Fordham Environmental Law Review

Volume 26, *Number* 2 2015 *Article* 4

The Application of Civil Liability for the Risks of Offshore Methane Hydrates

Roy Andrew Partain*

*Soongsil College of Law

THE APPLICATION OF CIVIL LIABILITY FOR THE RISKS OF OFFSHORE METHANE HYDRATES

*Roy Andrew Partain**

A potentially huge untapped resource of natural gas exists just offshore almost every coastal state in the world, the resource called methane hydrates. The opportunities for fiscal revenues, energy security, and freshwater resources will be attractive to many of those states; for many, the commercial development of offshore methane hydrates could bring substantial improvements to public welfare.

But offshore methane hydrates present new and potentially cataclysmic risks in their extraction and production. There are risks of voluminous greenhouse gas emissions, subsea landslides, and tsunamis. There are also a variety of non-cataclysmic risks posed by the development of offshore methane hydrates. Most of these risks are novel and were not present in earlier offshore oil and gas extraction projects.

The need to provide legal guidance to optimize the reduction of risk and hazards from the extraction and production of offshore methane hydrates should be addressed in advance of initial commercial operations. This paper calls for the application of civil liability rules to be a part of the governance mechanism of that environment risk, and in particular, for the rule of strict liability to be applied.

---

* Assistant Professor, Soongsil College of Law, South Korea. The author is most grateful to Prof. Dr. Michael Faure (Erasmus), Prof. Dr. Louis Visscher (Erasmus), Dr. Stefan Weishaar (Groningen), and Dr. Alessandra Arcuri (Erasmus) for all of their guidance and suggestions with this study.

1. INTRODUCTION

1.1 Legal clarity is needed to govern risks of offshore methane hydrates

The overall scale of this new energy resource, of offshore methane hydrates, has been estimated at 100-times the currently identified commercial reserves of petroleum and natural gas; bluntly put, the volumes of known petroleum and natural gas are a rounding error within the estimates of offshore methane hydrates. Unique to this form of natural gas are its icy structures of methane and water that could enable carbon sequestration simultaneous to the extraction of the methane volumes from the methane hydrate deposits; this replacement of methane with carbon dioxide could enable a 'green methane.' Additionally, the water volumes stored within methane hydrates could provide large volumes of fresh water, especially to arid states in Africa.

Offshore methane hydrates have not been previously developed for several reasons. First, until recently, they were unknown to exist in such large deposits; but extensive exploration and modeling since their discovery have revealed their abundance. Second, the technology to enable commercial production required substantial development beyond traditional offshore national gas production technologies; but the technology is now arguably functional, as Japan has operated continuous offshore methane hydrate wells, and continual cost improvements have brought the commercial feasibility of the technology in range of certain market conditions. Additionally, several states have committed to the production of offshore methane hydrates as part of national energy security planning; Japan has committed to begin commercial production of offshore methane hydrates by the 2020s.

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. Potential operators would want legal certainty in the consequences of their operations, protection of their licenses and safety from retroactivity and *ex post* determinations of liability. People living in the areas potentially affected would hope for a minimum of risk and hazard but also expect due processes to provide for the recovery of their harms and damages. Governments and other public organizations would want to monitor their stewardship of natural resources, to balance the economic growth opportunities presented by offshore methane hydrates against the potential welfare impacts of environmental hazards, and to provide social cohesion to enable all of the parties to remain engaged in solving the complex resource use problem; also, many states will be required to engage in environmental impact assessment reviews prior to issuance of production licenses or the onset of operations. All parties have incentives to prefer legal clarity prior to the onset of production.

1.2 Research question and methodology

This study will present a review of the risks and hazards of offshore methane hydrates, of the general theories of when civil liability rules might be efficiently employed, and a synthesis examining what rule of civil liability might optimally govern the risks and hazards of offshore methane hydrates.

First, the unique and distinguishing circumstances of offshore methane hydrates will be explored and explained. Insight into their unique and unusual risks and hazards will be developed. This study reviews the fundamental science of offshore methane hydrates. It provides a review of the benefits that the development of offshore methane hydrates might afford.

Second, a review of research literature from law and economics will be made, first for strict liability and then for negligence. The research question therein is under which scenarios is a rule of strict liability expected to be efficient and under which scenarios would a rule of negligence be expected to be efficient? A collection of answering scenarios for both rules will be provided.

Third, and contained within each respective section, strict liability and negligence will be evaluated against the particular facts and circumstances of offshore methane hydrates. Strict liability will be examined for fitness and robustness against the circumstances of offshore methane hydrates and similar analyses will be provided for the rule of negligence.

Finally, a recommendation will be made for the application of strict liability as the more robust rule of civil liability for offshore methane hydrates. The unique facts and circumstances of offshore methane hydrate appear to strongly align with the scenarios wherein rules of strict liability have been generally demonstrated to be more robust at optimizing the efficiency of risk reduction efforts. The conclusion does not draw a door shut on other forms of governance, such as public regulation, but rather reveals that rules of civil liability could efficiently reduce the risks of accidents and, second, that the rule of strict liability would be more robust than negligence in obtaining those results for offshore methane hydrate projects.

2. THE FACTS AND CIRCUMSTANCES OF OFFSHORE METHANE HYDRATES

Methane hydrates are physically and chemically different in the way that they manifest in nature from traditional oil and gas. Offshore methane hydrates might provide economic, environmental and other benefits not provided by traditional oil and gas. Furthermore, offshore methane hydrates would present novel risks and harms that traditional oil and gas have not. This section attempts to provide a primer on the facts and circumstances of offshore methane hydrates.

The following subsection will first set out the history and early development of methane hydrates. It will review the technological development and suggest that the onset of commercial development of offshore methane hydrates might be imminent. It will provide an introduction to the chemistry and energy content of methane hydrates. Finally, it will discuss where offshore methane hydrates might be found, both geo-physically and geo-politically.

The second subsection will provide an introduction to the potential or expected benefits of the commercialization of offshore methane hydrates. The vast potential resource base of offshore methane hydrates is detailed. The potential for offshore methane hydrates to provide a price-competitive alternative to liquefied natural gas ("LNG") imports is reviewed. The potential for hydrates to support green energy alternative is reviewed with regards to carbon sequestration, hydrogen fuel production, and as a 'healthier' alternative to coal and crude oil. Finally, the potential for offshore methane hydrates to support freshwater production is explored.

The third subsection will provide an introduction to the potential risks and hazards of offshore methane hydrates. The centrality of harm resulting from methane is detailed, as a greenhouse gas, as an asphyxiant gas, as a marine pollutant, and as a source of other harms, methane is the central problem, not crude oil as in traditional wells.

Both the non-cataclysmic and cataclysmic types of risks and hazards are explained.

2.1 An introduction to offshore methane hydrates

While methane hydrates have been recognized since the 1800s,[1] 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.[2]

Despite the novelty of the idea of offshore methane hydrates as an energy resource, the science and engineering related to their potential development has improved consistently in recent decades. The first initial offshore survey was undertaken in 1970, and the first recovery of offshore methane hydrates occurred in 1981.[3] The first offshore methane hydrate well was drilled in 1999.[4] The first continuously flowing methane hydrate well was tested offshore Japan in 2013.

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

1. Methane hydrates were first discovered by Humphrey Davies in 1810. Jorge F. Gabitto, & Costas Tsouris, *Physical Properties of Gas Hydrates: A Review*, 2010 J. THERMODYNAMICS 1, 1; Carolyn 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. *See* Ayhan Demirbas, *Methane Hydrates as Potential Energy Resource: Part 1–Importance, Resource and Recovery Facilities*, 51 ENERGY CONVERSION MGMT. 1547, 1548 (2010). The science of their internal composition was first reported by Michael Faraday in 1823. *See* Koh, *supra* note 1, at 157; Peter Englezos & Ju D. Lee, *Gas Hydrates: A Cleaner Source of Energy and Opportunity for Innovative Technologies*, 22 KOREAN J. CHEMICAL ENGINEERING 671, 672 (2005).

2. *See* Demirbas, *supra* note 1, at 1548; Yuri F. Makogon, Stephen. A. Holditch & T.Y. Makogon, *Natural Gas-Hydrates—A Potential Energy Source for the 21st Century*, 56 J. PETROLEUM SCI. & ENGINEERING 14, 16-18 (2007); Jill Marcelle-De Silva & Richard Dawe, *Towards Commercial Gas Production from Hydrate Deposits*, 4 ENERGIES 215, 216 (2011).

3. *See* Demirbas, *supra* note 1, at 1548; Makogon, Holditch & Makogon, *supra* note 2, at 16.

4. *See* Demirbas, *supra* note 1, at 1548; Makogon, Holditch & Makogon, *supra* note 2, at 16.

technologies will follow a similar progression.[5] Due to the strategic needs of countries like Japan and South Korea to obtain local secure energy supplies, researchers in the Global Carbon Project have forecasted that commercial methane hydrate investments would begin by 2020 and spread to fields globally by 2030.[6]

In the case of methane hydrates, the methane molecule is trapped within a water-ice framework.[7] The overall water-ice structure visually resembles white snow; the methane does not impact the overall appearance of the methane hydrate structure.[8]

Methane hydrates are crystalline solids composed primarily of methane and water.[9] The water forms polyhedral lattices that are stabilized by the inclusion of methane or other molecules.[10]

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 LNG at 430,000 btu per cubic foot.[11] The disassociation of 1 m^3 of methane hydrates produces 170 m^3 of methane at standard temperature and pressure.[12] In ad-

---

5. Englezos & Lee, *supra* note 1, at 675, 677. The time reference is stated as 3 decades on pp. 675 and as 20-25 years on p. 677.

6. Volker Krey et al., *Gas Hydrates: Entrance to a Methane Age or Climate Threat?,* 4 ENVTL. RES. LETTERS 34007, 4 (2009).

7. Richard A. Dawe & Sydney Thomas, *A Large Potential Methane Source—Natural Gas Hydrates*, 29 ENERGY SOURCES 217, 218 (2007). Kurihara refers to hydrates as "in the solid state and hence does not have a flowability." *See* Masanori Kurihara et al., *Gas Production from Methane Hydrate Reservoirs*, *in* PROCEEDINGS OF THE 7TH INTERNATIONAL CONFERENCE ON GAS HYDRATES (2011).

8. *See* Dawe & Thomas, *supra* note 7, at 218; Demirbas, *supra* note 1, at 1550.

9. *See* Dawe & Thomas, *supra* note 7, at 218; Koh, *supra* note 1, at 157; George 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) (page citations to working paper at SSRN); Demirbas, *supra* note 1, at 1550.

10. *See* Englezos & Lee *supra* note 1, at 672; Koh, *supra* note 1, at 157.

11. *See* Marcelle-De Silva & Dawe, *supra* note 2, at 217. In more general terms, see Englezos & Lee *supra* note 1, at 673; Demirbas, *supra* note 1, at 1548.

12. *See* Englezos & Lee *supra* note 1, at 673. *See also* Koh, *supra* 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.

dition, 0.8 m^3 of water is released from the same cubic meter.[13] It has been suggested that methane hydrates present 2 to 5 times greater energy density than traditional gas reservoirs and 10 times greater density than coal bed methane reservoirs.[14]

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.[15]

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.[16] Methane hydrates have complex geometries with major perturbances due to water flow, pressure and temperature changes, and other factors.[17] 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.[18]

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.[19] As of 2009, methane hydrates had been drilled and recovered from upwards of two-dozen countries in over 77 locations.[20]

2.2 On the benefits of offshore methane hydrates

The benefits expected from the development of offshore methane hydrates are primarily energy supply related; however, the benefits represent more than simply more natural gas reserves. Offshore me-

---

13. *See* Englezos & Lee *supra* note 1, at 673; Demirbas, *supra* note 1, at 1548.

