(x)}\right)x$

41 *Id. See* - $\left(\frac{u''(x)}{u'(x)}\right)z < 1$.

42 *Id.* An overestimate of damages costs reinforces the calculus to avoid damages by operating at the due care level.

43 *Id.*

44 *Id.*, at 174-175.

45 *Id.*

46 *Id.*

47 *Id.*, at 175, citing to Shavell 1986.

48 *Id.*, at 176.

49 *Id.*

the activity level increases; those costs "plummet to zero."[50] This drop in costs encourages the tortfeasor to engage in the maximum level of activity, z_{max}. This has a secondary effect on the precautionary level, which drops below the prescriptive level of care, $\tilde{x} \leq x^*$.[51]

These results are roughly in alignment with Shavell's analysis on insolvency, but they diverge from the mis-estimation analyses and thus clarify that the choice of civil liability rules need to take these matters into separate account.

50 *Id.*, at 175.
51 *Id.*

Appendix II E

NELL & RICHTER'S RISK ALLOCATION MODEL

Nell and Richter report that if a risky activities face imperfect insurance markets, then a negligence rule should be preferred to a rule of strict liability.[1] They hold that the central equivalency of strict liability and negligence in the standard models is based (or biased) on the assumption that the actors involved are risk neutral.[2] While not addressing all types of torts, they argue that for certain highly risky activities the assumption of risk aversion may both be unwarranted and incorrect.[3]

They provide a list of reasons that corporate entities might be risk averse: [4]

i. corporate notions of risk aversion operate only for well-financed diversified portfolio holders which is contrary to many investors both private and public,
ii. even for such parties as qualify as well-diversified portfolio holders, they can only achieve genuine risk neutrality if there is no system risk component which might not be true for certain highly risky (investment) activities,
iii. there is much evidence of structural imperfections in the capital market which could frustrate efforts to diversify risk,
iv. transaction costs tend to prevent portfolios from being sufficiently diversified,
v. entrepreneurial decisions within firms are made by risk averse humans who are guided by careful strategies to remain in employment and are often rewarded for conservative stewardship of capital, and
vi. those same human managers will have the potential to display risk aversion or pessimism against the risk of large losses.

1 Nell & Richter 2003, p. 31.
2 *Id.*, at 32.
3 *Id.*, at 33.
4 *Id.*

They developed a risk allocation model wherein the victims are risk averse, as are the injurers. [5] Risk allocation matters to risk averse actors; as such, the liability rules under risk aversion yield different results from the standard models. [6]A loss of rule symmetry is observable as soon as risk aversion is introduced. [7]They find that when a market-based relationship exists between the parties, the rule of negligence will be strongly preferable to strict liability. [8] Even when there is no market-based relationship between the parties, they also find a preference for negligence because strict liability leads to suboptimal levels of welfare enhancing activities. [9]

Table 1: Nell and Richter's Risk Aversion and Risk Allocation Model

Term	Explanation	
n	Number of victims	
	$n \geq 1$	There are a positive number of victims
$\tilde{L}$	The losses for each victim; subject to a 2 point distribution : $(L_1, p, 0)$	
	$0 < p < 1$	Losses are probabilistic.
	$L_1 > 0$	Losses are of a positive cost.
x	Tortfeasor's care or precaution level	
	x_{max}	Ceiling of prevention capacity
$c(x)$	Cost of care to the tortfeasor	
u	Utility of the tortfeasor	
v	Utility of the victim	
q	Division of loss borne by tortfeasor	
	$0 \leq q \leq 1$	Tortfeasor could have all or none of the losses.
α	Risk aversion of the tortfeasor	
	$\alpha > 0$	Tortfeasor is risk averse
β	Risk aversion of the victim	
	$\beta > 0$	Victim is risk averse

Further, they suggest that develop and use of the insurance market for stability in financial planning strongly supports the idea that even well financed corporations face risk-averse management and shareholders. [10] But even that market is flawed, suggesting that firms that turn to insurance in risk aversion strategies need retain elements of their risks, as unwanted as those risks might be. For highly risky activities, there is often insufficient data to determine actuarially fair rates,

5 *Id.*
6 *Id.*
7 *Id.*
8 *Id.*
9 *Id.*
10 *Id.*, at 34.

especially if the pool of parties with similar behaviours or scale of needs is small. [11] Thus rational decision makers would not leave their whole risk strategy to merely insurance. [12] Even if they did want to try to cover all of their liability needs with insurance, many liability insurance providers, if not most, require the retention of some level of risk by the purchaser to prevent fraud or mishandling of events. [13]

Nell and Richter suspect two reasons for the lack of attention paid to risk averse models of liability rules. [14] First, they suspect that the mathematics of risk aversion is complicated and efficiency in either negligence or strict liability is quickly lost. [15] Second, they suggest that to be able to enforce risk averse model rules in court might require the courts to know the utility functions facing the parties; such information would be at least expensive to obtain even if it could or would be produced by the parties. [16] Nell and Richter suggest that such a knowledge requirement is not involved for certain highly risky activities and so analysis and eventual application can be sustained. [17]

They also present an argument that it is mathematically important to differentiate between models of a singular victim and models of multiple victims, that risk neutrality provides equivalent results for both abstract singular victim and multiple count victims but that risk aversion has distinguishable results for the to cases.[18] They provide a proof that the optimal level of care increases as the number of potential victims is countably increased. They demonstrate that the marginal cost of loss prevention is the negated product of the number of countable victims and the marginal expected loss as activity is increased. That is,[19]

$$c'(x) = -n\left(\frac{dE[\tilde{L}|x]}{dx}\right) \tag{1}$$

Notably, the model does not take into account distinct injuries, just the overall composite total of injury across all of the victims and their harms. Thus, for specific

11 *Id.*

12 *Id.*

13 *Id.*

14 *Id.* As evidence of lack of attention to such models, they do provide reference to papers by A. ENDRES, & R. SCHWARZE, *Allokationswirkungen einer Umwelthaftpflicht-versicherung*, in HAFTUNG UND VERSICHERUNG FÜR UMWELTSCHÄDEN AUS ÖKONOMISCHER UND JURISTISCHER SICHT, 58 (Springer Berlin Heidelberg, 1992), and F. Privileggi, C. Marchese, & A. Cassone, *Agent's Liability Versus Principal's Liability When Attitudes Toward Risk Differ*, 21(2) Int'l Rev. L. Econ. 181 (2001), as well to as several articles by Shavell, but the references are without specifics of topics or models on point.

