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Review

Review on Fixed and Floating Offshore Structures. Part I: Types of Platforms with Some Applications

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Abstract: Diverse forms of offshore oil and gas structures are utilized for a wide range of purposes and in varying water depths. They are designed for unique environments and water depths around the world. The applications of these offshore structures require different activities for proper equipment selection, design of platform types, and drilling/production methods. This paper will provide a general overview of these operations as well as the platform classifications. In this paper, a comprehensive review is conducted on different offshore petroleum structures. This study examines the fundamentals of all types of offshore structures (fixed and floating), as well as the applications of these concepts for oil exploration and production. The study also presents various design parameters for state-of-the-art offshore platforms and achievements made in the industry. Finally, suitable types of offshore platforms for various water depths are offered for long-term operations. An extension of this study (Part II) covers sustainable design approaches and project management on these structures; this review helps designers in understanding existing offshore structures, and their uniqueness. Hence, the review also serves as a reference data source for designing new offshore platforms and related structures.

Keywords: offshore structure; offshore platform; fixed platform; floating platform; oil and gas platform; production platform; drilling platform rig; coastal structure; marine structure; offshore facilities and subsea systems; review; offshore

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1. Introduction

With the increase in the need for more energy sources, fossil fuel has recently had huge competition as a non-renewable energy source with other renewable energy sources. However, some of these newer platforms have extended technologies that stem from the existing offshore platforms used in oil and gas exploration. Currently, there are advances made in ocean engineering which include a variety of innovative offshore structure designs, ranging from fixed platforms to floating platforms [1–5]. Some of these structures include the deep-water semisubmersible platforms, jack-up rigs, floating offshore wind turbines (FOWTs), FPS (floating production systems) units, floating production storage and offloading (FPSO) units, FSO (floating storage and offloading) units, FSU (floating storage units), FPU (floating production units), FDPSO (floating drilling production storage and offloading), MODU (mobile offshore production unit) and FLNG (floating liquid natural gas vessel) [6–10]. However, there are other applications for offshore platforms, such as dynamic positioning, exploratory activities, drilling/production, navigation, (un)loading ships, fluid transport, and bridge support [11–16]. Offshore petroleum structures are utilized for a wide range of purposes and in a wide range of sea depths and environments around the world, hence they need supporting attachments such as drilling marine risers [17–23], composite production risers [24–30], marine hoses [31–40] and mooring lines [41–49]. Figure 1 shows different fixed and floating offshore platforms operating in varying water depths (see details in the caption).

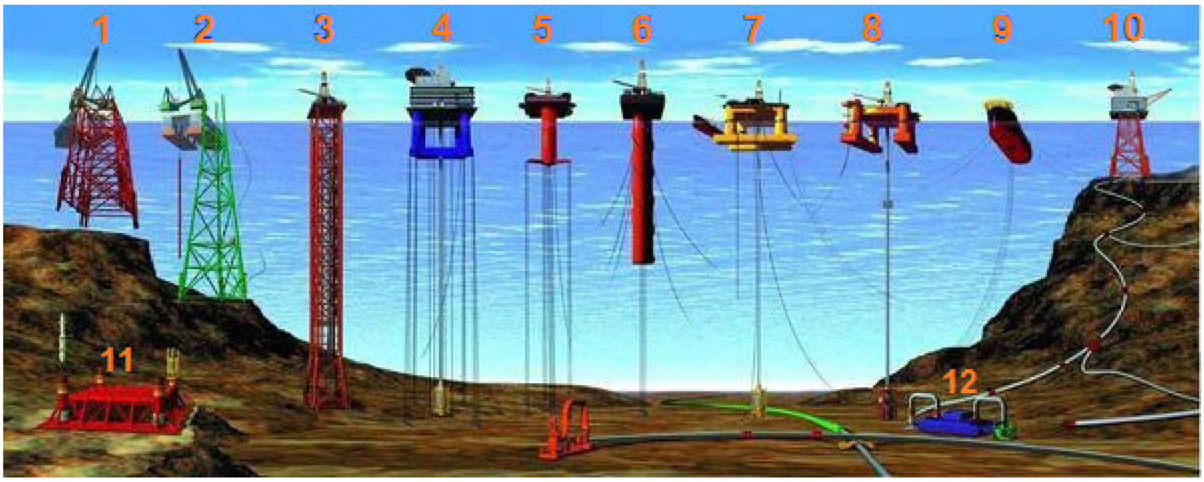


Figure 1. Different types of deep-water offshore production facilities, showing (1,2) conventional fixed platforms{150–412 m}; (3) compliant tower {457–914 m}; (4,5) tension leg platform (TLP) {457–2134 m}; (5) mini tension leg platform (TLP); (6) Truss SPAR {610–3048 m}; (7,8) semisubmersibles {457–1920 m}; (9) floating production, storage and offloading (FPSO) unit {1345–1500 m}; and (10) jacket platform {150–412 m}; and (11) subsea completion and tieback to a host facility, and (12) subsea manifold. (Adapted from public domain source, with permission obtained to re-use image; Courtesy: National Oceanic and Atmospheric Administration, NOAA).

Offshore platforms could be used as artificial reefs for many years, as they have also been used in a variety of aquatic environments. As a result, their design and upkeep are extremely difficult. Hence, it is pertinent that the design and maintenance of offshore structures are well considered, to prevent early decommissioning, high risks of corrosion, oil spillage, and other irreversible environmental damages. The applications of these offshore structures require different activities for proper equipment selection [50–57], design of platform types [58–64], engineering management of well bores [65–73] and other drilling/production methods [74–80]. Offshore oil production is one of the most visible of these applications, and it provides a significant task to the product designer or offshore engineer [81–83]. The design considerations include environmental loadings [84–88], hydrodynamics [89–96], hydroelasticity [97], corrosion [98], failure analysis [99], ocean wave mechanics [100–108], fluid content loadings [109–115], fatigue limits [116–120], reliability [121–128], etc. Therefore, the designer must ensure that there is safety, stability, high fatigue resistance with a long service life. The design with that is safe, but cost must be considered; hence the designer should make it economical for the client. Generally, these offshore assets must operate safely for at least twenty-five (25) years (depending on the purpose of the offshore structure), because they are exposed to extremely severe marine environments and varying sea depths. Hence the designs are conducted by using peak loads provided during the platform design life by the hurricane wind and waves. Environmental conditions are also important in designing different offshore structures [129–135]. Also, there are more developments made in oceanography and environmental sciences that reflect in different designs of offshore structures [136–142]. The fatigue loads caused by waves over the platform's lifetime and platform motion are all critical design issues considered in standards elaboration such as the American Petroleum Institute (API) [136–141], and Det Norske Veritas (DNV) [142–152]. Over time, these developed API standards have been revised to include hurricane conditions in the Gulf of Mexico (GoM), adaptable in other seas [153–157]. Strong currents can sometimes hit the platforms, putting strain on the entire system's integrity. Another challenge that oil corporations face is the project scheduling involving the length of time for the design and construction of these offshore assets. Furthermore, the size of these offshore structures is a consideration in designing their stability and hydrodynamics. Figure 2 shows the number of global deep water drilling activities across five (5) continents. Although it reflects a decrease in oil drilling/exploration activities due to the decline in oil price globally in 2016, it is evident that the highest drilling activities were recorded in South America in the time range from 2010 to 2021. Due to the recent COVID19 pandemic in 2020/2021, the exploration also had a decrease in oil well exploration; however, it was seen to pick up in 2021/2022.

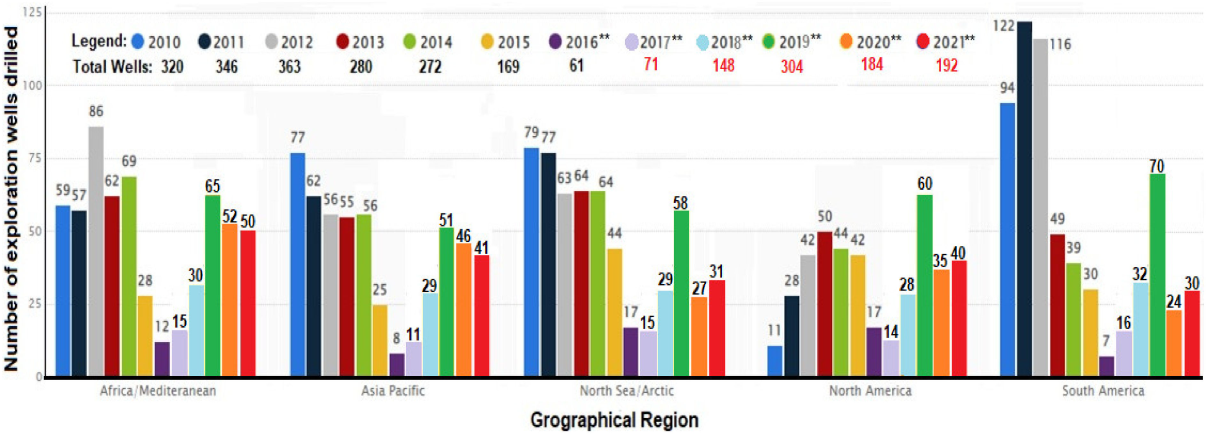


Figure 2. Global deep water exploration wells drilled by region for 2010–2021 with forecast for 2016**–2021** using data from QuestOffshore (Image Courtesy: Author 1—C.V.A.).