14. *See* Englezos & Lee, *supra* note 1, at 674; Demirbas, *supra* note 1, at 1550; Zhen-guo Zhang, et al., *Marine gas hydrates: Future Energy or Environmental Killer?,* 16 ENERGY PROCEDIA 933, 934 (2012).

15. *See* Dawe & Thomas, *supra* note 7, at 223; Makogon, Holditch & Makogon, *supra* note 2, at 19.

16. Ray Boswell, *Resource Potential of Methane Hydrate Coming into Focus*, 56 J. PETROLEUM SCI. ENGINEERING 9, 11 (2007); *see* Makogon, Holditch & Makogon, *supra* note 2, at 19-21.

17. *See* Boswell, *supra* note 16, at 11; Makogon, Holditch & Makogon, *supra* note 2, at 19-21.

18. *See* Dawe & Thomas, *supra* note 7, at 223.

19. Englezos & Lee, *supra* note 1, at 674.

20. *See* Gabitto & Tsouris, *supra* note 1, at 2.

thane hydrates would impact the overall global energy market by diversifying the locations of abundant natural gas resources; for many coastal countries offshore methane hydrates would be their first large domestic supply of an energy resource. Offshore methane hydrates are expected to soon become price competitive with LNG in general, and may already be price competitive against certain spot prices in that market.

Beyond the mere scale of energy supplies, offshore methane hydrates could support several green strategies. Offshore methane hydrates can be produced in coordination with carbon capture and sequestration, potentially enabling low-carbon or carbon-neutral energy supplies. Offshore methane hydrates might assist a hydrogen economy; given the presence of water and methane, the methane stock can be reformed into hydrogen fuel offshore alongside CCS for the carbon dioxide by-products. Methane is well established to have several environmental and health-related advantages over both coal and crude oil combustion.

Finally, offshore hydrates contain vast amounts of freshwater; for many arid countries these volumes could be significant in public welfare projects.

2.2.1 A potentially huge supply of energy

The forecasted supplies of offshore methane hydrates dwarf traditional oil and gas supplies.[21] Because of the geographical diversity, that almost every coastal country is expected to possess offshore methane hydrates, the potential impact of large and local energy supplies has potential game-changing status for many states and economies.

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,[22] by the end of 2012.[23]

---

21. *See infra* Table 1.

22. Much of the oil and gas industry utilizes Imperial Units instead of metric measures. $1m^3$ of natural gas is generally deemed equivalent to 35 ft^3 for commercial exchanges. *See* Dawe & Thomas, *supra* note 7, at 221. The BP Statistical Reviews lists the exchange ratio as 1 m^3: 35.3 ft^3. *See* BP STATISTICAL REVIEW OF WORLD ENERGY JUNE 2013 44 (2013), *available at* http://www.bp.com/content/dam/bp/pdf/statistical-

Another current estimate for global (conventional) natural gas supplies places their volumes at 150 Tcm.[24] At current levels of global production and consumption, this data forecasts 50 plus years of supply from traditional natural gas, *ceteris paribus*.[25]

But in turning to methane hydrates, Zhang *et al*. presented that there is probably enough producible methane hydrate to provide the whole world with sufficient energy supplies to last a millennium.[26] 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.[27] The Klauda and Sandler model of methane hydrate depositions forecast 120,000 Tcm of methane hydrates globally and over 80,000 Tcm of offshore methane hydrates.[28]

---

review/statistical_review_of_world_energy_2013.pdf (last visited Sept. 6, 2013, 5:00 PM).

23. *See id.* at 22.

24. *See* Moridis et al., *supra* note 9, at 3.

25. BP Statistical Review of World Energy June 2013, *supra* note 22. Note the reserves to production ratios. *Id.* at 22. 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* note 9, at 3.

26. *See* Zhang *et al.*, *supra* note 14, at 934; Moridis et al., *supra* note 9, at 2.

27. 30 U.S.C. § 2001(2)-(3) (2012).

28. The Klauda Sandler model has become the standard model because of its ability to forecast both expected and unexpected real-world methane hydrate discoveries. *See* Moridis et al., *supra* note 9, at 3. *See* Jeffery B. Klauda & Stanley I. Sandler, *Global Distribution of Methane Hydrate in Ocean Sediment*, 19 ENERGY & FUELS 459, *en passim* (2005).

Table 1: Estimates for Global Methane Hydrates Versus Conventional Natural Gas

Scientist(s)	Tcm	Energy Source
BP Statistics[29]	187	Natural Gas
Englezos and Lee[30]	370	Natural Gas
Walsh - Low[31]	2,800	Methane Hydrates
Chatti - Low[32]	3,100	Methane Hydrates
Demirbas[33]	7,104	Methane Hydrates
Collett[34]	9,000	Methane Hydrates
Englezos and Lee - Low[35]	10,000	Methane Hydrates
Englezos and Lee[36]	20,500	Methane Hydrates
Kvenholden and MacDonald[37]	21,000	Methane Hydrates
U.S. Methane Hydrate R&D Act[38]	24,000	Methane Hydrates
Englezos and Lee - High[39]	40,000	Methane Hydrates
Klauda Sandler[40]	120,000	Methane Hydrates
Walsh - High[41]	2,800,000	Methane Hydrates
Chatti - High[42]	7,600,000	Methane Hydrates

29. BP Statistical Review of World Energy June 2013, *supra* note 22.

30. Englezos & Lee, *supra* note 1, at 674.

31. Mathew R. Walsh et al., *Preliminary Report on the Commercial Viability of Gas Production from Natural Gas Hydrates*, 31 ENERGY ECON. 815 (2009). [The original data is cited in standard cubic feet, which has been converted to Tcm for this table.]

32. Imen Chatti, Anthony Delahaye, Laurence Fournaison, & Jean-Pierre Petitet, *Benefits and Drawbacks of Clathrates Hydrates: A Review of Their Areas of Interest,* 46 Energy Conversion Mgmt. 1333, 1336 (2005)

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

34. *See* Marcelle-De Silva & Dawe, *supra* note 2, at 221.

35. Englezos & Lee, *supra* note 1, at 673.

36. Englezos & Lee, *supra* note 1, at 673.

37. Referred to as the standard estimate, partially due to their age. MacDonald's numbers date from 1990. *See* Marcelle-De Silva & Dawe, *supra* note 2, at 219.

38. 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 U.S.C. § 2001(2)-(3).

39. Englezos & Lee, *supra* note 1, at 673.

40. Referred to as the most up-to-date model and likely the most accurate. *See* Marcelle-De Silva & Dawe, *supra* note 2, at 219.

41. *See* Walsh et al., *supra* note 31.

42. Chatti, Delahaye, Fournaison, & Petitet, *supra* note 32, at 1336.

2.2.2 Cost competitor to LNG

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.[43] 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 adopt methane hydrates for national energy policy and strategic energy supply concerns followed by broader private investment as investment costs drop.[44] 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.[45] Another forecast stated, based on technologies and costs prior to 2008, that the incremental costs of production from a medium-difficulty methane hydrate reservoir were $3/Mcf more expensive than production volumes from a conventional offshore natural gas well.[46] 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.[47] 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.[48] As none of these pricing scenarios are without historical precedence, it is reasonable to expect that, in the near future, offshore methane hydrates might become price competitive as an energy resource, a very abundant, geographically well-diversified, price competitive fuel source.

43. 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.

44. *See* Marcelle-De Silva & Dawe, *supra* note 2, at 230.

45. *See* Makogon, Holditch & Makogon, *supra* note 2, 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.

46. *See* Walsh et al., *supra* note 31, at 821.

47. *See* Marcelle-De Silva & Dawe, *supra* note 2, at 230.

48. *See* Krey et al., *supra* note 6, at 3.

2.2.3 A source of 'green energy'

The production of methane hydrates enables the potential sequestration of other GHG in the methane-depleted hydrates.[49] Ultimately, the production of methane hydrates could fit hand-in-glove with carbon capture systems/sequestration (CCS) technologies.[50] *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 of a primarily-purposed CCS project.[51]

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.[52]

2.2.4 A source of hydrogen fuel

Hydrogen fuel could be produced from the methane hydrates and the by-product carbon dioxide could be sequestered; methane hydrates would, thus, yield a fully green carbon-neutral energy supply.[53]

Hydrogen has been widely advocated as one of the cleanest fuel sources because its combustion with oxygen yields simply energy and water.[54] Should hydrogen transportation be sufficiently ad-

---

49. Ryunosuke Kikuchi, Analysis of Availability and Accessibility of Hydrogen Production: An Approach to a Sustainable Energy System Using Methane Hydrate Resources, 6 ENV'T, DEV. & SUSTAINABILITY 453, 467-468 (2005).

50. Marco J. Castaldi, Yue Zhou & Tuncel M. Yegulalp, *Down-Hole Combustion Method for Gas Production from Methane Hydrates*, 56 J. PETROLEUM SCI. & ENGINEERING 176, 178 (2007).

51. See more at Marine Biogeochemistry, GEOMAR, http://www.geomar.de/en/research/fb2/fb2-mg/projects/ [hereinafter the Sugar website].

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

53. W. Rice, *Hydrogen Production from Methane Hydrate With Sequestering of Carbon Dioxide*, 31(14) INT'L J. HYDROGEN ENERGY 1955, 1957 (2006). For a similar proposal by Japanese researchers, *see* Kikuchi, *supra* note 49, at 462.

54. *See* Kikuchi, *supra* note 49, at 454. *See also* Castaldi, Zhou, & Yegulalp, supra note 50, at 178.

vanced, methane hydrates would likely be one of the main feedstock for that future.[55]

Methane hydrates are a major potential source of a global hydrogen fuel supply via methane reforming.[56] Methane hydrates are unique in their coproduction of fresh water and methane enabling hydrogen to be produced at the point source.[57] Methane reforming requires methane as a fuel and a feedstock along with steam.[58] The chemical reaction is endothermic, requiring an energy input such as heat from combusted methane.[59] The resultant carbon monoxide can be converted to carbon dioxide, suitable for re-injection into the hydrate deposit.[60]

2.2.5 Environmental and health superiority to coal and crude oil

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.

There are three basic proposals for how methane hydrates could provide energy more 'greenly' than coal or crude oil. 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.[61] Hydrogen fuel can be produced efficiently from methane hydrates, as water and methane are basic feedstocks. What carbon dioxide is produced in the conversion process can be re-sequestered in the hydrate formation.[62] Finally,

---

55. *See id.* at 465.

56. *See id.*

57. *See id.* at 467.

58. The reaction equation is $CH_4 + H_2O \rightarrow CO + 3H_2$; methane and water can produce carbon monoxide and hydrogen. *See* Kikuchi, *supra* note 49, at 456.

59. 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. *See also id.*

60. 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. *See id.*

61. *See* Englezos & Lee *supra* note 1, at 671; S.Y. Lee & Gerald D. Holder, *Methane Hydrates Potential as a Future Energy Source*, 71 FUEL PROCESSING TECH. 181, 183 (2001).

