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OFFSHORE WELL COMPLETION AND STIMULATION

Using Hydraulic Fracturing and Other Technologies

PROCEEDINGS OF A WORKSHOP

Linda Casola, *Rapporteur*

Roundtable on Unconventional Hydrocarbon Development

Board on Earth Sciences and Resources

Water Science and Technology Board

Division on Earth and Life Studies

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Samantha Joye, University of Georgia
Michael Parker, Parker Environmental and Consulting, LLC
Azra Tutuncu, Colorado School of Mines

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the content of the proceedings nor did they see the final draft before its release. The review of this proceedings was overseen by **Christine Ehlig-Economides**, University of Houston. She was responsible for making certain that an independent examination of this proceedings was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the rapporteur and the National Academies.

Contents

Introduction

1

WORKSHOP MOTIVATIONS AND PROCEEDINGS OVERVIEW

While the public is generally aware of the use of hydraulic fracturing for unconventional resource development onshore, it is less familiar with the well completion and stimulation technologies used in offshore operations, including hydraulic fracturing, gravel packs, "frac-packs," and acid stimulation.[1] Just as onshore technologies have improved, these well completion and stimulation technologies for offshore hydrocarbon resource development have progressed over many decades. To increase public understanding of these technologies, the National Academies' Roundtable on Unconventional Hydrocarbon Development established a planning committee to organize and convene a workshop on Offshore Well Completion and Stimulation: Using Hydraulic Fracturing and Other Technologies on October 2-3, 2017, in Washington, DC. This workshop examined the unique features about operating in the U.S. offshore environment, including well completion and stimulation technologies, environmental considerations and concerns, and health and safety management. Participants from across government, industry, academia, and nonprofit sectors shared their perspectives on operational and regulatory approaches to mitigating risks to the environment and to humans in the development of offshore resources (see Box 1.1 for workshop Statement of Task). Specifically, the panelists, speakers, and audience drew on their collective expertise to consider the following questions:

- What is the purpose of these technologies in the offshore environment?
- How are these technologies different from those onshore?
- How does the geology of each environment impact the use of these technologies?
- How does the geology of the oil or gas reservoir impact project design?
- What safety concerns and potential environmental impacts exist in offshore operations when employing these technologies?

[1] See Glossary in Appendix F.

BOX 1.1
Statement of Task

An ad hoc planning committee will organize a 2-day public workshop to discuss well completion and stimulation technologies used to develop oil and gas in the offshore United States. Specifically, the workshop will focus on technologies such as hydraulic fracturing and the geological and technical circumstances under which these technologies are employed. The workshop will feature invited presentations and discussions that will include themes such as:

1. Technical development of offshore oil and gas fields, including those that use completion and stimulation technologies such as gravel packing, hydraulic fracturing, and acidizing treatments;

2. Reservoir and environmental monitoring, and technology development; and

3. Environmental and human health and safety.

The planning committee will develop the agenda for the workshop, select and invite speakers and other participants, and moderate the discussion. The workshop will result in a workshop proceedings, written by a designated rapporteur in accordance with institutional guidelines.

Chapters 2 through 6 summarize the presentations and moderated discussion for a set of three keynote presentations (Chapter 2) and four different panels (Chapters 3 through 6). The keynote presentations included Evan Zimmerman, Offshore Operators Committee; David Payne, Chevron Corporation; and William Y. Brown, Bureau of Ocean Energy Management who provided the underlying background regarding well completion and stimulation technologies used in the offshore. The speakers discussed general practices from exploration to production for offshore oil and gas development and unconventional resources, an overview of offshore well completion and stimulation technologies, and offshore regulatory and environmental considerations.

Substantial differences exist between oil and gas development in the onshore and offshore environments—for example, the equipment deployment logistics in offshore environments for drilling and production, and particularly at increasing water depths, require different approaches and strategies to facilitate oil and gas extraction and manage risk compared to onshore environments. The logistical differences between onshore and offshore drilling are also linked to differences in the geology of the intended drilling target. The geological history of the target rock formation influences, for example, its permeability and porosity, which in turn influence techniques and goals for well stimulation and completion. A summary of the panel presentation introducing readers to the life cycle of offshore oil and gas development from Azra N. Tutuncu, Colorado School of Mines, appears in Chapter 3, and summaries of presentations about technology deployment and practice in the offshore from Dennis McDaniel, Anadarko Petroleum Corporation, and Lisa Grant, Bureau of Safety and Environmental Enforcement, are provided in Chapter 4.

These decisions about stimulation techniques and goals also impact production costs, monitoring strategies, safety approaches, and policy decisions. The offshore industry has had a strong safety record related to deepwater production operations on the U.S. Outer Continental Shelf (OCS), according to Bud Danenberger, Independent Consultant. In terms of offshore safety, members of industry and regulating bodies alike play important roles in maintaining an operating culture that is safe for workers and the natural environment. Summaries of panel presentations from Benjamin Coco, American Petroleum Institute (Chapter 3), and from Danenberger; Paul Hebert, Chevron Corporation; and Nancy Tippins, CEB (Chapter 5) reveal more detailed information about regulatory initiatives, industry standards, and operational practices for increased safety in the offshore oil and gas industry.

In addition to the differences that exist between the onshore and offshore environments, differences are also evident when comparing one offshore region to another. Michael Schexnailder, Halliburton, and Mike Hecker, ExxonMobil provided overviews, respectively, of the operational differences between offshore development in the Gulf of Mexico and offshore California (Chapter 4). The different characteristics of these locations call for varied regulations and safety standards appropriate for each environment that, in turn, demand a high level of collaboration and coordination among multiple entities (e.g., service providers, operators and regulators). For example, states regulate operations in state waters, while federal agencies regulate operations in the OCS in conjunction with the appropriate states. Bradley Watson, Coastal States Organization, highlighted some of these state responsibilities and federal partnerships (Chapter 3).

Because the operating environments of the oil and gas industry are so diverse, it can be difficult to transfer this knowledge effectively among a broad audience that includes government decision makers, academic researchers, industry representatives, and members of the public. Accurate information is essential to support science- and technology-based decisions and to manage risk related to environmental and human health and safety. The data generated from decades of research on the environmental impacts of offshore oil and gas operations can be used to inform lease and permit approval decisions, to prevent or mitigate negative impacts to the environment, to increase system resilience, to inspire collaborative opportunities, and to educate affected communities. Environmental concerns, related research, relevant regulations, and useful technologies were addressed by the fourth and final panel in the workshop (Chapter 6): James Ray, Oceanic Environmental Solutions, LLC; Paul Montagna, Texas A&M University–Corpus Christi; Robert Habel, California Department of Conservation; and Desikan Sundararajan, Statoil.

To commence the workshop, Roundtable co-chairs David Dzombak, Carnegie Mellon University, and Wendy Harrison, Colorado School of Mines, offered an overview of the Roundtable's work. Since its formation in 2015, the Roundtable has held two prior workshops: they first discussed the reuse of flowback and produced waters,[2] and the second considered two separate topics, environmental legacy issues and induced seismicity, linked through the common theme of risk management.[3] Both of these workshops focused on unconventional hydrocarbon development in the onshore environments. Workshop co-chair Melissa Batum, Bureau of Ocean Energy Management, expressed the planning committee's hope that this third Roundtable workshop would begin to bring awareness of and clarity to the application of unconventional resource development technologies in offshore environments. She explained that the workshop would offer an introduction to the various stages of offshore oil and gas

[2] To read the proceedings of this workshop, visit https://www.nap.edu/catalog/24620.

[3] To read these two, separate proceedings of the workshop topics, visit https://www.nap.edu/catalog/25067 and https://www.nap.edu/catalog/25083.

operations and an overview of specific technologies for well completion, as well as a discussion of safety and environmental concerns associated with those technologies. Workshop co-chair Joe Lima, Schlumberger, indicated that the workshop would explore this information via comparisons between the offshore environments in the Gulf of Mexico and California.

This Proceedings of a Workshop was prepared by a rapporteur as a factual summary of what occurred at the workshop. The planning committee's role was limited to planning and convening the workshop. The views contained in this proceedings are those of the individual workshop participants and do not necessarily represent the views of all workshop participants, the planning committee, or the National Academies of Sciences, Engineering, and Medicine.

After the summaries of each presentation and accompanying moderated discussions are provided in the chapters that follow, supporting material is provided in the references and appendixes. Appendix A presents the workshop agenda; Appendix B contains a list of the Roundtable members; Appendix C provides biographies of the planning committee members; Appendix D offers biographical information of workshop moderators and presenters; Appendix E is a list of workshop participants; and Appendix F contains a glossary of frequently used terms. In addition to the summary provided here, materials related to the workshop, including videos, presentations, and discussion sessions can be found at http://nas-sites.org/uhroundtable/meetings.

Advanced Technologies for Offshore Oil and Gas Development: Resource Recovery, Environmental Stewardship, and Safety

2

The three keynote presentations and discussion summarized in this chapter provide an overview of practices and concerns associated with offshore development, well completion, and stimulation. Following the keynote presentations, Danenberger moderated a discussion between the panelists and workshop participants.

KEYNOTE PRESENTATIONS

From Exploration to Production: Offshore Oil and Gas Development and the Context of Unconventional Resources in the Offshore Environment

Evan Zimmerman, Offshore Operators Committee

Zimmerman explained that the primary impetus for offshore well completion design is sand control. He noted that high-volume hydraulic fracturing of unconventional formations, as is done, for example, for shales in the onshore, is not occurring offshore in the Gulf of Mexico. Offshore well completion activities are regulated extensively on both the operational and environmental sides. According to Zimmerman, because offshore completion operations occur by nature in remote areas, direct impact on public communities is minimized.

Zimmerman provided an overview of the Gulf of Mexico Outer Continental Shelf (OCS), which is divided into three regional planning areas: western, central, and eastern (see Figure 2.1). Overseen by several agencies,[1] energy production in the Gulf of Mexico represents a significant portion of federally derived oil and gas production. As of 2014, the Gulf's production generated the second largest source of income to the U.S. Department of the Treasury behind tax revenues collected by the Internal Revenue Service, and, as of 2013, OCS activities have created approximately 700,000 jobs and generated $62 billion (DOI, 2014), he said.

[1] Oversight agencies include the Bureau of Ocean Energy Management, the Bureau of Safety and Environmental Enforcement, the National Marine Fisheries Service, the Occupational Safety and Health Administration within the U.S. Department of Labor, the Office of Natural Resources Revenue, the U.S. Coast Guard, the U.S. Department of Homeland Security, the U.S. Department of Transportation, the U.S. Environmental Protection Agency, and the U.S. Fish & Wildlife Service.

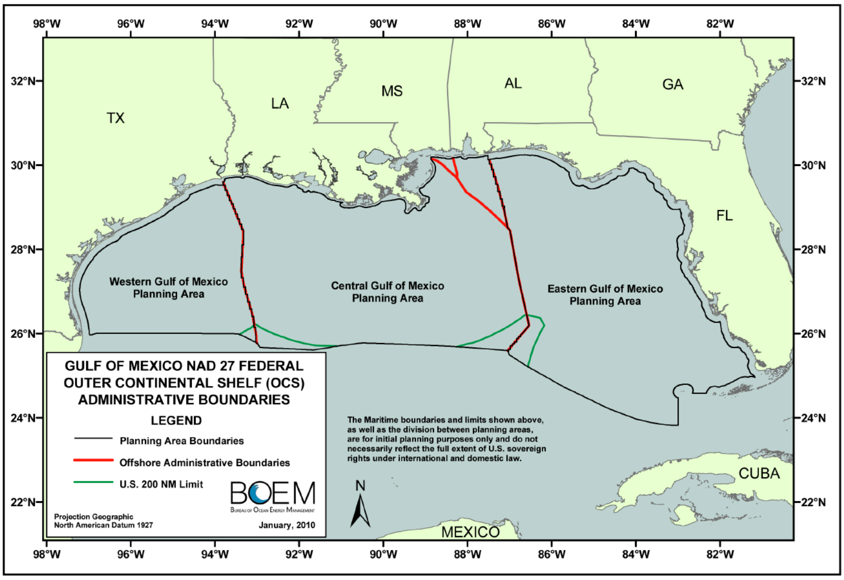

Figure 2.1 U.S. Gulf of Mexico Outer Continental Shelf overview. SOURCE: Zimmerman, Slide 4.

He noted that offshore well completion activities for both consolidated and unconsolidated sands are governed by a number of environmental regulations and/or permits. For example, air emissions are regulated by the Bureau of Ocean Energy Management's (BOEM's) air quality review process or the U.S. Environmental Protection Agency's (EPA's) permitting process, depending on the location in the Gulf of Mexico in which the completion activities will take place. Emissions that fall under these reviews or permits include those from permanent and temporary engines, support vessels, flares, and other well completion activities.

Water discharges are regulated and permitted by the EPA through the National Pollutant Discharge Elimination System (NPDES). These permits contain specific testing requirements and limits for discharges from completion, treatment, or workover-type byproducts and are renewed every 5 years to incorporate changes or initiate industry studies, Zimmerman said. Waste disposal is regulated by the EPA (via the Resource Conservation and Recovery Act and the Solid Waste Program), the U.S. Department of Transportation, and the individual states. He added that if used completion or stimulation fluids fail to meet NPDES criteria for discharge, they are shipped to shore for disposal, reuse, or recycle under state regulations. Regulations from the Occupational Safety and Health Administration, the U.S. Coast Guard, and the Bureau of Safety and Environmental Enforcement (BSEE) protect the workers themselves.

In conclusion, Zimmerman explained that because human populations are located at some distance from the OCS, impacts to community health, and related issues such as noise, traffic, or light considerations are absent. OCS wellbores also do not affect onshore drinking water aquifers, he continued. Offshore operations comply with zonal isolation[2] standards for water and hydrocarbon formations. Offshore operations primarily utilize seawater, although supplementary municipal water supplies from onshore Gulf States may be used occasionally.

[2] Zonal isolation involves placing cement barriers in the wellbore to prevent fluids such as water or gas in one zone around the wellbore from mixing with fluids such as oil in another zone.

Overview of Well Completion and Stimulation Technologies in Offshore Settings

David Payne, Chevron Corporation

Payne discussed a variety of well completion activities. He emphasized that while drilling is important, if completions are not done correctly, it is impossible to deliver the OCS oil or gas production needed to make wells economically sustainable. He explained that many different types of completions exist to address the requirements of the individual wells (see Figure 2.2). The simplest approach, an open-hole completion, is utilized only occasionally. Perforation through casing is another simple approach, best used for competent formations that do not need artificial support to maintain a borehole and thus do not require sand control. Two complex approaches that are used for sand control are the gravel pack and the frac pack. A gravel pack uses sieved sand as a filter to prevent formation sand from entering the wellbore, while the frac pack combines the gravel pack with hydraulic fracturing to create wide fractures filled with sieved sand that aid in connecting the reservoir to the wellbore.

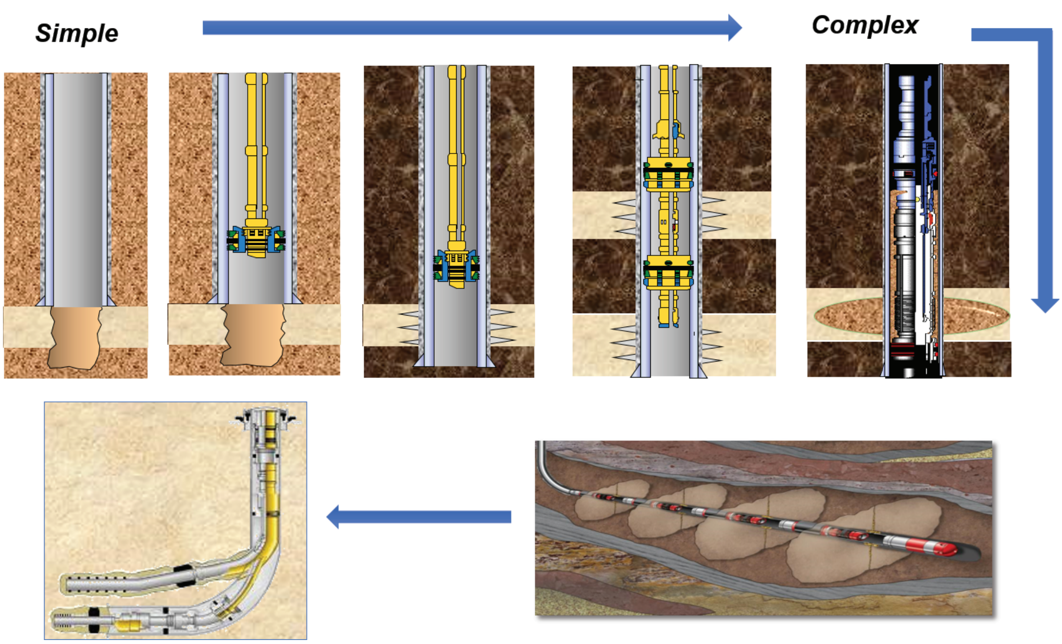

Figure 2.2 Types of well completions in order of complexity clockwise from upper left. The first two diagrams in the upper left depict open-hole completions. Very few of these are performed in the OCS. The diagram third from the upper left shows a completion that involves perforation through the well casing. In both examples, open hole and perforation through the casing, the rock formation has to be very competent and does not require any sand control (poorly consolidated sand does not occur and will not bleed into the wellbore). The figure second from the upper right is a stacked perforated completion where more than one interval in the rock formation of interest is perforated. The upper right figure illustrates a frac pack which is used for sand control. A frac pack places sand of a specific size into the wellbore essentially to work as a filter to prevent migration of fine particles and sand from the formation from getting into the wellbore as fluids (e.g., oil) are produced. The bottom right figure depicts the approach used in onshore situations with a combination of horizontal drilling and hydraulic fracturing along multiple zones of the same formation for low-permeabiltiy hydrocarbon-bearing formations such as shales. No wells in the OCS use this latter type of completion. The final figure on the lower left is a multi-lateral well—or a well with more than one wellbore extended into the formations of interest. Payne indicated that industry does not perform many completions this way. SOURCE: Payne, Slide 2.

Payne mentioned that open-hole sand control can be performed in many ways, the simplest of which is to put a standalone screen into the wellbore. This screen can be made of mesh, sand, or a series of rods. Proppant is not used in open-hole sand control, and sand is not pumped into the formation; sand is only present to filter fine-grained formation materials and prevent them from entering the tubing and being produced with the fluid. This process works best in wells with uniformly sorted sands. More recently, the industry has developed expandable screens: placing a screen against the sandface stops all sand movement, thus preventing the collapse of sand into the wellbore. This approach facilitates production, Payne said.

Sand control for cased boreholes[3] can be accomplished with the use of gravel packs, high-rate water packs, and frac packs. The gravel pack forces the gravel to remain in the wellbore and fill the perforations. This approach enhances productivity. High-rate water packs push the sand farther into the formation and allow pressure to rise to a level that improves the overall productivity of the wellbore, Payne remarked. The frac pack, one of the most commonly used completion techniques worldwide (particularly in deepwater wells), can create a 50- to 250-foot fracture to stimulate production in the well. He noted that although it is possible for such fractures to grow vertically, the preferred method is to keep the fracture inside of the reservoir. He explained that all of these completion techniques can also be used in the onshore environment.

Payne described another completion technique, hydraulic fracturing, that is most appropriate for use in sandstone, tight rock, and shales. In hydraulic fracturing, significant volumes of fluid are pumped to generate fractures (up to several hundred feet in length), which are then kept open with proppant. He noted that the high cost of this approach can be prohibitive, especially in the offshore environment. Acid stimulation, another type of completion that has been used for decades, can be used to stimulate the formation. Acid stimulation can be achieved through matrix acidizing (i.e., pumping acid into the formation below fracture pressure to dissolve minerals in the rock and create flow path channels) or acid fracturing (i.e., pumping a viscous fluid into the formation at or above fracture pressure and pumping acid into each fracture to create flow path channels).

Payne concluded by observing that industry has been completing wells offshore safely for decades. Although the techniques have evolved, there has not been a dramatic change in the primary approaches used to complete offshore wells. He noted that all aspects of drilling have been and remain highly regulated in the offshore environment and that collaboration among industry, regulators, and environmental nongovernmental organizations is necessary to continue to access these energy resources.

Regulatory and Environmental Considerations for Offshore Development

William Y. Brown, Bureau of Ocean Energy Management

Brown explained that BOEM, in cooperation with BSEE, manages energy and mineral resources for the approximately 2.2 billion-acre OCS. Of that area, about 1.7 billion acres falls within the oil and gas planning area under BOEM's purview.

