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Organizational Design for Spill Containment in Deepwater Drilling Operations in the Gulf of Mexico

Assessment of the Marine Well Containment Company (MWCC)

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Abstract

The *Deepwater Horizon* oil spill in the Gulf of Mexico in April 2010 led to the deaths of 11 workers, a six-month moratorium on deepwater drilling in the Gulf, and nearly three months of massive engineering and logistics efforts to stop the spill. The series of failures before the well was finally capped and the spill contained revealed an inability to deal effectively with a well in deepwater and ultradeepwater. Ensuring that containment capabilities are adequate for drilling operations at these depths is therefore a salient challenge for government and industry. In this paper we assess the Marine Well Containment Company (MWCC), a consortium aimed at designing and building a system capable of containing future deepwater spills in the Gulf. We also consider alternatives for long-term readiness for deepwater spill containment. We focus on the roles of liability and regulation as determinants of readiness and the adequacy of incentives for technological innovation in oil spill containment technology to keep pace with advances in deepwater drilling capability. Liability and regulation can significantly influence the strength of these incentives. In addition, we discuss appropriate governance structure as a major determinant of the effectiveness of MWCC.

Key Words: oil spill, containment, industry R&D, liability, regulation, governance, innovation

JEL Classification Numbers: Q4, Q55, K3

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Executive Summary

In this paper we assess the Marine Well Containment Company (MWCC) and alternative options for long-term readiness for deepwater spill containment. The MWCC is an early positive indication of major firms' willingness to enhance containment capacity. We focus on the critical roles of liability and regulation as determinants of readiness. We also consider the adequacy of incentives for technological innovation in oil spill containment technology to keep pace with advances in deepwater drilling capability. Liability and regulation can significantly influence the strength of these incentives. In addition, we discuss appropriate governance structure as a major determinant of the effectiveness of MWCC.

We offer the following recommendations regarding MWCC:

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- *Provide immediate third-party expert technical review.* The technical capacity, rapidity of response, and scenarios for operation specified by MWCC merit third-party expert technical review to assess adequacy, readiness, and likelihood of success. The review should include systematic analysis of what has worked and what has failed in previous efforts to contain well blowouts.
- *Provide ongoing third-party expert technical review*. Third-party review of MWCC should be undertaken periodically and on an ongoing basis to monitor expected changes in technologies and risk.
- *Undertake quantitative, state-of-the-art risk assessment.* MWCC's adequacy and readiness to address risks needs to be evaluated using state-of-the-art techniques of the risks associated with deepwater and ultradeepwater drilling, making use of tools such as expert elicitation and Bayesian belief networks. The assessment should include consideration of adequacy in the event of multiple, simultaneous, or near-simultaneous events, particularly given the anticipated increase in deepwater and ultradeepwater drilling in the Gulf of Mexico.
- *Conduct "war game" scenarios to test the functionality of the proposed rapid response.* At present, MWCC is an engineering solution; readiness requires evidence of personnel effectiveness and management capacity for actual deployment. Scenarios with simulated deployment could include "out-of-the-box input" from specialists other than engineers.
- *Evaluate liability limits.* Though federal liability caps are not generally binding, they may limit firms' liability in specific circumstances. Low financial responsibility requirements also allow some firms to undertake risks of spill-related damages that they, unlike BP, would never be able to cover. These limitations on effective liability curb incentives to invest in containment and put additional burdens on regulators.
- *Monitor containment investments.* To the extent that the *Deepwater Horizon* spill reveals industry's underinvestment in containment, it also reveals a failure of government, investors, and industry to identify that underinvestment in time to correct it. Monitoring, whether by government or by third parties, such as independent insurance providers, is needed.
- *Balance regulation and liability.* Given the limitations of the liability system and the incentives it generates, regulation is needed to ensure that firms make adequate containment investments. A showing of containment preparedness should be an element of spill response plans prepared during permit applications, and government should

inspect and license third-party containment providers, such as MWCC. At the same time, regulators should welcome competition and innovation in containment and should write and enforce regulations in such a way that, to the greatest extent possible, neither is penalized.

- *Avoid regulation that restricts competition in containment.* If regulation makes MWCC membership required, explicitly or in practice, nonmajors are likely to be disadvantaged and may exit the drilling business in the Gulf. Although well-capitalized drilling firms may arguably be preferable, since they can cover damages from large spills, the desired level of capitalization of firms is the subject of a different debate; containment is an inappropriate and unwieldy tool for achieving such results.
- *Balance membership structure.* A voting structure that gives equal voice to each member, regardless of firm size, appears to be appropriate for membership organizations like MWCC, but the membership fees should be structured in a way that encourages participation and does not shut out small companies.
- *Assess the need for innovation in deep and ultradeepwater spill response and containment.* Given the likely continued drilling in deepwater and ultradeepwater, the government and industry should evaluate the need and appropriate directions for innovation in equipment, technology, processes, and risk assessment for spill response and containment. The evaluation should include the role, if any, of MWCC.
- *Identify possible market failure for innovation.* The low probability of a spill, liability limits on damages, and overall incentives to underinvest in new technology combine to discourage innovation. If innovation in containment fails to keep pace with innovation in drilling in deep and ultradeep water, then government and industry, including MWCC, could consider cofunding containment R&D to mitigate against underinvestment.
- *Establish a research center for innovation in spill containment and response technology*. Relying on liability and regulation to induce adequate innovation in containment is problematic: these interventions are difficult to design, government lacks perfect information, and regulation can be expensive to enforce. An independent research entity—a center of excellence—could keep pace with anticipated increases in offshore drilling and draw on expertise from around the world. The research should include not only engineering but also risk assessment and management for low-probability, high-consequence accidents. MWCC could collaborate with, cofund, and draw from this effort.

- *Recognize the limits of MWCC if it evolves as a research consortium.* If MWCC's mission and vision include R&D in containment, it can spread R&D expense and appropriate returns to innovation, thus mitigating some of the usual disincentives to invest in new technology. However, a research consortium can lead to an overall reduction in industry-wide R&D, limit the spread of innovation to nonmembers, or fail to adopt innovation developed by nonmembers.
- *Develop a mission statement.* As currently constituted, MWCC is an industry consortium whose funding and expenditure decisions are focused on members' needs. Although this is a reasonable model for most industry groups, a clear mission statement would help regulators and the public understand the value of MWCC and the need for further government involvement. For example, a mission statement that focuses on providing compliance with current and future regulations has different implications for funding and expenditure levels than a mission that focuses on ongoing risk assessment, continual improvement, and development of new containment technologies.
- *Include external expertise to provide objectivity and balance.* Consider a governance structure that permits formal or *ad hoc* representation by experts outside the membership and outside the industry; perhaps include academics, former government officials, and senior executives from firms in other industrial sectors with expertise in technical risk management and response.
- *Constitute a standing expert advisory panel.* The MWCC board of directors should consider setting up a standing external advisory panel of scientists and other experts who can meet regularly to assess technological developments, new containment technologies, new risks, and other developments. This will assist the board in conducting due diligence to determine funding, expenditures, and investment needs.
- *Align executive compensation with the mission.* The compensation of top management of MWCC should be compensated according to their performance in fulfilling the mission. Although the performance evaluation criteria for top managers might include good fiscal management, they should also help align managers' and stakeholders' interests to ensure readiness and adequate investment in new technologies.
- *Develop a culture of reporting and transparency.* To enhance public confidence, MWCC should be transparent in its policies and operations. MWCC should regularly engage with and publicly report to its stakeholders on both financial and nonfinancial measures. A

good model for stakeholder engagement and reporting would be the internationally recognized Global Reporting Initiative.

Introduction

The *Deepwater Horizon* oil spill in the Gulf of Mexico in April 2010 was the result of a series of failures. The rig explosion and subsequent damage led to the deaths of 11 workers, a six-month moratorium on deepwater drilling in the Gulf, and nearly three months of massive engineering and logistics efforts to stop the spill. Of all the failures associated with the spill, perhaps the most glaring was BP's inability to contain the leaking well. For months, oil leaked into the Gulf despite junk shots, top kills, and other procedures. Although the initial blowout, explosion, and loss of life on the *Deepwater Horizon* rig were disastrous on their own, the oil that leaked over the months that followed caused additional huge damages, including large losses to industries and harm to marine and terrestrial ecosystems, and are estimated to be in the tens of billions of dollars.[1] In June 2010, BP agreed to place $20 billion into an escrow account to pay for damages. Containing the well quickly would obviously have prevented this damage, and it is therefore reasonable to conclude that failure to contain the spill ranks with failure to prevent it as the cause of the event.

More broadly, it is hard to escape the conclusion that drilling technology has outpaced the technology needed to contain uncontrolled wells. Over the past two decades, advances in petroleum exploration and drilling technology, combined with growing global demand for energy, have led oil suppliers to produce offshore from ever-deeper water. Global deepwater oil production has more than tripled since 2000, with about a third of all deepwater drilling operations located in the U.S. Gulf of Mexico (HIS Cambridge Energy Research Associates 2010; U.S. Department of the Interior 2009). The *Deepwater Horizon* spill occurred at a depth of about 5,000 feet—a depth at the breakpoint between "deep" and "ultradeep." The series of failures before the well was finally capped and the spill contained revealed an inability to deal with a well in water at this depth. Containment equipment had to be custom built or brought to

[1] BP has reportedly set aside $40 billion to cover anticipated cleanup and damages from the *Deepwater Horizon* spill. See "BP Returns to Profit in Third Quarter with Strong Operating Performance," BP Global/BP 2 November 2010. Web. 29 November 2010. http://www.bp.com/genericarticle.do?categoryId=2012968&contentId=7065828. This amount is likely to be an underestimate of the total damage caused by the spill, since it covers only BP's portion of the liability. See Krupnick et al. (2011) for a more detailed assessment of potential damages.

the region from distant sources, delaying effective action. When it did arrive, some of it did not work.

Ensuring that containment capabilities are adequate for deepwater and ultradeepwater operations is therefore a salient challenge for government and industry. Prior to the accident, the U.S. Department of Interior had tracked the industry's technological advances to develop exploration and drilling operations at these depths.[2] Now that the moratorium on deepwater drilling has been lifted, regulators are highly likely to scrutinize containment preparedness as well and to explicitly require greater containment investment. Whereas a large spill had been considered a very low probability event, the drilling industry now appears to be aware of the real possibility of a failed blowout preventer (BOP) at the extreme depths and high pressure of deepwater operations and the massive liability exposure that can result from inadequate containment capabilities. In July 2010, four major drilling firms responded to this concern by creating the Marine Well Containment Company (MWCC), a consortium aimed at designing and building a system capable of containing future deepwater spills in the Gulf. MWCC would use existing equipment from BP on a temporary basis; in the longer term, it would design and construct new devices and invest in improvements in containment technology.

In this paper, we address general issues related to current and future investment in containment, and the design and structure of MWCC itself. Although MWCC is an early positive indication of major firms' willingness to invest, we have several concerns regarding its structure, goals, and influence. In particular, we are concerned about its ability to sustain investments in innovation, verify the effectiveness of its technology, and provide transparent and effective governance. We also have general concerns regarding the level of incentives to invest in containment, the ability of regulators to monitor such investments, and the effect of regulation on competition in the market for containment services.

The paper begins in Section 1 by defining containment in relation to spill prevention and response. Section 2 details the current state of containment technology and the MWCC proposal; this section notes that one lesson learned from the spill is that effective containment requires not

[2] For example, Interior refers to "Challenges and Rewards" at these depths, reporting that "significant challenges exist in deep water in addition to environmental considerations. Deepwater operations are very expensive and often require significant amounts of time between initial exploration and first production. Despite these challenges, operators often reap great rewards" (U.S. Department of Interior 2009, 13). Because of the complexities of deepwater operation, Interior pointed out that lease terms vary with water depth, with longer terms for locations in deeper water (U.S. Department of Interior 2009, 23).

only adequate equipment but also appropriate systems, procedures, planning, and organization. Section 3 discusses the roles of the private sector and government in the provision of containment to meet the goal of protecting the public, and Section 4 looks at legal and regulatory incentives to invest in containment. In Section 5, we address innovation in containment for drilling in increasingly deeper water, with particular reference to the ability of MWCC to sustain investments in innovation over time. Section 6 identifies relevant industry consortia and collaborations with lessons for MWCC, and Section 7 analyzes MWCC's governance and membership structure in the context of these comparable organizations. We conclude with recommendations for the role of government in containment generally and MWCC specifically, and for MWCC itself.

1. Containment in Relation to Prevention and Response

It is important to define at the outset what we mean by spill or well containment—or, as we will refer to it throughout this paper, simply containment. Reducing the damage from hydrocarbon releases can, in principle, be done in three ways. First, some investments, such as safety procedures or BOPs, can prevent releases from occurring at all. We refer to these investments, naturally, as prevention. Second, when a release does occur, resources can be deployed to stop additional release and get a well back under control. It is these technologies, hardware, and practices that we refer to as containment. Finally, measures can be taken to deal with hydrocarbons that have escaped containment, such as booms, burning, skimming, and dispersants. These we term response. To slightly oversimplify these distinctions, prevention refers to measures taken before a spill, containment refers to measures taken to prevent more hydrocarbons from reaching the environment, and response refers to measures taken to clean up hydrocarbons that are already spilled.