62. *See* Krey et al., *supra* note 6, at 4.

electricity could be produced offshore from methane with simultaneous re-sequestration of the produced carbon dioxide back into the hydrate formation.[63]

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.[64] The combustion of coal releases significant pollution beyond greenhouse gases that can cause substantial risk to human health.[65] Coal ash also contains surprisingly substantial quantities of radioactive materials, which is carcinogenic.[66]

2.2.6 Co-production of fresh water

Methane hydrates are composed primarily of water and methane.[67] While the primary focus in methane production is the reduction of

63. *See id.*

64. *See* Zhang *et al.*, *supra* note 14, 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.

65. 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 pounds of lead annually. *See Environmental Impacts of Coal Power: Air Pollution*, UNION OF CONCERNED SCIENTISTS, http://www.ucsusa.org/clean_energy/coalvswind/c02c.html.

66. 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 1012 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* Alex Gabbard, *Coal Combustion, Nuclear Resource or Danger?*, 26 ORNL REV. 18 (1993), *available at* http://web.ornl.gov/info/ornlreview/rev26-34/text/colmain.html.

67. *E.g.*, type sI methane hydrates are composed of 48 water molecules to 8 gas molecules.

methane from the methane hydrates, there is a tremendous volume of water involved that can be captured as a by-product.

Table 2: Comparison of Produced Water Volumes

Type of Well	Bbls per Million scf
Conventional gas well[68]	10
Coal Bed Methane[69]	100
Methane Hydrates[70]	1,000

The contrast between traditional gas wells, coal bed methane wells, and methane hydrate production is essentially a sequence of magnitudal differences.[71]

2.3 On the hazards and risks 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 a Japanese environmental impact assessment,[72] the commercial development of methane hydrates contains a mixture of risks, including risks common to all offshore mining and risks unique to methane hydrates.[73]

What is most unique to methane hydrates is its hydrate structure. The greatest unique environmental problem is the uncontrolled release of methane hydrates from a collapse of the hydrate structures.

Methane is a known greenhouse gas.[74] 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.[75] Thus, emissions of methane are generally seen as

68. *See* Walsh et al., *supra* note 31.

69. CYNTHIA A. RICE & VITO NUCCIO, USGS, WATER PRODUCED WITH COAL-BED METHANE (2000), *available at* http://pubs.usgs.gov/fs/fs-0156-00/fs-0156-00.pdf.

70. *See* Walsh et al., *supra* note 31.

71. *See supra* Table 2.

72. *See infra* Table 3.

73. *See infra* discussion within Section 3.

74. *See* Zhang *et al.*, *supra* note 14, at 935.

75. *See id.*

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.

There are many activities that could lead to the onset of disassociation of methane from the hydrates and that disassociation process could occur in a variety of manners. That release of methane could be slow and over long periods of time or sudden and cataclysmic. Fast or slow, the uncontrolled release of methane is the primary risk to the environment from developing methane hydrates.[76]

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, and human activity adds onto that baseline.[77]

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.[78] Yabe's chart provides sixteen basic events that could give rise to environmental hazards, but only six basic hazards.[79] 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[80] and anthropogenic climate change. The following few items

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

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

78. ITSUKA YABE ET AL., *Environmental Risk Analysis of Methane Hydrate Development*, *in* 7TH INTERNATIONAL CONFERENCE ON GAS HYDRATES 4 (2011).

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

80. The chart provided by also listed the impact upon telecommunication cables and production pipelines at the bottom of the sea bed. In short, subsidence could

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.

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.[81] Surface ships will have a variety of emissions and discharges. Mooring lines will need to be installed. The seabeds are disrupting with submersible drilling equipment. Noise and vibration will be frequent and pervasive. Drilling mud and cementing may reach the environment. Gathering lines and their connecting manifolds need to 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 resuspension of sediments, and create a variety of seabed disturbances. Depending on the depth of the seabed, a variety of eco-systems can be disrupted.

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 sea bed gathering systems, but the landslide would obliterate them. Yabe et al., *supra* note 78.

81. *Id.* at 4.

Table 3: Chart of Risk Factors and Impacts for Offshore Methane Hydrate Development.[82]

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

2.3.1 Non-cataclysmic risks and hazards of offshore methane hydrates

2.3.1.1 Mechanics of methane venting and seeping

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.[83] Observation of the plumes reveal that the methane transports from 200m to 400m below the sea surface to approximately 50m below the

82. ITSUKA YABE ET AL., *supra* note 78, *en passim*. *See* Figure 3.

83. Magdalena A. K. Muir, Challenges and Opportunities for Marine Deposits of Methane Hydrate in the Circumpolar Arctic Polar Region, 32 RETFAERD AERGANG 61, 63 (2009).

surface, by which point the plumes are fully absorbed in the water and no longer trackable.[84]

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.[85] Given that long duration of transit and of the ocean's oxidation of the methane while in transit, it is forecast that most methane is converted to carbon dioxide before venting out of the ocean.[86]

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.[87] Ebullition can, and does, transport methane from seabeds 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 seabed seepage is dependent upon three factors:[88]

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.

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.[89] After the erup-

84. *See id.* at 63.
85. *See* Krey et al., *supra* note 6, at 4.
86. *See id.*
87. N. Shakhova & I. Semiletov, Methane Release and Coastal Environment in the East Siberian Arctic Shelf, 66 J. MARINE SYSTEMS 227, 236 (2007).
88. *See* Marcelle-De Silva & Dawe, *supra* note 2, at 230.
89. Martin Hovland, *Gas Hydrates*, in ENCYCLOPEDIA OF GEOLOGY 261, 266 (Elsevier, Oxford, 2005).

tions are completed, there are permanent structures left within the hydrate deposit.[90]

Similarly, mud volcanoes are often formed with gas hydrates as the methane source.[91] 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.[92] While it remains unclear whether or not the methane erupted from methane hydrates or other sources, it is clear that high speed methane can and does vent to the atmosphere; sometimes dramatically so.

2.3.1.2 Harms and hazards of vented and seeped methane

In the minimal case, the disruption of otherwise intact methane hydrates reserves could cause similar effects seen elsewhere in the world today. But non-cataclysmic venting and seeping of methane from disturbed methane hydrate beds could cause long-term risks and harms.

Methane can be biogenically created by the anaerobic decay of organic materials underwater.[93] Bubbling and burping up in swamps, it is considered a nuisance due to its distasteful aroma and potential for nuisance flames.

Ambient methane is not toxic *per se*, but it is a simple asphyxiant.[94] Methane has no noticeable smell to humans; the smell associated with natural gas in home cooking fuel has a second chemical added, mercaptan,[95] that provide that off-smelling stink to alert home owners to gas leaks. In an industrial accident of unmodified methane, as might erupt from a seabed, the workers would be challenged to evade an airborne poison that they cannot detect.

In the African nations of the Democratic Republic of Congo and Rwanda, there are lakes that emit noxious but odourless volumes of

---

90. *See id.* at 266.

91. *See id.* at 267.

92. *See id.*

93. Ashna A. Raghoebarsing et al., Methanotrophic Symbionts Provide Carbon for Photosynthesis in Peat Bogs, 436 NATURE 1153, 1155 (2005).

94. *Methane*, WISCONSIN DEP'T. OF HEALTH SERVICES (Dec. 2010), http://www.dhs.wisconsin.gov/eh/chemfs/fs/Methane.htm

95. *Methyl Mercaptan*, CDC.GOV, http://www.atsdr.cdc.gov/mhmi/mmg139.pdf.

methane and carbon dioxide.[96] This type of emission is called *mazuku*; etymologically *mazuku* means "evil winds that travel and kill in the night," in Kiswahili.[97] The emissions come from dissolved gases within the lakes; the deep lakes stratify into three or more levels.[98] The ambient methane levels have been detected within the necessary concentrations to enable air-borne combustion.[99] These *mazuku* emissions have been known to kill both livestock and humans.[100] 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.[101] Observational histories detail that the lakes emit these gases with little warning and the *mazuku* fills the valleys that the lakes are situated within.[102] There is essentially no escape for all respirant life forms close to the lakes.[103]

---

96. D. Tedesco et al., January 2002 Volcano-Tectonic Eruption of Nyiragongo Volcano, Democratic Republic of Congo, 112 J. GEOPHYSICAL RESEARCH B09202 5 (2007). *See also* Benoît 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).

97. *See* Smets et al., *supra* note 96, at 788.

98. 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). D. M. WAFULA ET AL., *Natural Disasters and Hazards in the Lake Kivu Basin, Western Rift Valley of Africa*, *in* REPORT ON THE INTERNATIONAL WORKSHOP ON NATURAL AND HUMAN INDUCED HAZARDS AND DISASTERS IN AFRICA 1 (2007). 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. *See id.* at 25. 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. *See* Tedesco et al., *supra* note 96, *en passim*. *See also* Wafula et al., *supra* note 98, at 26.

99. *See* Tedesco et al., *supra* note 96, at 5.

100. *See* Smets et al., *supra* note 96, at 787.

101. *See* Tedesco et al., *supra* note 96, at 6.

102. *See* Smets et al., *supra* note 96, at 789.

103. *See id.* at 794. 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. For the Environmental and Social Impact Assessment summary generated by the African Development Bank for the KivuWatt project. *See* SINCLAIR KNIGHT MERZ LTD., ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT (ESIA) SUMMARY: KIVUWATT POWER PROJECT (2009), *available at* http://www.afdb.org/fileadmin/uploads/afdb/Documents/Environment

Additionally, there are concerns that a field of leaking methane could cause buoyancy problems for waterborne craft.[104] Indeed, it has been modeled 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.[105] Non-buoyancy examples also exist. Offshore oilrigs and boats have been lost when methane suddenly erupted from below, and the boats became upended by the displaced water pushed by the emerging methane.[106]

Large amounts of methane could become dissolved into the benthic waters and substantially impact sea life.[107] While the resource assets at that depth are well studied, the ecologies of those depths are not.[108] 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."[109] Additionally, the energy levels of the benthic oceans are generally much lower than upper levels of the ocean, preventing effective removal of polluting debris.[110]

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.[111] Glasby provides a broad review of the recent litera-

---

alandSocialAssessments/EX%20summary%20ESIA%20KIVUWATT%20may%2026th%202010%20English.pdf.

104. Ira S. Leifer et al., *Engineered and Natural Marine Seep, Bubble-Driven Buoyancy Flows*, 39 J. PHYSICAL OCEANOGRAPHY 3071 (2009). *See also* Edward A. Keller et al., Tectonic Geomorphology and Hydrocarbon Induced Topography of the Mid-Channel Anticline, Santa Barbara Basin, California, 89 GEOMORPHOLOGY 274 (2007).

105. D. Adam, *Methane Hydrates: Fire From Ice*, 418 NATURE 913, 914 (2002).

106. *See id.* at 914.

107. G. P. Glasby, Potential Impact on Climate of the Exploitation Of Methane Hydrate Deposits Offshore, 20 MARINE AND PETROLEUM GEOLOGY 163, 169 (2003).

108. Adrian G. Glover & Craig R. Smith, The Deep-Sea Floor Ecosystem: Current Status And Prospects Of Anthropogenic Change By The Year 2025, 30 ENVTL. CONSERVATION 219, 220 (2003).

109. *See* Glover et al., *supra* note 108, at 232.

110. *See id.* at 220.

111. *See* Glasby, *supra* note 107; Keith A. Kvenvolden, *Potential Effects of Gas Hydrate on Human Welfare*, 96 PROCEEDINGS NAT'L ACAD. SCI. 3420 (1999).

ture and finds that both modelers 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.[112]

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.[113] 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.[114]

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.[115] Not only do micro-fauna such as zooplanktons and micronektons live near methane hydrates, but so do macro-fauna such as tubeworms and mussels.[116]

Deepwater organisms already test positive for sea-borne chemical pollutants.[117] 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.[118] 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.[119] The problems of toxicity are not limited to the micro-fauna, as the food-chain presents toxicity in birds and fish eaten by humans.[120] Those animals can carry toxicity

---

112. *See* Glasby, *supra* note 107, at 170.