BOEM evaluates mineral resource availability and economics, handles permits, leases offshore blocks, approves plans for exploration and development on lease blocks, sets financial

[3] A cased borehole is one that has had a pipe inserted into a section of the borehole and is typically cemented in place. The casing helps to isolate the oil or gas from communication with other fluids in the borehole or from contact with other fluids or rock formations along the wellbore.

responsibility for decommissioning facilities, and undertakes environmental research assessment and regulation. According to Brown, BOEM also provides environmental analysis to BSEE in support of its decisions and activities. BSEE, on the other hand, handles permits for drilling and authorizations for laying pipelines and decommissioning facilities at end of life; ensures that safety and environmental requirements are implemented fully by operators; and maintains engineering expertise needed to carry out inspection and enforcement duties.

Brown highlighted BOEM's resource development programs: (1) oil and gas, which make up the largest share of its work; (2) renewable energy, which currently focuses on wind energy; and (3) marine minerals (e.g., sand and gravel) and response to storm beach erosion. BOEM also leads a program that conducts environmental studies on the impacts of BOEM-authorized activities and evaluates impact mitigation options. This program ensures that environmental protection is at the forefront of BOEM's decision-making processes.

The Outer Continental Shelf Lands Act (OCSLA) serves as the foundation for BOEM's governance, Brown said. BOEM uses OCSLA's environmental standards, in addition to other statutes and directives, as a guide to informed decision making. BOEM also uses the National Environmental Policy Act as a framework to analyze its authorized activities, to evaluate alternative approaches, and to create scientifically motivated mitigation strategies. BOEM's oil and gas program begins with a 5-year national program of lease sales, moves to individual lease sales, reviews exploration and production plans, and then approves site development. Brown clarified that while BOEM leases blocks to companies and approves exploration, development, and protection plans, BSEE handles requests for facilities whose plans have already been approved by BOEM but that seek a permit to modify their wells.

Brown defined well stimulation as any treatment of a well to enhance oil or gas production or recovery onshore or offshore, often involving fracturing by pressure from injected fluids or treatment with acid. He explained that well stimulation may affect air and water quality as well as people and biological resources, owing to the discharge of waste water containing small amounts of chemicals, release of greenhouse gases to the atmosphere, and induced seismicity. He explained that the potential for these impacts varies between the onshore and offshore environments (see Figure 2.3), emphasizing that well stimulation offshore, which has been in practice for decades, shows far fewer negative impacts than well stimulation onshore.

Brown shared some of the potential environmental impacts that BOEM considers before authorizing offshore activities, including oil spills, bottom disturbance obstructions, noise, air emissions, lighting, vessel traffic, and viewscape. While these are all valid concerns, he noted that BOEM has already developed mitigation strategies and that there are appropriate existing regulations to address these concerns. He emphasized that the addition of well stimulation with offshore oil and gas production generally lessens such environmental impacts—more energy can be recovered with less new infrastructure.

MODERATED DISCUSSION

A participant asked for clarification on the suggestion that methane emissions are negligible in the offshore environment and that completions onshore are the major source of methane emissions. The participant explained that the majority of methane emissions in the onshore environment correspond to the supply chain from production, not completion, and, with the addition of green completions, methane emissions have decreased overall in the on-

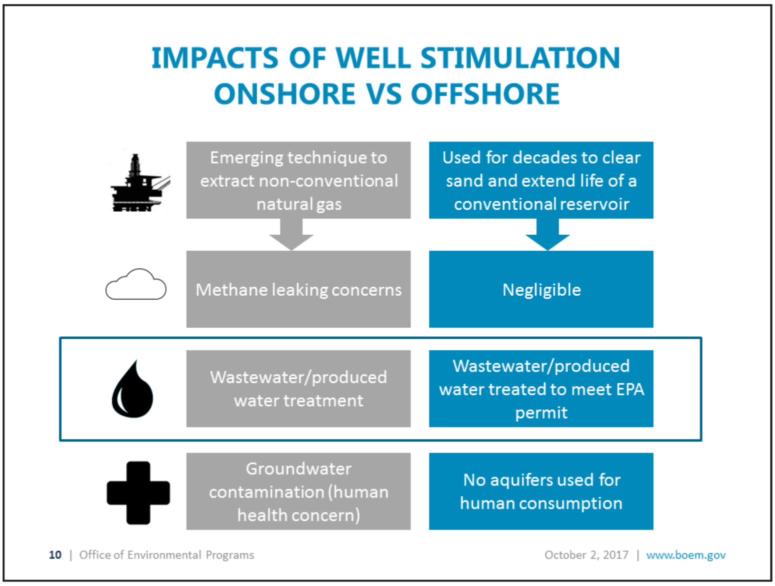

Figure 2.3 Differences in well stimulation impacts onshore versus offshore. The onshore processes and potential impacts are in the left-hand (gray boxes) column while the offshore processes and potential impacts are shown in the right-hand (blue boxes) column. The impact symbols in the far-left column, top to bottom are drilling and completion, air, water, and human health. SOURCE: Brown, Slide 10.

shore. He asked the keynote speakers if data have been collected in the offshore environment, using top-down or similar approaches that confirm that the emissions are actually negligible. Brown responded that data show fugitive methane emissions to be limited in the offshore environment, and that recent studies may suggest significant releases of methane in the onshore. Danenberger noted that there are clear differences in the offshore and onshore environments, adding that offshore production is much less dispersed than that onshore. He explained that in the offshore, production from a small group of large, modern facilities is managed effectively with careful inspection of potential release points. Brown acknowledged that the issue of emissions is worth further study and suggested the Gulfwide Offshore Activity Data System[4] as a starting point for future discussions on pollutants, while Payne suggested that methane emissions could be the central focus of a future workshop.

Another participant asked about the differences in injection pressures between an offshore frac pack and an onshore shale gas well. Payne explained that, relative to the formations, injection pressures are generally higher in the onshore than in the offshore. In the offshore, the injection pressures are not as high relatively speaking because only small fractures, requiring lower pumping rates, are needed. Payne added that, depending on the depth of the offshore well, injection pressures can range from only a few thousand pounds per square inch (psi) to as high as 10,000 psi.

Another participant wondered how the panelists' assessments might apply in Alaska where there are both fewer regulations than in the Gulf of Mexico and increasing opportunities for drilling in the Artic environment. The participant added that the use of fresh water for stimulation and hydraulic fracturing is a concern for Alaskans, especially in Cook Inlet.

[4] Available at https://www.boem.gov/Gulfwide-Offshore-Activity-Data-System-GOADS (accessed November 22, 2017).

Payne responded that, from a completion perspective, the issues for Cook Inlet are similar to those in the western region of the Gulf of Mexico: it is important to ensure that discharges meet requirements of discharge permits and that contaminants are not being placed in the sea. OCS operations strive to use as much seawater as possible because the supply of fresh water is limited, and it would be too expensive to haul fresh water for stimulations. He encouraged industry to continue to identify approaches that use less fresh water. The participant noted that Cook Inlet has fewer discharge requirements than other coastal areas and suggested that there are areas in which industry could also strengthen standards.

Regarding active fracturing operations, a participant asked whether the operator or the drilling contractor bears responsibility. Payne emphasized that because decisions need to be made quickly during operations, the point of contact is identified before well stimulation begins. He explained that a drilling contractor is not responsible for decision making during the stimulation; the stimulation company makes decisions and, owing to the high costs and high impacts of such activities, OCS drilling and completion jobs are also monitored remotely. Danenberger added that Safety and Environmental Management System requirements make clear that operators are responsible and held accountable for everything that happens on a lease.

Another workshop participant asked the panelists to discuss how geological differences affect completions in the onshore and offshore environments. Payne noted that while there is no difference between the rocks onshore and those offshore, there is a difference in play types, especially in the consideration of shale plays, which generally are not seen offshore.

Continuing the discussion on the differences between the onshore and offshore environments, a participant asked whether there are different degrees for monitoring well completion quality. Payne responded that although quality may be monitored in different ways, the highest quality completion possible is desired in both environments. He added that the type of monitoring utilized depends on the size, cost, and setting of the well. To maximize production, for example, more money may be spent on a deepwater well than on an onshore shale well because the deepwater well itself was initially more costly. Wellbore integrity is a high priority in both environments, according to Payne, and decisions about monitoring center around the desire to avoid failure and prevent risk to the community and the environment. In response to the participant's follow-up question about the regulatory role in monitoring well quality, Payne highlighted the high number of regulations in the offshore related to water discharge. Brown added that the OCS and the onshore environments are governed by different agencies and different laws, and Payne noted that onshore regulations can be especially difficult to navigate, owing to the high number of jurisdictions. Danenberger stated that BSEE reviews every completion program and reviews subsequent data, and he reiterated that quality control is an important and challenging issue in all environments.

Another participant asked about the future of offshore technologies, including possible innovations and their relationships to regulations. Zimmerman suggested that the current hydraulic stimulation and completion technologies and their corresponding regulations will still be valid in the future. Before new technologies are implemented offshore, a design technology review is completed. Thus far, Zimmerman explained, agencies have adjusted regulations appropriately based on potential risks of new technologies. He added that most new technology has proactively focused on safety and efficiency in the offshore—for example, offshore supply vessels run on natural gas to improve air quality and reduce emissions. Brown commented on the importance of performance-based innovation rather than design-based innovation, given that performance relates most closely to risk. Payne added that outcome-based regulations may be more effective than prescriptive regulations, which could stifle innovation. He explained that the industry can also become more economically viable with innovations that limit infrastructure while increasing production efficiency, such as by joining remote fields into single hubs in the subsea infrastructure. Danenberger explained that the number of niche companies interested in taking advantage of oil and gas still in place is shrinking. For example, while there used to be approximately 4,000 platforms on the Gulf OCS, there are now approximately 2,000, only half of which are active. He added that because the industry functions more as a decommissioner (of old platforms) now, it is imperative to find new fields to tie back to existing production sites instead of creating new platforms.

In response to a participant's inquiry about the use of desalination operations on platforms to generate fresh water, Payne explained that every rig operating in deep water has a desalination unit on board to generate its own fresh water, though the units are small and can generate only a limited volume each day. Most of this water will be used to support the rig, as opposed to sustaining drilling operations. When a larger volume is needed for drilling activities, Payne continued, water has to be hauled in from onshore at great expense. He reiterated that the rigs prefer to use seawater whenever possible.

Another participant asked the panelists to discuss how robotics, artificial intelligence, and remote sensing could impact the offshore environment. Zimmerman expressed confidence in the industry's ability to find applications of such technologies as they mature and noted that drone technology is already regularly used to conduct offshore inspections. Payne suggested a better balance of regulation and innovation for the industry moving forward. He hypothesized that in the future drilling rigs could be run without people on board and that remote monitoring will improve safety and efficiency. Brown noted that the industry is especially interested in the use of remote sensing to reduce the cost of air quality monitoring in the offshore as well as the use of biological monitoring to better understand the environments. Danenberger recalled that the implementation of automation approximately 30 years ago significantly reduced the number of injuries from falls and falling objects in drilling operations, and he added that new technologies, such as the possibility of monitoring U.S. operations from abroad, raise broader questions about regulation and safety. Because information technology and big data stand to have the most substantial impact on the industry, Payne encouraged undergraduate programs to adapt curricula accordingly so as to better prepare future regulators and operators.

Offshore Oil and Gas Development 101

3

The first panel of the workshop included three presentations that highlighted the common elements of offshore oil and gas development including the life cycle of offshore operations, the industry's best practices and risk management strategies, and the state regulatory landscape. The panel and subsequent discussion between panelists and audience was moderated by Jill Lewandowski, Bureau of Ocean Energy Management.

PANEL PRESENTATIONS

Life Cycle for Offshore Development and the Offshore Footprint

Azra N. Tutuncu, Colorado School of Mines

Tutuncu opened her presentation with a historic overview of onshore and offshore exploration and production in the United States (see Figure 3.1). Since the first offshore operation out of sight of land began in 1947, offshore operations have expanded in the Gulf of Mexico, with additional activity off the coast of California. Production increased in the central Gulf throughout the 1970s, while migration toward the western Gulf (which has geological differences relative to the central Gulf) did not occur until after 2000. Tutuncu explained that much of today's Gulf operations occur in ultra-deep water.

Tutuncu categorized the life cycle of an oil and gas field into five stages that take place over several decades. Exploration for viable hydrocarbon reservoirs occurs in the first 5 to 10 years during which many data are collected and, if an exploration well determines that a formation is carrying economically recoverable hydrocarbons, the reservoir is evaluated for production well placement. In the 15 to 30 years of production that follow, the field is developed, data about the reservoir continue to be collected, and the number of subsea wells tied back (with flow lines) to existing surface facilities may be increased to reach other parts of the reservoir. Decommissioning begins when production is no longer economically viable and at the end of this stage, the wells are ultimately reclaimed or plugged.

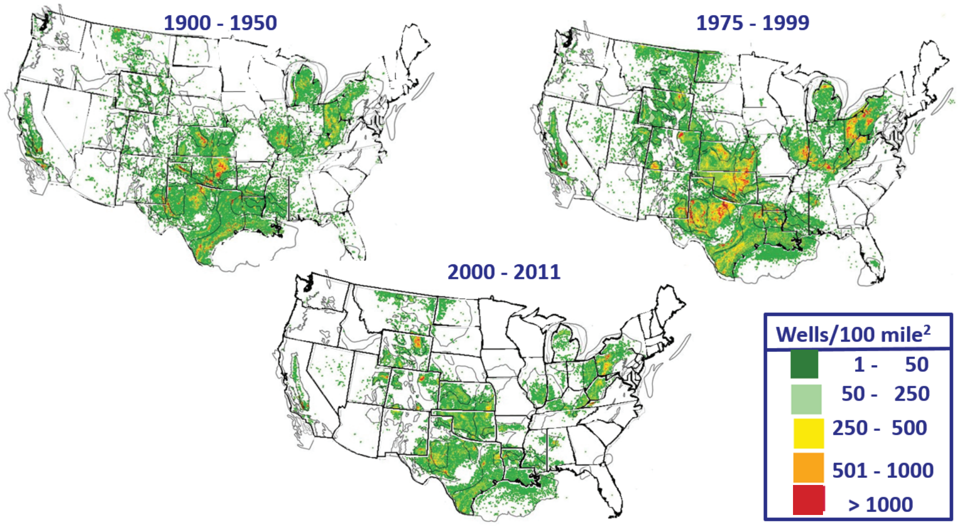

Figure 3.1 U.S. onshore–offshore exploration and production from 1900 through 2011. The green colors represent the number of wells per 100 square miles with increasing numbers of wells per that square area increasing as colors grade from green to yellow, orange, and red (which represents more than 1,000 wells per square 100 miles). SOURCE: Tutuncu, Slide 2; NPC, 2011.

She explained that drilling, completion, production, and the length of the life cycle itself are influenced by the geology of the location. The geology of the Gulf of Mexico is particularly complex, given the large amount of salt that accumulated in 29 different depositional stages that began millions of years ago. This creates an especially challenging environment for exploration, drilling, completion, and production, according to Tutuncu. Prior to the development of advanced seismic processing techniques, geomechanical modeling, data integration, and better tomography efforts, it was difficult to collect clear images of some portions of the subsurface because of the salt, and thus difficult to obtain accurate information about sub-salt rock formations that might contain oil or gas. Additional challenges for drilling arise in the offshore environment as a result of lower fracture gradients and lower vertical stresses alongside higher pore pressures relative to the onshore environments, with higher pore pressures in the rock formations particularly as salt is approached. Advanced techniques such as managed pressure drilling or casing drilling can be used to overcome some of these challenges, Tutuncu explained.

Regarding asset evaluation, Tutuncu remarked that modeling how these formations will compact and how fluid pressure will change, in combination with real-time monitoring, can be useful in understanding the overall life cycle of production. She emphasized that offshore drilling allows for a smaller surface footprint with increased well productivity. Production continues to ramp up with the development of more wells and, when production stabilizes, advanced oil recovery techniques can then be used to extend maintenance of the reservoir pressure before the reservoir begins to decline in production. Tutuncu reiterated that a central objective in all offshore operations is to prevent or manage sand production and associated erosion within the well. High pressures and high temperatures in the offshore environment can make achieving this goal particularly difficult. Once production falls too low, she explained, the platform and field will be decommissioned—wells are flushed, plugged, and cemented to secure the residual hydrocarbon reserves for future use. Tutuncu closed with a few comments about the progress in offshore deepwater technology: The first fixed offshore platform in greater than 1,000-foot water depth (Cognac well) was built in 1978, while the world's deepest oil and gas project at around 9,500-foot water depth (Stones well) was built in 2016. She expects this arena will continue to evolve with the introduction of new technologies to confront the challenging deepwater environment.

Industry Risk Management—Industry Practices and Approaches for Managing Safety and Integrity of Well Stimulation Technologies

Benjamin Coco, American Petroleum Institute

Coco began his presentation with a brief history of the American Petroleum Institute (API). Founded in 1919 as a nonprofit national trade association, API represents all segments of the oil and natural gas industry and strives to have a completely transparent process in its development of industry standards. API published its first standard in 1925. By 1969, API also became active in public policy issues. He explained that the organization is accredited by the American National Standards Institute and has more than 660 member companies. API aims to improve safety, reliability, and equipment; reduce compliance and procurement costs; and offer a foundation for company standards. Although following API standards is a voluntary process, federal and state regulators cite API standards more than any other industry standards, according to Coco.

He defined three key terms that may be essential to understanding API's standards:

- Risk management. Identification, assessment, and prioritization of risks followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events or to maximize the realization of opportunities.
- Hydraulic fracturing. Well completion technology for the development of unconventional resources that creates a fracture network through which oil and gas can migrate to the wellbore.
- Consensus-based standards. Substantial agreement has been reached by directly and materially affected interests. (Not all standards fit this definition.)

Coco noted that attention to detail and best practices are crucial during well stimulation activities to avoid lasting negative impacts. He described well design and construction as featuring multiple layers of casing and cement. He mentioned four main components: conductor casing, surface casing, intermediate casing, and production casing (see Figure 3.2). Well-by-well design is determined by jurisdictional regulations and influenced by relevant standards.

Coco commented that prior to 2005, shale gas constituted only 4 percent of U.S. gas production; in 2013, it constituted more than 30 percent. He explained that domestic gas and oil production and reserves are now displacing gas and oil imports. He reiterated that onshore operations are quite different from those offshore in terms of accessibility, resources, logistics, and economics. He added that because of the increased volume of domestically produced natural gas (see Figure 3.3), an increase in production and a decrease in imports of natural gas over time have taken place: U.S. exports will likely surpass U.S. consumption by 2020. Coco expects to see more growth in dry natural gas production, specifically, in the U.S. onshore environment and more opportunities in the offshore environment as well. He explained that reliance on natural gas and natural gas liquids will rise as industrial energy use grows and that there is no one-size-fits-all approach to managing associated risks.

Coco provided an overview of API documents specific to hydraulic fracturing that were developed in response to onshore activity.[1] RP 100-1 contains best practices for well design as it relates to well integrity and fracture containment. RP 100-2 provides best practices for planning and operating a well that has been stimulated, including advice on managing environmental aspects during construction. RP 100-3 is a community engagement document that offers guidance on how industry can work with communities, address public concerns, and share mitigation strategies.[2] Coco emphasized that standards documents do not contain "how to" guides, which can be found in academic texts instead. He added that the combination of standards documents and academic resources plays an important role in managing risk and planning operations.