15 Nell & Richter, *supra* at note 1, at 34.

16 *Id.*

17 *Id.*, at 34-35.

18 *Id.*, at 35.

19 Wherein $c(x)$ is the cost of loss prevention, $E[\tilde{L}|x]$ are the expected losses given an activity level of x, and n is the countable number of identical potential victims, $n \in$ Zahlen. *See id.*, at 36.

forms of highly risky activities, an abstract victim might be used in the model, so long as the underlying assumptions are kept in mind.[20]

The model then develops an optimal liability rule given a framework perspective of risk sharing. The risk aversions coefficients for the tortfeasor and the victim are denoted as α and β, respectively.[21] The tortfeasor's share of liability is $q \in (0 \leq q \leq 1)$; the victim's share of risk is similarly $(1-q)$. The optimal liability for the injurer, meeting due care x_{max}, is found to be:[22]

$$q^* = \frac{\boldsymbol{\beta}}{n\alpha + \beta} \tag{2}$$

This result provides that as the number of potential victims increases (and the tortfeasor is exercising due care x_{max}) the correct assignment of risk allocation should shift from the injurer to the victims at large. This match the results of the negligence rule; the negligence rule emerges from this equation as $q^* \to 0$ as $n \to \infty$. Strict liability provides the opposite result, in $q^* \to 1$ as $n \to \infty$, and assigns all of the risk to the injurer. Negligence with a due care level set at the maximum level of care is the optimal rule, whereas strict liability is equally not optimal.

The next step of the risk allocation model looks to the provision and impact of insurance on the parties risk allocation strategies. The end result is revealed to be that negligence is more robust than strict liability when n is large or when the insurers are risk averse.[23] If insurance markets were perfect, then injurers and victims could both eliminate their risks in exchange for purchasing insurance policies; but in the real world liability insurance limits coverage to leave some risks with the purchasers.[24]

In the first sub-model, wherein insurers are assumed to be risk neutral, insurance premiums are assumed to be a combination of expected payments to claims, i.e. expected losses, and some form of proportional loadings. The loading factor is denoted m in the model and the level of coverage is denoted as $d \in (0 \leq d \leq 1)$.[25] If the insurer charges a positive loading fee, $m > 0$, then customers will choose coverage less than unitary because their expected claims and premiums would otherwise be equivalent, thus paying for the load and premium would be irrational. Thus they elect to pay for a coverage $d < 1$, yet they do rationally choose insurance because it addresses their risk aversion, so they buy coverage $d > 0$, thus integrated we obtain $0 \leq d \leq 1$.[26] This, plus the analysis related to optimization, results in a new optimal social liability sharing rule:

20 *Id.*, at 35.
21 Where $\alpha > 0$ and $\beta > 0$. *Id.*, at 37.
22 *Id.*, at 39.
23 *Id.*, at 42.
24 *Id.*, at 40.
25 *Id.*
26 *Id.*

$$q^* = \frac{\boldsymbol{\beta}}{n\alpha(1-d^*)+\beta} \qquad (3)$$

As the amount of insurance coverage available increases, the amount of risk to be allocated to the injurer increases, $q^* \to 1$ as $d \to 1$.[27] Another way of saying this is that the optimal amount of liability for the injurer increases as the amount of insurance becomes available; the intuition herein is that if the injurer can purchase insurance efficiently then it is more efficient for social welfare for the risk to be moved from victim to injurer and onto the insurer, i.e. from the most risk averse towards less risk averse parties. [28]. But there is a limit, in that injurers won't buy full insurance so long as there is a positive loading fee, $m > 0$, so d will remain $d < 1$, and q^* will not reach 1. However, there is simply no convergence to the negligence rule as was seen above. [29]

Yet, at sufficiently high levels of n, the maximum level of care becomes optimal. [30] Given the result that insurance companies will charge for claims and for loading fees, and that customer cum injurers will not pay for full coverage, neither strict liability nor negligence approximate the optimal solution. [31]

The efficiency of loading is critical, as $m \to 0$, strict liability becomes more robust and as m, diverges from zero negligence becomes more robust. [32] Ergo, the more costly it is to provide insurance, the more negligence is preferable and the less costly insurance is the more strict liability is preferable.

When the sub-model is altered to reflect risk averse insurers, then risk premiums would be expected to grow at a faster than linear rate. [33] As the insurers become wealth-affected, and as they bear proportionately more of the risk, their loading factor would grow. This would create a large m, so that loading costs would be high. In a repeat of analysis, *supra*, the negligence rule is preferable when m diverges from zero. In short, strict liability has been preferable only when parties are risk neutral or when insurance is readily available, which in turn appears to require risk neutral insurance providers. [34] When the ideal terms for strict liability are not present, then strict liability leads to insufficient activity levels and increasingly less so as $n \to 0$. [35]

Nell and Richter then make a clear argument that for sufficiently "large n the risky activity would be completely prevented, even if it is socially desirable according to," the social welfare function. [36]

27 *Id.*, at 41.
28 *Id.*
29 *Id.*
30 *Id.*, at 42.
31 *Id.*
32 *Id.*
33 *Id.*
34 *Id.*
35 *Id.*
36 *Id.*, at 43.

Finally, Nell and Richter load the whole wagon; if the injurer decides the level of activity as well as the level of care, and if there is a market relationship between the injurers and the victims, then the optimal rule would be negligence with a standard of care set to the maximum level of care; it would be superior to strict liability for highly risky activities. [37] Negligence is said to yield both optimal care and activity levels. In terms of risk allocation, negligence is seen as superior to strict liability for those activities with potential to affect large numbers of victims; also the same obtains when insurance markets display significant transaction costs or imperfections. [38].