Another consideration factored in the design is the material density. Most offshore platforms are fabricated in shipyards using massive steel, or in-situ using concrete, as seen in gravity-based structures. These offshore structures- both fixed and floating structures are mostly used for energy generation or oil production. Offshore constructions are meant to be installed thousands of kilometers from shorelines in the open sea, lakes, gulfs, and other bodies of water. Steel, reinforced concrete, or a combination of the two, may be used to construct these buildings. Most oil and gas platforms are produced from a variety of steel grades. These range from mild steel to high-strength steel, despite some earlier structures being made of reinforced concrete called the Concrete Gravity Based Structures (CGBS). Steel platforms come in different sizes and shapes, based on their intended function and, most importantly, the water depth in which they will operate [29–34]. However, proper failure analysis and reliability studies have to be carried out on these offshore structures. Offshore platforms are extremely hefty and among the world's tallest man-made structures. Floating structures have been classified, based on water depths, such as shallow water (91–120 m and lesser than 91 m), mid water (121–305 m), deep water (306–1219.50 m) and ultra-deep water (1220.50–2285.69 m and greater than 2285.69 m). These offshore structures are available at different locations, from Offshore West Africa (OWA) to the Baltic Sea, the Persian Sea, the North Sea (NS) and the Gulf of Mexico (GoM). These seas have different oil companies and energy operators involved in offshore operations across different geographical locations. Presently, different oil companies have high impact oil wells as seen in some operators of various offshore platforms. These oil operators range from Exxon, Total, Petronas, CNOOC, Equinor, Qatar Energy, BP, Petrobras, Pemex, Hess, Aker BP, Lukoil and Lundin, as seen in the high impact drilling represented in Figure 3.

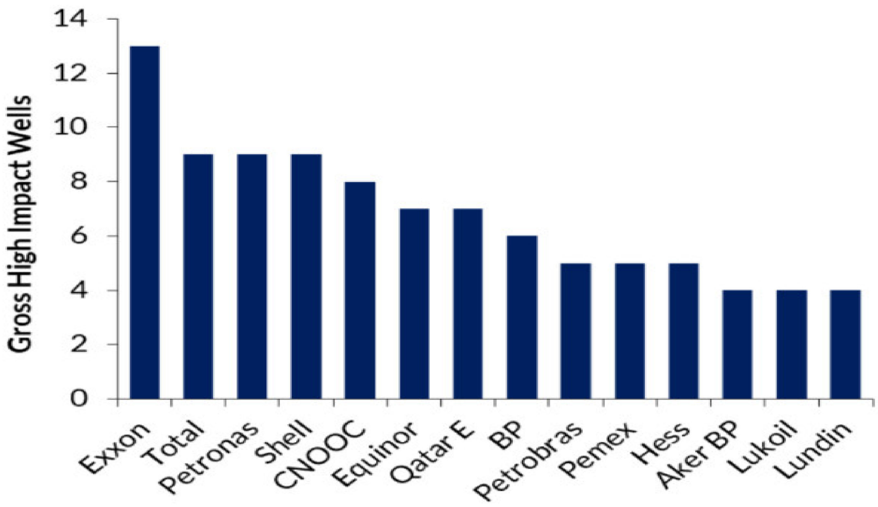


Figure 3. High impact exploration drilling activities in 2021 by different oil companies (Courtesy: Westwood Global Energy Group).

Part I of the review is conducted on different types of fixed and floating offshore structures. Details of the sustainable design approaches and project management for these offshore structures are given in Part II [5]. In this review, Section 2 provides an overview of sustainable drilling/production operations, the platform classifications and applications. Section 3 presents different types of offshore structures. Section 4 discusses various applications, advantages and disadvantages of various offshore structures. Section 5 presents the conclusions and recommendations for future research. This review helps designers in understanding existing structures and their uniqueness and helps to serve as a reference data source for designing new offshore platforms and other related structures.

2. Overview of Platform Installations

The historical development of different offshore platforms differ over varying timelines, as seen in designs, inventions and patents. This section presents the historical backgrounds of certain offshore structures, depending on the classification of the structure. In addition, these platform installations have evolved with different standards. In addition, various standard bodies have also evolved in the general design of offshore structures such as the following: API [158–170], DNV [171–181], Det Norske Veritas and Germanischer Lloyd (DNVGL) [182–186] the American Bureau of Shipping (ABS) [187–198] and International Organization for Standardization (ISO) [199–211]. Historically, most of the earlier offshore constructions had standards as bulletins, and they were developed over time. These standards ensure that the design of the offshore structure, including its attachments (such as the marine risers and the mooring system), as well as different dynamic effects (such as vortex shedding) are specified [212–219]. Today, there are more standards that are used for the design and analysis of offshore structures, oil and gas exploration, and production and extraction activities [220–231]. Figures A1–A6 of Appendix A show the variety of offshore platforms deployed in deep waters. Table 1 shows an inventory of deep-water offshore platforms in the Gulf of Mexico (GoM).

Statistically, the number of offshore platforms is not as high as that of land buildings such as high-rise buildings or sky-scrapers. However, some of these offshore platforms are taller than the tallest structures (such as high-rise buildings), although some of their lengths are underneath the sea, as seen in Appendix A. From the image illustrated in Figure A1 of Appendix A, the tallest Truss SPARs (Perdido SPAR in GoM and Aasta Hansteen in Norway) has been compared along the tallest structures in the world such as the Eiffel Tower in Paris, France, the Burj Khalifa in Dubai, United Arab Emirates (U.A.E.) and the One Twin Towers in New York, United States of America (U.S.A.), NICOM House in Lagos, Nigeria, and ONE Shell Plaza in Houston, U.S.A. These structures were found to be tall but not quite as much as the depth of these offshore structures, as most of the structural length of the offshore structures lie under water. However, the illustration in Appendix A also showed that, compared to other offshore structures such as semisubmersibles and the Tension Leg Platforms, the Truss SPARs are very tall.

Table 1. Inventory of deep water platforms in GoM; (Courtesy: BOEM, data retrieved in 2016).

Platform	Sidetrack Subsea Well	Sidetrack Dry Trees Well	Amount	Subsea Field
FPSO	1 (2)	2 (0)	1	1 (1)
Mobile offshore production units (MOPU)	6 (13)	– –	1	– (2)
Semisubmersible	32 (28)	22 (16)	9	6 (18)
Mini TLP	17 (17)	11 (16)	5	1 (6)
Tension Leg Platform (TLP)	51 (60)	123 (150)	10	8 (14)
Single Point Anchor Reservoir (SPAR)	34 (43)	133 (129)	16	13 (18)
Fixed Platform (FP)	47 (49)	630 (449)	50	49 (30)
Compliant towers (CT)	3 (1)	76 (46)	3	4 (2)
AGGREGATE	191 (213)	997 (806)	95	82 (91)

By function characterization, the fixed structures are fixed while the floating structures float [232–241]. Generally, a platform can be physically anchored to the sea floor in shallow water in some cases which is referred to as a fixed platform setup. The 'legs,' which extend down from the platform and are secured to the bottom with piles, are made of concrete or steel. The weight of the legs and seafloor platform on some concrete constructions is so vast that they do not need to be physically anchored to the seafloor and can just rest on their mass. These fixed, permanent platforms can be designed in a variety of ways. The main advantages of these platforms are their stability and minimal vulnerability to movement due to wind and waves because they are anchored to the sea floor [242–250]. However, these platforms cannot be used in ultra-deep water since the cost of construction columns (or legs) that are very lengthy is not economically viable. For ultra-deep waters, specific offshore platforms are designed and deployed in such cases. Although offshore platforms could be fixed or floating structures used, the size of an offshore platform can differ as well as the type of the platform and the water depth where it will be operating [251–261]. Various types of offshore floating platforms operating in varying water depths are illustrated in Figure A2 of Appendix A and Section 3.