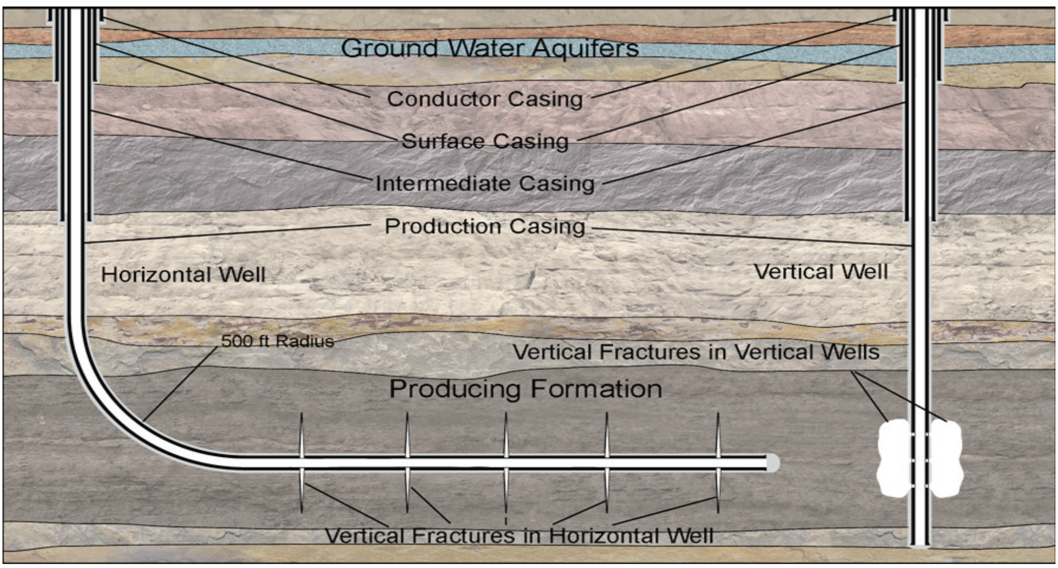

Figure 3.2 General example of two types of well configurations which could apply to onshore or offshore circumstances. The well on the left is a vertical well with an added horizontal extension through the formation of interest and which is then hydraulically fractured (if the formation has very low permeability, such as a shale). The well on the right is a vertical well with production from viable rock units along the length of the well and which does not require hydraulic fracturing because the rock formation has adequate permeability and porosity to support conventional production of oil or gas. With the exception of the horizontal leg on the well on the left, the basic elements of the wells in terms of casing placement are similar. Note, however, that in the offshore, horizontal drilling accompanied by hydraulic fracturing is not at all common. SOURCE: Coco, Slide 5.

[1] API has more than 600 other types of standards relating to issues such as cement design, completion zones, and lease operations, indicating that many considerations exist when designing and executing a well. Available at http://www.api.org/products-and-services/standards/purchase#tab_catalog (accessed October 31, 2017).

[2] Other organizations with relevant publications include the Center for Offshore Safety, the International Association of Drilling Contractors, the International Organization for Standardization, the International Organization of Oil & Gas Producers, the Offshore Operators Committee, and the Society of Petroleum Engineers.

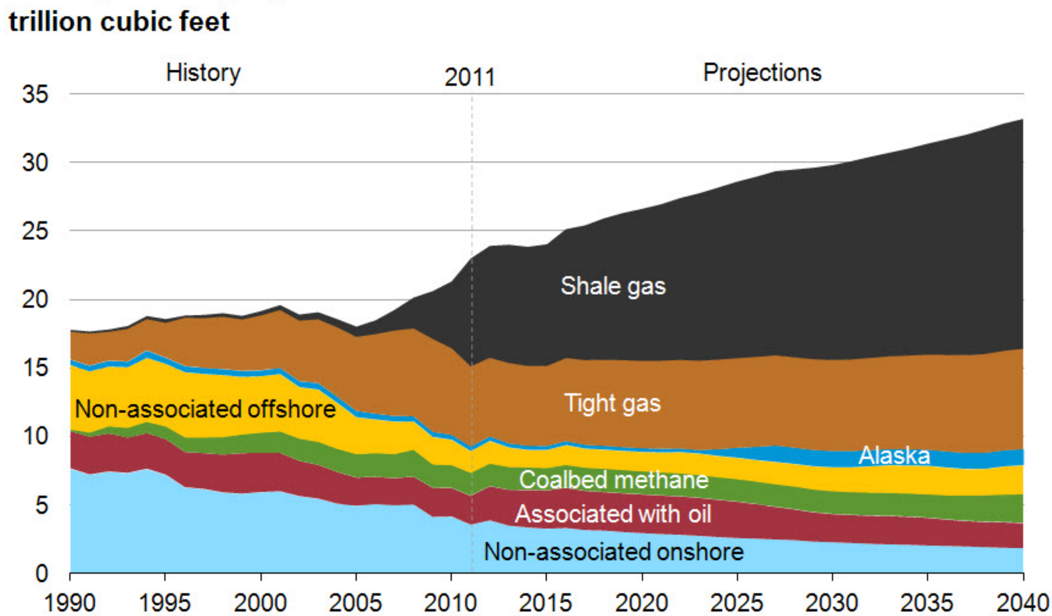

Figure 3.3 U.S. dry natural gas production. SOURCE: Coco, Slide 9.

The State Regulatory Landscape—State Responsibilities and Cooperation with Federal and Private Entities

Bradley Watson, Coastal States Organization

According to Watson, the Coastal States Organization (CSO)[3] was created in 1970 and represents 34 coastal states/Great Lakes states/territories. The CSO has members appointed by the governors and the organization's central mission is to increase collaboration among state, local, and federal agencies.

Watson explained that the Coastal Zone Management Act of 1972 (CZMA) recognizes a national interest in effective management, beneficial use, protection, and development of the coastal zone (boundaries defined differently in each state), which offers a natural, commercial, recreational, industrial, and aesthetic value. CZMA looks at economic development and environment concerns in balance; ensures that resources are available to people and industry; and reaffirms state sovereignty over coastlines while reinforcing a national interest. He remarked that CZMA created the following three entities: (1) National Coastal Zone Management Program, (2) National Estuarine Research Reserve System, and (3) Coastal and Estuarine Land Conservation Program.

The National Coastal Zone Management Program (see Figure 3.4) allows the states to take the lead when working with federal agencies to manage coastal resources and on issues of coastal development, public access, water quality, coastal hazards, and consistency of federal agency actions.[4] Watson noted that federal agency actions that affect state coastal zones include such components as issuing licenses, implementing Outer Continental Shelf plans,

[3] The website for the Coastal States Organization is www.coastalstates.org (accessed November 1, 2017).

[4] Federal consistency refers to the notion that federal agency actions, in or outside the coastal zone, that affect any land or water use or natural resource of a state's coastal zone must be consistent to the maximum extent possible with the enforceable policies of state CZMA programs (CZMA § 307 (16 U.S.C. § 1456)).

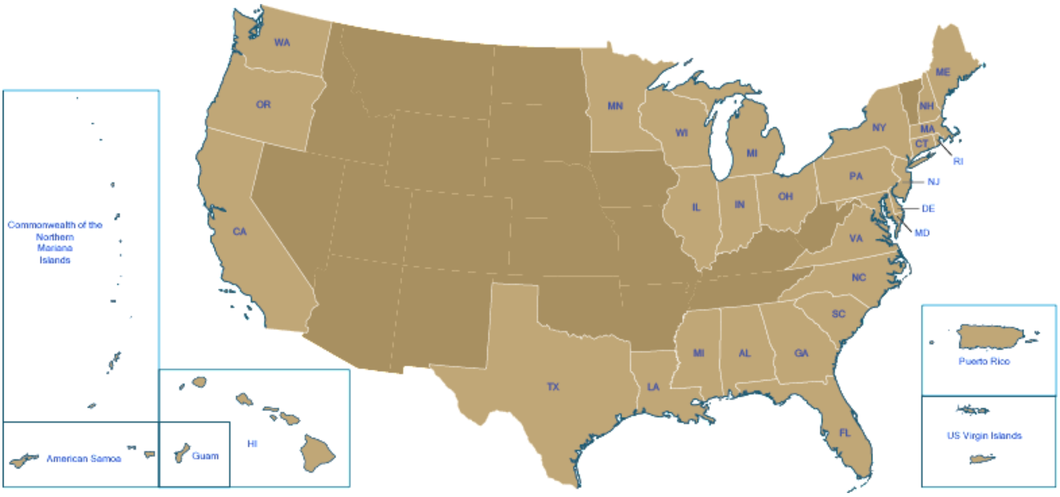

Figure 3.4 The National Coastal Zone Management Program. SOURCE: Watson, Slide 6.

installing gas pipelines, and altering wetlands. Coastal effects of these actions may be direct, indirect, or cumulative, as well as positive or negative. If the agency identifies reasonably foreseeable effects, then a consistency determination will be submitted, according to Watson. An item under consistency review will be linked to a policy enforceable by the state that does not discriminate, assert jurisdiction over federal agencies or properties, and is not preempted by federal law, Watson continued. States then have the opportunity to respond to a consistency determination in one of four ways: concurrence, conditional concurrence, objection and appeal to the Secretary of Commerce, or, if no decision is made by the state, assumed concurrence. Historically, states have concurred with 93 to 95 percent of federal actions reviewed.

Watson emphasized that federal consistency helps avert disputes, streamline permits, increase collaboration, and decrease uncertainty and potential litigation in a timely fashion over activities in federal waters that affect state coastal zones. Ultimately, consistency allows for early consultation, cooperation, and coordination.

MODERATED DISCUSSION

Jill Lewandowski, Bureau of Ocean Energy Management

A participant asked about the potential for hydraulic fracturing and other unconventional technologies to be employed in ultra-deep water. Tutuncu explained that onshore, it takes an enormous amount of pressure to break a formation and start propagating a fracture. However, although the offshore environment has lower overburden stress, it also has lower fracture gradients than the onshore, which can make hydraulic fracturing easier in the offshore environment. She added that offshore formations are deposited differently from onshore shale formations—most offshore operations engage conventional deposits, though unconventional operations are possible in ultra-deep water. Tutuncu suggested that offshore unconventional operations may even be slightly easier than those onshore. Thus, although operations in ultra-deep water can be difficult from a well-integrity perspective, owing to the uncertainty in the stress state, they are not difficult from a fracturing perspective. She reiterated that advanced technologies (e.g., advanced cementing, tubulars, and casing drilling) may be essential before drilling deeper in the offshore.

Another participant asked Watson about issues for unconventional hydrocarbons in the coastal zone regulatory environment. Watson emphasized that the issues are expansive and depend on the impact (e.g., harm to a species) to a state's coastal zone from a specific action. Each state's leadership has its own positions on the appropriateness of pursuing production after identifying an impact; however, the leadership is required to justify the impact to the Secretary of Commerce if the discussion proceeds to a higher level. Watson confirmed that although the specifics of conventional and unconventional hydrocarbon development vary, the process for identifying issues and addressing potential impacts are the same for both.

Because Alaska recently dropped its coastal zone management program, another participant noted that it deals with even more complicated decision-making issues. The participant voiced concerns about relying on standards in lieu of regulations in instances where standards can be difficult to enforce or may have gaps owing to a lack of consensus. While the participant acknowledged the good intentions of allowing the public to weigh in on standards, such an approach can add to the complexity of such a process. Coco responded that while some standards may present gaps in content or use non-consensus language, he asserted that it is better to offer some guidance rather than none. He added that it is the responsibility of a company to enforce a standard by incorporating and/or amending it as an official policy or by allowing the spirit of the standard to influence the company's decision-making processes.

A participant asked Coco if API plans to publish specific guidance to address barriers in hydraulic fracturing. Coco reiterated that API does not issue prescriptive literature—that responsibility falls under the purview of the company instead. Because API's standards are developed around the industry's priority issues and the volunteers' time and expertise, it is impossible for the organization to address every issue. However, Coco continued, API provides helpful risk-management tools. Another participant added that because there are myriad ways to solve a particular problem, it is best to avoid creating overly prescriptive standards that stifle innovation and limit opportunities for progress and safety. This participant encouraged workshop participants to attend API's meetings to witness the rigor that goes into developing standards.

Given the complexity of offshore operations, a participant asked how coordination and communication are handled among the various units involved. Lewandowski responded that it depends on the statute, as there are differing oversight responsibilities, but the use of memoranda of understanding, standard operating procedures, and regular communication are indispensable. Despite this level of coordination, it remains challenging when different federal entities have different responsibilities. She noted that although the process is not perfect, it is continually improving with the use of communication spaces and streamlined opportunities as well as the avoidance of overregulation.

Offshore Technologies in Practice

4

The second panel of the workshop included four presentations that focused on the well completion and stimulation technologies and operations utilized in the Gulf of Mexico and in the Pacific offshore environments, as well as strategies to address challenges and manage risks in these environments. The panel and large-group discussion were moderated by George Wong, University of Houston.

PANEL PRESENTATIONS

Offshore Well Completion and Stimulation Operations Using Hydraulic Fracturing and Proppant: Technologies, Operational Practices, Challenges, and Risk Exposures

Dennis McDaniel, Anadarko Petroleum Corporation

McDaniel explained that reservoir characteristics determine well completion requirements in the offshore environment. These characteristics include porosity (i.e., void space between the sand grains of the rock), permeability (i.e., interconnected void space and the ability of fluids like oil and gas to flow through that rock matrix), pressure, and temperature. He noted that completions are done in either unconsolidated or consolidated sands. In designing offshore completions, sand control is the central objective. Typically, unconsolidated sands are shallower, younger Cenozoic-era rock formations (Pliocene and Miocene in age, or between about 3 and 23 million years old) with high-permeability reservoirs, while consolidated sands are deeper, older Cenozoic rock formations (Oligocene, Eocene, Paleocene in age, or between about 23 and 66 million years old) characterized by higher pressures and temperatures and lower-permeability reservoirs. As a result, different completion techniques are used in each of these environments. Gravel packs and frac packs can be used in unconsolidated sands for sand control; however, in consolidated sands, a fracture stimulation (i.e., hydraulic fracturing) is performed to aid production of oil or gas from the well (see Figure 4.1), according to McDaniel. He remarked that all three techniques have been applied successfully for years in the Gulf of Mexico.

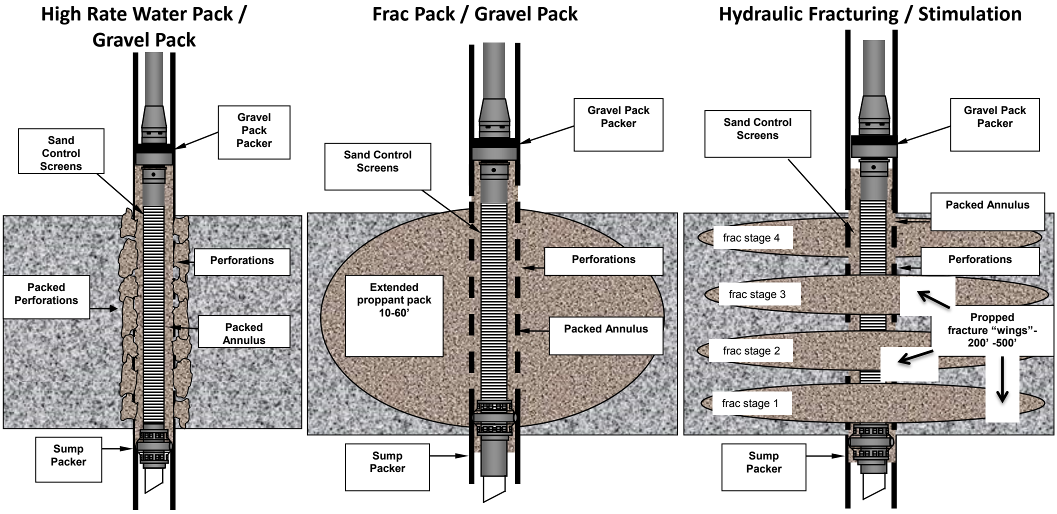

Figure 4.1 Completion techniques for the offshore environment. SOURCE: McDaniel, Slides 6-8.

McDaniel explained that in a gravel pack (also known as an annular pack or a high-rate water pack), one fills the perforation tunnels and the screen annular volume with sand. This significantly reduces the amount of formation sand flowing into the wellbore. Gravel pack technology has been used for more than 50 years and historically represented 100 percent of the sand control well completions in the Gulf of Mexico, though, due to technological evolution, it is now used in less than 10 percent of completions. A frac pack induces near wellbore fracture geometry that is then filled with proppant to bypass near wellbore damage from drilling and to extend the proppant pack a farther distance from the wellbore into the reservoir (approximately 10- to 60-foot fracture half-lengths[1]). This technology is not, however, intended for significant reservoir stimulation like hydraulic fracturing. The frac pack has been in use for 25 years and currently is used for approximately 75 percent of the completions in the Gulf of Mexico, McDaniel said. It offers greater reliability and reduced interventions than the traditional gravel pack. Hydraulic fracturing is a technique used for stimulation in consolidated reservoirs. While this technique has been used onshore for decades, it has only been utilized offshore for approximately 10 years and is deployed in less than 10 percent of Gulf completions. He noted that hydraulic fracturing minimizes the number of wells needed to develop a reservoir (less environmental impact) and allows for the development of natural resources not previously considered commercially viable. McDaniel emphasized that all three completion techniques are covered by existing operational and environmental regulations and permits.

McDaniel then described the step-by-step process for frac pack sand control completion operations. Gel and water are mixed together into a viscous oil-like substance, and then proppants and additives are blended into the gel, creating a Jell-O-like substance. This substance is pumped down hole, and the fluid transports proppant into the created fracture. Once the fracture is filled with proppant, the pumping stops. Aided by the additives, the fluid reverts to a liquid, the fracture closes onto the proppant, and the fluid flows out of the well during production. The proppant that has been trapped in place during this process provides a highly conductive channel

[1] The fracture half-length is the distance from the well to the tip of the fracture.

for the reservoir fluids to flow through toward the wellbore, increasing the well's productivity. He added that mini-fracs (small fractures created using fracturing fluid without any proppant to determine stress magnitude) are sometimes used in the offshore to learn about the reservoir and aid in design of treatment.

McDaniel next provided an overview of well treatment volumes. For example, in unconsolidated sands in the offshore conventional environment, less than 5,000 barrels[2] of proppant may be needed in the main stage of treatment. In consolidated sands in the same environment, more than 5,000 barrels may be needed per stage, with two to five stages likely. For the onshore unconventional environment, main treatment volumes may exceed 30,000 barrels[3] per stage, with more than 10 stages possible. He emphasized that reservoir properties dictate what each well needs in the design stage.

The technologies used onshore as compared to technologies used offshore for well completion vary, according to McDaniel. He reiterated that in the onshore, the primary driver is to create fractures in tight rock for productivity, while the primary driver in the offshore environment is sand control. He added that gravel packs, frac packs, and hydraulic fracturing can be used onshore or offshore. However, another difference between the uses of the technologies is that high-volume hydraulic fracturing of unconventional formations onshore is not yet occurring offshore in the Gulf of Mexico. Echoing what Evan Zimmerman, Offshore Operators Committee, said in a keynote address at the beginning of the workshop, McDaniel explained that concerns about implications for drinking water aquifers are not pertinent to offshore operations, and the remoteness of offshore operations ensures minimal public impacts from completion activities.

Approaches in the Gulf of Mexico: Technologies, Operational Practices, Challenges, and Risk Exposures

Michael Schexnailder, Halliburton

Schexnailder provided an overview of land-based fracturing operations prior to discussing stimulation vessels and their operations in the Gulf of Mexico. He explained that for onshore operations, water, proppant, and additives are first blended to generate the stimulation fluid that is delivered to high-pressure pumping units. These units then send the fluid down into a well. Monitoring of this complex process is done in real time and on-site in a technical command center. For offshore operations, all of this equipment is built into the vessel, which has five zones (see Figure 4.2): (1) fluids and bulk storage of proppants are on the bottom; (2) an active storage section for proppants is above; (3) the fluids from below deck are added to the proppant in the blender section in the middle (with additives specific to offshore stimulation); (4) the blended fluid is delivered to high-pressure pumps; and (5) the fluid is sent to the high-pressure flexible Coflex hose (approximately 400 feet in length) mounted on a reel and transferred to the drill ship. On a vessel such as the Stim Star IV, for example, a typical job for a consolidated frac pack stimulation would have approximately 3 million pounds of proppant and 40,000 barrels of fluid, according to Schexnailder. Jobs are pumped at a rate of 25 to 45 barrels per minute, and the pressures range from 8,000 psi to 13,000 psi.

Schexnailder explained that the vessel is safely placed in close proximity to the drill ship through the use of dynamic positioning. Dynamic positioning utilizes a system of thrusters and

[2] Equivalent to 210,000 gallons.

[3] Equivalent to 1.26 million gallons.

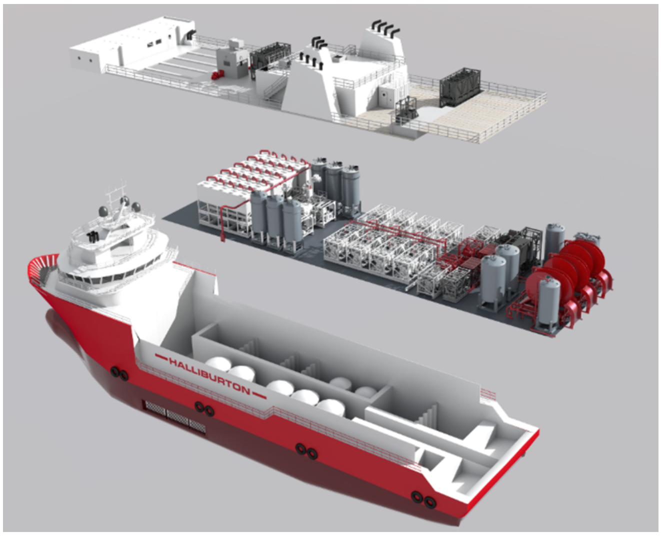

Figure 4.2 An example of a multi-zone stimulation vessel. SOURCE: Schexnailder, Slide 9.

high-precision measurement and monitoring systems to ensure that the vessel stays in a specific location. The U.S. Coast Guard routinely inspects the dynamic positioning system. Redundant safety measures include the use of a global positioning system, optics, and radar.