Nell and Richter find that strict liability rules that exclude events that could not have been prevented by modern technology or were otherwise unknown to science are actually functionally negligence rules with very restrictive senses of due care; it is the notion in their model of negligence with maximum care. [39] *I.e.*, to avoid liability to victims all known feasible means must be undertaken. [40]

[37] *Id.*
[38] *Id.*, at 44.
[39] *Id.*, at 45.
[40] *Id.*

Appendix II E

Appendix II F

GLACHANT'S ASYMMETRIC INFORMATION MODEL

Glachant offers a critical appraisal of the Shavell analysis; informational asymmetry may present an intractable problem for policy makers in the choice of civil liability, regulation, or nothing at all.[1]

1. Information acquisitions bear transaction costs.

At the root of Glachant's concerns is that Coase may have suggested a deeper paradigmatic shift than accounted for by Shavell, that costs of information searches are themselves a form of transaction costs and if they are included in the overall cost analysis the clarity to pursue regulatory guidance in the face of informational uncertainty or asymmetry might incomplete.[2]

In fact, Glachant argued, it may be impossible to discern when civil rules, regulations or no policy at all might be preferable if the sum of the overall set of transaction costs is not readily resolvable.[3] In such models, it is assumed that the regulator is less informed than the actor; the actor is closer to the facts or technologies that affect the safety levels.[4] But in turn, the actor is less informed about the potential harms and hazards, particularly as they impact third parties beyond the actor. [5]

Due to the state of incomplete or imperfect data, economic tools are employed instead of direct quota systems, to enable the actor to integrate sufficient data to

[1] M. GLACHANT, *The Use of Regulatory Mechanism Design in Environmental Policy: A Theoretical Critique*, *in*: SUSTAINABILITY AND FIRMS: TECHNOLOGICAL CHANGE AND THE CHANGING REGULATORY ENVIRONMENT, 179, *en passim* (Edward Elgar, Cheltenham, 1998).

[2] *Id.*, at 9-10.

[3] *Id.*

[4] *Id.*, at 3.

[5] *Id.*

determine an efficient level of activity and of care. [6] A tax may be used to transfer information to the actor. [7]

2. Information Exchange as a Game Model

If the regulator were to ask the actor for his estimated impact costs of pollution abatement, the actor would be tempted to over-report his costs in order to minimize the policy decision's impact on his operations. [8] As Glachant stated the problem:

> "[C]ommunication between agents is subject to strategic manipulation if (i) the objectives sought by the emitter and the receptor differ and (ii) the receptor's decision influence emitter's gains." [9]

Table 8-1: Elements of Glachant's Asymmetrical Model

Term	Explanation	
i	Actor i; there are n actors	
C_i.	Private pollution abatement costs for each actor i. [10]	
	$C_i''(q_i) > 0$	Higher safety objectives are increasingly expensive for each actor. [11]
	$C_i(0) = 0$	The costs of no regulated objectives is no costs. [12]
B	Social welfare benefit due to avoided external costs. [13]	
	$B''(Q) < 0$	Higher safety standards for the regulator result in decreasingly lower marginal social welfare benefits. [14]
	$B'(0) > C'(0)$	At the beginning, the marginal increase in social welfare benefits exceeds the marginal costs to achieve them[15]
q_i.	Private pollution abatement objective to be met by actor i.[16]	

6 *Id.*

7 *Id.*

8 *Id.*

9 *Id.*

10 *Id.*, at 4.

11 *Id.*

12 *Id.*

13 *Id.*

14 *Id.*

15 Thus providing the logical operand to regulate the private actors. *Id.*

16 *Id.*

Glachant proposed using a model between a regulator and n actors. The goal of the regulator in such a scenario is to design a policy which allows the efficient allocation of private objectives,[17]

$$A^* = (q_1^*, \dots, q_n^*) \quad (1)$$

with, [18]

$$C_1'(q_1^*) = \dots = C_i'(q_i^*) = \dots = C_n'(q_n^*) = B'\left(\sum q_i\right) \quad (2)$$

In order to obtain the necessary information, we need to addm_i, the message sent by actor i about his costs, C_i.[19] The contents of message m_i can be true or false. [20] The regulator is then required to commit to a message, that for each n -tuple of messages $(m_1, \dots, m_n)$ there will be a policy result A that is the space of allocations, [21]

$$F: (m_1, \dots, m_n) \to A = (q_1, \dots, q_n) \quad (3)$$

By making this *ex ante* commitment to connect the actors' messages with specific policy results, the regulator has provided each actor with sufficient information to understand the consequences of each actor's m_i. [22] Because of the regulator's transparent commitment to $F \to A$, each actor has an incentive to take into account not only his own strategy but also the strategies of all of the other actors. [23]

These strategic interactions are the structure of a mathematical game. [24] $G(R)$ is a game between the n actors that strategically determine which values to place into their messages m_i about their private pollution abatement costs, R, so as to their respective gain from the message choice against the responsive regulation A. [25]

The regulator searches for a collection of methods, F, to transform the receipt of the messages into a functional policy A that holds true for two conditions:

i. that the regulator's method can yield a specific policy each unique set of messages: $F(m^*) = A^*$,[26] and
ii. that for all combinations of private pollution abatement costs there will exist some set of messages from the n actors that will establish an equilibrium

17 *Id.*
18 *Id.*
19 *Id.*
20 *Id.*
21 *Id.*
22 *Id.*, at 5.
23 *Id.*
24 *Id.*
25 Id.
26 *Id.*

of the game: $\forall R, m^*$ is the equilibrium of $G(R)$. [27]

Glachant states that indeed there is a menu of such methods to transform the messages from the actors into specific policies that will reveal the necessary information to the regulator.[28]

It is the dynamic of the messages on the likely policy results that drive this potential to reveal information and balance the earlier recognized asymmetry.[29]

3. Impacts of Transaction Costs on Policy Determination

However, there are several concerns that this analysis reveals.

First, an assumption of budgetary neutrality cannot be maintained, *i.e.*, there will always be an effective capital flow from the regulator to the actors; subsidies will be provided for the information received. [30]

Second, because of the aforementioned capital leakage, the system is second best optimal. The results can be improved, but examples in the literature suggest that the mapping of F → A might actually require drafting of unique policy instruments for each actor. [31]

As such, Glachant projects, in a Coasean manner, that the overall problem with routine mechanism design is that it assumes too readily zero-cost transaction costs to obtain information relevant for policy design. [32] As he states, "we are especially suspicious towards the zero administrative costs assumption." [33]

He documents six problematic areas that are likely to not be zero-costs in the collecting or processing of information:

i. The design of the menu options by the regulator. This is an exercise in scientific, engineering, and economic analysis of $(n+1)$ participants.[34]
ii. The means of communicating the menu to the n actors. [35]
iii. The strategic calculations undertaken by each actor to determine their message m_i back to the regulator. [36]. Frankly, the interlinearity of actors responding to each other's anticipatory strategies could be

27 *Id.*

28 *Id.*, at 5-6.