These definitions are not necessarily conclusive, and certainly the meanings overlap. As we emphasize in our discussion of containment in Section 2, some technologies, practices, and investments might reasonably be classified in more than one category or defy easy categorization. Whereas the containment domes specifically created during the response to the *Deepwater Horizon* spill are useful only for containment—they do one job for a very specific set of circumstances—and have little or no value outside containment operations, other elements of the containment process are less restricted. Many resources, including underwater remotely operated vehicles (ROVs), well maintenance equipment and vessels, and oil storage tankers, can be considered dual-use technologies: they are a critical part of containment efforts but are also commercially valuable even if spills do not occur. Containment, therefore, is simply an additional use for these resources. This observation is important conceptually, since such resources should not be disregarded when considering containment issues. It is also important practically, since the ability to use resources for both day-to-day operations and for containment purposes spreads associated R&D and capital costs.

Another example of a dual-purpose technology is the BOP, which might be designed primarily as a preventive measure but also includes features that make interfacing with containment devices easier. BOPs themselves could also be considered either a preventive device or a containment device, since they come into operation after at least some well control has been lost. Although we generally consider BOPs to be preventive devices and do not discuss them in detail, some of the same incentives to innovate that we discuss in this paper will influence the extent to which BOPs are designed to interface with containment technologies.

Damage from oil spills can in principle be reduced or eliminated by investments in prevention, response, or containment. Preventing a spill in the first place, containing it if it does happen, and responding to keep spilled oil from causing damage all have the same ultimate aim. Industry, therefore, faces a choice of how to spend its resources across all three categories. In theory, additional resources should be invested until the next dollar spent on prevention, containment, or response technologies exceeds the expected social damages that will be prevented by that dollar. In practice, estimating both the absolute and the relative effectiveness of prevention, containment, or response efforts is difficult, as is estimating the investment required to achieve desired results, especially when innovation is required. Estimating the damage from spills at different phases is also difficult because relative investment between containment and response depends in large part on the damage that oil causes in the water (to ecosystems, fishing, or other uses) relative to damage that it would cause if it reached land.[3] Because of these factors, balancing investment among the three options is difficult. Nevertheless, efficiency in these investments should be the goal; doing so keeps costs down for firms and consumers and achieves the maximum level of protection for the public given limited resources.

In the wake of the *Deepwater Horizon* spill, there is a widespread perception of underinvestment in containment technology to date, either in general terms or relative to prevention and response. We discuss the basis for this concern in the next sections. Underinvestment likely stems from the fact that the risk of a catastrophic spill was assumed to be

[3] Krupnick et al. (2011) identify and discuss damages in greater detail.

so low that there was little need for additional technologies—in other words, the expected reduction in oil spill damages (or liability)[4] was less than the cost of developing and deploying containment technologies. The shortcomings in containment technology became apparent after the *Deepwater Horizon* spill, particularly with regard to the single-use, seafloor elements. Containment domes were constructed *ad hoc*, and various attempts to contain the well failed. *Ex post*, it appears that in some critical areas, effective containment technology was lacking.

Those observations do not necessarily mean that there has been relative underinvestment in containment, however. It is possible that, *ex ante*, investments in prevention (better well or BOP design or maintenance) or response (better use of dispersants, booms, and skimmers) would have been more cost-effective. It is also possible that there was underinvestment in all three areas. Making these determinations is difficult—and beyond the scope of this paper. It is important to emphasize, however, that money spent on containment is money not spent on prevention, response, or other investments that might reduce risks or increase the long-term profitability of firms in the oil production industry.

2. Containment Technology and MWCC Proposal

Operators of deepwater wells prevent leaks to or from the wellbore in their design of the wells and by cementing them. In addition, well operators use a BOP atop the main wellbore casing as the main line of defense against blowouts.[5] In shallow water there have been many well blowouts, resulting in spills and sometimes fatalities.[6] In deeper water, however, where more than 14,000 wells have been drilled, there had been only very minor spills until the *Deepwater Horizon* accident (Joep Coppes, GIRG). Accident reports suggest that although BOP failures are relatively common, particularly with natural gas wells, few of these incidents have resulted in the

[4] Whether a firm considers the full expected damages from a spill or just its own liability is discussed at length in Krupnick et al. (2011).

[5] Several mechanisms within a BOP are available to activate hydraulic rams that can close an open wellbore, seal around tubing inside the well, or shear the drill pipe. The operating crew can then increase the weight of drilling mud to bring the well under control until it is safe to open the BOP and resume drilling. Activating mechanisms include electronic controls, touch plates that can be pushed by undersea robotic vessels, and acoustic sensors. In the U.S. Gulf of Mexico acoustic sensors normally are not used; however, they are required in the deep waters off Norway and are in general use off Brazil. Acoustic sensors add to the cost of a BOP and require additional equipment on the drilling rig but do offer a means of activating the BOP if electronic contact is severed and the BOP rendered inaccessible to robotic vessels by a catastrophic failure of the rig or the riser housing the electronic cables connecting the BOP to the rig.

[6] Appendix 2 lists about 50 of the most notable during 1955 to 2010. With a few major exceptions, these blowouts were rapidly brought under control.

release of significant amounts of oil. An investigation for the Minerals Management Service looked at 83 wells drilled from 1997 to 1998 in Gulf waters deeper than 400 meters and identified 117 BOP failures (SINTEF 1999).

Many technological advances since then have brought several layers of redundancy to BOPs, to the point where a catastrophic failure was considered almost impossible. First developed by Cameron in the 1920s, BOPs had become increasingly complex, sophisticated, and reliable, when maintained properly. Currently, 10 firms supply BOPs for subsea applications. The largest market shares are held by Cameron International, Hydril (a unit of General Electric), and Shaffer (a unit of National Oilwell Varco).

If a BOP does fail to close, however, several steps can be taken to control hydrocarbon leakage[7]:

- junk shots, the injection of various material intended to slow the flow within the blowout preventer;
- top kill, the injection of heavy drilling mud into a well to neutralize the force of oil and gas coming from the well;
- injection of dispersants into or beside a damaged blowout preventer to reduce surface oil spills and shoreline damage;
- attachment of a containment dome to a damaged blowout preventer;
- connection of a containment dome to a surface vessel via a riser;
- capture of the fluids coming up from the well and sending the petroleum fraction to a tanker for transport to a refinery;
- drilling of relief wells; and
- plugging of the well.

All of those methods (described in more detail in Appendix 1) were used with varying degrees of success following the *Deepwater Horizon* accident.

[7]BP defines these steps in its containment and response report; the steps include “efforts to disperse, cap, close and ultimately stop the release of hydrocarbons at the source.” Containment thus includes actions taken to capture oil and gas leaking from the seabed in the vicinity of a well. Such leaks might be caused by a damaged well casing that allows hydrocarbons to enter rock formations or seabed sediments or by a poor cementing job.

2.1 The Marine Well Containment Company Proposal

Because so many of containment technologies failed after the *Deepwater Horizon* accident, four companies (Chevron, ConocoPhillips, ExxonMobil, and Shell) announced in July 2010 that they would form the nonprofit Marine Well Containment Company. MWCC would serve to improve capacity for well containment in the event of deepwater accidents in the Gulf. Major provisions of MWCC are listed in Box 1.

Box 1. Marine Well Containment Company (MWCC): Organization, Technical Capacity and Membership Provisions, as of November 2010

Organization

- Established as a nonprofit industry organization to improve capabilities for containing potential future underwater blowouts in the U.S. Gulf of Mexico.
- Led by ExxonMobil on behalf of ExxonMobil, Chevron, ConocoPhillips, and Shell.
- Through ExxonMobil, executed an agreement with BP for its existing containment capacity.
- Made initial commitment to invest $1 billion to fund startup costs.

Technical capacity

- Provide rapid response to fully contain oil flow in underwater blowouts under a variety of scenarios in the deepwater U.S. Gulf of Mexico.
- Use specially designed subsea and surface equipment.
- Mobilize within 24 hours and be operational within weeks.
- Operate in deepwater depths up to 10,000 feet.
- Add containment capability of 100,000 barrels per day.
- Will incur additional costs for operation, maintenance and contracts for existing equipment and vessels.
- Will conduct extensive testing and research on new containment technology.

Membership

- Open to all oil and gas operators in the U.S. Gulf of Mexico.
- Equipment and all services available to all members.
- Access to nonmembers through service contracts.

Source: http://www.marinewellcontainment.com/index.php (accessed November 13, 2010).

Organization

As of November 2010, the management structure of MWCC has not been fully developed. Thus far, it includes a lead manager from ExxonMobil to head up the effort and staff in key management positions. The company will have a nine-member board of directors comprising member representatives. Whether MWCC will have a mission statement to guide its future activities or provide opportunities for input from external experts—for example, a scientific advisory panel of outside experts—is unknown at this time.

The four partners in the effort have pledged initial contributions of $250 million each, for a total commitment of $1 billion, and assigned a total of 100 employees to the project. The partners also pledged to contribute additional funds as needed for operation and maintenance, acquisition of equipment, contracting with existing vessels, and possibly constructing additional vessel processing capacity. Once its status is formalized, MWCC will seek additional members. In September 2010, BP announced its intention to join and will fund its share in part with equipment used to respond to the *Deepwater Horizon* spill. There is considerable interest in MWCC on the part of petroleum companies worldwide; for example, Statoil, the Norwegian State Oil Company, announced in August 2010 its desire to join MWCC.

Technical Capacity

The MWCC system is intended to improve significantly on currently available well containment equipment. The company would design, construct, and maintain in readiness a rapid response system to contain and recover oil leaking from blown-out wells in waters up to 10,000 feet deep (Chevron 2010). The system would be designed to capture up to 100,000 barrels per day, an amount significantly in excess of the peak flow rate from the blown-out Macondo well. Individual components of the system include a subsea containment assembly, a system for injecting dispersants into that assembly, an accumulator unit, a manifold, and risers that connect to surface vessels that can store and offload oil. Although MWCC plans to use existing equipment from BP on a temporary basis, in the longer term, it also intends to design and construct new devices and a suite of adapters that could be used on any well in the Gulf of Mexico and to fund R&D for improved containment technology.[8] All equipment would be tested

[8]On October 8, 2010, ExxonMobil, acting on behalf of MWCC, awarded the French engineering company Technip a front-end engineering and design (FEED) contract for underwater well containment equipment (Offshore Energy Today, October 8). According to Lloyd Guillory, the executive in charge of MWCC operations, the scope of the work includes system engineering and design of specific subsea components, including the containment assembly,

and maintained in a state of readiness for mobilization within 24 hours and subsequently made operational within days or weeks, not the months required for the recent *Deepwater Horizon* spill.[9]

One element deserves special mention: surface processing and transport vessels. BP strained to find sufficient capacity to process and transport oil captured from the blowout and was forced to flare oil as well as gas until more capacity could be contracted. MWCC plans to contract in advance of need so that these vessels can be deployed more rapidly. In addition, MWCC is considering commissioning an additional vessel to augment current capacity.

Membership

Membership in MWCC would be open to all companies that operate in the U.S. Gulf. Two classes of membership are planned. Full membership would be available to any operator willing to pay a pro rata share of the initial $1 billion capitalization. That is, if 10 operators eventually decide to join, each would contribute $100 million. All members would have equal voting rights in future decisions. Nonmembers would still have access to MWCC services on a contract basis for individual projects. Pricing for these services has not been announced but will be more expensive on a per well basis than full membership for operators with several projects.

The founding companies held information sessions for interested operators in the U.S. Gulf on September 29 and October 14, 2010, and provided several briefings to other parties. An ExxonMobil representative characterized the information sessions as well received, with several operators expressing interest in MWCC membership.[10]

2.2 Other Efforts

MWCC is far from the only activity currently underway to evaluate and improve on subsea well control and containment. Several petroleum industry trade associations joined forces to develop a joint industry proposal dealing with well control and containment; however, the output is expected to be reports and recommendations, not actual containment capabilities. Helix

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manifold, control umbilicals, accumulator, dispersant injection system, risers, and flowlines. The equipment must be capable of operating in water depths of 10,000 feet and handling 100,000 barrels a day. The new system is to be flexible, adaptable, and available for mobilization within 24 hours of notification of an incident and designed for use on a range of well designs and equipment, oil and natural gas pressure and flow, and weather conditions.

[9] Briefing Materials, September 2010, Industry Initiatives to Ensure Safe, Protective Drilling Practices in the Deepwater Gulf of Mexico; and October 12, 2010, Marine Well Containment Company Update.

[10] Susan Carter, ExxonMobil, personal communication, October 28, 2010.

Energy Solutions has proposed an alternative containment option to MWCC that might appeal to independent producers in the Gulf. Finally, two additional efforts are underway overseas to investigate current industry capabilities and make recommendations for subsea well control and containment.

