33. Offshore Platforms

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An overview of the state-of-the-art on offshore platforms is provided, highlighting the various structural concepts (such as fixed, gravity, and compliant, floating, and subsea platforms) developed during the past 75 years of active offshore exploration and exploitation. It starts with a birds-eye-view of the various platforms that dot the ocean space. Some of the advantages and disadvantages that influence the choice of the structural concepts to be used are discussed. The holistic and integral structural behavior depends on the environmental influences exerted on the important components of the platform in terms of permissible stresses, allowable rotations/deformations, fatigue endurance, vortex-induced-vibration, unobstructed flow of hydrocarbons and overload on the total structural performance; the overview also mentions some effects of the above on marine risers, conductors, wells and pipelines. Finally, possible offshore structural developments that are likely to take place in future are discussed.

Offshore drilling and storage platforms play an important role in oil and gas developments around the world. The ever-increasing demand for augmenting our energy needs by offshore exploration and production activities across the globe, and especially by the drilling activities occurring at ultra-deep-water depths, is driving the market. Depending on the water depths at which the oil and gas reserves are available, different types of fixed, floating, and subsea platforms are used for the purpose. In addition, the transportation of oil and gas through subsea pipelines has facilitated the transfer of offshore resources to onshore facilities. For ultra-deep-water depths, semi-submersibles have the highest growth rate and are the most preferred rigs deployed for drilling, in conjunction with other FPSO (floating production storage and offloading) units. Other floating platforms, such as drill-ships, also are being utilized at a decent growth rate for ultra-deep waters, in conjunction with subsea structures. Latin America dominates the global offshore floating drilling platform market since it has high offshore potential reserves of oil and gas in deep and ultra-deep waters. The Asia-Pacific region has the largest increase in shallow-water exploration and production in the waters of Indonesia, Malaysia, and Australia, with the highest growth rate for shallow-water framed and gravity platforms. In spite of the *fracking* of shale (onshore and offshore) decreasing the need for new energy sources in USA and worldwide, dependence on crude oil and natural gas will continue to increase as the global energy demand continues to increase worldwide. In order to satisfy this growing demand for energy, drilling for exploration and exploitation will continue to move offshore from deeper to ultra-deep and colder Arctic waters. In addition, improvements in platform technology in the form of stronger, modular and light-weight construction will impact the structural innovations of existing offshore platforms for many years to come.

33.1 Relevance

A number of platforms, installed in the ocean, exploit the available natural resources, as shown in Fig. 33.1 [33.1]. In addition to the offshore platforms mentioned above, ship types and modes seen in the field of ocean transport include containerization, catamarans, hovercraft, floating terminals, and very large

Fig. 33.1 Opportunities for developing marine structures (after [33.1])

crude oil carriers, along with large numbers of boats and barges that ply the inland rivers. The development of transportation has increased the capability to exploit more of the oceans' alternate energy resources, such as ocean thermal energy conversion (OTEC) and wave and current energy conversion, through direct drive wave energy converters and ocean energy turbines, which have a strong potential for producing energy. Ocean sediments are recognized as a major source of mineral wealth, both hard minerals and petroleum. Offshore oil and gas now supply almost one third of the world's energy needs. While manganese nodules have been recovered from the deep ocean floors of the tropical and subtropical areas, coastal sediments have also been exploited using dredging structures, since they are rich in *industrial minerals* of gold, tin, chromium, platinum, and even sand and gravel [33.2].

Offshore hydrocarbons, a much sought after energy resource, are associated primarily with the continental margins of the world. These margins surround the continents and constitute 25% of the total ocean area. Extending from the shore to the deep ocean floor, the continental margin consists of three units – shelf, slope, and rise. Sediments generally accumulate on the coastal plains and continental shelves. These sediments periodically flow down the continental slopes as turbidity currents to form giant channels of submarine fans and debris flows at their base [33.3].

Due to their thick sedimentary nature, continental margins contain an estimated 99% of the oceans recoverable hydrocarbons, and the deep-ocean sediments only 1% thereof. Furthermore, it has been provisionally estimated that 65% of these hydrocarbons will be found at water depths less than 200 m, 30% from 200 to 2500 m, and only 5% at greater water depths [33.4]; these data are nearly 30 years old. This scenario is likely to change as more of the currently acquired offshore data are consolidated and made available [33.5]. According to the data given in Indexmundi's 2015 crude oil forecast [33.6], the total world consumption of oil per day (for 2013) is given as 90.35 m b/day, and for a year as 32.98 billion barrels.