29 *Id.*, at 6.

30 *Id.*

31 *Id.*

32 *Id.*, at 7.

33 *Id.*

34 *Id.* And here is a latent assumption of a singular policy challenge; imagine the complexity facing real administrators facing numerous industrial settings.

35 *Id.*

36 *Id.*

computationally vexing in a way that would require next-best approximations.

iv. The messages need to be correctly and timely collected and sorted by the regulator. [37]

v. The mapping of the received messages into a coherent and workable policy, especially if the policies need to be actor-specific, could be especially cost intensive. [38]

The results of Glachant's study are that informational strategies do exist to rectify the observed informational asymmetries, but they will likely be costly and fail to efficiently resolve the needs of regulators. Thus, regulations might not be appropriately seen as more efficient than lawsuits in civil liability when informational asymmetry is too costly. But, the application of a regulatory process can suss out information that once acquired might aid either regulators or petitioners in addressing their Coasean negotiations or lawsuits.

[37] *Id.*

[38] *Id.*

Glachant's Asymmetric Information Model

Appendix III

OFFSHORE METHANE HYDRATES AND CLIMATE CHANGE HAZARDS

Anthropogenic climate change is a serious hazard from the development of offshore methane hydrates. The release of large volumes of carbon dioxide or of methane would be sufficient to cause worrisome impacts to climate stability.

Climate change, it almost goes without saying, is one of the most severe threats facing humanity today. The signing of the UN's Framework Convention on Climate Change was a turning point in the struggle for both recognition of the problem and a beginning of international legal standards to recognize the causes of anthropogenic climate change.[1] It has been followed by a succession of agreements and understandings, most notably the Kyoto Accords.[2]

The potential hazards of climate change are numerous and well-known; they include increasing severity of precipitation events, rising surface temperature with dramatic impacts on agriculture and livestock, rising ocean levels as ice sheets melt which turn threatens to flood many coastal and low-level areas of inhabitation, and the potential displacement of hundreds of millions of people around the globe. There are so many potential impacts that it is difficult to find any location or population that would not be substantially impacted by climate change; climate change is a global crisis in that every person would be affected.

Methane hydrates release methane, that methane can in some cases become converted to carbon dioxide. Both methane and carbon dioxide are greenhouse gases and both enable additional climate change. There are multiple pathways in which either gas could become released from methane hydrate development projects.

Thus, the risks from methane hydrate projects for increasing climate change hazards are both substantial and realistic and those risks must be squarely addressed prior to any development of such projects.

1 92 United Nations Framework Convention on Climate Change, May 9, 1992, New York, USA. 1771 U.N.T.S. 107, 31 ILM 849 [hereinafter UNFCCC].

2 1997 Kyoto Protocol to the UN Framework Convention on Climate Change (UNFCCC). December 11, 1997, 2303 U.N.T.S. 148, 37 ILM 22 [hereinafter Kyoto Protocol].

1. Threat of Anthropogenic Climate Change from Methane Hydrates

Several questions need to be addressed:

i. What impact would the development of methane hydrates pose to the vectors of anthropogenic climate change?
ii. Are the risks of offshore methane hydrates limited to their extraction sites, or do they persist downstream as well?
iii. Would the recommendations of this present study have any effect on the prevention of anthropogenic climate change risks from offshore methane hydrate projects?

1.1. Impact of Methane Hydrates on Anthropogenic Climate Change

The development of offshore methane hydrates would enable both carbon dioxide and methane emissions to occur.[3]

It is unclear what percent might be carbon dioxide or methane after oceanic metabolism of methane volumes and after atmospheric combustion events, but it would appear that most of the released emissions would be carbon dioxide. There are two primary reasons for this result;

i. oceanic biota would metabolize the methane, and
ii. all of the marketed methane would be combusted and most of the atmospherically vented methane would also be combusted.

Thus, while volumes of methane would reach the atmosphere, the vast bulk of the greenhouse gas emissions from offshore methane hydrates would be from various sources of carbon dioxide.

To what volume would be released would greatly depend on the future extent and scale of development project, on their locations *vis-à-vis* safe or unsafe deposit beds, and to the technologies and prevention methods employed; such are yet to be determined. It is the position of this present study that the *ex ante* development of appropriate governing mechanisms for offshore methane hydrates would assist to optimally set those decisions.

1.2. Location of Risks

The risks of emissions are not limited to their extraction locations. Those risks extend from the well site to the ultimate consumer. However, what risks extend beyond the offshore project to the consumer are already met in conventional offshore natural gas extraction projects. There are laws in place to both regulate the operational standards for safety, for the permitted emission and venting of natural gas, and for the safe distribution of natural gas in marketing lines.

3 *See* the discussion, *infra*, at sec, 2.

To the extent that additional methane volumes would arise from the development of offshore methane hydrates, the problem might be characterized as an increase in activity level that might increase the likelihood of harm.[4]

What is unique to offshore methane hydrates are the potential for novel harms that arise near to the hydrate deposits. The bulk of this study has focused on those harms. Those hazards are not properly addressed within existing mining or pollution laws.

1.3. Addressing Climate Change Risks

Methane hydrates are composed of methane and water. [5] Both in nature and in engineered settings, methane hydrates can be vented or emitted and subsequently be converted from methane into carbon dioxide. As such, the two gases of concern from the development of offshore methane hydrates are methane and carbon dioxide.

Both carbon dioxide and methane are *per se* greenhouse gases under the UNFCCC and its Kyoto Protocol. The Kyoto Protocol called for the monitoring of all anthropogenic greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).[6]

Similarly, carbon dioxide and methane are both listed as greenhouse gases to be monitored under the EU's Greenhouse Gas Mechanism program.[7] The EU has committed itself and its Member States to reducing their emissions of greenhouse gases.[8]

Such emissions are also arguably covered by the U.S.'s Clean Air Act, under the Mandatory Greenhouse Gas Reporting for Petroleum and Natural Gas Systems,[9]

4 While it is tempting to make an argument that abundant and cheap methane could displace dirtier fuels such as coal or crude oil, the underlying economics might be complex as those other energy resources competed on price and became available at lower costs to consumers. One possible outcome would include that cheaper methane might lead to increased consumption of cheaper dirty fuels as well.