Joint Industry Proposal

In parallel with the four-member MWCC, the principal petroleum industry trade associations formed four joint industry task forces to address issues in well design, well control, containment, and spill response. The joint industry task force addressing subsea well control and containment will review current capabilities and design and implement a strategy to address needs in equipment, practices, procedures, and standards regarding oil spill control and containment. [11]

Helix Subsea Containment Proposal

Helix Energy Solutions played a major role in the Macondo well containment efforts. The company provided a multiservice vessel, MSV Q4000, to work above the stricken well, plus a processing vessel and other essential equipment. In addition, Helix has considerable expertise in plugging deepwater wells that have finished their productive life. With a suite of existing equipment and a few relatively minor investments in flexible high-pressure hoses and the addition of vents to a Helix-owned containment cap (costing a total of $25 million), Helix has expressed confidence that it will soon be prepared to provide containment services for at least moderate-sized blowouts. To expand capacity to 100,000 barrels a day would require an additional surface processing vessel, something that Helix has said that it cannot justify financially on its own. Helix has proposed its interim containment solution to 23 companies other than the five currently involved in MWCC. Apparently, the Helix offering would be priced below that of MWCC and could attract considerable interest among some independent operators in the Gulf. Whether the Helix proposal will be accepted by the U.S. Bureau of Ocean Energy Management, Regulation and Enforcement as an adequate containment plan, especially longer term, given the uncertainty of capacity expansion, is unknown. Further, the Helix proposal would not deal with seabed leaks, something that may also be of concern to regulators. (In its briefing materials, MWCC includes a caisson to deal with seabed leaks.) Much of the equipment that

[11] Joint Industry Subsea Well Control and Containment Task Force 2010.

MWCC proposes to use on an interim basis is also part of the Helix proposal. It is not entirely clear how both companies would have the same pieces of equipment available simultaneously.

Foreign Activities Related to Well Containment

Outside the U.S. Gulf of Mexico, oil and gas exploration and development in waters exceeding 1,000 meters deep takes place near Trinidad, in the North Sea, in the Bay of Bengal, and off eastern Canada, Angola, Nigeria, and Tanzania.

Worldwide, well control and containment options and capacities are not well known. That issue is being examined by the Global Industry Response Group (GIRG) of the International Association of Oil and Gas Producers (OGP 2010). GIRG will report on ways to contain oil in case of an incident similar to the *Deepwater Horizon* accident. Discussions with MWCC will help determine whether the technologies being developed by MWCC would be applicable in parts of the world where environmental parameters such as currents, reservoir pressures, and seabed topography may be quite different from those in the Gulf. Additionally, local legislation and regulation that may affect containment options will be considered. Ten companies committed staff to GIRG on a full-time basis for two months in fall 2010.

Another joint industry research effort is the Oil Spill Prevention and Advisory Group (OSPRAG), a unit of Oil and Gas UK. With a focus on UK North Sea activities, OSPRAG will have four subgroups (Oil and Gas UK 2010):

- technical issues, including the protection of workers;
- spill response and remediation;
- insurance requirements and indemnity provisions of law; and
- regulations and response mechanisms for the broader North Sea.

2.3 Well Control and Containment

The discussion above suggests that there is at present no “well containment” industry per se. Rather, capabilities, equipment, and knowledge are spread among dozens of firms. Coordinating efforts from many parties requires considerable time and effort; advance planning and contingent contracting would be the keys to a timely response to a future large subsea spill. Many weeks elapsed while new equipment was being fabricated to address the *Deepwater Horizon* spill. Many of the technologies for the equipment were known and based on prior experience, but the suite of tools, vessels, and other equipment was not readily available and had to be constructed under extreme time pressure.

Although MWCC is intended to address a variety of scenarios in the Gulf of Mexico, it is not designed to contain all possible catastrophic failures. For example, it would have been unable to contain the 1979 Ixtoc oil spill in the Gulf, which involved the collapse of the rig on top of the well. Nor would it protect against simultaneous well blowouts. Although the likelihood of multiple coincident events might seem remote, an earthquake or extreme weather in the Gulf region could precipitate such a disaster.[12] MWCC's planned containment capabilities do not go beyond 10,000 feet even though current drilling capacity extends beyond this depth.

A question that we address in the next sections of this report, and that has been asked often following the *Deepwater Horizon* accident, is whether the pace of technological change in well containment has kept pace with deepwater exploration and production. Most of the technologies and equipment used to contain a well blowout are the same or minor variants of technologies used to drill and complete wells. Two exceptions should be noted: containment caps and dynamically positioned surface vessels that capture and transport oil to shore. These two exceptions are the principal focus of MWCC. In addition, MWCC plans to design, develop, and test a large caisson for potential use on seabed leaks near a wellbore. Approximately 50 feet in diameter and 200 feet tall, this watertight chamber could be driven into the seabed and used to direct oil and gas flows to the surface through a riser assembly. Currently, no such device exists, so this would be an important addition to the arsenal of tools available for future spills.

Even though most technology and equipment for drilling and containment are similar, there is evidence that the full suite of actions required to contain a deepwater spill had not kept pace with advances in deepwater drilling at the time of the *Deepwater Horizon* event. In a report following the *Deepwater Horizon* spill, BP lists more than 50 discrete "innovations" that served as "lessons learned" in responding to the spill. These innovations included advances not only in equipment but also in systems, processes, procedures, and organizational schemes. Box 2 lists the suite of technical and nontechnical innovations required for the containment effort; see the appendix for more detail on selected procedures.

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[12] Spills caused by such events are especially problematic because drilling firms would likely escape any liability for resulting damages because of exceptions in federal law for spills caused by war or acts of God. See 33 U.S.C. 2703(a).

Box 2. Innovations Listed by BP as Required in Responding to the *Deepwater Horizon* Spill

Equipment

- Open and closed containment
- Subsea hydraulic distribution and tools for remotely operated vehicles
- Hydrate mitigation
- Acoustic telemetry
- Information technology
- Multipurpose vessels
- Ranging technologies
- FPSOs and riser systems
- Subsea dispersant injection
- Surveillance communications and data management

Systems, process, and procedure

- System integration tests
- Diagnostic pressure measurements
- Removal of damaged risers
- Closed-system construction
- Redundant systems
- 4D planning
- Storyboarding
- Marine SIMOPS
- Visualization tools for marine ops
- Diagnostics and measurement
- Dynamic positioning
- Containment disposition
- Relief well operations
- Kill strategy

<u>Organizational schemes</u>

- Near-source containment
- Relief wells
- Containment disposal
- SIMOPS
- Branch office organization
- Strategic planning

Source: Drawn from *BP Deepwater Horizon Containment and Response: Harnessing Capabilities and Lessons Learned*, 1 September 2010, p. 69.

Advances in equipment included open and closed containment, subsea hydraulic distribution and tools for remotely operated vehicles, and hydrate mitigation. Advances in systems, processes, and procedures included diagnostics, testing, relief well operations, kill strategy, storyboarding, and visualization. Advances in organizational schemes included branch office organization and strategic planning.

The list serves as a reminder that effective containment actions must necessarily couple technology and equipment with adequate systems, procedures, and organization. With these concerns in mind, the MWCC plan could be strengthened by several actions. For example, third-party review of the plan from experts outside the founding companies could include assessment of the technical capacity, rapidity of response, and scenarios for operation specified by MWCC. Over time, a standing external group of experts could provide ongoing review periodically to monitor expected changes in technologies and risk. Third-party review of engineering solutions is commonplace after many accidents involving large-scale infrastructure (Columbia Accident Investigation Board 2003).[13]

With respect to procedures and organization, and given that MWCC is intended to respond to a probabilistic event, the plan could be strengthened by incorporating state-of-the-art techniques (such as expert elicitation and Bayesian belief networks) to assess adequacy and risks associated with containment actions in the event of a deepwater spill. Such assessments could include consideration of adequacy in the event of multiple simultaneous or near simultaneous

[13] For example, see discussion in the report following the accident of the space shuttle *Columbia*. The Columbia Accident Investigation Board (2003) called for the establishment of an independent safety and mission assurance board for the space shuttle program.

events, particularly given the anticipated increase in deepwater drilling in the Gulf.[14] Another often-used practice to assess adequacy of preparedness for unprecedented or major disruptive events is use of scenario techniques to test the overall functionality of the proposed response in terms of processes and management.[15]

At present, the MWCC plan largely describes technology, but readiness requires evidence of the capacity and effectiveness of personnel and management during actual (or simulated) deployment. Scenarios with simulated deployment could also include out-of-the-box input from other than engineers.

3. Organizational Design

The industry efforts described above suggest that the likely model for provision of containment services will be a private market, though one governed by government regulation and perhaps dominated by a single provider (MWCC). This model is similar to that for spill response services, in which the Marine Spill Response Corporation (MSRC) and for-profit competitors operate in the shadow of regulation.[16] The MSRC model, MWCC's rapid development, and the emergence of possible competitors all suggest that this outcome is likely.

This model is not, however, the only plausible one for provision of containment services. As discussed above, containment is an investment in protecting the public (it also protects companies from business losses due to spilled hydrocarbons, but in the case of the *Deepwater Horizon* spill, these losses were small compared with third-party damages). In this sense, containment serves as a public good. It is therefore reasonable to suggest that containment services be provided by government and funded from lease or permit fees—essentially a tax on drilling. An analogy is firefighting: like well containment, firefighting is an emergency service designed to protect the public from risks of injury and damage to property. The government could similarly charge the Coast Guard or another agency with responding to uncontrolled wells. Alternatively, the government could contract out for the provision of containment services, just

[14] See Cooke et al. (2011) for discussion of the use of precursor analysis as a tool to inform the risk associated with future catastrophic spills.

[15] For example, see Bradfield et al. (2005) for an overview of the applications of scenario analyses.

[16] MSRC, an independent nonprofit corporation formed in response to the 1990 Oil Pollution Act, operates mostly in shallow water to clean up spills.

as government contracts out for the supply of other specialized products and services.[17] Contracting out would overcome the problem that government has little experience with containment technology and may not have all the equipment required.

Public provision would have advantages and disadvantages over private provision of containment services. Presumably, government would administer containment services for the public benefit alone. As a result, there would be no conflict in mission between members or customers of a private organization and the public interest—a possible conflict we describe further in our discussion of MWCC governance. And although regulatory capture would still be an issue, it would be less likely.[18] Government-run containment might also engender a greater level of public trust.

Several disadvantages could arise from government provision of containment, however. Much of the equipment needed for containment is, as discussed above, dual use. This could complicate government cost estimation in contractual procurement of containment services when containment costs are bundled into the cost of acquisition, maintenance, operation, and depreciation of dual-use equipment. It is difficult to see how government-owned equipment could be used commercially when not deployed to contain a well, significantly raising capital costs. Government also has no experience with well containment and very little relevant technical expertise, making it hard for government to provide the service itself or monitor the service provided by a contractor. Perhaps of most concern, government-run containment might create moral hazard among drilling firms, especially if they believe that they could escape liability by shifting it to the government if containment efforts failed.

For these reasons, we conclude that some private role in the provision of containment services is probably preferable.[19] The role of government remains, however, insofar as it must determine the adequacy of private efforts to provide containment. We next turn to consideration of the roles of liability and regulation in providing incentives to invest.

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17 Walls et al. (2005) survey the literature on private provision compared with government contracting for public goods and services.

18 Drilling firms might seek a lower level of government containment investment if they believed it would result in a lower tax burden.

19 This does not, however, resolve the further question of what level of competition among private containment providers is preferable. In principle, the structural options for containment services can be understood as a continuum of consolidation, with government as the sole provider on one extreme and a competitive market of private providers on the other.

4. Incentives for Readiness to Contain: The Roles of Liability and Regulation

As discussed above, containment is one option, alongside prevention and response, for reducing the expected direct business loss and third-party damage from spills.[20] But beyond business loss, why are firms interested in limiting this damage at all, regardless of the method? Public relations and negative reputational effects from spills surely play some role,[21] but the primary drivers of measures taken by firms are legal and regulatory.[22]

In this section we discuss the relationship among liability, regulation, and incentives to invest in containment beyond the current technology as described in the preceding section. We first note that the relationship is one of government and industry coproduction of the readiness to contain, insofar as liability and regulation influence firms' level of investment.

4.1 Containment as an Outcome of Private and Public Coproduction of Risk

Because of government intervention, in the forms of liability and regulation, the "riskiness" of damages from a spill is coproduced with industry.[23] By playing a pivotal role in industry oversight through liability rules and regulation, the government determines a portion of the likelihood of the damages to the public. Taken together, the actions of both government and

[20] It is possible that the details of liability rules might bias investment toward particular measures, whether they are classed as prevention, response, or containment. Liability caps for some types of damage might have this result. For example, if damages to oceanic ecosystems due to release of hydrocarbons or dispersants are subject to a federal liability cap, but onshore economic damages that are litigated under state law are not, then firms might rationally react by investing more in response technology (which prevents onshore harms) relative to containment technology (which prevents both), even if containment technology were more cost-effective considering all types of damages. Such scenarios are speculative, however, and it is probably appropriate to assume that liability rules are unlikely to bias investment, even in their currently complex form.

[21] We address this further below. The reputation effects should not be underestimated. Public distrust of nuclear power generation after the Three Mile Island accident discouraged further development of the industry in the United States.

[22] Third parties, such as insurance providers, currently play a limited role but could in principle generate incentives to invest in safety (including containment) and provide important monitoring. Discussion of the role of insurance is outside the scope of this task.

[23] Other examples include flood risk and terrorism risk. Flood risk is coproduced by individual property owners, local regulators of floodplain development and building codes, and the federal government, which offers insurance and builds some structural protection measures. Terrorism risk is influenced by government activities conditional on private entities' undertaking certain standards of security.

industry determine the level of care provided to the public (Brennan et al. 2010; Brennan and Boyd 2006).[24]

For purposes of this analysis, we assume that one lesson learned from the *Deepwater Horizon* spill is that there has been at least some relative underinvestment in containment. The central question for the analysis, therefore, is how private industry and/or government can correct this underinvestment. Because of the lack of solid data on the relative and absolute costs and benefits of prevention, containment, and response, our analysis is necessarily qualitative.