The world's largest proven oil reserves(in million barrels) are given as (within brackets) [33.7]:

i) Venezuela (297 600)
ii) Saudi Arabia (267 910)
iii) Canada (173 105)
iv) Iran (154 560)
v) Iraq (141 035)
vi) Kuwait (104 000)
vii) UAE (97 800)
viii) Russia (80 000)
ix) Libya (48 010)
x) Nigeria (37 200).

In addition, the top ten oil-consuming countries of the world are listed as [33.8]:

i) USA (19.15 m b/day)
ii) China (9.40 m b/day)
iii) Japan (4.45 m b/day)
iv) India (3.18 m b/day)
v) Saudi Arabia (2.64 m b/day)
vi) Germany (2.50 m b/day)
vii) Canada (2.22 m b/day)
viii) Russia (2.21 m b/day)
ix) South Korea (2.20 m b/day)
x) Mexico (2.07 m b/day).

As a result, the development and use of the older and newly innovated offshore platforms will depend on the investments made in developing the offshore fields by most of the countries mentioned above.

Despite the challenges of offshore ocean exploration, exploitation, and maintenance, nearly 35% of global oil production and 27% of gas production comes from offshore areas. Although it is expected that continental shelves will satisfy a significant part of the future oil and gas requirements, and also that dependence on fossil hydrocarbon resources will last for at least another 50 years, the oil industry is already looking to the ultra-deep-water zones on the continental slopes for future oil supplies. The industry has continued to invest in infrastructure and new techniques for exploitation in deep waters, leading to enhanced underwater facilities. It appears that the huge fixed steel platforms used today will in future be increasingly replaced by floating production platforms and smaller-scale subsea production technology deployed directly on the seabed, similar to those already in existence on the North and Norwegian Sea basin margins, Brazil's Campos Basin, and the Gulf of Mexico. Exploiting and transporting oil and gas reserves in the harsh and inhospitable Arctic regions, containing nearly 30% of world's undiscovered hydrocarbons, would require innovative structural development and management strategies [33.9].

33.2 Types of Offshore Platforms

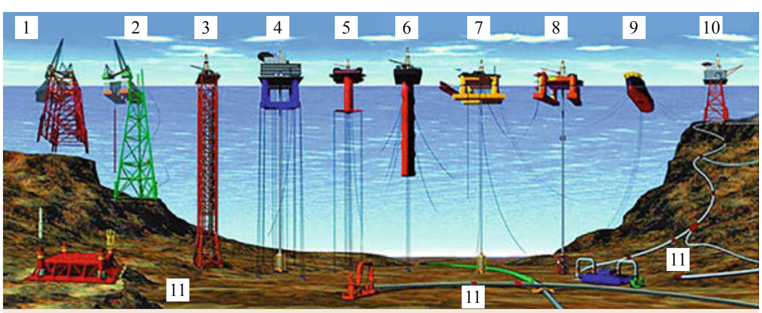
At the present juncture, more than 9500 offshore platforms are being used worldwide, operating in water depths ranging from 10 ft to nearly 10 000 ft. Topside weights range from 5 to 50 000 t, producing oil, gas, or both. Some of the major offshore oil and gas platforms, used in the context of ocean oil and gas exploitation, are shown in Fig. 33.2 [33.10, 11]:

i) Conventional fixed platforms (including gravity platforms) (Shell's *Bullwinkle* at 412 m deep water, in the Gulf of Mexico)
ii) Compliant tower (ChevronTexaco's *Petronius* at 534 m deep water in the Gulf of Mexico)
iii) Vertically moored tension leg and mini-tension leg platform (Conoco-Phillips' *Magnolia* in 1425 m deep water, in the Gulf of Mexico)
iv) Spar (Dominion's *Devils Tower* in 1710 m deep water, in the Gulf of Mexico)
v) Semi-submersibles (Shell's *NaKika* field in 1920 m deep water, in the Gulf of Mexico)
vi) Floating production, storage, and offloading facility (in 1600 m deep water, in the Campos Basin offshore Brazil)
vii) Subsea cluster completions and tie-back to host subsea facility (Shell's *Coulomb* field at 2307 m deep water tied to the *NaKika* field in the Gulf of Mexico)
viii) Subsea system with flow lines to a host fixed framed platform (Shell's *Mensa* field in 1620 m deep water, tied to a shallow-water jacket platform, in the Gulf of Mexico).