Based on platform classification, the selection of offshore platforms for any specific site is determined by the environmental and operational water depth where the oil and gas deposits are discovered. Hence, the following alternatives for the offshore fields were presented by Sadeghi [83], based on the environment and seawater depths:

(a) Jack-up rig or Tender rig for extraction of oil/gas, drilling and templates (jackets) in water depths up to 150 m;
(b) A semi-submersible drilling rig with a template (jacket) platform for extraction of oil/gas, at sea depths of 150 to 300 m;
(c) A semi-submersible drilling rig with guyed-tower platforms for oil/gas extraction at depths of 300 to 400 m;
(d) Semi-submersible drilling rig with tension leg platform or semi-submersible oil/gas extraction platform for water depths of 400 m to 1800 m;
(e) Drillship rig with tension leg, subsea system, or spar platforms for oil/gas extraction in depths greater than 1800 m;
(f) Floating production storage and offloading (FPSO) are found operating in water depths ranging from 200 m to more than 3000 m [260] and depending on the environmental condition, they are maintained in position using either a spread or turret mooring system.

2.1. Floating Production Systems

Floating production systems are similar to semi-submersible drilling rigs, but they also include petroleum production equipment in addition to drilling equipment. Ships can potentially be utilized as floating manufacturing platforms. Large, heavy anchors or the dynamic positioning mechanism utilized by drillships can be used to keep the platforms in place. With a floating production system, the wellhead is attached to the seafloor rather than the platform once the drilling is completed. The extracted petroleum is delivered by risers from the wellhead to the semi-submersible platform's production facilities. These production devices can work in up to 6000 feet of water.

2.2. Fixed Offshore Platform Design

Fixed Offshore Platforms such as the template type platforms made of steel are the most often used offshore platforms in the U.S.A.'s Gulf of Mexico, California shorelines, Niger Delta regions of Nigeria, and the Persian Gulf for oil/gas exploration and production [14,83]. These offshore constructions must be designed and analyzed in compliance with the American Petroleum Institute (API)'s recommendations. There are four different types of fixed offshore platforms, which are conventional fixed platforms, compliant towers, junction platforms and bridged platforms (or complexes, as seen in Figure 4).

(**a**) (**b**)

Figure 4. Typical platforms showing (**a**) conventional jacket platforms and (**b**) bridged fixed jacket platform on Zuluf oil field in Arabian Gulf, offshore northeast Saudi Arabian coast, with the water depth of about 40 m (Image (**b**) Courtesy: Saudi Aramco).

2.3. Subsea System

Wells on the sea floor, rather than at the surface, are used in subsea production systems. Petroleum is extracted at the seafloor, similar to a floating production system, and then 'tied-back' to an existing production platform. The well can be drilled with a mobile rig, and instead of constructing a production platform for that well, the recovered oil and natural gas can be delivered to a nearby production platform through a riser or even an undersea pipeline. This enables a single strategically located production platform to service a large number of wells across a vast area. Subsea systems can be installed in both shallow waters and deep waters. They are normally utilized at depths of 2100 m (6890 feet) or more, and they can only extract and transfer, not drill. Subsea systems are typically those systems whereby their wells have the wellhead mounted upon the floor of the seabed after drilling operations from the wells, by any of the drilling platforms deployed. Recent advances made in sea systems can be seen in the realization of Statoil's Subsea Factory [232–234], as seen in Figure 5. The targeted ambition for such subsea systems is summarized in Table 2.

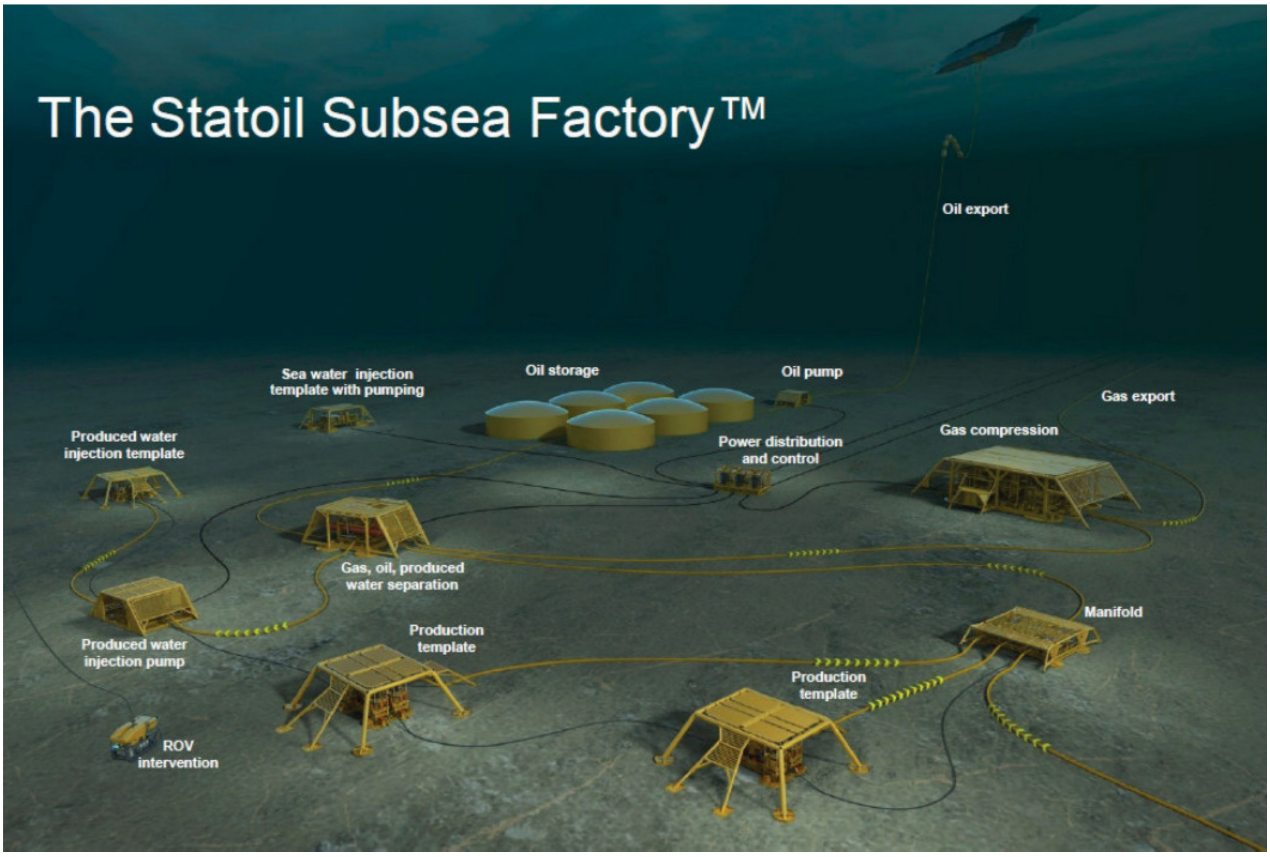


Figure 5. Subsea Production Systems in the Statoil Subsea Factory^{TM} (Courtesy: Statoil).

Table 2. Targeted ambitions for subsea factory.

Key Parameters	Heavy Oil Fields	Oil Fields	Gas/Condensate Fields
Colder (heavy/complex fluids)	Cold transport	Cold flow	Sour/Acid gas issues
Colder (arctic environment)	Harsh environment	Under ice	Under ice
Deep water (deeper environment)	2000 m	3000 m	3000 m
Longer power	50 MW	20 MW	100 MW
Longer transport	50 km	200 km	250 km

3. Types of Offshore Platforms

Different types of offshore oil rigs and platforms are utilized depending on the water depth and location of the offshore oil/gas field. To drill wells and produce oil and gas, rigs are employed, and platforms are set up in the field. To achieve fossil fuels from oil products, drilling and production activities must be carried out using oil rigs and platforms. Drilling can be used for obtaining natural gas and oil offshore, offshore. Most of the oil deposits are far from the closest mainland, which involves a series of obstacles not encountered when drilling onshore. When drilling at sea (i.e., offshore), the sea floor could be many meters below sea level. As a result, while onshore drilling uses the land as a platform, drilling at sea necessitates the construction of an artificial drilling platform. Since there are different types of offshore structures as depicted in Figures 1 and 6, a comparative analysis of offshore structures is necessary.