113. *See* Glover et al., *supra* note 108, at 225.

114. *See id.*

115. Craig R. Smith et al., *The Near Future of Deep Seafloor Ecosystems, in* AQUATIC ECOSYSTEMS: TRENDS AND GLOBAL PROSPECTS 334, 22 (2008).

116. E. Allison & R. Boswell, Dept. Energy, Methane Hydrate, Future Energy Within Our Grasp, an Overview 9 (2007). *See also* Smith et al., *supra* note 115, at 22.

117. *See* Smith et al., *supra* note 115, at 22.

118. *See id.*

119. *See id.*

120. *See id.* at 23.

levels higher than health limits for human consumption, making them effectively poisonous to human diets.[121]

2.3.2 Cataclysmic risks and hazards of offshore methane hydrates

2.3.2.1 Mechanics of cataclysmic methane venting

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 methane continued to vent from the shaken depths.

The gas hydrate stability zones, wherein the deposits accumulate, are fragile on both pressure and temperature vectors, and "[a]ny change in temperature and pressure will cause it to decompose ...".[122] A rapid release of substantially large amounts of methane could result in short-scale climate change.[123] 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

121. *See id.*
122. *See* Zhang et al., *supra* note 14, at 935.
123. *See id.*

from methane hydrate deposits might always remain an extremely hazardous activity even if otherwise desirable.

The resulting behaviour of the high-volume 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.[124] So long as the buoyancy of the methane bubbles and the pressure from the emitted methane can be maintained, the chimney would 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 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.[125] 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 when a drilling attempt through a subsea permafrost encountered a hydrate layer.[126] 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.[127]

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, and there are subsea craters that reflect massive

---

124. *See supra* Section 3.1.

125. "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* Section 3.3.2.

126. *See* Shakhova & Semiletov, *supra* note 87, at 240.

127. *See id.*

sudden blow-outs of methane.[128] Up to 1 to 5 gigaton of carbon were released in those events, mostly in the form of methane.[129]

2.3.2.2 Harms and hazards of cataclysmic methane venting

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.[130] This is not an easy condition to induce, because the disassociation of water and methane requires an energy source.[131] The beginning of a disassociation in one location increases the pressure and thus improves the stability of hydrates near the disassociation event.[132]

It takes an unusual amount of energy or a unique displacement of the methane hydrate bed to cause landslides,[133] 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.[134]

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.[135] This is doubly so for those techniques that combine volume extraction with in-situ heating to spur disassoc-

128. *See* Krey et al., *supra* note 6, at 4.

129. *See id.*

130. 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).

131. *See id.* at 315.

132. *See id.*

133. *See id.*

134. N.L. Bangs et al., *Massive Methane Release Triggered by Seafloor Erosion Offshore Southwestern Japan*, 38 GEOLOGY 1019 (2010).

135. 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. *See* Nixon & Grozic, *supra* note 130, at 315.

iation;[136] a combination of field wide depressurization and field-wide warming.

There are certain limiting parameters for operational safety. Early modeling suggests that shallow water hydrates, in waters shallower than 300m, the hydrates will generally lack the conditions to enable a landslide result.[137] 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.[138] 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.[139]

Thus, there are envelopes of safety, albeit fuzzily described, wherein hydrates could be extracted with high certainty of triggering no landslide events. Some geological locations 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.[140] However, even the safest areas were seen as capable of landslides under sufficient conditions.[141]

The prehistoric landslide of Storegga, offshore Norway, is perhaps one of the best-known examples of a landslide believed to have been caused by a methane hydrate event. It has been measured at over 800km long.[142] 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.[143] While the evidence for events such as Storegga

136. *See* Roy A. Partain, *Avoiding Epimetheus: Planning Ahead for the Commercial Development of Offshore Methane Hydrates,* 14:2 SUSTAINABLE DEV. L. & POL'Y (forthcoming December 2014) [The section "Extracting Offshore Methane Hydrates" provides details of the extraction processes.].

137. *See* Nixon & Grozic, *supra* note 130, at 317.

138. *See id.*

139. *See id.* at 317, 319.

140. *See id.* at 321-322.

141. *See id.* at 323-324.

142. *See* Marcelle-De Silva & Dawe, *supra* note 2, at 232.

143. *See* Bangs et al., *supra* note 134, at 1021.

and Kumano are ancient by human standards, geologically they are recent events and the geophysical data suggests that similar processes can occur today.[144] 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.[145] If a field is already weakened by commercial development, an earthquake that might not have originally triggered a landslide might find the depleted field more readily susceptible to collapse.

3. RULES OF CIVIL LIABILITY TO GOVERN ACCIDENTAL HARMS

Liability rules stem from the legal traditions, first enunciated under the Roman *lex Aquilia*,[146] that tortfeasors[147] 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.[148]

---

144. *See id.*

145. *See id.* at 1022.

146. Guiseppe Dari-Mattiacci, *Economic Analysis of Law: A European Perspective, in* TORT LAW AND ECONOMICS 2 (2006).

147. A note on the vocabulary choices of this study. This study 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. 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*.

148. *See* Dari-Mattiacci, *supra* 146, at 2.

3.1 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.[149] 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.[150] 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.[151]

In the last fifty years, a new school of thought has developed on the proper role of liability rules.[152] Economists began to see liability rules as a system of incentives to prevent unwanted behaviors and outcomes.[153] 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.[154] These two ideas, although espousing different teleological ends, can be broadly compatible with each other.[155] Micro-economic analyses suggest that incentives can be created or utilized that will

---

149. *See id.* at 3; Michale G. Faure, *Environmental Liability*, *in* TORT LAW AND ECONOMICS 247, 249 (Edward Elgar, 2009).

150. *See* Dari Mattiacci, *supra* note 146, at 3; *see also* STEVEN SHAVELL, ECONOMIC ANALYSIS OF ACCIDENT LAW 263 (Harvard University Press, 1987) [hereinafter Shavell, ACCIDENT LAW].

151. *See* Faure, *supra* note 149, at 249.

152. *See id.*

153. *See id.*

154. M. G. Faure, *Liability and Compensation for Damage Resulting from CO_2 Storage Sites*, 26 (2013) (unpublished manuscript) (on file with author).

155. 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 accident victims, then the overall effectiveness to accomplish either goal could be substantially diminished. *See* Faure, *supra* note 154, at 32. *See also* Faure, *Environmental Liability*, *supra* note 149, at 249 (citing Gary T. Schwartz, *Mixed Theories of Tort Law: Affirming Both Deterrence and Corrective Justice*, 75 TEX. L. REV. 1801 (1997)).

push the actors to reach efficient levels of activity and risk; and thus minimize wasteful compensation to victims.[156]

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.[157] 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,"[158] 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.[159] Finsinger and Pauly have added that normatively, the net social welfare of any risky activity should be positive in value.[160]

The main goal of tort law is to internalize the externalities in order to enhance optimal decisions on the level of precaution.[161]

---

156. Matthieu 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).

157. 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.

158. Faure, *supra* note 154, at 27 (paraphrasing Benjamin Franklin in the February 4, 1735 issue of The Pennsylvania Gazette).

159. Hans-Bernd Schäfer & Andreas Schönenberger, *Strict Liability Versus Negligence, in* ENCYCLOPEDIA OF LAW AND ECONOMICS 598 (Edward Elgar, 2000) (citing GUIDO CALABRESI, THE COSTS OF ACCIDENTS: A LEGAL AND ECONOMIC ANALYSIS, (Yale University Press, New Haven, Conn., 1970)).

160. *See* Schäfer & Schönenberger, *supra* note 159, at 602 (citing J. Finsinger, & M. Pauly, *The Double Liability Rule*, 15 GENEVA PAPERS ON RISK INS. 159 (1990)).

161. *See* Dari-Mattiacci, *supra* note 146, at 4.

The goals of liability rules are to find efficient levels of activity and efficient levels of care or precaution for the parties involved.[162] Liability rules can be used to control the behavior of one or of both parties.[163] Liability rules can also directly impact or ignore activity levels.[164] Liability rules are generally employed where transaction costs appear to be barriers to Coasean negotiations to clarify contrasting assertions of rights.[165]

Liability rules are effective because they force actors to consider *ex post* requirements to pay damages and compensation in *ex ante* decision making.[166] Including those impacts in *ex ante* decisions processes should affect both care level and overall activity level decisions.[167] This mixed paradigm has been in place for a longtime, and as such is generally seen as uncontroversial.[168]

3.2 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.[169] 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.[170] He demonstrated

---

162. *See id.*

163. *See id.*

164. *See id.* at 4-5. *See also, en passim*, Steven Shavell, *Strict Liability Versus Negligence*, 9 J. LEGAL STUD. 1 (1980) [hereinafter Shavell, *Strict Liability*].

165. *See* Roy A. Partain, *Public and Private Regulations for the Governance of the Risks from Offshore Methane Hydrates* (on file with Rotterdam Institute of Law and Economics, *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2466079).

166. *See* Dari-Mattiacci, *supra* note 146, at 3.

167. *See id.*; Faure, *supra* note 149, at 251.

168. *See* Glachant, *supra* note 156, at 2. *See also* Guido Calabresi, *Some Thoughts on Risk Distribution and the Law of Torts*, 70 YALE L. J. 499 (1961); Richard A. Posner, *A Theory of Negligence*, 1 J. LEGAL STUD. 29 (1972); Shavell, *supra* note 164; Hans-Bend Schäfer & Frank Müller-Langer, *Strict Liability Versus Negligence*, *in* TORT LAW AND ECONOMICS (2009).

169. *See* Steven Shavell, *On Moral Hazard and Insurance*, 93 Q. J. ECON. 541 (1979) [hereinafter Shavell, *On Moral Hazard*]; Shavell, *Strict Liability, supra* note 164; *and* Shavell, ACCIDENT LAW, *supra* note 150.

170. 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

that both strict liability and negligence could, under the right circumstances, provide efficient results to optimally manage the potential harms and hazards from accidents.[171]

A standard economic model of tort law emerged several decades ago and has been considerably refined.[172] 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 application of negligence rules under certain circumstances.[173] The theoretical impacts of *ex post* avoidance strategies,[174] of risk allocation,[175] of the (a)symmetries of externalized costs and benefits[176] and of general informational shortages[177] 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?[178]

---

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." *See* Shavell, *Strict Liability, supra* note 164, at 1.

171. *See* Shavell, *Strict Liability, supra* note 164.

172. Jacob Nussim & Avraham D. Tabbach, *A Revised Model of Unilateral Accidents*, 29 INT'L REV. L. & ECON. 169, 169 (2009). *See also id.* at 169 n.2. *See also* Calabresi, *supra* note 159; Shavell, *Strict Liability, supra* note 164; Richard A. Posner & William M. Landes, *The Positive Economic Theory of Tort Law*, 15 GA. L. REV. 851 (1980); Schäfer & Schönenberger, *supra* note 159; Schäfer & Müller-Langer, *supra* note 168.

173. *See* Keith N. Hylton, *A Positive Theory of Strict Liability*, 4 REV. L. ECON. 153 (2008) (page references are to his working paper available at SSRN); Nussim & Tabbach, *supra* note 172; Tim Friehe, *Precaution v. Avoidance: A Comparison of Liability Rules,* 105 ECON. LETTERS 214 (2009).