Though a full discussion of the legal framework of spill liability and regulation is beyond the scope of this paper,[25] some elements of that framework are particularly relevant to containment and are therefore worth mentioning here.

4.2 Liability and Containment

Generally, firms take measures to prevent spills, including investing in containment, because they are liable for the damages those spills cause. Law governing liability for damages resulting from oil spills is complex. Although one statute, the Oil Pollution Act of 1990 (OPA 90),[26] is dominant, other federal and state statutes play significant roles in defining the limits and types of liability. The common law of torts also governs spill liability in states with no specific statute. Generally, however, firms are liable in one form or another for most or all of the physical, economic, and natural resources damages proximately caused by spills – at least so far as legal definitions and measures of damages accurately reflect actual harms.[27]

In some cases, current spill liability law insulates firms from the full cost of spill damages. OPA 90 includes liability caps far below the damages likely to result from major spills. Although these caps, for a variety of reasons, are not generally binding on responsible parties (Richardson 2010), they can limit recovery of some types of claims, especially when state laws also include caps.

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[24] Brennan et al. (2010) formally model the choice of care by government and industry in the case of government indemnification of the nation's commercial space launch industry and the risks posed to third parties near the flight path of a rocket launch. The Federal Aviation Administration is responsible for establishing standards of care in this industry. Brennan and Boyd (2006) discuss the situation of regulatory decisionmaking in the context of justifications for compensation for regulatory takings.

[25] For a broader discussion of spill-related law and its influence on firms, see Cohen et al. 2011.

[26] 40 U.S.C. §2701 et seq.

[27] Krupnick et al. 2011.

Firms may also have insufficient resources to pay claims. Responsible parties have no incentive to take precautions to prevent spill damages beyond their ability to pay; in such a case, they would simply declare bankruptcy. This problem of judgment-proof responsible parties is probably the most significant limitation on the ability of liability to force internalization of costs and, thereby, generate incentives to avoid damages (including investing in containment; Boyd 2002)). Although financial responsibility provisions in OPA 90 mitigate this risk to some extent, these requirements are also well below expected damages from large spills. Many Gulf oil companies would have been unable to cover the damages associated with the *Deepwater Horizon* spill (Muehlenbachs et al. 2011).

To the extent that liability caps, low financial responsibility requirements, or other limitations of liability law prevent full internalization of spill-related damages, firms are likely to underinvest in containment and other means of reducing expected damages.

Does—or Can—Liability Specifically Provide Incentives for Containment?

Liability alone does not generally create incentives to invest in one method of reducing expected spill damage over another.[28] Since liability operates by forcing firms to internalize the costs of spills, firms will—in theory, at least—seek to reduce the expected damages by whatever means are most cost-effective. This is the chief advantage of liability, since decisions are made by those who generally have the best information. As technology and individual circumstances change and as new information becomes available, levels of investment in different technologies and practices related to safety can change, too.

In other words, liability does not force specific types of investment in advance, but it does create ongoing incentives to reassess and reallocate those investments. For example, BP's substantial liability for damages is a direct result of its inability to quickly contain the *Deepwater Horizon* spill. Even absent any regulatory change, BP and other firms are likely to react by increasing their investment in containment: the financial consequences for BP have undoubtedly focused minds in the industry. Liability is both the reason for this focus and the driver of changes in investments that result.

Liability rules could, in principle, be modified in such a way that investments in containment are given additional value. For example, the OPA 90 liability caps are not available

[28] There are plausible, though unlikely, scenarios in which interactions between different laws governing spill liability might create incentives to invest in some methods of reducing expected spill damages over alternatives.

if a driller commits “gross negligence.” OPA 90 could be amended to define gross negligence as including failure to have effective containment resources available, or containment availability could be made a separate requirement for access to the caps. Liability (or civil or criminal penalties) could also be increased for damages to oceanic natural resources, giving firms an additional incentive to contain spills at the wellhead.[29]

As with the regulatory mechanisms for increasing containment investment, discussed below, such measures are appropriate only if the current legal system results in underinvestment in containment. If this is the case, modifying liability rules has some advantages over regulation. As with liability generally, decisions about containment technology and effectiveness are left with firms rather than with regulators. To the extent that firms have better information than regulators do, they should make better decisions about containment technology and practices. On the other hand, a liability regime makes it difficult or impossible to know in advance what investments firms are making, and whether they are effective.[30]

Liability and Containment Contractors

Under OPA 90 and some state laws, liability is also “channeled” to specific responsible parties—in the case of offshore platforms, the holder of the lease or drilling permit is the responsible party. This channeling feature is important for containment and other safety investments because it gives responsible parties an incentive not only to invest in their safety but also to monitor the safety practices of subcontractors and other parties. Channeling reduces the complexity of spill-related litigation and protects the public from blame-shifting onto judgment-proof defendants.

This has particular relevance to containment, since it is likely that containment services will be provided by third parties (such as MWCC), not the responsible parties themselves. A driller, for example, cannot hire a subcontractor to provide containment services and then attempt to shift liability to that subcontractor if containment fails. In this scenario, the driller would remain liable even if it acted with care while the subcontractor acted negligently

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[29] It is also possible that research on ocean ecosystems could lead to a greater appreciation of such damages, exposing firms to greater liability without any change to the underlying law. If this were to occur, it would similarly shift incentives from response to containment.

[30] This problem of opacity is endemic to liability-driven systems and is discussed at greater length in Cohen et al. (2011).

(responsible parties are strictly liable for spill damages under OPA 90).[31] RPs may be able to recover from a negligent containment provider, but whether an RP can do so has no effect on its liability to third parties for spill damages; a small containment contractor, or even a large one, such as MWCC, cannot be used to evade this liability.

4.3 Regulation and Containment

Offshore drilling firms' decisions about safety measures, including containment, are driven in large part by federal regulatory requirements implemented by the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE, formerly the Minerals Management Service, or MMS). Regulatory requirements apply at two stages of offshore operations: some are predrilling requirements that govern the permit process, and others apply during ongoing exploration and production.

The following sections discuss regulation that influences firms' containment investments; for a full discussion of drilling regulation, see Scarlett et al. (2011).

Existing Regulation

MMS (now BOEMRE) regulations generally require operators of offshore facilities to "immediately control, remove, or otherwise correct any hazardous oil and gas accumulation or other health, safety, or fire hazard."[32] Within this general requirement, regulations in place before the *Deepwater* spill made some reference to containment requirements but did not explicitly require firms to have adequate containment technology and resources. Moreover, the containment requirements that did exist were, at least in the case of the Macondo well, enforced in cursory fashion, if at all.

For example, MMS regulations require that operators of offshore facilities prepare an "emergency response action plan" listing "procedures [the operator] will follow in the event of a spill or a substantial threat of a spill."[33] These response plans must be prepared before drilling begins and must be updated regularly. However, a new plan need not be prepared for every

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[31] Responsible parties can, of course, sue subcontractors and other parties under negligence or other theories of liability in what are termed *contribution* actions. If the responsible party prevails in such an action, it can recover some or all of the spill-related damages it has to pay from the third party. But contribution actions are relevant only between the responsible party and the third party; if the third party prevails (or loses but cannot pay), the responsible party remains liable. Third parties might also be liable under state law.

[32] 30 CFR 250.107(b).

[33] 30 CFR 254.23(g).

well—regional plans are considered adequate. The plan must include "methods to ensure that containment and recovery equipment as well as the response personnel are mobilized and deployed at the spill site."[34] Regulations specifically require the plan to address preparedness for a "worst-case discharge" by including the following:

> A description of the response equipment that you will use to contain and recover the discharge to the maximum extent practicable. This description must include the types, location(s) and owner, quantity, and capabilities of the equipment. You also must include the effective daily recovery capacities, where applicable. You must calculate the effective daily recovery capacities using the methods described in §254.44. For operations at a drilling or production facility, your scenario must show how you will cope with the initial spill volume upon arrival at the scene and then support operations for a blowout lasting 30 days.[35]

The regulations further require that operators supply an inventory of spill response equipment but do not specifically require disclosure of containment equipment.[36]

These regulations superficially appear to be quite comprehensive regarding containment: they at least nominally require drillers to invest in containment, identify and prepare for a worst-case spill, and document their plans and preparations. In practice, however, the effect of these regulations on containment measures was limited, for at least two reasons.

First, as the response plan requirements show, MMS regulations do not appear to distinguish cleanly between containment and response, certainly not to the degree we have done for this paper. The terms are sometimes used interchangeably, and in some cases "containment" is used to refer to devices, such as booms, that we would clearly classify as response.[37] There appears to be no reference in the regulations to specific devices, technologies, or practices that fall within our definition of containment. Most notably, there is no requirement that operators show any ability to stop the flow of hydrocarbons from a well with a failed blowout preventer. The regulations refer to surface storage capacity, showing some awareness of the need for containment operations at the wellhead, but not to subsea containment.

Despite that limitation, however, the regulatory language is sufficiently broad that MMS could have interpreted it to require that plans include evidence of real containment capability and

[34] 30 CFR 254.23(g)(5).
[35] 30 CFR 254.26(d)(1).
[36] 30 CFR 254.24.
[37] See 30 CFR 254.45.

preparedness. The general requirement that operators "immediately control" hazardous conditions implicitly requires containment preparedness, as does, arguably, the specific language that follows. For example, a requirement that the plan include "methods to assure that containment … equipment" is available at a spill site could easily have been interpreted by MMS in this fashion. MMS could have relied on such language to reject any response plan with inadequate evidence of containment preparedness.

Second, MMS did not require such evidence in practice. Neither BP's regional response plan for the Gulf of Mexico nor its specific plan for the Macondo well contains any significant detail regarding containment. The regional plan complies with MMS containment and response regulations by referencing the response capabilities of MSRC, National Response Corporation, and other oil spill *removal* organizations—none of which have containment capability.[38] The plan goes into some detail regarding response operations, including use of booms, skimming vessels, *in situ* burning, and dispersants, but has almost no evidence of containment preparation. Generally, the same is true for BP's specific response plan for the Macondo well.[39] The plan broadly asserts that BP "has the financial capability to drill a relief well and conduct other emergency relief operations" but does not detail what those containment operations would be, and what steps and investments BP had taken to prepare.[40] The plan further notes that MMS did not require BP to address a blowout scenario[41]; addressing such a scenario would have required a discussion of containment.

Because of the limitations of the response plan regulations as written and MMS's decision not to interpret them strictly or enforce them vigorously, containment was only trivially addressed in such plans. MMS's decision to issue a categorical exemption for offshore drilling from the National Environmental Policy Act's requirement of environmental impact statements further prevented containment preparedness (or lack thereof) from being exposed to regulators. As a result, existing regulatory requirements gave firms almost no incentive to invest in containment beyond that provided by liability. Furthermore, the absence of substantial containment disclosure requirements from response plans meant that regulators (and by

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[38] BP regional plan at 74, 270, 495, 510–20.
[39] Deepwater plan.
[40] Deepwater plan at 12.
[41] Deepwater plan at 12; specifically, BP was given an exception from the requirements at 30 CFR 250.213(g) that such a blowout scenario analysis be included in the Macondo well's response plan.

extension, the public) had no realistic way of knowing what investments firms had made in containment.

This lack of containment-specific regulation is not necessarily a failure—it may have been rational given the then-low estimated likelihood of large spills, for example. We make no claim here that MMS containment regulations were improper before the DH spill. Two lessons from this evidence are useful, however. First, the nearly complete lack of containment-related regulation means that even basic requirements would raise the regulatory bar substantially. Second, however, evidence suggests that what MMS regulations did exist were interpreted and enforced rather loosely—the same may be true of future containment regulations, however strict they appear to be.

Future Regulation

As discussed above, the *Deepwater* spill and in particular the significant difficulties BP endured in its attempts to contain the well have led to a widespread perception of substantial underinvestment in and underregulation of containment. BOEMRE has apparently concluded that containment investments have been insufficient in the past, asserting that the *Deepwater Horizon* spill “laid bare the gap between the oil and gas industry’s drilling technology and the technology available to contain and control blowouts in deepwater” and that until this disaster, “oil spill response planning had not anticipated a spill of such a scale and duration” (U.S. Department of Interior 2010a).

It is therefore highly likely that future regulation will require more investment in containment, stronger evidence that such investments are being made, or both. Such a change may not require significant alterations to existing regulations. As discussed in the previous section, MMS (now BOEMRE) could interpret the existing regulations in such a way as to require containment preparations in response plans. Nevertheless, stronger regulatory language is likely. In its October 2010 announcement that the deepwater drilling moratorium had been lifted, the Department of the Interior cited completed and future revisions to regulations that it says will make drilling safer, and in particular address containment:

> We have more work to do in our reform agenda, but at this point we believe the strengthened safety measures we have implemented, along with improved spill response and blowout containment capabilities, have reduced risks to a point where operators who play by the rules and clear the higher bar can be allowed to resume. (U.S. Department of Interior 2010c).