The platform concepts range from fixed and compliant, floating and subsea systems.

Referring to Fig. 33.2, platforms listed as categories 1–6 (along with 10) can be classified as fixed and compliant systems. Thus fixed and compliant systems include: steel jackets/towers (with or without tie-backs), concrete gravity platforms, jack-up, compliant towers, tension leg platforms (TLP), and spar concepts. The floating systems include: semi-submersibles, floating production storage, and off-loading units (FPSO), moored ship platforms and barges (listed under categories 7–9 in Fig. 33.2). The subsea systems include: (i) drilling and production units located on the seabed, listed under category 11 in Fig. 33.2 (economical for marginal fields and others in ultra-deep waters – tied to existing installations for access); and (ii) pipeline transportation systems for oil and gas.

Generally speaking an offshore platform has the primary function of allowing the extraction of hydrocarbons from below the sea-bottom, with the minimum treatment and maximum safety. The produced hydrocarbons are then transported safely to hydrocarbon refining plants on the nearby coasts, for treatment prior to commercialization. Due to the high costs of offshore construction, requisite offshore facilities are thus kept



1 & 2: Conventional fixed production platforms
3: Compliant tower production platform
4 & 5: Moored tension leg production platform
6: Spar production platform
7 & 8: Semi-submersible drilling rigs
9: Floating production storage and offloading facility
10: Subsea completion and tie-back to host facility
11: Subsea systems and flow lines

Fig. 33.2 Offshore structural concepts used offshore (after [33.10], courtesy of NOAA)

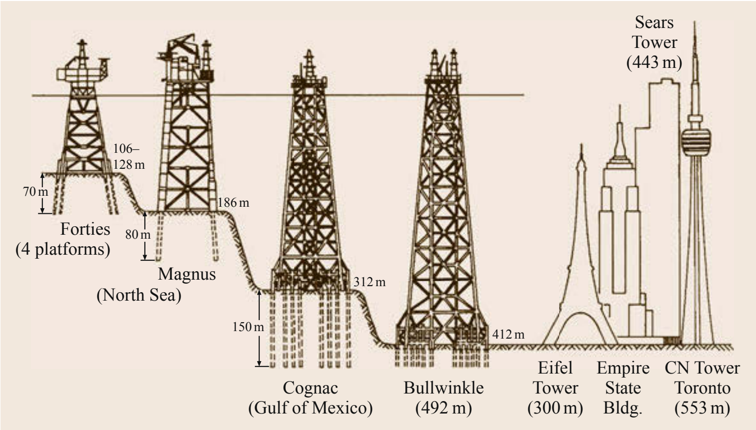


Fig. 33.3 Fixed platforms compared with known landmarks (after [33.12])

to a bare minimum by maximizing onshore prefabrication and modular assembly.

33.2.1 Fixed and Compliant Offshore Platforms

As stated earlier, this group of platforms is governed by fixity to the ocean bed. Depending on the fixity (or bottom supported) conditions the platforms can be classified as:

i) Fixed (rigidly or elastically)
ii) Bottom supported (with or without skirts and piles, providing transverse resistance)
iii) Compliantly restrained.

Use of these platforms is governed mainly by the maximum seawater depths at which they are to be located. Figure 33.3 [33.12] gives a typical comparison of various fixed platforms used in the offshore contexts, comparing them with some noted onshore landmarks. When water depths become deeper than 450 to 500 m, the fixed jacket and bottom supported gravity platform costs become exorbitant; hence the compliantly restrained platforms (at sea bottom) are needed to increase the depths (up to 1300 m), at which these platforms can be located economically. Even though the tension leg platforms and spars are moored to the ocean bottom through elastically restraining tension legs, mooring cables, and marine risers (similar to some floaters like semi-submersibles and FPSOs), they are still listed under fixed or compliant platforms, since their transverse motion is limited by the depths under which the marine riser systems can function properly due to:

i) Large bending stresses exerted on the conductors (from loads transmitted from the riser system)
ii) The need for uninterrupted hydrocarbon flow through the risers due to limited rotation (2°) permitted at its bottom.