174. *See* Friehe, *supra* note 173.

175. Martin Nell & Andreas Richter, *The Design of Liability Rules for Highly Risky Activities - Is Strict Liability Superior When Risk Allocation Matters?*, 23 INT'L REV. 31 (2003).

176. *See* Hylton, *supra* note 173.

177. *See* Nussim & Tabbach, *supra* note 172.

178. *See* Schäfer & Schönenberger, *supra* note 159, at 598.

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.

4. 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 a single actor, then strict liability has been found to be optimal over negligence.[179]

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.[180]

Third, when decentralization is a policy goal, strict liability is preferable.[181]

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.[182]

179. *See infra* discussion, at 4.1.
180. *See infra* discussion, at 4.2.
181. *See infra* discussion, at Section 4.3.

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.[183]

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. 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.[184]

4.1 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 models. Both strict liability and negligence achieve efficiency with regards to preventative measures within unilateral accident models.[185] Strict liability is superior to negligence in that strict liability efficiently ob-

182. *See infra* discussion, at Section 4.4.

183. *See infra* discussion, at Section 4.5.

184. *See infra* discussion, at Section 6.

185. While Schäfer & Müller-Langer 2009 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* note 168, at 25.

tains optimal levels of tortfeasor activity but negligence often cannot.[186]

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.[187] 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,[188] 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.[189] 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.[190] 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.[191] Strict liability enables control of activity levels and correctly sets an efficient level of activity.[192]

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.[193] 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.[194] The tortfeasor will select a higher level of activity than the welfare efficient level of activity given the due care level, because

186. *See id.*

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

188. 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.

189. *See* Shavell, *Strict Liability, supra* note 164, at 11.

190. *See id.* at 11-12. *See* Equation (2).

191. *See* Schäfer & Müller-Langer, *supra* note 168, at 25.

192. *See id.*

193. *See* Shavell, *Strict Liability, supra* note 164, at 11.

194. *See id.* at 12.

the tortfeasor does not bear the costs of injuries incurred whilst operating at due care levels.[195] 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.[196] This results in the tortfeasor engaging in an excess of activity, excessive accidents result, and negligence is seen as inefficient.[197] 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.[198]

Table 4: Shavell's 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[199]	Yes	Yes	Yes
	Yes	Yes	No
	Yes	No	No

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 personal utility, as affected by his selections of precaution and activity levels, [200] 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

195. *See id.*
196. *See id.*
197. *See id.*
198. Schäfer & Müller-Langer, *supra* note 168, at 25.
199. Entries to the right reflect three orders of knowledge. In the top row, the customer knows the risk of each seller. Middle row, the sellers' average risk. In the bottom row, there is uncertain knowledge or misperception.
200. *See* Shavell, *Strict Liability, supra* note 164, at 11.

> the negligence rule, which is superior to having no liability at all.[201]

In effect, strict liability forced the tortfeasor to internalize and adopt Kaldor-Hicks-type welfare efficiency.[202] The same scenario under negligence requires only that the tortfeasor maintain a duty of care but no additional costs from whatever accidents occur, so long as the duty was met.[203] 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.[204]

4.2 Abnormally hazardous activities

Usually the first introduction a young law student has to strict liability is in relation to 'abnormally hazardous activities;'[205] 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

201. *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* note 173, at 6. An identical result is reached for Shavell's seller-stranger scenario. *See* Shavell, *Strict Liability, supra* note 164, at 14.

202. *See id.* at 11-12. *See* Equation (2).

203. *See id.* at 11-12.

204. 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* note 173, at 23.

205. 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."

See id. at 18-19. *See* UNITED STATES RESTATEMENT (SECOND) OF TORTS §520.

activities that other actors, not conjoining or consenting to such adventurism, should not be expected to suffer for resulting harms of those dangerous activities.[206]

4.2.1 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?'[207] 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.[208]

Shavell suggested that ultra-hazardous activities have two characteristics which especially merit the application of strict liability rules.[209]

First, the activities are

(i) "uniquely identifiable" and

(ii) "impose non-negligible risks on non-participant victims which "make[s] the activity worthwhile controlling."[210]

Second, the victim's engagement with the risky activity is entirely routine in normal life, thus "activity that cannot and ought not be controlled."[211]

Shavell's definition focuses on the rights of the non-participant victims to remain undisturbed in their routine activities; this has

206. 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 via an abnormally dangerous activity. *See* "Concluding Comments #4." *See* Shavell, *Strict Liability*, *supra* note 164, at 24.

207. *See* Shavell, *Strict Liability, supra* note 165, within 'Concluding Comment #3' at 23.

208. *See* Schäfer & Müller-Langer, *supra* note 168, at 10. *See* Calabresi, *supra* note 159.

209. 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. *See* Shavell, *Strict Liability*, *supra* note 164.

210. *See* Shavell's "Concluding Comments #4." Shavell, *Strict Liability*, *supra* note 164, at 24.

211. *See id.*

ready application to industrial activities that could be characterized as ultra-hazardous but occurring near populated areas.[212]

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.[213]

> 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 without the defense and no liability are each inferior to whichever rule is better: either strict liability with the defense or the negligence rule.[214]
> PROPOSITION 6. Suppose that injurers are sellers and that victims are strangers. Then the results are as given in Propositions 4 and 5.[215]

As such, the goal becomes to efficiently incentivize the tortfeasor to control his activity level and leave the victim unaffected in his activity level;[216] this is best achieved by the rule of strict liability with defense of contributory negligence.

212. 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 his "Concluding Comments #4." *Id.*

213. 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. See "Concluding Comments #4." *See id.*

214. *See id.* 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* note 173, at 7, 10. *See also* Shavell, *Strict Liability*, *supra* note 164, *en passim*.

215. *See id.* at 20.

216. See Shavell's "Concluding Comments #4." *See id.* at 24.

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.[217] 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.[218] Further, no liability rule and strict liability without contributory negligence are rated as inferior to either of the two previous results.[219] 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.[220]

Indeed, Shavell proves that in stranger-stranger encounters, no simple liability rule can be efficient.[221] These results are identical when the seller-stranger scenario is modeled; 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.[222]

Table 5: Shavell's Bilateral Accidents - Are Liability Rules Efficient? [223]

Encounter	Strict[1]	Strict[1]	Negligence	No Liability
Stranger-Stranger	No*[1]	No***[1]	No**[1]	No***
Seller-Stranger	No*	No***	No**	No***
Seller-Customer[1]	No	No	Yes	Yes
Durable Goods	No	No	Yes	No
	No	No	No	No
Seller-Customer[1]	Yes	No	Yes	Yes
Non-Durable Goods	Yes	No	Yes	No
	Yes	No	No	No

217. *See id.* at 19. Specifically, Shavell targets the condition of $s = \bar{s} = s^*$ as the cause.

218. *See id.*

219. *See id.*

220. *See id.*

221. *See id.* at 19-20. *See* Proposition 5.

222. *See id.* at 20. *See* Proposition 6.

223. See Shavell, Strict Liability, supra note 165, at 21-21.

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.[224] But, if the least cost avoider can be identified *ex ante*,[225] 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.[226] 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.[227]

As such, strict liability tends to require net positive social welfare results whereas negligence rules tend to enable net negative social welfare results.[228] If an activity is abnormally hazardous and has the potential to expose victims to very expensive injuries, then strict lia-

224. 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* note 168, at 11.

225. 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?

226. *See id.*

227. *See* Schäfer & Schönenberger, *supra* note 159, at 606. For the case of over-engagement under a negligence rule, they cite to A. Mitchell Polinsky, *Strict Liability Versus Negligence in a Market Setting* (National Bureau of Economic Research, Inc, Working Paper No. 0420, 1980); for under-engagement under a strict liability rule, they cite to Shavell, *Strict Liability*, *supra* note 164.

228. 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. *See* Schäfer & Schönenberger, *supra* note 159, at 606.

bility 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.

4.2.2 Landes Posner strict liability conditions

Landes and Posner provided an approach was similar to Shavell's analysis of stranger-stranger bilateral accidents.[229] 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.[230]

Landes and Posner's conditions of strict liability do provide guidance as to both the character of abnormally hazardous activities.[231] 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 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.[232]

---

229. *See* Shavell, *supra* note 164, at 18

230. *See* Proposition 4, that "strict liability is superior to the negligence rule if it is sufficiently important to lower tortfeasor activity levels." *See id.* at 19.

231. *See* Faure, *supra* note 154, at 37 (citing Landes & Posner, *supra* note 172).

232. *Id.* 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.

4.2.3 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.[233] 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.[234] 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.[235]

Under strict liability, the more externalized risk there is, the more damages will be assigned to the actor based upon his own activity level.[236] But under negligence, the actor will have an incentive to reduce his activity in response to the risks externalized by other actors.[237]

This led Hylton to propose the following two propositions: [238]

> 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

233. 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* note 173, at 18-20.

234. *See* footnote 68, *supra* Section 4.2.1 (discussing Shavell's fourth proposition).

235. *See* Hylton, *supra* note 173, at 10.

236. *See id.*

237. *See id.*

238. Hylton did not thusly label the propositions, so this labeling follows the sequence in which they were presented in the article.

> 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.[239] (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.[240]

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.[241] 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.[242]

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.

4.3 Strict liability enables decentralization

Decentralization occurs when each tortfeasor can determine his level of preventative activities based on his unique costs; tortfeasors

---

239. *See id.* at 11.

240. *See id.*

241. 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* note 175, at 35.

242. *See* Hylton, *supra* note 173, at 12.

are not identical in that they might face different technology and cost choices.[243] 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.[244]

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 level of care.[245] Variations to the standard negligence rule can provide for decentralization.[246] The application of both partial liability and a "highest degree of care" standard can effectively provide full self-selection of tortfeasors to enable decentralization.[247] 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.[248] In response to Kahan, Miceli proposed to establish due care levels at the efficient due care level of the least cost of care tortfea-

243. 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.

244. *See* Schäfer & Müller-Langer, *supra* note 168, at 18.

245. 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.

246. *See* Daniel L. Rubinfeld, *The Efficiency of Comparative Negligence*, 16 J. LEGAL STUD. 375 (1987); Omri Bar-Gill & Oren Ben-Shahar, *The Uneasy Case for Comparative Negligence*, 5 AM. L & ECON. REV. 433 (2005); Thomas J. Miceli, *On Negligence Rules and Self-Selection*, 2 REV. L. & ECON. 349 (2006).

247. *See* Schäfer & Müller-Langer, *supra* note 168, at 17-18; ROBERT COOTER & THOMAS ULEN, LAW AND ECONOMICS 388 (Pearson Addison Wesley, 2004).

248. *See id.* at 17.

sor, holding each tortfeasor to the "highest degree of vigilance, care and precaution."[249]

4.4 In the face of uncertainties

4.4.1 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, Shäfer, 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.[250]

Shäfer, 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.[251]

4.4.2 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 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.[252]

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. Negligence provides a safety net for the tortfeasor, in that as long as certain estab-

---

249. *See id.* at 18 (citing to Miceli, *supra* note 253, who in turn was citing to Marcel Kahan, *Causation and Incentives to Take Care Under the Negligence Rule*, J. LEGAL STUD. 427 (1989)).

250. *See* Schäfer & Müller-Langer, *supra* note 168, at 26.

251. That said, Schäfer, et al., did caveat that efficiency might be obtained under a negligence rule, just unreliably so. *See id.*

252. *See* Schäfer & Schönenberger, *supra* note 159, 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.

lished historical norms are met, then no additional damages from harms can be assessed against the tortfeasor.