5 Methane hydrates are primarily the mixture of methane and water, of CH_4 and H_2O. The interactions of these two molecules can result in the release of various greenhouse gases such as carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_2), and methane (CH_4).

6 Kyoto Protocol. Annex A. Greenhouse Gases. *See also* discussion on UNFCCC and the Kyoto Protocol, *supra* at ch. 8, sec. 4.

7 Decision No 280/2004/EC of the European Parliament and of the Council of 11 February 2004 concerning a mechanism for monitoring Community greenhouse gas emissions and for implementing the Kyoto Protocol. O.J. (L 49). 1. [hereinafter Decision No 280/2004/EC] *See* Decision No 280/2004/EC , art. 3, sec. 1(a). *See also* Decision No 406/2009/EC, art. 2, sec. 1.

8 Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020. O.J. (L 140), 136

9 *See* 40 CFR 98.232(a) and (b);
"(a) You must report CO_2, CH_4, and N_2O emissions from each industry segment specified in paragraph (b) through (i) of this section, CO_2, CH_4, and N_2O emissions from each flare as specified in paragraph (b) through (i) of this section, and stationary and portable combustion →

or by the federal Mineral Lands and Mining statutes within the U.S.[10] Even where federal law is weak on methane gas emissions or on venting, state law often fills the gap within areas of state jurisdiction.[11]

As such, potential greenhouse gas emissions are currently regulated in many jurisdictions. But those regulations assume a certain character of foreseeable emissions, as might be found at a factory or at a landfill. Methane hydrate extraction could enable greenhouse gas emissions of a character more in line with industrial accidents, thus additional governance might be usefully applied to the emissions of greenhouse gases from methane hydrate projects, such as was proposed in Chapter 7. It has been found that those events that lead to methane and carbon dioxide leaks leading to climate change harm are also the events and acts that lead to other harms. Optimized incentives from a portfolio of governance mechanisms can be provided to operators and owners of offshore methane projects to impact their decisions on their activity level and care levels. By so doing, the risk of climate change causing emission could be controlled.

Further, while this study does not advocate for the development of offshore methane hydrate resources, it does strongly advocate for the development and advancement of the governance mechanisms that could address these hazards from methane hydrates prior to the onset of such commercial investment projects.[12] Particularly for the issues related to anthropogenic climate change, it would be of pressing importance to ensure that the correct incentives were in place prior to project planning.

2. Notes on Greenhouse Gas Emissions from Offshore Hydrates

Offshore methane hydrates, in essence, are a problem of handling, treating, and transporting methane. Methane is a well-established greenhouse gas that is generally considered more dangerous than carbon dioxide for its potential to result in anthropogenic climate change. Methane's presence in water and in the atmosphere can also result in its conversion to carbon dioxide, the greenhouse most commonly referred to in discussions on anthropogenic climate change.

emissions as applicable as specified in paragraph (k) of this section."
"(b) For offshore petroleum and natural gas production, report CO_2, CH_4,and N_2O emissions from equipment leaks, vented emission, and flare emission source types as identified in the data collection and emissions estimation study conducted by BOEMRE in compliance with 30 CFR 250.302 through 304. … ."

10 *See* the discussion at ch. 11, sec. 8.

11 *E.g.*, *see* Texas Administrative Code, Title 16, pt. 1, ch. 3, Rule 3.32(d) and (e), which limits the types of gas emissions and sets flaring regulations. But such state law does not extend to where much of the offshore methane hydrates would lie, which are in federally administered waters. Those waters are governed by 30 CFR 250.1160, which strictly regulate venting or flaring of methane from a licensed field location. That federal regulation is founded in the code on Mining and Minerals at 30 U.S. Code § 1751, *et seq.*

12 For a longer essay on point, *see* R. A. Partain, *Avoiding Epimetheus: Planning Ahead for the Commercial Development of Offshore Methane Hydrates*, 14:2 Sustainable Dev. L. & Pol'y (December 2014 Forthcoming).

Below, the study explores two avenues for climate change impact from methane hydrate extractions. The first pathway is the intended pathway, which is fairly identical to contemporary means of producing and marketing conventional natural gas form offshore wells. The second pathway explores the novel risks due to the hydrates being fragile and under mud barriers.

2.1. Routine Opportunities for Greenhouse Gas Releases

Methane can become released at many points in its journey downstream from the deposit to the consumer, the industrial term of art is 'fugitive gas.'[13] This section explores the manners in which methane could leak from the extraction, production, treating, processing, transporting and marketing activities.

These scenarios are more or less identical to the current problems facing conventional offshore natural gas well systems.[14] It is important to note that these risks are already well regulated and addressed within developed economies;[15] the concern here is could the increased volumes of gas from methane hydrate development projects place additional strain on these regulatory systems? In Shavell's terminology, would the increased volumes from those projects effect an increased activity level that could result in additional harm under the existing rules?

The wells could enable methane to become free within their internal layers and allow methane to vent to the mouth of the well at the christmas tree. The subsea assemblies, gathering lines, and manifolds could all have fissures that enable leakages of methane. The pipes that rise from the seabed to the offshore structures or vessels would be subject to the powerful momentum of ocean currents and waves; such wear and tear could enable fissures and seal breaches that could vent methane. Once on board the treating and processing vessel or structure, there would be hundred of pipes and pieces of equipment that might have flaws that could enable methane venting. Once treated and processed, the methane would need to be treated for transport to onshore reception facilities for downstream marketing. That transportation could be ship-borne or pipeline-bound. Ships rupture or sink, pipes burst or leak. Methane could escape in many moments prior to reaching the shoreline.