In some of the recent TLP and spar systems, these restrictions have been removed (by using new tension riser systems) and they are now listed under floaters where there is no limit on the transverse surge motions [33.13]. These floaters can operate in up to 3000 m water depths.

Fixed platforms have a number of advantages over compliant and floating systems. These platforms can support very large deck loads (with facilities for refining the extracted oil and gas), can be prefabricated (in

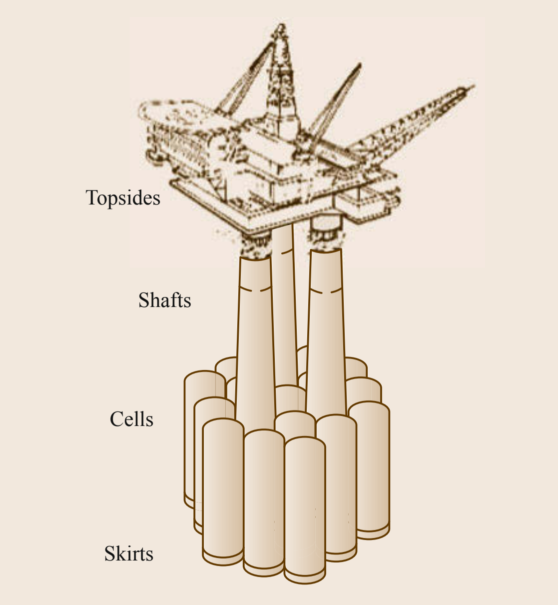


Fig. 33.4 Components of a gravity platform (after [33.14])

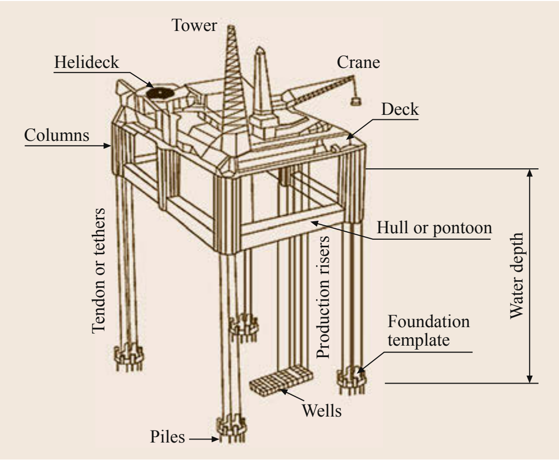


Fig. 33.5 Components of a tension leg platform (after [33.15])

on-land areas or dry docks) off their installation site in modular sections, assembled, and transported to the installation site, provide a stable support for a long-term usage, and are affected very little by sea-bottom scour around the piles. Some of their disadvantages are that the platform costs are very high initially, they have large maintenance costs due to fatigue and corrosion, and they are not reusable. The gravity platform (maximum permissible wear depth is 350 m) (Fig. 33.4 [33.14]), also enjoys similar advantages like the fixed jacket platforms with lower maintenance costs; they are also more resistant to fatigue and corrosion degradation. The main disadvantages are that they are more costly than framed steel jacket platforms and experience much larger foundation settlement/scour during their lifetimes. The jack-up platforms have retractable legs and are used for exploratory drilling and for servicing offshore wind farms. They are easily removable from one site to another. The depth of operation is limited to a maximum of 165 m.

Compliant offshore platforms (listed under this category) have a maximum water depth limitation of 1300 m. These platforms withstand and dissipate large transverse wave forces by moving laterally under the wave excitation. Due to their lower rigidity at the supporting base (with hinged end conditions at its bottom), the surge natural frequencies of these structures are much lower than the wave excitation frequencies. Hence, the phenomenon of resonance is avoided and the structure moves back and forth, executing a slow surge oscillatory motion. The tension leg platform (TLP), shown in Fig. 33.5 [33.15], is similar to a four-legged semi-submersible (with transverse submerged pontoons) held in place (with very small lateral motions) by vertically tensioned tendons, connected to the seafloor through templates and piles driven into the soil through them. TLPs have a water-depth limit of 1300 m; recently TLPs were also used at 2000 m.