4.4.3 Complex interactions of precaution and activity levels

Nussim and Tabbach noted that 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.[253] 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.[254]

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.[255] 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.[256] When the fatigue effect is strong, then precaution and activity levels become substitutes.[257]

Nussim and Tabbach found that for the negligence rule, this complexity provides an unexpected result; when faced with high costs of

253. *See* Nussim & Tabbach, *supra* note 172, at 170.

254. 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 id.* at 171.

255. As formulated: $c_{xz}(x, z) < 0$. *See id.*

256. As formulated: $c_{xz}(x, z) > 0$. *See id.*

257. The input of either reduces the other, ceteris paribus: $\frac{\delta^2 J(x,z)}{\delta x \delta z} < 0$.

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.[258] 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.[259]

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.

4.5 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

258. At some $x > x^*$. *See id.*

259. *See 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.

litigation was higher than the costs of filing.[260] Additionally, strict liability requires less information to be 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.[261]

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.[262] 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.[263]

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.[264] 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.[265] Third, this foreseeability will lead to more pre-trial settlements, enabling lost cost transference of wealth from tortfeasor to victim.[266]

---

260. S. Shavell, *Liability for Harm Versus Regulation of Safety*, 13 J. LEGAL STUD. 357 (1984). *See* Schäfer & Schönenberger, *supra* note 159, at 604 (citing Shavell, ACCIDENT LAW, *supra* note 150, at 264).

261. Michael G. Faure, *Regulatory Strategies in Environmental Liability*, *in* THE REGULATORY FUNCTION OF EUROPEAN PRIVATE LAW, 129, 137 (Fabrizio Cafaggi, Horatia Muir Watt, eds., Cheltenham, Edward Elgar, 2011). *See also* Michael G. Faure, *Designing Incentives Regulation for the Environment*, (Maastricht Faculty of Law, Working Paper No. 2008-7, 2008), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1290523.

262. *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 have divergent views as to the extent or scale of the harms received by the victim. *See* Schäfer & Schönenberger, *supra* note 159, at 604.

263. *See* Schäfer & Müller-Langer, *supra* note 168, at 16.

264. *See id.*

265. *See id.*

266. *See id.*

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.[267] 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.[268] Thus, the overall costs of resolving conflicts under a negligence rule would be expected to run higher than under a strict liability system.[269]

4.6 Arguments for applying strict liability to offshore methane hydrates

Given the scenarios wherein strict liability would be expected to be more efficient or robust than negligence, as discussed *supra*, an analysis can be undertaken to evaluate the unique facts and circumstances of offshore methane hydrates under those scenarios. That analysis will reveal that a rule of strict liability well matches the circumstances of offshore methane hydrates.

4.6.1 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

---

267. 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.

268. *See* Schäfer & Schönenberger, *supra* note 159, at 604.

269. *See id.*

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.[270]

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.[271] 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.

4.6.2 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. First, a review of Shavell's Ultra-Hazardous Strict Liability Rule is developed,[272] followed by a review of the Landes-Posner conditions for strict liability.

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."[273]

---

270. 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.

271. 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.

272. *See* discussion on point, *supra* Section 4.2.

273. *See supra* Section 4.2.

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.[274] 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.[275]

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, fauna, and flora. The first aspect of the Landes-Posner conditions would likely be met in offshore methane hydrate accidents.

274. 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.

275. *See supra* discussion, at Section 4.2.1.

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, 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.

4.6.3 Achieving decentralization

The ability to achieve decentralization is a key concern; as discussed, *supra*,[276] 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.[277]

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,[278] 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.[279] 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

---

276. *See supra* discussion, at Section 4.3.

277. *See supra* discussion, at Section 4.3.

278. 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. *See* Miceli, *supra* note 253, *en passim*.

279. *See supra* discussion, at Section 4.4.2. *See also* Schäfer & Schönenberger, *supra* note 159, at 605.

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 attained under strict liability, variants of negligence should not be preferred to it without additional reasons to avoid strict liability being noted.

4.6.4 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;[280] 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*.[281] 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 ex-

280. *See supra* discussion, at Section 4.4.1.

281. 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.

pected 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,[282] 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.

4.6.5 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.[283]

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 ad-

---

282. For a more complete discussion, *see* Roy A. Partain, *A Comparative Legal Approach for the Risks of Offshore Methane Hydrates: Existing Laws and Conventions,* 32 Pace Envtl. L. Rev. (forthcoming January 2015).

283. *See supra* discussion, at Section 4.1.

vance 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.

4.6.6 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.[284]

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.[285] However, as will be argued *infra*,[286] the preferred solution would be a combination of a rule of strict liability alongside public regulations.

4.6.7 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 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.

---

284. *See supra* discussion, at Section 4.4.
285. *See infra* discussion, at Section 6.3.
286. *See infra* discussion, at Section 6.3.

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.[287]

5. WHEN NEGLIGENCE IS PREFERABLE

As noted in the first section of this study, 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."[288]

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.[289] 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.[290] Civil law nations provide specific enactments for when strict liability is to be applied and common law countries

287. *See supra* discussion, at Section 4.5.
288. *See* Schäfer & Müller-Langer, *supra* note 168, at 18.
289. *See id.*
290. *See id.*

generally reserve strict liability for abnormally dangerous activities.[291]

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.[292]

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.[293]

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.[294]

Fourth, even though an activity might display high risks and costly externalized hazards, if those risks and hazards are symmetrical to their 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

291. *See id. See also* the United States Restatement (2nd) on Torts for a demonstration of the limited historical application of strict liability. The Restatement is currently in process to the 3rd edition.

292. *See* discussion, *infra* Section 5.1.

293. *See* discussion, *infra* Section 5.2.

294. *See* discussion, *infra* Section 5.3.

of activity at a due level of care than a rule of strict liability would enable.[295]

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.

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.[296] 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 that 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.[297]

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

---

295. *See* discussion, *infra* Section 5.4.

296. 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.

297. This avenue of accident governance is directly addressed in Section 6.3.

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 Section 2, 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 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.[298] 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.

5.1 Imperfect tortfeasors

5.1.1 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 liabili-

298. Israel Gilead, *Tort Law and Internalization: The Gap Between Private Loss and Social Cost*, 17 INT'L REV. L. & ECON. 589 (1997).

ty within the standard models.[299] Risk aversion was not generally included in earlier accident models, such as in Shavell's unilateral and bilateral models.[300]

Nell and Richter suggested that risk aversion could be added to the standard models.[301] They provided a demonstration that the application of risk aversion to unilateral accident models would break the standard symmetry of both strict liability rules and negligence rules to efficiently set precaution levels.[302] They provided two levels of analysis: the first focused immediately on the risk adverse parties and second on the insurance might play in such settings.

Nell and Richter found that for risk adverse actors, negligence was more robust than strict liability.[303] 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.[304] When the ideal terms for strict liability are not present, then strict liability

---

299. For a discussion on the connection between risk neutrality and the standard models, *see* Michael G. Faure & Roger Van den Bergh, *Competition on the European Market for Liability Insurance and Efficient Accident Law*, 9 MAASTRICHT J. EUR. & COMP. L. 279 (2002). *See also* A. Endres, & R. Schwarze, *Allokationswirkungen einer Umwelthaftpflicht-versicherung*, in HAFTUNG UND VERSICHERUNG FÜR UMWELTSCHÄDEN AUS ÖKONOMISCHER UND JURISTISCHER SICHT 58 (Springer Berlin Heidelberg, 1992).

300. *See* Nell & Richter, *supra* note 175, at 33.

301. 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. *See id.*

302. *See id.* at 33.

303. *See id.* at 31.

304. *See id.* at 42.

leads to insufficient activity levels.[305] 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.[306]

They then modeled 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.[307] 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.[308] 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.[309]

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.[310] *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, neither strict liability nor negligence approximate

305. *See id.*

306. *See id.* at 43.

307. *See id.* at 40.

308. *See id.* at 41.

309. In the modeling 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.

310. In the modeling 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. *See* Nell & Richter, *supra* note 175, at 42.

the optimal solution.[311] However, there is simply no convergence to the negligence rule as was seen above.[312] Yet, at sufficiently high levels of victims, the maximum level of care becomes optimal.[313] Thus, negligence was found to be more robust than strict liability for risk adverse tortfeasors with incomplete insurance options when the number of victims is large or when the insurers themselves are risk averse.[314]

Nell and Richter found that when insurance is imperfectly provided then negligence is a superior rule.[315] 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.[316]

Friehe found a similar result when the number of potential victims is large and insurance is provided.[317]

5.1.2 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.[318]

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.[319] However, if the margin-

---

311. *See id.*
312. *See id.* at 41.
313. *See id.* at 42.
314. *See id.*
315. *See id.*
316. *See id.*
317. *See id.*
318. *See* Nussim & Tabbach, *supra* note 172, at 175 (citing to Steven Shavell, *The Judgment Proof Problem*, 6 INT'L REV. L. & ECON. 43 (1986)).
319. "Assets exceed the expected costs of damages" as formulated: $> z^*h$. *See* Nussim & Tabbach, *supra* note 172, at 176.

al utility to the tortfeasor of additional activity does not decline, as in diminishing returns, then the tortfeasor is likely to pursue maximum activity levels.[320]

When the assets are less than or equal to the expected costs of damages,[321] then the tortfeasor would face declining marginal costs of damages as the activity level increase; those costs are said to "plummet to zero."[322] This drop in costs encourages the tortfeasor to engage in the maximum level of activity. This has a secondary effect on the precautionary level, which drops below the prescriptive level of care, $\tilde{x} \leq x^*$.[323]

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.

5.1.3 Strategic avoidance plus precaution

When tortfeasors can invest in both precaution and avoidance, negligence will outperform strict liability in unilateral accidents.[324] 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 that both rules produce precaution levels less than the socially optimal level.[325] Negligence achieves first-best performance in all ranges of the avoidance parameters, but strict liability can only do so in limited settings.[326] As negligence is

---

320. *See id.*

321. "Assets are less than or equal to the expected costs of damages," as formulated: $A \leq z^*h$." *See id.* at 175.

322. *See id.*

323. *See id.*

324. *See* Friehe, *supra* note 173, at 216. Avoidance is defined as the efforts made to reduce the likelihood of 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. *Id.*

325. *See id.* at 215, at Lemmas 1 and 2.

326. *See id.*

socially less costly than strict liability, it is preferable when avoidance is exercised.[327]

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[328] notion of optimal due care.[329] This is 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.

5.1.4 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.[330] Negligence appears to be preferable primarily because it separates the decision processes of the tortfeasor from the determination of the appropriate level of precaution whereas strict liability would leave that determination with the tortfeasor who would be suffering from certain cognitive biases.

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.[331] Humans tend to be overly optimistic about avoiding accidents or about environmental risks.[332]

---

327. *See id* at Proposition 1.

328. Here naive refers to the model's level of due care as if no avoidance were undertaken by the tortfeasors.

329. *See* Friehe, *supra* note 173, at 215, Proposition 2.

330. *See* Schäfer & Müller-Langer, *supra* note 168 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.

331. *See id.* at 25 (citing to Joshua C. Teitelbaum, *A Unilateral Accident Model Under Ambiguity*, 36 J. LEGAL STUD. 431 (2007), with special reference for pessimism models).

