JISEA Joint Institute for Strategic Energy Analysis

Highly Reliable Organizations in the Onshore Natural Gas Sector: An Assessment of Current Practices, Regulatory Frameworks, and Select Case Studies

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NREL Technical Monitor: Jeffrey Logan

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NREL National Renewable Energy Laboratory · Colorado School of Mines · Colorado State University · Massachusetts Institute of Technology · Stanford University · University of Colorado Boulder

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Foreword

Natural Gas and our Changing Energy Economy

Unconventional natural gas produced from shale is reshaping the U.S. energy sector. In 2011, the Joint Institute for Strategic Energy Analysis (JISEA) published its first major report in a series of studies on natural gas and the U.S. energy sector. *Natural Gas and the Transformation of the U.S. Energy Sector: Electricity* provides a new methodological approach to estimate natural gas-related greenhouse gas emissions, tracks trends in regulatory and voluntary industry practices, and explores various electricity futures.

Since then, our work has examined additional critical topics related to the role of natural gas in our energy economy, including potential synergies between natural gas and renewable energy in the power and transportation sectors; the state of knowledge about emissions from natural gas systems compared to other fuel sources; and the research required to better characterize the potential role that natural gas can play in a more environmentally sustainable energy economy. We have also convened panels of energy thought leaders on numerous occasions to discuss topics related to gas and the U.S. energy economy. Our ongoing work in this space will explore economic, environmental, and systems impacts of natural gas development and use.

As the natural gas landscape continues to shift in the United States and globally, JISEA believes that bringing objective views and analytical expertise to bear on these issues can help move the discussion forward on a productive path. It is part of our mission to provide leading-edge, objective, high-impact research and analysis to guide global energy investment and policy decisions. JISEA has a growing portfolio of natural gas research that reflects our commitment to "getting gas right."

This report focuses on onshore natural gas operations and examines the extent to which oil and gas firms have embraced certain organizational characteristics that lead to "high reliability"—understood here as strong safety and reliability records over extended periods of operation. The key questions that motivated this study include whether onshore oil and gas firms engaged in exploration and production and midstream operations are implementing practices characteristic of high reliability organizations (HROs) and the extent to which any such practices are being driven by industry innovations and standards and/or required by regulators.

We look forward to your feedback and thank you for your interest in the work of JISEA.

Doug Arent
Executive Director, Joint Institute for Strategic Energy Analysis

Acknowledgments

This report was funded by the U.S. Department of Energy (DOE) Office of Energy Policy and Systems Analysis (EPSA). The authors would like to thank Kevin Easley of EPSA for supporting this research. We are incredibly grateful for the participation from the four companies that provided invaluable insight into their operations, practices, and policies. The report benefited from the input, review, and feedback from a number of experts. In particular, the authors would like to thank Karlene H. Roberts, (University of California – Berkeley), Earl Carnes (formerly DOE), and Doug Arent (Joint Institute for Strategic Energy Analysis) for their reviews of the report. These reviews serve to make this report as technically sound as possible, however, any remaining errors or omissions are those of the authors. Furthermore, the views and opinions of authors expressed herein do not necessarily state or reflect those of the reviewers, their associated institutions, or the United States government, or of any institution thereof.

List of Acronyms

AGA	American Gas Association
API	American Petroleum Institute
ASIAS	Aviation Safety Information Analysis and Sharing
AXPC	American Exploration & Production Council
BOEM	Bureau of Ocean Energy Management
BOEMRE	Bureau of Ocean Energy Management, Regulation, and Enforcement
BSEE	Bureau of Safety and Environmental Enforcement
CDP	Carbon Disclosure Project
CEO	chief executive officer
DOC	Department of Conservation
DOE	U.S. Department of Energy
DOGGR	California Division of Oil, Gas, and Geothermal Resources
DOI	Department of Interior
DOT	Department of Transportation
E&P	exploration and production
EDF	Environmental Defense Fund
EHS	environment, health, and safety
EPA	Environmental Protection Agency
FERC	Federal Regulatory Energy Commission
GHG	greenhouse gas
HCA	high consequence area
HLPSA	Hazardous Liquid Pipeline Safety Act of 1979, as amended
HRO	high reliability organization
HSE	health, safety, and environment (also known as EHS)
IMP	integrity management plan
INGAA	Interstate Natural Gas Association of America
INPO	Institute of Nuclear Power Operators
JSA	job safety analysis
LNG	liquefied natural gas
MFL	magnetic flux leakage
MMS	Minerals Management Service
MOC	management of change
NGA	Natural Gas Act of 1938
NGPSA	Natural Gas Pipeline Safety Act of 1968
NOV	notice of violation
OCS	outer continental shelf
OSHA	Occupational Safety and Health Administration
PHMSA	Pipeline and Hazardous Material Safety Administration
PIPES	Protecting our Infrastructure of Pipelines and Enhancing Safety Act of 2016
PSMS	Pipeline Safety Management System

RP	recommended practice
SEMS	Safety and Environmental Management System
STOP	Safety Training and Observation Program
T&D	transmission and distribution
TRI	total recordable incidents
VP	vice president

Executive Summary

Rapid growth of unconventional natural gas production in the United States has resulted in increased attention to the safety, reliability, and sustainability of industry practices. Driven by technological advancements that allow operators to access previously untapped and difficult-to-reach resources, U.S. natural gas production increased by 50% between 2005 and 2015 and is expected to continue to grow in the coming years.

The rapid increase in natural gas production has been accompanied by an expansion of oil and gas activities into more populated areas, causing an increase in public scrutiny regarding impacts associated with development. In addition, several serious high-profile accidents involving fatalities and significant environmental harm have occurred over the last decade. The most recent incident involved an explosion that killed two members of the public and severely injured another in Firestone, Colorado. In addition, last year the largest natural gas leak from an underground natural gas facility in recorded U.S. history occurred at the Aliso Canyon underground storage facility in California. The operator of the facility, SoCal Gas, spent approximately $763 million in response costs. Moreover, the leak resulted in the displacement of over 5,790 families. Incidents such as the Firestone explosion and Aliso Canyon have the potential to erode public trust in the reliability of oil and gas companies and significantly undermine (and ultimately limit) the industry's social license to operate in production areas.

It is against this backdrop that industry leaders, policymakers, and academic researchers have begun to look more systematically at ways to ensure and improve the safety and reliability of oil and gas operations. Prior research focused on safety in offshore oil and gas operations; however, this study focuses on onshore natural gas operations and examines the extent to which oil and gas firms have embraced certain organizational characteristics that lead to "high reliability"—understood here as strong safety and reliability records over extended periods of operation. The key questions that motivated this study include whether onshore oil and gas firms engaged in exploration and production (E&P) and midstream (i.e., natural gas transmission and storage) are implementing practices characteristic of high reliability organizations (HROs) and the extent to which any such practices are being driven by industry innovations and standards and/or regulatory requirements.

After a brief introduction, Section 2 of this report provides an overview of HRO theory and its relevance to operations across the onshore natural gas sector. It takes as its starting point previous research on HROs in the aviation, nuclear, and electric grid sectors, and the associated development of HRO theory to provide a framework for identifying and understanding industry efforts to promote safe, reliable, and sustainable practices and organizational structures in onshore natural gas operations. Key HRO characteristics that we considered in our research included:

- Preoccupation with avoiding failure and commitment to organizational culture where safety is inherent (e.g., track failures, encourage and reward reporting of incidents)
- Use of comprehensive safety management systems
- Reluctance to oversimplify (e.g., avoiding categorizing or labeling, questioning assumptions)

- Sensitivity to operations (e.g., attention to, and involvement in, risky activities such as well drilling)
- Commitment to resilience (e.g., ability to react swiftly, rebound from adverse circumstances)
- Respect for experience, with attention to safety-critical, informed decision-making approaches and encouraging improvisation/innovation by line-level operators
- Ability to operate in either a centralized or decentralized manner
- Communication of and openness to new information/approaches and transparency in operations and decision-making
- Incident reporting with appropriate and positive incentives for reporting errors and incidents (because failures can provide important lessons learned)
- Redundancy (i.e., checks and balances in place to prevent accidents)
- Mindful leadership with a focus on safety
- Strong internal review and oversight that drives reflective learning and sound decision-making
- Training, including simulation training, to ensure a learning organization
- Strong culture of learning, sharing, and innovating.

While onshore natural gas production, transportation, storage, and distribution look quite different than the activities and organizations studied by HRO researchers previously, many oil and gas operators have adopted various practices and organizational structures that look similar to those discussed in the HRO context and the literature surrounding the subject. And there is considerable room for additional cross-fertilization as the oil and gas industry and its regulators continue to think more systematically about safety and reliability in this vitally important industry.

Section 3 of this report summarizes the results of interviews with management and executives at four onshore oil and gas companies known for their commitments to safe and sustainable practices. Specifically, we surveyed a small independent onshore E&P company, a large E&P company with international operations onshore and offshore, a major U.S. pipeline company, and a vertically integrated utility with significant natural gas assets, including transmission pipelines and underground natural gas storage facilities. We asked the participating companies a series of questions designed to identify HRO-like practices based on a review of HRO literature and accident reports from the 2010 Macondo well blowout. Our limited research into practices adopted by the firms queried in the four case studies reveals some familiarity with HRO theory and application of techniques by industry leaders. Specifically, the companies we queried are implementing policies and initiating practices designed to strengthen their safety culture, improve process safety, and manage risks posed by human and organizational factors. Key examples include non-punitive incident and near-miss reporting structures; implementing a comprehensive safety management plan; borrowing practices from HRO practitioners in industries outside the oil and gas sector; utilizing independent third parties to perform audits; employing data analytics to identify the root cause of incidents and to build or enhance management systems capable of predicting and preventing future accidents; and investing in emerging technologies such as continuous emissions monitors and simulators capable of predicting future accidents.

Section 4 of the report examines state and federal regulations applicable to onshore E&P and midstream activities as well as recent industry standards that incorporate HRO elements. Specifically, we examine select federal requirements promulgated by the Pipeline and Hazardous Material Safety Administration, the Bureau of Safety and Environmental Enforcement, and select state requirements in jurisdictions with significant E&P activity. Our research revealed that state and federal requirements for midstream operations (i.e., storage facilities and transmission pipelines), as well as requirements applicable to offshore operators in the Outer Continental Shelf, are beginning to incorporate some HRO elements. Examples include: requiring operators to conduct risk-detailed risk assessments; developing emergency response plans; ensuring oversight of contractors; and implementing stop-work authorities and non-punitive incident reporting programs. Corollary requirements for the onshore E&P operators appear to be lacking. We identified a number of instances where industry standards have formed the basis for federal rules aimed at increasing safety and reliability.

In Section 5, we discuss the challenges and opportunities to broader adoption of HRO practices in the onshore natural gas sector. The diverse and fragmented nature of the oil and gas industry—ever-shifting nature of its workforce that relies heavily on the use of contractors, decentralized operations, rapid technological innovation, and fragmented nature of the regulatory framework applicable to onshore operations—poses challenges to greater adoption of HRO practices. Nevertheless, we identified a number of pathways available to industry and policymakers that could lead to greater adoption of HRO practices. These include:

- The development of formal structures to facilitate sharing information regarding both accidents and near misses and applying best practices to prevent and mitigate the impacts of accidents and near misses
- Agreement on what systems, processes, behaviors, and policies are necessary to move the entire oil and gas industry closer to becoming an HRO
- The establishment of an independent, multidisciplinary body qualified to evaluate HRO adoption and drive continuous improvement by employing a suite of methods such as interviews, work observations, and validated questionnaire/survey instruments
- Government programs that encourage and reward early innovators that adopt HRO practices, systems, structures, and mentalities
- Programs to help develop the next generation of industry leaders
- Enhanced transparency and communications relating to accidents, incidents, and inspection data.

Section 6 presents conclusions and recommendations for further inquiry and research. We conclude that the application of HRO theory and practices to the onshore natural gas sector appears to be in its nascence, and there are limited regulatory requirements that explicitly require HRO practices. While the four firms we queried as case studies are implementing policies and initiating practices recommended by HRO and other industry experts, the oil and gas industry as a whole does not appear to be driven by HRO theory and leadership practices.

The research to date (including this project and other scholarly efforts reviewed during our research) has been limited in scope and leaves a number of questions unanswered. Opportunities for further research include: (1) a deep dive into the differences and similarities between the onshore and offshore players and activities, combined with an analysis of the pitfalls and successes of the regulatory framework applicable to offshore activities in the Outer Continental Shelf; (2) an investigation into the cost-effectiveness of HRO practices and a nuanced exploration into the potential barriers to greater adoption by the oil and gas industry; (3) analysis of lessons learned from prior accidents and a review and distillation of literature analyzing such accidents in order to identify incentives and drivers of positive change, both at the company and regulatory level; (4) a deep dive into industry and joint industry-regulatory programs implemented by HROs such as the nuclear and aviation industry to identify programs and practices that, if adopted by the oil and gas industry, could help prevent accidents; and (5) investigation into the practices, policies, culture, and governance of a major publicly traded multinational oil and gas firm with a strong safety and sustainability record.

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1 Introduction

1.1 The Importance of High Reliability in Onshore Natural Gas Production

Rapid growth of unconventional natural gas production in the United States has resulted in increased attention to the safety, reliability, and sustainability of industry practices. Driven by technological advancements that allow operators to access previously untapped and difficult-to-reach resources, U.S. natural gas production increased by 50% between 2005 and 2015[1] (as depicted in Figure 1) and continues to ascend. Most of this growth can be attributed to the production of unconventional natural gas shale, which now accounts for approximately half of U.S. gas production.[2]

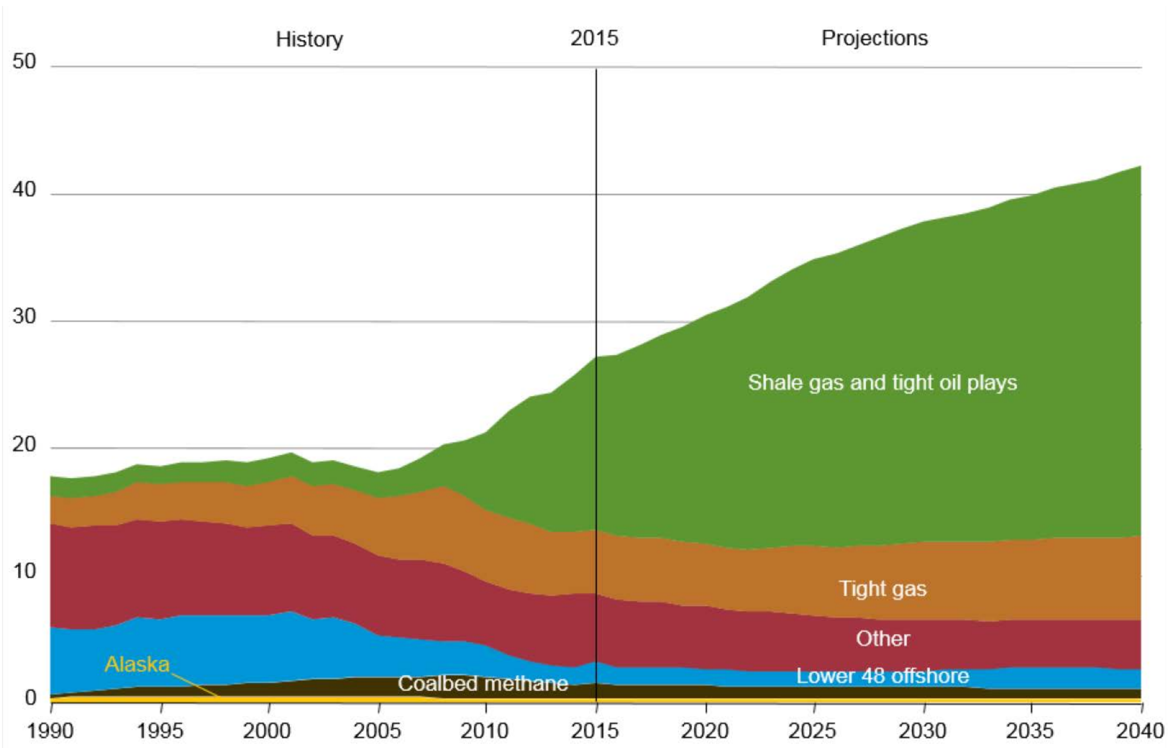

Figure 1. U.S. dry natural gas production by source, 1990–2040 (trillion cubic feet)[3]

This newly abundant and low-cost supply of natural gas, combined with federal and state policies aimed at reducing pollution associated with coal-fired power plants, is contributing to an ongoing shift from coal to gas in the electric utility sector. Natural gas-fired power generation now exceeds coal-fired production,[4] and, irrespective of the direction of federal climate and environmental policy in the United States, this trend will likely continue. Natural gas use is also

[1] EIA, "U.S. Dry Natural Gas Production." https://www.eia.gov/dnav/ng/hist/n9070us2A.htm.

[2] *Id*.

[3] EIA, Annual Energy Outlook, available at https://www.eia.gov/outlooks/aeo/executive_summary.cfm. This figure represents the reference case analyzed by EIA.

[4] According to the March 2017 "Monthly Energy Review," U.S. natural gas generation for 2016 was 1,380 million megawatt-hours (MWh), while coal generation was 1,240 million MWh. See https://www.eia.gov/totalenergy/data/monthly/archive/00351703.pdf.

growing in other sectors of the economy, providing an important feedstock for the chemicals industry and for various industrial processes such as steel manufacturing. Plans are moving forward to export large volumes of liquefied natural gas (LNG) from the United States.[5] In sum, as depicted in Figure 1, U.S. natural gas production is expected to continue to grow in the coming years, placing a premium on efforts to ensure the reliability, safety, and environmental performance of the natural gas supply chain.

The rapid increase in natural gas production has been accompanied by an expansion of oil and gas activities into more populated areas. This has led to an increase in conflicts between members of the public and the industry over issues involving local control of development patterns and impacts. In addition, over the past decade, a number of serious accidents involving fatalities and significant environmental harm have occurred. High-impact events—such as the Firestone incident (where an improperly abandoned flowline leaked natural gas into a home, destroying the house, killing two people, and severely injuring a third), the Macondo well blowout (where 11 people were killed, 17 were seriously injured, and significant environmental harm occurred) and, more recently, the Aliso Canyon gas storage facility methane leak, which cost the operator of the failed well approximately $763 million in response costs, resulted in the displacement of over 5,790 families, and released the equivalent greenhouse gas (GHG) emissions of a half-million cars[6]—have the potential to significantly erode public trust in the reliability of oil and gas companies and significantly undermine (and ultimately limit) the industry's social license to operate in production areas.

[5] The Sabine Pass Liquefied Natural Gas (LNG) export terminal, the first operational LNG export terminal in the U.S. lower 48, is now entering the commercial phase after fully commissioning its first liquefaction train in early 2016. The first commissioning cargo of LNG, produced from the first liquefaction train ("Train 1") of the Sabine Pass liquefaction project in Cameron Parish, Louisiana, was loaded on the LNG carrier *Asia Vision*, chartered by Cheniere Marketing, LLC, and shipped to Brazil. "First LNG Commissioning Cargo is Loading and Will Depart from the Sabine Pass LNG Terminal Imminently," PR Newswire (Feb. 24, 2016), http://www.prnewswire.com/news-releases/first-lng-commissioning-cargo-is-loading-and-will-depart-from-the-sabine-pass-lng-terminal-imminently-300225551.html.

[6] PHMSA Interim final rule, Pipeline Safety: Safety of Underground Natural Gas Storage Facilities, 81 Fed. Reg. 91860 at 91862 (Dec. 19, 2016), available at https://www.gpo.gov/fdsys/pkg/FR-2016-12-19/pdf/2016-30045.pdf.

Figure 2. The Macondo well blowout in the Gulf of Mexico on April 20, 2010, killed 11 people and caused significant environmental damage

Photo courtesy of EPA

Against this backdrop, industry leaders, policymakers, and academic researchers have begun to look more systematically at ways to ensure and improve the safety and reliability of oil and gas operations. There is, of course, a rich tradition of research on safety in offshore oil and gas operations (see Sections 2.2 and 2.3); however, this study was not scoped to cover the same ground. Rather, this research project focused on an area that has received less attention from researchers to date: onshore natural gas operations. More specifically, this report focuses on the organizational and behavioral practices of oil and gas firms directed at advancing safety and reliability in both conventional and unconventional[7] production operations—in rural and urban areas alike. These practices have received less attention from researchers to date. An important issue to consider, therefore, is the extent to which oil and gas firms have embraced certain organizational characteristics that lead to "high reliability"—understood here as strong safety and reliability records over extended periods of operation.