The spar platform structure consists of a relatively long cylindrical tower of 200–250 m length (other types of spars, called trussed spars, are square in plan form), with watertight vertical cylindrical tanks (located inside the long cylindrical tower, with ballasting and de-ballasting capabilities). The spar is anchored to the seafloor by tensioned long cylindrical cables, connected to the seabed by suction anchors. Conventional spars have a limit imposed on their transverse motions by the permissible bending stress on the conductor, due to tensioned drilling risers and vortex-induced vibrations. In addition, the rotation at the base of the riser string is limited to 2° to permit proper flow of drilled

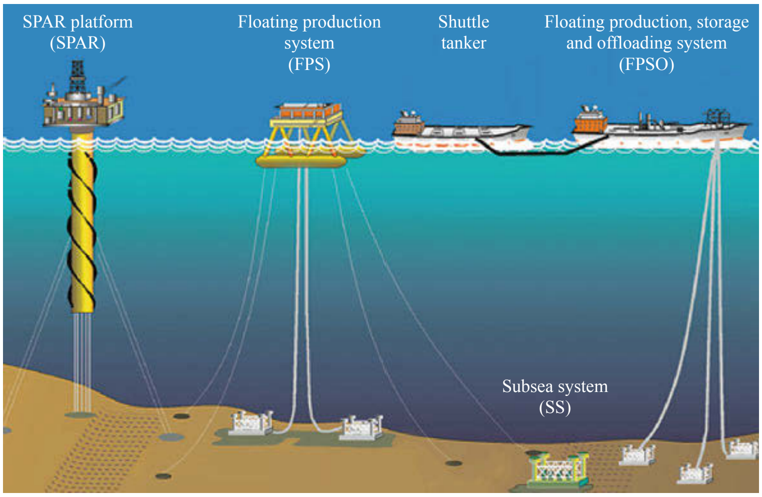


Fig. 33.6 Floating offshore structures (courtesy of The Bureau of Ocean Energy Management, after [33.16] BOEM)

hydrocarbons [33.13]. Initial spars were depth-limited to 1300 m.

33.2.2 Floating Offshore Platforms

As was mentioned before, floating offshore platforms, shown in Fig. 33.6 [33.16], consist of improved spars and TLPs, semi-submersibles, floating production storage and off-loading units (FPSO), moored ship-type platforms, and barges. In using these structures for water depths deeper than 1300 m, the previous limitation on the bending stresses in marine conductors is removed by using large diameter conductor pipes with increased wall thicknesses; the use of large diameter pipes increases their fatigue lives 5 to 10 times [33.13]. The blow-out-preventer (BOP) stacks provided at the top of the conductors have reduced lengths, along with the stick-up length (viz., the distance between the ocean bottom and the bottom of BOP stacks) of the conductors, to optimize the permitted stress levels. In addition, buoyancy provided at riser joints is increased by using syntactic foam elements with embedded micro glass or ceramic spheres. Along with an increase of the tension provided for riser strings, the risers are also provided with strakes to minimize or suppress vortex-induced vibration stresses; moreover the riser joints are provided with choke and kill lines made of titanium to minimize corrosion problems. These improvements have enabled spar platforms and other floating structures to operate efficiently at depths greater than 3000 m.

Floating production storage and off-loading (FPSO) units may be semi-submersibles or ship-shaped vessels, which float by their buoyancy. They are generally moored in place with flexible catenary-shaped wire ropes and/or polyester ropes, although they can also be kept in place by the use of dynamic positioning, if necessary. They are provided with subsea production systems, in which a group of wells is pre-drilled on a template installed on the seabed. Then the production unit is installed over the drilled wells and completed with subsea well heads. The FPSO unit is moored in a central position, with respect to the drilled subsea wells; these subsea wells are then connected by rigid (or flexible) pipelines to carry the reservoir fluids from the wellheads to surface storage vessels (with loading buoys) from which they can be offloaded to oil carriers. Other small-diameter flexible tubes, called umbilicals, connect the subsea production units to the surface units located on the floating vessel; these contain the electrical cables and hydraulic fluids required to control the wellheads from the surface. Drill-ships are vessels that are fitted with drilling equipment. Most often they are used for exploratory drilling for oil or gas wells in deep waters. Most drill-ships are fitted with dynamic positioning systems to maintain position over the well. They can drill in water depths up to 3660 m.