332. *See* Schäfer & Müller-Langer, *supra* note 168 at 24 (citing to Andy Guppy, *Subjective Probability of Accident and Apprehension in Relation to Self-Other Bias, Age, and Reported Behaviour*, 25 ACCIDENT ANALYSIS PREVENTION 375 (1993), Cass R. Sunstein, *Behavioral Analysis of Law*, 64 U. CHI. L. REV. 1175,

In such optimism, the tortfeasor underestimates their expected harms to victims and thus enact a lower level of precaution.[333] 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.[334]

Humans tend to be excessively pessimistic about catastrophic accidents such as earthquakes;[335] excessive care will result. Excessive care will result in certain inefficiency under strict liability,[336] whereas negligence might be efficient in this setting.[337] Again, the negligence rule might be preferable because the determination of precaution is set exogenous to the tortfeasor by the prescribed duty of care.

5.2 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,[338] but strict liability will need the sanctions to equal the harms imposed in order to yield an optimal re-

---

(1998); and Neil D. Weinstein, *Optimistic Biases About Personal Risks*, 246 SCIENCE 1232 (1989)).

333. *See* Schäfer & Müller-Langer, *supra* note 168, at 24.

334. *See id.*

335. *See id.* (citing to Gerd Gigerenzer, *The Law and Economics of Irrational Behavior, in* IS THE MIND IRRATIONAL OR ECOLOGICALLY RATIONAL? 37 (Stanford, Stanford University Press, 2005); and to Christine Jolls, Cass Sunstein & R. Thaler, *A Behavioral Approach to Law and Economics*, 50 STAN. L. REV. 1471 (1998)).

336. *See* Schäfer & Müller-Langer, *supra* note 168, at 24.

337. 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.

338. *See* Schäfer & Schönenberger, *supra* note 159, at 605.

sult.[339] Strict liability loses its efficiency in the face of inaccurate damages.[340]

Court errors are likely to frustrate efficient governance of accident risks.[341] 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.[342] There are a variety of transaction costs problems that frustrate correct damage setting.[343] Punitive damages attempt to correct for some of those issues, but they are likewise frustrated by transaction costs problems.[344]

E.g., in the case of a tortfeasor choosing to increase their care level and to thus over-comply,[345] 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.[346] Given this mix of directions in costs changes, it is difficult to forecast what the tortfeasor would choose to do without the specific costs be-

---

339. *See id.*

340. Robert Cooter, *Prices and Sanctions*, 84 COLUM. L. REV. 1523 (1984). *See also* L. T. Visscher, *Tort Damages, in* 1 TORT LAW AND ECONOMICS, ENCYCLOPEDIA OF LAW AND ECONOMICS 153, *en passim* (2d Ed., Michael G. Faure ed., Cheltenham, UK: Edward Elgar, 2009),

341. 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. *See* Schäfer & Müller-Langer, *supra* note 168, at 8.

342. *See* Nussim & Tabbach, *supra* note 172, at 173.

343. *See id.*

344. *See id.* at 174.

345. 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. *See* Schäfer & Müller-Langer, *supra* note 168, at 8.

346. 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. *See* Schäfer & Müller-Langer, *supra* note 168, at 9.

ing detailed; but it is most likely that either way the tortfeasor is not likely to land on an efficient result.[347]

5.2.1 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 rule provide any certainty as to effect and under no certain case was efficiency found by Nussim and Tabbach.[348]

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.[349]

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.[350] 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.

There is no efficient outcome under a strict liability rule, only inefficient over or under compliance.[351] This is a rational, albeit inefficient, result of responding to errant court judgments.

347. *See id.*

348. Nussim & Tabbach at 174-175.

349. *See* Schäfer & Müller-Langer, *supra* note 168, at 26.

350. 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. *See* Nussim & Tabbach, *supra* note 172, at 174.

351. $m > 1$ always leads to over-deterrence and $m < 1$ always leads to under-deterrence. *See* Schäfer & Müller-Langer, *supra* note 168, at 9.

5.2.2 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.[352]

Multiple studies found that for a tortfeasor under a negligence rule, there are several foreseeable results.[353] Under systematic overestimation of damages, the tortfeasors would operate at the prescribed duty of care level and at maximum levels of activity.[354] Under systematic underestimation of damages, the tortfeasors would face strategic choices.[355] If the estimate error is small, then the tortfeasor will exercise due care, x*, and operate at maximum levels of activity.[356] The major exception to that finding was when extreme underestimation of damages set the 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.[357]

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.[358] 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.[359]

---

352. *See id.*

353. *See id.* at 26. *See also* Nussim & Tabbach, *supra* note 172, at 174-175.

354. *See id.*, at 174. An overestimate of damages costs reinforces the calculus to avoid damages by operating at the due care level.

355. *See id.* at 174.

356. *See id.* at 174-175.

357. *See id.*

358. The error rate is defined as $m \in \{0 < m < \omega\}$; wherein "zero error" would be $m = 1$ and ω is a very large positive real number. *See* Schäfer & Müller-Langer, *supra* note 168, at 9.

359. *See* Nussim & Tabbach, *supra* note 172, at 174-175

5.3 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 they provide information to the public to better inform them and the courts on the efficient, and hence appropriate, duty of care.[360]

Strict liability enables a tortfeasor to make a private decision with regards to precautionary efforts.[361] 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.[362] 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.[363] Furthermore, this information can be transmitted to other potential tortfeasors to both improve the cost efficiency of precautionary measures and to measure their own levels of care vis-à-vis the now-effective ex ante prescribed duty of care.[364]

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.[365] When legislators and

---

360. *See* Schäfer & Müller-Langer, *supra* note 168, at 18.

361. *See id.*

362. *See id.*

363. *See id.* 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 supra* discussion, at Section 4.5.

364. *See id.* at 19.

365. *See* Nussim & Tabbach, *supra* note 172, at 173. Similarly, if the legal institutions or if the technical complexity of the risky behavior create conditions that

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.[366]

5.4 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 case of substantially asymmetrical risk externalization not offset by counterbalancing externalized benefits.[367]

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.[368] Negligence was robust when the externalized risks and the externalized benefits were well paired.[369] 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.[370]

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;[371] (i) the ratios of externalized probabilistic risks between tortfeasor and victim(s), (q_A:q_B), and (ii) the ratios of externalized probabilistic benefits between tortfeasor and victim(s), (w_A:w_B).[372]

---

prevent clear *ex ante* determinations of judgment damages, then negligence may provide a more robust means of achieving socially efficient outcomes. *See* Schäfer & Müller-Langer, *supra* note 168, at 9.

366. *See* Nussim & Tabbach, *supra* note 172, at 173.

367. *See* Hylton, *supra* note 173, at 14.

368. *See id.* at 15. For no liability rules, Hylton supported the idea of subsidization when the net welfare results were positive. *See infra* Quadrant III in Table 6.

369. *See id*, at 15, 22.

370. *See id*, at 23.

371. In Hylton's model, there are two parties, tortfeasor A and victim(s) B.

372. *See id.* at 14.

Table 6: Liability Rule Expectations based on Externalized Benefits and Risks

External Risks		External Benefits: $w_A > w_B$	$w_A \leq w_B$
	$q_A > q_B$	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 6:

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.[373]

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.[374]

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.[375]

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.[376]

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-

373. *See id.*
374. *See id.*
375. *See id.*
376. *See id.*

externalize similar risks."[377] 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, causing inefficiently high numbers of accidents to B, who would reduce his own activity to minimize his damages.[378]

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.[379]

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,[380] the correct assignment of risk allocation should shift from the tortfeasor to the victims at large.[381] Negligence with a due care level set at the maximum level of care is the optimal rule, whereas strict liability is equally not optimal.[382]

377. *See id.* at 15. *See supra* Quadrant I and IV of Table 6. 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.

378. *See supra* Quadrant II of Table 6.

379. *See supra* Quadrant III of Table 6.

380. Maximal level of due care as x_{max}. *See* Nell & Richter, *supra* note 175, at 37.

381. The risk aversions coefficients for the tortfeasor and the victim are denoted as α and β, respectively; where $\alpha > 0$ *and* $\beta > 0$. The tortfeasor's share of liability is $q \in (0 \leq q \leq 1)$; the victim's share of risk is similarly $(1 - q)$ *See* Nell & Richter, *supra* note 175, at 37, 39. The optimal liability for the tortfeasor, meeting The optimal liability for the tortfeasor, meeting due care x_{max}, is found to be:

$$q^* = \frac{\beta}{n\alpha + \beta}$$

382. 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.

5.5 Arguments for applying negligence to offshore methane hydrates

5.5.1 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.[383] 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 away 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 management strategies. As such, there is no particularly strong reason to promote a rule of negligence merely to address risk-averse actors.

5.5.2 Insolvency of operators

The problem of potentially insolvent tortfeasors is more robustly addressed with a rule of negligence.[384] While one hopes that inves-

383. *See supra* discussion, at Section 5.1.1.
384. *See supra* discussion, at Section 5.1.2.

tors 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,[385] 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.[386] *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.[387]

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.

5.5.3 Strategic operators: avoidance and precaution

The traditional operators of offshore oil and gas installations are financially sophisticated; they routinely have very large-scale in-

---

385. 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.

386. *See* discussion, *infra* Section 6.3.

387. *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.

vestments in offshore projects in multiple jurisdictions around the globe.[388] 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.[389] Similarly, operational control might be structured in a manner that the operational joint venture sits beyond the local jurisdiction.[390] 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 op-

---

388. 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. JORGE LEIS, JOHN MCCREERY & JUAN C. GAY, BAIN & CO., NATIONAL OIL COMPANIES RESHAPE THE PLAYING FIELD 1-2 (2012), *available at* http://www.bain.com/publications/articles/national-oil-companies-reshape-the-playing-field.aspx.

389. Such planning could be required for various corporate law compliance requirements or to efficiently structure dividend and tax obligations.

390. *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.

erations, 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.

5.5.4 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 routine errors identified by behavioral economists.[391] Humans are generally observed underestimating the chances that they can avoid environmental accidents. 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.

5.5.5 Insurance markets and the operators of offshore methane hydrate projects

A rule of negligence is more robust when insurance markets are imperfect.[392] The insurance market for methane hydrate accidents

391. *See supra* discussion, at Section 5.1.4.
392. *See supra* discussion, at Section 5.1.1.

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.

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, 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 5.1.1 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.[393] 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.

5.5.6 Addressing imperfect or inaccurate sanctions against methane hydrate accidents

If the expected judgments do not match the actual harms,[394] or if there is systematic slack in the assignment of judgments,[395] negligence has been found more robust at achieving proper levels of precaution. To the extent that real world conditions following a methane

393. *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.

394. *See supra* discussion, at Section 5.2.

395. *See supra* discussion, at Section 5.2.

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 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.[396] 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.

This particular concern, of inaccurate damages and the potential to provide insufficient incentives to maintain sufficient levels of precautionary efforts, is perhaps one of the stronger arguments for the deployment of a negligence rule. However, it remains unclear, given the private incentives of the tortfeasors, that such would be necessary.

5.5.7 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.[397]

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

---

396. 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.

397. *See supra* discussion, at Section 5.3.

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.

5.5.8 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.[398] 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 stakeholder might envision lower potential benefits of additional methane exploitation.

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 development of methane hydrate projects is also potentially of substantial externalized benefits in significant excess over the externalized benefits posed by the potential victims. Thus, it is questionable that the ratios of a methane hydrate project support the application of strict liability. Hylton suggests that when the tortfeasor externalizes asymmetrical benefits and costs that a rule of negligence should probably be applied.

Such is the case herein that the externalized risks are more readily foreseeable but one could reasonably expect some divergence amongst policy makers on the balance of externalized benefits. For

398. *See* Gilead, *supra* note 305. *See also* Hylton, *supra* note 173.