[7] Unconventional oil and gas production is an umbrella term for oil and natural gas that is produced by means that do not meet the criteria for conventional production. Note: What has qualified as "unconventional" at any particular time is a complex interactive function of resource characteristics, the available exploration and production technologies, the current economic environment, and the scale, frequency, and duration of production from the resource. Perceptions of these factors inevitably change over time, and they often differ among users of the term. EIA, https://www.eia.gov/tools/glossary/index.cfm?id=U.

This study represents a modest but necessary first step by the U.S. Department of Energy (DOE) toward investigating the extent to which such characteristics have been and/or are being embraced by firms in the upstream, midstream, and downstream segments (i.e., natural gas transmission, storage, and distribution) of the onshore oil and gas sector. As a starting point, it takes previous research on high reliability organizations (HROs) and the associated development of HRO theory to provide a framework for identifying and understanding industry efforts to promote safe, reliable, and sustainable practices and organizational structures in onshore natural gas operations. Furthermore, the key questions that motivated this study include whether onshore oil and gas firms engaged in exploration and production (E&P) and midstream (i.e., natural gas transmission and storage) are implementing practices characteristic of HROs and the extent to which any such practices are being driven by industry innovations and standards and/or required by regulations.

To answer the questions that motivated this study, we researched state and federal environmental and safety requirements and conducted a series of interviews with executives, managers, and directors at a select few oil and gas companies and gas storage operators. Based on our research, we identified firms that are generally viewed as leaders and progressive "first actors" within the oil and gas production, midstream, and downstream sectors and gas utility operators.

Specifically, we identified four onshore oil and gas companies known for their commitments to safe and reliable practices. In choosing these firms, we first interviewed experts and regulators and surveyed publicly available reports and information related to a specific company's commitments to safe and responsible oil and gas production and transportation. Based on this information, we chose to survey a small independent onshore E&P company, a large E&P company with international operations onshore and offshore, a major U.S. pipeline company, and a vertically integrated utility with significant natural gas assets, including transmission pipelines and underground natural gas storage facilities. We subsequently conducted a series of interviews with managers, directors, and executives at each company in order to identify practices, policies, and organizational structures designed to increase reliability and safety and minimize risk. We based the interview questions on our review of the HRO literature, research on industry practices, and reports from accidents such as the 2010 San Bruno pipeline explosion (where a pipeline rupture in a suburb of San Francisco killed 8 people and injured many more), Aliso Canyon, and Macondo.

Figure 3. The Aliso Canyon gas storage facility methane leak cost the well operator approximately $763 million in response costs, displaced over 5,790 families, and released the equivalent GHG emissions of a half-million cars.

Photo courtesy of EARTHWORKS

To identify regulations applicable to onshore E&P activities, we focused on rules applicable to onshore production in three states with significant E&P activity (historically as well as present day): Texas, Pennsylvania, and Colorado. In addition, our focus on regulations for the midstream sector was driven by the aforementioned Aliso Canyon incident, and accordingly, we narrowly focused on federal as well as select state (California, Texas, Pennsylvania, and Colorado) requirements applicable to underground natural gas storage facilities. We also identified recent industry standards that incorporate HRO elements—namely American Petroleum Institute (API) Recommended Practice (RP) 1171, *Functional Integrity of Natural Gas Storage in Depleted Hydrocarbon Reservoirs and Aquifer Reservoirs*; API RP 1170, *Design and Operation of Solution-Mined Salt Caverns Used for Natural Gas Storage*; API RP 1173, *Pipeline Safety Management Systems*; and API RP 75, *Development of a Safety and Environmental Management Program for Offshore Operations and Facilities, Third Edition, May 2004*. Notably, three of these standards (Recommended Practices 1170, 1171, and 75) have formed the basis for federal rules aimed at increasing safety and reliability at underground natural gas storage facilities and offshore facilities.

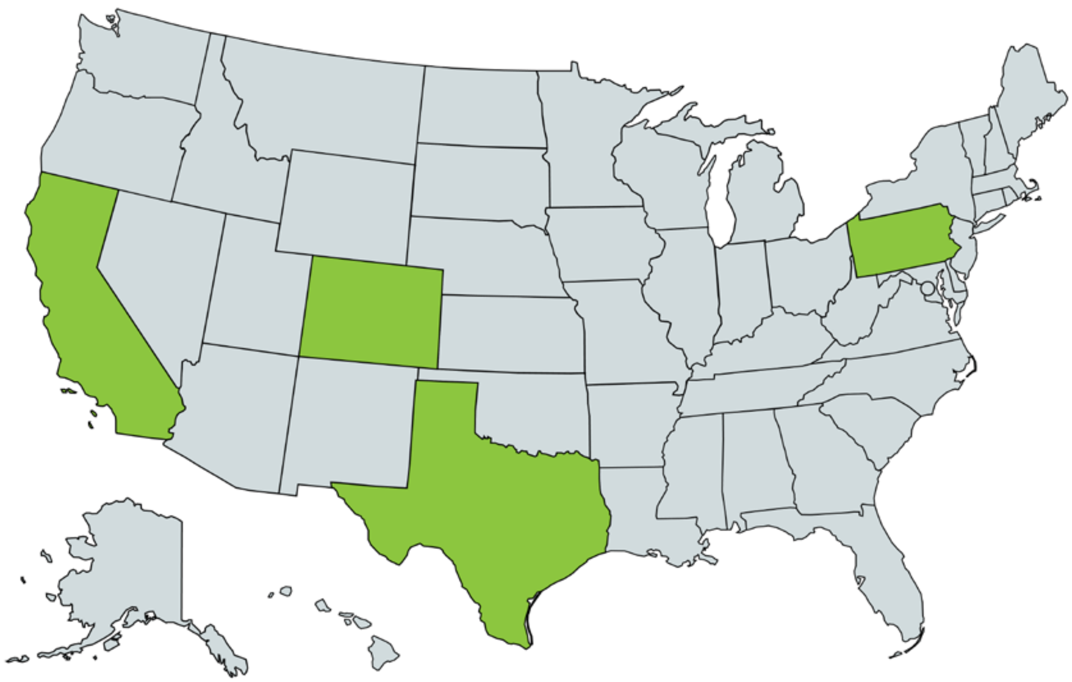

Figure 4. We focus on rules applicable to onshore production in three states with significant E&P activity: Texas, Pennsylvania, and Colorado.

We narrowly focused on federal as well as select state (California, Texas, Pennsylvania, and Colorado) requirements applicable to underground natural gas storage facilities.

1.2 HRO Theory and Its Relevance to Onshore Natural Gas Production, Transportation, and Storage

HRO theory emerged out of research on specific organizations and activities in complex "safety critical" areas that achieved high levels of reliable performance over long periods of time (hence, the name "high reliability organizations"). The major focus on this early research was on air traffic control and aircraft carrier operations, with later research focused on operation of the electric utility grid. All three cases involved safety-critical operations where the consequences of accidents could prove catastrophic. HRO researchers recognized from the beginning that their findings, particularly with respect to the common characteristics of HROs and practices, might be limited when applied to other industries. But they and others have also recognized the benefits of considering these characteristics in the context of any investigation of the organizational and behavioral aspects of safety and reliability in areas where the consequences of accidents are serious.

Onshore natural gas production, transportation, storage, and distribution are quite different from the activities and organizations studied by HRO researchers previously. In particular, as depicted in Table 1, the natural gas supply chain is marked by a diversity of different actors and activities—from drilling to pipeline operations to storage and downstream distribution and end use. The natural gas industry itself is quite competitive and complex, subject to boom-and-bust price cycles and a wide diversity of operating contexts. There is often a premium on innovation, and the industry has seen rapid technological change in some areas (the evolution of hydraulic fracturing, or "fracking," serves as perhaps the best example). In addition, the structure of the industry is complex, with many different kinds of actors, from large multinationals to small "wildcatter" operations, and with overlapping layers of regulation by numerous state and federal authorities. Drilling operations, in particular, are marked by multiple layers of contracting and subcontracting. A typical well site, for example, involves multiple contractors and suppliers, as well as company personnel of varying technical and managerial expertise, over the course of its production cycle.

Table 1. An Overview of Unconventional Gas Exploration and Production

Shale Gas Development: Site Management, Operational Oversight, and Liability Issues

Step	Description
Gaining Access to the Gas Resources (Leasing)	It is necessary to gain access to the property under which the prospective natural gas resources are located and on which surface facilities will be located. Unless the natural gas developer already owns the mineral rights for a piece of land, the company must lease the mineral rights from the owner. The terms of the lease are negotiated with the mineral rights owner.
Searching for Natural Gas	Companies typically perform seismic studies to learn about formations most likely to hold recoverable natural gas and may drill exploratory wells to confirm the results of these studies.
Preparing a Site	Before well drilling can begin, the company must clear vegetation and construct a pad for the drilling rig and other equipment used in drilling the well. Drill pad sites are often located some distance from public roadways. Therefore, operators must also construct an access road between the public road and the well site. The access road and pad are covered with gravel to stabilize the area from erosion and to allow access for heavy oil field equipment. Operators also often excavate one or more pits that are used to temporarily hold drilling fluids and storm water.
Drilling the Well	When natural gas companies are confident that they have located economically viable and recoverable resources, they begin to drill wells to access the natural gas in the subsurface. Natural gas wells are constructed with multiple layers of pipe (casing) cemented into place to protect fresh water formations. Many shale gas wells are drilled vertically to the depth of the formation, and the route of the well eventually bends and runs horizontally for several thousand feet to access the reservoir and enable recovery of the shale gas.
Preparing a Well for Production (Hydraulic Fracturing)	For natural gas from shale deposits to move from the formation into the well, at least two processes must take place. First, openings (perforations) must be made in the casing to allow the natural gas to enter the well. Next, specialized fluids and sand are pumped into the shale at high pressure to create fractures in the rock (hydraulic fracturing). When the pressure is later released, most of the fluid flows back through the well to the surface. However, the sand remains behind and props open the fractures to allow gas to flow freely into the wellbore. Operators may repeat this process of completing the well at a later date in order to increase production.
Producing Gas and Managing Water	After a well is completed, operators begin producing natural gas and water from the formation. The gas is separated from the water and is sent to a nearby gas processing plant. The fluids used in the hydraulic fracturing job that return to the surface (flowback water) are collected and disposed of or subsequently treated for beneficial reuse. After the initial flowback volumes have been collected, the well may continue to produce lower amounts of water from the shale formation (produced water). That water is also collected and disposed of or reused. Portions of the well site that are no longer needed for the production phase are soon reclaimed.

Step	Description
Gathering, Field Processing and Moving Natural Gas to Market	Once natural gas has been produced from a well and separated from the water, it is ready to be transferred to market. Natural gas is first sent to a metering station at the well site for volume measurement and later leaves the well site through small field gathering lines that connect with larger natural gas pipelines. The pipelines move the natural gas out of the field to gas processing plants. Siting and installation of gas pipelines involves substantial preparation and construction as well as scheduled maintenance to maintain integrity of operations.
Closing and Reclaiming the Well	When a well reaches the end of its productive life, it will be plugged and abandoned in accordance with the prevailing regulatory requirements at that time. When the end of production is reached, the operator removes tubing and any pumps from the well, and the well is plugged with cement. The wellhead, tanks, other structures, and the gravel pad are removed. As mentioned above, the site is regraded and revegetated to be compatible with the surrounding area.

All of which is to say that the upstream and midstream onshore oil and gas sectors in the United States look quite different from air traffic control, naval vessel operations, and operation of a nuclear power plant or the electricity grid. Specifically, onshore production facilities are dispersed over large geographical areas and in no way resemble a single, unified plant, vessel, or facility operation. While some well sites are monitored remotely by personnel in a single control room, many are unmanned and visited intermittently by contractors and company personnel who are not in close communication. Worker retention is often dictated by the boom-and-bust cycle of natural gas prices, which can challenge company efforts to ensure a strong safety culture as firms downsize staff but not necessarily the activities to be successfully manned.

Still, many oil and gas operators have adopted various practices and organizational structures that look similar to those discussed in the HRO context and the literature surrounding the subject. And there is considerable room for additional cross-fertilization as the oil and gas industry and its regulators continue to think more systematically about safety and reliability in this vitally important and growing industry.

1.3 Overview of Report

Section 2 of this report provides an overview of HRO theory, its application in nuclear power and aviation, and its relevance to operations across the onshore natural gas sector. Section 3 summarizes the results of interviews with management and executives designed to identify HRO-like practices employed by four oil and natural gas operators that represent a cross-section of the industry: (1) a small, independent gas producer with onshore operations; (2) a large, multinational, and independent E&P company with onshore and offshore operations; (3) a major pipeline company; and (4) a major, vertically integrated utility that operates significant natural gas storage and transportation assets. Section 4 examines state and federal regulatory frameworks, as well as industry-recommended practices that aim to increase reliability and safety in the production, transportation, and storage of natural gas. Section 5 discusses challenges and opportunities to broader adoption of HRO practices in the onshore natural gas sector. Finally, Section 6 presents conclusions and recommendations for further inquiry and research.

2 Background on HRO Theory

2.1 A Brief History of HRO Theory

Academic interest in the organizational aspects of safety and reliability in complex technological systems can be traced to the late 1970s and early 1980s.[8] In particular, the accident at Three Mile Island, involving the partial meltdown of a nuclear reactor near Middletown, Pennsylvania, led to much more systematic attention to the role of organizational factors in causing accidents and errors at nuclear power plants as well as other technological systems and organizations where accidents could result in significant damage. In 1984, sociologist Charles Perrow advanced what came to be known as "Normal Accident Theory" as a framework for understanding accidents such as Three Mile Island.[9] As formulated by Perrow, normal accident theory observed that complex technological systems were marked by high interaction and tight coupling between various components and subsystems. According to Perrow, this inevitably generated unpredictable interactions that in turn led to accidents as part of the normal course of operations, hence the term "normal accident."[10]

Perrow's work has had a major influence on the study of accidents in complex technological systems, pointing to the human and organizational causes of such accidents and raising hard questions about how to manage risk in these systems. At the most basic level, Normal Accident Theory is essentially pessimistic in its conclusions: over time, major accidents are inevitable ("normal"), and there is only so much that operators and regulators can do to prevent them. In this respect, the theory has also proved to be oddly self-fulfilling: With every new accident, we have further evidence that such accidents are, in fact, normal.

However, normal accident theory left some researchers unsatisfied. In many ways, it begged the question of why some organizations and activities in "safety-critical" fields seemed to have very good safety records over long periods of time. This was and continues to be the central question asked by researchers working on HROs.

> In the 1980s and 1990s, researchers at the University of California – Berkeley defined an HRO as an organization in an industry with high stakes—accidents were serious, even catastrophic—yet select operators within the sector, nonetheless, maintain good safety records over long periods of time.

This more "optimistic" line of research took shape in the 1980s and 1990s at the University of California – Berkeley, where a group of researchers began to look specifically at organizations and activities in particular fields (again, marked by organizational and technological complexity with the potential for catastrophic accidents) that exhibited HRO characteristics.[11] Their initial research focused on

[8] Gene Rochlin, one of the pioneers of HRO theory, cites Barry Turner, Man-Made Disasters (1978), as the first person to "point out the capacity of organized human beings to bring about events that could not be composed or analyzed at the individual level and, thereby, began the analysis of organizational sources of risk and error." *See* Gene Rochlin, Reliable Organizations: Present Research and Future Directions. 4 J. Contingencies & Crisis Mgm't 55, 58 (1996). Earlier studies of "high reliability systems" focused much less on the human and organizational aspects of safety and performance over time. *See, e.g.*, A.E. Green and A.J. Bourne, Reliability Technology (1972).
[9] *See* Charles Perrow, Normal Accidents: Living with High-Risk Technologies (1984).
[10] *Id*.
[11] Scott Sagan is credited with the characterization of HRO theory as "optimistic" when compared to Perrow's more "pessimistic" approach. *See* Scott Sagan, The Limits of Safety (1993).

two activities: air traffic control and aircraft carrier operations; it later focused on electric utility grid management.[12] According to these researchers, an HRO was characterized as an organization in an industry where the stakes were high—accidents were serious, even catastrophic—yet select operators within the sector were able, nonetheless, to maintain good safety records over long periods of time.[13]

Although there were important differences between the various activities that provided the empirical basis for this early HRO work, the HRO researchers were struck by a number of commonalities and similarities in organizational structures and practices. Over time, they identified key characteristics that mark these HROs, including flexible delegation of authority and structure under stress; commitment to skill and dedication of operators and workers at all levels; constant and effective training; positive incentives for encouraging error and incident reporting (including one's own); and evaluation of technical and organizational change based on an overarching commitment to long-term reliability.[14] HRO theory was thus about much more than a "culture of safety" or a "culture of reliability." Rather, it entailed ongoing inquiry into specific practices and commitments, particular forms and strategies for organization, and a deep commitment to learning and adaptation.

A central insight was that organizations could learn how to be highly reliable and, thus, could improve their safety records by structuring incentives and cultivating appropriate behavior among key personnel. HRO research found that workers on the front lines were often critical actors—that safety was something they practiced in real time in response to conditions on the ground rather than through the enactment of predetermined bureaucratic routines.[15] Across all of the industries and activities studied, there was (and is) a strong commitment to learning from experience and encouraging employees to report incidents and near misses as a basis for learning and improving the safety and effectiveness of operational practices.[16] Experience trumped

[12] *See* Rochlin, Reliable Organizations, *supra* note 8 at 55 (discussing early work on HROs); Karlene H. Roberts, New Challenges in Organizational Research, 3 Industrial Crisis Q. 111, 112-16 (1989) (discussing HRO research program at University of California).
[13] *See* Todd R. La Porte and Paula Consolini, Working in Practice but not in Theory: Theoretical Challenges of High-Reliability Organizations, 1 J. Pub Admin: Research & Theory 19 (1991).
[14] Rochlin, Reliable Organizations, *supra* note 8 at 56 (summarizing key characteristics); La Porte, High Reliability Organizations, *supra* note 13 at 63-66 (discussing HRO characteristics in context of internal processes and external relations); Karlene H. Roberts, Some Characteristics of One Type of High Reliability Organization, 1 Organization Science 160 (1990) (discussing HRO characteristics of aircraft carrier operations); Karl E. Weick *et al.*, Organizing for High Reliability: Processes of Collective Mindfulness, in Research in Organization Behavior (Sutton and Staw eds., 1999) (identifying five key characteristics of HROs: preoccupation with failure, reluctance to simplify interpretations, sensitivity to operations, commitment to resilience, and underspecified structuring).
[15] Among other things, there was recognition in these studies that local authority was an important component of highly reliable systems. In the aircraft carrier context, low-level line seaman could abort landings. Such an approach worked well in the aircraft carrier context, where decisions needed to be made very quickly. Questions have been raised, however, regarding how applicable the aircraft carrier experience is to other industries. *See, e.g.*, Leveson (44-45) (suggesting limits of aircraft carrier example and need for higher-level systems thinking to ensure safety in more complex organizations and environments).
[16] Incident reporting has become common in a number of "safety critical" industries. *See, e.g.*, Russell W. Mills and Dorit Rubenstein Reiss, Secondary Learning and the Unintended Benefits of Collaborative Mechanisms: The Federal Aviation's Voluntary Disclosure Programs, 8 Regulation & Governance 437 (2014) (discussing incident reporting in aviation industry).

routine, and front-line workers were expected to improvise "work arounds" in the face of surprises.

Although most of the seminal research on HROs was done in the 1990s, HRO theory has continued to inform investigations into the organizational and behavioral aspects of safety and reliability in a number of sectors. Discussion continues about its applicability beyond the special cases that formed the basis of the initial research and theoretical development, and a fair amount of the subsequent literature on the organizational aspects of safety and reliability has often been framed in the context of the original "debate" between Normal Accident Theory and HRO theory.