Once on shore, the methane would likely be fed into an onshore distribution network of pipelines to move the gas downstream to a variety of customers and

13 *See* Texas Administrative Code, Title 16, pt. 1, ch. 3, Rule 3.32(a)(1): "Fugitive emissions--Releases of gas from lease production, gathering, compression, or gas plant equipment components, including emissions from valve stems, pressure relief valves, flanges and connections, gas-operated valves, compressor and pump seals, pumping well stuffing boxes, casing-to-casing bradenheads subject to the provisions of §3.17 of this title (relating to Pressure on Bradenhead), pits, and sumps, that cannot reasonably be captured and sold or routed to a vent or flare."

14 The methane can leak directly from the deposit through the muddy barriers to the ocean and above. More on this potential pathway is discussed in the following subsection, sec. 2.2.

15 See the notes on UN, EU, and American laws on point, *infra*, in sec. 3.1.

marketing facilities. Those pipelines would likely be transboundary and international in many locations and be subject to varying levels of safety standards and inspections. The length of those pipes and their remoteness might make it challenging to fully inspect the pipelines for leaks and venting from poor welds, climate-exposure wear and tear, and from seasonal heating and cooling of the pipes. But those pipelines would also run through areas of habitation and transport and would thus be exposed to a variety of accidental ruptures.

Gas marketing runs to two extremes, large industrial users and small consumer customers. Electrical generations plants, iron-smelting plants, and other manufacturing plants might rely on natural gas for generating large amounts of heat. Restaurants and smaller installations might use natural gas for cooking or room heating. A more recent technology has seen an increase in the sale of natural gas for fleet automobiles and buses to displace diesel engines. All of these applications of natural gas result in its combustion; that combustion process combines methane with ambient oxygen to result in carbon dioxide and water.[16]

Thus, methane could vent at any point from deposit to customer and if it does not leak prior to the customer, the ultimate use of methane by most customers would be combust the methane and render carbon dioxide. *Ergo*, the extraction of natural gas, be it from conventional natural gas or from methane hydrates, results in the eventual venting of a greenhouse gas, either of carbon dioxide or of methane.

To the extent that offshore methane hydrates are commercially developed as a source of natural gas and that gas is delivered on shore for industrial, commercial and residential purposes, it will potentially expand the scale of the existing in-place natural gas marketing networks and the volumes in play. As far this piece of the analysis goes, it is a danger from increasing the activity level of a pre-existing activity. Because the harm in question is climate change, and because the leaks provide the damaging carbon dioxide and methane gases, the increased activity level would be expected to increase the probability of harm.

2.2. *Alternative Means of Greenhouse Gas Release*

The above section attempted to sketch the possible opportunities for methane or carbon dioxide to enter the atmosphere from pipes, fittings, and such infrastructure. This section undertakes to establish the potential pathways for greenhouse gas release from natural locations. As explored in earlier chapters,

16 In chemical notation, the basic reaction is $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$. The actual reaction sequence is fairly complex and multi-factored. E.g., a certain sub-portion of the combustion will result in methyl groups, CH_3, which are likely to result in the production of ethane, C_2H_6. However, ethane combustion similarly results in carbon dioxide and water vapor. The U.S. EPA has listed nitrogen oxides (NO_x), carbon monoxide (CO), and carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), volatile organic compounds (VOCs), trace amounts of sulfur dioxide (SO_2), and particulate matter (PM) as contaminants of methane combustion when combusted in ambient air conditions. See the EPA guidance on natural gas combustion, *available* at http://www.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf.

Offshore methane hydrates are primarily found under mud layers, not under rock or salt structures as conventional natural gas deposits are normally found. Mud lacks the structural stability of the rock or salt traps; this presents several novel problems with regards to the safe extraction of methane from deposits underlying to the mud layers.

Key among those risks is the potential for the hydrate deposits to lose their structural integrity and to begin the disassociation of the methane from the hydrate. Once the methane volumes become free of the hydrate structures, they could become emitted and released through the mud layers. Such leaks could be either persistent and stable or unstable and catastrophic.

Persistent and stable leaks are not likely to lead to substantial volumes of methane reaching the atmosphere as most of the leaked or vented methane volumes would be metabolized into carbon dioxide before being emitted from the ocean waters.[17] This process has been observed in conjunction with the BP Macondo spill event, wherein more methane was released than crude oil into the ocean.[18] It was found that the methane was almost fully metabolized and that resulted in high oxygen levels in the ocean, leading to secondary problems of altered oceanic ecologies.[19] Yet, there are also findings where methane could reach the atmosphere from depths in excess of 500m if the methane bubbles were covered in a surfactant,[20] so the evidence on methane transmission remains in development.

However, this process would still result in greenhouse gas emissions. Within certain circumstances, the carbon dioxide can become stable within the water and persist therein for very long periods of time; it might also potentially interact with certain oceanic flora that can further metabolize the carbon dioxide into other gases and outputs. When methane is released, either it directly or carbon dioxide or other greenhouse gases will eventually be released to the atmosphere.

Unstable and catastrophic situations provide the most likely scenarios for large volumes of methane to reach the atmosphere. For methane to exit the ocean and reach the atmosphere intact as methane, the transmission must be quick. When large volumes moving at sufficiently velocity exit from methane hydrate deposits,

17 "Methane emitted at the seafloor only rarely survives the trip through the water column to reach the atmosphere. At seafloor depths greater than ~100 m, O_2 and N_2 dissolved in ocean water almost completely replace CH_4 in rising bubbles" C. D. Ruppel, *Methane Hydrates and Contemporary Climate Change*, 3(10) Nature Education Knowledge 29 (2011)

18 J. D. Kessler, *et al., A persistent oxygen anomaly reveals the fate of spilled methane in the deep Gulf of Mexico*, 331.6015 Science 312 (2011). "Based on methane and oxygen distributions measured at 207 stations throughout the affected region, we find that within ~120 days from the onset of release ~3.0 × 1010 to 3.9 × 1010 moles of oxygen were respired, primarily by methanotrophs, and left behind a residual microbial community containing methanotrophic bacteria. We suggest that a vigorous deepwater bacterial bloom respired nearly all the released methane within this time, and that by analogy, large-scale releases of methane from hydrate in the deep ocean are likely to be met by a similarly rapid methanotrophic response." *Id*.

19 *Id*.