New regulations finalized or proposed to date include a requirement to address worst-case discharge scenarios (including blowouts) in drilling or exploration plans.[42] This "Blowout Scenario" notice to lessees (NTL) further requires operators to disclose some containment capabilities, including "the likelihood for surface intervention to stop the blowout" and the operator's ability to drill a relief well.[43] It also generally requires operators to

> Describe the measures you propose that would enhance your ability to prevent a blowout, to reduce the likelihood of a blowout, and conduct effective and early intervention in the event of a blowout, including your arrangements for drilling relief wells, and any other measures you propose.[44]

This NTL is an interpretation of existing 30 CFR 250 requirements and, therefore, is probably best understood as an indication that BOEMRE intends to more aggressively interpret those and other regulations to require investment in containment and disclosure of containment plans.

A further NTL was issued by BOEMRE on November 8, 2010, providing additional requirements for lessees and permittees regarding containment. It states,

> … BOEMRE will evaluate whether each operator has submitted adequate information demonstrating that it has access to and can deploy surface and subsea containment resources that would be adequate to promptly respond to a blowout or other loss of well control.[45]

The NTL does not specify the requirements for this demonstration but does list a variety of technologies as "applicable," such as containment domes and capping stacks, ROVs, and capture and support vessels.[46]

Taken together, these NTLs indicate a trend toward increasing specificity in regulatory requirements regarding containment. They do not yet, however, embody firm and well-defined

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[42] Blowout Scenario NTL; note that this and related NTLs were thrown out by a federal district judge for failure to comply with notice and comment procedures required by the Administrative Procedure Act. See *Ensco v. Salazar,* Ruling on Motions for Summary Judgment, Case 2:10-cv-01941-MLCF-JCW, Document 126 (October 19, 2010). This decision may be appealed, and even if that is unsuccessful, the NTLs are likely to eventually be reissued—though the notice and comment process may affect their content.

[43] Blowout Scenario NTL at 2.

[44] Blowout Scenario NTL at 3.

[45] NTL 10 at 2; note that NTL 10 did not undergo notice and comment and is therefore presumably vulnerable to a similar legal challenge as that which prevailed against the blowout NTL (see note 42).

[46] Ibid.

standards. There is no link between worst-case discharge volumes from wells and the level of containment capability that must be demonstrated, or any other grounding in objective criteria. At most, the NTLs can be characterized as an announcement that BOEMRE will interpret the language in its regulations to require *some* evidence of containment preparedness. This evaluation will, at least until standards are specified, be necessarily subjective.

In any case, new regulatory requirements are likely to increase incentives for firms to invest in containment technology, though it is not clear whether they or increased awareness of liability will be the primary driver of the new investment. Even if regulatory requirements are below the level of investments firms will decide to make on their own, the disclosure elements of regulation will still play an important role. These disclosure requirements for permitting and for ongoing operations will expose the containment investments that firms are making. Assuming that the public and regulators are vigilant (and this is a significant assumption over the long term), it will be easier to correct any future underinvestment in containment with further regulation.

Regulatory requirements for offshore drilling will likely continue to be strengthened, particularly regarding containment. Industry efforts to publicly show investment in containment, most notably MWCC, can be plausibly viewed as a reaction to this expectation. Viewed positively, MWCC is therefore a preemptive move in anticipation of stricter regulation—an example of how regulation can be effective even before it is implemented and a tacit admission by the industry that such regulation is sure to come. More cynically, MWCC could be viewed as an attempt to undermine support for future containment regulation with a public demonstration of ostensible self-regulation. Based on the available information, it is difficult to determine which of these views is more accurate, though it is possible that elements of both are correct.

The Effect of Future Regulation

Future regulation will likely play a significant role in drilling firms' choices regarding containment investments. Even if liability, not regulation, is the primary driver of containment investments generally, regulation is likely to influence the specifics of those investments. Because of this, regulation will likely have a large effect on the containment industry—the number and size of participants, whether those participants are independent firms or collaborations such as MWCC—and decisions about services and innovation made by those participants will depend at least in part on decisions made by regulators. At the very least, regulators will set, define, and verify the minimum level of containment preparedness required to obtain a drilling permit, though liability or other concerns may cause firms to invest beyond this level.

Because of this influence, regulators' decisions are important and highly relevant to some of the concerns we raise in this paper regarding future containment investments. This is most readily apparent in two areas: market structure and innovation.

Market structure.[47] Containment technology and services could be provided in the Gulf of Mexico by a single firm (presumably by MWCC) or by a variety of firms offering different levels of service and specializing in different elements of well containment. Competition among providers of containment technology and services would likely drive down costs and might increase incentives to innovate.[48] However, major drilling firms' decision to create MWCC suggests (though it does not prove) that the challenges inherent in containment are such that some level of consolidation is needed (on the other hand, planned containment service packages offered by independent firms suggest the opposite).[49] The cost structure may include economies of scale in financing, maintaining, and operating containment equipment, facilities, and personnel, particularly if deployment is infrequent. From the perspective of the costs to government in regulatory oversight, a larger number of firms providing containment services places a higher burden on regulators to evaluate and certify those firms. Because of uncertainty about the benefits and costs of competition in the containment field, and the number of entrants who will offer containment services, we make no firm conclusions about what level of competition is appropriate.

But it is possible that regulators—not the marketplace—will determine the number of containment providers and, therefore, the degree of competition. For example, BOEMRE could

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[47] As a collaboration among competitors, MWCC may be scrutinized by federal antitrust regulators concerned that it could reduce incentives to innovate or have other anticompetitive effects. Although suits against such competitor collaborations have been filed relatively rarely in recent years, some level of scrutiny is likely. Since MWCC is not a type of agreement considered *per se* illegal, regulators would analyze it under rule of reason principles, attempting to determine whether any procompetitive benefits associated with MWCC outweigh anticompetitive effects. We make no attempt to predict the outcome of any such analysis, but potential anticompetitive effects and the risk of antitrust scrutiny or litigation are underappreciated problems associated with MWCC that deserve further investigation.

[48] See Section 5 for a discussion of the effects of market structure on incentives to innovate. Some research suggests that consolidation gives greater incentives, but other research suggests the opposite—that competition breeds innovation.

[49] See discussion of the Helix proposal in Section 2.

explicitly require MWCC membership as a condition of drilling in the Gulf. Regulations could also force MWCC membership in practice even if they do not do so explicitly if MWCC is the only provider of containment services blessed by regulators.

Since MWCC has been created by just four major firms, with a membership and fee structure that arguably places nonmajor firms at a disadvantage, regulation that requires MWCC membership (or contracting) to drill in the Gulf is likely to have the most significant consequences for these nonmajor firms. Alternative providers of containment services, if they emerge, would allow firms some choice. If MWCC's structure is attractive, these firms can sign up; if not, they can obtain containment services from a competitor (or provide them in-house). To frame the issue differently, MWCC's major-firm structure is deleterious to nonmajor firms if these firms lack other options. If they are forced to join MWCC or exit the Gulf, then further scrutiny of MWCC's structure is warranted.

This is not to suggest that nonmajor drilling firms should necessarily be protected. If the costs of operating in the Gulf rise—and this could be for a variety of reasons, only some of which have to do with containment and regulation—some firms will likely exit in any case. Assuming that firms have assessed their position and liabilities and decided to continue operating in the Gulf, imposing higher relative costs on nonmajor operators because of MWCC's structure is not likely to improve safety. Instead, it will benefit major firms at the expense of their competitors. If judgment-proof small firms are viewed as a problem, the best solution is probably larger financial responsibility requirements. The MWCC is the wrong tool for the job.

Innovation. Regulators are also likely to have a significant influence on innovation decisions made by containment providers. We discuss innovation in detail in Section 5, below, but some discussion of the interrelationship of regulation and containment innovation investments is useful here. As discussed above, it is likely that containment providers will be subject to some form of BOEMRE inspection and licensing, and that evidence of some level of containment preparedness will be necessary to obtain a drilling permit or operate a well.

To whatever extent that regulation, rather than liability, drives decisions regarding containment investment, firms will have an incentive to invest beyond the effort required to protect business loss only up to the level required by regulators. If this level does not change over time, there will be no incentive to invest in higher levels of containment safety, only an incentive to innovate on cost. There is some evidence that after the *Exxon Valdez* accident, regulation of spill response (as distinct from prevention and containment) suffered from such a lack of innovation. Regulatory response requirements did not increase over time, and although firms appear to have innovated, they did so in terms of cost rather than effectiveness.[50]

A possible solution is for regulators to ratchet up requirements over time through technology-forcing regulation. This may or may not be effective in practice. The elements of containment technology that are dual-use—those that have day-to-day commercial value separate from their role in containment, such as relief well–drilling equipment, ROVs, and storage tankers—are likely to benefit from innovation driven by these noncontainment uses. Regulators can identify these improvements and adjust containment requirements to match. This might give firms (either drilling firms or containment contractors) an incentive to innovate in quality, not just cost, since competitors would be forced to adopt better technology. Lagging firms might face higher costs and might even have to obtain the technology by license if it is controlled by the innovating firm. This approach has been used elsewhere in environmental regulation, notably in the Clean Air Act's best available control technology (BACT) requirements.

But for those elements of containment technology that have no other use, technology-forcing regulation will be more difficult. It is hard for regulators to know what improvements are possible and what kinds of innovation to push. Some targets will be relatively obvious; for example, regulations could require that firms drilling in a given depth of water or into a reservoir with a given estimated pressure have containment equipment capable of dealing with those conditions. Firms that want to access hydrocarbons under such conditions would then have to innovate in containment. But it is less clear how effective regulators would be at identifying and providing incentives for innovation in containment-specific equipment and practices under existing drilling conditions. BACT-style technology-forcing regulation might be effective here too, though evaluation of technology—determining what is the "best available"—will be difficult.

4.4 Third Party–Generated Incentives

Liability and government regulation are not the only sources of firms' incentives to reduce the likelihood of damage from spills by investing in containment. Firms are concerned about their reputation, particularly among investors and consumers. Both sets of stakeholders, and indeed public opinion generally, are capable of exerting pressure on firms. Because

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[50] See National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, Draft Staff Working Paper, Response/Clean-Up Technology Research & Development in the BP Deepwater Horizon Oil Spill at 22.

containment is widely perceived to be an area in need of significant investment, these groups are likely to exert particular pressure in this area. For more discussion of these sources of incentives, see [task 5].

Offshore hydrocarbon resources are publicly owned, and drilling operations are governed by government regulation that is driven in large part by policy decisions. Petroleum firms therefore depend, ultimately, on public goodwill for access to these resources. The *Deepwater* spill has led to widespread public support for stricter regulation and some public support for restricting drilling operations, particularly in deep water. Firms know that if they want continued access to the profitable hydrocarbon reserves in the Gulf—not to mention other areas, such as Alaska—the industry can ill afford another major spill. This knowledge creates a powerful incentive to invest in safety and in particular in containment, possibly beyond the incentives generated by liability concerns or government regulation. In a sense, the potential for public pressure or backlash against an industry perceived as dirty or unsafe creates an incentive to invest in safety.

4.5 Conclusions on Incentives

Liability, regulation, and to some extent, third-party pressure all create incentives for petroleum firms to invest generally in safety. In different ways, each of these influences may particularly provide incentives to invest in containment. The *Deepwater* spill gave firms new information about risks, primarily by making it apparent that BOPs can fail catastrophically, leading to an uncontrolled leak and, in deep water, a situation in which containment is very difficult. Awareness of this liability risk will drive firms to make safety investments in prevention and possibly spill response, but most of all in containment. Simultaneously, regulators are reacting to the same information by strengthening permit requirements, again with particular emphasis on containment. Third parties may exert pressure in similar fashion.

The result is substantially increased incentives to invest in containment technology, resources, and planning. MWCC was created in response, but as these incentives grow and are better appreciated by industry, competitors to MWCC and/or substantially increased investments by individual firms are likely.

We offer several recommendations in light of this discussion. As a general matter whose implications extend beyond containment incentives, a reevaluation of liability limits is appropriate. Though federal liability caps are not generally binding, they may limit firms' liability in specific circumstances. Low financial responsibility requirements also allow some firms to undertake risks of spill-related damages that they, unlike BP, would never be able to cover. These limitations on effective liability curb incentives to invest in containment and put additional burden on regulators. To the extent that liability is relied on to generate containment incentives, government or third-party monitoring (though not necessarily actual regulation) of containment investments should improve. Though the *Deepwater Horizon* spill reveals industry underinvestment in containment, it also reveals a failure of government, investors, and industry to identify that underinvestment in time to correct it. Monitoring, whether by government or by third parties such as independent insurance providers, is needed.

In creating incentives for effective containment, a balance between liability and regulation is desirable. Given the limitations of the liability system and the incentives it generates, at least some regulation is needed to ensure that firms make adequate containment investments. A showing of containment preparedness should be an element of spill response plans prepared during permit applications, and BOEMRE should inspect and license third-party containment providers, such as MWCC. At the same time, regulators should welcome competition and innovation in containment, and write and enforce regulations in such a way that, to the greatest extent possible, neither is penalized.

Finally, regulators should avoid unduly restricting competition in the containment field. If MWCC membership is required, explicitly or in practice, nonmajors are likely to be disadvantaged and may exit the drilling business in the Gulf. Larger, well-capitalized drilling firms may arguably be preferable, since they can cover damages from large spills, but this is a larger debate, and containment is an inappropriate and unwieldy tool for achieving such results.