In recent years, some safety engineers have re-engaged with these debates, seeking to reclaim some of the ground that has previously been occupied by social scientists and organizational theorists. Their goal is to get beyond the debate between HRO and Normal Accident Theory to recognize that both of these fields contain important insights even though they sometimes talk past each other and that the industries they study are often special cases that do not provide a good basis for extrapolation to other sorts of organizations and activities.[17] In their place, these researchers seek to develop a more systems-oriented approach to safety that takes industries on their own terms and sees safety and reliability as distinct properties of the organizations and management systems they employ.[18]

2.2 Applications to Oil and Gas

Certain aspects of the oil and gas industry would seem to be a good fit for the application of HRO research and possibly the adoption of specific HRO practices. In particular, the technically demanding, complex, and high-stakes nature of offshore drilling has spawned a considerable amount of research on safety practices and safety culture within these operations. High-profile accidents such as the Firestone explosion, 2010 Macondo well blowout and subsequent oil spills have put the question of accidents (and safety) front and center for the industry. Detailed investigations in the wake of these accidents, moreover, have raised questions about the role of inadequate regulatory frameworks, organizational practices, and operator behavior in leading to accidents.[19] A number of these post-accident analyses have used insights from HRO theory as a basis for recommended reforms. Incident reporting and more detailed focus on operator behavior and learning have become important topics in the literature on offshore safety practices.[20]

[17] *See, e.g.*, Nancy Leveson *et al.*, Moving Beyond Normal Accidents and High Reliability Organizations: A Systems Approach to Safety in Complex Systems, 30 Organization Studies 227 (2009); Nancy G. Leveson, Engineering a Safer World: Systems Thinking About Safety (2011).

[18] Leveson argues, for example, that safety and reliability are not the same; that reliable organizations can be unsafe and safe organizations can be unreliable. She criticizes HRO theory for conflating the two and argues instead for a more systemic approach to safety. Leveson, Engineering a Safer World, at 7-11.

[19] *See, e.g.*, Chief Counsel's Report, Macondo: The Gulf Oil Disaster, National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling (2011); P. Smith *et al.*, Human Error Analysis of the Macondo Well Blowout, 32 *Process Safety Progress* 217 (2013); D. Borthwick, Report of the Montara Commission of Inquiry, Commonwealth of Australia (2010).

[20] *See generally* Risk Governance of Offshore Oil and Gas Operations (Lindoe *et al.*, eds., 2014).

Norwegian regulators and oil and gas operators have also embraced more explicitly "mindful" approaches to promoting safety that resonate with some of the earlier work in HRO theory.[21]

That said, explicit engagement with HRO theory and practice within the offshore oil and gas sector has not been widespread, although there does appear to be a long-standing effort to understand the organizational aspects of safety and safety culture in the industry that exhibits some of the same characteristics.[22] Indeed, despite a handful of high-profile accidents, the largest and most sophisticated oil and gas multinational firms appear to have strong safety and reliability records. Understanding the extent to which this expertise and orientation has translated into specific organizational strategies and practices advanced in the onshore operations of these same multinationals would be an important area for further inquiry and research.

With respect to onshore oil and gas production and midstream operations, we have found very little explicit discussion of HRO theory and practice. As elaborated below, however, we have found examples of company practices—as well as some discussion in the literature and select regulations—of what one might call HRO-type practices.

It is important to recognize, moreover, that oil and gas industrial activities—particularly onshore oil and gas production, transportation, and storage—are quite different from the types of organizations and activities that provided the initial, empirical basis for HRO theory. As noted above, the natural gas supply chain is comprised of a number of different actors—from drilling to pipeline operation to storage and downstream distribution. The industry is structurally competitive, subject to boom-and-bust price cycles. It is marked by high rates of technological innovation. Over the last decade in particular, the industry has witnessed rapid, disruptive technological change in some areas (e.g., fracking). Many different kinds of actors operate within the sector, including large multinationals, small "wildcatter" operations, mid-sized companies, and regulated utilities. The various components of the industry are subject to overlapping layers of regulation by numerous state and federal regulators. Perhaps most relevant for this study, drilling operations are marked by multiple layers of contracting and subcontracting. A typical well site, for example, might involve dozens of contractors, suppliers, and company employees over the course of its production cycle.

[21] *See, e.g.*, A.B. Skjerve, The Use of Mindful Safety Practices at Norwegian Petroleum Installations, 46 Safety Science 1002 (2008); David L. Collinson, "Surviving the Rigs": Safety and Surveillance on North Sea Oil Installations, 20 Organization Studies 579 (1999).
[22] *See, e.g.*, Risk Governance of Offshore Oil and Gas Operations (Lindoe *et al*., eds., 2014).

Figure 5. A natural gas field in Montgomery County, Texas

Photo courtesy of Roy Luck

All of this makes simple application of HRO concepts and practices to the oil and gas industry challenging. Indeed, in contrast to air traffic control, aircraft carriers, and the electricity grid, the oil and gas sector is marked by significant uncertainty regarding broader economic and technological trends, a more diffuse and complex regulatory environment, and more rapid innovation. Safety and reliability thus need to be approached in the context of these specific industry characteristics.

However, the original question that motivated HRO research seems particularly apt in the case of oil and gas: Why are some operators and activities able to achieve high rates of safety and reliability over time while others fall well short of such exemplary behavior? Answering this question will be particularly important as natural gas production continues to grow in the United States. Moreover, it may be that additional research will conclude that the oil and gas sector has its own set of HROs that have successfully cultivated their own organizational strategies and practices to achieve consistently high performance. This study is a modest first step in trying to frame that larger research effort.

2.3 Key HRO Characteristics

The key HRO characteristics that we took from the broader literature and used as the basis for our investigation include:[23]

[23] *See e.g.*, Roberts, K.H., *Improving Major Risk Management in the Oil and Gas Industry*, EXPLORATION AND PRODUCTION: OIL AND GAS REVIEW (2010); Steinzor, R, *Lessons from the North Sea: Should "Safety Causes"*

- Preoccupation with avoiding failure and commitment to organizational culture where safety is inherent (e.g., track failures, encourage and reward reporting of incidents)
- Use of comprehensive safety management systems
- Reluctance to oversimplify (e.g., avoiding categorizing or labeling, questioning assumptions)
- Sensitivity to operations (i.e., attention to, and involvement in, risky activities such as well drilling)
- Commitment to resilience (i.e., ability to react swiftly, rebound from adverse circumstances)
- Respect for experience, with attention to safety-critical, informed decision-making approaches and encouraging improvisation/innovation by line-level operators
- Ability to operate in either a centralized or decentralized manner
- Communication of and openness to new information/approaches and transparency in operations and decision-making
- Incident reporting with appropriate and positive incentives for reporting errors and incidents (because failures can provide important lessons learned)
- Redundancy (i.e., checks and balances in place to prevent accidents)
- Mindful leadership with a focus on safety
- Strong internal review and oversight that drives reflective learning and sound decision-making
- Training, including simulation training, to ensure a learning organization
- Strong culture of learning, sharing, and innovating.

Come to America?, 38 B.C. ENVTL. AFF. L. REV. 417 (2011), http://lawdigitalcommons.bc.edu/earl/vol38/iss2/10; Antonsen, *et al.*, *The Role of Standardization in Safety Management - A Case Study of a Major Oil & Gas Company*, SAFETY SCIENCE 50 (2012); Mellor, N., *High Reliability Organisations and Mindful Leadership*, HAZARDS 25 (2015), https://www.icheme.org/~/media/Documents/Subject%20Groups/Safety_Loss_Prevention/Hazards%20Archive/XXV/XXV-Paper-32.pdf; Kehoe, T., *et al.*, *Exploring The Need for a Checklist Culture in the Oilfield,* OFFSHORE MAGAZINE (2014) http://www.offshore-mag.com/content/os/en/whitepapers/offshore/2014/november/exploring-the-need-for-a-checklist-culture-in-the-oilfield.whitepaperpdf.render.pdf; Aase K. and T. Tjensvoll, *Learning in High Reliability Organizations (HROs): Trial Without Error* (2003) http://www2.warwick.ac.uk/fac/soc/wbs/conf/olkc/archive/oklc4/papers/oklc2003_aase.pdf; J.L. Thorogood, *Is There a Place for High-Reliability Organizations in Drilling?*, SPE DRILLING & COMPLETION (2013); A. Hopkins, *Why Safety Cultures Don't Work*, DECOMWORLD (2014) http://www.decomworld.com/offshore-safety/pdf/AndrewHopkins.pdf; Global Industry Response Group recommendations for Deepwater Wells (May 2011).

3 Case Studies of Onshore Oil and Gas Companies

We conducted a series of phone and email interviews with managers, directors, and executives at the four companies that comprised the case studies for this report. We chose to keep the identities of the companies anonymous to avoid the appearance of picking "winners." The goal of the study was to identify practices rather than individual companies. The interviews consisted of questions designed to provide insights into company practices, structures, and policies intended to increase safety, reliability, and environmental sustainability. We based the questions on our review of HRO theory literature and accident reports of the Macondo well blowout. The questions are grouped into four categories: (1) key factors that shape the company's culture (e.g., programs and incentives designed to shape human behavior and provide opportunities for learning and adaptation); (2) organizational structures and training designed to support a high degree of reliability and safety; (3) the degree to which the company reaches out to other sectors for information, shares information with other companies, relies on experts, and is transparent; and (4) voluntary efforts to increase safety and reliability, with a specific focus on the use of emerging technologies. A summary of the questions and answers appears below and detailed matrices of the interviews are available in the Appendix.

3.1 Case Study Responses

3.1.1 Behavior, Culture, and Incentives

We asked a series of questions related to how each company maintains a preoccupation with failure, commitment to a culture where safety is inherent, and a culture of learning and adaptation. As a starting point, all four companies emphasized that safety is a core value or main priority of their respective organizations.[24] The way in which each company queried approaches and maintains safety as a core value has, however, evolved over time. The focus on safety has shifted over the last several years at each company in the direction of process safety, risk management, and behavior-based safety.[25] The reason for the shift differed somewhat at each company, for the most part either stemming from a change in leadership or an accident at the company or within the industry that prompted a shift in behavior or priorities.[26] As one manager noted, a new chief executive officer (CEO) made it clear that "integrity is more important than profit"[27] and influenced the culture to be one "of reliability first and efficiency later."[28] The gas utility noted that a change in "culture and training, structure, and management" has resulted in its ability to respond much more swiftly to pipeline incidents. For example, it recently cut off gas to a ruptured portion of a transmission pipeline within 13 minutes—something that previously it

[24] Vice President (VP) EH&S, major pipeline company; Health, Safety, and Environment (HSE) Director, large independent E&P company; VP EH&S, small independent company; Gas Regulatory Strategy Principal and Senior Director, major utility.

[25] HSE Manager, large independent E&P company; HSE Manager-Corporate, small independent company; Gas Regulatory Strategy Principal and Senior Director, major utility; VP EH&S, major pipeline company.

[26] VP EH&S, major pipeline company; VP EH&S, small independent company; HSE Director, large independent E&P company; Gas Regulatory Strategy Principal and Senior Director, major utility. In one instance, following a significant pipeline accident, the company restructured, brought in entirely new leadership and made a conscious effort to change safety policies and the culture by reaching out to HRO industries, such as aviation. Interview, Senior Director, major utility.

[27] VP, small independent company.

[28] HSE Manager-Corporate, small independent company.

was unable or unwilling to do.[29] The company attributes this rapid response time to technological changes (i.e., installation of automated valves) as well as leadership and cultural changes that prioritize safety.[30]

> As one manager noted, a new CEO made it clear that "integrity is more important than profit" and influenced the culture to be one "of reliability first and efficiency later."

Maintaining a constant state of unease, high sensitivity to sound operations, and high degree of communication and open dialogue around safety are characteristics of an HRO.[31] All four companies described policies and systems that train and encourage employees, managers, and executives to remain vigilant for unsafe behaviors or activities. Specific processes and policies include: conducting job safety analysis (JSA), or "tailgate" safety meetings whereby all contractors and employees discuss the potential threats and hazards of a job before they begin work;[32] training on incident management systems that authorize and encourage employees and contractors to respond to and report unsafe behavior, near misses, and incidents;[33] exercising stop-work authorities that encourage employees and contractors to request a job cease if it raises safety or environmental concerns;[34] and training related to safety and environmental performance, including efforts to conduct frequent emergency response drills and simulate accidents such as spills or blowouts.[35]

With respect to the use of incident management systems, all four companies train employees and contractors to report a near miss or an incident. The companies track, assess, and respond to this information using their incident management systems.[36] At one company, the CEO receives all daily incident and near-miss reports.[37] In another instance, the CEO receives only those reports that are determined by managers or other executives to be particularly serious.[38] In all instances, reports are reviewed daily, consistent with API Recommended Practice 1173.[39] One company conducts a daily briefing where 120–130 senior people in the gas operation go over the daily incident and near-miss reports, as well as other issues affecting the safety and reliability of the

[29] Senior Director, major utility.
[30] Id.
[31] O'Connor, *et al*., "Measuring safety climate in aviation: a review and recommendations for the future", Safety Science 49 (2011)128-138 (listing high threat perception as a key characteristic of an HRO); J.L. Thorogood, *et al*., "Is There a Place for High-Reliability Organizations in Drilling?" Society of Petroleum Engineers (Sept. 2013) 263-269, 265 (a characteristic of an HRO is preoccupation with failure); Aase and Tjensvoll, "Learning in HROs: Trial without Error" (a characteristic of an HRO is mindfulness with attention to hazards and weak signals and willingness to consider alternatives).
[32] HSE Director, large independent E&P company; VP Operations, small independent company; Gas Regulatory Strategy Principal, major utility.
[33] VP EH&S, major pipeline company; HSE Director, large independent E&P company; VP EH&S, small independent company; Senior Director, major utility.
[34] Id.
[35] VP EH&S, major pipeline company; HSE Director, large independent E&P company; VP EH&S, small independent company; Gas Regulatory Strategy Principal, major utility.
[36] VP EH&S, major pipeline company; HSE Director, large independent E&P company; VP EH&S, small independent company; Senior Director, major utility.
[37] VP EH&S, small independent company.
[38] HSE Director, large independent E&P company.
[39] VP EH&S, major pipeline company; HSE Director, large independent E&P company; VP EH&S, small independent company; Senior Director, major utility.

operations and organizational assets. The company learned this practice from working directly with an airline company that employs this same method.[40] The small independent production company also has a "safety training and observation program" (STOP) whereby employees routinely go into the field to make observations and discuss contractor and employee behavior. The top 10 to 20 observations of both "good" and "bad" behavior are then shared with everyone in the company and all contractors.[41]

All four companies surveyed have programs and incentives in place to encourage employees to remain focused on how to achieve safe and reliable operations.

The data collected in incident management systems and similar programs, such as the small independent company's STOP program, provide opportunities for learning and adaptation. Each of the companies queried responded that they analyze reported data for trends, and in some cases perform a root-cause analysis. Moreover, they use the data to inform revision of work or safety processes, such as pre-work JSA, where necessary.[42]

All four companies train employees and contractors on the authority to stop work on an activity if, in their opinion, the continuation of the job poses a threat to human health or the environment.[43] This is a practice required by the Bureau of Safety and Environmental Enforcement (BSEE) for offshore facilities operating in the OCS[44] and, like having a robust incident management system, helps maintain sensitivity to operations and an open dialogue around safety.[45] Organizations supporting the U.S. Naval Reactors program employ a different approach of proceeding only when workers are confident they can accomplish the work safely as intended. It requires an affirmative statement of safe to proceed rather than to stop if not safe.[46]

All four companies have programs and incentives in place to encourage employees to remain focused on how to achieve safe and reliable operations, both in terms of identifying unsafe practices and implementing above-and-beyond practices.[47] For example, the large independent E&P company queried has an annual event where employees from operations around the globe attend and present on above-and-beyond measures they have taken. At the next annual event, individuals or teams from different programs who have implemented one of these measures is recognized.[48] In addition, this company has both an Employee Excellence Program, designed to recognize an individual who makes an above-and-beyond observation or takes an action that adheres to one of the company's core values, and a Health, Safety, and Environment (HSE) Recognition and Awards Program, whose goal is to "promote a positive attitude with regard to

[40] Senior Director, major utility.
[41] VP Operations.
[42] VP EH&S, major pipeline company; HSE Director, large independent E&P company; VP EH&S, small independent company; Gas Regulatory Strategy Principal and Senior Director, major utility.
[43] VP EH&S, major pipeline company; HSE Director, large independent E&P company; VP EH&S, small independent company; Senior Director, major utility.
[44] 30 CFR § 250.1902(a) (14), 30 CFR § 250.1930.
[45] API RP 1173.
[46] Communication with retired DOE HRO expert.
[47] VP EH&S, major pipeline company; HSE Director, large independent E&P company; VP EH&S, small independent company; Senior Director, major utility.
[48] HSE Director, large independent E&P company.

HSE compliance and promote a proactive and innovative HSE culture."[49] Within the major pipeline company queried, field group managers develop plans to ensure operations are safe. If the manager completes 100% of the plan, the company recognizes the group on its website—honoring the leader for his/her efforts as well as providing an example to others who peruse that company's web pages and may have the ability to implement similar recognition efforts within their organizations.[50]

> Visible management commitment to safety and engagement with employees on work activities is one indicator of an HRO.

In various ways, each company interviewed ties compensation to maintaining or enhancing the safety and, in some cases, the environmental record of the individuals or the company. The E&P companies queried tie bonuses to safety and environmental metrics. At the small independent company, bonuses for all employees, including executives, are tied to leading and lagging safety and environmental metrics, including contractor safety.[51] The large independent company similarly ties bonuses to both individual and company-wide safety and environmental metrics but, unlike the small independent operator queried, does not include a review of the safety records of its contractors in awarding bonuses.[52] Compensation for employees and executives, including the CEO, at the major pipeline company queried is similarly tied to meeting safety metrics, including such things as attending trainings, turning in safety observations, and reporting and potentially mitigating any unsafe activities.[53] In addition, Environmental, Health, and Safety (EHS) performance is part of each employee's performance assessment. If an employee performs poorly in an environmental management area, it would adversely impact his/her performance evaluation and the related bonus amount.[54] The utility queried tracks public and employee safety and process safety and imbeds performance of these metrics into bonuses.[55]

Visible management commitment to safety and engagement with employees on work activities is another indicator of an HRO.[56] The amount of time that senior leadership is in the field varies from company to company. For example, the senior vice president (VP) of operations at the major utility queried is in the field multiple times a month.[57] At the major pipeline company interviewed, managers are in the field on a weekly basis, directors typically on a monthly schedule, and officers 3–4 times per year.[58] At the small independent E&P company we contacted, the CEO and senior VP are in the field quarterly, and area VPs visit operations on a monthly basis.[59] Managers set goals as to how often they are in the field, but generally this firm believes that management personnel need to be in the field more frequently than executives.[60]

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[49] HSE Director, large independent E&P company.
[50] VP EH&S, major pipeline company.
[51] VP EH&S and HSE Corporate Manager, small independent company.
[52] HSE Director, large independent E&P company.
[53] VP EH&S, major pipeline company.
[54] *Id*.
[55] Senior Director, major utility.
[56] O'Connor *supra* note 31 at 135; J. Thorogood *supra* note 31 at 265; API RP 1173.
[57] Senior Director, major utility.
[58] VP EH&S, major pipeline company.
[59] VP EH&S, small independent company.
[60] *Id*.

Within the large independent E&P company, VPs are in the field at least semi-monthly and operations managers visit field operations on a bi-weekly basis.[61]

Management commitment to safety is further demonstrated by practices that confirm employees' ownership in the reliability, safety, and sustainability of operations.[62] One of the suggested practices of API RP 1173 followed by the pipeline company queried is routine management engagement with employees on matters related to safety, as indicated by frequently asking safety-related questions, raising safety-related issues, and encouraging employees to speak up regarding safety concerns and ideas for how to improve safety.[63] Management responsiveness to employee safety concerns and programs that recognize employees for going above and beyond, such as those noted in this paper, help to strengthen the safety culture by confirming the importance of employee behavior and actions.

> The CEO of one pipeline routinely communicates that, even in tough economic times, safety and environmental compliance cannot be sacrificed. The company particularly communicates the importance of the stop-work authority during economically challenging times when the pressure to find shortcuts and cost savings is at its greatest.