It is important that measures to ensure operational safety begin far in advance of the time that the vessel arrives on location, according to Schexnailder. There is an initial coordination of materials and plans to load them onto the vessel, as well as coordination between the vessel captain and the drill ship regarding weather conditions that could delay the job. Once the vessel arrives on location, the dynamic positioning system is checked. Next, a pre-job meeting occurs in which all of the parameters of the stimulation and monitoring operations are discussed and a system pressure test is conducted. The stimulation is then ready to begin and will range in duration from 8 to 18 hours, he explained.

Schexnailder emphasized the importance of communication paths; the stimulation vessel captain remains in constant communication with the drill ship captain regarding weather or dynamic positioning issues because vessel safety is their primary operational concern. Personnel on the stimulation vessel are also in constant contact with the drill ship, maintaining stability while as much as 25,000 pounds of material is moving per minute. He remarked that if the dynamic positioning system cannot hold its position, due to weather or other performance issues, the job can be shut down, with the hose placed back on the stimulation vessel and the vessel departing the location within approximately 30 minutes. Alternatively, in an emergency situation, the hose can be disconnected from the stimulation vessel in approximately 5 seconds, allowing the vessel to depart immediately. Schexnailder noted that it is possible to put the hose back into service in the future if it passes inspection and testing.

In the deepwater Gulf of Mexico, 95 percent of the stimulation fluid is composed of seawater or brine, Schexnailder explained. The fracturing fluids have high viscosity to reduce potential leak-off and to deliver the proppant to the appropriate parts of the fracture. The additives (i.e., non-priority pollutants subject to static sheen and oil and grease testing from the industry) are then used to degrade the viscosity down to that of water, at which point production begins in the well and any fracturing fluids that would be produced go through and into the production facility to be processed.

Schexnailder commented that stimulation vessels in the Gulf of Mexico are of limited capacity: only five vessels now operate and conduct approximately 100 completions offshore per year. Because these logistics are challenging, he suggested that companies mobilize modular components of a stimulation vessel and place them onto an offshore supply vessel with the dynamic positioning system already in place in order to fill a short-term demand for stimulation services.

Approaches in the Offshore Pacific: Technologies, Operational Practices, Challenges, and Risk Exposures

Mike Hecker, ExxonMobil Corporation

Transitioning from a discussion of the offshore environment in the Gulf of Mexico to that in the Pacific, Hecker remarked that the rock formations are the main difference between the two. In the Gulf of Mexico, the sandstone in many locations is so weak that it falls apart, and sand control is the primary focus of well completion activities in this region. In the Pacific, the rock is hard and contains natural fractures. Some of these fractures are damaged while drilling the well, so the major focus in this region is to stimulate and to remove damage.

Most wells in the offshore Pacific are simple, cased and perforated completions. To perforate a well, Hecker explained, one perforates into the reservoir through the steel casing, through the cement, and into the formation. This process allows the oil and gas to enter the wellbore and establishes a connection to the natural fractures. Fractures that have been damaged from drilling can then be cleaned up and carbonate material can be dissolved with acid. Because the wells will not always flow by themselves, artificial lift can be used to bring a well online. He noted that of the 745 offshore California wells producing in 2013, only 22 hydraulic fracturing stimulations were recorded, indicating that little fracturing is occurring in the offshore Pacific environment. The majority of well stimulation activities in the offshore Pacific involve matrix acid jobs.

Hecker indicated that typical acid volumes are between 100 and 150 gallons per foot of perforations in the offshore Pacific. So in a short interval of approximately 100 feet, 15,000 gallons of acid would be used. The acid treatment volumes for jobs in California are drastically less than those for unconventional fracture treatments onshore (e.g., 600 to 6,000 versus 30,000 to 50,000). However, the challenge in the Pacific is to divert the acid so that it treats the entire interval, and thus the entire well, instead of just the top perforations. He suggested that one way to address this problem is by using a diversion technique. With this approach, the injection rate is continuously increased (without fracturing) to force the fluid to more and more of the perforations. If that approach proves insufficient after starting to pump acid, ball sealers can be dropped into the wellbore. These balls will seal each treated perforation, diverting the acid to other perforations so as to treat the entire interval. Hecker commented that another technique, selective perforating, is more appropriate when contrasts in permeability exist. The lowest permeable (i.e., most difficult to stimulate) interval is perforated first, and a multi-treatment method is used (i.e., as the acid is pumped down, a thick gel [a diverter] is added) to open up more perforations into which the acid can flow. A third option is to run

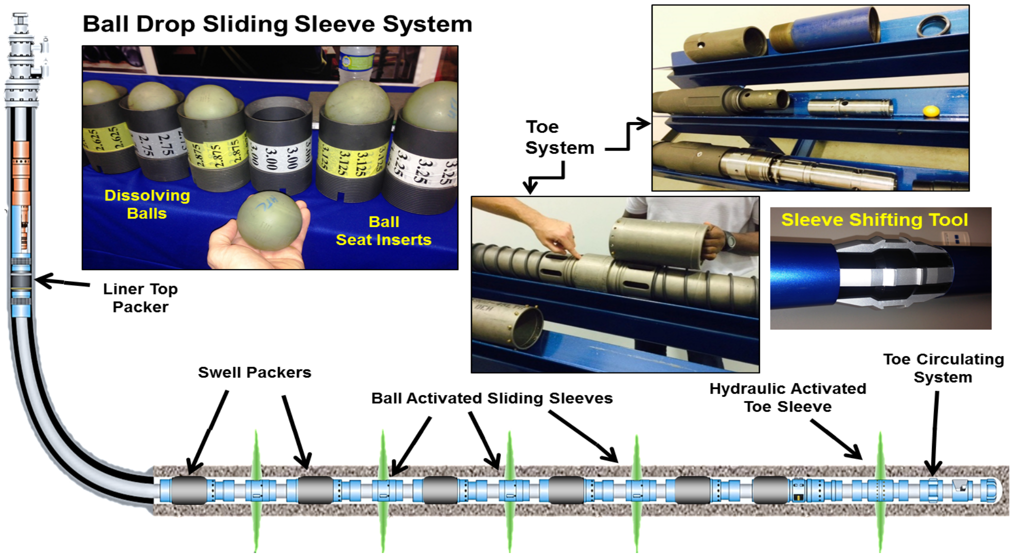

Figure 4.3 Ball-activated sleeves help to treat the full interval. SOURCE: Hecker, Slide 8.

coiled tubing across the perforations and jet acid up and down the wellbore. While this does not ensure injection into the formation, it does ensure that the acid is placed at the location of the coil. This technique is most appropriate for cleaning up drilling mud or removing damage. According to Hecker, new technologies from the unconventional arena, such as ball-activated sleeves (see Figure 4.3), are emerging in the offshore Pacific to ensure that acid is placed in each individual zone, treating the full interval.

Well Integrity Considerations for Technology Deployment and Practice

Lisa Grant, Bureau of Safety and Environmental Enforcement

Grant highlighted the variability in the terminology used throughout the oil and gas industry. For example, while some do not use the phrases "well integrity" and "safety" interchangeably, Grant prefers to treat them as the same. Well integrity means having control over a well by maintaining dual barriers and understanding its state. Thus, references to well integrity imply safe operation in which unexpected well control events and pollution events do not occur. She also clarified that fracturing is done in completions, not during drilling, and emphasized the importance of managing both activities. In the drilling stage, drilling and reservoir fluids are maintained in the well and are prevented from propagating into the formation. While there are many unknowns in drilling, completions are performed around known conditions, she said, and the installation of completions is a highly technical, well-planned activity. Because these drilling and completion activities are so different, unique decision-making processes are utilized in each.

Grant explained that when there is a lack of permeability in unconventional formations or when it is important to move past the damage left behind by drilling to achieve better production, hydraulic fracturing is useful. She highlighted the ways in which the development and application of technologies for unconventional formations have ramped up very quickly.

As a result, she cautioned against looking at fracturing design independent from the rest of the well. In other words, well integrity is an integral part of completion design, according to Grant. Evolution in fracturing design chemistry has occurred in the offshore, but the overall process of moving past the damage zone around the well has evolved more slowly than it has in the onshore. Offshore, she explained, it is somewhat easier to ensure that the completions are not outrunning the well integrity.

Challenges in the offshore environment emerge especially in work with deep formations, which call for larger completions with design lives of 20 to 30 years. The industry is working to address such challenges in the overall scope of the operating envelope by considering whether the design life and pressures are appropriate for anticipated production as well as how the metallurgy and seals, for instance, play a role in well construction and long-term maintenance. Because of the extreme conditions offshore, it is even more important to understand the loads and the long-term impacts on well integrity. Grant encouraged considering the entire construction process in order to truly understand risk, instead of focusing solely on fracturing. She remarked that a key aspect of understanding well integrity is the understanding of barrier envelopes. The well and blowout preventer system have to be competent to withstand the pressures and fluids being exerted on them, and a two-barrier system decreases the likelihood of complete failure.

Grant noted that over time the industry has become safer while increasing production and reducing production costs. She emphasized the importance of understanding operating environments and their impacts on well design and unintended loads. She reiterated the importance of properly assessing design changes to ensure that proper barriers are maintained to protect people, the environment, and the asset itself. She added that current regulations focus on ensuring that barriers are appropriately manufactured, installed, and validated as well as that the environment meets the barrier envelopes of what is in use. Grant cautioned against using historical data when assessing risk: different safety measures apply to different places at different times.

MODERATED DISCUSSION

An online participant asked if there is consensus on the stimulation of near well fracturing with large bed proppant packs versus far field fracturing and partial layer proppant packs. Wong responded that in the onshore environment, because the formation rocks have no permeability, fractures are long and likely narrow. However, because the rocks in the offshore environment are highly permeable, it is common practice to make wide fractures (i.e., frac pack). Another participant added that the rock determines the types of fractures that emerge, while McDaniel noted that completions are tailored to the specific needs of the reservoir. Another participant asked if it is possible to generalize a maximum fracture length, acknowledging that the fracture length is limited by the hydraulic horsepower and volume available to pump the job. McDaniel responded that it is more reasonable to create a longer fracture in a consolidated reservoir than in an unconsolidated formation. He reiterated that the rock dictates the limits: two formations with similar pressures and volumes can end up with fractures of different lengths. Wong noted that the challenging logistics of the offshore environment can also limit the length of the fracture, and Hecker reiterated that permeability in offshore wells is also a consideration.

A participant asked the panel how often acid dissolution is used both in the Gulf of Mexico and in the Pacific, as well as how often acid injection is used in both the onshore and the offshore environments. McDaniel said that from a Gulf completion standpoint, this can vary according to operator preference, though pre-acid jobs will usually be pumped ahead of the gravel pack jobs. Doing so alleviates near wellbore damage from drilling, cementing, or perforating. Hecker emphasized that whether one is working in the onshore or the offshore, it is imperative to understand what the problem is and what is causing the damage before choosing a stimulation method. In response to the participant's follow-up question about similar considerations for onshore shale, Hecker said that a bit of acid (or even just pressure, in some cases) is often pumped down the formation at the beginning to try to open up as many perforations as possible.

Another participant asked if there is a unique relationship between the wellbore and the rocks in the offshore environment. Grant said that from a drilling perspective one never wants to lose fluid, yet the permeability of offshore formations provides many places for the fluid to go. However, sealing the formation during drilling to avoid taking on any more fluid can have detrimental effects for production.

Wong asked the panelists if subsea development has different considerations in terms of hydraulic fracturing or in terms of completion more generally. Hecker responded that it is quite easy to diagnose and repair problems on a platform. However, in a subsea well that is in 7,000 feet of water, it is incredibly difficult and can cost tens of millions of dollars to run diagnostics and make repairs. As a result, it is crucial that the subsea well completion is done correctly and can last for at least 25 years.

Another participant wondered how to maintain fracture propagation in a target zone so as to avoid contact with fresh water. Hecker explained that companies correlate core data with physical properties in a fracture model, which helps them to better understand the barriers and to keep the fracture in the appropriate zone. This also helps prevent wasting proppant, Hecker continued. In addition to using models, companies design both perforation locations and fluids and study high leak-off zones in an effort to control the location of the fracture. McDaniel added that more data are usually gathered in the drilling phase in the offshore environment than in the onshore. He cautioned that models are only as reliable as their inputs, so mini-fractures can be used to calibrate an initial fracture design and gather additional information, while after-fracture logs can also be helpful to better design and carry out future completions. Grant said that although groundwater contamination is a valid concern, it is not necessarily a result of fracturing—the well itself can serve as a conduit. To avoid water-related incidents, she encouraged better education about both fracturing and maintaining well integrity. Wong advocated for high-quality wells, despite the associated high costs. He added that access to and visibility of the fracture (through the use of monitoring devices) is better in vertical wells than in horizontal wells.

Continuing the conversation about the use of data and tools for offshore operations, a participant asked what data analytics have revealed about the geological model evolution in the Gulf of Mexico and how this information influences exploration. Wong said that within a relatively immature theoretical background (in terms of conventional development), many analytic tools and measurement devices, and thus more data, have emerged over time in the offshore. He acknowledged that although the industry has much knowledge, it can always learn more to achieve better results and improve production. Grant added that a tremendous amount of data are collected on different types of depositional environments when drilling.

The participant then asked whether companies are prone to protecting information or if they are open to sharing data about the geologic framework to advance operations in this environment. Another participant responded that the geologic model of the Gulf of Mexico is one of the best known of all the sedimentary basins because it has been drilled extensively for so many years. Despite this level of knowledge, the participant explained, there is still always a surprise at the level of a well in a particular play.

In light of the conversation about knowledge sharing and technological improvements, a participant asked when a better advancement for more cost-effective sleeves may emerge. Hecker noted that improvements have been made in the number of treatments that can be done, owing to the limited number of ball sizes; pressure pulsing and radio frequency identification technology are being used to enable automatic opening and closing of sleeves. McDaniel said that the industry will be at a disadvantage until it can increase equipment pressure ratings. He emphasized that communication occurs often, especially for those with both onshore and offshore operations—they share different types of technology and ideas about enhancing operations. Wong noted that sand management may not be addressed with a pinpoint application of fracturing, which means that tools may need to be modified. He asked Grant what challenges would exist for well integrity if such a pinpoint fracturing tool was used for an offshore deepwater application. Grant noted that because increased sand production can lead to erosion, monitoring for potential integrity issues becomes even more important as new issues are introduced and boundaries are pushed. Schexnailder added that there are few unconventional development projects in the Gulf of Mexico, so the potential for them not to go as planned (and the associated implications) is significant, which can be a barrier to introducing new technologies.

An online participant asked how improvements in completion treatment techniques have impacted recovery rates. Hecker said that it is now possible to pull tens of millions of barrels of oil out of a well, all while keeping that well online for 20 years. McDaniel explained that productivity is higher in high-permeable, offshore wells than in conventional land wells. Wong added that making the development of lower permeability formations more economical is the next critical challenge. Schexnailder said that operational efficiency is key for maintaining economic viability of a deepwater or frac pack treatment (i.e., keep the same functionality but repurpose to establish a more efficient means of delivery). In response to a question from Grant about enhanced recovery, Wong agreed that increasing recovery is important and is thus a consideration in injector design. Tertiary development is another area of interest—McDaniel said that most technological advances occur in the subsea infrastructure because the greatest potential for reserves comes from deeper wells.

5 Safety in the Offshore Environment

The third panel of the workshop included three presentations focused on safety in the offshore environment. Discussions highlighted historical lessons, current risk management strategies, and future improvements for offshore safety. Charlie Williams, Center for Offshore Safety, offered an introduction to the session and moderated the discussion following these three presentations.

Williams shared that from 1968 until 2007, the loss time incident rate for offshore oil and gas development decreased 98 percent, with a 10-fold increase in work hours. He acknowledged that the industry has drastically improved its ability to protect people.

Williams explained that personnel safety and protection from major incidents are two different yet equally important issues that necessitate two strategies. The Bureau of Safety and Environmental Enforcement's (BSEE's) Safety and Environmental Management Systems (SEMS) is a performance-based (not rule-based) regulatory system that includes process, personnel, and safety programs. While rule- and inspection-based systems are important, they do not fully address the safety management system errors often seen in major incidents, according to Williams. All operators in the Outer Continental Shelf (OCS) are required to have a SEMS, which emphasizes the fact that operators are responsible for making good plans and decisions that will keep people and operations safe. SEMS include the following elements:

- safety and environmental information,
- hazards analysis,
- management of change,
- operating procedures,
- safe work practices,
- training,
- pre-startup review,
- emergency response and control,
- incident investigation,
- third-party audit,
- records and documentation, and
- contractor management.

Williams emphasized that this combination of technical standards, safe work practices, skills and knowledge/competencies, and operating procedures and processes helps to develop a strong safety culture and reduce the number of major incidents during operations. The success of SEMS is contingent on the audit, accreditation, and certification; data collection, analysis, and reporting; good practice development; and the sharing of industry knowledge.

PANEL PRESENTATIONS

Historical Regulatory Perspectives

Bud Danenberger, Independent Consultant

Danenberger asserted that offshore operations and regulatory programs are really just a progression from those onshore, starting in California in the 1890s. By the 1970s and 1980s, there were 52 wells drilled in the Atlantic Ocean, some of which were pioneering at the time in terms of total well depth. According to Danenberger, the prevention of undesirable events stems primarily from having appropriate barriers in place for drilling as well as for the structures, marine systems, workplace safety, fall protection, spill and debris prevention, and handling of hazardous substances.

From 1964 until 2016, fatalities in the U.S. OCS steadily decreased. According to Danenberger, SEMS can help sustain a low level of fatalities and injuries in the offshore. Shallow gas formations that are encountered before well integrity has been established have been a major threat to safety, but drilling wells less often in shallow, gas-prone sediment, using improved survey techniques, and implementing diverter systems has helped avoid related problems.

He described the 1969 blowout in Santa Barbara with its major environmental impacts, owing to poor well integrity, after 80,000 barrels of oil were released into the Santa Barbara Channel and onto the beach. Of approximately 60,000 wells drilled in the OCS, only two major oil blowouts have occurred. The probability of such a blowout during drilling again depends on the barriers that are in place. If barriers are managed effectively, there would be a less than 10^{-5} chance of major oil blowout, Danenberger explained. For poorly managed systems, the probability of a major blowout could be more than one in a hundred.

From 1984 until 2010, during which time approximately 25,000 wells were drilled, there were no fire or explosion fatalities during OCS drilling operations. Danenberger attributes this to good well control training, well control research, and appropriate regulations. Yet, on April 20, 2010, a classic example of a management disaster occurred with the Macondo blowout. He noted that, had the blowout preventer system, the well integrity, the fire prevention and detection mechanism, and the human and organizational factors barriers been maintained, the blowout could have been either much less severe or prevented entirely (see Figure 5.1).

He noted that with its attention to risk assessment deepwater production (waters deeper than 1,000 feet) has an excellent record, with only one fatality since 1979 (while 7 billion barrels and 20 trillion cubic feet of gas were produced) from a crane incident and no significant fires or explosions. He highlighted a disconnect in the offshore regulatory program between deepwater production, which is regulated in a more barrier-focused way, and drilling, which is still treated as an extension of shallow water activities.

BOP System	**Redundancy** **Design** **Actuation** **Maintenance** **Flow not diverted overboard**
Well Integrity	**Casing Point** **Cement** **Secondary plug above shoe** **Removal of weighted mud** **Verification of barriers**
Fire Prevention and Detection	**Hazardous area classification and safeguards** **Gas detectors** **Generator shutdown** **Engine overspeed devices**
Human and Organizational	**Planning, Risk Assessment** **Communication** **Management of change** **Training** **Chain of command** **EDS actuation**

Figure 5.1 Macondo barrier failures. NOTE: BOP = Blowout Preventer; EDS = Emergency Disconnect System. SOURCE: Danenberger, Slide 8.