5. Technological Innovation in Containment

As discussed in Section 2, a question in considering the effectiveness of MWCC and other efforts is how best to ensure adequate investment in new containment technology to keep pace with deepwater exploration and production. The difficulty of relying on liability and regulation to induce adequate containment has been made apparent by reports that found inadequate investment in innovation for deepwater containment.[51] One report notes that “the

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[51] Although focusing on response and cleanup rather than containment, a separate working paper by the staff of the Oil Spill Commission reviewed private sector investment in response and cleanup technology and the funding appropriated to government agencies to maintain response and cleanup preparedness since the 1989 *Exxon Valdez* oil spill. The conclusions were that neither industry nor government had allocated adequate resources to cleanup technology (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling 2010).

urgency in containing the spill and dealing with its effects has driven innovation in technology, tools, equipment, processes, and know-how," and Box 2 (above) lists 30 innovations that took place in responding to the *Deepwater Horizon* event (BP 2010b, 2, 3, 62). The Joint Industry Subsea Well Control and Containment Task Force (2010, 5) concludes its report by calling for continuing research and development and "a focus on researching new technology for subsea containment." Other experts agree; for example, Jerome Milgram, an MIT professor with expertise in the analysis of oil spills, has noted that "there hasn't been enough research into subsea containment devices" (Chick 2010, p.9). As further evidence of underinvestment in containment, the President has proposed increased funding by the Department of the Interior specifically for improvement in deepwater spill containment capabilities and understanding of how best to respond. The effort is to be coordinated with other federal and nonfederal partners (White House 2010).

5.1 Determinants of Technological Innovation in Containment

Going forward, the extent of innovation likely to be undertaken by industry as a whole, as well as by MWCC, is far from clear. Incentives to innovate depend on the extent to which the externality of damages to third parties is internalized by firms through liability and regulation. But even if those institutions perfectly internalized those externalities, the determinants of innovative effort remain one of the most-studied but as yet incompletely answered questions in technology policy.[52] Incentives to innovate depend on the ability to fund R&D, appropriate the returns to invention, and protect intellectual property embodied in the invention. Joint ventures such as that created by MWCC can alleviate some of the problems associated with funding, appropriation, and the protection of intellectual property but can also introduce other concerns.

Incentives to Innovate as a Function of Ability to Appropriate

Innovation requires money to invest in research and development and an expectation of a commensurate return on the investment. Realizing the return to a new idea—whether it is a process, a product, or other creative output—requires in turn a means of protecting the intellectual property produced by the innovative effort. If an innovation produced by one

[52] In Section 2, we discuss the history of deepwater spills. Although outside the scope of our report, another defining characteristic of innovation in deepwater spill containment may be a perceived or actual low probability of the need to contain, although we are unaware of any formal modeling of the likelihood of a spill. Kunreuther and Michel-Kerjan (2010) emphasize the myopia that can lead companies to underinvest in measures to decrease the likelihood of a spill as well as limit the damages if one does occur.

company provides net benefits to other companies, the innovating company would be unable to appropriate fully the benefits of the innovation. On balance, most studies of incentives to innovate find the problem of appropriating the returns to be one of the largest barriers to innovation.[53] Protection of intellectual property, such as patents and licensing, allows the innovator to reap some but generally not all of the reward.[54] Taken together, research has found that these determinants—the cost of innovation, the uncertainty of the return to innovation, and the need for sound intellectual property rights—generally conspire to lead to too little innovation. This finding has become one of the rationales for a role of government in supporting R&D through tax credits, research grants, prizes, and the funding of federal research laboratories.

Incentives to Innovate as a Function of Externalities

Incentives to invest in technological innovation to avoid damages can be further weakened if the damages are partly borne by society at large and not fully internalized by industry (Krupnick et al. 2011). This is a direct extension of the general proposition that limits on liability will lead to less effort to prevent, contain, or respond to an oil spill. Limited liability in the event of a spill is an example. In the absence of "prices" for ecosystem services, for example, the penalties for failing to contain a spill are small. Through regulation and assignment of liability for externalities, government strengthens these incentives. If regulation and liability could be perfectly designed, then government intervention would serve as the fulcrum to balance the private costs to industry of investing in containment techniques and the social costs to the public in the event of a spill. As noted above, this situation is a case of government and private coproduction of the risk of damages. By playing a pivotal role in industry oversight, the government determines a portion of the risk. Industry responds by taking action subject to the oversight provisions. Taken together, the actions by both parties determine the level of care provided to the public.

As emphasized in Section 4, the incentives for technological innovation are partly determined by this coproduction of risk. The incentives may be too weak if the consequence of failure to contain are too small, thus leading to undersupply of innovation in containment

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[53] For example, see discussion and examples in Stoneman (1995), especially Chapters 4, 5, 6 and 12; and Scotchmer (2004), Chapters 2 and 3.

[54] Whether patents should allow full appropriability is itself an extensively researched question. If the marginal effect of innovation on appropriating more than some percentage of the returns I slow, the gains in inducing investment from full appropriability may be less than the costs of increasing restrictions on the use of the patented innovation, particularly as an input to subsequent innovation.

technology. The same reasoning would lead to an oversupply of containment technology and innovation if the consequences of failure to contain are too large.

Incentives as a Function of Market Structure

Another well-studied but unsettled question is what type of market structure best fosters innovation in an industry (Schumpeter 1934; Arrow 1962; Scotchmer 2004, Chapter 4). According to some research, monopoly situations are conducive to R&D because the monopolist can better appropriate the returns to the invention without concern that competitors will make use of the knowledge. Consumers may also benefit, because prices under a monopoly supplier of the good or service are already higher than they would be in a competitive market, and cost-reducing innovation by the monopolist can reduce those prices (Blair and Kaserman 1985). Other research finds that large firms, regardless of market structure, may innovate more because they may have more capital, may be willing to take more risk, and can act faster to commercialize new technology than smaller firms. Another line of research finds that competitive markets are more conducive to innovation because cost-saving technological advance can give the innovating firm a short-run competitive advantage. Moreover, because competitive markets have higher levels of production than monopoly markets, all else equal, the benefits of a cost-reducing innovation are greater as they are reaped over a larger level of output. Research joint ventures among firms—which could possibly characterize MWCC, insofar as its planning documents indicate that it will engage in innovation—can overcome some of the problems associated with both monopoly and competitive markets. Research joint ventures bring additional concerns, however. We address the advantages and disadvantages for MWCC as a research joint venture in the next section.

5.2 MWCC and Innovation

The plans for MWCC include “research on new containment and technology,” “ongoing training and utilizing the most advanced technologies,” and the intent “to design and construct new devices and a suite of adapters that could be used on any well in the Gulf.”[55] Whether MWCC will undertake research in other equipment, processes, risk management, or other aspects of response capacity—the kinds of activities listed by BP as lessons learned in responding to the *Deepwater Horizon* spill—is not clear.

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[55] Marine Well Containment Company at http://wwwmarinewellcontainment.com/faq.php accessed 20 October 2010.

As a consortium in which R&D activities are carried out much like a research joint venture, MWCC could be expected to reduce some problems of underinvestment in innovation because members can share R&D costs and appropriate results. Disadvantages are that the consortium may reduce or slow overall inventive effort by lessening competition in the industry as a whole, and free riding may lead members to invest less than promised, assign less talented people, and limit the flow of member-specific information to the cooperative effort. By excluding nonmembers, the governance structure has a potentially limiting effect on access to innovation as well. The current governance structure of MWCC, with one vote per member and no independent directors, raises further questions about the incentive of MWCC to accommodate new containment technologies that might be developed by either nonmembers or individual members.

A related issue is the nature of the intellectual property protection to be accorded any innovation developed by MWCC. Discussion of the specific types of protection—for example, patents and licensing—are outside the scope of this report. However, from society's perspective, opportunities for all parties to use the new technology in the event of an accident would be desirable. That intellectual property protection can limit widespread deployment of a new technology is well known, but at the same time, without such protection, incentives to innovate are blunted.

As a joint venture, MWCC would allow for some coordination of the research effort and sharing of technical information (Brocas 2004; Aoki and Tauman 2001). Avoiding duplication of effort is a known advantage of research collaboration. This advantage needs to be balanced against the other problems of a consortium in its possible exclusionary effects in limiting access to new technology or reducing or slowing overall inventive effort by reducing the competition in the market (Grossman and Shapiro 1986; Ordover and Willig 1985; Katz and Ordover 1995). If the Helix Subsea Containment project or other industry efforts bear fruit, this concern may be alleviated. A related concern is the risk of collusion in related markets if cooperation in R&D requires firms to share information about the conditions of input and output markerts (exploratory drilling and fossil fuel prices, for example, in the case of MWCC).[56]

This discussion leads to several recommendations. One is an assessment of the need for innovation in deepwater spill containment. Given the likely continued drilling in deepwater, the

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[56] See Geroski (1995).

government and industry should evaluate the need and appropriate directions for innovation in equipment, technology, processes, and risk assessment. The evaluation should include the role of MWCC but also consider how innovation by MWCC will be made available widely, to nonmembers as well as members. A related recommendation is to identify possible market failure for innovation. The low probability of a spill, the liability limits on damages, and overall incentives to underinvest in new technology combine to discourage innovation. If innovation in containment is seen as failing to keep pace with innovation in drilling in deepwater, then government and industry, including MWCC, could consider cofunding containment R&D to mitigate underinvestment. Both of these recommendations—ascertaining the need for innovation, and correcting any market failure—could be addressed by establishing a standing center of excellence or other academically based entity for state-of-the art innovation in deepwater containment and response technology. Relying on liability and regulation to induce adequate innovation in containment is problematic for the reasons noted earlier: these interventions are difficult to design, government lacks perfect information, and regulation can be expensive to enforce. An independent research center could keep pace with anticipated increases in drilling activity and draw on research expertise from around the world. The research should include not only engineering but also state-of-the-art risk assessment and management for low-probability, high-consequence accidents. MWCC could collaborate with, cofund, and draw from this effort.

Finally, policymakers need to recognize the limits of MWCC if it evolves into a research consortium while serving as an operational entity. If its mission and vision include R&D for innovation in containment, then as a research consortium it can spread R&D expense and appropriate returns to innovation, thus mitigating some of the usual disincentives to invest in new technology. However, research consortia can lead to an overall reduction in industrywide R&D, limit the spread of innovation to nonmembers, or fail to adopt innovation developed by nonmembers.[57]

[57] According to the OSC staff report (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling 2010), the Marine Spill Response Corporation obtained $30 million to $35 million for a five-year R&D program when the corporation was formed in 1990, but later the members eliminated the program, and now the corporation has no research budget.

6. Lessons and Best Practices in Similar Situations

Industry-wide collaboration in response to a catastrophic event and resulting government regulation is not unprecedented. Soon after the *Exxon Valdez* spill, the Marine Spill Response Corporation, a nonprofit membership organization, was created to provide services for companies engaging in petroleum exploration and reduction. MSRC continually updates its range of services to match government regulations that members are mandated to follow.[58] Similarly, in the nuclear power industry, the Institute of Nuclear Power Operations (INPO), an industry-supported nonprofit organization, was formed in response to the Three Mile Island accident; it oversees safety operational objectives for U.S. nuclear power facilities. These past efforts give future organizations created under similar circumstances an opportunity to learn from their success and failures.

Industry consortia are composed of multiple firms whose potentially varying motivations can make creating an organizational structure very difficult. However, since the organizational structure must be designed to attract and retain members and to maintain incentives to carry out the goals of the mission statement, it should be given careful consideration (Grindley et al. 1994). Upon the creation of INPO, it was decided that the board of directors would be made up of CEOs from the member companies that have the final say on all safety standards. Executives cite this decision as a "vital" component to the general success of the INPO model (Ellis 2010). Each member company has one vote in election of new board members (990 tax form). In addition, the U.S. Nuclear Regulatory Commission exercises influence over INPO by conducting an annual assessment of its safety standards (Ellis 2010). This combination of industry input and government oversight creates a structure that maintains the incentive for INPO to engage in best practices.

Industry-wide consortia are often created for purposes of research and development, industry self-regulation, or information sharing (Hayton et al. 2010). Additionally, protecting the industry's overall reputation is also a motivating factor for firms to act collectively (Barnett 2006). Barnett suggests that industry reputation be thought of as a common resource that could be damaged by the poor practices of any one firm. Individual firms can act to protect their own reputations, but they may also need to engage in a collective effort if the industry's reputation is suffering (Barnett and King 2008). For example, when studies revealed overwhelming public

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[58] http://www.msrc.org/ (accessed 28 November 2010).

distrust of the chemicals industry in regard to environmental practices, the Chemicals Manufacturing Association (CMA), an industry-only membership organization, created the “Responsible Care” program and implemented a strict environmental code of conduct (King and Lenox 2000). Now that the reputation of offshore drilling has been damaged by the *Deepwater Horizon* spill, the formation of MWCC and the subsequent membership of the major offshore producers could improve the reputations of both individual firms and the industry. Firms would benefit from cost-effectiveness in outsourcing activities that meet government regulations while also being perceived as socially responsible by the public.

However, recent research has found that if the motivation to engage in collective action is mostly the improvement of industry reputation, a potential free-rider problem exists, with nonparticipants benefiting from improved industry reputation (Lenox 2006). Data from the Responsible Care program in the chemicals industry suggest that for such collective action to be sustainable, there needs to be a group of firms that are intent on maintaining the consortium. These firms will most likely be the largest producers or the strongest brand names within the industry, since they have the most to lose from a poor industry reputation. If these firms join the consortium and it improves the industry’s reputation, smaller firms benefit even if they choose not to participate. Furthermore, Lenox found that the largest members of the Responsible Care program did not experience benefits greater than nonparticipants, a result replicated later in the literature (Lenox 2006; Barnett and King 2008).

