Offshore Oil and Gas

Technological and environmental challenges in increasingly deep water

Introduction

Many of the world's oil and gas resources lie beneath the oceans. Advances in exploration, drilling, and production technologies allow production in water more than 10,000 feet deep and more than 100 miles offshore. Major spills are rare but damage sensitive ocean and coastal environments, affect local economies, and are difficult and expensive to clean up. Federal regulations and industry standards have advanced to improve the safety and reduce the environmental impacts of offshore oil and gas production, particularly since the 2010 *Deepwater Horizon* disaster and oil spill. As drilling and production become possible under increasingly extreme physical conditions, the issues surrounding environmental protection and safety in offshore oil and gas continue to evolve.

Seaward Progress of Oil and Gas Exploration

Over the last 120 years, offshore drilling has advanced seaward from drilling rigs mounted on shoreline piers, to rigid platforms mounted on the seafloor, to floating and seafloor systems (see figure) in water depths up to 10,000 feet. The complexity and high cost of drilling in deep water – several hundreds of million dollars per well – can be justified by the high productivity of the oil fields if the oil price is sufficiently high to make them profitable.[1] Oil and gas exploration has also moved offshore in the Arctic, an area with shallow water depths but severe weather hazards. The challenges relating to Arctic offshore drilling differ substantially from those in other offshore regions – see "Oil and Gas in the U.S. Arctic" in this series for more on this topic.

Economic Constraints

Deepwater oilfield development may take ten years from the first exploratory well to the first barrel of oil sold, and pre-production costs, including development wells and specially designed production facilities, may be several billion dollars.[1] Safe and successful offshore drilling and production requires extensive seismic imaging and geologic analysis, engineering design and planning, construction of highly specialized equipment, and compliance with federal or state environmental regulations, all of which take a lot of time and money. Companies therefore make decisions about offshore drilling and development based on expected future (rather than current) oil prices. Offshore oil

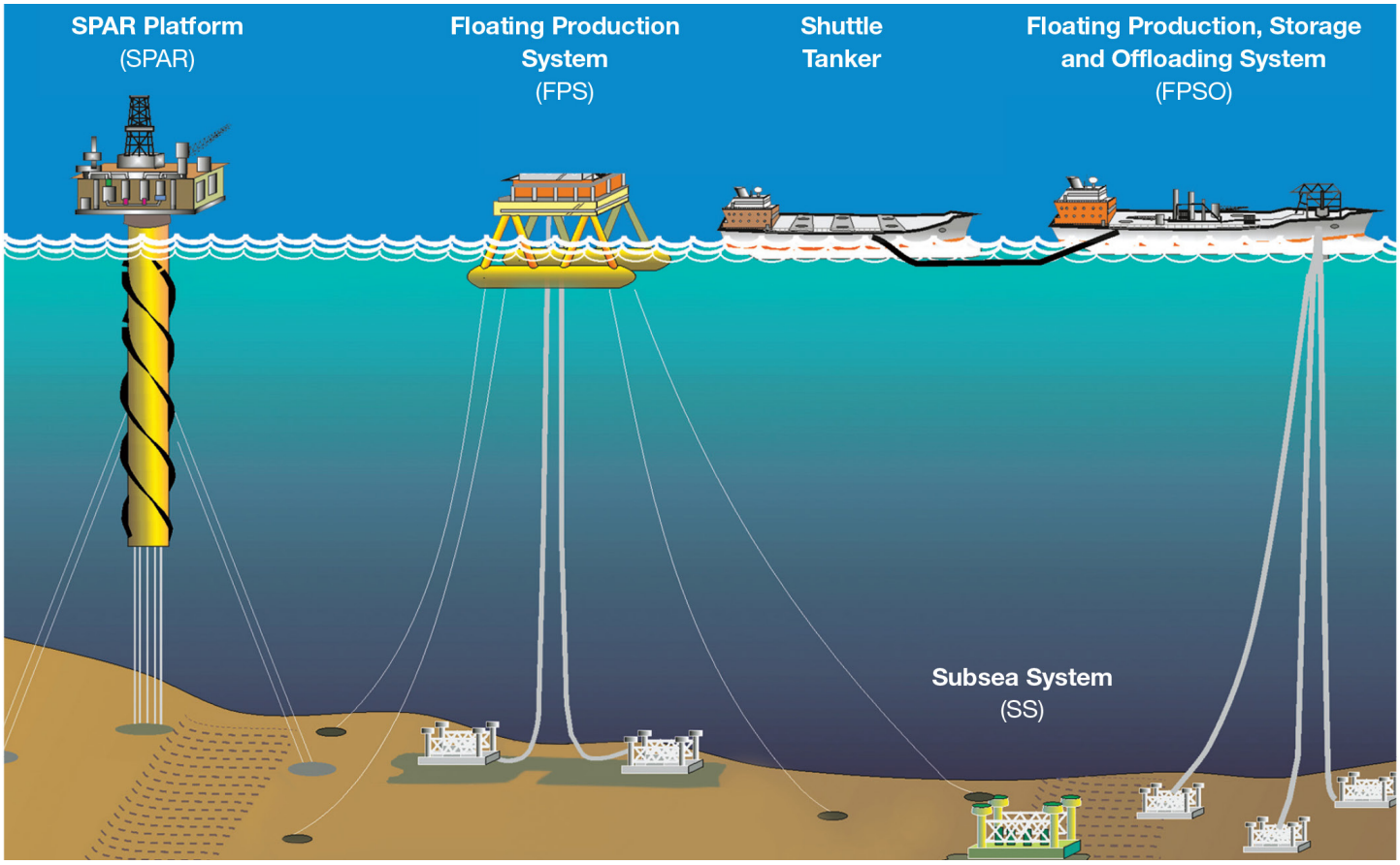
Offshore Oil and Gas Production in Brief