Industry Risk Management Experience for Performing Stimulation Treatments in Offshore Settings

Paul Hebert, Chevron Corporation

Hebert noted that the oil and gas industry has a 20-year safety track record in offshore hydraulic fracturing and acid pumping operations. He reiterated that offshore hydraulic fracturing operations are different from onshore operations with unconventional shale resources. Offshore hydraulic fracturing is designed with multiple mechanical barriers and procedures in place to protect people and the environment. Comprehensive risk management processes, including management of change processes, are used for planning and pumping operations offshore.

At the onshore well site, pumping operations are run from a remote control cabin, removing people from close proximity to the operations. Hebert remarked that operational procedures, risk assessments, and job site safety analyses are performed routinely, and multiple layers of physical barriers are in place. He emphasized the importance of these processes: no two wells are alike, and all have to be designed and assessed individually for risk. At the offshore well site, because the pumping vessel is in close proximity to the oil rig, a Simultaneous Vessel Operations Plan is in place to maintain appropriate position and safe operations. Such a plan always includes risk assessment and a plan for emergency shut down. This risk assessment model allows for anyone on the job site to have the opportunity and the autonomy to stop work.

Hebert described an integrated approach for safe operations of offshore hydraulic fracturing/acidizing, which includes safety processes and physical barriers for pumping operations. Dynamic positioning as well as redundant power and management systems are utilized. These fracture jobs are monitored in real time by engineers on land, who have the opportu-

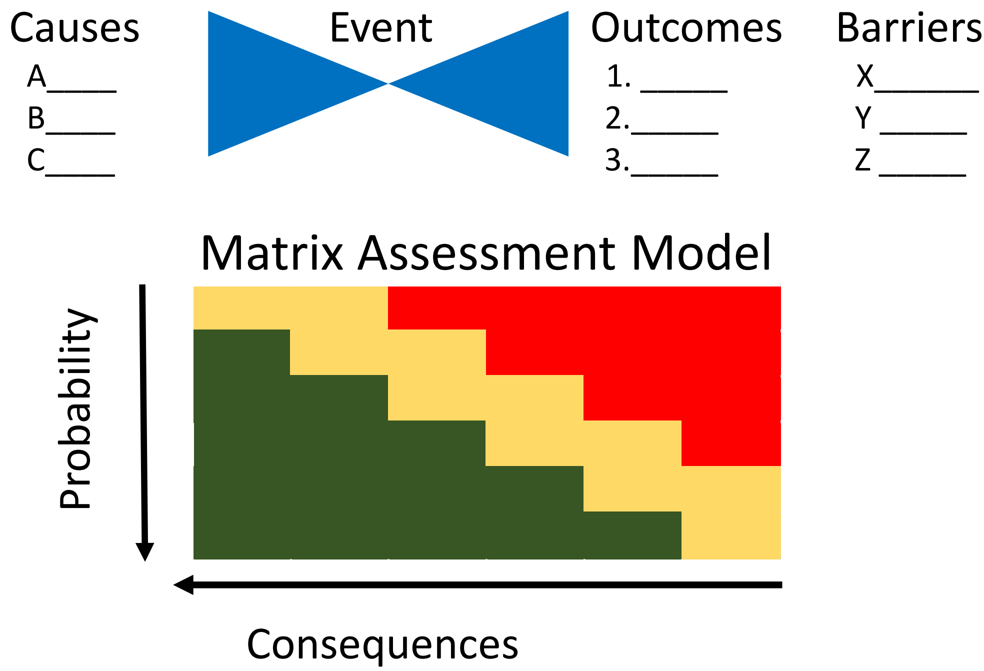

Figure 5.2 The bow-tie model and the matrix assessment model. SOURCE: Hebert, Slide 6.

nity to modify the design of the job if necessary, and from a remote operations cabin on the vessel located away from at-risk areas. He explained that physical barriers include the use of inspected and mechanically engineered systems, a wellbore kill weight fluid that is automatically built into the design in case operations have to stop, and the use of a subsea stack to isolate pressure.

Hebert commented that the bow tie model and the matrix assessment model are effective models for risk assessment and management (see Figure 5.2) and are consistent with SEMS requirements. In the bow-tie model, the causes and potential outcomes of an event are identified, mitigations are developed, and the outcome impact is reduced. In the matrix assessment model, office and field personnel work together to design out of a potentially at-risk scenario—line-by-line procedural steps are identified, event probability and impacts are identified, and mitigations are developed so as to move from a high-consequence, high-probability area to a low-consequence, low-probability area.

According to Hebert, a study that looked at 80 percent of the jobs pumped over the past decade revealed that the average number of significant safety events was approximately 1.1 per year. The average probability of having a safety event is also low, at 0.52 percent per well operation, as is the average total recordable incident rate (TRIR) at 0.83 per year.[1] Hebert concluded that the industry has an excellent safety track record for offshore hydraulic fracturing and acid pumping operations because the industry utilizes both hydraulic and mechanical barriers to protect people and places. The hydraulic fracturing/acidizing processes used in the offshore allow fewer wells to be drilled, which leads to lower risk and fewer safety issues for both humans and the environment, Hebert explained.

[1] The TRIR for all industries and government was 1.7 per year in 2015 (BLS, 2016).

Beyond Compliance

Nancy Tippins, CEB

Tippins chaired the National Academies' Committee on Offshore Oil and Gas Industry Safety Culture, which focused on aiding industry, government, and other stakeholder efforts in strengthening offshore industry safety culture.[2] The committee was tasked with identifying the characteristics of and barriers to a strong safety culture, developing strategies to measure and assess safety culture effectively, and evaluating the role of regulators in achieving an appropriate safety culture. The study's report recommended opportunities for industry, regulators, and policy makers to establish and maintain safety culture, as well as areas for further research to close knowledge gaps surrounding safety culture. Tippins emphasized that the committee did not recommend increasing regulations to achieve these goals.

Before the committee could begin its work, it agreed on a definition of safety culture. It adopted BSEE's definition—"core values and behaviors of all members of an organization that reflect a commitment to conduct business in a manner that protects people and the environment" (DOI, 2013). The committee also generated nine essential elements of a safety culture (NASEM, 2016) for incorporation in both offshore organizations' safety culture efforts and in the American Petroleum Institute's Standard RP 75 (Recommended Practice for Development of a Safety and Environmental Management Program for Offshore Operations and Facilities):

1. Leadership commitment to safety values and actions,
2. Respectful work environment,
3. Environment for raising concerns,
4. Effective safety and environmental communication,
5. Personal accountability,
6. Inquiring attitude,
7. Hazard identification and risk management,
8. Work processes, and
9. Continuous improvement.

Tippins highlighted a number of barriers to developing and sustaining a safety culture: (1) Safety culture is an ambiguous concept that is difficult to measure; (2) Levels of leadership commitment vary across organizations; (3) The industry is fragmented and diverse, which makes communication more difficult; (4) A gradual, uneven shift in industry culture is moving it as a whole from risk-taking to a commitment to safety; and (5) Regulators have difficulty building expertise to support this industry transformation.

Tippins explained that the first set of recommendations in the report was aimed toward regulators. The committee recommended that methods for and frequency of inspections be based on results of past audits. They also recommended that regulators collect and help analyze data on all incidents, so as to determine causes of incidents, improve transparency, and promote data sharing. The committee also recommended that regulators share the responsibility of establishing safety culture with one another (through a memorandum of understanding) as well as with industry leaders. The report stated that regulators need to develop competence

[2] The report from this committee is available at https://www.nap.edu/catalog/23524.

in safety culture assessment so as to be able to offer guidance, tools, and training to industry, while organizations should also exchange information about safety instead of competing against one another.

The second set of committee recommendations was directed toward industry, Tippins explained. The committee asked that industry adopt the BSEE definition of safety culture and its essential elements; work collectively and collaboratively to affect change; help regulators to define an optimal mix of regulation and voluntary activities; create guidance on safety culture expectations and responsibilities for all parties involved offshore; and develop an independent safety organization modeled after the Institute of Nuclear Power Operations (INPO) in which all those who work offshore would participate. The committee recommended that company leadership make safety a top-down effort. Tippins summarized the report's findings that leaders have to model safety behavior and empower their employees to institute a safety culture; assess safety culture regularly; use multiple indicators of success; build internal company safety competence; and take advantage of resources from other companies, industry associations, and regulators (NASEM, 2016).

MODERATED DISCUSSION

A participant opened the discussion acknowledging that although the industry is good at understanding personal safety, it is difficult to articulate process safety and wondered how to deliver the message that process safety is extremely important. Williams responded that one should be able to ask the following questions of any person on a job site: What are the major hazards? What are the barriers, and are they effective? What is your personal responsibility for those barriers? If even a single person cannot answer those questions, a safety culture problem exists, Williams explained. He noted that because the industry has spent so much time emphasizing personal safety, it has perhaps overlooked the management of work issue, which can lead to more serious safety issues. He suggested increased participation in job safety analysis meetings as a potential solution. Danenberger added that a lack of understanding of process safety is a leadership/management problem. Tippins cautioned that changing an organization's safety culture takes a substantial amount of work: an organization has to provide specific evidence about why process safety is important and tailor this argument to diverse audiences. She emphasized that this message has to be repeated and lived every single day as well as reinforced with incentives or consequences, when appropriate.

In response to a question from a participant about managing risk, Hebert responded that the dynamic positioning system employs a 3-meter watch circle for pumping while the two vessels are in close proximity to avoid unsafe conditions during a job. That participant then asked about the industry's progress in regards to barrier management. Hebert explained that in the operational procedure plan there is an option for an automatic stop job if a condition outside of the safety envelope arises. Danenberger mentioned that although many companies are extremely effective in identifying risks and setting up barriers, issues of well integrity may still need to be addressed.

A participant commented that it is important to acknowledge companies that participate in safety audits. He also voiced support for the Center for Offshore Safety; he noted that because the nuclear industry is so different from the oil and gas industry, INPO is not a good model of an independent safety organization. Tippins clarified that not all of INPO's attributes apply to the oil and gas industry. She also applauded the companies who conduct safety audits and encouraged others to follow their lead. Hebert noted that SEMS has a built-in audit feature, while other organizations use self-imposed audits.

Referring to the bow-tie model for risk assessment and management, another participant questioned the seemingly linear depiction of the model given that safety is a non-linear concern. Hebert clarified that each individual procedure is placed in its own bow-tie model, as opposed to having only one bow-tie for an entire fracture job. All of these procedures then have to be integrated, which is why it often takes up to 2 full days to do the analysis. The participant followed-up by asking how unanticipated instances (outside of the bow-tie model) are handled, and Hebert noted that there is always a back-up plan, a barrier in place, and an option to shut down operations. He added that the vast majority of people working in the OCS have authority and will be held accountable for issuing a stop work. Williams reiterated that the stop work authority is a SEMS requirement and that the bow-tie is only a visual representation; in actual operations, problems cascade and barriers are multiple.

Regarding issues of communication, a participant asked how technological, social, and awareness obstacles are addressed. Tippins noted that the National Academies' study committee focused on the human interface and the clarity of roles as opposed to the technology in establishing a safety culture. Hebert added that there are multiple open communication channels on both the rig and the vessel and that the simultaneous operations plan makes clear who is in charge of stopping work when something goes awry. While Williams acknowledged that there are many ways to improve communications related to safety, he prioritized situational awareness (i.e., the level of risk associated with decisions) as most urgent.

Another participant asked the panel to comment on lessons learned from the Macondo incident, BSEE's role in such an evaluation, and public assurance that such an event can be prevented in the future. Williams said that the panel chose not to discuss Macondo in detail because it has been so well investigated by so many different groups (including regulators), and such expansive literature already exists. He added there were multiple responses to Macondo, including the emergence of both the Marine Well Containment Company and the Center for Offshore Safety. Hebert noted that more than 500 regulations were implemented and Danenberger commented that the SEMS rule was finalized, both as a result of the Macondo incident.

Recognizing that gaps in safety culture may exist, a participant emphasized that the industry is relentless about continually improving its safety culture. He asked the panel for its perspective on the human performance side of safety culture. Tippins acknowledged that while many companies have strong safety cultures, there are others that still prioritize profit and productivity over safety. She added that even places with the strongest safety cultures will only sustain them if they are reinforced daily, and she agreed that the human factors aspect (i.e., awareness of how human behaviors can cause or prevent accidents) of safety culture is critical. Danenberger agreed with Tippins's perspective and noted the value of increased data analysis and sharing in strengthening the safety culture.

Another participant asked the panel for ideas about how to make safety training more interesting. Williams suggested incorporating safety simulation exercises that, while engaging, do not have to be expensive or elaborate. He noted that targeted safety data relevant to particular jobs can also be shared with each job group. Hebert suggested personalizing the experience by focusing on the fact that people are working to support their families and emphasizing the value of integrity: people tend to step up to the task when they consider their roles in keeping themselves and their co-workers safe. Tippins agreed that personalization of safety training is key. She also suggested that trainers read literature on adult learning to gather strategies about delivering complex material to adults in an interesting way.

6 Environmental Considerations, Advanced Technologies, and Solutions

The final panel of the workshop served as a complement to the previous panel on safety considerations by introducing the environmental components of offshore operations in four presentations. Lois Epstein, The Wilderness Society, provided a brief introduction to the session and then moderated a large group discussion after the panel presentations.

Epstein offered a brief overview of the situation in her home state of Alaska. She said that Alaska has only a small amount of offshore oil production, which is from a manmade gravel island, in Alaska state waters. Alaska has, however, a number of near-shore Outer Continental Shelf (OCS) projects in the planning stages. Cook Inlet, in particular, has had offshore platforms in state waters since the 1960s, and while that location is not producing as much as before, some hydraulic fracturing projects are in place. In addition to concerns about the use of fresh water in Alaska, Epstein also raised concerns about noise and drilling discharge impacts on marine mammals. When these mammals change their migration patterns as a result of such disturbances, people who rely on those mammals for subsistence are also affected. She mentioned that because the Arctic freezes in the winter, drilling schedules also have to be adjusted. Ultimately, there are many uncertainties in this area.

PANEL PRESENTATIONS

Offshore Oil and Gas Operations—Ecosystem Considerations: What Have We Learned Over the Past Four Decades?

James Ray, Oceanic Environmental Solutions, LLC

Ray explained that although industry, regulators, and scientists have decades of both laboratory and real-world environmental science data related to offshore oil and gas operations, they do not (and may never) know everything about the effects of oil and gas on offshore ecosystems. There are many contributors to this foundational knowledge base, including the federal government,[1] industry, academia, the private sector, and the international community. Reports that have compiled this wealth of data over time have been used by companies and regulators alike for decision-making purposes.[2] The Bureau of Ocean Energy Management (BOEM) Environmental Studies Program website[3] provides access to some of these texts as well as information about the funding and planning of current projects. The National Academies Press website[4] also offers access to many other key sources of information.

Ray noted that current regulations require ongoing monitoring and reporting of discharge systems. Permits, in particular, often require additional studies and data collection. He encouraged participants to review two general permits from the Gulf of Mexico that regulate discharges, including the Western Gulf of Mexico General Permit GMG 290000[5] and the Eastern Gulf of Mexico General Permit GEG460000.[6] Ray explained that permits are updated every 5 years based on new details, standards, and analytical techniques, and a new permit for the Central and Western Gulf was released just prior to this workshop.

Much data have been collected on a range of environmental programs including fate and effects of water column and seafloor discharges using dispersion modeling and field verification, methods development for toxicity testing and analyte measurements, laboratory studies on toxicity and bioaccumulation, containment studies, baseline studies, and acoustic effects on the marine environment. He mentioned that the industry also studies and tests various species, including invertebrates (crustaceans are an especially valuable test species) and vertebrates, to better understand the environment. The geographical distribution of these studies varies widely, including numerous coastal areas in the United States—Alabama, Alaska, California, Florida, Louisiana, Mississippi, Oregon, Texas, Washington, East Coast states and abroad—Canada, Denmark, England, Germany, India, Indonesia, Norway, and the North Sea.

Ray remarked that completion, treatment, and workover fluids (including fracturing fluids) have for years been permitted to be routinely processed offshore in produced water treatment systems. If the combined produced water and treatment fluids meet the produced water discharge permit requirements, then they are considered to be produced water and will be discharged as part of the produced water stream. If the discharge permit standards are not met, the returns have to be segregated and shipped to shore for handling.

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[1] According to Ray, the Bureau of Land Management, the Minerals Management Service, and the Bureau of Ocean Energy Management alone have invested $1.3 billion in environmental studies since 1973.

[2] A few of these influential texts include *Response of Marine Animals to Petroleum and Specific Petroleum Hydrocarbons* (Neff and Anderson, 1981), *Drilling Discharges in the Marine Environment* (NRC, 1983), *Long-Term Environmental Effects of Offshore Oil and Gas Development* (Boesch and Rabalais, 1987), *Oil Dispersants: New Ecological Approaches* (Flaherty, 1987), *Produced Water* (Ray and Engelhardt, 1992), *Bioaccumulation in Marine Organisms: Effects of Contaminants from Oil Well Produced Water* (Neff, 2002), and *Oil in the Sea III: Inputs, Fates, and Effects* (NRC, 2003).

[3] Available at https://www.boem.gov/Studies (accessed November 17, 2017).

[4] Available at https://www.nap.edu (accessed November 19, 2017).

[5] Available at https://www3.epa.gov/region6/water/npdes/genpermit/gmg290000final/gmg290000finalpermit2012.pdf (accessed November 17, 2017).

[6] Available at https://www.federalregister.gov/documents/2016/08/18/2016-19099/notice-of-draft-national-pollutant-discharge-elimination-system-npdes-general-permit-for-the-eastern (accessed November 17, 2017).

Marine Ecology and Water Research, Gulf of Mexico

Paul Montagna, Texas A&M University–Corpus Christi

Whereas Ray focused on knowledge accumulated during the past 40 years, Montagna focused on more recent lessons learned in marine ecology and water research. He first suggested that workshop participants read the high-level summary of the *Deepwater Horizon* research initiatives published in 2016 in *Oceanography Magazine*.[7] Since the *Deepwater Horizon* accident, there has been an influx of information emerging from studies on the ecology of the Gulf of Mexico—for example, the $800 million National Resource Damage Assessment program involved 400 researchers who collected 100,000 samples and generated 13 million data records,[8] and the $500 million Gulf of Mexico Research Initiative involves 3,000 researchers from 278 institutions worldwide who have already published 800 peer-reviewed publications, with more than 2 years remaining in the 10-year program.[9]

Montagna believes that knowledge gains will continue under the 2012 RESTORE Act[10] and the $20 billion settlement from the *Deepwater Horizon* accident that will be distributed among the states' restoration programs. He noted that restoration lags only when monitoring, data, and follow-up measures are not in place. With the Act's requirement for monitoring specific restoration projects, Montagna expects to see an improvement. The Act also includes monetary designations for the Centers of Excellence in each of the five Gulf states (more than $130 million), the National Oceanic and Atmospheric Administration's (NOAA's) Science Program (more than $130 million), and the Gulf Research Program at the National Academies ($500 million). These investments ensure that the flow of information will increase substantially during the next 10 to 15 years.

Montagna referred back to the existing ecological and environmental issues discussed by William Brown, BOEM, during the keynote session of the workshop and highlighted oil spills, bottom disturbance, noise, and lighting as the most pressing issues. He explained, however, that when offshore activities go according to plan, the effects are localized, and there are no long-term chronic effects. He explained that ecological zones depend on depth in the offshore. There are approximately 1,200 active platforms and 25,000 miles of active pipelines (and 18,000 miles of inactive pipelines) in the Gulf of Mexico (see Figure 6.1).

He noted that shelf and deep sea mud is unremarkable unless something is added to it, but because benthic elements are not charismatic, little attention is paid to the bottom of the ocean. However, according to Montagna, benthos have important roles (i.e., the Benthic Effect) in coastal and marine food webs. The benthos regulate or modify nearly all physical, chemical, and geological processes, and they continuously sample the ocean. This makes benthic organisms extremely good indicators of any changes in the environment. Benthos can be defined by size, distribution, taxonomy, or even by genetic bar codes. However, the genetic bar codes only indicate presence or absence, not diversity. According to Montagna, benthic diversity is the best indicator of ecosystem health, and because scientists currently know only approximately 25 percent of species, further exploratory research would be beneficial.

[7] Available at http://tos.org/oceanography/issue/volume-29-issue-03 (accessed November 17, 2017).
[8] Available at dwhdiver.orr.noaa.gov (accessed November 18, 2017).
[9] Available at http://gulfresearchinitiative.org (accessed November 18, 2017).
[10] Available at https://www.restorethegulf.gov/history/about-restore-act (accessed November 18, 2017).