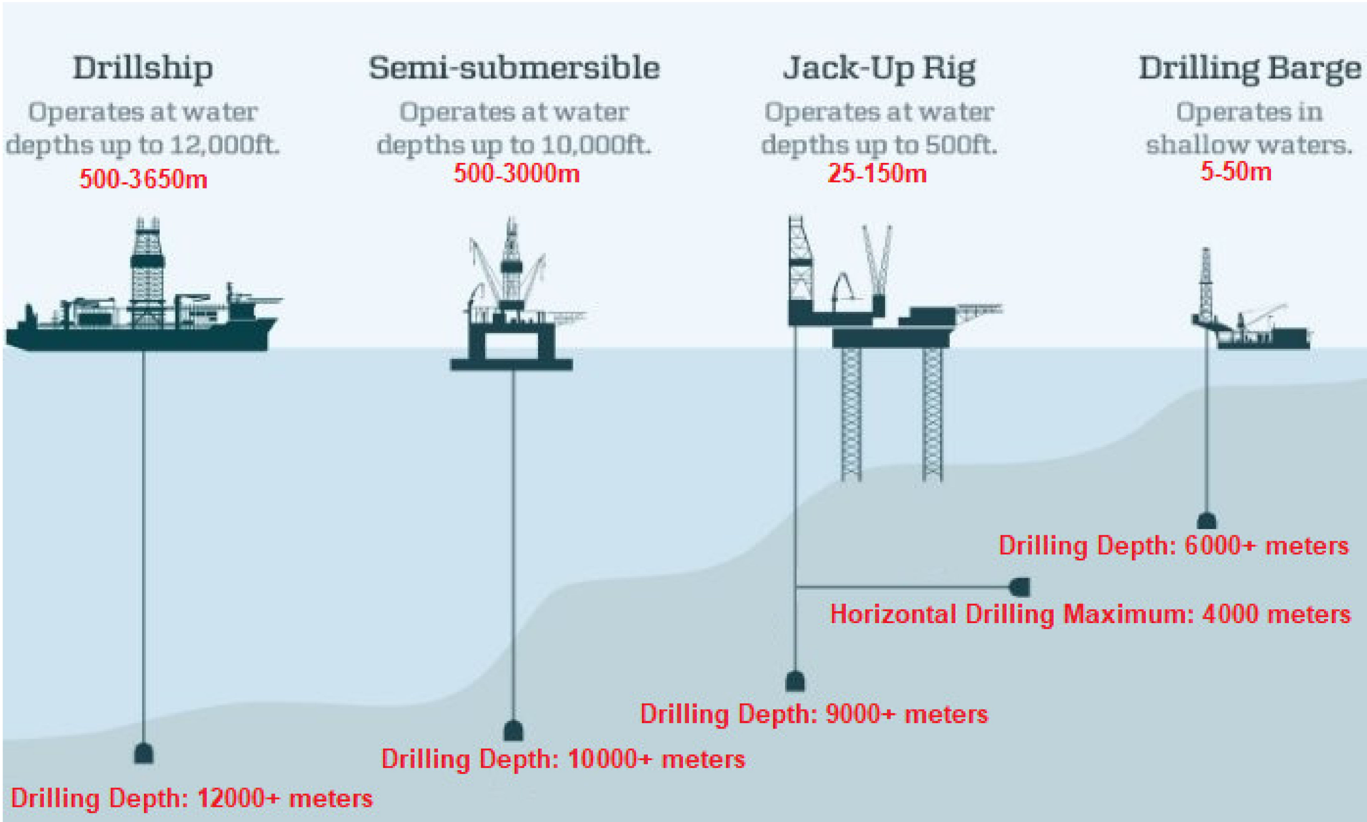


Figure 6. Types of Drilling Rigs.

3.1. Moveable Offshore Drilling Platforms

Offshore drilling rigs/platforms are divided into two categories. The first is a mobile offshore drilling rig that can be moved from one location to another, while the second is a stationary offshore drilling rig. Historically, the first submersible mobile drilling equipment to drill offshore in 1954 was called Mr. Charlie [261]. Over the years, newer developments have been made on moveable platforms. Offshore drilling platforms (and drilling rigs) are those platforms that can be moved from one drilling location to another or even higher application in the industry, as seen in recent leases. A mobile offshore drilling unit (MODU) or unit is a ship that can conduct drilling operations to explore for petrochemical minerals or exploit resources such as liquid or gaseous hydrocarbons, sulfur or salt that are present beneath the seabed. MODU can be jack-up, semi-submersible, barge-type or ship-shaped. For offshore oil and gas drilling, rigid platforms are necessary for drilling operations. They can be moved and retained in place by their own azimuth thrusters with dynamic positioning or hauled into place by a tugboat and moored. A recognized design and operational standard for semi-submersible mobile offshore drilling units (MODU) is the IMO's MODU Code.

3.2. Drilling Barges

Drilling barges are commonly used for shallow-water inland drilling. Drilling barges are massive floating platforms that require tugs to transport from one location to another. Canals, lakes, rivers, marshes, and other bodies of water are frequent areas for this to occur. Drilling barges are only suitable for still, shallow waterways and cannot survive the water movement found in vast open sea conditions. Figure 7 shows some drilling barges used in earlier oil explorations.

Figure 7. Drilling barge.

3.3. Jackup Drilling Platforms/Rigs

With one difference, jackup rigs are identical to drilling barges. After a jack-up rig is towed to the drilling location, three or four 'legs' are lowered until they land on the seafloor. Unlike a floating barge, the working platform can be raised above the water's surface. Jackup rigs, on the other hand, are only suitable for shallower seas due to the impossibility of extending these legs too far. This rig can only operate in waters up to 500 feet deep. These rigs are usually safer to operate than drilling barges since their working platform is elevated above the sea level [262]. In addition to exploration operations, jack-ups are utilized for drilling operations and wind farms service. Figure 8 shows a Jack-up platform in operation and a labelled projection.

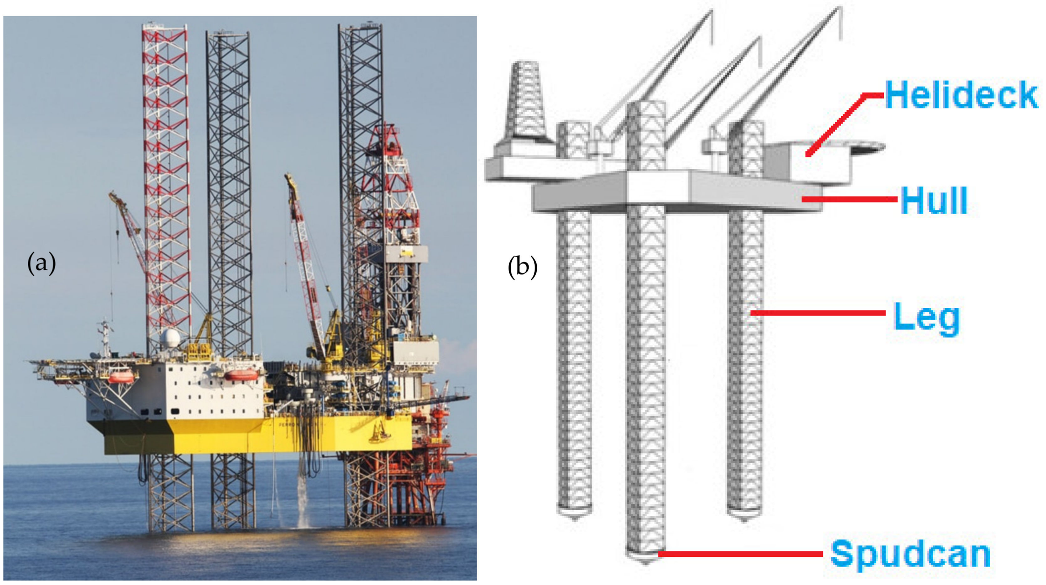


Figure 8. Typical Jack-up Structures showing (**a**) a jack-up in operation and (**b**) a labelled projection of the jack-up platform.

3.4. Offshore Wind Turbine Platforms

The global concern about the emission of greenhouse gases has provided a line of research into alternative renewable and clean energy. In this regard, wind power is one of the fastest-growing alternative technologies. However, this technology could help power a clean energy transition only if it can overcome hurdles of cost, design and opposition from fishing. More so, the application of offshore structures in renewable energy has taken more interests on breakwater devices, water energy converters, and wind turbines (such as FOWTs). The scale of wind turbines are larger and more adaptable forms of offshore structures are seen today. Offshore wind turbines may either be fixed-bottom or floating types [263]. The fixed-bottom platform is quite common in off the coast of Denmark, consisting of 91 wind turbines [264]. By design, offshore wind turbines, which are anchored to the seabed with monopile or jacket foundations, can only operate in waters less than 50 m deep. This eliminates sites with the greatest winds and, in many cases, easy access to large markets. However, there are exceptions as the application of Fixed-bottom wind turbines is more economical as it operates in shallow water depths of 50 or 60 m [265]. On the other hand, the floating wind turbines are anchored to the seabed using mooring lines, thus, are suitable for deeper water locations and areas with the soft seabed. Floating wind turbines have been used in water depths of up to 700 m [264,265]. Different concepts have been identified in on FOWTs projects with different platform types. The projects include DeepCWind, HyWind, WindFloat, NRMI, DTU and MARINTEK wind turbines. The ability to install FOWTs in deeper waters has an open huge amount of the oceans for the generation of renewable wind power. Table 3 shows some existing wind turbines with details.

Table 3. List of some offshore wind farms by capacity.