We asked the organizations what safeguards are in place to address the risk that front-line supervisors may feel compelled to cut corners or not adhere to standard operating procedures during challenging economic times or in order to, for example, meet a deadline or control costs. The utility company queried noted that it tries to address this "real challenge" by "drilling into the mindset of supervisors that ensuring safety and efficiency can both be achieved but that safety and compliance comes first."[64] Other ways the utility company surveyed tries to reduce this risk is by having a mentor training program for supervisors and relieving supervisors of certain administrative duties so that they can spend more quality time in the field.[65] The pipeline company responded that there are checks and balances in place to help mitigate the problem of supervisors cutting corners. For example, supervisors must document the steps they take to ensure a job is completed according to procedures, and managers subsequently review such documentation, which provides an opportunity for any errors of falsifications to be uncovered.[66] The company also noted that business pressures (e.g., improving the firm's profitability) are always a concern and that the industry needs to evolve to the point where leadership reinforces that safety always comes first—even if that means profitability will sometimes be impacted by prioritizing safe and reliable operations at all times. In addition, the pipeline company's CEO routinely communicates that, even in tough economic times, safety and environmental compliance cannot be sacrificed, and they particularly communicate the importance of the stop-work authority during economically challenging times when the pressure to find shortcuts and cost savings is at its greatest.[67] Similarly, the small independent company noted that "this is a common issue we talk about quite a lot" and that they tackle this by maintaining "a clear and

[61] HSE Director, large independent E&P company.
[62] API RP 1173.
[63] VP EH&S, major pipeline company.
[64] Gas Regulatory Strategy Principal, major utility.
[65] Gas Regulatory Strategy Principal, major utility.
[65] Senior Director, Gas Systems Operations, major utility.
[66] VP EH&S, major pipeline company.
[67] VP EH&S, major pipeline company.

consistent" message from all levels of the organization from the CEO down that "safety is priority number one" and is "first before that project coming in on time or under budget."[68]

In sum, among the companies queried, all have systems in place that facilitate learning from internal experience and adaptation. Incentives are in place to encourage all members of the organization to prioritize safe and responsible activities, and employees who go above and beyond are recognized and rewarded for their efforts. Management and leadership commitment to safety and reliability is communicated frequently to employees, and a two-way dialogue between line employees and supervisors exists with respect to safety-critical information sharing.

3.1.2 Organizational Structure/Training

We asked a series of questions relating to the use of safety management systems, training, and control over contractors. In particular, we were interested in how each company assesses its safety management system, what procedures are in place to manage change, whether the company uses simulations to train for accidents or emergencies, and how each firm manages its contractors.

> Management of change procedures are important elements of each company's management systems, and such practices are indicative of an HRO, as they are designed to avoid creeping change and cascading failures.

One of the most important systems a company can put in place to foster a robust safety culture is a safety and environmental management system that is subject to periodic review and revision and, ideally, third-party audits.[69] All four companies interviewed have management systems that are based on industry standards and are periodically reviewed.[70] However, only the utility company interviewed primarily relies on a third party to audit and certify its compliance with industry standards.[71]

The other three companies primarily conduct in-house audits of their management systems.[72] Three out of the four companies routinely conduct surveys to assess the strength of the safety culture and employee engagement. All noted that they use the results of the surveys to identify areas in need of improvement, as well as practices or structures that are working well. Conducting periodic surveys to assess safety culture and revise safety policies and procedures is a recommended API practice.[73]

Management of change (MOC) procedures are important elements of each company's management systems, and such practices are indicative of an HRO, as they are designed to avoid creeping change and cascading failures. API defines creeping change as "the accumulation of

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[68] VP EH&S, small independent company.
[69] J. Thorogood, *supra* note 31 at 267 (one of the characteristics of an HRO is the reluctance to oversimplify, which is characterized by openness to multiple perspectives, adversarial reviews, and independent audits); Global Industry Response Group recommendations for Deepwater Wells (May 2011); INGAA 2012 Guidance "Building Confidence in Pipeline Safety" (noting that a management system is a critical element of HRO industries, including the aviation industry).
[70] API RP 1173 is the standard used by both the major pipeline company and the utility. The small independent company's management system is based on an ISO standard.
[71] Gas Regulatory Strategy Principal, major utility.
[72] Gas Regulatory Strategy Principal, major utility; VP EH&S, major pipeline company.
[73] API RP 1173.

small changes that often goes unnoticed but can add up to a significant change, but because of their gradual nature, no hazard identification study or risk assessment has been performed."[74] MOC procedures ensure that specified changes, including changes in equipment or organizational changes, are documented, analyzed, and receive approval before they are implemented.[75] All four companies utilize MOC procedures,[76] although one of the E&P companies noted that these techniques are used more widely in the midstream sector.[77] The utility company queried conducts quality assurance procedures to ensure that the changes were executed correctly and trains employees on proper implementation of MOC procedures.[78]

HROs focus on bottom-up training, learning by simulations (i.e., trial and error), and being able to deal with the unexpected, anticipate trouble, and improvise and respond competently to inevitable surprises.[79] The large independent oil and gas company has a training center where it conducts training on completion units and drill rigs.[80] The utility has a gas control center that contains a simulator room and, as noted above, is constructing a pipeline simulator that will be able to proactively spot problems on its pipelines. The pipeline simulator is modeled after a simulator used by airline companies to train pilots.[81] The utility is also building a mock-up storage well at the training center that can be used to simulate emergencies such as well blowouts.[82] All companies conduct annual drills and more frequent table-top exercises to prepare for emergencies as part of their emergency response plans.[83] The utility simulates a well blowout any time they have a drill rig at a storage facility. In 2016, they conducted four such exercises.[84] In addition, all have a mentor program whereby new employees are paired up with more senior employees for on-the-job training.[85]

HROs focus on bottom-up training, learning by simulations (i.e., trial and error), and being able to deal with the unexpected, anticipate trouble, and improvise and respond competently to inevitable surprises.

Accident reports investigating the Macondo well blowout identified improper oversight of contractors as one of the contributing causes to the incident.[86] Following Macondo, the BSEE added requirements to its rules for offshore operations intended to address this issue. We asked companies how they attempt to ensure sufficient oversight of their contractors. All four

[74] *Id*.
[75] API RP 1173, 8.3.
[76] Gas Regulatory Strategy Principal, major utility; VP EH&S, major pipeline company; HSE Director, large independent E&P company; VP EH&S and HSE Manager-Corporate, small independent company.
[77] VP EH&S, small independent company.
[78] Gas Storage Director, major utility.
[79] J. Thorogood *supra* note 31 at 265, 267.
[80] HSE Director, large independent E&P company.
[81] Senior Director, Gas Systems Operations, major utility.
[82] Gas Storage Director, major utility.
[83] VP EH&S, major pipeline company; HSE Director, large independent E&P company; VP EH&S, small independent company; Gas Regulatory Strategy Principal, major utility.
[84] Gas Storage Director, major utility.
[85] *Id*.
[86] See e.g., U.S. Chemical Safety and hazard Investigation Board, investigation report, Executive summary; See e.g., Baram, M, Deepwater Study Group Working Paper, Preventing accidents in Offshore oil and gas operations: the US approach and some contrasting features of the Norwegian approach (Jan. 2011); *See* Transportation Research Board Report on Safety Culture in Offshore Sector.

companies noted that they utilize a third party to screen contractors before hiring them to ensure they meet minimum qualifications.[87] This screening includes a review of a potential contractor's safety and compliance record, as well as whether it meets the company's minimum requirements for skills and expertise. Once hired, all companies interviewed conduct audits of its contractors. The pipeline company also noted it conducts audits once during a construction or maintenance project, and if there are any issues, they follow up to make sure the issues have been corrected. The utility noted in some cases it conducts daily inspections of contractors.[88] The utility, the pipeline company, and the small independent E&P company responded that they require contractors to adhere to their own internal safety standards, although the pipeline company noted that contractors may follow their own procedures as long as they meet the company's standards.[89] The small independent E&P company noted that it holds contractors to the same standards as its own personnel.[90]

In sum, all companies queried utilize and periodically review a comprehensive safety management system that includes procedures for managing change. Only the utility uses third parties to audit its management system. All companies utilize diverse tools to train employees for accidents and operational activities, including drills, table-top exercises, and mentor programs. The utility also employs advanced technologies to simulate pipeline incidents and is working toward being able to predict accidents. All companies utilize a third party to screen contractors; conduct inspections of contractor work, including as frequently as daily; and expect contractors to adhere to the company's safety policies and standards.

3.1.3 Sharing of Information, Reliance on Experts, Data Analytics, and Transparency

Outreach to other industries, sharing of information within and outside of one's industry, data analysis, and transparency are additional key characteristics of an HRO.[91] We asked a series of questions aimed at understanding the extent to which the companies queried reach out to other highly reliable industries (such as the aviation and nuclear industries), share safety-related information with other oil and gas companies, utilize experts to audit or certify compliance with industry standards, utilize data analytics and visualization tools, and publish safety and sustainability-critical information.

> Outreach to other industries, sharing of information within and outside of one's industry, data analysis, and transparency are additional key characteristics of an HRO.

The utility indicated that it has reached out to the aviation industry in order to learn practices that have helped reduce aviation incidents. For example, after a significant incident involving fatalities, the utility reached out to a member of the aviation industry to learn about specific HRO practices, which it then adopted. These practices include the daily safety briefing, review of

[87] VP EH&S, major pipeline company; HSE Director, large independent E&P company; VP EH&S, small independent company; Gas Regulatory Strategy Principal, major utility.
[88] Gas Regulatory Strategy Principal, major utility.
[89] VP EH&S, major pipeline company.
[90] VP EH&S, small independent company.
[91] *See* Section 2, *infra*.

incidents and near-miss calls (where in some instances the president of the company is in attendance), and use of checklists and simulators.[92]

Unlike HRO industries such as aviation, no formal mechanism exists in the oil and gas industry to facilitate the sharing of information about near misses, incidents, and best practices across companies. Each of the companies we interviewed noted, however, that they do share such information on a voluntary, ad-hoc basis with other oil and gas companies. This is primarily done though industry association meetings or conferences. In addition, the American Gas Association (AGA) has a system whereby operators can send a question to AGA about a specific procedure or task, and the AGA then emails its members for responses. Responses can be anonymous. While association meetings and mechanisms provide an opportunity for learning and sharing information, they are wholly voluntary. It is also worth noting that in the EHS professions, information sharing that helps to promote greater awareness and public safety is widely encouraged even within the most competitive industries, such as the oil and gas sector operations, which fiercely guard proprietary and business competitive information.

The gas utility company we interviewed routinely relies on outside experts to audit its compliance with industry standards, including API RP 1173, as well as its safety policies and procedures. For example, they have been certified in API RP 1173, BSI PAS 55/ISO 55001 (asset management standards), and Responsible Care 14001 (i.e., the American Chemistry Council health and safety standard).[93] The small independent company worked with a third-party consulting firm, DuPont Sustainable Solutions, to perform a perception audit that they relied on to enact much of their behavior-based system.[94]

The field of data analytics and visualization offers important tools to help dynamic industries manage complex and voluminous data.[95] We asked all four companies about their use of data analytics and tools. The responses varied. All track data contained in incident and near-miss reports, pursuant to incident management systems, as discussed above, as well as capture and assess the leading indicators of safety within their respective operations. In addition, the utility company queried tracks-specific metrics such as the response time to olfactory detection of gas, time to shut-in gas, and reduction of leaks. In 2013, using a wide range of gas-detection technologies, the utility reduced its minor leaks by 99%.[96] In addition, the utility is building an online pipeline simulator that will be able to conduct predictive analytics to identify potential threats to pipelines, including ruptures, before they occur. Discussing this emerging technology, one director commented “we want to be predictive and proactive rather than reactive, and data are the key to this.”[97] The small independent E&P company and the major pipeline company

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[92] Gas Regulatory Strategy Principal, major utility.
[93] *Id*.
[94] HSE Manager-Corporate, small independent company.
[95] *See e.g*., ABS Group, “Data Analytics and Data Management: Solutions for Compliance with New PHMSA Regulations,” (2016) (commenting that the NAS noted that the regulatory community has not made effective use of real-time data analysis, information on precursor incidents or near misses, or lessons learned in the Gulf of Mexico and worldwide to adjust practices and standards appropriately, NAS, 2012, P.114).
[96] Interview with Senior Director, major utility.
[97] Interview with Senior Director, Gas Systems Operations, major utility.

noted they are beginning to use data visualization tools but that this is an area that could benefit from further refinements and improvement.[98]

Our research indicates that all companies we communicated with have room for improvement with respect to making data and information regarding leading and lagging indicators of safety and sustainability public. In terms of current practices, the pipeline company provides information on employee and contractor safety performance, pipeline incidents, and U.S. Environmental Protection Agency (EPA) reportable spills and releases on its website.[99] Notably, they have had only one pipeline incident in the last five years.[100] As for the utility company, they provide information on the number of Grade 2 pipeline leaks repaired and the response time involved.[101] The large production company provides information on employee safety performance, GHG emissions generated, and water analysis reports as required by the Carbon Disclosure Project. The small independent E&P company provides information on methane-emission reductions but not actual emissions generated/measured.[102] Lastly, none of the companies provide data on notices of violation or other regulatory compliance violations.[103]

In sum, opportunities exist to facilitate greater outreach to other sectors and sharing information involving best practices, incidents, and near misses across oil and gas companies. In addition, among the few companies we queried, most do not rely on outside experts to audit or certify compliance with industry standards. Lastly, there appears to be room for enhanced transparency regarding safety and environmental performance.

HROs are often at the forefront of innovation and able to swiftly adopt and integrate new technologies into their operations.

3.1.4 Voluntary Effort and Technological Advances to Increase Safety and Reliability

HROs are often at the forefront of innovation and able to swiftly adopt and integrate new technologies into their operations. There are a number of emerging technologies that have the potential to significantly improve the safety, environmental performance, and reliability of oil and gas operations. These include the use of sensors that can measure changes in physical attributes such as pipeline pressure or can measure the amount of methane at a site and transmit the data through fast, extensive communication networks to central facilities.[104] Companies are also testing the use of drones to inspect remotely

[98] VP EH&S, small independent company; VP EH&S, major pipeline company. This is consistent with at least one report that has analyzed the use of data management and analytics in the oil and gas industry. ABS Group (2016) at 1 (noting that while business analytics is becoming more commonplace for many industries, data analytics for the oil and gas industry is "less mature…").
[99] VP EH&S, major pipeline company.
[100] PHMSA, "Distribution, Transmission & Gathering, LNG, and Liquid Accident and Incident Data," available at https://www.phmsa.dot.gov/pipeline/library/data-stats/distribution-transmission-and-gathering-lng-and-liquid-accident-and-incident-data.
[101] The Gas Piping Technology Committee, which writes guidance for complying with 49 CFR Parts 191 & 192, defines a Grade 2 leak as a leak that is recognized as being non-hazardous at the time of detection but justifies scheduled repair based on probable future hazard.
[102] Website, small independent E&P company.
[103] Whether or not a company discloses information related to notices of violations or violations was one of the indicators of a company's management and accountability analyzed by Disclosing the Facts 2015.
[104] ABS group at 3, *supra* note 95; Rhonda Duey, E&P Hart Energy, Hope on the Horizon (Dec. 6, 2016), available at http://www.oilandgasinvestor.com/hope-horizon-1455681.

located and hard-to-access facilities, thus decreasing the risk to personnel and increasing the amount of information available about such processes at such sites.[105] We asked the companies about voluntary best practices aimed at increasing safety and sustainability. Each of the companies we interviewed engage in voluntary initiatives to prevent and mitigate impacts associated with oil and gas production or transportation, and many are at the forefront of technological innovation.

The small independent onshore E&P company is a founding member of ONE Future Coalition, an industry coalition committed to reducing methane emissions below a loss rate of 1% across the entire natural gas supply chain.[106] As a member of this coalition, the company measures its methane emissions throughout its supply chain and then sets emissions targets to ensure attainment of the 1% goal.[107] As noted previously, achievement of these targets is a determining factor in management and staff bonuses. In addition, the company participated in joint industry/non-governmental organization/academic studies to measure emissions[108] and is one of seven companies participating in the Environmental Defense Fund (EDF) Methane Detectors Challenge.[109] The main point of the challenge is to have participating companies develop low-cost continuous methane detection systems that can alert operators to the existence of leaks. Presently, two such technology systems are being piloted in the United States.[110]

Each of the companies we interviewed engage in voluntary initiatives to prevent and mitigate impacts associated with oil and gas production or transportation, and many are at the forefront of technological innovation.

The small independent onshore E&P company has also achieved a goal of becoming freshwater neutral, meaning that it either offsets or replenishes each gallon of freshwater used in resource extraction operations.[111] It has reduced its demand for freshwater through increased recycling of flowback fluid and offset its use of freshwater by participating in stream-mitigation projects. It has also worked with non-governmental organizations to develop a model regulatory framework for well construction to reduce potential impacts caused by well-integrity flaws.

The major pipeline company is also a member of the ONE Future Coalition.[112] In addition, the pipeline company pioneered its own pipeline assessment tool that uses circumferential magnetic flux leakage (MFL) tools to identify longitudinal weld anomalies such as hook cracks and analyze the threat each defect poses to the pipeline.[113] It also helped to develop API RP 1173 and

[105] The Washington Post, How Technology Makes Oil and Gas Safer, available at http://www.washingtonpost.com/sf/brand-connect/wp/video/how-technology-makes-oil-and-gas-safer/.
[106] VP, Strategic Solutions, small independent company.
[107] Website, small independent E&P company.
[108] Website, small independent E&P company.
[109] EDF, The Methane Detectors Challenge, State of the Challenge, available at http://www.edf.org/sites/default/files/content/mdc_factsheet_2016.pdf.
[110] *Id*.
[111] VP, Strategic Solutions, small independent.
[112] Website, major pipeline company.
[113] *Id*.

worked with the Pipeline and Hazardous Material Safety Administration (PHMSA) to develop its rules for underground natural gas storage facilities following the Aliso Canyon leak.[114]

The utility company is committed to reducing leaks and fugitive methane emissions along its pipeline system. It is a founding partner of the EPA Natural Gas Methane Challenge, wherein it has agreed to utilize best management practices to reduce emissions from venting, transmission blowdowns, pneumatic controllers, rod packing, and excavation damages beyond regulatory requirements. It is also piloting a stationary continuous leak monitoring technology at one of its storage sites, in collaboration with EDF.[115] It has been recognized by the Carbon Disclosure Project as a leader with respect to its disclosure of emissions data.[116] In addition, it has collaborated with the National Aeronautics and Space Administration Jet Propulsion Laboratory to develop a hand-held, laser-based technology to identify leaks;[117] was one of the first companies to use the Picarro mobile technology to inspect distribution pipelines for leaks; is piloting innovative leak detection technologies such as continuous monitors at storage facilities; and is pursuing the use of drones to conduct inspections.[118] The utility company also noted that it had been doing nearly all of what the California Division of Oil, Gas, and Geothermal Resources (DOGGR) required of operators in response to the Aliso Canyon leak, with the exception of conducting daily leak surveys, semi-annual valve inspections, and field-specific risk management plans for their storage operations.[119]

The large independent E&P company similarly has undertaken a number of voluntary measures to improve the safety, reliability, and sustainability of its operations. Of particular note, the company supports scientific research into climate and recognizes the need to reduce emissions—particularly GHG emissions.[120] In 2004, the company formed the GHG and Air Quality Committee, which reports to the Board of Director's Governance and Risk Committee. Since 2005, the company annually reports GHG emissions data and additional information regarding carbon-management strategies and actions to the Carbon Disclosure Project. The company participated in the EPA's Natural Gas STAR program and Climate Registry & American Carbon Registry and employs a number of technologies to reduce GHG emissions, including undertaking voluntary inspections of facilities to check for methane leaks, installing solar-powered pumps to replace natural-gas-fired pumps, limiting venting during downhole maintenance activities by employing specific technologies such as plunger lifts, and converting part of their fleet to natural gas vehicles.[121]

In sum, the companies queried are investing in new technologies such as water recycling and continuous emission monitors, leveraging data visualization tools to help pinpoint and predict potential problems, and working with diverse stakeholders, including non-governmental

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[114] VP EHS, major pipeline company.
[115] Gas Regulatory Strategy Principal, gas utility.
[116] New Climate Institute, Out of the Starting Blocks, Tracking Progress on Corporate Climate Action (Oct. 2016), https://b8f65cb373b1b7b15feb-c70d8ead6ced550b4d987d7c03fcdd1d.ssl.cf3.rackcdn.com/cms/reports/documents/000/001/228/original/CDP_Climate_Change_Report_2016.pdf?1477993118#page=41.
[117] Website, utility.
[118] Interview with Gas Regulatory Strategy Principal, gas utility.
[119] Interview with Director, Storage.
[120] Website, large independent E&P company.
[121] *Id*.

organizations, to minimize risks associated with oil and gas development such as methane leaks and pipeline ruptures. While each company shares some safety- and sustainability-critical information with the public, opportunities remain for greater transparency.