33.2.3 Subsea Systems and Pipelines

A subsea well consists of a wellhead template assembly and a wet Christmas tree, which is the underwater assembly of valves, spools, and fittings, used to control the flow of oil and gas out of the drilled well; since the system functions on the seabed, it is designed

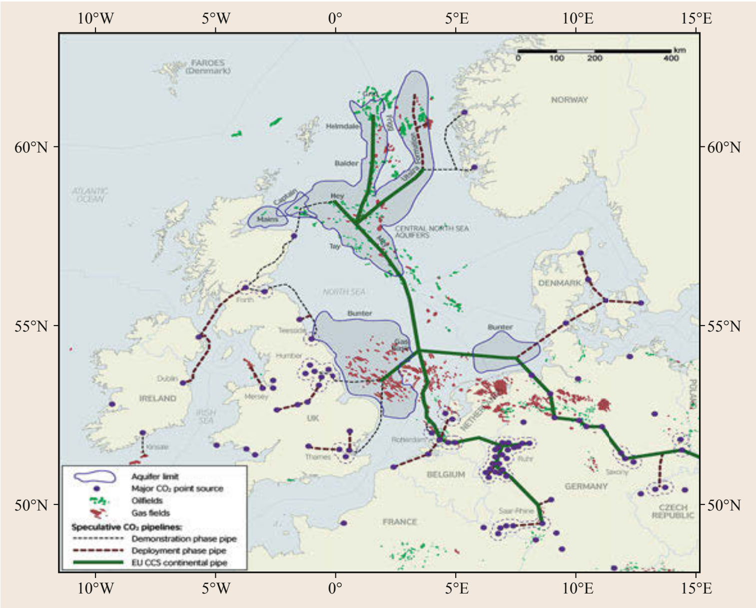


Fig. 33.7 Integrated pipelines in the North Sea Region (after [33.17])

such that it will always operate reliably. Generally, independent subsea wells are used for fixed or floating platforms for recovering reserves located beyond the reach of the horizontal drill-strings. Large multi-well subsea systems have also been installed with remote operating vehicle (ROV) intervention. In some of these subsea system operations they are tied to some existing deep-water or shallow-water platforms. A notable tieback (to a fixed platform located at a depth of 113 m) is the Mensa subsea development connected by flow lines of 101 km length, at a water depth of 1645 m in the Gulf of Mexico. Recently, much longer and deeper water-depth ($\approx$ 1830 m) subsea systems have been developed with tiebacks to onshore systems in Brazil [33.18].

Submarine pipelines, which are laid on the seabed or buried inside a trench on the seabed, are used to carry produced oil and gas from the ocean depths to onshore systems. Figure 33.7 [33.17] shows one of the best and optimally used interconnections of pipelines around the North Sea offshore developments, transporting oil and gas to countries around its shores, viz., Ireland, Scotland, UK, Norway, Denmark, Sweden, Belgium, Holland, France, Germany, and the Czech Republic. The pipeline design and construction took into account the existing seabed ecology to preserve its biodiversity along its route to the shore [33.19, 20], international boundaries, geo-hazards, and the environmental loadings that will be exerted on the system. The pipeline diameters generally vary from 76 mm (for gas lines) to 1800 mm (for high capacity flow), and the wall thicknesses vary between 10–75 mm. The pipelines are protected against corrosion with epoxy or bituminous coatings and are often weighted down with concrete lining. The maximum internal pressure for design is taken as 10 MPa.

33.3 Future Trends and Developments in Offshore Platforms

Global energy consumption is forecast to expand 1.8 times by 2035 compared to that of 2010, and during the same period consumption of crude oil is expected to increase just over 30%, mainly in developing countries. Consumption of natural gas is forecast to rise greatly, by 50% or more in 2035, as compared with 2010. The depletion of existing fields will call for the discovery of new offshore drilling sites to maintain secure oil and gas supplies.