Name	Installation Year	Diameter	Tower Height	Capacity	Status
Hornsea 2	2002	167 m	190 m	1396 MW	Active
Burbo Bank Extension	2017	164 m	113 m	800 MW	Active
Westermost Rough	2014	154 m	102 m	600 MW	Active
Anholt	2012	120 m	82 m	360 MW	Active
Horns Rev 2	2009	93 m	68 m	230 MW	Active
Nysted	2003	82.4 m	69 m	230 MW	Active
Middelgrund	2000	76 m	64 m	200 MW	Active
Vindeby	1991	35 m	35 m	4.95 MW	Inactive

Although, the floating wind energy is still in its early stage of utilization, close to 80% of the wind power potential is found in deeper water. However, only about 80 megawatts of a total of about 32 GW (0.25%) of the installed offshore wind capacity is from floating wind turbines [265]. This narrative may change in the near future with the US government under USA's President Joe Biden pledging to build more than 30 GW of offshore wind turbines by the year 2030, worth more than $100 m [265]. Hence, this might bring the assertions of the National Renewable Energy Laboratory (NREL) to reality, which suggests that the floating turbine projects could achieve cost parity with the fixed turbines by the year 2030.

By classification, there are four main types of floating platforms, namely the spar-buoy, the tension leg platform, the semi-submersible and the Pontoon-type (Barge-type) floating wind turbines. However, there are other types and design concepts because these are the most common platform already installed and adapted for various planned projects, such as the Semi-submersible platforms which are expected to be used in about 50% to 75% of projects. Figure 9 shows four (4) types of offshore wind turbines.

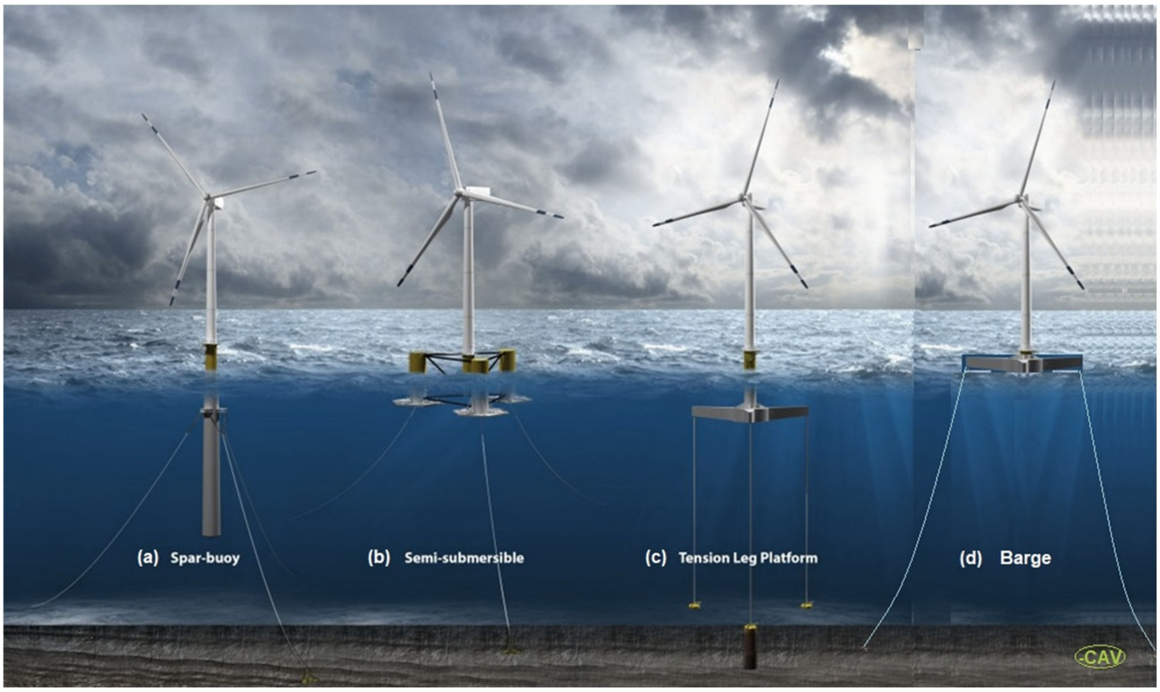


Figure 9. Different types of offshore wind turbines, showing (**a**) the spar-buoy, (**b**) the tension leg platform, (**c**) the semi-submersible and (**d**) the Pontoon-type (Barge-type) floating wind turbines (Original Illustration by Josh Bauer of NREL, Courtesy: NREL and DNV; Image adapted with permission from NREL and DNV, by Author 1—C.V.A.).

3.5. Semisubmersible Platform

Semisubmersible platforms are offshore oil rigs with floating drill units that incorporates pontoons and columns that, if flooded, will sink to a predetermined depth. The most common type of offshore drilling rig is a semi-submersible rig, which combines the advantages of submersible rigs with the ability to drill in deep water. Historically, the first semi-submersible was BlueWater Rig 1 in 1961 [64]. Semisubmersible rigs are similar to submersible rigs in that the lower hull 'inflates' and 'deflates.' Despite being partly underwater, the rig floats over the drill site. The rig is stabilized while drilling by the lower hull, which is filled with water. Semi-submersible rigs are held in place by massive anchors weighing up to 10 tons each. The platform is sturdy and safe to use in turbulent offshore waters thanks to these anchors and the rig's submerged component.

Semisubmersible drilling rigs are also floating production systems. It is made up of drilling and petroleum production equipment that is simultaneously positioned on the system. This mechanism is properly grounded at the seabed's bottom. In small oil storage facilities, this type of technique is more effective. Based on the system working described, it can be utilized from 1500 to 6000 feet. In general, these systems are less stable when subjected to high wave stress. Submersible rigs, such as jackup rigs, are ideal for shallow water and come into contact with the ocean or lake floor. Platforms with two hulls stacked on top of one another make up these rigs. The living accommodations for the crew, as well as the actual drilling platform, are located in the upper hull. The lower hull functions similarly to a submarine's outer hull: when the platform is moved from one location to another, the lower hull is filled with air, making the entire rig buoyant. The air is released out of the lower hull when the rig is positioned over the drill location, and the rig submerges to the sea or lake floor. This style of rig has the benefit of being mobile in the water, but it can only be used in shallow water.

By classification, there are three types of semisubmersibles: ship-shaped semisubmersibles, column-stabilized semisubmersibles and bottle-type semisubmersibles. These three types of semisubmersibles are classified by the method of rig submergence in water.

While the ship shaped semisubmersibles can be designed as ships, as the name implies, they are also one of the most often used hull systems for the design and construction of offshore deep water drilling and production platforms, followed by the column stabilized semisubmersible platform [56,58,219,252,253]. The bottle-type semisubmersible platform, on the other hand, is made up of bottle-shaped hulls that are positioned beneath the drilling deck and can be submerged by filling them with water. Bottle-type semisubmersibles, the first manifestation of this type of drilling rig, were designed as submersible rigs. The bottles below the rig were totally submerged due to this design consideration for the submersible, which rests on the ocean floor. Furthermore, the rig of the bottle-type semisubmersible provided remarkable drilling stability. It also provides stability for rolling, as well as reducing pitching caused by waves and wind. This type of semisubmersible needs to be studied because of the various environmental conditions. Some drilling sites are always difficult, with turbulent waves and occasional weather concerns such as hurricanes, storms, cyclones, high tides, and strong winds. As a result, it is necessary to dig into deeper and more turbulent seas. Semi-submersibles have recently opened up a new path for exploration and development operations. However, as time went on, naval architects understood that if the bottles were only partially submerged, the rig would keep its stability when drilling in deeper seas. The semisubmersibles are moored using mooring lines, and the anchors are the only connection the rig has with the seafloor. These bottle-type rigs were eventually designed to only be used as semisubmersibles. Bottle-type semisubmersibles' configuration and design have a different impact on their hydrodynamic behavior in rough weather situations, and hence on their use and functionality in ocean engineering. The semisubmersibles can have other classifications based on evolution such as sixth generation semisubmersibles, and by design, such as the Dry-Tree Semisubmersible (DTS). Since the construction of drilling rigs have traditionally taken place during economic booms, different "batches" of drilling rigs have been constructed. Depending on the year of construction and water depth capability, offshore drilling rigs have been roughly categorized into nominal "generations". Table 4 gives different generations for classifying semisubmersibles.