4 State Rules and Emerging Industry, State, and Federal Standards that Reflect HRO Concepts

4.1 Overview of State and Federal Environmental Regulatory Frameworks for Onshore Natural Gas Production, Transportation, and Storage

The framework for regulating HSE in onshore natural gas activities is fragmented and complex. Unlike the nuclear power industry, there is no single federal agency with responsibility for ensuring worker safety, environmental protection, and accident prevention in oil and gas production and related midstream and downstream activities. For both onshore and midstream operations, worker safety is primarily regulated by the Occupational Safety and Health Administration (OSHA).[122] To some extent, the Pipeline Safety Statutes[123] integrate accident prevention and environmental protection; however, rules implementing these laws have thus far focused nearly exclusively on pipelines, and preventing major accidents from pipelines, rather than encompassing environmental protection more broadly or applying to other facilities integral to the fabric of midstream operations, such as underground natural gas storage. This appears to be changing, however. PHMSA recently promulgated the first-ever federal standards for underground natural gas storage facilities.[124] Moreover, former PHMSA Administrator Marie Therese Dominquez signaled intent to move the agency and its regulated industries toward becoming more proactive, predictive, and data driven[125]—changes which, if implemented, could drive greater adoption of HRO practices in the midstream and downstream sectors.

The regulation of onshore natural gas production primarily rests with state oil and gas and environmental regulators. State oil and gas agencies are often charged with fostering development of oil and gas resources in a manner consistent with public health and environmental protection,[126] while state environmental protection agencies have the sole task of protecting water and air resources from potential impacts associated with industrial activities such as oil and gas operations.[127]

At the federal level, Congress has entrusted the EPA with the duty to promulgate national rules to protect air, water, and land resources, and EPA has promulgated a select number of rules

[122] Occupational Safety and Health Act of 1970.
[123] The "Pipeline Safety Statutes" refers to two statutes that provide the framework for the federal pipeline safety program. The Natural Gas Pipeline Safety Act of 1968 as amended (NGPSA) authorizes the department to regulate pipeline transportation of natural (flammable, toxic, or corrosive) gas and other gases as well as the transportation and storage of LNG. Similarly, the Hazardous Liquid Pipeline Safety Act of 1979 as amended (HLPSA) authorizes the Department to regulate pipeline transportation of hazardous liquids (crude oil, petroleum products, anhydrous ammonia, and carbon dioxide). Both of these acts have been recodified as 49 U.S.C. Chapter 601. In addition, Congress has enacted the Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011 and the Protecting our Infrastructure of Pipelines and Enhancing Safety Act of 2016 (PIPES Act).
[124] 81 Fed. Reg. 91860.
[125] C-SPAN, Video of Marie Therese Dominquez May 3, 2016, available at https://www.c-span.org/video/?409026-1/marie-therese-dominguez-discusses-transportation-hazardous-materials.
[126] *See e.g.*, Colorado Oil and Gas Conservation Act, § 34-60-102.
[127] *See e.g.*, 5 C.C.R. 1001-9.

applicable to oil and gas activities.[128] Similarly, the Department of Interior (DOI) has jurisdiction over oil and gas activities that occur on tribal and federal lands and has promulgated rules and onshore orders that apply to various aspects of development activities.[129]

For midstream and downstream operations, including transmission pipeline gas flows and underground natural gas storage operations, the Department of Transportation (DOT), through PHMSA, is the primary regulator. Specifically, PHMSA has broad rulemaking authority to issue minimum safety standards for natural gas and hazardous liquid pipelines and pipeline facilities.[130] To date, PHMSA has exercised this jurisdiction by promulgating risk-based rules for transmission, distribution, and a subset of gathering lines.[131] On December 19, 2016, PHMSA released its first-ever rules for underground natural gas storage facilities.[132] The rule requires operators to follow API RP 1171, *Functional Integrity of Natural Gas Storage in Depleted Hydrocarbon Reservoirs and Aquifer Reservoirs*; API RP 1170, *Design and Operation of Solution-Mined Salt Caverns Used for Natural Gas Storage;* and API RP 1173, *Pipeline Safety Management Systems*.[133]

Under the Natural Gas Act of 1938 (NGA), the Federal Energy Regulatory Commission (FERC) has primary responsibility for the siting of interstate natural gas pipelines and for regulating transmission and wholesale sales of natural gas in interstate commerce.[134] Responsibility for siting intrastate pipelines varies significantly among states and often involves multiple federal, state, and local stakeholders.[135]

4.2 Federal and State Efforts to Increase Safety and Reliability in Response to the Aliso Canyon Gas Leak

On October 23, 2015, SoCal Gas identified a massive leak from its Aliso Canyon underground natural gas storage facility.[136] By the time the utility capped the well, it had released nearly

[128] *See, e.g.*, Standards of Performance for New Stationary Sources (40 CFR Part 60); National Emission Standards for Hazardous Air Pollutants for Source Categories (40 CFR Part 63); Oil and Gas Extraction Effluent Guidelines and Standards (40 CFR Part 435).
[129] *See, e.g.*, Methane and Waste Prevention Rule (43 CFR Parts 3100, 3160 and 3170); Consolidated Federal Oil & Gas and Federal & Indian Coal Valuation Reform (30 CFR Parts 1202 and 1206).
[130] 49 U.S. Code. § 60102 *et seq*. Safety standards may apply "to the design, installation, inspection, emergency plans and procedures, testing, construction, extension, operation, replacement and maintenance of pipeline facilities." *Id*. at § 60102(a) (2). *See also* M. Diamond, et al., *Pipeline Safety: An Overview of the Legal Framework, the Regulation of Gas Gathering, and How Current and Future Regulation May Affect Producers*, 34 Energy & Min. L. Inst. 5, 163 (2013). Pipeline facilities include gas pipeline and hazardous liquid pipeline facilities as well as rights-of-way, facilities, buildings, or equipment used in the transport or treating of gas during transportation. 49 U.S.C. § 60101(a).
[131] 71 Fed. Reg. 13289 (Mar. 15, 2006).
[132] 81 Fed. Reg. 91860.
[133] *Id*.
[134] Natural Gas Act § 7, 15 U.S.C. § 717c, *Id*. at § 4, 15 U.S.C. § 717f.
[135] GAO Report, Pipeline Permitting: Interstate and Intrastate Natural Gas Permitting Processes Include Multiple Steps, and Time Frames Vary (Feb. 2013), http://www.gao.gov/assets/660/652225.pdf.
[136] California DOC, State Regulators Confirm Aliso Canyon Natural Gas Well is Permanently Sealed, Feb. 18, 2016, available at http://www.conservation.ca.gov/index/Documents/2016-05%20State%20officials%20confirm%20Aliso%20Canyon%20gas%20leak%20has%20been%20halted,docx.pdf.

100,000 metric tons of methane into the atmosphere, approximately 12% of the total methane emitted from all natural gas underground storage and natural gas transmission sources in 2014.[137]

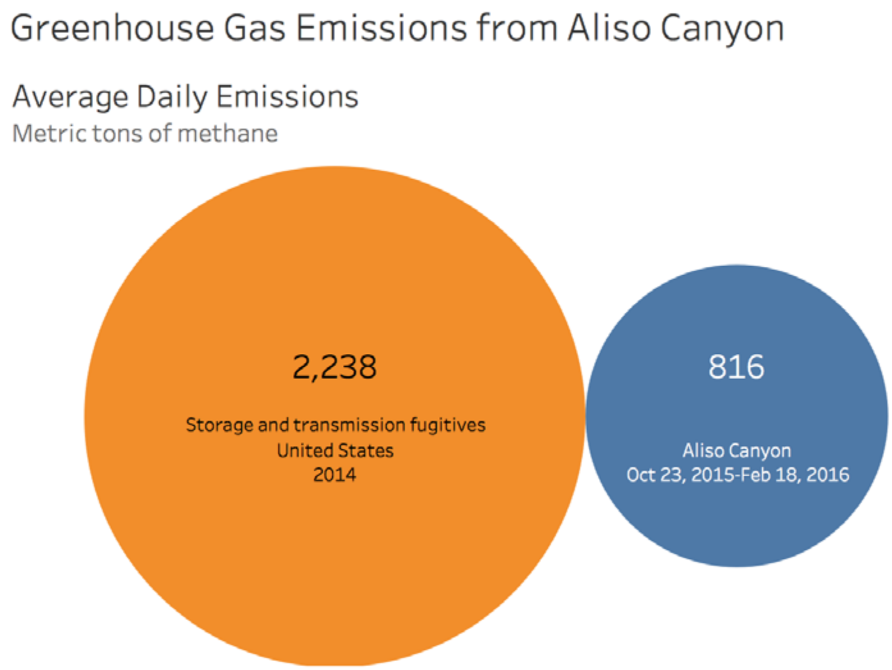

Figure 6. Average daily greenhouse gas emissions from Aliso Canyon (MmtCh4) compared to average daily greenhouse gas emissions from U.S. transmission and storage facilities in 2014

This amounted to the largest natural gas leak from an underground natural gas facility in U.S. history.[138] According to PHMSA, the volume of natural gas leaked from the one failed well at the facility is equivalent to the yearly GHG emissions from approximately one-half million cars.[139] Moreover, the agency estimates the social costs of climate-related impacts from these emissions equal approximately $123 million.[140] In addition, the utility had to relocate over 5,790 families living near the facility.[141]

The Aliso Canyon incident triggered immediate action on the part of state and federal regulators to mitigate the potential for harm and further methane leaks. In addition, the agencies responded by increasing the regulatory oversight of the facility as well as other underground natural gas facilities potentially vulnerable to leaks and storage system outages.

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[137] Subpart W reports submitted by operators in the storage and transmission natural gas segments to EPA pursuant to EPA's Mandatory Greenhouse Gas Reporting Rule. Operators reported releasing 817,000 metric tons of methane from transmission and storage facilities in 2014.
[138] DOE website, Federal Task Force Issues Recommendations to Increase the Safety and Reliability of U.S. Natural Gas Storage Facilities (Oct. 18, 2016), http://www.energy.gov/articles/federal-task-force-issues-recommendations-increase-safety-and-reliability-us-natural-gas.
[139] 81 Fed. Reg. at 91862.
[140] *Id*.
[141] *Id*.

4.2.1 Federal Efforts

Federal efforts to respond to the Aliso Canyon disaster involved a suite of agencies, including PHMSA, DOE, DOI, and FERC.

PHMSA immediately issued two advisory bulletins urging operators to comply with newly established industry standards for natural gas storage: (1) API RP 1171, *Functional Integrity of Natural Gas Storage in Depleted Hydrocarbon Reservoirs and Aquifer Reservoirs*, and (2) API RP 1170, *Design and Operation of Solution-Mined Salt Caverns Used for Natural Gas Storage*.[142]

In addition, pursuant to congressional direction,[143] PHMSA issued an Interim Final Rule for over 400 interstate underground natural gas storage facilities in the United States.[144] As noted above, the rule requires operators to comply with the safety standards contained in API RP 1170 and 1171.[145] The rules, PHMSA noted, are necessary to reduce the risk of a similar incident occurring at one of the other 399 storage facilities in the nation and to address the regulatory gap that exists in the absence of federal requirements. Like the well that failed at Aliso Canyon, many storage wells in the United States are aging, constructed for purposes other than gas storage, and do not adhere to modern construction standards.[146] In order to ensure the safety and integrity of such wells and to prevent another incident similar to Aliso Canyon, the rules must be updated to reflect current technologies and approaches.[147] Moreover, PHMSA has exclusive jurisdiction over interstate natural gas storage facilities, and up until this year, they had failed to exercise this authority. The result has been a lack of standards for interstate underground natural gas storage facilities. Moreover, federal standards for interstate facilities often provide the basis for state standards for intrastate facilities. While a handful of states have adopted rules for intrastate facilities, these rules are not uniform.[148] Accordingly, PHMSA found the new storage facility rules were necessary to protect human lives, health, and the environment.[149] Notably, Interstate Natural Gas Association of America (INGAA), API, and AGA all support the rules.[150]

Issuing the first-ever federal rules to increase the safety and reliability of underground natural gas storage facilities keeps with commitments made by former PHMSA Administrator Dominquez in May 2016. In a speech about the future of the agency and its regulated entities, Administrator Dominquez expressed a desire to implement changes at the agency and throughout the pipeline industry designed to drive the adoption of HRO practices. Specifically, the former administrator expressed the following intentions for PHMA:

- Make the agency "more predictive and data driven"
- "Leverage data and research to develop a more proactive regulatory agenda"

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[142] 81 Fed. Reg. 6334 (Feb. 5, 2016).
[143] Protecting our Infrastructure of Pipelines and Enhancing Safety Act of 2016 (PIPES Act), Section 12, directs PHMSA to establish minimum safety standards for underground natural gas storage by June 21, 2018.
[144] 81 Fed. Reg. 91860.
[145] *Id*.
[146] *Id*. at 91862-91863.
[147] *Id*. at 91862.
[148] *Id*. at 91864.
[149] *Id*. at 91862-91863.
[150] *Id*. at 91864-91865.

- Enhance the agency's ability to leverage its investments into research and development in order to "understand and learn from incidents."[151]

For the pipeline industry, Administrator Dominquez expressed similar goals. Specifically, she expressed a desire:

- "To advance the culture within the pipeline and hazardous materials" industry
- To advance the use of pipeline management systems that "account for that human behavior and human factor in decision-making"
- To provide for greater organization insight and leaders "to champion safety and allow employees at all levels to raise safety concerns."[152]

Discussing the successes achieved in the aviation industry, she underscored the importance of having a culture that allows for non-punitive reporting" and "developing a platform to share and analyze data in a no-fault environment."[153] Importantly, the PIPES Act includes a requirement that PHMSA, states, industry stakeholders, and safety groups form a working group to develop recommendations on how to create an information-sharing system to improve safety outcomes and gives PHMSA authority to study the feasibility of a national integrated pipeline safety database to have a clearer picture of federal and state safety oversight efforts.[154]

Beyond these regulatory efforts, the White House formed the Interagency Task Force on Natural Gas Storage Safety in the spring of 2016. The task force activities are consistent with congressional requirements contained in the PIPES Act and include representatives from PHMSA, EPA, FERC, DOI, and state and local government representatives.[155] The task force spent six months investigating the cause and contributing factors of the Aliso Canyon leak. In October, the task force published its recommendations regarding measures operators and regulators can take to improve the safety and reliability of underground natural gas storage facilities.[156] One of the key recommendations is that operators prepare risk management plans that identify threats and hazards to facilities and assess the risks that such threats and hazards pose to the safety and reliability of facilities. [157] This recommendation mirrors requirements contained in API RP 1170 and 1171.

4.2.2 State Efforts

The State of California acted swiftly with a suite of actions in response to the Aliso Canyon leak. On February 5, 2016, the Department of Conservation (DOC) issued emergency regulations. The regulations required underground storage operators to provide data to DOGGR regarding well characteristics and safety devices, conduct daily monitoring of the annulus pressure and gas

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[151] Maria Therese Dominguez, Administrator of the Pipeline and Hazardous Materials Safety Administration, speech before the Center for Strategic and International Studies, The Future of PHMSA (May 3, 2016), available at http://www.c-span.org/video/?409026-1/marie-therese-dominguez-discusses-transportation-hazardous-materials.
[152] *Id*.
[153] *Id*.
[154] S. 2276, Sec. 10 and 11 (June 21, 2016).
[155] U.S. DOE, "Federal Task Force Issues Recommendations to Increase the Safety and Reliability of U.S. Natural Gas Storage Facilities, Oct. 19, 2016.
[156] *Id*.
[157] *Id*. at Topic II.

flow, test safety valves semi-annually, develop a protocol to detect and repair gas leaks, test the master valve and wellhead pipeline isolation valve annually, submit a risk management plan for review and approval by DOGGR and receive DOC approval of an emergency response plan.[158] DOC followed up with the release of preliminary draft regulations in July that closely mirrored the emergency regulations.[159]

At the legislative level, Governor Brown issued a state of emergency in response to the leak[160] and signed "urgency" legislation in May. The legislation established a rigorous protocol of safety testing for all wells at Aliso Canyon and prohibited a resumption of gas injections until all wells either passed a regimen of six specified tests or were plugged and isolated from the reservoir.[161] On September 26, 2016, Governor Brown signed another bill, SB 887, establishing proactive safety standards for natural gas storage wells. SB 887 builds upon the May urgency legislation by establishing permanent safety standards for wells at California's 14 natural gas storage fields (Figure 7). They include facilities near Playa del Rey, Santa Clarita, and Goleta, which, like Aliso Canyon, are in close proximity to populated areas.[162] At the time of publication of this report, the DOC has completed its comprehensive inspection and safety review of the Aliso Canyon facility and is planning to make a decision as to whether to re-open it following two public meetings in early February.[163]

[158] Final text of the Emergency Regulations (effective Feb. 5, 2016). http://www.conservation.ca.gov/index/Documents/DOC%202016-0126-03E%20Gas%20Storage%20Requirements%20-%20Final%20Text%20of%20Emergency%20Regulations.pdf.

[159] Draft 14 C.C.R. Section 1726 *et seq*.

[160] 81 Fed. Reg. at 91862 (Dec. 19, 2016).

[161] SB 380.

[162] CA Senate Bill No. 887, http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB887. Additional requirements include: continuous monitoring of natural gas concentrations; consideration by DOGGR in its regulations of redundant safety mechanisms for wells to ensure that no single point of failure can result in a leak (such mechanisms include subsurface safety valves and the use of tubes inside well casings to inject and extract gas); regular testing of all wells, with a full set of testing for each well begun by January 1, 2018; and an assessment of potential impacts to human health by the California Public Utilities Commission that will lead to the establishment of minimum setbacks to separate new wells from homes, schools, and other sensitive facilities.

[163] DOC, Aliso Canyon Updates and Resources, available at http://www.conservation.ca.gov/dog/Pages/AlisoCanyon.aspx.