- U.S. offshore oil production in 2017: 602 million barrels (18% of U.S. total)[2]
- U.S. offshore natural gas production in 2016: 1.7 trillion cubic feet (5.2% of U.S. total)[3]
- Federal revenues from offshore oil and gas (2017): $3.8 billion[4]
- Globally, offshore oil production in 2015 was roughly 10 billion barrels, about 29% of total global production.[5]
- Largest offshore producers: Saudi Arabia, Brazil, Mexico, Norway, U.S.[5]
- Largest producers in deepwater (>125 m, roughly 400 ft) and ultra-deepwater (>1500 m, roughly 5000 ft): Brazil, Angola, Norway, U.S.[6]

U.S. offshore oil and gas production is focused in the central and western Gulf of Mexico, with some production off the coast of southern California and in the Cook Inlet and Beaufort Sea of Alaska.

Globally, offshore leaks and spills account for a small amount of the total oil that gets into ocean waters. Natural oil seeps on the seafloor contribute up to half of the oil in the ocean, although these are distributed widely and so do not have the same local effects as a large spill. Other sources include boat engines, discharged ballast water from tankers, contaminated river water and wastewater drainage on land, and oil drips and exhaust from automobiles.[7]

Major spills are rare but can cause extensive damage to sensitive ocean ecosystems due to the large amount of oil leaked in a small area.



A wide variety of technologies are used to drill offshore in increasingly deep water. Image credit: Bureau of Ocean Energy Management.[2]

production therefore does not respond to oil prices in the same way as onshore production. For example, while oil prices fell and onshore U.S. oil production plateaued in 2014-2015,[9] production on the Gulf of Mexico Outer Continental Shelf (OCS) increased by almost 25% from November 2014 to December 2016.[10]

Technological Advances in Offshore Drilling

Drilling and producing technologies for progressively more complex operating environments are often developed by collaborations between industry, service companies, academia, and research institutions sponsored by the federal government[11] or industry.[12] Some of the deepest Gulf of Mexico wells are in water more than a mile deep, with some wells extending more than 20,000 feet below the seafloor.[13] Companies are planning to explore in deeper and more hazardous regions in the U.S. and around the globe, which will depend on continuing technological advances. Frontiers in this area include:

- **Seismic imaging beneath salt layers** – in the Gulf of Mexico and offshore Brazil, some oil reservoirs are found in complexly folded and faulted rock formations beneath thick layers of salt. Salt layers reflect seismic waves, making it difficult to image underlying rock layers with those waves. New analytical techniques are continuously being developed to improve imaging beneath salt layers, using supercomputers to process huge quantities of seismic data.[14] Salt also dissolves in drilling fluids, and at high temperatures and pressures the salt itself can flow, squeezing and damaging the wellbore and drilling equipment, so drilling through salt requires advanced well stabilization and drilling techniques.[15]