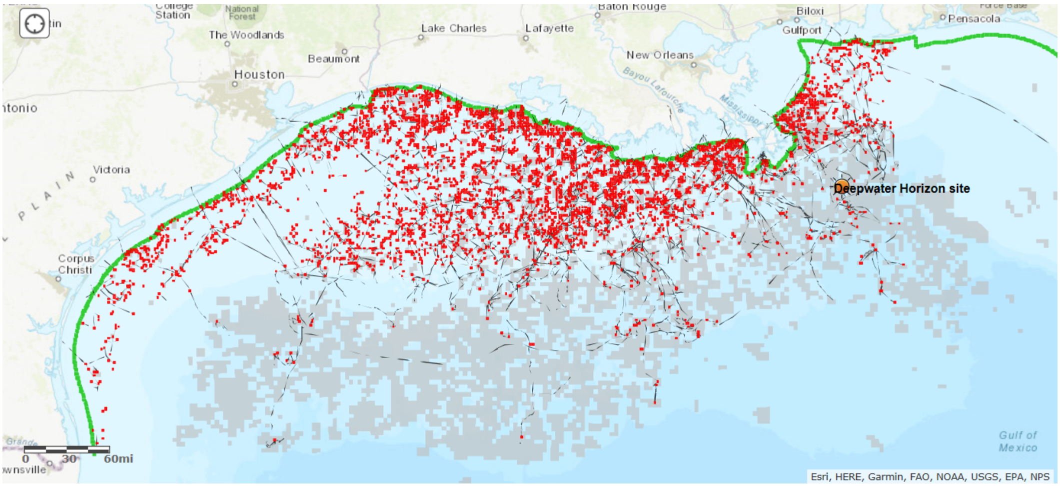

Figure 6.1 Oil and gas infrastructure in the Gulf of Mexico. SOURCE: Montagna, Slide 8.

Montagna described the Gulf of Mexico Offshore Operations Monitoring Experiment that considered whether offshore structures had chronic, sublethal effects in the mid-1990s. Studies revealed that nearly all effects were limited to within approximately 100 meters of a platform. Prompted by a question about contaminant effects versus ecological or reef effects, he conducted further experiments that revealed that the offshore platforms actually serve as artificial reefs. Montagna explained that while there is some contamination and some disturbance, he believes the positives of the reef effect outweigh the negatives, when offshore operations are normal.

A new human-dimension framework for studying the offshore that has emerged over the past 20 years is "ecosystem services." He defined ecosystem services as the free benefits people obtain from the ecosystem. For example, the ocean provides 17 services to people, including nutrients, food, culture, biology, and gas (see Figure 6.2). Oceanic ecosystem services are also a substantial benefit to the offshore industry—for example, the Gulf of Mexico's natural removal of spilled oil saved BP between $20 billion and $40 billion after the *Deepwater Horizon* incident. Montagna concluded by reiterating that the Gulf of Mexico is productive, diverse, and worth protecting.

Regulatory Approaches and Considerations for Environmental Risk Offshore California

Robert S. Habel, California Department of Conservation

Habel provided an overview of the California Department of Conservation Division of Oil, Gas, and Geothermal Resources, which was created in 1915 to protect hydrocarbon zones from being watered out by poorly constructed neighboring wells. The Division's work eventually shifted to focus primarily on the protection of freshwater and groundwater sources. The Division mandates include supervising drilling, operation, and maintenance of wells to prevent damage to life, health, property, and natural resources; supervising and permitting the

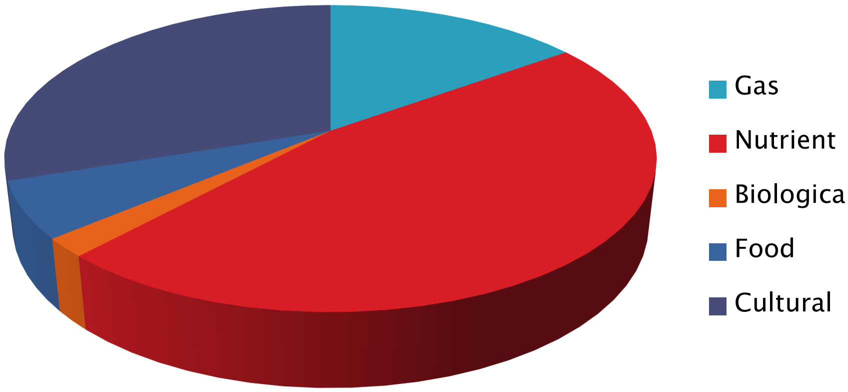

Figure 6.2 Five of the 17 ocean ecosystem services. SOURCE: Montagna, Slide 29.

owners/operators to utilize all methods and practices known to industry for the purpose of increasing well production; and supervising the wise development of oil and gas resources. He noted that prior to 2013, the Division had not been permitting hydraulic fracturing.

Because the legislature was concerned about problems arising in California from hydraulic fracturing, Senate Bill 4 was developed by the State Senate, Habel explained. The Bill determined the level of monitoring required before, during, and after development, both onshore and offshore. With the passage of this Bill, California had new laws for well stimulation activities (i.e., hydraulic fracturing and other treatments that increase the flow of hydrocarbons to wells and then to the surface for recovery) performed by oil and gas operators. Senate Bill 4 includes stringent regulations, according to Habel. It requires a study of well stimulation, a statewide environmental impact report, and the development of well stimulation regulations for the onshore and the offshore. Senate Bill 4 also requires groundwater monitoring plans, permits for well stimulation, and increased transparency through public disclosure and notification to adjacent landowners. The bill also establishes procedures for protecting trade secrets and amendments to the oil and gas fee structure. These regulations aim to protect drinking water, the environment, and public health and safety.

Habel noted that the first step in regulating well stimulation treatment is to evaluate nearby wells (to ensure there were no old, poorly constructed wells that would provide a conduit outside of the intended zone) and geology (to ensure there was no natural conduit that could become problematic). Then pre-fracture well testing is conducted, allowing for water well testing in the case of concerns about contaminants, and notifications are provided to both the Division and the public. Monitoring is also required during and after the fracturing operations, Habel continued, and information about the materials used in the fracturing fluid are disclosed to the public. The regulations also cover methods for storage of these fluids.

The Division protects fresh waters in the hydrocarbon zone by ensuring that the wells have mechanical integrity (i.e., strong well casing and tubing) and by evaluating the cementing requirements to ensure that all zones that could be in contact are isolated so as to avoid crossflow. Habel emphasized that while such practices were always occurring, they are now officially regulated. The Division's sister agency, the California State Water Resources Control Board, oversees groundwater monitoring plans (including sampling and neighbor notification) for any area in which hydraulic fracturing occurs where there are underground sources of drinking water. While in offshore operations there are not many "neighbors" to notify, in the onshore a third party sends notifications to people within 1,500 feet of a well head and within 500 feet of the projection of the wellbore at least 30 days in advance of when hydraulic fracturing will occur. The tenant has the right to request sampling of the well or of the surface water, and expenses for such testing will be paid by the operator and conducted by a certified laboratory. All groundwater data are posted to the State's website.[11] During the well stimulation, surface injection pressure, slurry rate, proppant concentration, fluid rate, and annuli pressures are monitored and put into public record, according to Habel.

When the Division was first developing the regulations, he remarked, there was much concern about seismicity associated with hydraulic fracturing. If there were to be seismic activity during fracturing, the operations would stop and investigations would begin (although this is unlikely, given that most of their fracturing occurs in shallow waters). Because water is so important in drought-ridden California, operators handle fluids associated with well stimulation carefully. All of the fracturing fluid recovered from a fractured well has to be reinjected, which causes some challenges for California because some fields produce oil with fresh water and some of that water is then used to water non-food crops. Monitoring is also conducted on production pressures post-stimulation, in which samples are collected both immediately after the well stimulation and 30 days later to ensure that there are no anomalies associated with hydraulic fracturing. Habel reiterated that all reports (pre-, syn-, and post-stimulation) are posted on the Division's website for public viewing. Because people are concerned about acid being put in wells located near fresh water, all uses of acid are recoded in these reports to distinguish between regular well maintenance and an acid job. Habel emphasized that the Division has paid special attention to keeping everything in the zone of intent—even if acid goes into the hydrocarbon zone, it is unlikely to cause any problems to fresh water. These regulations would apply in offshore and state waters as well.

During the 2016 reporting period, there were 579 well stimulation treatments performed in the onshore environment. According to Habel, there were no well failures associated with hydraulic fracturing and no emergency responses to spills or releases in 2016.

Air Emissions from Offshore Platforms

Desikan Sundararajan, Statoil

Sundararajan suggested that emissions management in the onshore is more pressing than that in the offshore—offshore operations are already heavily regulated and thus have better emissions control than onshore operations. He explained that a good air emissions program would be comprised of science, technology, operator protocols, and policy (STOP). He believes that all four have to come together; otherwise, the industry will never be in control of acceptable emissions or have strong climate policies for oil and gas operations. Sundararajan added that while emissions-related technology has evolved, outdated emissions factors are still used for emissions reporting both onshore and offshore.

Sundararajan explained that although the U.S. Environmental Protection Agency's (EPA's) emissions inventories are revised every other year, there is inconsistency in how emissions fac-

[11] Available at http://www.water.ca.gov/groundwater/gwinfo (accessed November 22, 2017).

tors are used and how operators extrapolate their emissions data. He commented on the importance of having a robust methodology for emissions estimation and noted that bottom-up approaches to emissions inventories have been supported in the past by industry and by regulators. Bottom-up approaches involve conducting measurements at the component level where the emissions occur, developing a mathematical model, and extrapolating emissions.

In the past 10 to 20 years, NOAA has been working to better understand the emissions footprint from the oil and gas industry from a top-down fashion. NOAA has combined effective measurement technologies and techniques with strong algorithms to create box models and allocate emissions. In addition, NOAA has installed analytical instrumentation on airplanes, because measurements observed 20,000 feet into the atmosphere likely indicate an issue emerging from the operations on the ground. However, as a result of NOAA's work, there is now a substantial gap between its papers and the EPA's inventories, causing confusion and concern for the industry, according to Sundararajan.

While Sundararajan asserted that the bottom-up approach may not capture all of an operation's emissions, top-down approaches can overestimate or over-allocate emissions, resulting in a debate about the true emissions numbers. He explained that if the right methodology for emissions estimation is developed, policy makers can more appropriately regulate the oil and gas industry.

The Norwegian Environment Agency has worked with Sundararajan's company Statoil and other companies during the past 5 years to refine its methodology for emissions estimation in Norwegian operations. The new methodology includes a focus on measuring performance, recognizing what operators and instruments look like, and understanding the types of maintenance protocols that are implemented, all of which play a role in reducing emissions. The Norwegian Environment Agency continues to refine its methodology, given that more emissions are being reported from the offshore platforms than are actually being emitted. Sundararajan suggested that the Gulf of Mexico could benefit from similar acceleration in methodological development.

According to Sundararajan, regulators have historically steered clear of requiring continuous emissions monitoring on offshore installations, owing to the high costs and inadequate technology that exist. He encouraged further dialogue between industry and regulators (especially given that technology has advanced, costs have decreased, and accuracy has increased) to revisit this issue and motivate better pollutant-monitoring practices.

Sundararajan commented that continuous monitoring of methane, in particular, is emerging—the Environmental Defense Fund has a detector challenge,[12] and the Advanced Research Projects Agency–Energy (2016), has a program to develop methane sensors. Where sensors are already installed, data are being collected and analytics and digitization are being applied to identify where equipment maintenance could correct a problem. This concern about methane has prompted both regulations onshore and discussions about regulations offshore. Sundararajan explained that there is a dramatic difference in methane emissions between the offshore and onshore worlds. In terms of safety and process instrumentation, the onshore world is not as heavily regulated as the offshore world, which is why it is so important to invest more money and research in understanding the true footprint of methane emissions in the onshore arena.

[12] Available at https://www.edf.org/energy/natural-gas-policy/methane-detectors-challenge (accessed November 20, 2017).

MODERATED DISCUSSION

Responding to Ray's presentation, a participant asked how all of this knowledge that exists about the oil and gas industry gets translated to an operator or a regulator. The participant also asked if an example exists internationally where this knowledge and experience come together cohesively. Ray noted that the publication of all of these reports was driven by the desire for regulatory agencies to have information to properly manage resources and the environment. Oil and gas development spans a wide range of areas and costs, so justifications for investments have to be carefully presented. Ray continued that there is much cross-communication among governments and agencies, the concerned public, and the nongovernmental organizations internationally. Such synthesis activities are especially valuable for scientists because many academic disciplines do not engage with one another or participate in information sharing. He suggested that moving forward industry focus on what it does not know, what its concerns are, where the data are weak, and what needs to be verified. This approach of building on previous knowledge is more effective and less costly than "reinventing the wheel," according to Ray. Montagna reiterated that synthesis is critical—for example, the Gulf of Mexico Research Initiative has dedicated $50 million in research grants toward synthesis activities in support of the offshore industry. He emphasized that humans are embedded in the environment, and so it is important to model the fact that people are connected to each other and the environment in the framework and context of ecosystem services.

A participant expressed concern about the industry's prioritization of onshore emissions to the degree that it would not do independent top-down studies of offshore emissions. Sundararajan concurred with the value of conducting top-down studies offshore, and he reiterated that onshore operations would benefit from stronger emissions regulations. Another participant noted that data on methane emissions for completion exist, but questioned whether the data are being transmitted up through organizations appropriately. Sundararajan acknowledged that industry has not always utilized data as wisely as it could and added that moving forward he expects to see data handled better and communication processes strengthened.

The industry's reliance on data was discussed further after a participant observed that while it is easier to study phenomena after negative effects are already present, it is vital to collect baseline data before effects occur so as to be able to make effective comparisons. The participant wondered how resources could be allocated to support this step in the process. Ray agreed that it is much more difficult to secure funding for proactive research than for investigating a problem that already exists. He suggested focusing on priority setting and emphasized the value of being able to articulate a need. He added that joint industry projects, where partners can share cost, may be an effective strategy to collect data and anticipate potential problems. Montagna agreed that this is a challenge that has existed for decades: it is impossible to have baseline data without monitoring, but people are usually reluctant to invest in monitoring systems. He reiterated Ray's point that it is difficult to convince people to "study" things they might need in the future. He highlighted the Gulf of Mexico Coastal Ocean Observing System, part of the international Integrated Ocean Observing System, as a successful program that collects routine measurements. He mentioned that the industry would benefit from better, larger-scale monitoring in conjunction with better synthesis of information—for example, this is the only way to determine whether restoration dollars have been effective and to better understand the structure and function of the Gulf of Mexico.

Thinking about the function of the Gulf of Mexico more specifically, Epstein wondered about the process used to identify areas that are unique in relation to biodiversity. Montagna said the Gulf has many diverse habitats and protected areas would be beneficial to have because of the valuable ecosystem services the Gulf provides. He also clarified that "management" does not prevent actions; it simply means that something can be protected by better decision making. He added that if humans take care of the Gulf of Mexico, it will take care of humans.

Another participant asked if different ecosystem effects develop when platforms reach end of life and are left in place or cut far below the surface. Montagna said that this is another instance in which it is crucial to integrate natural science, social science, and engineering research to generate solutions, especially because this issue affects people. For example, he noted that while some fishermen love to fish on artificial reefs and offshore platforms, others believe fish in those locations will be contaminated and prefer to see them removed. He added that cutting platforms in half and toppling them over seems to be the most efficient approach, although this can create navigation issues for the U.S. Coast Guard. He emphasized that it is imperative to ensure that no contaminants are added during decommissioning. Personally, Montagna favors the Rigs to Reefs program.

A participant asked how the utilization of subsea dispersants has affected the overall recovery of a system. Montagna noted that this topic is still under discussion: Dispersants can put more oil on the sea floor, causing longer-term, more widespread impacts and mobilizing toxins in the food chain, but they can also enable work in the area because there are no fumes for the public to inhale. Ray responded that dispersants have been controversial for a long time and noted the importance of understanding the overall environment where the work occurs (i.e., where dispersed oil will go and what it might impact). The potential impacts on beaches, mammals, and wetlands if the oil is not dispersed are also important to understand. Resource managers and the environmental community have to weigh the environmental trade-offs with the knowledge base before making decisions about dispersants. Epstein said that the fact that no incentives are currently in place to push for oil recovery and to better manage major spills in the marine ecosystems indicates a failure on the parts of industry, the engineering community, and the regulatory bodies.

Referring back to the discussion of Senate Bill 4, a participant noted that its level of monitoring required onshore and offshore is a significant development for the United States. He asked what kinds of hydraulic fracturing data will be fully available to the public and to researchers. Habel said that the Groundwater Protection Council created a national database for operators to voluntarily load data about hydraulic fracturing, and the state of California created an additional space which contains extensive data on specific amounts and types of chemicals used in hydraulic fracturing. Habel added that even though all operator reports are also available to the public (which would include information on groundwater monitoring, downhole pressures, and post-fracturing monitoring, for example), he cautioned that fracturing in California is different from that in other sections of the United States, so the data may not be as useful for people working in other locales or for people engaged in other offshore operations.

A participant added that the Groundwater Protection Council is in the process of implementing a new risk-based data management system, WellSTAR (Well Statewide Tracking and Reporting System), that will contain an extensive data collection. The data will be both downloadable and manipulatable. He added that because hydraulic fracturing in California takes place at relatively shallow levels in the subsurface, one will not see many trade secret claims in California. He also emphasized that data generated from environmental studies allow operators to continue working in the offshore environment by balancing operational and environmental concerns.

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Appendix A
Workshop Agenda

A

Monday, October 2

7:45 **REGISTRATION AND CONTINENTAL BREAKFAST**

8:30 **WELCOME AND OPENING REMARKS**
Roundtable Co-Chairs David Dzombak, Carnegie Mellon University, and Wendy Harrison, Colorado School of Mines

8:40 **WORKSHOP OVERVIEW AND OBJECTIVES**
Planning Committee Co-Chairs Melissa Batum, Bureau of Ocean Energy Management, and Joe Lima, Schlumberger

8:50 **KEYNOTE PRESENTATIONS: ADVANCED TECHNOLOGIES FOR OFFSHORE OIL AND GAS DEVELOPMENT: RESOURCE RECOVERY, ENVIRONMENTAL STEWARDSHIP, AND SAFETY**
Moderated by Bud Danenberger III, Independent consultant

FROM EXPLORATION TO PRODUCTION: OFFSHORE OIL AND GAS DEVELOPMENT AND THE CONTEXT OF UNCONVENTIONAL RESOURCES IN THE OFFSHORE ENVIRONMENT
Evan Zimmerman, Offshore Operators Committee

OVERVIEW OF WELL COMPLETION AND STIMULATION TECHNOLOGIES IN OFFSHORE SETTINGS
David Payne, Chevron Corporation

REGULATORY AND ENVIRONMENTAL CONSIDERATIONS FOR OFFSHORE DEVELOPMENT
William Y. Brown, Bureau of Ocean Energy Management

9:50 MODERATED DISCUSSION

10:20 BREAK

10:45 PANEL 1: OFFSHORE OIL AND GAS DEVELOPMENT 101
Moderated by Jill Lewandowski, Bureau of Ocean Energy Management

LIFE CYCLE FOR OFFSHORE DEVELOPMENT AND THE OFFSHORE FOOTPRINT
Azra N. Tutuncu, Colorado School of Mines

INDUSTRY RISK MANAGEMENT—INDUSTRY PRACTICES AND APPROACHES FOR MANAGING SAFETY AND INTEGRITY OF WELL STIMULATION TECHNOLOGIES
Benjamin Coco, American Petroleum Institute

THE STATE REGULATORY LANDSCAPE—STATE RESPONSIBILITIES AND COOPERATION WITH FEDERAL AND PRIVATE ENTITIES
Bradley Watson, Coastal States Organization

12:30 LUNCH

1:30 PANEL 2: OFFSHORE TECHNOLOGIES IN PRACTICE
Moderated by George Wong, University of Houston

OFFSHORE WELL COMPLETION AND STIMULATION OPERATIONS USING HYDRAULIC FRACTURING AND PROPPANT: TECHNOLOGIES, OPERATIONAL PRACTICES, CHALLENGES, AND RISK EXPOSURES
Dennis McDaniel, Anadarko Petroleum Corporation

DISCUSS APPROACHES IN THE GULF OF MEXICO: TECHNOLOGIES, OPERATIONAL PRACTICES, CHALLENGES, AND RISK EXPOSURES
Michael Schexnailder, Halliburton

APPROACHES IN THE OFFSHORE PACIFIC: TECHNOLOGIES, OPERATIONAL PRACTICES, CHALLENGES, AND RISK EXPOSURES
Mike Hecker, ExxonMobil Corporation