20 E. A. Solomon, M. Kastner, I. R. MacDonald, & I. Leifer. *Considerable methane fluxes to the atmosphere from hydrocarbon seeps in the Gulf of Mexico*, 2 Nature Geosci 561 (2009)

they can form bubble columns that act as protective chimneys that enable the inner zones of that column to function as a gas pipeline to the surface. So long as the volume and velocity of the methane is sustained, the pipeline to the surface will remain fluid and open.

A secondary means of transmission would be the structural failure of the deposit, enabling chunks of hydrates to break off from the main bed and float to the surface of the ocean. The chunks of hydrates would arrive at the surface and experience the lower pressure levels which would cause the hydrate chunks to disassociate rapidly into methane and water. Both forms of methane transmission routinely occur in nature. Chunks of floating methane hydrates have been observed offshore of Vancouver Island in western Canada and just recently it was announced that hundreds of chimneys lay offshore the east coast of the United States.

The key to both means of methane transportation is the destabilization of the hydrate deposits and the disassociation of the methane volumes from the hydrates. While these events do happen in nature, they do not appear to be as easily triggered as some might fear, because hydrates are endothermic. An endothermic chemical reaction needs the introduction of energy to achieve the reaction; hydrates will not weaken or disassociate on their own, they need external stimuli to begin and sustain the reaction. Because of this endothermic character, hydrates are generally seen as self-stabilizing if no marginal energies are injected into them.

It bears repeating, these sustained release events happen in nature and are observable. A recent study found over 570 active continuous methane hydrate seeps off of the mid-Atlantic coast of the U.S.[21] Stark et al. found that many of the seeps had been active for more than a thousand years.[22] Thus, methane does vent from the seabed and there are active emissions today. So, it is more than feasible that the endothermic reactions could be overcome and that such emissions could be sustained over long time periods; such is a daily event.

The processes of hydrate extraction are focused on overcoming that endothermic character; they melt hydrates with heat, with chemical surfactants, and with pressure reductions that lower the energy required to begin and sustain those reactions. Once those reactions are started by commercial extractors, volumes of loose methane or water could accumulate within the deposit structure. Those volumes are also suspected in being able to set off disassociation sequences. But even with present triggering events, the continued disassociation of methane would require continued stimulation.

A danger presents if the extractor operator is unaware of the subsurface accumulations and continues to artificially stimulate methane disassociation to support the production plans. Unknowingly, the operator might both have provided the means of a trigger and the continued energy required for a massive

21 A. Skarke, C. Ruppel, M. Kodis, D. Brothers & E. Lobecker, *Widespread methane leakage from the sea floor on the northern US Atlantic margin*, 7 Nature Geoscience 657, 657 (2014). Ths population of seeps stands in contrast to previous estimates of less than a dozen such seeps. *See id.*

22 *Id.*

disassociation event to occur. It is possible that such an event might lay unobserved for a sufficient period that the hydrate bed could be floated by disassociated water, become loosened by fluidized methane volumes and to generally lose its structural integrity. In such a case, it might be apparent till too late that a very large volume of methane hydrates is about to erupt and escape. Once that event occurs, because hydrates generally lay on a sloping floor, the removal of one area of hydrates might well enable a landslide of material lying above it on the sloping hillside. Once that landslide event is triggered, the mass of the mud and hydrate slurries falling onto lower lying hydrate deposits would supply the energies required for additional disassociations and further structural collapses.

It bears repeating that this cataclysmic sequence, in order to overcome the endothermic character of methane hydrates, requires a class of Markov events rapidly following each other in stochastic succession;[23] however, with sufficient time and sufficient number of fields in play, such an event might eventually be a foreseeable hazard of methane hydrate extraction operations.

Once the methane reached the atmosphere, combustion with ambient oxygen would be expected. For every gram of methane vented, 2.25 grams of water and a gram of carbon dioxide would be created;[24] the balance of the mass is drawn from the ambient oxygen. While the immediate combustion is not expected to be completely efficient, meaning some methane would not combust,[25] given sufficient time, most of the methane would likely combust in subsequent reactions. Those remaining non-combusted volumes methane would be expected to survive in the atmosphere for about 12 years, a much shorter time period than carbon dioxide's potential for centuries of atmospheric presence.[26]

23 This would be in contrast to a more stable and consistent melting of hydrates due to sustained geologic heat sources or warm water currents.

24 Presentation of the Colorado Oil & Gas Association. *Available* at http://www.coga.org/pdf_articles/CombustionMethane.pdf.

25 Methane has upper and lower limits on its methane to oxygen ration that enable combustion. If the methane represents higher than 15% of the ration, over the upper explosive limit (UEL), it will not combust. If it is under 4%, under the lower explosive limit (LEL), it will not combust. *See* Matheson Gas chart, available at https://www.mathesongas.com/pdfs/products/Lower-(LEL)-&-Upper-(UEL)-Explosive-Limits-.pdf. It would be expected that the methane would reach the atmosphere at a rich density above the UEL and gradually drop to the UEL as the gas dispersed. The resultant combustion would both aid in greater dispersion and in additional ignition sequences, as the ambient temperatures would increase.

26 "Carbon dioxide's lifetime is poorly defined because the gas is not destroyed over time, but instead moves among different parts of the ocean–atmosphere–land system. Some of the excess carbon dioxide will be absorbed quickly (for example, by the ocean surface), but some will remain in the atmosphere for thousands of years, due in part to the very slow process by which carbon is transferred to ocean sediments." EPA, *Overview of Greenhouse Gas Emissions: Carbon Dioxide Emissions* (U.S. Environmental Protection Agency, Washington, DC, USA, 2010) Available at http://www.epa.gov/climatechange/ghgemissions/gases/co2.html. *See also* EPA, *Overview of Greenhouse Gas Emissions: Methane Emissions* (U.S. Environmental Protection Agency, Washington, DC, USA, 2010) Available at http://www.epa.gov/climatechange/ghgemissions/gases/ch4.html.

The point to be drawn herein is that the unique risks of methane hydrates to erupt from the seabed directly, in novel ways different from conventional offshore natural gas wells, will potentially enable large volumes of greenhouse gases to reach the atmosphere. But the composition of those vented gases is expected to be mostly carbon dioxide. While the initial feedstocks would be methane, it does appear that the bulk of greenhouse gas emissions to last beyond the immediate venting events would be carbon dioxide volumes. The slower release events that enable methane to remain in ocean waters for longer periods are expected to be almost fully metabolized into carbon dioxide before venting to the atmosphere. Even those volumes that might reach the ocean surface immediately and vent as methane to the atmosphere are expected to convert to carbon dioxide via combustion events. [27] Nevertheless, a mix of both methane and carbon dioxide would be emitted and both are greenhouse gases.