- **High-temperature, high-pressure materials and electronics** – current technologies allow for drilling at temperatures up to 350°F, but future deep wells may require operating temperatures as high as 500°F: good for baking

pizza, but not so friendly for sophisticated electronics or drilling mud. Wells can currently operate under very high pressures, up to 15,000 pounds per square inch (psi), but future ultradeep wells will be expected to withstand as much as 30,000 psi (2000 times atmospheric pressure).[16] Very high temperatures require special materials for drilling, but the major constraint on operating in these extreme conditions may be the fragility of the electronics that guide directional drilling equipment inside the well.[17]

- **Installation and monitoring** – deepwater production is shifting from floating platforms to seafloor wellheads connected to seafloor pipelines. These systems rely on improved autonomous installations and remote monitoring equipment, including unmanned underwater vehicles.[18]

- **Preventing well blowouts** – especially since the *Deepwater Horizon* disaster, an ongoing concern is ensuring that well blowout preventers (BOP) are reliable, and that well designs and operations are safer to reduce the need for a BOP (see "U.S. Regulation of Oil and Gas Operations" in this series).[13]

- **Hurricanes** regularly cross oil-rich parts of the Gulf of Mexico and are expected to increase in intensity in the future.[19] Improvements to equipment reliability and performance, and remote underwater systems, will be key to improving the resilience of offshore oil and gas infrastructure.

Transocean Development Driller drilling a relief well in the Gulf of Mexico to relieve the pressure on the leaking Macondo well, 2010. This rig can drill to depths of 37,500 feet in as much as 7,500 feet of water. Image credit: U.S. Coast Guard.[20]

- Improved systems to prevent the drilling mud that travels between the drilling rig and the seafloor wellhead from putting too much pressure on the well itself.[13]

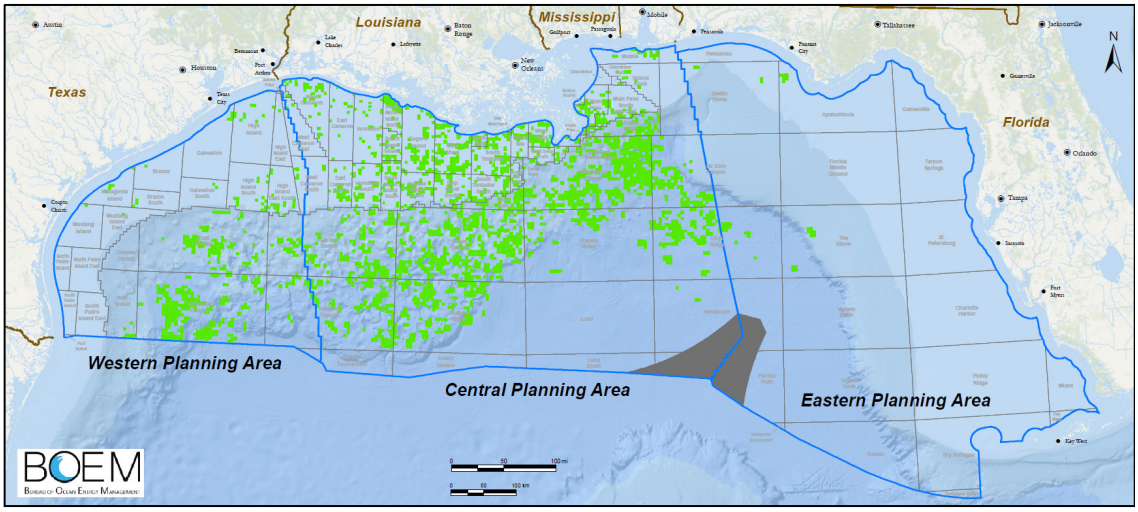
Oil Spills

Major offshore oil spills are rare but can cause great harm to coastal and marine wildlife and the people who depend on marine and coastal resources. Developments in offshore environmental policy and activity over the last 50 years have been punctuated by a few major events:

- In 1969, an offshore well blowout near Santa Barbara, California, deposited thick layers of oil along 35 miles of coastline and killed thousands of birds and marine animals. The spill paved the way for major environmental laws and was one of the events that led to the establishment of the U.S. Environmental Protection Agency in 1970.[21]

- Three shipping oil spills in 1989, including the Exxon Valdez accident in Alaska, prompted developments in environmental-protection regulations, including the requirement for all new tankers to have double hulls.[22]

- In April 2010, the Macondo well blowout and oil spill occurred 50 miles off the coast of Louisiana in approximately 5,000 feet of water. Eleven crew on the *Deepwater Horizon* drillship were killed and approximately 4.9 million barrels of oil were spilled (205 million gallons, equivalent to 320 Olympic-size swimming pools or 3 days of all Gulf of Mexico oil production). In response to the spill, industry and state & federal agencies launched massive cleanup operations; a National Academies assessment of the spill recommended changes for the industry and regulators;[23] and federal regulatory agencies were reorganized.[24] Regulators have continued to issue revised requirements for equipment and procedures from 2012 to the present day. In 2016, a $20.8 billion environmental damage settlement was reached between the United States, the five Gulf states, and the well operator (BP).[25] This settlement provided $1.86 billion for ecological and economic recovery; $1.6 billion for region-wide restoration; over $130 million for research and technology development by the National Oceanic and Atmospheric Administration to support Gulf ecosystems,



Planning areas (blue), region blocks (grey), and active leases (green) in the Gulf of Mexico as of February 1, 2018, as administered by the U.S. Bureau of Ocean Energy Management. There are several thousand leases in the Gulf of Mexico, covering almost 15 million acres. Image credit: U.S. Bureau of Ocean Energy Management.[26]

recreation, and fishing; and $133 million to establish "Centers of Excellence" for Gulf science and technology. BP also provided $500 million in 2010 for the Gulf of Mexico Research Initiative, a 10-year effort to improve understanding of the environmental stresses and public health implications of spill events.[27] The Gulf of Mexico Research Institute and others continue to assess the fate of the spilled oil and impacted land and wildlife.[28]

Some large spills have occurred in the Gulf of Mexico since the Deepwater Horizon disaster. An underwater pipeline near the Delta House production facility, 40 miles southeast of Venice, Louisiana, is estimated to have spilled as much as 672,000 gallons in October 2017.[29,30] Most of the oil dispersed into the surrounding ocean rather than reaching the shore. In 2004, the Taylor Energy Mississippi Canyon 20A platform, with 25 connected wells, was seriously damaged by Hurricane Ivan. Since then, the company, the U.S. Coast Guard, and several federal agencies have worked to remove the platform, decommission the oil pipeline, and decommission 9 of the 25 connected wells (as of early 2015) using funds provided by Taylor Energy. The remaining wells continue to leak oil into the Gulf of Mexico: in 2014-2015, it was estimated that the leak rate varied from 42 to 2,329 gallons per day.[31]

Regulation

Individual states control waters from the coast outward to 3 to 9 nautical miles, depending on the state. Federal regulation covers the Outer Continental Shelf (OCS) – the area beyond state waters out to 200 nautical miles offshore, or to the border with another country's exclusive economic zone (e.g., in the Gulf of Mexico). The U.S. Bureau of Ocean Energy Management, established in 2011, issues OCS leases for oil, gas, and wind energy development. The U.S. Bureau of Safety and Environmental Enforcement (BSEE), also established in 2011, regulates energy activities on the OCS. Other federal agencies contribute biologic, geologic, environmental, and security expertise and regulatory authority.

BSEE issued its Well Control Rule in 2016 to improve the effectiveness of the equipment that prevents well blowouts.[32] Other 2016 rules included updated regulations for production facilities and equipment, and for Arctic drilling. All rules are developed with public input, including public comment sessions. As of 2018, these regulations are being reviewed and revised by the Administration.

In 2016, President Obama banned new offshore oil and gas activities in parts of the Atlantic and Alaska. In 2017, the Administration started work on a revised offshore leasing plan that may expand areas open for oil and gas development.[33]

References & More Resources

For a complete listing of references, see the "References" section of the full publication, *Petroleum and the Environment*, or visit the online version at: www.americangeosciences.org/critical-issues/petroleum-environment