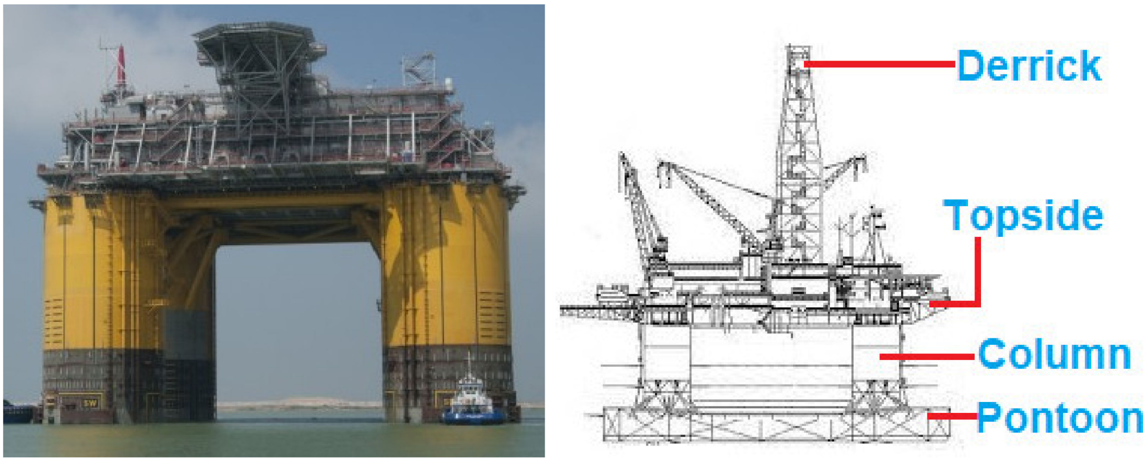
Table 4. Classification of semisubmersibles by generations.

Generation	Timelines	Water Depth	
		Meters (m)	**Feet (ft)**
First	Early 1960s	200 m	about 600 ft
Second	1969–1974	300 m	about 1000 ft
Third	Early 1980s	500 m	about 1500 ft
Fourth	1990s	1000 m	about 3000 ft
Fifth	1998–2004	2500 m	about 7500 ft
Sixth	2005–2012	3000 m	about 10,000 ft
Seventh	2013–2022	>3000 m	over 10,000 ft

Generally, semisubmersibles are multi-legged offshore floating structures consisting of a large deck, with several legs interconnected at the bottom underwater with horizontal buoyant members referred to as pontoons. The semisubmersibles are one of the preferred floating offshore platforms alternatives due to their advantages, including, stability and motion. However, their natural frequencies vary inversely with the draft and length, the appropriate selection of the geometric shape constitutes an essential criterion in the design of semisubmersibles [266]. Semi-Submersible may be stationed using dynamic positioning systems or anchored using mooring systems. For example, in 2002, a semi moored was deployed using spread mooring lines at a water depth 1875 m in offshore Malaysia, while another installation using a dynamic positioning system in 2003 was deployed in Brazil operating at a water depth of 2890 m. In the same year, a semi operating in 2730 m water depth was also positioned in the Gulf of Mexico (GoM) [267]. However, more recent developments have been made. Table 5 presents the list of some semisubmersible platforms used in recent developments. The most recent is the Appomattox semisubmersible platform operated by Shell in GoM, which was installed in 2019, as shown in Figure 10a. Figure 10b illustrates the parts of a semisubmersible.

Table 5. List of some semisubmersible platforms for deep water drilling and production.

Platform	Water Depth (m)	Operator	Installation Year	Location
Appomattox	2195 m	Shell	2019	GoM, USA
Thunder Horse PDQ	1841 m	BP & ExxonMobil	2010	GoM, USA
Na Kika	1829 m	Shell & BP	2003	GoM, USA
Atlantis PQ	2134 m	BP & BHP	2007	GoM, USA
Argos /Mad Dog Phase 2	1311 m	BP	2022	GoM, USA
Vito	1189 m	Shell	2022	GoM, USA
Delta House	1370 m	LLOG	2015	GoM, USA



(**a**) (**b**)

Figure 10. Semisubmersibles showing (**a**) Appomattox Semi-Submersible oil platform in GoM installed in 2019 (Courtesy: Shell), and (**b**) an illustration of part of a semisubmersible.

3.6. Dynamic Positioned Drillships

Drillships are exactly what they sound like: ships that are used to conduct drilling operations. These boats are designed specifically to transport drilling platforms to deep-sea areas. A typical drillship will feature a drilling platform and derrick in the middle of its deck, in addition to all of the other equipment found on a huge ocean ship. Drillships also have a hole called a "moonpool" that runs the length of the ship and down through the hull, allowing the drill string to extend through the boat and into the water. This offshore oil rig is capable of drilling in extremely deep water. 'Dynamic positioning' systems are used by drillships. Drillships have electric motors mounted on the underside of the hull that can move the ship in any direction. These motors are incorporated into the ship's computer system, which employs satellite positioning technology and sensors on the drilling template to guarantee that the ship is always directly over the drill site. Dynamic positioning can also be used to keep semi-submersible rigs in place. Drilling rigs that are Semi-submersible drilling rigs can drill in much deeper water than the rigs mentioned earlier. Deeper depths of up to 6000 feet (1800 m) may now be reached safely and quickly thanks to technological advancements. Figure 11 shows a drillship semisubmersible by Transocean.

Figure 11. DrillShip semisubmersible (Courtesy: Transocean).

3.7. SPAR Platforms

Spar platforms are among the most often used offshore platforms. The acronym SPAR stands for Single Point Anchor Reservoir. The SPAR platform is an offshore floating platform with a relatively large draft to diameter ratio (aspect ratio). Its deep draft made the natural periods outside the wave ranges thereby attributing to its wide acceptance for different operational scenarios, especially in deeper waters.

The Spar platform is the world's largest oil extraction platform which can be employed at depths up to 10,000 feet. This platform is mainly comprised of a massive cylinder support system and a standard fixed rig platform. This large cylinder does not stretch all the way to the seabed. It is held together by large steel cables that are attached to the seabed. The extraction devices are mounted above this cylinder and will perform their duties. A big cylinder supports a standard fixed rig platform on these massive platforms. The cylinder, on the other hand, does not reach all the way to the seafloor and is instead held in place by several cables and wires. The big cylinder helps to keep the platform afloat while also allowing for mobility to absorb the energy of any impending hurricanes.

Currently, the Perdido platform, operated by Shell, is the tallest SPAR, and is comparatively one of the tallest structures in the world at 267 m, as depicted in Figure 12. However, the Perdido SPAR which operates in a water depth of 2450 m installed in 2010 has been overtaken by Stone FPSO operating in a water depth of 2925 m installed in 2016, and both are operating in the Gulf of Mexico (GoM).

Figure 12. Perdido deep water SPAR platform in the Gulf of Mexico (GoM), (Courtesy: Statoil).

In September of 1996, the first SPAR platform was placed in the Gulf of Mexico (GoM) was commissioned. The platform's cylinder was 770 feet long and 70 feet in diameter, and it functioned at a sea depth of 1930 feet (see details in Table 6). Unlike the semi-submersible, the spar platform consists of a single large diameter cylinder supporting a deck. The hull is normally maintained in position using a taut mooring system consisting of lines ranging from 6–20 [267]. Based on the design, spar platforms are available in three configurations, namely: Truss spar, cylindrical, and cell spar, as illustrated in Figure 13. Table 6 gives a list of some SPARs, while Figure A3 of Appendix A shows a list of different SPAR platforms that have evolved over the years.

Table 6. List of some SPAR platforms constructed.

Platform	Water Depth (m)	Type	Length (ft)	Diameter (ft)	Operator	Installation Year	Location
Neptune SPAR	1935 ft	Classic	705 ft	72 ft	Noble Energy	1996	GoM, USA
Medusa SPAR	2223 ft	Truss	586 ft	94 ft	Murphy E&P	2003	GoM, USA
Front Runner SPAR	3350 ft (1021 m)	Truss	587 ft	94 ft	Murphy E&P	2004	GoM, USA
Mad dog SPAR	4500 ft (1311 m)	Truss	555 ft	128 ft	BP	2005	GoM, USA
Perdido SPAR	7817 ft (2450 m)	Truss	555 ft	118 ft	Shell	2010	GoM, USA
Genesis SPAR	2590 ft	Classic	705 ft	122 ft	Chevron USA	1998	GoM, USA
Hoover Diana DDCV SPAR	4825 ft	Classic	705 ft	122 ft	Exxon Mobil	2000	GoM, USA
Boomvang SPAR	3450 ft	Truss	543 ft	90 ft	Anadarko	2002	GoM, USA
Nansen SPAR	3680 ft	Truss	543 ft	90 ft	Anadarko	2001	GoM, USA
Horn Mountain	5400 ft	Truss	555 ft	106 ft	Anadarko	2002	GoM, USA
Gunnison	3122 ft	Truss	549 ft	3122 ft	Anadarko	2003	GoM, USA
Holstein	4344 ft	Truss	746 ft	149.28 ft	Anadarko	2004	GoM, USA
Constitution SPAR	5000 ft	Truss	550 ft	98 ft	Anadarko	2005	GoM, USA
Kikeh SPAR	4364 ft	Truss	465 ft	106 ft	Murphy	2007	Malaysia
Tahiti SPAR	4200 ft	Truss	555 ft	128 ft	Chevron USA	2008	GoM, USA
Lucius SPAR	7000 ft	Truss	605 ft	110 ft	Anadarko	2014	GoM, USA
Devils Tower SPAR	5610 ft	Truss	586 ft	94 ft	Eni US	2004	GoM, USA
Heidelberg SPAR	5300 ft	Truss	605 ft	110 ft	Anadarko	2016	GoM, USA
Gulfstar SPAR	4600 ft	Classic	584 ft	85 ft	Hess	2014	
Aasta Hansteen SPAR	4265 ft	Truss	643 ft	164 ft	Equinor	2019	North Sea, Norway
Red Hawk SPAR	5300 ft	Cell	560 ft	64 ft	Kerr McGee & Devon Energy	2004	GoM