WELL INTEGRITY CONSIDERATIONS FOR TECHNOLOGY DEPLOYMENT AND PRACTICE
Lisa Grant, Bureau of Safety and Environmental Enforcement

3:15 BREAK

3:40 PANEL 3: SAFETY IN THE OFFSHORE ENVIRONMENT
Moderated by Charlie Williams, Center for Offshore Safety

HISTORICAL REGULATORY PERSPECTIVES
Bud Danenberger III, Independent consultant

INDUSTRY RISK MANAGEMENT EXPERIENCE FOR PERFORMING STIMULATION TREATMENTS IN OFFSHORE SETTINGS
Paul Hebert, Chevron Corporation

BEYOND COMPLIANCE
Nancy Tippins, CEB

5:20 DAY 1 WRAP-UP
Melissa Batum and Joe Lima, Planning Committee Co-Chairs

5:50 RECEPTION

Tuesday, October 3

8:15 REGISTRATION AND CONTINENTAL BREAKFAST

9:00 DAY 2 OVERVIEW AND OBJECTIVES
Melissa Batum and Joe Lima, Planning Committee Co-Chairs

9:15 PANEL 4: ENVIRONMENTAL CONSIDERATIONS, ADVANCED TECHNOLOGIES, AND SOLUTIONS
Moderated by Lois Epstein, The Wilderness Society

OFFSHORE OIL AND GAS OPERATIONS—ECOSYSTEM CONSIDERATIONS: WHAT HAVE WE LEARNED OVER THE PAST FOUR DECADES?
James Ray, Oceanic Environmental Solutions, LLC

MARINE ECOLOGY AND WATER RESEARCH, GULF OF MEXICO
Paul Montagna, Texas A&M University–Corpus Christi

AIR EMISSIONS FROM OFFSHORE PLATFORMS
Desikan Sundararajan, Statoil

REGULATORY APPROACHES AND CONSIDERATIONS FOR ENVIRONMENTAL RISK OFFSHORE CALIFORNIA
Robert S. Habel, California Department of Conservation

11:00 PLENARY WRAP-UP
Melissa Batum and Joe Lima, Planning Committee Co-Chairs

11:30 NEXT STEPS
Dave Dzombak and Wendy Harrison, Roundtable Co-Chairs

11:45 PUBLIC WORKSHOP ADJOURNS

Appendix B
Members of the Roundtable on Unconventional Hydrocarbon Development

B

DAVID A. DZOMBAK (NAE), *Co-Chair*, Carnegie Mellon University
WENDY J. HARRISON, *Co-Chair*, Colorado School of Mines
BRIAN J. ANDERSON, West Virginia University
MELISSA BATUM, Bureau of Ocean Energy Management, U.S. Department of the Interior
SUSAN L. BRANTLEY (NAS), The Pennsylvania State University
DAVID COLE, The Ohio State University
DAVID CURTISS, American Association of Petroluem Geologists
PAUL DOUCETTE, Baker Hughes, a GE Company
L. DAVID GLATT, North Dakota Department of Health and The Environmental Council of the States' Shale Gas Caucus
JULIA HOBSON HAGGERTY, Montana State University
STEVEN P. HAMBURG, Environmental Defense Fund
MARILU HASTINGS, The Cynthia & George Mitchell Foundation
JOE LIMA, Schlumberger Services, Inc.
JAN MARES, Resources for the Future
ELENA S. MELCHERT, Office of Fossil Energy, U.S. Department of Energy
EVAN S. MICHELSON, Alfred P. Sloan Foundation
KRIS J. NYGAARD, ExxonMobil Upstream Research Company
AMY PICKLE, Duke University
GEOFF PLUMLEE, U.S. Geological Survey
CRAIG SIMMONS, Flinders University
TIMOTHY R. SPISAK, Bureau of Land Management, U.S. Department of the Interior
BERRY H. (NICK) TEW, JR., Geological Survey of Alabama, State of Alabama Oil and Gas Board, Interstate Oil & Gas Compact Commission, and Groundwater Protection Control
SCOTT W. TINKER, Bureau of Economic Geology, The University of Texas at Austin
SANDRA WIEGAND, Bureau of Safety and Environmental Enforcement, U.S. Department of the Interior

Appendix C
Biographies of the Workshop Planning Committee

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Melissa Batum (Workshop Planning Committee Co-Chair) is a senior program analyst and a technical subject-matter expert for the U.S. Department of the Interior's Bureau of Ocean Energy Management (BOEM). As a senior analyst she manages complex program issues and initiatives, drives strategic planning, and influences policy decisions and procedure development. With her education in geology, she serves as the BOEM principal representative for policy and technical issues regarding subseabed CO2 use and sequestration on the Outer Continental Shelf (OCS). She is a liaison for and within the Department and Bureau and works collaboratively across other federal agencies, state and local governments, foreign governments, and international groups. She also works on policy and technical issues regarding hydraulic fracturing on the OCS. She received her B.S. in geology from the University of Alabama at Birmingham and her M.S. in geology from Texas Tech University. She is also a Licensed Professional Geologist in the Commonwealth of Virginia.

Joe Lima (Workshop Planning Committee Co-Chair) is the global environmental solutions manager and director of environmental sustainability for Schlumberger Services, Inc. Before this role, Mr. Lima served as the unconventional resources theme manager for North America where he was responsible for directing technology development and application throughout the region specifically for shale and tight gas environments. From 2004 through 2008 he was the oilfield services marketing manager for the western United States, developing strategic growth plans for Schlumberger as well as managing the sales organization and executive level client relationships. Previously, he was the business development manager for Schlumberger's multistage hydraulic fracturing technologies. Mr. Lima also served in various management roles for Well Services facilities throughout the United States hydraulic fracturing markets including the San Juan, Anadarko, and Arkoma Basins. He spent 4 years as an in-house completions engineer for various Schlumberger clients and has served on the boards of Colorado Oil and Gas Association, Independent Petroleum Association of Mountain States, and California Independent Petroleum Association. He holds a B.S. in petroleum engineering from Marietta College, Marietta, Ohio.

David A. Dzombak (NAE) is the Hamerschlag University Professor at Carnegie Mellon University and is currently serving as the head of the Department of Civil and Environmental Engineering. The emphasis of his research and teaching is water quality engineering, environmental restoration, and energy-environment issues. His current research, all of which is being conducted collaboratively, is focused on climate change adaptation for infrastructure, forecasting the sustainability of water supplies, recovery of rare earth elements from brines, and the use of low-grade heat for membrane treatment processes for wastewater management and reclamation in power production. Dr. Dzombak served on the U.S. Environmental Protection Agency Science Advisory Board, the U.S. Department of Defense Strategic Environmental Research and Development Science Advisory Board, the Water Science and Technology Board of the National Academies of Sciences, Engineering, and Medicine, and the Roundtable on Science and Technology for Sustainability of the National Academies. He received his Ph.D. in civil engineering from the Massachusetts Institute of Technology in 1986. He also holds an M.S. in civil engineering and a B.S. in civil engineering from Carnegie Mellon University, and a B.A. in mathematics from Saint Vincent College. He is a registered Professional Engineer in Pennsylvania, a Board Certified Environmental Engineer by the American Academy of Environmental Engineers and Scientists, and a member of the National Academy of Engineering.

Wendy J. Harrison is a professor of geology and geological engineering at the Colorado School of Mines (CSM). Her fields of scholarly expertise are in geochemistry and hydrology as well as geoscience education. She has published papers in topics that range from impact shock metamorphism in lunar materials, the formation of gas hydrates and their role in CO2 sequestration, metals uptake by trees in mined lands, and mitigating respiratory quartz dust hazard. During her career in academia at CSM, she has served as the president of the Faculty Senate, the director of the McBride Honors Program in Public Affairs for Engineers, the associate provost and dean of Undergraduate Studies and Faculty, and a faculty trustee of the CSM Board of Trustees. Dr. Harrison completed an appointment at the National Science Foundation as the Division Director for Earth Sciences in the Geosciences Directorate. She currently serves as an advisor to the Petroleum Institute, Abu Dhabi, and Nazarbayev University, Kazakhstan, in the foundation of in-country educational and research programs in earth resources. Dr. Harrison is a member of the Kazakhstan-U.S. Joint Commission on Scientific and Technological Cooperation. She received her B.Sc. and Ph.D. in geology from the University of Manchester, United Kingdom. Dr. Harrison held a pre-doctoral fellowship at the Geophysical Laboratory of the Carnegie Institution of Washington and a National Research Council research fellowship at NASA-Johnson Space Center. Her work experience includes 8 years as a senior research geologist for Exxon Production Research Company in Houston, Texas.

Jan Mares is a senior policy advisor at Resources for the Future. He was previously a business liaison and the deputy director at the Private Sector Office of the U.S. Department of Homeland Security. During the Reagan administration, Mr. Mares was an assistant secretary of commerce for import administration and a senior policy analyst at the White House, where he was involved with environment, energy, trade, and technology issues. He also served as assistant secretary of energy for international affairs and energy emergencies; assistant secretary of energy for policy, safety, and environment; and assistant secretary of energy for fossil energy. For 6 months, he was the acting under secretary of energy. Before entering federal service, Mr. Mares was with Union Carbide Corporation for 18 years, half in the Law Department, working on antitrust compliance and purchasing issues, and half in its chemical business, including leading an effort for 3 years to create a chemicals joint venture with a Middle East government company and being the operations/profit manager for several groups of industrial chemicals. Subsequent to his service in the Reagan administration, he worked with the Washington, DC, law firm Shaw Pittman, the Synthetic Organic Chemical Manufacturers Association, and the EOP Group (a Washington, DC, environment, energy, and budget consulting firm). He received his B.A. in chemistry from Harvard College, his M.S. in chemical engineering from the Massachusetts Institute of Technology, and his L.L.B. from Harvard Law School.

Elena S. Melchert is the director for the Upstream Oil and Gas Research Division at the U.S. Department of Energy. She was a program manager at U.S. Department of Energy headquarters from 1990-2013 and led the development of several U.S. Department of Energy technology research plans and research programs, including Advanced Drilling, Completion and Stimulation Research Program Plan, and the Offshore Technology Roadmap. Starting in 1985, she was a production engineer at the U.S. Department of Energy's commercial oilfield, producing oil and natural gas for 4 years, after spending 5 years in field operations for Getty Oil/Texaco, all in California. From 1995 through 2000, she served as the U.S. Department of Energy's U.S. coordinator for natural gas in the Western Hemisphere under the President's Summit of the Americas/Western Hemispheric Energy Initiative. In 2001, she served as a member of the Senior Professional Staff for oil and gas technology at the Executive Office of the President of the United States/National Energy Policy Development Group, and provided subject-matter expertise for the President's National Energy Policy. In 2010, she served as the committee manager for the President's National Commission on the BP *Deepwater Horizon* Oil Spill and Offshore Drilling where she also served as the Designated Federal Officer for several of the Commission's subcommittees, and at times for meetings of the full Commission. In 2011, she supported the Shale Gas Subcommittee, Secretary of Energy Advisory Board. In 2012, she served as a subject-matter expert on the Spill Prevention Subcommittee of the U.S. Department of the Interior's Ocean Energy Safety Advisory Committee. In 2014, she led the development of the "fuels" section of the Department's Quadrennial Technology Review. Ms. Melchert received her B.S. in soil science at California Polytechnic State University, San Luis Obispo, and her M.Sc. in petroleum engineering from the University of Southern California in Los Angeles. She earned an Executive Certificate in international business at Georgetown University and is a graduate of the Federal Executive Institute.

Kris J. Nygaard is a senior stimulation consultant at the ExxonMobil Upstream Research Company. In his senior technical professional role, Dr. Nygaard is the Corporation's recognized expert on hydraulic fracturing and related well construction technologies. Dr. Nygaard advises the research and development program at ExxonMobil's Upstream Research Company and works with ExxonMobil's business units on technology strategy, deployment, and applications. He began his career at Exxon Production Research in 1992 following a postdoctoral research and teaching assignment at the University of Arizona. During his time with ExxonMobil, he has held technical and management positions in the areas of drilling, subsurface engineering, well completions, and unconventional resources. In 2010, he was assigned to lead the Upstream Fracturing Center of Excellence, coordinating ExxonMobil's worldwide hydraulic fracturing resources and fracturing related technical interfaces. During the past several years he has also led ExxonMobil's efforts to address risks of induced seismicity, serves as chair of the American Petroleum Institute's induced seismicity workgroup, and is currently a technical advisor to several oil and gas regulators in the United States (via the States First Initiative). In addition, he has served as consultant to the U.S. Environmental Protection Agency related to studies associated with hydraulic fracturing and underground injection. He is a member of the Society of Petroleum Engineers, American Society of Mechanical Engineers, and the Seismological Society of America. He holds a B.S. in mechanical engineering, an M.S. in aerospace engineering, and a Ph.D. in mechanical engineering all from the University of Arizona.

Michael P. Parker is a principal of Parker Environmental and Consulting, LLC, which provides environmental and regulatory policy development, technical, and advocacy support on a range of issues, focusing on nonconventional oil and gas development including hydraulic fracturing, produced water management, water resource management, onshore and offshore environmental management issues, and carbon capture and storage issues. Prior to establishing his consulting practice, Mr. Parker worked for ExxonMobil Production Company for more than 35 years in a variety of engineering and technical assignments. At retirement, Mr. Parker was a technical advisor in ExxonMobil's Upstream Safety, Health, and Environment organization. Mr. Parker provided technical support and guidance to ExxonMobil affiliates worldwide on a range of issues including drilling and production discharges, underground injection control, spill prevention and control, facility decommissioning, artificial reef programs, marine environmental issues, carbon capture and storage, hydraulic fracturing, and general issue management coordination. Mr. Parker has served as chair of the American Petroleum Institute's (API's) Upstream Environmental Subcommittee, the Hydraulic Fracturing Workgroup, the Carbon Capture and Storage Work Group and the Water Issues Group, and was involved in the revisions to API's Hydraulic Fracturing Guidance Documents and Recommended Practices. He holds a B.S. in civil engineering from The University of Texas and an M.S. in ocean engineering from Texas A&M University.

Sandra Wiegand is a petroleum engineer in the Houston office of the Bureau of Safety and Environmental Enforcement (BSEE)—part of the Houston Engineering and Technology Center, which evaluates new or current technologies and provides guidance and recommendations on current or potential technical challenges. Prior to BSEE, she spent 14 years in the oil and gas industry with Petrobras America Inc. and Shell where she focused on production engineering and, specifically, production surveillance, inflow/outflow modeling, production optimization, and decommissioning projects. She has extensive experience interfacing with non-operated ventures as the liaison between international and domestic partnerships. She received her M.S. in engineering management from The University of Texas at Austin and her B.S. in petroleum engineering from Universidad Surcolombiana, Colombia. Fluent in three languages (English, Portuguese, and Spanish), she was also an exchange student at the University of Oklahoma and has a certificate in advanced international affairs with emphasis in diplomacy from Texas A&M University.

Appendix D
Biographies of the Workshop Moderators and Presenters

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William Y. Brown is the chief environmental officer of the Bureau of Ocean Energy Management in the U.S. Department of the Interior, where he oversees science and regulation for protection of the environment in energy and non-energy minerals development on the Outer Continental Shelf of the United States. Dr. Brown's former positions include nonresident senior fellow at the Brookings Institution; science advisor to Secretary of the Interior Bruce Babbitt; president and chief executive officer of the Woods Hole Research Center in Massachusetts; president and chief executive officer of The Academy of Natural Sciences of Drexel University in Philadelphia; president and chief executive officer of the Bishop Museum in Hawaii; vice president of the National Audubon Society; vice president of Waste Management, Inc.; senior scientist and acting executive director of the Environmental Defense Fund; executive secretary of the U.S. Endangered Species Scientific Authority; and assistant professor, Mount Holyoke College. Dr. Brown is a member of the District of Columbia Bar, a fellow of the College of Physicians of Philadelphia, and a member of the International Union for Conservation of Nature Environmental Law Commission. He is a former member of the advisory committee for the Division on Earth and Life Studies of the National Academies of Sciences, Engineering, and Medicine. He is a former president of the Natural Science Collections Alliance, former chairman of the Ocean Conservancy, and former chairman of the Global Heritage Fund. He is a former board member of the Environmental and Energy Study Institute, Environmental Law Institute, U.S. Committee for the United Nations Environment Programme, U.S. Environmental Training Institute, and The Wistar Institute. He is the author of two novels: *Valley of the Scorpion* and *Ruffner's Cave*. He is a graduate of the University of Virginia (B.A. biology, with highest distinction), Johns Hopkins University (M.A.T.), University of Hawaii (Ph.D., zoology), and Harvard Law School (J.D.).

Benjamin Coco currently serves as a senior associate in the American Petroleum Institute's (API) Standards Department. His responsibilities include managing the standards development process in accordance with API's procedures by providing leadership and support to API's committees that develop technical standards to the oil and gas industry. In doing so, Mr. Coco facilitates industry participation in global standards activities and coordinates joint activities with other industry or standards developing organizations. He promotes the role of technical standards in support of public policy goals and identifies technical areas where standards development initiatives can support API's objectives. Additionally, Mr. Coco is responsible for identifying, proposing, and supporting the implementation of new initiatives in programmatic areas such as derivative publications, training seminars and certification programs, and research opportunities that are in support of standards development activities. Prior to joining API, Mr. Coco worked for 10 years with the U.S. federal government, Bureau of Safety and Environmental Enforcement and Minerals Management Service. During his time with the agency, Mr. Coco conducted inspections and reviewed permit applications related to production safety systems and drilling/completion/workover/decommissioning operations, as well as conducted accident/incident investigations, for both the shelf and deepwater in the Gulf of Mexico. Mr. Coco also provided support in matters related to policy and regulation development, and on international special assignments that represented the agency. Mr. Coco is a graduate from Louisiana State University with a B.S. and an M.S. in petroleum engineering. During this time he worked both offshore and onshore in roles as a roustabout, roughneck, wireline logging engineer, production engineer, and laboratory and teaching assistant.

Elmer "Bud" Danenberger III is currently a consultant specializing in offshore safety, pollution prevention, and regulatory policy. He has worked for the National Commission on the BP Deepwater Horizon Oil Spill, major and independent oil companies, state and federal agencies, law firms, and a safety equipment manufacturer. He was part of the first panel to testify before the U.S. Senate Committee on Energy and Natural Resources following the Macondo blowout. He is a member of the Marine Board of the National Academies of Sciences, Engineering, and Medicine and served on the National Academies' panel that published the report (2016) titled *Beyond Compliance: Strengthening the Safety Culture of the Offshore Oil and Gas Industry*. After a 38-year career, Mr. Danenberger retired from the U.S. Department of the Interior's offshore oil and gas program in January 2010. During his career, he served as a staff engineer in the Gulf of Mexico regional office, chief of the Technical Advisory Section at the headquarters office of the U.S. Geological Survey, district supervisor for Minerals Management Service (MMS) field offices in Hyannis, Massachusetts, and Santa Maria, California, and chief of the Engineering and Operations Division and chief of Offshore Regulatory Programs at MMS Headquarters. Mr. Danenberger received the Distinguished Service Award, the U.S. Department of the Interior's highest honor award, was inducted into the Offshore Energy Center's Hall of Fame as a Technology Pioneer for Health, Safety, and the Environment, and in 2015 received the Offshore Technology Conference's Distinguished Achievement Award. Mr. Danenberger earned a B.S. in petroleum and natural gas engineering and a master's degree in environmental pollution control, both from The Pennsylvania State University.

Lois Epstein, an Alaska-licensed engineer, is the Arctic Program Director for The Wilderness Society, a national conservation organization. Her efforts focus on ensuring that onshore and offshore Arctic oil and gas operations are as safe and environmentally sound as possible and protecting sensitive areas from new resource development. Previously, Ms. Epstein was a private consultant on environmental and policy issues and a senior engineer for several national and regional nonprofit advocacy organizations. Ms. Epstein has presented invited testimony before the U.S. Congress on more than a dozen occasions largely focusing on release prevention in the oil and gas sector. Additionally, she has served on several federal advisory committees covering offshore operations, pipeline safety, and refineries; on the Transportation Research Board Committee for a Study of Performance-Based Safety Regulation; and currently is president of the board of the Bellingham, Washington-based, nonprofit Pipeline Safety Trust. Ms. Epstein has appeared in *The New York Times*, *The Washington Post*, BBC, and *NewsHour* with Jim Lehrer. In May 2010, Ms. Epstein advised the U.S. Department of the Interior on its safety report to the President following BP's Gulf spill. Ms. Epstein has a master's degree from Stanford University in civil engineering with a specialization in environmental engineering and science, and undergraduate degrees from both Amherst College (English) and the Massachusetts Institute of Technology (mechanical engineering).