To the extent that offshore methane hydrates are extracted from their deposits in ways that could loosen them and enable persistent or massive venting events, this would be the introduction of a novel form of risk.[28] It would appear that while large amounts of methane could be released or emitted at the point of breach, the vast majority of those methane emissions would be converted to carbon dioxide either prior to atmospheric contact or very shortly thereafter. Thus, these novel forms of harm would primarily enable large releases of carbon dioxide into the atmosphere.

Thus the development of offshore methane hydrates poses a new activity, the risk of disturbing otherwise in-place methane hydrate deposits. These risks are different and distinguishable form the risks in the previous section, which were essentially increases in activity levels for a recognized risky activity. Here, the activity is new, the risk is somewhat unclear, and the proper care level remains debatable. How much damage might result is difficult to forecast, how the damage might occur or when it might occur is also difficult to forecast. There are reasons to believe that the risk is manageable in certain circumstances; offshore methane hydrates have been produced safely by Japanese researchers and methane hydrates appear stable in many situations as monitored by scientists.

But the novelty of the situation remains. The potential risk for major climate change impacts remains.

27 This is not to suggest in any form that the emissions of carbon dioxide are in any way preferable to methane emissions, but merely to indicate that the problem to be addressed by these novel greenhouse gas emissions might be primarily climate change events related to carbon dioxide emissions and not primarily those of methane emissions.

28 While a variety of 'bad things' could occur, such as incidence of tsunamis, the discussion here focuses on climate change impacts.

Appendix III

Appendix IV

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Appendix V

CURRICULUM VITAE

Roy Andrew Partain was born near Atlanta, Georgia, in the United States on July 14, 1970. He graduated from Myers Park High School in Charlotte, North Carolina in 1988. He received a Bachelor of Science in Economics from the Georgia Institute of Technology in 1991. After completing a thesis on mathematical models of altruism, he was awarded a Master of Science.

He continued his studies in Economics at the University of North Carolina at Chapel Hill. After completing a thesis on transaction costs and their role in the theory of the firm, he received a second Master of Science in 1995. He was the recipient of a U.S. Department of Education Fellowship for Foreign Language and Area Studies for the study of Mandarin Chinese in Taiwan.

He returned from the Fellowship to Vanderbilt University Law School, where he joined the editorial staff of the Vanderbilt Journal of Entertainment and Technology Law and served as a teaching assistant for the Legal Research and Writing program. He graduated with a Doctor of Jurisprudence in 2001. After graduation he passed the professional licensing examination of the State Bar of Texas in 2001. He remains in license to practice law.

He first practiced law as in-house counsel to the Exxon Mobil Corporation in their Upstream Business Services division in Houston, Texas. His portfolio of responsibilities included oversight of ExxonMobil's upstream activities, both on- and off-shore. He remained with ExxonMobil from 2001 until 2006. In 2006, he joined the Chevron Corporation at its headquarters in San Ramon, California. At Chevron, his portfolio of responsibility included Chevron's global upstream activities.

In 2010, he became an assistant professor of Economics at Keimyung University, in Daegu, South Korea. In the Spring semester of 2011, he served as interim Dean of Keimyung Adams College, within Keimyung University.

Since September 2011, he has served as an assistant professor of Law at Soongsil University's College of Law. His published research has primarily focused on environmental law, energy law, and the philosophy of law. He has taught a variety of classes: contract law, tort law, corporate law, private international law, American constitutional law, history of Western law, history of Anglo-American contract law, and legal research and writing.

SAMENVATTING

Offshore methaanhydraten vormen een potentiële overvloedige bron van energie en vers water en kunnen nieuwe wegen voor groene energie openen. Het ontwikkelen en produceren van offshore methaanhydraten kan echter gepaard gaan met onvoorspelbare risico's en schade. Zowel rampzalige kleinere risico's moeten worden geïntegreerd in de beleidsplanning aangaande het exploiteren van deze nieuwe energiebron. De regulering van deze offshore methaanhydraten staat centraal in dit onderzoek.

Het onderzoek bestaat uit vier delen. Het eerste deel van het onderzoek geeft een introductie op de wetenschappelijke, technische en commerciële kenmerken van offshore methaanhydraten projecten. Het geeft ook een overzicht van zowel de mogelijke voordelen als de potentiële gevaren van offshore methaanhydraten.

Het tweede deel van het onderzoek bespreekt de rechtseconomische inzichten aangaande het ongevallenrecht, toegepast op milieuschade. Het aansprakelijkheidsrecht wordt onderzocht teneinde te bepalen wanneer risico- of schuldaansprakelijkheid kunnen worden toegepast met het oog op risicobeheersing. Vervolgens wordt dezelfde analyse op publieke en private regulering toegepast. Uit de eigenschappen van offshore methaanhydraten volgt dat de optimale regelgeving een combinatie vormt van het aansprakelijkheidsrecht in aanvulling op de implementatie van publieke regulering.

Het derde deel van dit proefschrift onderzoekt bestaande wetgeving en verdragen om te bepalen welke van toepassing zouden kunnen zijn op offshore methaanhydraten. Tevens wordt onderzocht of deze risicobeheersing strategieën ook in overeenstemming zijn met de aanbevelingen in het tweede deel van dit onderzoek. Geconcludeerd kan worden dat het merendeel van de onderzochte wetgeving een strategie volgt, gebaseerd op aansprakelijkheid, in combinatie met publieke regelgeving, maar dat veel van de huidige wetgeving gericht op de regulering van offshore olie en gas activiteiten niet gekoppeld kan worden aan de specifieke omstandigheden van methaanhydraten.

In het vierde deel van het onderzoek wordt een samenvatting van de drie eerdere delen geboden en wordt een aantal aanbevelingen gedaan om de bestaande wetgeving aan te passen, zodat deze eveneens toepasbaar is op de ontwikkeling van de exploitatie en productie van offshore methaanhydraten.