One way to discourage free-riding is to encourage small firms to join. In the example of SEMATECH, a research and development consortium in the semiconductor industry, membership dues are based on semiconductor sales per member so that smaller firms can participate (Grindley et al. 1994). Sterner methods of correcting the free-rider issue include publicizing a list of nonmembers and reporting organizations guilty of bad practices (Gunningham 1995; King and Lenox 2000). Even more coercive approaches can be taken. For example, to be a member of the CMA, firms are required to follow the Responsible Care program, and membership to INPO was made mandatory for all nuclear power facilities by the industry’s sole insurer. Additionally, INPO members have a strong incentive to comply with INPO standards because facility insurance rates and membership dues increase if they receive poor ratings from INPO inspections (Ellis, James O., Jr. 2010).

7. Governance: Why It Matters for MWCC

As discussed in Section 2, MWCC is still in the process of defining its governance structure, but our understanding is that it will be set up as a nonprofit organization. Each member company will pay the same share of the initial investment and ongoing operating costs. MWCC will include member and nonmember provisions. Nonmembers will be assessed fees based on the number of days they need MWCC assurance provisions.

In many ways, these provisions will establish MWCC as a hybrid organization—a nonprofit with member organizations as shareholders. In serving the interests of its member organizations, a well-designed governance structure will align management with member interests (including compliance with regulations and sensitivity to liability). It is less clear whether MWCC's mission includes a broader social component, such as pushing the technology frontier for the industry as whole, or protecting the environment beyond the interests of individual members' shareholders. As discussed earlier, policy tools, chiefly liability and regulation, could be inadequate to generate sufficient long-term incentives to invest and innovate in containment. If these tools are sufficient (or can be made sufficient) and there is a competitive market for containment services, there is little need for government or other outside intervention in MWCC's governance structure. The proposals and recommendations we advance in this section regarding that structure therefore assume that some social component of MWCC's mission is desirable.

Furthermore, our governance recommendations are directed at the nonprofit MWCC as the most plausible candidate for a private containment organization with a social mission. They do not apply to possible for-profit competitors, since we assume that such organizations will aim only to meet the needs of their members or clients in complying with regulation and reducing expected liability. If MWCC does develop a social component to its mission but faces private competitors that do not, the competitive balance in provision of containment services is made more complex; MWCC is likely to be at a competitive disadvantage. In some respects, the MSRC experience in spill response and its lower-cost, for-profit competitors illustrates this problem. In such a case—and again, if liability and regulation are deemed inadequate to generate containment incentives—some public support for MWCC might be warranted.[59] It is well recognized by both academic researchers and government regulators that governance structure is a critical factor in determining the success or failure of both for-profit and nonprofit organizations. In the context of nonprofit organizations, *governance* is usefully defined as "a set of instruments and mechanisms that support the (nonprofit) board of directors in its global

[59] See Section 5, above, for specific proposals regarding external support for MWCC innovation.

leadership of the organization and assure the completion of the purpose, legitimacy, and the accountability of a nonprofit organization" (von Schnurbein 2006). The academic literature on governance largely began about 35 years ago with Jensen and Meckling's (1976) study, whose basic insight was to use agency theory to show the potential conflict of interest between owners and managers when managers do not own 100 percent of the firm. The literature since that time has focused mostly on ways to align incentives and to ensure that the managers of firms maximize firm value. A review of the corporate governance literature noted,

> The fundamental insight from the field of corporate governance is that there are potential problems associated with the separation of ownership and control that is inherent in the modern corporate form of organization. Corporate governance, then, encompasses the set of institutional and market mechanisms that induce self-interested managers (the controllers) to maximize the value of the residual cash flows of the firm on behalf of its shareholders (the owners). (Denis 2001, 192)

Among the reasons that managers might deviate from the interests of shareholders are (1) their desire to remain in power; (2) risk aversion; and (3) personal utility or wealth maximization (e.g., income, perks, or empire building) (Denis 2001).

The fundamental insights on governance issues in nonprofit organizations are much the same, with a few important differences. According to one summary of the literature,

> Although not every nonprofit board in the United States performs exactly the same functions, the practitioner literature converges on a set of board roles and responsibilities that are characteristic of good governance. These behaviors and activities include things such as determining the organization's mission and purpose, selecting, supporting, and evaluating the chief executive; engaging in strategic planning; monitoring programs and services; providing sound financial management; advancing the organization's public image; raising money; and assuring that the organization fulfills its legal and ethical obligations. (Miller 2002, 430)

Whereas the corporate mission in the United States is generally agreed to include a clear mandate to maximize shareholder value, the mission of a nonprofit organization is uniquely determined by the mission statement of the organization. Nonprofit organizations do not generally have owners, such as shareholders, but they do have stakeholders, who are largely defined by the mission. From the perspective of an effective board of directors, the mission statement becomes particularly important for a nonprofit organization because the more familiar financial measures, such as revenue and budgets, while important, are not the primary goal. Without a defined mission and performance metrics, it is difficult for boards of directors to monitor and provide appropriate oversight (Miller 2001). This is true even for trade associations (Boleat 2001), which oftentimes lack an explicit statement of mission.

The role of a nonprofit board as a monitor of management's activities is less clear. Theory suggests that this role is equally important in a nonprofit (see, e.g., Fama and Jensen 1983 and, more recently, Jeger 2009 for reviews of the literature), but Miller (2001) found that nonprofit board members rarely saw themselves in a principal-agency relationship with management despite the clear need for oversight. von Schnurbein (2007), in a study of Swiss trade associations, observed that nonprofit directors often used a cooperative model in dealing with management and warned that without a clear delineation of responsibility, no one would carry out the important work of governance. Thus, weak governance appears to be more a failure of many nonprofit boards than any inherent difference between for-profit and nonprofits. However, it is generally thought that the principal-agency relationship and inherent conflict of interests between owners and managers seen in for-profit organizations is less of a problem in industry trade associations, primarily because the boards of directors of trade associations are made up of members themselves and thus directly represent the owners (Boleat 2001).

Four types of governance mechanisms are often cited in the literature (Jensen 1993):

- legal and regulatory mechanisms;
- internal control mechanisms;
- external control mechanisms; and
- product market competition.

We focus on the first two mechanisms, since the latter two are more applicable to for-profit firms that are subject to market competition. As Denis (2001) points out, legal and regulatory mechanisms might help or hinder good corporate governance. Examples of such mechanisms include provisions that limit shareholder lawsuits against decisions of the board of directors. On the positive side, numerous laws and regulations at both state and federal levels are designed to protect shareholders. Many of these laws refer to transparency and the provision of adequate information so that investors can properly evaluate the firm's future profitability.

The literature on internal controls has focused primarily on (1) the makeup of the board of directors; (2) executive compensation; and (3) the role of large institutional investors. For our purposes, the first two are relevant. A central empirical finding of the corporate governance literature is that managers are more likely to be aligned with shareholders when there are a significant number of independent directors (Denis 2001). Independent (or "outside") directors are not employed by the firm and have no personal or business ties to management. Well-designed governance structures often limit membership in important board committees, such as the compensation and audit committees, to outside directors. There is also empirical evidence suggesting that outside board members' participation in other boards can affect the extent to which managers are aligned with shareholders. For example, Baker and Powell (2009) report evidence that as a board grows (apparently beyond eight or nine members), it becomes less effective, presumably due to free-riding and/or the difficulty of collective action. They also note that as outside board members become busy with other board memberships, they become less effective.

Another finding is that managers are more likely to act in shareholders' interest if doing so results in greater personal reward in the form of compensation. Although much of the literature in this area in not relevant to a nonprofit organization, the basic insight—that performance evaluations should be aligned with the mission of the organization—holds.

The empirical evidence on nonprofit boards is not as developed. Nonetheless, there is some evidence that agency problems do exist and board governance is important. For example, Brickley et al. (2003) find that when CEOs of nonprofit hospitals are voting members of their boards, their compensation is about 10 percent higher than when they are *ex officio* members or simply staff—consistent with the view that boards are more effective at controlling agency problems when they do not have internal managers as voting members. In a study of nonprofit hospitals, Brickley and Van Horn (2002) find that CEO compensation is positively related to financial performance and that turnover is highly likely following bad financial performance—much as it is for their for-profit counterparts—again suggesting that nonprofit boards act as an important monitor of managerial behavior.

Noting that many "best practice" guidelines lack strong empirical foundations, Boozang (2007, 41–42) assesses the state of research on nonprofit governance and draws the following conclusions:

> … it makes sense for nonprofits to focus on diverse boards whose experience matches enumerated governance needs, with some proportion of directors whose role is primarily one of monitoring the firm's ethics and legal compliance …
>
> As a general matter, then, nonprofit boards should consist of multiple members who are committed to the mission, who together have the skills required for leadership, and at least one or more members who understand their role to be that of the monitoring directors …

> A strong and qualified board will work only if it knows what is really going on inside the organization …
>
> Voice in nonprofit governance is rendered meaningless without attendant access to information. Robust transparency has multiple layers—transparency between management and the board; between board committees and the full board; between the entity and members; between the nonprofit and the IRS and state attorney general; between the entity and its constituencies, including donors, beneficiaries, bond holders, etc.; and between the entity and the public at large.

In summary, it is clear that governance structure can affect important elements of a nonprofit's performance—particularly its legitimacy in the minds of stakeholders and its adherence to the organization's mission.

We are unaware of any explicitly defined mission statement of MWCC, and thus we do not know whether its founders view the organization as serving the industry or the public interest. Regardless, the board of directors will be made up exclusively of member company representatives—one member, one vote. There is no provision for independent directors or a standing external advisory panel.

Our understanding of MWCC governance structure, as articulated to date, leads to several recommendations. The first is to develop a mission statement. MWCC as currently constituted is an industry consortium whose funding and expenditure decisions are focused on members' needs. While this is a reasonable model for most industry groups, a clearly defined mission statement would help regulators and the public understand the value of MWCC and the need for further government involvement. For example, a mission statement that focuses on providing compliance with current and future containment readiness regulations has different implications for funding and expenditure levels than a mission that focuses on ongoing risk assessment, continual improvement, and developing new containment technologies.

Second, we recommend that MWCC undergo external technical review by a standing external advisory panel of scientists and other experts who meet regularly to assess technological developments, new containment technologies, new risks, and other developments. This will allow the board of directors to conduct its due diligence in deciding on funding, expenditures, and investment needs. Extending external expertise in the governance of MWCC as well as in technical oversight would enhance objectivity and balance. The structure could permit formal or *ad hoc* representation by experts outside the membership and outside the industry, perhaps including academics, former government officials, and senior executives from firms in other industrial sectors with expertise in technical risk management and response.

Executive compensation and a culture of reporting and transparency are additional concerns. Here we recommend that executive compensation be aligned with the mission of the organization. Although the evaluation criteria for top managers might include good fiscal management, it should also encourage alignment of managers' and stakeholders' interests to ensure readiness and adequate investment in new technologies. Finally, to enhance public confidence, MWCC should develop a culture of transparency in its policies and operations. MWCC should regularly engage with and publicly report to its stakeholders on both financial and nonfinancial measures.[60]

8. Conclusions and Recommendations

The *Deepwater Horizon* spill revealed serious underpreparedness on the part of both industry and government to contain an uncontrolled deepwater blowout.[61] Both industry and government have begun to respond to these problems. The major drilling firms' creation of MWCC suggests industry's reevaluation and reprioritization of containment in light of BP's vast liability exposure. Regulators have begun to interpret more strictly the existing regulations, requiring evidence of containment in the leasing and permitting process. Regulatory scrutiny of containment is likely to increase.

It seems likely that greatly enhanced containment capabilities will be required not only by regulators but also as part of drilling firms' social license to operate. A second uncontained spill, even if smaller than the *Deepwater Horizon* incident, is unlikely to be tolerated by the public and would put the future of U.S. offshore drilling at risk. Drilling firms are undoubtedly

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[60] A good model for stakeholder engagement and reporting would be the internationally recognized Global Reporting Initiative (see www.globalreporting.org). We note, for example, that the Association of Chartered Certified Accountants (ACCA) recently issued a GRI-based corporate responsibility report (http://www.accaglobal.com/pubs/about/reports/csr/csr0910.pdf). ACCA is an interesting model for MWCC to consider in formulating its governance strategy for several reasons. ACCA is a professional membership organization with a clear mission statement that includes advancement of the public interest. Although its governing board (Council) appears to be made up of all accountants, its interests extend beyond the financial remuneration of association members, since it includes a broad range of stakeholders, such as academics and members of nonprofit foundations.

[61] National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, *Stopping the Spill: The Five-Month Effort to Kill the Macondo Well*, OSC Staff Working Paper No. 6 (Draft), November 22, 2010, at 1, available at http://www.oilspillcommission.gov/document/stopping-spill-five-month-effort-kill-macondo-well.

aware of this and perhaps consider it an even greater threat than the liability exposure. Demonstrating improved capacity to contain is one key to reducing this risk.

We emphasize that regulatory and liability provisions by government, combined with actions by industry, represent the complex although not unique situation of coproduction of third-party risk. The setting of rules by government to induce an appropriate level of care by industry, and industry's response, jointly determine the degree to which the public is protected. Despite the actions thus far by industry and government, our research indicates significant remaining problems. MWCC's creation and BOEMRE's regulations to date are unlikely alone to create adequate, long-term well containment capability.