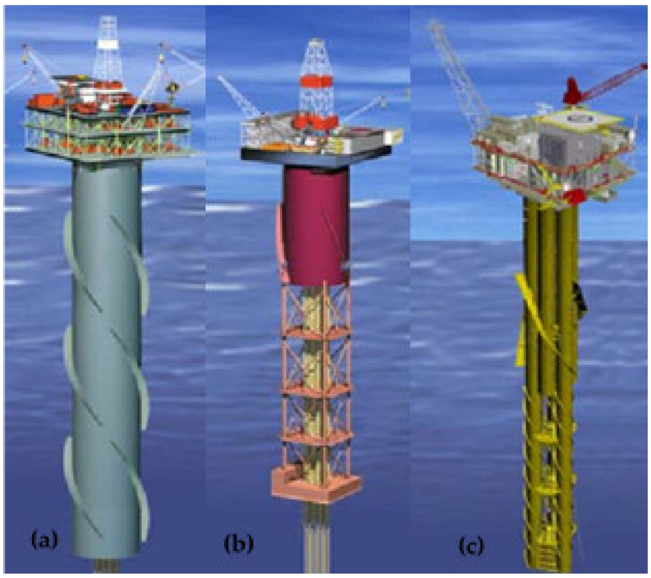


Figure 13. Types of Spar Platform: (**a**) Classic (**b**) Truss (**c**) Cell.

3.8. Jacket Platforms

Jacket platforms are simply platforms for template (jacket) development. This steel-based fixed platform is commonly found along the shorelines of the Persian Gulf, Gulf of Mexico (GoM) USA, Niger Delta regions of Nigeria, etc. [14,83,87]. Jackets, decks, and heaps are the most common components of template platforms [116,119]. The Template (Jacket) type is used on different petroleum platforms and Seas like the Persian Gulf. Jack-Up platform is shallow water floating offshore structure used for exploration of offshore oil and gas. As the name implies, it has movable legs which can be retracted and extended vertically, that is, once in contact with the seabed the platform begins moving upwards and outside the water surface [268]. Jacket platforms are used for drilling and exploration operations. However, there are other platforms that are also used, based on the requirement of the drilling/production field [269–281]. Tables 7 and 8 respectively show the list of some jacket platforms constructed, and some wellhead jacket platforms (WHP).

Table 7. List of some jacket platforms constructed.

Platform	Water Depth, m (ft)	Operator	Installation Year	Location
Amberjack	314 m (1100 ft)	BP	1991	USA
Pompano	393 m (1290 ft)	BP/Stone Energy	1994	USA
Heritage	326 m (1070 ft)	Exxon	1993	USA
Harmony	366 m (1201 ft)	Exxon	1993	USA
Virgo	344 m (1129 ft)	Elf/W & T Energy	2000	USA
Cyrus	134 m (440 ft)	Chevron USA	2002	USA
Salsa	211 m (693 ft)	Shell	1998	USA
Ligera	282 m (924 ft)	Fieldwood SD	1982	USA
Tequila	201 m (660 ft)	Fieldwood SD	1984	USA
Snapper	263 m (863 ft)	Fieldwood SD	1985	USA
Tarantula	148 m (484 ft)	Fieldwood Energy	2004	USA
Cerveza	285 m (935 ft)	Fieldwood SD	1981	USA
Coelacanth	361.5 m (1186 ft)	Water Oil & Gas	2015	USA
Simba	203 m (667 ft)	Ankor Energy	2005	USA
Spirit	220 m (722 ft)	Fieldwood Energy	1998	USA
Enchilada	215 m (705 ft)	Shell	1997	USA
Spect. Bid	165 m (541 ft)	Flextrend Development	1995	USA
Phar Lap	205 m (673 ft)	Flextrend Development	1995	USA
Alabaster	145 m (476 ft)	Energy XXI GOM	1991	USA
Corrla	189 m (619 ft)	Eni US	1992	USA
Pimento	219.8 m (721 ft)	Triton Gathering	1993	USA
Tick	219.5 m (720 ft)	Chevron USA	1991	USA
Lobster	236 m (775 ft)	EnVen Energy Ventures	1994	USA
Marquette	184 m (604 ft)	MC Offshore Petroleum	1989	USA
Boxer	229 m (750 ft)	Shell Oil	1988	USA
Boxer	229 m (750 ft)	Whistler Energy II	1986	USA
Boubon	130 m (428 ft)	Fieldwood Energy	1978	USA
East Belumut A	73 m (240 ft)	Newfield	2008	Malaysia
Agbara	70 m (230 ft)	Agip Energy	2000	Nigeria
Amenam	40 m (131 ft)	TotalFinaElf	2003	Nigeria
Litchendjili	30 m (98 ft)	Eni Congo	2015	Congo
Dong Fang 13-2	70 m (230 ft)	Offshore Oil Eng. Co.		China
Lu Feng	241 m (791 ft)	Offshore Oil Eng. Co.	2021	China

Table 7. *Cont.*

Platform	Water Depth, m (ft)	Operator	Installation Year	Location
CaNgu Vang	113 m (371 ft)	Hoan Vu Joint Oper. Co. (HVJOC)	2008	Vietnam
Annamaria B	59 m (194 ft)	Eni E &P		Italy
Erskine jacket	90 m (295 ft)	Texaco NS UK	1997	UK
West Franklin	90 m (295 ft)	Elf Exploration	2011	UK
Tiffany field	126 m (413 ft)	Agip UK	1993	UK
Zuluf field	40 m (131 ft)	Saudi Aramco	2020	Saudi Arabia

Table 8. List of some wellhead jacket platforms (WHP) constructed.

Platform	Water Depth (m)	Operator	Installation Year	Location
Valhall flank West WHP	70 m (230 ft)	BP	1982	Norway
Huldra Phase 1 WHP	125 m (410 ft)	Statoil	2001	Norway
Eldfisk 2/4 B WHP	70 m (230 ft)	ConocoPhillips	1979	Norway
Blacktip WHP	50 m (164 ft)	Eni	2006	Australia
Elgin B WHP	90 m (295 ft)	Elf Exploration	2012	UK

3.9. Compliant Towers (Tower Platforms)

Fixed platforms are similar to compliant towers. They are made up of a slender tower that is attached to a seafloor foundation and extends up to the platform. In contrast to the relatively hard legs of a permanent platform, the compliant tower is flexible [241]. Since it can 'absorb' most of the pressure placed on it by the wind and waves, it can function in much deeper water. The compliant tower system is sturdy enough to survive hurricane conditions despite its flexibility. A compliant tower (CT) is a fixed rig structure utilized for offshore oil and gas production. The rig is made up of compliant towers that are flexible, narrow, and made on a pile foundation that supports. This foundation holds the tower, its standard drilling and production deck. Compliant towers are utilized in water depths ranging from 450 to 900 m and are designed to withstand substantial lateral deflections and stresses (1500 to 3000 feet) [282–286]. These structures are self-contained, and free-standing but their media are given supports by water. They exhibit static stability but have a far higher degree of lateral deformation/flexibility (about 2.5%:0.5%) than land-based structures, and are partially supported by buoyancy. In the early 1980s, the commissioning of Exxon's Lena oil platform led to the development of the first compliant tower. The Chevron's Petronius compliant tower, which was 531 m and is now 623 m deep, is currently the deepest, as recorded in Figure 14 and detailed in Table 9.

The compliant towers are designed by considering the natural frequency of the structure. Resonance is minimized and wave forces are de-amplified when flex elements such as axial tubes and flex legs are used. This rig construction can be customized to fit existing fabrication and installation machinery [287–289]. Production risers are more traditional than floating systems such as tension-leg platforms and SPARs, and are subjected to less structural loads and bending. However, constructing compliant towers in water depths larger than 1000 m gets uneconomical. Even with the higher cost of anchorage (or moorings) and marine risers, it becomes most appropriate to use of a floating production system [290–293]. However, one good advantage of the compliant tower system is that it is quite sturdy enough to survive hurricane conditions, despite its flexibility [294–299]. Figure 15 shows different concepts of the compliant tower. It shows a cross-section of different concepts of compliant towers used in the oil and gas industry, showing: (a) "dumb" tower; (b) compliant piled tower; (c) compliant tower with 'mass trap'; (d) buoyant tower with flex joint; (e) guyed tower with flex joint; and (f) articulated column [298].