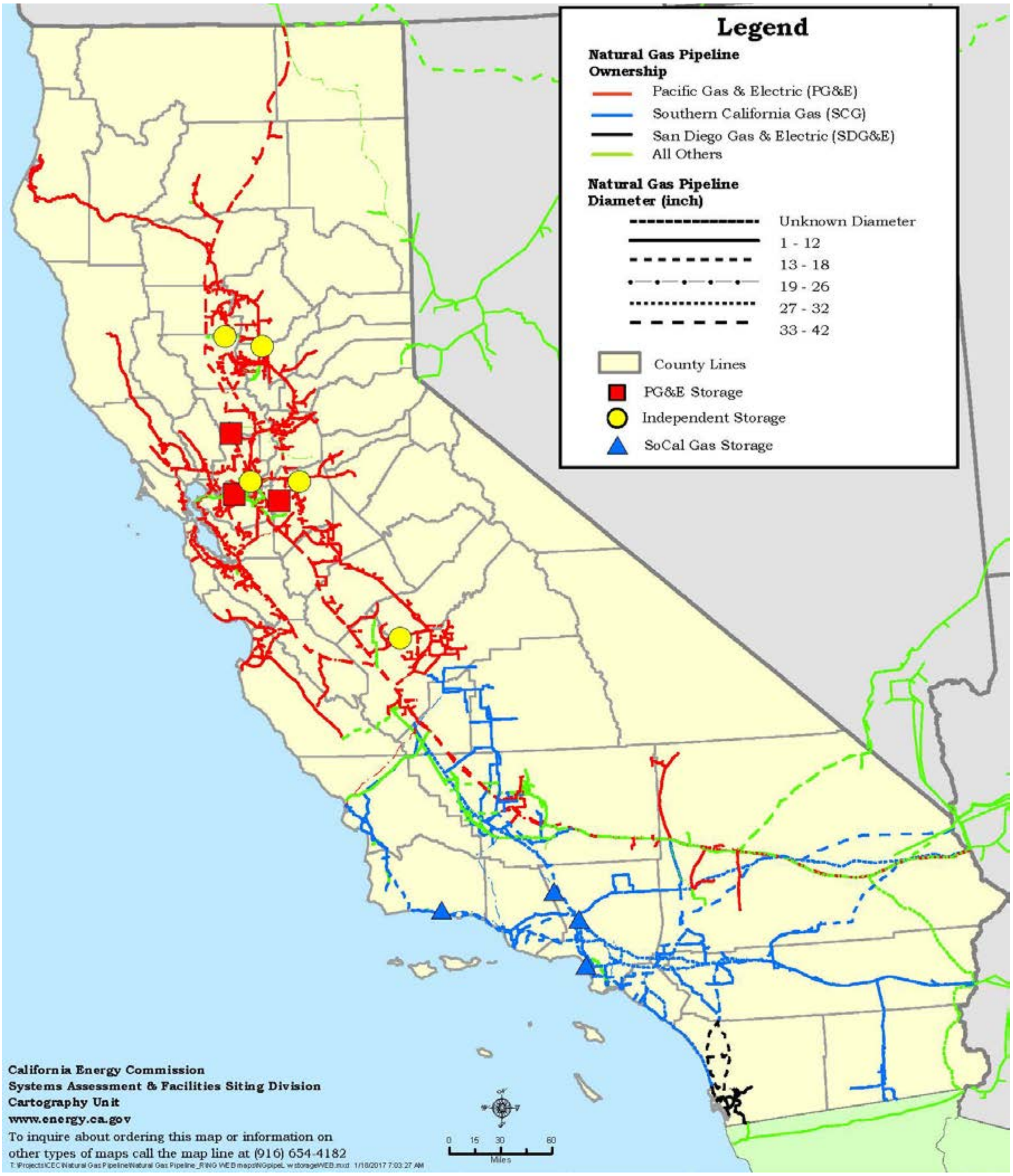

Figure 7. California natural gas pipelines and storage facilities

Map courtesy of the California Energy Commission

4.3 Federal Rules Intended to Increase the Safety and Reliability of Onshore Natural Gas Pipelines and Offshore Production Operations

4.3.1 Bureau of Safety and Environmental Enforcement Rules for Offshore Operations on the Outer Continental Shelf

On June 17, 2009, the former Minerals Management Service (MMS) of DOI issued a rulemaking proposal to require operators in the OCS to develop and implement a Safety and Environmental Management System (SEMS). In proposing the rule (called the "SEMS I" rule), MMS noted that "[M]ost industrial accidents and spills result from human error or organizational errors, not device or equipment failures." [164] The agency further underscored that implementing a SEMS would "address human factor issues in safety and environmental protection."[165]

> According to the former Minerals Management Service, a Safety and Environmental Management system would "address human factor issues in safety and environmental protection."

Per the proposal, MMS required operators to implement four elements of API's Recommended Practice 75, "Development of a Safety and Environmental Management Program for Offshore Operations and Facilities, Third Edition, May 2004." The four elements relate to conducting a hazards analysis,[166] MOC,[167] operating procedures,[168] and mechanical integrity.[169] MMS chose to propose to implement these four elements based on its comprehensive review of accident panel investigation reports, incident reports, and incidents of noncompliance that indicated that these four elements were the "root cause of most safety and environmental accidents and incidents."[170]

In addition, the agency's review of accident panel investigation reports found the following six contributing causes to the majority of accidents:

- Lack of communication between the operator and contractor(s)
- Lack of written safe work procedural guidelines
- Failure to identify workplace hazards
- Failure to conduct JSA before commencing work

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[164] 74 Fed. Reg. 28639 (June 17, 2009).
[165] *Id*.
[166] Hazards analysis requires operators "identify, evaluate, and, where unacceptable, reduce the likelihood and/or minimize the consequences of uncontrolled releases of oil and gas and other safety or environmental incidents." *Id*. at 28640.
[167] MOC would require documentation and analysis of "all proposed facility changes to determine possible adverse safety and environmental impacts…" 74 Fed. Reg. 28640.
[168] Operators must also have "written procedures designed to enhance efficient, safe, and environmentally sound operations." 74 Fed. Reg. 28641.
[169] Lastly, procedures are in place to ensure equipment is installed, tested, and monitored consistent with manufacturer recommendations and industry standards "to promote safe and environmentally sounds operations in the OCS. 74 Fed. Reg. 28641.
[170] 74 Fed. Reg. 28640.

- Failure of onsite supervisors to enforce existing procedures or practices
- Failure to properly maintain integrity of equipment and facility.[171]

The proposal also included important reporting and audit requirements, which, per MMS, were intended to help individual companies know how they rank compared to their peers, help management identify areas for improvement, and provide information about the overall performance of the offshore industry.[172] These requirements included reports regarding the number of operator and contractor injuries, illnesses and hours worked, incidents of non-compliance with EPA point source discharge permits, and oil spill requirements.[173]

MMS finalized the SEMS I rule on October 15, 2010, approximately six months after the Macondo well blowout.[174] The final rule included the four elements noted above as well as additional measures contained in API RP 75 relating to the management of contractors and audits of SEMs. In finalizing the rule, MMS noted that only 54% of OCS operators had SEMS programs as of 2009, and not all of these included the entirety of API RP 75.[175]

With respect to contractors, the final SEMS I rule added a number of provisions applicable to operators but not contractors directly. Specifically, an operator's SEMS must contain the following: (1) procedures to ensure and verify that contractors have their own written safe work practices, or alternatively, adopt an operator's safe work practices; (2) procedures to evaluate a potential contractor's safety performance and ensure that its contractors are performing their operations in accordance with the operator's SEMS.[176] The provisions applicable to operators were intended to "hold the operator accountable for the overall safety of the offshore facility, including ensuring that all contractors and subcontractors have safety policies and procedures in place that support the implementation of the operator's SEMS program and align with the principles of managing safety set forth in API RP 75."[177] The final rule also required operators to conduct an audit of their SEMS every three years. The audit could be performed by designated in-house personnel or third-party, independent auditors.[178]

Approximately two years later, one of the successors to MMS, the BSEE, proposed to revise the SEMS rules.[179] This revision was partly in response to the Macondo well disaster.[180] In proposing to update the SEMS I rule, the BSEE recognized that "the success of a SEMS program ultimately depends on how effectively the operator engrains principles underlying SEMS into the safety culture of their operations."[181] The BSEE's SEMS section chief also noted that the

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[171] 74 Fed. Reg. 28642.
[172] 74 Fed. Reg. 28644.
[173] *Id*.
[174] 75 Fed. Reg. 63610 (Oct. 15, 2010).
[175] *Id*. at 63613.
[176] *Id*. at 63612.
[177] *Id*. at 63610.
[178] *Id*. at 63611.
[179] 76 Fed. Reg. 56683 (Sept. 14, 2011). On May 19, 2010, the MMS was renamed the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE). October 1, 2011, the DOI reorganized BOEMRE, creating two new Bureaus, the BSEE and the Bureau of Ocean Energy Management (BOEM). The BSEE is tasked with implementing and enforcing the SEMS rules.
[180] *Id*. at 56688.
[181] *Id*. at 56684.

effectiveness of the rule "will also grow when workers are provided a say in how to best mitigate the recognized hazards in the context of their operations…"[182]

The proposal, which was adopted in full into the final rule on April 5, 2013, amended the audit requirement to require that only independent third parties could conduct audits of an operator's SEMS program. [183] BSEE noted that the new rule requiring the use of independent third-party auditors was likely to result in audit reports containing better qualitative assessments of the impact the operators' adoption of a SEMS would have on safety and environmental performance.[184] The final rule also added the following new requirements:

- Stop-work authority. Procedures to authorize employees and contractors to implement a stop-work authority program when witnessing an activity that is regulated under BOEMRE jurisdiction and create an imminent risk or danger to an individual, property, and/or the environment.[185]
- Ultimate work authority. Clearly defined requirements establishing who has the ultimate work authority on the facility for operational safety and decision-making at any given time.[186]
- Employee participation plan. A plan that demonstrates how employees will be involved in implementation of the SEMS plan.[187]
- Incident reporting. Procedures authorizing the reporting of hazardous or unsafe working conditions or violations of safety and environmental rules to BSEE.[188] Per the rule, the identity of the person would not be disclosed without the permission of the reporting individual other than to select employees of BOEMRE.[189]
- Training. The SEMS program must include procedures that ensure all employees and contractors receive training on required aspects of the SEMS.[190]

At the time, the agency noted that it planned to "share information with the public on aggregated results from SEMS audits…[and] develop metrics that demonstrate industry's degree of compliance with this new regulatory requirement."[191]

In November 2015, BSEE completed its first review of the audits that operators submitted to the agency of their SEMS programs. The agency's summary presents some initial indicators of the success of the SEMS requirements.[192] BSEE found that while 86% of the regulated operators had

[182] *Id*.
[183] 78 Fed. Reg. 20424 (Apr. 5, 2013).
[184] 76 Fed. Reg. 56684 (Sept. 14, 2011).
[185] *Id*. at 56684.
[186] *Id*. at 56684, 56686.
[187] *Id*. at 56685.
[188] *Id*. at 56685.
[189] *Id*. at 56687.
[190] *Id*. at 56685.
[191] *Id*. at 56684.
[192] SEMS Program Summary—First Audit Cycle (2011–2013), July 23, 2014. http://www.bsee.gov/uploadedFiles/BSEE/Regulations_and_Guidance/Safety_and_Environmental_Management_Systems_-_SEMS/SEMS%20Program%20Summary%208132014.pdf.

implemented the required elements of a SEMS, most were not implementing a SEMS "as an effective management tool."[193] Furthermore, the maturity and level of SEMS awareness and understanding among operators differed significantly depending on whether the company had "long-standing, established internal safety and environmental management systems" in place.[194] For those that had systems that pre-dated the SEMS rule, the reporting and auditing requirements in the rule provided an opportunity to evaluate and recommit to their existing systems. For those that were implementing a SEMS for the first time, the exercise was primarily one of rule compliance rather than "developing a tool to manage their respective operating health, safety, and environmental risks."[195]

While the SEMS rule is the best example we identified that attempts to address human and organizational factors that contribute to accidents, many have critiqued it for not going far enough to drive behavioral and systematic cultural change.[196] Moreover, while BSEE added requirements that provide metrics to gauge worker safety and environmental performance, these indicators do not provide information on the business metrics that lead to sound decision-making characteristics of an HRO.

4.3.2 PHMSA Requirements for Natural Gas Pipelines

PHMSA sets minimum safety standards for gathering lines, transmission, and distribution pipelines. While not specifically containing explicit HRO elements, many of PHMSA's requirements are intended to minimize the risks of major accidents. One particular standard that PHMSA is considering revising to better enhance the safe transportation of natural gas is the requirement that operators of transmission and distribution pipelines develop Integrity Management Plans (IMPs).[197] IMP regulations provide a structure for operators to focus resources on improving pipeline integrity in the areas where a failure would have the greatest impact on public safety (so-called "high consequence areas" or [HCAs]).[198] IMP requirements direct operators to periodically monitor pipelines in order to identify threats, analyze risks, identify mitigation measures, implement measures to address risks, and continuously re-evaluate pipeline integrity, threats, and risks.[199]

PHMSA recently proposed new requirements for pipelines that enhance IMP requirements and add new provisions intended to increase the safety and reliability of natural gas transportation.[200] The proposal "strengthens protocols for IM, including inspections and repairs, and improves and streamlines information collection to help drive risk-based identification of the areas with the greatest safety deficiencies."[201] In addition, PHMSA has proposed to extend integrity management requirements to pipelines located outside high-consequence areas that nevertheless contain significant populations.

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[193] *Id*.
[194] *Id*.
[195] *Id*.
[196] U.S. Chemical Safety and Hazard Investigation Board, investigation report, Executive summary Findings, http://www.csb.gov/macondo-blowout-and-explosion/.
[197] 81 Fed. Reg. 20722 at 20735 (Apr. 8, 2016).
[198] *Id*. at 20725.
[199] 49 C.F.R. at §§ 192.703, 192.1007.
[200] 81 Fed. Reg. 20735 (Apr. 8, 2016).
[201] *Id*. at 20724.

PHMSA has also proposed that operators of transmission pipelines be required to develop and follow an MOC process. Specifically, operators must implement an MOC process to address technical, design, physical, environmental, procedural, operational, maintenance, and organizational changes to transmission pipelines or processes, whether temporary or permanent.[202] MOC is one of the key elements of the SEMS II rule for offshore operators added in response to Macondo and, as noted previously in Section 3, all four companies queried have adopted MOC procedures to a varying extent.

4.4 State Rules Intended to Increase Safety and Reliability of Onshore Natural Gas Production

We researched requirements in Colorado, Pennsylvania, and Texas governing natural gas E&P operation. Our research focused on requirements related to organizational structures and processes intended to minimize risks posed by human factors, strengthen safety culture within the oil and gas sector, and enhance the safe and reliable production, transportation, or storage of natural gas. We searched for corollary requirements to those identified above in the PHMSA, BSEE, and California DOC rules. We specifically looked for requirements that operators develop risk management plans, emergency response plans, or comprehensive safety and environmental management system plans.

[202] *Id*. at 20735.

Figure 8. A remote natural gas well near Parachute, Colorado

Photo courtesy of the National Institute for Occupational Safety and Health

We identified very few requirements that met our criteria for HRO rules. Rather, state rules governing natural gas E&P traditionally contain a suite of performance and equipment standards designed to ensure the safe extraction and processing of natural gas. For example, states require operators install and monitor equipment designed to prevent well blowouts,[203] spills,[204] leaks, and other releases.[205] However, we identified no rules related to MOC, stop-work authorities, management of contractors, or other elements contained in the SEMs rules, which were specifically designed to address human factors that contribute to accidents. Perhaps the only example of a relevant HRO requirement is Pennsylvania's recent law requiring operators of unconventional wells to develop and implement emergency response plans for each well site.[206]

[203] *See e.g.*, PA Act 13, Section 3219; TAC Rule 3.13.
[204] *See e.g.*, PA Act 13, Section 3218.2.
[205] *See e.g.*, 5 C.C.R. 1001-9, CO Reg. 7, §§ XVII.C.2.b. (ii), XVII F, (Feb. 24, 2014).
[206] PA Act 13 § 78.55(f) (5).

4.5 State Rules Intended to Increase Safety and Reliability of Onshore Underground Natural Gas Storage

We similarly researched California, Colorado, Pennsylvania, and Texas rules governing the storage of natural gas in depleted or productive reservoirs or salt caverns. While none of these rules contain explicit HRO requirements,[207] there are a few provisions in the California rules, discussed above, and also in the Texas rules worth mentioning. In addition to the California rule, Texas requires operators to develop an emergency response plan,[208] implement safety training for employees,[209] conduct safety trainings with contractors prior to commencing work, and explain emergency response procedures to contractors.[210]

4.6 Industry-Recommended Practices and Initiatives that Contain Elements Related to Safety and Safety Culture

We identified select industry standards and initiatives aimed at increasing reliability and safety at oil and gas production and storage facilities. As noted above, industry standards provide the basis for the SEMs rules for offshore facilities as well as recently finalized PHMSA requirements for underground natural gas facilities.

API recently issued two recommended practices to enhance the integrity and ensure the safe and reliable operation of underground natural gas storage facilities: (1) API RP 1171, *Functional Integrity of Natural Gas Storage in Depleted Hydrocarbon Reservoirs and Aquifer Reservoirs* and (2) API RP 1170, *Design and Operation of Solution-Mined Salt Caverns Used for Natural Gas Storage*.[211] API 1171 contains elements related to risk management, emergency preparedness, monitoring, training, and procedural documentation and training for the MOC. API RP 1170 includes functional recommendations for salt cavern facilities used for natural gas storage service and facility geomechanical assessments, cavern well design and drilling, and solution mining techniques and operations, including monitoring and maintenance practices. As API 1171 has more elements that fall squarely within the HRO framework, we summarize these below.

Specifically, API 1171 requires operators "develop, implement, and document" a program to manage risk that includes identification of potential threats and hazards, risk analysis, and preventative, mitigation, and monitoring processes to reduce the likelihood of occurrence and/or the likelihood and severity of consequences.[212] In addition, operators should develop a provision for data feedback and validation.[213] The standard also recommends annual monitoring for the

[207] Colorado does not have any rules for underground natural gas facilities. Pennsylvania has a number of requirements aimed at ensuring the safe and reliable storage of natural gas, although these requirements do not include a requirement that operators develop risk management plans, emergency response plans, or comprehensive safety and environmental management system plans. Rather, the Pennsylvania requirements focus on well construction;[207] monthly inspections to identify signs of integrity problems, such as gas leaks; and gas well integrity requirements, including a requirement to test the integrity of each gas storage well at least once every five years.
[208] Texas Administrative Code Rules 3.96 and 3.97.
[209] *Id*.
[210] *Id*.
[211] 81 Fed. Reg. 6334 (Feb. 5, 2016).
[212] API 1171 § 8.2.
[213] *Id*. at § 8.5.2.

presence of annulus gas and inspecting valves,[214] the development of an emergency preparedness/response plan,[215] an MOC process,[216] procedures to ensure that employees and contractors recognize abnormal operating conditions and understand their respective roles in emergency procedures, and specific recommendations related to the hiring and use of contractors.[217] In particular, API RP 1171 recommends that operators define minimum qualification or experience requirements for contractors; develop a method to verify contractor training to ensure contractors are familiar with the company's procedures and recordkeeping requirements; and provide training to contractors.[218] The AGA and INGAA endorse these as best practices, and INGAA recently petitioned PHMSA to adopt a regulation for interstate natural gas storage that incorporates both standards by reference.[219]

Both INGAA and API have put out guidance materials and a recommended practice to encourage and guide operators in developing and implementing a pipeline safety management system (PSMS).[220] Similar to BSEE's SEMS requirements, the purpose of a PSMS is to improve standard management by adding systematic and coordinated discipline and structure. In addition, a PSMS is designed to provide better feedback loops on the effectiveness of risk management and other processes,[221] with the ultimate goal that having a comprehensive PSMS will strengthen the organization's safety culture. Key elements of a comprehensive PSMS, per API RP 1173, are:

- Leadership and management responsibilities, including documenting and communicating the "pipeline operator's policies, goals, and commitment to safety, as well as identifying safety responsibilities of personnel at all levels"
- Outreach to internal and external stakeholders, such as members of the public and regulators, regarding risk identification and management
- Risk management, whereby the operator maintains a process to identify threats to pipeline assets, assess risks, and at least annually review such risk assessments

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[214] *Id*. at § 9.3.2.
[215] *Id*. at § 10.6.
[216] MOC addresses changes in equipment, processes, materials, or procedures. MOC ensures that before a change is implemented, certain analysis is undertaken: first, operators must identify impacts associated with the change and determine the effect of the change on the facility. Second, the change must be approved and formally documented. The operator's formal MOC program should include a process for approving changes and deviations from the approved process when necessary, such as in the case of an emergency. The MOC should also specify what the process operators should use when updating procedures, communicating and documenting changes to procedures, and training personnel on the changes. The MOC should define the types of changes that must go through the MOC process. Insignificant changes may not need to be included. *Id*. at §11.11.
[217] API 1171.
[218] API 1171.
[219] 81 Fed. Reg. at 91864.
[220] INGAA 2012 Guidance re safety management systems; API RP 1173. Other industry recommended practices for environmental management systems include ISO 9001. Quality Management Systems-Requirements and ISO 14001. Environmental Management System Requirements.
[221] INGAA; *see also* API RP 1173, 3.1.21 (describing a pipeline safety management system as "a framework of elements that an organization uses to direct and control work to achieve its objectives in an intentional and continual manner").

- Operational controls, including procedures identifying processes for normal and emergency operations, MOC, and contractor oversight
- Incident investigation, evaluation, and lessons learned from internal and external events
- Safety assurance, including at least triennial audits of the PSMS by internal or external personnel, the effectiveness of risk management procedures, the safety culture, and procedures to analyze data in order to assess key performance indicators
- Management review and continuous improvement to ensure attainment of the PSMS goals and objectives and foster improvement
- Emergency preparedness and response, including procedures for notifications, drills, and periodic review of plans
- Emergency response plans must be shared with employees and contractors
- Competence, awareness, and training to ensure that employees and contractors are aware of relevant PSMS elements, changing risks, and potential consequences of failure to follow procedures
- Documentation and recordkeeping to ensure procedures for the identification, distribution, and control of documents required by the PSMS.