To give a context in terms of possible offshore development around USA, Fig. 33.8 [33.21] gives the undiscovered technically recoverable oil and gas resources available offshore. Hence, there is still a lot of scope for innovative structural developments to take place when the above-mentioned federal offshore acreages become available for development. Figure 33.8 gives the scope for possible offshore development for oil and gas resources around the federal offshore acreage in USA; the area shown consists of 89.9 billion barrels of oil and 404.6 trillion cubic feet of gas. Offshore industries are predicting a large investment (by a factor of three to four times current levels) on offshore structures and related facilities during the coming years [33.22]. It is believed that the Arctic re-

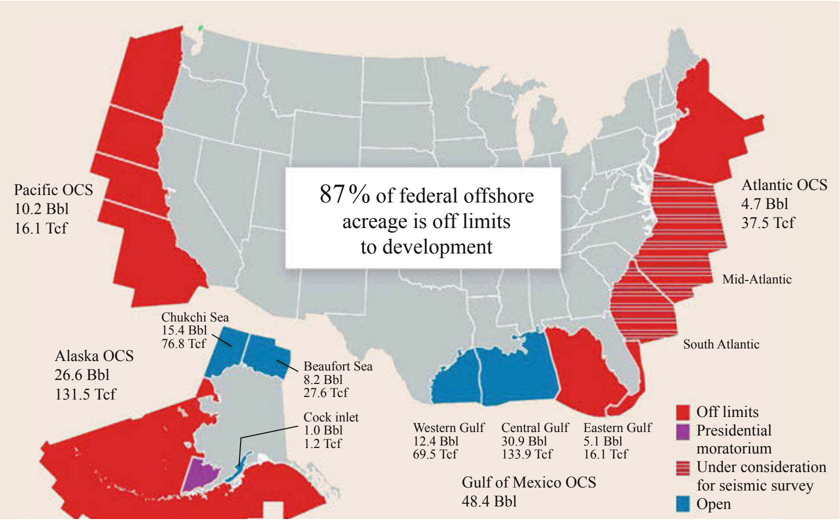


Fig. 33.8 Offshore technically undiscovered recoverable oil and gas resources around USA in federal acreage (Bbl and Tcf) (after [33.21])

gion holds significant volumes of oil and gas; until now investment in Arctic development and production has been rather small and most of it has been in areas with light to moderate ice conditions and relatively shallow waters, using artificial islands or gravity base structures [33.9].

A number of technology development targets are being set and will continue to be pursued. Some of these targets include [33.5, 9, 11, 13, 23, 24]:

- Lightweight, strong, and modular jackets, FPSO, and subsea concepts with storage capabilities for requisite water depths (varying from 1000 m to 4000 m), and with efficient long-distance tie-backs, would require more investment in offshore projects. Multi-phase pumping through pipelines would minimize costs considerably.
- Innovative developments in the float-over and self-installation of complete topsides of jackets and FPSOs (and their mooring systems) in a reliable and optimal manner (to avoid heavy offshore lift, intricate hook-up/commissioning and consequent accidents) is required. Reliable and automatically controlled seabed processing of oil and gas resources, with minimum intervention from above will make the operations economically more attractive.
- Advances in large-diameter, top-tensioned dry-Christmas-tree risers (the connecting valves, spools, and fittings are located on top of riser arrays), and arrays with catenary profiles that permit contact, optimal clashing, flow assurance, and long-term structural integrity at ultra-deep-water depths are very important [33.25].
- Prevention of the specific risks of a blowout in the ultra-deep waters by smart down-the-hole remote monitoring of conductors and risers, and provision of extra horizontal drilling conductors, that will become operative when reservoir pressures build up.

References

33.1 T. Moan: *Marine Structures for the Future – A Sea of Opportunities* (National University of Singapore, Singapore 2003)

33.2 D.V. Reddy, A.S.J. Swamidas: *Essentials of Offshore Structures – Framed and Gravity Platforms* (CRC, Boca Raton 2014) pp. 1–2

33.3 J. Morelock: Terrigenous Sediments. http://geology.uprm.edu/Morelock/dpseaterrig.htm (2015)

33.4 G.A. Lock: Technological factors in offshore hydrocarbon exploration, The Future of Offshore Petroleum. United Nations, Natural Resources and Energy Division, Ocean Economics and Technology Branch, Expert Meeting on the Future of Offshore Petroleum (McGraw-Hill, New York 1981) pp. 87–146

33.5 Offshore Operations Subgroup, Operations and Environment Task Group: Working Document of the NPC North American Resource Development Study. Subsea Drilling, Well Operations and Completions, Paper No. 2/11, 27–45, available at https://www.npc.org/Prudent_Development-Topic_Papers/2-11_Subsea_Drilling-Well_Ops-Completions_Paper.pdf