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.[399] Gilead does provide insight into when strict liability might be robust than negligence in such conditions, and that is when the internalized "Gap" is small.[400] Additionally, Gilead advised that strict liability should be applied when externalized costs are high and only limited welfare benefits are generated for third parties;[401] in this he and Hylton align.

6. COMPLEXITY IN IMPLEMENTION

One of the problems of implementing rules of civil liability is simple complexity, 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 made to both the impact on selection of strict liability versus negligence and on the impact of the circumstances of offshore methane hydrate operations.

6.1 Difficulties of long-term liability issues.

From the dateline of the FID[402] for a methane hydrate project, the development period might last 5 to 10 years and the production pe-

---

399. *See* Gilead, *supra* note 302, *en passim*.

400. *See id.* at 607.

401. *See id.* at 608.

402. 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.

riod 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 study 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.[403] On the other hand, if operators suspect that additional future liabilities may be determined *ex post*, then they might actually be receiving an incentive to reduce their overall precautions;[404] 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 du-

---

403. *See* Faure, *supra* note 149, at 261.

404. *See* Faure, *supra* note 149, at 261; (citing to James Boyd & Howard Kunreuther, *Retroactive Liability or the Public Purse?*, 11 J. REG. ECON. 79 (1997)).

ty of care levels would increase over time so that they should take such foreseeable adjustments into account *ex ante*.[405]

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.[406]

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.[407] 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.[408]

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 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 economic decisions related to the project will strong-

---

405. *See* Faure, *supra* note 149, at 262 (citing Steven Shavell, *Liability and the Incentive to Obtain Information About Risk*, 21 J. LEGAL STUD. 259 (1992)).

406. *See* Faure, *supra* note 149, at 262.

407. *See id.* at 263 (citing Claus Ott & Hans-Bernd 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 Alfred Endres & Regina Bertram, *The Development of Care Technology Under Liability Law*, 26 INT'L REV. L. & ECON. 503 (2006)).

408. *See* James Boyd & Daniel E. Ingberman, *The Search for Deep Pockets: Is "Extended Liability" Expensive Liability?*, 13 J. L., ECON., & ORG. 232 (1997). *See also* Faure, *supra* note 149, at 263.

ly limit the serous and due consideration of some of the risks of the project. 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 sites 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;[409] CCS within and without methane hydrate projects should face a common regulatory structure.

6.2 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 Oil Pollution Act (OPA) provides for a rule of strict liability to be imposed on those who spill oil into a marine environment;[410] 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.[411] 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.[412] 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.[413] *E.g.*, when the courts find reasonable exchange benefits and harms, the courts will find no occurrence of nuisance.[414]

409. 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.

410. Oil Pollution Act of 1990, PL 101-380, 104 Stat 484 (codified as amended at 33 U.S.C. § 2701 *et seq.* (2012)).

411. Gregory C. Keating, *Nuisance as a Strict Liability Wrong*, 4 J. TORT L. 11 (2012).

412. Keith N. Hylton, *When Should We Prefer Tort Law to Environmental Regulation*, 41 WASHBURN L.J. 515, 531-533 (2001); *see also* Hylton, *supra* note 173, *en passim*.

413. *See* Hylton, *supra* note 419, at 9.

414. *See id.*

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.[415] 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.[416] As such, the model presented integrates nuisance alongside strict liability in alignment with his model's externalized risk versus benefit analysis.[417]

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.

6.3 Roles for public and private regulations to complement strict liability

There are many reasons to suspect that the rules of civil liabilities and systems of regulation could be used in a complementary manner.[418] Indeed, Gunningham and Sinclair have stated that "'single in-

415. In the mathematical phrasing of his model, $q_A > q_B$. *See also* Hylton, *supra* note 173, at 21-22.

416. In the mathematical phrasing of his model, $wA \leq wB$. *See id.* at 21.

417. *See* Hylton, *supra* note 173, at 15, 21-22. Hylton stated that nuisance could also be identified by the six-part test for abnormally dangerous activities from the Restatement (Second) of Torts.

418. *See* Charles D. Kolstad, Thomas S. Ulen & Gary V. Johnson, *Ex Post Liability for Harm vs. Ex Ante Safety Regulation: Substitutes or Complements?,* 80 AM. ECON. REV. 888 (1990). *See also* Susan Rose-Ackerman, *Environmental Liability Law, in* INNOVATION IN ENVIRONMENTAL POLICY, ECONOMIC AND LEGAL ASPECTS OF RECENT DEVELOPMENTS IN ENVIRONMENTAL ENFORCEMENT AND LIABILITY 223 (Thomas H. Tietenberg ed., 1992); Susan Rose-Ackerman, *Public Law Versus Private Law in Environmental Regulation: European Union Proposals in the Light of United States Experience*, 4 REV. EUR. COMMUN. & INT'L ENVTL. L. 312 (1995). *See also* Michael G. Faure & M. Ruegg, *Environmental Standard*

strument' 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"[419] 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.[420] This section provides but a brief introduction into the potential overlap of public and private regulations with rules of civil liability.[421]

Rules of strict liability provide optimally for the accident risks of unilateral accidents, certain bilateral accidents, and abnormally hazardous accidents, among others;[422] but rules of strict liability cannot efficiently provide incentives for certain circumstances; complementary regulations could assist to remedy those circumstances.[423] Thus, where strict liability might be inefficient, public or private regulations might complement it.

Even if strict liability found itself within a robust scenario, effective enforcement of any civil liability would still be predicated on three issues; [424] (i) the probability of the violation's detection, (ii)

Setting Through General Principles of Environmental Law, in ENVIRONMENTAL STANDARDS IN THE EUROPEAN UNION IN AN INTERDISCIPLINARY FRAMEWORK 39 (Michael G. Faure, John A. E. Vervaele & Albert Weale, eds., 1994). *See also* P. Burrows, *Combining Regulation and Legal Liability for the Control of External Costs*, 19(2) Int'l Rev. L. & Econ. 227 (1999); and *see* Alessandra 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* note 268, at 143; and *see* Faure, *supra* note 268, at 24.

419. Neil Gunningham & Darren Sinclair, *Regulatory Pluralism: Designing Policy Mixes for Environmental Protection*, 21 L & POL'Y 49, 50 (1999).

420. Michael G. Faure & Stefan E. Weishaar, *The Role of Environmental Taxation: Economics and the Law, in* HANDBOOK OF RESEARCH ON ENVIRONMENTAL TAXATION 399, 405-406 (Jane E. Milne & Mikael S. Andersen eds., Edward Elgar, 2012).

421. *See* Roy A. Partain, *Public and Private Regulations for the Governance of the Risks of Offshore Methane Hydrates* (working paper) (on file with Rotterdam Institute for Law & Economics (RILE)), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2466079.

422. *See supra* discussions on when strict liability is more robust than negligence.

423. *See supra* discussions on when strict liability is less robust than negligence.

424. *See* Hylton, *supra* note 419, at 12.

once detected, the probability of prosecution, and (iii) the probability of punishment once prosecuted.[425] Problems at any one of more of these stages can cause otherwise effective civil liability regimes to be frustrated; public regulations are seen as potentially able to address those problems.[426] Given the complexity of the science and engineering related to methane hydrates and the vast variety of states and legal systems that would face the development of offshore methane hydrates and their potential harms, such conditions would be neither rare nor hard to imagine.

And even if strict liability were in a robust scenario and if none of the above problems were present, Shavell found three criteria that suggested when liability rules might not be effective despite otherwise appearing to be functional.[427] The three reasons were: (i) problems of information asymmetry, (ii) risks of insolvent tortfeasors, and the (iii) effective absence of lawsuits from victims. Thus for multiple reasons, public and private regulations might become needed to gap-fill and balance the portfolio of risk governance mechanisms.

Public regulations may be expensive to operate,[428] 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.[429] Many of these flaws are inherent in the benefits of regulation; *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

---

425. *See id.* at 4.

426. *See id.*

427. *See* Shavell, *supra* note 267; *see also* Steven Shavell, *A Model of the Optimal Use of Liability and Safety Regulation*, 15 RAND J. ECON. 271 (1984); Shavell, ACCIDENT LAW, *supra* note 150.

428. 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* Roger Van den Bergh & Louis T. Visscher, *Optimal Enforcement of Safety Law, in* MITIGATING RISK IN THE CONTEXT OF SAFETY AND SECURITY. HOW RELEVANT IS A RATIONAL APPROACH? 29 (Richard V. de Mulder ed., Rotterdam: Erasmus University Rotterdam 2008).

429. *See* Faure, *supra* note 268, at 26.

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.

Private regulations are sometimes proposed as alternatives to public regulations, but increasingly in the literature private regulation is spoken of as a complement to public regulation and rules of civil liability. 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.[430] Also, where legal institutions are less likely to be able to process the technological or scientific challenges of the risky activity,[431] 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.

However, there are concerns on the capability of private regulation to provide fair and efficient regulation of risky activities:[432] (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 "condi-

---

430. Shavell addressed the theoretical origins of regulatory stickiness in a discussion on insurance contracts over long time periods. *See* Steven Shavell, *Sharing Risks of Deferred Payment*, 84 J. POL. ECON. 161 (1976). Stickiness is related to a variety of phenomena, primarily the complex interactions of various transaction costs, which 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.

431. Anthony Ogus & Emanuela Carbonara, *Self-regulation*, *in* PRODUCTION OF LEGAL RULES, 232-234 (Francesco Parisi ed., Edward Elgar Publishers Ltd., 2011). *See also* Michael G. Faure, Morag Goodwin & Franziska Weber, *Bucking the Kuznets Curve: Designing Effective Environmental Regulation in Developing Countries*, 51 VA. J. INT'L L. 95 (2010).

432. Ogus & Carbonara, *supra* note 438, at 234.

tional self-regulation." Historical experience is full of examples wherein industrial groups failed to exercise due care, or at least levels of care that would have been socially acceptable by the rest of society. Thus again, one might fin it reasonable that if private regulations were to play a significant role in addressing the risk and hazards of offshore methane hydrates, that rules of civil liability should be kept in play, and in particular, a rule of strict liability to provide economic incentives to the those private regulators to remind them that they will bear the costs of whatever damages their activities might cause.

In summary, while a rule of strict liability would appear to be the most robust rule of civil liability against the facts and circumstances of offshore methane hydrates, there will likely be events or situations that frustrate the application of that rule. As such, public and private regulation could be adopted in a complementary implementation to provide a more complete set and balanced set of incentives to the tortfeasors.

7. GOVERNING OFFSHORE METHANE HYDRATES WITH STRICT LIABILITY

This study 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; *ergo*, strict liability was found likely to be more robust than negligence in efficiently governing the risks and hazards of offshore methane hydrates.

7.1 Summary of theoretical analysis

This study 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. 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. 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, 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.[433]

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. The more likely that risk neutrality is replaced with risk aversion, the more likely negligence will be more robust. 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.

7.2 Applied Analysis to risks and hazards of offshore methane hydrates

The present study 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

433. See a similar conclusion on the potentially more robust application of strict liability to environmental pollution by Faure & Weishaar, *supra* note 427, at 403.

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 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 misestimated 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.

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 of civil liability operate in a vacuum free of regulatory framework somehow addressing safety and responsibility in one form or another. But no foundation was discovered within those concerns for switching from a recommendation for strict liability to efficiently govern the risks and hazards of offshore 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.[434]

434. See a discussion on the passage of strict liability rules within European states and the European Union in Faure, *supra* note 268, at 138.