In sum, industry standards play an important role in helping regulators develop common-sense and practical requirements. Rules that incorporate industry standards, such as the SEMs rules, and PHMSA's recent rules for underground natural gas storage facilities, are likely to have the support of industry, as they have been developed by industry and, in some cases, are already being followed by some members of the industry. Importantly, however, as the SEMs rules illustrate, at times, requirements beyond those contained in industry-recommended practices or standards are necessary to protect fully human health and the environment.

5 Challenges and Opportunities Facing Efforts to Broaden Adoption of HRO Policies in Onshore Natural Gas Operations

As discussed at the outset of this report, the oil and natural gas industry is unlike other industries that have adopted HRO policies to enhance their operations. Several of the unique characteristics of the industry pose challenges to greater adoption of HRO policies across all members of the industry. That being said, there are a number of HRO or HRO-like practices that are applicable to the industry, and if adopted, could potentially improve the safety and reliability of high-risk activities significantly. [222] The four companies profiled in this report provide ample validation to that assertion.

5.1 Challenges

Perhaps one of the greatest challenges facing the oil and gas industry is the fact that it is highly diverse and fragmented. Companies range from small, privately owned businesses to international publicly traded multinational corporations. As an example of the complexity of the industry, there are over 6,000 independent oil and natural gas producers and service and supply companies in the E&P segment alone.[223] Resource development activities occur both onshore and offshore and consist of various types of drilling techniques and technology systems, including vertically, horizontally, and deep-water drilled wells. Midstream and downstream activities are similarly diverse, encompassing activities in the transportation, processing, storage, and delivery segments of onshore gas operations that are a focal point of this report.

In addition, the highly diverse and ever-shifting nature of the workforce poses a real challenge to onshore operators.[224] The oil and gas industry relies heavily on the use of contractors, and ensuring that a contractor not only follows company procedures but is also integrated into the company's safety culture can pose challenges. This is particularly true for a "drilling permit" holder overseeing a vast array of activities—from siting the well to completing it. In addition, the cyclical nature of the industry, often driven by highly variable commodity prices, can result in an employee pool that changes frequently—in terms of both the size and expertise of the workforce. Maintaining a strong safety culture under these circumstances can be extremely challenging. Yet there are leading operators (a handful of them profiled herein) that have made the organizational commitment to adopt HRO practices and structures in the face of numerous challenges.

Operations that occur across various segment and activity types occur in a highly decentralized environment. This is true even within the umbrella of a single company. Communicating and enforcing a strong safety culture and a high degree of adherence to policies and practices is more challenging in such an environment. This is one area where offshore operators may be better situated to adopt HRO practices, as an offshore oil rig arguably shares more in common with a nuclear power plant or aircraft carrier—large, centrally located facilities featuring an enormous amount of capital investment—than a production field.

[222] The scope of this report did not include an evaluation of the costs or other challenges that adoption of HRO or HRO-like practices by individual companies may present.
[223] Independent Petroleum Association of America, About, available at http://oilindependents.org/about/. Independent producers on average employ 11 workers.
[224] *See* Transportation Research Board Report on Safety Culture in Offshore Sector.

In addition, the very thing that has contributed to the significant growth in the natural gas industry—rapid technological innovation—also poses a challenge to greater adoption of HRO policies. This rapid innovation can pose a challenge to company policies designed to ensure that employees and contractors are familiar with practices intended to ensure the safe and reliable application of such technologies. On the other hand, technological innovation also presents promising solutions to increase the safe and reliable development and transportation of our country's oil and gas resources.

Lastly, the fragmented nature of the regulatory framework applicable to onshore operations—in particular exploration and production—poses a challenge to greater adoption of HRO practices. Various federal and state regulators are tasked with ensuring the safe and sustainable development of onshore oil and gas resources. Some of these regulators are similarly charged with ensuring the efficient development of resources (and the cultivation of government revenues), which can, at times, conflict with mandates to protect the environment or public. Some have criticized the fragmented structure and organization of the regulatory framework applicable to the offshore sector as substantively contributing to the Macondo disaster,[225] and many of the same criticisms could be leveled at the onshore regulatory framework governing oil and natural gas production, transportation, storage, and distribution. Notably, following Macondo, the federal government restructured the regulatory framework governing offshore operations, creating separate agencies with independent authority to collect revenues, manage development, and enforce safety and environmental regulations.[226] Similar reforms to the agencies that oversee onshore development could potentially help drive greater safety and environmental performance within this sector.

5.2 Opportunities

Despite these substantial challenges, HRO theory offers many opportunities and potential advantages to the onshore gas industry, and many HRO practices are applicable to the full range of industry operations. As demonstrated above, a number of companies are integrating key HRO practices, such as non-punitive reporting, incident management systems, comprehensive environmental and safety management systems, a high degree of communication around safety, learning from other sectors, data analytics, and other components designed to strengthen the company's safety culture and manage risk. These companies are helping to develop the next generation of technologies that can predict, prevent, and help mitigate accidents. These companies have also been pivotal to the development of industry standards that are now mandatory for underground natural gas storage facilities per PHMSA's December 2016 Interim Final Rule noted above, such as API RP 1170 and 1171.

From a structural standpoint, there are a number of key practices that the industry and policymakers could implement. The first is the development of formal structures to facilitate sharing information regarding accidents, near misses, and best practices. Ensuring that any self-

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[225] *See e.g.*, Baram, M, Deepwater Study Group Working Paper, Preventing accidents in offshore oil and gas operations: the U.S. approach and some contrasting features of the Norwegian approach (Jan. 2011), https://ccrm.berkeley.edu/pdfs_papers/DHSGWorkingPapersFeb16-2011/PreventingAccidents-in-OffshoreOil-and-GasOperations-MB_DHSG-Jan2011.pdf.

[226] *See e.g.*, Bureau of Ocean Energy Management, The Reorganization of the Former MMS, available at https://www.boem.gov/reorganization/.

reported data are confidential and protected from potential enforcement actions is a critical component of any program that incentivizes the sharing of incident and near-miss data.[227] As discussed above, self-reporting of accident and near-miss information is a key attribute of HROs. One of the recommendations in the wake of the Macondo disaster was the formation of a permanent Well Expert Committee to share lessons learned by analyzing incidents, advocating harmonized standards, communicating good practices, and promoting continued research and development.[228] The Federal Aviation Administration's Aviation Safety Information Analysis and Sharing (ASIAS) program provides an example of a successful program that facilitates self-reporting of incidents and has been instrumental in increasing the safety and reliability of an industry. While participation is voluntary, all major air carriers participate, representing 99% of U.S. air carrier commercial operations. [229] Self–reported information is confidential and carrier-reported information is exempt from the Freedom of Information Act, which helps encourage employees to report without fear of retribution. Moreover, data are aggregated and cannot be used for enforcement.

Stakeholder agreement is also needed on what systems, processes, behaviors, and policies are necessary to drive greater adoption of HRO practices in the oil and gas industry.[230] While API RP 1173, 1170, and 1171 provide some standard for midstream and downstream operators, no similar consensus standards have been developed for the E&P sector. Developing corollaries to these RPs for the E&P sector could be a joint effort on the part of industry, regulators, and other experts, including non-governmental organizations, that could result in the issuance of guidance documents and/or industry-recommended practices.

A third mechanism that could help drive deployment of HRO practices and ensure continuous improvement is the establishment of an independent body qualified to evaluate companies' adoption of essential HRO characteristics. An example in the nuclear industry is the Institute of Nuclear Power Operators (INPO), which was established within one year of the Three Mile Island accident. INPO's mission is to "promote the highest levels of safety and reliability—to promote excellence—in the operation of nuclear electric generating plant."[231] INPO ranks plants on highest performers to lowest performers, and that ranking is constantly changing. What is excellent today may be merely acceptable five years from now. Key attributes of INPO include agreement among all members to share information, practices, and experience to maintain high levels of operational safety and reliability. The INPO is comprised of nuclear industry leaders, including CEOs, presidents, and representatives from boards of directors.[232]

A government program that encourages adoption of HRO practices and rewards leaders via public recognition and other incentives could also be helpful. Such a program could, for example, recognize and reward companies who have demonstrated adoption of HRO practices

[227] A number of the company representatives queried noted that legal concerns regarding the use of self-reported data currently act as a bar to greater sharing of information. Therefore, ensuring that self-reported data are confidential and cannot be used for enforcement purposes, as is done in the aviation industry, seems to be a critical component of a well-designed self-reporting program.
[228] Global Industry Response Group recommendations for Deepwater Wells (May 2011).
[229] Federal Aviation Administration, Fact Sheet-Aviation Safety Information Analysis and Sharing Program, available at https://www.faa.gov/news/fact_sheets/news_story.cfm?newsid=18195.
[230] *See* Transportation Research Board Report on Safety Culture in Offshore Sector.
[231] INPO website, http://www.inpo.info/AboutUs.htm.
[232] Karlene H. Roberts, "Improving Major Risk Reduction in the Oil and Gas Industry" at 5.

by relieving these companies of administrative burdens (e.g., reporting requirements). Doing so not only has the potential to motivate greater adoption of HRO practices among industry members, it also frees up limited regulatory staff to focus compliance and enforcement efforts where most needed. Perhaps a program for the oil and gas industry could be patterned after successful voluntary programs such as the EPA's former "National Environmental Performance Track" program[233] or the Malcolm Baldridge National Quality Award, which is a governmental program that recognizes organizations that demonstrate quality and performance excellence.[234]

In addition, the industry might benefit from programs specifically tailored to develop the next generation of oil and gas leaders. In the U.S. commercial nuclear industry there is a strong management and leadership development effort from first-line leaders, managers, executives, and boards of directors. INPO has an extensive development program that aspiring managers and executives must attend, and many utilities have in-house corporate universities. These help shape shared values, shared language, and shared culture within the industry as well as the individual utilities.

Lastly, enhanced transparency relating to accidents, incidents, and inspection data could serve to drive greater adoption of HRO practices.[235] Enhanced disclosure of GHG emissions, for example, has been credited with incentivizing companies to take steps to voluntarily limit the carbon footprint of their operations.[236]

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[233] Coglianese, C. and Nash, J., "Beyond Compliance, Business Decision Making and the U.S. EPA's Performance Track Program"

[234] Malcolm Baldridge National Quality Award, available at http://asq.org/learn-about-quality/malcolm-baldrige-award/overview/overview.html.

[235] See e.g., U.S. Chemical Safety and hazard Investigation Board, investigation report, Executive summary (recommending enhanced reporting and disclosure of factors related to accidents for the offshore industry).

[236] Carbon Disclosure report.

6 Conclusions and Suggestions for Further Research

6.1 Conclusions

The application of HRO theory and practices to the onshore oil and gas industry appears to be in its nascence. There are limited regulatory requirements that promote adoption of HRO practices, and, for the most part, these rely entirely on industry-recommended practices and have generally been developed or adopted in response to major accidents. The fragmented regulatory framework (applicable especially to E&P activities) is one reason for the lack of rules aimed at addressing the human and organizational factors contributing to accidents, but other factors play a role as well.

Our limited research into practices adopted by the four companies we profiled reveals some familiarity with HRO theory and application among industry leaders. These companies are implementing many of the policies and practices recommended by HRO and other industry experts focused on workforce protection and total quality management to strengthen a company's safety culture, improve process safety, and minimize the risk of catastrophic failures. That being said, the oil and gas industry as a whole does not appear to be driven by HRO theory and leadership practices. There are many steps companies and policymakers could take moving forward to improve the safety and sustainability of onshore natural gas production, storage, and transportation.

In closing, the research to date (including this project and other scholarly efforts reviewed during our research) has been limited in scope and leaves a number of questions unanswered. Ensuring the safe and reliable development, transportation, storage, and distribution of natural gas resources remains a critical goal as experts predict the continued development and broad use of unconventional natural gas resources well into the future. Accordingly, we offer some suggestions for future research.

6.2 Further Research

To date there has been some analysis of the adoption of HRO practices to offshore activities and at least an initial foray into regulations designed to address the human and organizational factors that have led to accidents on offshore drilling platforms. A comparison of the factors at play in onshore and offshore resource development, combined with an analysis of the aforementioned SEMS rules, could help identify additional pathways for greater adoption of HRO practices in both the onshore and offshore sectors.

A deep dive into the lessons learned from prior accidents could also help identify pathways for greater adoption of HRO policies. For example, it would be helpful to understand what factors drive improvements in safety and reliability among pipeline operators following major accidents. Research into the federal and state investigations and regulatory and voluntary efforts that ensued within the natural gas pipeline sector following events such as the San Bruno pipeline accident could help identify both the "carrots" and "sticks" that lead to positive change. There is extensive literature analyzing the causes for numerous industry accidents, which, combined with a review of accident reports and records, could provide significant data and inform subsequent analysis and insights.

A second avenue for further research would be an investigation into the cost-effectiveness of HRO practices and a nuanced exploration into the potential barriers to greater adoption by the oil and gas industry.

In addition, the nuclear and aviation industries have developed programs to increase the safety and reliability of their industries. Examples include the INPO and ASIAS programs. A deep dive into these and similar industry and joint industry-regulatory pathways and practices applicable to the oil and gas industry could help prevent accidents, reduce environmental impacts, and improve the industry's social license to operate.

Lastly, some of the largest and most sophisticated multinational firms operating in the oil and gas sector appear to have strong safety and reliability records. An interesting area for further research would be an investigation into the practices, policies, decision-making, leadership, and governance of a major publicly traded multinational with a strong safety and sustainability record in order to identify practices, systems, and structures applicable to other oil and gas companies. Lessons learned from such an endeavor could provide a framework that could be used by an independent body to evaluate the adoption of HRO practices by individual companies as well as used by the government to recognize industry leaders.

Appendix. Summary of Interviews

Table A-1. Small Independent E&P Company

Questions	VP of Health, Safety, Environment, and Regulatory	VP Operations	HSE Manager-Corporate	VP, Strategic Solutions
Safety culture/behavior	Reliability is now prioritized over efficiency, reflecting a change at the company over time. HSE culture has evolved at the company, and the CEO was essential in this change. Safety is a core value and a part of the culture. Company uses a behavioral-based system, the DuPont System. People are bought into the vision/core values of the company.	HSE is core to the behavior of employees. Has always been a priority but has become more important over time and especially in last three years because the CEO is prioritizing it as a core behavior. Emphasis on looking out for co-workers and speaking out about safety concerns. Does not see efficiency roadblocks in prioritizing HSE. Believes it helps get the job done right the first time. Innovations to value plus: system where anyone in the company can make a suggestion to improve the company. Suggestions are reviewed and good ideas are disseminated to everyone.	Culture has changed over time. Safety has become a priority. It is a culture of reliability first and efficiency later. CEO has changed the culture—interviewee has seen this over the eight years he has been with company. Try to grow the culture from the top down—management sets example. Questioning is welcomed to ensure they are doing the right thing. Focus on accountability and strive for excellence. Employees know jobs need to be done right, both from a safety and environmental perspective. Employees know they have an obligation to raise concerns if they witness improper or unsafe behavior.	Integrity is more important than profit. If you make a commitment, keep it, even if you later learn it is not in the best interest of the company. When you drill a well, do it as if it is in the CEO's backyard. The same goes for all environmental impacts. Employees and contractors are trained in the culture. Be proactive: if you see something wrong, fix it.
Maintaining state of unease/sensitivity to operations		Safety training and observation program (STOP: employees go out to the field, observe operations, and then discuss their observations. These observations (both good and bad) are shared with	Standard procedures around hazard identification. HSE personnel and operations professionals assess all areas 1–2 times per week regarding compliance procedures. Use results of the assessments to create company-wide broadcasts related to hazard identification. For high-risk jobs,	

Questions	VP of Health, Safety, Environment, and Regulatory	VP Operations	HSE Manager-Corporate	VP, Strategic Solutions
		everyone in the company. Field workers use these to keep fresh and focused on safety. Utilize JSA to encourage people to ask questions. Utilize company-wide incident command system that originated in the offshore sector. There is a system in place to address every incident. An incident commander onsite, with people below keeping him informed. Among other things, the incident commander is responsible for coordinating with state regulators and keeping track of equipment. Checklists are heavily utilized.	develop a plan prior to execution called a JSA. Plan ahead, look for risks and hazards during every step, and eliminate as many as possible. Train how to look for common hazards and review old JSAs to inform new ones. Consult with trained HSE personnel. Most of the time an operational person leads the JSA. Employee concerns are given as much weight as supervisors. Contractors are treated the same as employees. Anyone can raise a suggestion during the development of the JSA.	
Incident management systems	Safety, training, and observation are utilized in leading indicators at the company. Employees make observations of safety behaviors and these are tracked. This practice raises awareness of proper safety procedures. Utilize targets for employees for raising awareness. Company belief that every single incident (near misses or actual injury to person/environment) can be prevented. Take corrective actions and investigate incidents. For recordable incidents, perform	Safety informational management system: any type of near hit or actual impact gets reported and immediately distributed to senior management and people in the field where incident occurred. For serious incidents, safety alert issued and information circulated company-wide. If someone sees something amiss, the job is stopped and incident is reported as a near hit.	Employees are encouraged to report concerns to HSE coordinator or supervisor. Safety training and observation program (STOP) is where employees fill out a card when they witness unsafe behavior and can stop unsafe activity. Works as an internal driver and is practiced company-wide. Emphasis on hiring the right kind of people.	

Questions	VP of Health, Safety, Environment, and Regulatory	VP Operations	HSE Manager-Corporate	VP, Strategic Solutions
	formal investigations led by operations personnel and put out alerts. Track leading and lagging metrics. Lagging metrics have improved over time and include: total recordable injury rate, environmental rate, and vehicle incident rate. CEO receives all incident reports (including reportable incidents, minor incidents, and near misses).			
Stop-work authority		Stop-work authority applies to everyone. Anyone can stop an operation if they have a concern.	Stop-work authority is encouraged, especially with contractors.	
Employee recognition				
Financial incentives	Bonus is tied to major metrics of safety. 15% of bonus is tied to HSE metrics. For corporate side, bonus is tied to company-level metrics.		Both lagging and leading indicators are considered when deciding bonuses. Part of developing "balance scorecards," which are reviewed periodically. Contractor and employee safety performance are both tied to bonuses.	Part of compensation comes from safety and part from environmental record.
Management commitment	Encourage managers to participate in, and even lead, field-based safety meetings. Having managers in the field has contributed to the change in culture. Even the CEO goes out in the field.	CEO and senior VPs go to the field approximately every other quarter for a safety address and town hall meeting. Some area VPs go to the field monthly. Managers go to the field more often, and frequent field visits are part of their goals.		
Overcoming pressures on	Maintain a clear and consistent message from all levels of the			

Questions	VP of Health, Safety, Environment, and Regulatory	VP Operations	HSE Manager-Corporate	VP, Strategic Solutions
supervisors	organization, from the CEO down, that safety is first priority and trumps project timelines and budgets.			
Safety and environmental management system	Yes.			
Management of change	MOC and incidents are the main drivers for revising safety processes. The midstream sector is more advanced regarding MOC, but other sectors are trying to improve in this area.		MOC is an evolutionary process that the company is constantly refining. MOC applies to both contractors and employees.	
Training	Multiple types of training. Large, on-the-ground operational office with completion units and drilling rigs used for onsite training. Attend external and internal training classes. Best-practices manuals authored by internal and external technical experts. Utilize training in the field. Use computer training for tasks that are not hands on. For emergency response, have annual major crisis drills that involve internal and external personnel. Some divisions practice these drills on a quarterly basis. An example of a recent drill at the organization was a day-long drill at a gas field that included first responders and	Combination of training types. Computer-based training around safety. Short-service employee program: new employees with little or no experience wear green hard hats and are assigned a mentor for six months or until the mentor certifies that the employee is properly trained. Hold tabletop drills and enactments in the field. Have annual re-enactments of spills or other incidents. Fire departments sometimes participate. Everyone is encouraged to take notes on the drills. These are compiled by the HSE group and are	Employee competency program wherein new employees have a mentor for the first 90 days. Process management plan guides emergency situations. Have drills for everything and plan for many different incidents including well blowouts, pipeline ruptures, and natural disasters. Each business unit (production/midstream) does a drill at least annually. Submit lessons-learned document from drills, which feed into JSAs.	