33.6 IndexMundi: Oil production country by country. In: *The World Factbook 2013–2014* (Central Intelligence Agency, Washington 2013), available at http://www.indexmundi.com/map/?v=88

33.7 A. Nagraj: Top Ten Countries With the World's Biggest Reserves, Gulf Business in Home/Energy/Features/Insights at http://gulfbusiness.com/2013/04/top-10-countries-with-the-worlds-biggest-oilreserves/#.Vi5kb4QnWFI (2013)

33.8 Central Intelligence Agency: The World Factbook, https://www.cia.gov/library/publications/resources/the-world-factbook (2014)

33.9 Eurasia Group: *Opportunities and Challenges for Arctic Oil and Gas Development*, http://www.wilsoncenter.org/sites/default/files/Artic%20Report_F2.pdf (Wilson Center, Washington 2013)

33.10 NOAA Ocean Explorer Gallery: Types of Offshore Oil and Gas Structures, http://oceanexplorer.noaa.gov/explorations/06mexico/background/oil/media/types_600.html (2010)

33.11 P. O'Connor, J. Buckness, M. Lalani: Offshore and subsea facilities. In: *Petroleum Engineering Handbook*, Vol. 3, ed. by L.W. Lake (Society of Petroleum Engineers, Richardson 2014)

33.12 Offshore Structures, Course Material Presented for OCE 3016 on Introduction to Coastal and Oceanographic Engineering, available at http://www.essie.ufl.edu/~sheppard/OCE3016/Offshore%20Structures.pdf (2015).

33.13 B. Middleditch: *Deepwater drilling riser technical challenges*, Technical paper (2H Offshore, Aberdeen 2011) pp. 10–35, http://www.2hoffshore.com

33.14 N. Terdre: Refloating Norway's Concrete Giants – Is it practical?, Offshore **71**(8), 88–91 (2011)

33.15 H.M. Refat, A.R. El-gamal: Influence of the density of water on the dynamic behavior of square tension leg platform, Amer. J. Civil Eng. Architecture **2**(4), 122–129 (2014)

33.16 American Petroleum Institute: Offshore Access to Oil and Natural Gas Resources, Unlocking America's Offshore Energy Opportunity, available at http://www.api.org/oil-and-natural-gas-overview/exploration-andproduction/offshore/~/media/Files/Oil-and-Natural-Gas/Offshore/OffshoreAccess-primer-highres.pdf, p. 15, (2015) 33.17 R.S. Haszeldine: Carbon capture and storage – How green can black be?, Science **325**(5948), 1647–1653 (2009)

33.18 J.M. Masset: Deep offshore, Proc. ASPO Conf. (2011)

33.19 D.V. Reddy: Offshore pipelines. In: *Offshore Structures*, Vol. 2, ed. by D.V. Reddy, M. Arockiasamy (Krieger Publications, Malabar 1991)

33.20 N. Huddleston: *Ocean Exploration*, *Highlights of National Academies Reports*, Ocean Science (National Academics, Washington 2008), available at http://dels.nas.edu/resources/staticassets/osb/miscellaneous/exploration_final.pdf

33.21 American Petroleum Institute: Offshore Access to Oil and Natural Gas Resources, Producing Offshore, available at http://www.api.org/oiland-natural-gas-overview/exploration-and-production/offshore/~/media/Files/Oiland-Natural-Gas/Offshore/OffshoreAccess-primer-highres.pdf, p. 1, (2015)

33.22 Kobelco Welding Worldwide, Trends in Global Demand for Offshore Structures, http://www.kobelco-welding.jp/education-center/technical-highlight/vol04.html (2014)

33.23 petrofed.winwinhosting.net: Offshore Oil and Gas Production Systems, available at http://petrofed.winwinhosting.net/upload/OffshoreoilandProd.pdf (2014)

33.24 M. Efthymiou: In deep water, http://www.offshore-technology.com/_features/feature52918/ (2009)

33.25 Det Norske Veritas: Riser Interference, Recommended Practice DNV-RP-F203 (Det Norskie Veritas, Høvik 2009)https://rules.dnvgl.com/docs/pdf/DNV/codes/docs/2009-04/RP-F203.pdf