Lisa Grant is considered an industry subject-matter expert on well integrity and wellbore positioning with extensive experience both domestically and internationally in deepwater and onshore operations. She started her career at Schlumberger in Drilling and Measurements working High Temperature and High Pressure projects and field testing new technologies. Ms. Grant joined Shell Oil in 2004 to work as an operations engineer in deepwater Gulf of Mexico. She continued in Shell as one of the global principal technical experts. In 2014 she moved to Noble Drilling as the global technology and assurance manager where she was responsible for quality, assurance, and targeted technologies for global drilling and completions operations. Ms. Grant has recently joined the Bureau of Safety and Environmental Enforcement as the subject-matter expert for well control and well integrity. Ms. Grant has pioneered extensive technology developments to better manage the ever-changing challenges of the downhole environment. She has been active in many industry organizations, including president of the American Association of Drilling Engineers–New Orleans chapter, various leadership roles in the Society of Petroleum Engineers, and the chair of an American Petroleum Institute technical workgroup on wellbore positioning and an officer or contributing member of other technical sections. Ms. Grant has numerous publications and patents related to her industry service. She graduated from Tulane University in 1995 with a B.S.E. in chemical engineering and is a registered Professional Engineer.

Robert S. Habel is currently the program manager over the Idle Well and Enforcement Programs for the Division of Oil, Gas, and Geothermal Resources in California. He has worked in the oil, gas, and geothermal industry for more than 35 years. While working for the Division, he has been involved with permitting geothermal power plants, underground injection projects, including gas storage facilities, and permitting the drilling of oil, gas, and geothermal wells. Although he has worked in Oregon and Washington, he has primarily worked throughout California, addressing both onshore and offshore operations. He has extensive experience with writing regulations and was one of the primary authors to California's well stimulation (hydraulic fracturing) regulations. He received a B.S. in geology from San Diego State University and is a registered geologist with the State of California.

Paul Andre Hebert has worked for 36 years with Chevron in Gulf of Mexico and Nigeria areas with predominance in deepwater drilling and subsea completions. Mr. Hebert has held both field operational and office engineering levels leading up to senior drilling superintendent and engineering manager positions. Mr. Hebert started working in deepwater in 1984 and has been actively engaged in the industry growth curve of deepwater drilling and subsea smartwell completions over this 30-year deepwater time period. Mr. Hebert has served in multiple Society of Petroleum Engineers Advanced Technical Workshops related to subsea equipment and subsea smart well completions, and has served on the American Association of Drilling Engineers leading to president level at both New Orleans Chapter and National American Association of Drilling Engineers organizational levels. Mr. Hebert's current role is Drilling and Completions Special Projects Manager focused on industry-wide related topics, supporting Chevron Projects, and Chevron internal processes. Mr. Hebert is currently based in Chevron's Covington, Louisiana, office. He received his B.S. in petroleum engineering from Louisiana Tech University.

Mike Hecker has been with ExxonMobil since 1999 and currently provides completion support for drill teams around the world from concept selection through implementation. He began his career with Mobil in South Texas as a production engineer focusing on a wide range of workover, completion, and artificial lift design. He was later responsible for the stimulation design and completion of 450 Hugoton infill wells over 3 years in Kansas and for the completion/workover design and onsite technical supervision of high rate, high temperature/high pressure, sour gas wells in the Mobile Bay area while in New Orleans. After transferring to ExxonMobil with the merger, Mr. Hecker worked extensively with frac packs, providing design, real-time support, and post-job analysis on all of ExxonMobil's frac packs. He later provided critical support in the conception, development, testing, and successful field installations of the NAFPac process, Internal Shunt Alternate Path Technology screen, Shunted Zonal Isolation openhole packers, and Mazeflo technology. Mr. Hecker established and coordinated the Completion Engineering Network within ExxonMobil in 2008 to further develop and sustain completion engineering knowledge and expertise. He assisted in the development of an ExxonMobil Sand Control manual and school where more than 350 ExxonMobil students have been trained through 17 sessions of the Sand Control School. In his current position, Mr. Hecker actively participates in industry trade groups. He is the co-author of 18 technical papers relating to sand control and hydraulic fracturing and co-inventor on 23 completion related patents. He graduated with a B.S. in petroleum engineering from The University of Texas.

Jill Lewandowski currently serves as the chief of the Division of Environmental Assessment in the Bureau of Ocean Energy Management (BOEM) where she leads a national-level team of experts in providing environmental science and policy advice to decision makers. In this role, Dr. Lewandowski manages strategic initiatives to strengthen scientific rigor, stakeholder engagement, and transparency in environmental risk assessments and overall improve the effectiveness of BOEM's environmental policies. Dr. Lewandowski previously served as BOEM's subject-matter expert on protected species and marine sound issues and also managed the Division's compliance with environmental consultations. Prior to joining BOEM in 2005, Dr. Lewandowski worked as a marine biologist with the National Marine Fisheries Service and a conservation programs administrator for the National Wildlife Federation. Dr. Lewandowski received her Ph.D. in environmental science and policy at George Mason University where her research centered on transforming stakeholder conflict on complex environmental issues, particularly the effects of anthropogenic sound on marine mammals.

Dennis McDaniel is currently Anadarko Petroleum Corporation's completion engineering manager for the Gulf of Mexico and International deepwater operations. He is a registered professional engineer with 35 years of industry experience and his technical background involves design and operational execution in completion, drilling, production, and reservoir engineering on land and offshore locations. His areas of expertise are completions, workovers, stimulation, and well integrity, and he has co-authored two Society of Petroleum Engineers papers, helped develop and patent new tool technology, and made presentations at the Offshore Technology Conference, U.S. Environmental Protection Agency, Bureau of Safety and Environmental Enforcement, and the Bureau of Ocean Energy Management. He is an active member of the Texas Society of Professional Engineers, Society of Petroleum Engineers, and the American Association of Drilling Engineers. He has a B.S. in petroleum engineering from the University of Missouri–Rolla.

Paul Montagna is professor and endowed chair for ecosystems studies and modeling at the Department of Physical and Environmental Sciences and the Harte Research Institute for the Gulf of Mexico Studies at Texas A&M University–Corpus Christi. His research on ecosystem studies of estuaries and the deep sea focuses on benthic components, freshwater resources, water quality, ecological modeling, environmental statistics, and integrating natural science with human dimensions research. Prior to joining Texas A&M, he served in various research, teaching, and management capacities with the Marine Science Institute and the Department of Marine Science at The University of Texas at Austin, Port Aransas. The author of numerous peer-reviewed articles and book chapters, he is also a member of the American Association for the Advancement of Science, the Association for the Sciences of Limnology and Oceanography, the Coastal & Estuarine Research Federation, and the Gulf Estuarine Research Society, among others, and co-editor in chief for the journal *Estuaries and Coasts*. He received his B.S. from the State University of New York at Stony Brook, his M.S. from Northeastern University, and his Ph.D. from the University of South Carolina.

David Payne is the vice president of Drilling and Completions for Chevron. He assumed the position in May 2006 and is based in Houston, Texas. He began his career with the Getty Oil Company in Santa Maria, California in 1981. Prior to his current position he was the drilling manager in Bangkok, Thailand. He has held various engineering and management positions in California, Indonesia, Louisiana, Thailand, Tobago and Trinidad, and Vietnam. Mr. Payne graduated from The Pennsylvania State University in 1981 with a B.S. in petroleum and natural gas engineering. Mr. Payne is a member of the Society of Petroleum Engineers and has served in various roles for local chapters, including section chairman in Santa Maria, California. He currently serves on the board of directors for the Houston Food Bank.

James Ray retired from Shell Oil in 2004 and started his consulting business, Oceanic Environmental Solutions, LLC. His recent interest has been the development of marine vibroseis as an alternative to air guns for offshore seismic surveying. His career at Shell included various roles as a technical specialist and an environmental manager. He was an integral member of environmental scientists from across the industry that assisted in building our knowledge base on the fate and effects of discharges related to offshore oil and gas operations. His career included the early research and offshore studies related to drill muds and cuttings discharges. In the following years, mostly under joint industry programs through the American Petroleum Institute and the Offshore Operators Committee, the focus switched to research related to the offshore discharges of produced water and sand. This included research involving radionuclides. Over a number of years, the focus switched to issues related to the offshore discharge of synthetic based drill muds and associated cuttings. This research also included seafloor studies related to trace metal speciation, accumulation, and distribution. Dr. Ray served 6 years on the Minerals Management Services' Environmental Studies Program Advisory Committee. He also served for 3 years on the Ocean Studies Board and 6 years on the Marine Protected Areas Federal Advisory Committee. He served on numerous National Academies' panels and study groups, including issues such as drilling fluids, offshore environmental monitoring, and the National Academies' Oil in the Sea reviews. He also served on the Marine Mammal Commissions Federal Advisory Committee on the effects of sound on marine mammals. He was chairman of the 1995 International Oil Spill Conference and the 2008 recipient of the Offshore Technology Conferences Individual Achievement Award. He received a Ph.D. in biological oceanography from Texas A&M University.

Michael Schexnailder is a completion technical sales manager for Halliburton Gulf of Mexico. He received a B.S. degree in mechanical engineering from Louisiana State University. He has 11 years of industry experience focused on deepwater completion work in the Gulf of Mexico. He has spent 3 years with various operators and 8 years working for Halliburton Energy Services. He supported the first installations of Single Trip Multizone fracpac completions in the Gulf of Mexico as outlined in OTC 27222-MS. His current role focuses on identifying operator challenges and development needs to assure future success for Gulf of Mexico completions.

Desikan Sundararajan is currently working with Statoil as a team lead and a technical program manager in the shale oil and gas research and technology sector in Austin, Texas. In his current role, his research is focused on investigating, developing, and implementing new technologies to facilitate clean oil and gas production from shale plays with specific emphasis production optimization and sustainability management. Methane and volatile organic compound emissions form the oil and gas industry have always been a focal point of his current work at Statoil. He is involved in developing various strategic policy and technology based alternatives to reduce Statoil's carbon footprint. Dr. Sundararajan has more than 15 years of industrial and academic research and development experience across automotive, glass manufacturing, and oil and gas industries. He has served on advisory committees of several U.S. Department of Energy's National Energy Technology Laboratory and Research Partnership to Secure Energy for America studies and has authored numerous peer-reviewed publications. Dr. Sundararajan obtained his Ph.D. in chemical engineering from the University of Toledo in 2009, M.S. in environmental engineering from the University of Arizona in 2004, and B.E. in chemical engineering from the University of Pune.

Nancy T. Tippins is a principal consultant at CEB where she brings more than 30 years of experience to the company. She manages teams that develop talent acquisition strategies related to work force planning, sourcing, acquisition, selection, competency identification, succession planning, and employee and leadership development. She also conducts executive assessments and coaching and provides expert support in litigation matters. Active in professional affairs, Dr. Tippins has a longstanding involvement with the Society for Industrial and Organizational Psychology where she served as president (2000-2001). In addition, she served on the Ad Hoc Committee on the Revision of the Principles for the Validation and Use of Personnel Selection Procedures (1999) and is co-chairing the committee for the current revision of the Principles. She was one of the U.S. representatives on the International Organization for Standardization

9000 committee to establish international testing standards. She also served on the Joint Committee to revise the Standards for Educational and Psychological Tests (2014). She has served on a number of National Academies' committees and recently chaired the Committee on Offshore Oil and Gas Industry Safety Culture. Dr. Tippins has authored numerous articles on tests and assessments. Recently, she co-authored *Designing and Implementing Global Selection Systems*, co-edited the *Handbook of Employee Selection*, and another edited volume, *Technology Enhanced Assessments*. Dr. Tippins received an M.S. and a Ph.D. in industrial and organizational psychology from the Georgia Institute of Technology, an M.Ed. in counseling and psychological services from Georgia State University, and a B.A. in history from Agnes Scott College.

Azra N. Tutuncu is a professor, the Harry D. Campbell chair, and the director of the Unconventional Natural Gas and Oil Institute at the Colorado School of Mines Petroleum Engineering Department. Before joining the Colorado School of Mines faculty, Dr. Tutuncu held various research and leadership assignments in well engineering, rock physics, geomechanics, and subsurface research and development groups at Shell International Exploration and Production Company and Shell Oil Company in Houston and in the Netherlands. Her interest areas include rock-fluid interactions, integrated borehole stability, geomechanics, reservoir characterization, and formation damage detection, mitigation, and removal. She has more than 200 publications in peer-reviewed journals and conference proceedings in addition to more than 150 reports in research and implementation of novel technologies in deepwater Gulf of Mexico, unconventional gas and oil shale, heavy oil sands and carbonates integrated borehole stability, in situ stress and rock property determination, nonlinear rock deformation and failure, pore pressure and fracture gradient prediction, stimulation, drilling and drill in fluid design and compatibility analysis. She holds several patents on pore pressure prediction, attenuation, and acoustic stimulation. Dr. Tutuncu is a member of the Society of Petroleum Engineers (SPE), Society of Exploration Geophysicists (SEG), Sigma Xi, Association of Records Managers and Administrators (ARMA), American Association of Drilling Engineers, and Pi Epsilon Tau and has been actively involved in SEG, SPE, and ARMA organizations for more than 25 years. She is a licensed Professional Petroleum Engineer and Geoscientist in the State of Texas and received her B.S. from Istanbul Technical University, two M.S. degrees from Stanford University and The University of Texas at Austin, and also her Ph.D. from The University of Texas at Austin.

Bradley Watson is Coastal States Organization's acting executive director. Spanning parts or all of four Congresses, Mr. Watson worked for the Committee on Transportation and Infrastructure under the late Chairman James L. Oberstar, as a member of the investigations team for the Senate Armed Services Committee under Senator Carl Levin, and as a senior legislative staffer for Congresswoman Eddie Bernice Johnson. Mr. Watson is a graduate of Gonzaga College High School in Washington, DC; Tulane University in New Orleans, Louisiana; and the evening program at the Columbus School of Law at The Catholic University of America. Mr. Watson is a native of Prince Georges County, Maryland, is admitted to the bar in the State of Maryland, and resides on Capitol Hill.

Charlie Williams was named the executive director for the Center for Offshore Safety (COS) in March 2012. Prior to joining COS, he retired from Shell Oil as chief scientist—well engineering after a 40-year career. At Shell he held other senior management positions, including vice president—global research and development. Mr. Williams received the 2012 Offshore

Technology Conference Special Citation and the Society of Petroleum Engineers (SPE) Regional Safety Award for his offshore safety work. He serves on the U.S. Department of the Interior Ocean Energy Safety Federal Advisory Committee, and he has presented extensively on safety management and drilling technology, including to the Presidential Commission, Center for Strategic and International Studies, and the National Academy of Sciences. Mr. Williams chaired the post-Horizon Joint Industry Task Force—Subsea Well Control and Containment and the Bureau of Safety and Environmental Enforcement/Argonne Labs Workshop—Effects of Water Depth on Offshore Equipment and Operations. Mr. Williams is a recipient of the U.S. Department of the Interior Corporate Citizenship Award and has been awarded the National Ocean Industries Association Safety in the Seas Award. He has also served on the Petroleum Engineering curriculum advisory committee at The University of Texas. He has been a lifetime member of SPE. He is a mechanical engineering graduate of the University of Tennessee and a Professional Mechanical Engineer.

George Wong is a faculty member of the Petroleum Engineering Department at the University of Houston (UH). Prior to joining UH he worked with Shell R&D and producing companies for 31 years. He served as the Deepwater Completion/Sand Control Technology Lead and the Production Engineering Advisor in Shell E&P Company, USA. Dr. Wong also held the position of principal technical expert (PTE) in Sand Control and Sand Management for the global Shell organizations. PTE is the highest technical expert for a given technical area in Shell. Dr. Wong has played key roles in the development and deployment of frac pack completion and the current maximum rate operating guidelines in Shell's deepwater operations. His expertise is in areas of production engineering, sand control completion design and execution for producers and injectors, production operations on bean-up and ramp-up, geomechanics and fracture mechanics for both consolidated and unconsolidated sand formations. He received the Society of Petroleum Engineers (SPE) Distinguished Membership in 2015 and the SPE Gulf Coast Regional Completion Optimization and Technology Award in 2013. Dr. Wong has been the chairperson for the last four SPE-Applied Technology Workshops (ATWs) on Injectors Requiring Sand Control since 2009. He has also served as technical committee member, session chair, discussion leader, moderator, and speaker in different SPE conferences, ATWs, and forums. Dr. Wong received his B.S. and M.S. degrees from the University of California, Davis, and his Ph.D. from Stanford University, all in civil engineering. He is also a registered Civil Engineer from the State of California.

Evan H. Zimmerman is the executive director of the Offshore Operators Committee and has two decades of experience in offshore related engineering, technology development, and risk management. Mr. Zimmerman has held senior management roles in the offshore oil and gas service sector in the United States, North Sea, and Australia. He has received numerous patents for offshore related technology, served in key roles in many industry and academic initiatives, and received many awards for service or accomplishments including a Corporate Leadership Award from the U.S. Department of the Interior. Mr. Zimmerman holds a J.D. from the South Texas College of Law and a B.S. in ocean engineering from Texas A&M University.

Appendix E
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Appendix F
Glossary

F

Acid stimulation: Also known as acidizing, acid stimulation refers to pumping a stimulation fluid contains a reactive acid into a reservoir formation in order to improve permeability and productivity of a well (API, 2014; Schlumberger, 2017).

Annulus: The space around the pipe in a wellbore (Schlumberger, 2017).

Bow-tie: The bow-tie method is a technique commonly used in high-hazard industries for identifying operational (or process) risk. Bow-ties identify a variety of barriers and help communicate safety principles that link causal factors and subsequent actions to a specific event—such as a loss of well control event (Fraser et al., 2015).

Conventional well: A reservoir formation in which the resources can be produced commercially without altering permeability or viscosity (Houseworth, 2014).

Deepwater production: Production in water of depths greater than 125 meters (EIA, 2016).

Frac pack: An approach that combines the production improvement from hydraulic fracturing with the sand control provided by gravel packing. It involves simultaneous hydraulic fracturing of a reservoir and the placement of a gravel pack with the objective of achieving a high-conductivity gravel pack to create a conduit for the flow of reservoir fluids at lower pressures (Sanchez and Tibbles, 2007).

Fracture gradient: The pressure necessary to initiate and propagate fractures in a rock at a particular depth in a well (Schlumberger, 2017).

Gravel pack: A sand-control method used to prevent production of formation sand in which a steel screen is placed in the wellbore and the surrounding annulus is packed with prepared gravel of a specific size (Schlumberger, 2017).

Hydraulic fracturing: A controlled, high-pressure injection of fluid and proppant into a well to generate fractures in the rock formation containing the oil or gas, used to increase production of oil and gas (NASEM, 2017).

Hydrocarbon: Any organic compound, gaseous, liquid, or solid, consisting solely of carbon and hydrogen (USGS, 2014).

Play: A set of discovered, undiscovered, or possible hydrocarbon accumulations that exhibit similar geological characteristics (DOE, 2013; Schlumberger, 2017).

Proppant: Sand or ceramics that help keep hydraulic fractures open after fluid injection is completed. The injected fluid can comprise water and small amounts of chemical additives that reduce friction in the pipe and help carry the proppant into the fractures (NASEM, 2017).

Reservoir: A subsurface, porous, permeable body of rock in which oil or gas resources have accumulated (USGS, 2014).

Sandstone: Sedimentary rock composed of abundant rounded or angular fragments of sand set in a fine-grained matrix (silt or clay) (USGS, 2002).

Shale: Fine-grained sedimentary rocks of low permeability comprised mostly of consolidated clay or mud (DOE, 2013; USGS, 2014).

Treatment fluid: A fluid used to resolve a specific wellbore or reservoir condition, such as stimulation, isolation, or control of reservoir gas or water (Schlumberger, 2017).

Unconventional well: A well in which oil and/or gas is extracted using stimulation or techniques including hydraulic fracturing. Fracturing is needed to extract economic quantities of oil and gas (NASEM, 2017).

Well control: Method for maintaining pressure on open formations to prevent or direct the flow of formation fluids into the wellbore, including procedures to safely stop a well from flowing should an influx of formation fluid occur (Schlumberger, 2017).

Well stimulation: A type of treatment where the rate of oil flow from the reservoir to the well is increased in situations where the natural reservoir flow characteristics are not favorable and require improvement for effective oil recovery (Houseworth, 2014).

Wellbore: A drilled hole to aid exploration and recovery of natural resources including oil, gas or water. Wellbore can be cased using materials such as steel casing and cement, or it may be uncased (Petropedia, 2018).