Questions	VP of Health, Safety, Environment, and Regulatory	VP Operations	HSE Manager-Corporate	VP, Strategic Solutions
	operations personnel.	used to generate a lessons-learned document.		
Contractors	Contractors participate in safety meetings. Contractors' safety performance has improved over time.		Contractors are treated the same as employees, and the same expectations apply.	Contractors are held to the same standards as employees. Contractors are trained the same as employees. Company performs some operational services (drilling, fracking, well-pad construction) and can use operational knowledge to control and influence contractors. Contractor safety is one metric included in employee compensation.
Learning from other sectors				
Sharing information	Sharing information has increased in the industry. "Lifesaver" program: program to raise awareness about eight of the most dangerous types of activities that occur. Contractors are included in these programs. Regularly scheduled meetings on monthly or quarterly basis and annual multi-session meeting where all committees report to the American Exploration and Production Council. Monthly meetings of local HSE professionals.	Lagging data includes total recordable incidents and Recordable Vehicular Incident rate. Company is a member of a consortium that shares incident data. Use data to see ranking in terms of peers.	Company shares information with oil and gas industry as much as possible. Lawyers can be an impediment to sharing information.	

Questions	VP of Health, Safety, Environment, and Regulatory	VP Operations	HSE Manager-Corporate	VP, Strategic Solutions
	Legal barriers to sharing some information.			
Audits			Worked with DuPont to perform a perception audit and used this information to develop many of the behavior-based systems at the company.	
Data analytics	Company has room to grow in this area but is starting to use these types of tools.		Company is working on this.	
Transparency				
Voluntary efforts				Member of One Future coalition. Goal to reduce loss rate to less than 1% to ensure natural gas is truly a better fuel substitute than coal for power generation and diesel for cars. Perform voluntary annual leak detection and repair. Company is freshwater neutral, which it achieved through reducing its use of water and 100% recycling. Involved in stream-mitigation projects to remove acid mine drainage in Pennsylvania and elsewhere. Company receives offsets. Worked with Environmental Defense Fund to develop model regulatory framework on well integrity.

Questions	VP of Health, Safety, Environment, and Regulatory	VP Operations	HSE Manager-Corporate	VP, Strategic Solutions
				Framework has been adopted by multiple states. Believes in smart regulation.

Table A-2. Large, Multinational, Independent E&P Company

Questions	Interview HSE Manager	Interview HSE Manager
Safety culture/behavior	Safety is first priority and is even in company mission statement. Part of employee compensation. Focus has changed over time toward behavior-based safety. Hold day-long training sessions called SafeStart for onshore operations. Motto: "These four states, rushing, frustration, fatigue and complacency, can cause or contribute to these critical errors which are eyes not on task, mind not on task, being in the line of fire or balance, traction and grid which can increase the risk of injury." Encourages people to self-trigger, be mindful, and aware. Heinrich's safety triangle: increase the bottom of the triangle in the hope that you never get to the top. Encourage people to be more observant in order to decrease amount of unsafe acts. Goal of zero accidents.	Messaging has evolved over time to be more focused on prevention and response. Company strives to be a leader of crisis emergency management. Focus on risk assessments and incident mitigation planning to work to avoid incidents.
Maintaining state of unease/sensitivity to operations	Employees feel comfortable reporting concerns. If employees see something concerning while on the job, they can call a hotline. If the operator deems it important, will get security involved and determine how to respond. Incident reports are tracked. Tailgate safety meeting prior to job.	Track a variety of metrics around incidents that allows for evaluation of all types and levels of incidents. This includes near misses and other observations that do not rise to a reportable incident. Assess data for trends and communicate the information company-wide. Encourage employees to report observations of issues of concern as well as strong safety behavior in the field. Goal is zero incidents including prevention of low-probability/high-consequence incidents. If an incident occurs, work to investigate using root-cause analysis. Corrective actions are implemented to prevent recurrence.
Incident management systems	System records all HSE data (spills, safety incidents, etc.). Includes observations that are near misses (e.g., not using a ladder). Data are logged into database. SAP-based system: daily reports to manager; monthly roll-up, trending reports (which may result in safety alerts); quarterly, semiannual, annual roll-ups of incidents. Employee incident rate has gone down year over year. Daily reports sent automatically by email every day to regional managers and anyone in the company that wants them. Monthly incident reviews wherein field operations teams meet to review incidents/near misses, take action items, circulate summaries	Management system that provides policies and procedures outlining details on how to accomplish goals.

Questions	Interview HSE Manager	Interview HSE Manager
	of lessons learned/things to pay attention to, sent to management team and operations teams, and reviewed at tailgate meetings. Incidents with potentially more significant repercussions are included in safety alerts that are posted to internal system or sent out to management team for circulation. Reports go to VPs, and depending on the incident, may also go to president/CEO/executive committee. If there is emergency response the communications go to the executive committee.	
Stop-work authority	Not just authority but "obligation."	Give everyone the authority to stop work if observe unsafe condition or behavior.
Employee recognition	Employee Excellence Program: recognition given if someone makes an observation/action that adheres to core values or goes above and beyond in one of the five core values. Week-long Safety and Environmental Excellence Program: operations people from all over the world come to present about above-and-beyond measures they have taken. If someone implements a program, they share about this and receive recognition.	Multi-faceted internal awards program. The goal of the HSE Recognition and Awards Program is to promote positive attitudes with regard to HSE compliance and a proactive and innovative HSE culture. Each eligible employee has the opportunity to be recognized for individually contributing to work groups. In particular, the Safety and Environmental Excellence Program provides best practices across the company to continually improve HSE and sustainability efforts and performance. The company is currently evaluating the HSE and sustainability award programs in order to focus and optimize the benefit to the organization.
Financial incentives	Bonuses are tied to individual safety and environmental record and company-wide safety record. Bonuses are not tied to contractor safety/environmental performance. Annual incentive plan includes five categories, one of which is safety (both company-wide and individual employee).	
Management commitment	Foremen are in the field daily. Superintendents are in field offices daily (not on location daily). Operations managers for each state are in the field every other week. VPs are in the field or in communication with the field semi-monthly or more frequently.	
Overcoming pressures on supervisors		
Safety and environmental management system		Management system is focused on continuous improvement. In addition, we review and update policies, procedures, and other documents to ensure we are always focused on

Questions	Interview HSE Manager	Interview HSE Manager
		continuous improvement. Each requirement is structured with periodic assessments regarding the degree of implementation, which may trigger subsequent modifications for continuous improvement. Performance and progress are assessed with periodic audits and data management so that feedback can be continually incorporated and targets adjusted.
Management of change		
Training	Intern program: students shadow experienced drilling personnel. Company uses national incident management system, which requires training and has procedures to prepare for emergencies. Program includes yearly training. Practice emergency response drills. Conduct annual drills at certain facilities. Weekly tabletop drills. Large drills held quarterly (including well blowout, tank rupture, power outage, etc.) based on previous experience and potential for future issues. Unannounced drills are held at random times to make sure that equipment dispatched has everything required. Involve the specialty companies necessary for the incident.	
Contractors	Contractors subject to safety standards. Use ISNetworld to evaluate contractor HSE record. Periodically audit contractors being utilized. Contractors expected to report near misses and incidents and utilize stop-work authority.	Conduct HSE audits on contractors throughout the various assets.
Learning from other sectors	Less frequently in terms of lessons learned from other industries. Sometimes look to mining industry and refineries to a certain extent.	
Sharing information	Association meetings. Trade groups. Word of mouth.	
Audits	Conduct HSE audits of field locations every four years. Audits conducted by in-house personnel (HSE personnel and sometimes operations people) from different regions (even from offshore for onshore or vice versa). Audits produce reports and action items that must be closed out.	HSE audit team regularly conducts audits on each of our operations.
Data analytics	Analyze for root cause anytime an incident occurs. Incident data are tracked over time with	

Questions	Interview HSE Manager	Interview HSE Manager
	an SAS Data Management system.	
Transparency		Disclose TRIs and information requested in Carbon Disclosure Project GHG and water reports.
Voluntary efforts	Improvements in drilling allow personnel to drill more quickly and can end risky operations sooner. Use greener compounds that allow for water recycling. Move to greater use of tankless facilities, which are safer, because they remove possibility of accidental exposure when inspecting tanks. Operators now have to carry gas monitors. Foot pad is getting smaller, leading to less surface disturbance, which is more environmentally friendly.	

Table A-3. Major Pipeline Company

Questions	VP of Environment, Health, & Safety	VP of Storage
Safety culture/behavior	Importance of safety has increased over time in response to incidents. Company had incident at facility about 10 years ago, which led them to ramp up. About 10–15 years ago, the energy industry started identifying that OSHA incident rates[237] were declining, but fatalities and life-altering incidents were either flat or going up. This resulted in interest in assessing and evaluating this trend.	Increased focus and dollar commitments on storage after Aliso Canyon.
Maintaining state of unease/sensitivity to operations	Employees and contractors are encouraged to report any unsafe behaviors and conditions. All potentially serious issues are addressed. Safety issues (including near misses) are discussed at weekly, monthly, and quarterly meetings in order to determine what should be done differently. Supervisors and managers have weekly safety meetings. Employees have monthly safety meetings. Representative from all five business units meet monthly to discuss trends. Managers ask employees questions, raise safety issues, and encourage employees to speak up about concerns and share ideas for improving operations. Part of API 1173. Safety observation program to identify unsafe acts or conditions. Risk management group utilizes a third party to examine equipment to ensure it is constructed and operated according to industry specifications or standards. Corporate EHS group that conducts audits and assessments. Annual risk assessments of everything, high as well as low risk. Ensure have sufficient risk mitigation to address. At times will reallocate resources based on assessment. Internal survey on safety culture: In 2013, 79% of people responded. In 2016, 89% of people responded. Indicates people see leadership stressing importance of safety culture. Leadership and operation training on safety reinforces a culture where always working on improving safety. Goals for both lagging and leading indicators. Goal is to always improve over three-year running average.	
Incident management systems	See above.	
Stop-work authority	Stop-work authority: regardless of what regulation says, if someone thinks something is unsafe, encouraged to stop work. This applies to both safety and the environment.	
Employee recognition	Annual safety action plan: field group manager develops plan to ensure operations are safe. If manager completes 100% of plan, then group is recognized on the website for achievements. Use both leading and lagging indicators.	
Financial incentives	Individuals and groups have safety action plans, and bonuses are tied to achieving goals. Bonus pool is predicated on improving three-year average and doing better than the rest of the industry. Salary	

[237] Recordable incident rate is the number of employees per 100 full-time employees that have been involved in a recordable injury or illness. Total incident rate is a mathematical calculation that describes the number of recordable incidents per 100 full-time employees in any given timeframe.

Questions	VP of Environment, Health, & Safety	VP of Storage
	adjustments and annual bonuses have EHS components that include attending training and safety observations. (Were you observed doing anything unsafe? Did you follow procedure?) This applies to line employees all the way up to the CEO. Company has an internal EHS auditor, and management salary adjustment and bonuses are impacted by audits.	
Management commitment	Supervisors and managers routinely meet with employees. Directors and officers interface with employees less frequently, but when they do, one objective is to discuss with employees what is working and what is not.	
Overcoming pressures on supervisors	Checks and balances. Supervisors document the steps they take to ensure a job is completed according to procedures, and managers subsequently review documentation. CEO routinely communicates that safety and environmental compliance cannot be sacrificed, even in tough economic times. CEO particularly communicates the importance of stop-work authority during economically challenging times.	
Safety and environmental management system	Have operating management system that clearly defines the processes to manage people and the environment safely. Currently updating this to make sure it addresses all standards in API RP 1173. President of product business helped to develop it. They are 80% compliant in it.	
Management of change	Follow OSHA's Process Safety Management MOC process. Use an electronic system to manage MOC process, which is something the chemical and refinery assets did before.	
Training	Use computer training. Company has a mentor program wherein every new employee is assigned a mentor for a few weeks. Use face-to-face training as well.	
Contractors	Utilize IHS network, which certifies contractors. All major oil and gas companies participate. Contractors must meet company qualifications before they can even bid on a contract. Company rules apply to contractors.	
Learning from other sectors		
Sharing information	Company shares information at monthly meetings per API 1173. INGAA workshops: Every three years participating members conduct surveys and INGAA holds workshop on safety culture and methods to improve.	
Audits	Occasionally use third-party auditors but mostly done internally.	
Data analytics	Track lagging indicators (observations, agency inspections, near misses). Internally track agency inspections, training attendance, audit assessment reports, etc. Use third-party assessments to track all environmental compliance.	
Transparency	Transparency around safety performance, pipeline incidents, and EPA reportable spills and releases. This does not include notices of violations.	

Questions	VP of Environment, Health, & Safety	VP of Storage
Voluntary efforts		

Table A-4. Gas Utility Company

Questions	Gas Regulatory Strategy Principal	Senior Director, Gas System Operations	Director, Storage
Safety culture/behavior	Culture has changed over time so that safety is now the top priority. A recent initiative is ingraining a process safety mentality. The culture of safety is more evolved in the chemical industry and is a new concept for utilities.	Safety always comes first. A good example of this is stop-work authority, wherein people are celebrated for stopping work, even if means service is disrupted. Company's approach to safety has changed over time and now uses a risk management approach.	Part of the culture and policy is to conduct business according to risk management principles. There is a specific policy for safety in the pipeline management system. Any changes to risk figures require providing support for the change to the risk management committee.
Maintaining state of unease/sensitivity to operations	Communicate to employees that safety is top priority. Hold a daily call that starts with a safety message and is an overview of operations and safety. Annual threat assessment to identify hazards. Company is expanding the scope of this to identify additional hazards, such as slow land movement. Daily tailgate meetings.	Frequently communicate to employees the importance of safety. For example, stop-work authority is celebrated, even if it causes delay. Falls to every individual to ensure job safety.	Company's storage division has internal safety experts inspecting safety issues daily. Tailboard meetings are an important way to communicate about safety. At these meetings, personnel including contractors, supervisors, and others, discuss topics related to safety and environmental issues and stop-work authority. Important to have people who are specifically trained in personal safety at the location during well maintenance.
Incident management systems	Corrective Action Program: anyone can enter a concern on any day via a mobile app, phone call, or other means. All entries from the day before are reviewed daily and ranked by risk. Reviewer determines next steps. Receive around 50–60 entries per day.	Employees are encouraged to report safety concerns and company has different ways to report. Corrective Action Program is a heavily used program wherein any employee can enter any type of concern into the system (through a mobile app). Entries are reviewed every day by a notification review team. The team assigns a prioritization to the entry and a responsible person to follow up. The entry is tracked and may even go through a root-cause analysis. Enterprise standard is used for root-cause analysis and apparent-cause analysis is used for issues that are lower priority or of less concern. Have a 24/7 nurse helpline for any employee concerns. Guardian system: specific to	

Questions	Gas Regulatory Strategy Principal	Senior Director, Gas System Operations	Director, Storage
		safety (e.g., someone not wearing a hard hat). Available on mobile app.	
Stop-work authority	Push hard stop-work authority. Encourage stop-work authority by recognition.		
Employee recognition	Monthly keys-to-success meetings where awards are given. One award is to someone who stuck neck out regarding safety.		
Financial incentives	Short-term incentive program wherein all management employees are eligible for a percentage of their base salary as a bonus. Program is based on hitting goals, and 50% of short-term goals are based on safety across all assets. Short-term incentive program does not include contractor safety and/or environmental metrics.	Track public safety, employee safety, and process safety. All of these metrics are imbedded into bonuses.	
Management commitment	Management is in the field pretty regularly. Each officer sets a goal to be out in the field a certain percentage of time. Senior VP of operations goes out to the field multiple times a month and sits in the crew room.		Executives are in the storage field once a year to meet with personnel on the ground. Directors are in the field once a month. Hold weekly safety meetings as a team. On a particular job, hold daily calls with all personnel before the company-wide daily safety call.
Overcoming pressures on supervisors	Pressure on supervisors can definitely be an issue. Try to address by: (1) strengthening safety culture and drilling into the mindset of supervisors that safety and efficiency can both occur, but that safety and compliance comes first; (2) new mentor training program for supervisors because they have hired many new supervisors; (3) have tried to relieve supervisors of administrative work in order		

Questions	Gas Regulatory Strategy Principal	Senior Director, Gas System Operations	Director, Storage
	for them to spend more time in the field.		
Safety and environmental management system	Survey administered every two years. Survey measure topics like employee engagement and safety culture. Use survey as benchmark against others in the industry.		
Management of change			Procedural changes go through the MOC process. This process is pretty efficient and is driven by a small group. Important to be able to review safety processes to ensure current process is still the right thing to do. Review safety processes at job safety meetings and as part of hazard analysis.
Training	Company recently revamped their transmission and distribution Gas Control Center. The control center simulator is a room where control room operators are trained using simulations that use SCADA system. Moving toward predictive systems. Utilize drills of emergency events on a regular basis. Practice drills internally and with fire department and/or emergency responders.	Building an online pipeline simulator to train employees similar to the way airline pilots train. Utilize simulators, drills, and tabletop drills. Exercise with other regulators and industries. Company is very focused on emergency response, and a significant part of the organization focuses on planning and preparing. Company has a gas emergency response process, an incident command structure, and teams that are on call 24/7. There is always a leadership structure standing by to assist in emergencies. When events occur, we are prepared. Everyone knows their roles.	Learning is mostly on-the-job training. Hold some formal classes for engineers called blowout school where employees receive certification. Building a mock-up storage well in the training center. Hold emergency response drills at least annually. Sites with rigs do a simulation of a well blowout. Have completed four of these this year. Continue to enhance emergency response plans. Moving toward more specific plans for each location.
Contractors	Contractors are screened before hired, and there is active inspection of contractors, often on a daily basis. Contractors must adhere to company safety standards.	Contractors can use stop-work authority and the corrective action program to raise concerns.	
Learning from other sectors	Looked to Alaska Air crash for lessons learned. Have learned a lot from airline industry, especially regarding the use of	Spent quite a bit of time with Alaska Airlines. Out of this, developed a daily briefing where 120–130 senior gas operations people have a phone call and talk about safety and reliability and	

Questions	Gas Regulatory Strategy Principal	Senior Director, Gas System Operations	Director, Storage
	checklists.	issues that could impact human health. On the call, discuss abnormalities, incidents, and near misses that the company tracks daily through automated system. Discuss both lagging and leading indicators. Celebrate when someone stops work. Often president of company is on the call.	
Sharing information	Through AGA and INGAA.		Review major accidents from other companies. Participate in associations with storage committees where operators report accidents. The committees meet once or twice a year and provide operators with an opportunity to share information.
Audits	Utilize audits, quality assurance (making sure work was done right), and quality control (putting controls in place to ensure work is done right). Use field audits to make sure work was done right and procedures were followed. Have an internal audit group on corporate side to make sure controls are in place and a compliance group to make sure regulations are being followed. Hold annual risk refresh using a third party, either a consultant or someone from another company. AGA has "peer to peer" program where people from other companies come in for a week and do assessment on safety. They have been third-party certified in "ISO 55000", an international standard for the management of physical assets. They are in the process of being certified in "Responsible Care 1431"-a leading management		

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	system standard. Had third party come in to assess whether company was compliant with API RP 1173. Jim Hall (former Chairman of the National Transportation Safety Board) comes in every couple months and is given access to all information in order to assess company safety.		
Data analytics	Company has built metrics that are good indicators of safety. Some of these include response time if someone smells gas and amount of time to shut in gas from time of notification. Have targets for improving these metrics.	Utilizing more devices in the field that send information to the control system and different alarming protocols. Building technologies that allow for visualization and creation of intelligence from our data. This technology did not exist five years ago. Data visualization: want to be predictive and proactive rather than reactive, and data are the key to this. Have built an operations center that brings all data to the central system. Company is now building data to create situational awareness. Moving toward situational intelligence and predictive analytics. Simulation: have tremendous amount of knowledge about hydraulics of system. Building online pipeline simulator pulls real-time data from the pipelines using SCADA and compares to model to identify problems. This is still being developed but will eventually identify major events, like ruptures. The goal is to predict, be proactive, and respond immediately.	Metrics: track incidents such as spills, injuries, etc. Focus on sharing information during tailboard meetings. Use software to track other things, such as valve reliability. This is part of asset management, and the company has increased this side of the data-tracking business. Each asset in the natural gas sector is charged with knowing the condition of the asset and assessing risk.
Transparency			
Voluntary efforts	Company, along with EDF, is piloting continuous monitors at storage facilities.		