We have significant reservations about MWCC's capabilities, governance structure, and membership terms. First, containment providers can and should do more to prepare for future spill events that may be different from the *Deepwater Horizon* spill. A *Deepwater Horizon*–type spill was viewed as highly unlikely, and without broader thinking—particularly by outsiders—similar mistakes could be made again, with similar results. Third-party review is common practice for engineering solutions proposed after large-scale accidents, and objective experts should also be engaged to monitor expected changes in risk and to carry out state-of-the-art risk assessment. We recommend both immediate third-party review of MWCC and establishment of a standing external group of experts to provide advice to industry and MWCC.

Second, preparedness to contain a future spill is complicated by the rapid advance of drilling technology in ever deeper water. The experience with response technology after the *Exxon Valdez* spill indicates that maintaining the pace of innovation requires attention from private providers and from government in particular. Whether MWCC has adequate incentives to innovate at all, let alone innovate as much as may be necessary, is far from clear. As a consortium of companies, MWCC can spread R&D expense among its members and share the returns to innovation. However, research consortia can lead to an overall reduction in industry-wide R&D, limit the spread of innovation to nonmembers, or fail to adopt innovation developed by nonmembers. If MWCC has a public component to its mission, it should dedicate resources to R&D on an ongoing basis, allow external review of its research agenda, and make innovation widely available. Means to accomplish these objectives could include establishment of an independent research center that draws on research expertise from around the world. Incentives to innovate also depend on liability and regulatory rules. Even if MWCC and its competitors act only to benefit their members, investment in R&D would remain important as a way to reduce liability exposure but may not be adequate for a level of care beyond this exposure. Regulatory requirements, too, will likely need to increase over time to keep pace with technology.

Third, MWCC's membership structure appears to favor major drilling firms over smaller operators. Both equal-share full membership and per well contractual arrangements may prove too expensive, too inflexible, or both for independents. The optimum range of size of drilling firms in the Gulf is a larger question with policy relevance, but the membership structure of a private containment organization is an improper tool for modifying the mix of drilling firms; increasing financial responsibility requirements would be more transparent and likely more effective. For these reasons, we caution against regulatory requirements that explicitly or implicitly require MWCC membership.

Fourth, if MWCC has a public component to its mission, its governance structure should reflect and support this component. A mission statement articulating an intention to act in the public interest is an important first step. Further moves, such as including independent board members from government or public-interest organizations, would strengthen the credibility of MWCC's public commitment.

The questions of MWCC's mission and the level of competition in containment services are linked. Competition may have advantages in efficiency but is not generally compatible with a nonprofit organization that has a public mission (since it would be difficult to compete with for-profit rivals). It is also not implausible to suggest that containment be a government responsibility. Generally, however, we feel that the advantages of private provision of containment exceed the disadvantages.

If MWCC does not have a public mission, government policy must generate the incentives for it to invest in containment and maintain innovation. The primary drivers are liability and regulation.

Because of a variety of factors, but primarily the inability of liability to fully compensate victims and the presence of federal liability caps, liability alone cannot create sufficient incentives for investment in containment. Drilling firms' apprehension of the massive liability to which BP is exposed as a result of its failure to contain will promote containment investment, but liability rules should be changed to increase these incentives. Above all, liability caps should be increased to reflect the social cost of a worst-case spill.[62]

[62] See Cohen et al. (2011) for a more complete discussion of this recommendation.

Even if liability caps are increased, the imperfections of liability as a generator of incentives leave a role for regulation, including regulation aimed at containment. This role is correspondingly larger if liability caps are unchanged. Regulators must ensure that requirements generate sufficient containment under current conditions. But they must do more: regulations must strengthen over time as drilling technology improves, as new drilling conditions emerge, and as new risks become apparent. Without such evolving regulations, incentives to innovate will be blunted or absent and preparedness for a future spill is likely to be inadequate. Regulators should therefore require evidence of capability to contain not only a worst-case spill but also evidence of a thorough investigation of the types of spill possible at a given well (and ability to contain such spills). These assessments should be updated over time for both new and existing wells.

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Appendix 1.

This appendix describes the containment activities listed in Section 2.

Junk shots. Materials such as shredded tires, pieces of rope and even golf balls pumped into the blowout preventer are sometimes successful in bringing the well under control sufficiently to allow heavy drilling mud to be pumped in. Pemex tried a variety of junk shots to control the 1979-1980 Ixtoc spill in the southern Gulf of Mexico (Bay of Campeche) without success. Later the company pumped lead balls into the wellbore but was till unable to control the flow of oil and gas. During the *Deepwater Horizon* spill, BP also tried junk shots without success. The principal reason for failure apparently was the very high pressure of the escaping hydrocarbons, which forced all the debris through the blowout preventer and LMRC without clogging.

Top kill. Heavy drilling mud is injected into the well to halt the upward flow of oil and gas, followed by cement to plug the well from the top. In the *Deepwater Horizon* incident, the upward pressure of the escaping oil and gas was too strong and the top kill failed. In other situations with lower pressure blowouts, top kills have been successful.

Dispersants. Oil spill dispersants change the chemical and physical properties of oil, affecting its transport, fate, and potential impacts. Dispersants are considered an integral part of containment because they may be used in conjunction with containment activities to cope with oil that leaks before a containment cap can be secured and capture any oil still leaking once a containment cap is in place. The intent is to improve mixing of oil in the water column and thereby reduce the amount of surface oil that can reach sensitive shoreline habitats and beaches. The resulting dispersion of oil in the water column, however, can have its own set of adverse impacts. Thus the use of dispersants reflects a trade-off between surface oil and shoreline protection and a potential risk to organisms in the water column. The type of oil, the length of time it has been in the water, and water temperature affect the choice among several different dispersants. One encouraging feature is that today’s dispersants are less toxic than those generally available 10 or 20 years ago. Nonetheless, a National Research Council (2005) report notes that much additional research on the use and effects of dispersants would be desirable. In the *Deepwater Horizon* incident, dispersants were first used on the surface oil slicks. On May 13, 2010, the Coast Guard allowed dispersant injection at the leak itself, vastly improving the mixing of oil in the water column. Apparently, this was the first time that dispersants had been injected at the wellhead of a subsea blowout. The fate and effects of this dispersant use are the subject of ongoing studies.

Containment domes. A containment dome is placed over a leak, whether at the blowout preventer or in the seabed, to capture leaking oil. Containment domes can be open, loose-fitting domes, or small and tight fitting. In an effort to contain the Ixtoc blowout, Pemex constructed a loose-fitting "sombrero" that was lowered over the well; it failed to contain the well. The first dome deployed in the *Deepwater Horizon* accident also was an open dome, four stories high, designed by Shell Oil as a precautionary measure against possible subsea pipeline leaks. This dome failed to function because of the formation of hydrates that plugged the riser. Hydrates contain a low-molecular-weight gas surrounded by water molecules in a crystalline structure. The outer continental shelves of the continents contain vast quantities of methane in the form of hydrates. These hydrates have greater energy content than twice the world's known reserves of coal, oil, and other hydrocarbons. In the cold, near-freezing temperatures found at the Macondo wellhead, hydrates rapidly formed when methane was exposed to seawater. It soon became apparent that a closed cap or dome would be needed. BP had anticipated this problem, and eight tight-fitting caps were being made even as the open containment dome that ultimately didn't work was being deployed. After a remotely operated vehicle cut the pipe extending just above the BOP, a small cap (a "lower marine riser package") was installed and connected via a riser to the semisubmersible *Q4000.* Leaks from the seabed in the vicinity of a troubled well could be contained by an open dome provided the dome penetrates the sea floor sufficiently to prevent the ingress of water. MWCC is proposing to construct an open dome for this purpose. Because the technology is basically untested, simulations and small-scale models may be advisable prior to making large investments in equipment.

Riser system. Attempts to capture oil spewing from a subsea blowout rarely are successful. Capturing oil leaking from the Macondo well was challenging in a number of respects. The surface vessel (the *Q4000,* owned by Helix Energy) had to be dynamically positioned. Its position relative to the wellbore could not vary by more than a few feet or the riser could become disconnected from the containment cap. Moreover, dynamic positioning was essential so that the *Q4000* could offload the oil it processed into waiting transport vessels.

Capturing and processing of oil. In the Gulf of Mexico, several firms have offshore service vessels (OSV) that can transport supplies to a drilling rig or drilling vessel. Some of the more prominent names include Helix Energy, Hornbeck Offshore Services, Seacor Holdings, and Tidewater. New technologies are a selling feature for all the companies offering OSV services. Among the innovations and features of their vessels are greater capacity, dynamic positioning, faster loading and unloading, double hulls, and zero-discharge waste systems. Apparently only Helix Energy had dynamic positioning vessels that could process oil captured by a containment device, flare off the gas portion, and send the oil fraction to a waiting dynamically positioned tanker. In the *Deepwater Horizon* spill, not enough vessels were capable of storing and transporting all the recovered oil. As a result, significant quantities of oil brought up through the riser were flared along with the gas.

Relief wells. The intent is to intercept the leaking well far below the blowout preventer so that drilling mud or cement plugs can be used to stop the flow of hydrocarbons. The relief well must hit the wellbore of the leaking well, a very small target only a few inches wide under several thousand feet of rock.[63] Only a handful of people are considered relief well experts. BP hired a specialist who had directed the drilling of some 45 successful relief wells, many on land. The drilling itself was performed by Transocean, which brought in the drillship *Deepwater Enterprise* to drill the relief well. That effort was successful on the first attempt.[64]

Plugging. Government regulations require that wells that have ceased production or designated never to produce be plugged before they are abandoned. The technology for plugging a well is well established and reliable. Generally, plugging is done with cement, poured into the wellbore to permanently seal it. The entire wellbore is not filled with cement; rather, cement is introduced only at strategic intervals, with the remainder of the wellbore filled with drilling mud. In the case of onshore wells, a major concern is to install plugs that not only prevent the escape of oil and gas from a well and prevent objects from falling into a well, but more importantly prevent the migration of oil and gas within the well bore that might contaminate water-bearing

[63] Relief wells are extremely difficult to complete. The technology involves sending an electric current down the wellbore of the leaking well to create a magnetic field. A sensor is inserted into the relief well that can detect magnetism. Computer analysis allows a skilled specialist to adjust the direction of the drilling and close in on the target.

[64] The Ixtoc well, in the Mexican Bay of Campeche in the southern Gulf of Mexico, gushed uncontrollably for 297 days in 1979 and 1980. Only after multiple attempts did a relief well find the original wellbore and was the well permanently closed. Off the northern coast of Australia, a subsidiary of the Thai state-owned oil company PTT experienced a subsea blowout in a well being drilled from the Montara platform. Over a period of 74 days, the well spewed an estimated 400 barrels of oil a day until the fifth attempt at a relief well intercepted the wellbore and the well was stabilized with mud injections and later killed with a cement plug. These incidents illustrate just how difficult it can be to stop a leak with a relief well. In 1966 the Soviet Union drilled a well about 25 meters from a leaking onshore natural gas well in Urt-Bulak Uzbekistan and set off a large nuclear explosion. The explosion collapsed the leaking pipe and turned the surrounding rock to a glasslike consistency, sealing the leak permanently. Attempts by the Soviet Union to replicate this success with nuclear explosions were less satisfactory.

strata. Citing environmental concerns, the Department of the Interior issued an order in September 2010 that some 3,500 wells in the Gulf of Mexico that had completed production be plugged.

Appendix 2. Notable Offshore Well Blowouts

Year	Rig name	Rig owner	Type	Notes
1955	*S-44*	Chevron	Sub recessed pontoons	Blowout and fire; later returned to service
1959	*C.T. Thornton*	Reading & Bates	Jackup	Blowout and fire damage
1964	*C.P. Baker*	Reading & Bates	Drill barge	Blowout in Gulf of Mexico; vessel capsized, 22 killed
1965	*Trion*	Royal Dutch Shell	Jackup	Destroyed by blowout
1965	*Paguro*	SNAM	Jackup	Destroyed by blowout and fire
1968	*Little Bob*	Coral	Jackup	Blowout and fire; 7 killed
1969	*Wodeco III*	Floor drilling	Drilling barge	Blowout
1969	*Sedco 135G*	Sedco Inc	Semi-submersible	Blowout damage
1969	*Rimrick Tidelands*	ODECO	Submersible	Blowout in Gulf of Mexico
1970	*Stormdrill III*	Storm Drilling	Jackup	Blowout and fire damage
1970	*Discoverer III*	Offshore Co.	Drillship	Blowout in South China Sea
1970	*Discoverer II*	Offshore Co.	Drillship	Blowout off Malaysia
1971	*Big John*	Atwood Oceanics	Drill barge	Blowout and fire

1971	*Unknown*	Floor Drilling	Drill barge	Blowout and fire off Peru, 7 killed.
1972	*J. Storm II*	Marine Drilling Co.	Jackup	Blowout in Gulf of Mexico
1972	*M.G. Hulme*	Reading & Bates	Jackup	Blowout and capsize in Java Sea
1972	*Rig 20*	Transworld Drilling	Jackup	Blowout in Gulf of Martaban
1973	*Mariner I*	Sante Fe Drilling	Semi-sub	Blowout off Trinidad; 3 killed
1974	*Meteorite*	Offshore Co.	Jackup	Blowout off Nigeria