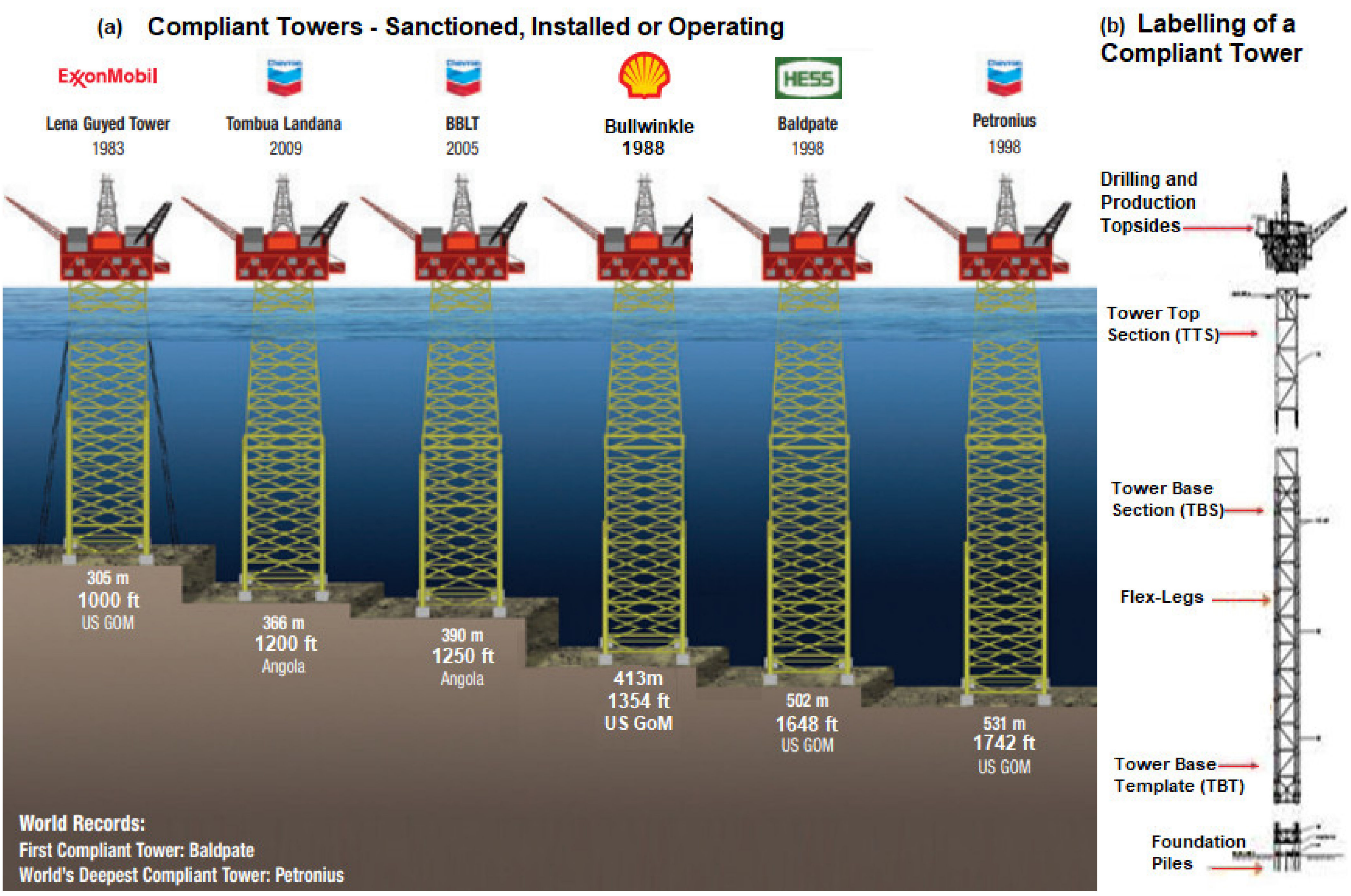


Figure 14. Illustrations showing (**a**) the Five Compliant Tower Platforms in the World including those sanctioned, installed and operating platforms while (**b**) shows a labelled compliant tower. (Revised image (**a**), adapted from Offshore Magazine Poster, Courtesy: Wood Group Mustang).

Table 9. Parameters of compliant towers showing the structural weights.

Platform Parameters	Petronius	Lena Guyed Tower	Baldpate	Bullwinkle (Fixed)	Cognac	Benguela-Belize Lobito-Tomboco (BBLT)	Tombua-Landana
Location	GoM	GoM	GoM	GoM	GoM	Angola	Angola
Installation Year	1997	1983	1998	1988	1978	2006	2009
Design Type	Type ‘b’	Type ‘e’	Type ‘a’	Type ‘a’	Type ‘a’	Type ‘e’	Type ‘e’
Operator	Chevron	ExxonMobil	Hess	Shell	Shell	Chevron	Chevron
Natural Period (s)	33	28	~30	~30	~30	~29	~28
Wave height Hs (m)	22.49	12.5	18.2	18.2	21.34	8.84	8.84
Water Depth, (m)	535 m	305 m	503 m	413 m	314 m	390 m	366 m
Topside weight, (tons)	8800	9500	9000	2033	14,000	43,500	36,000
Structure weight, (tons)	43,000	23,400	28,900	49,375	59,000	49,800	56,400
Well slot	21	21	19	60	62	40	46
Base Dimension (m)	33.53 × 33.53	37 × 37	42.67 × 42.67	148 × 124	122 × 116	33.53 × 33.53	33.53 × 33.53
Section	2	2	2	2	3	2	2
Diameter of flex-leg	2.13 m (84″)	1.37 m (54″)	-	-	2.1 m (83″)	2.59 m (102″)	2.59 m (102″)
No. of flex-legs	12	8	12	12	24	12	12
Diameter of foundation piles	2.44 m (96″)	1.83 m (72″)	2.13 m (84″)	-	2.4 m (96″)	2.74 m (108″)	2.74 m (108″)
No. of Foundation piles	12	8	12	12	24	12	12
Max. pile penetration (m)	141.7 m	167.6 m	162 m	-	137.2 m	154.8 m	160.8 m

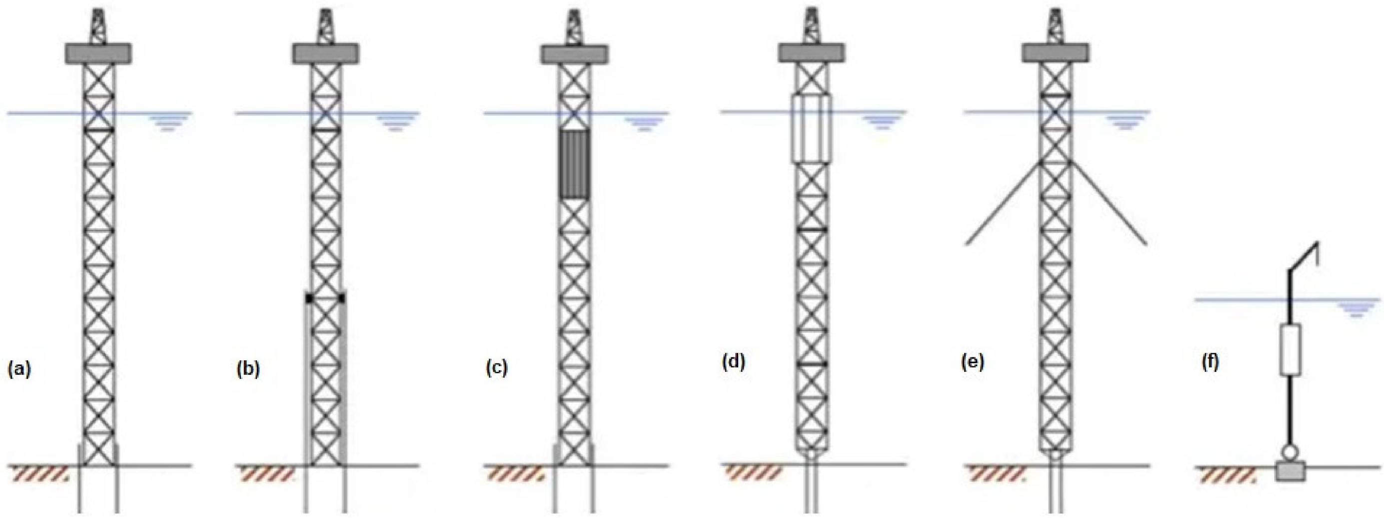


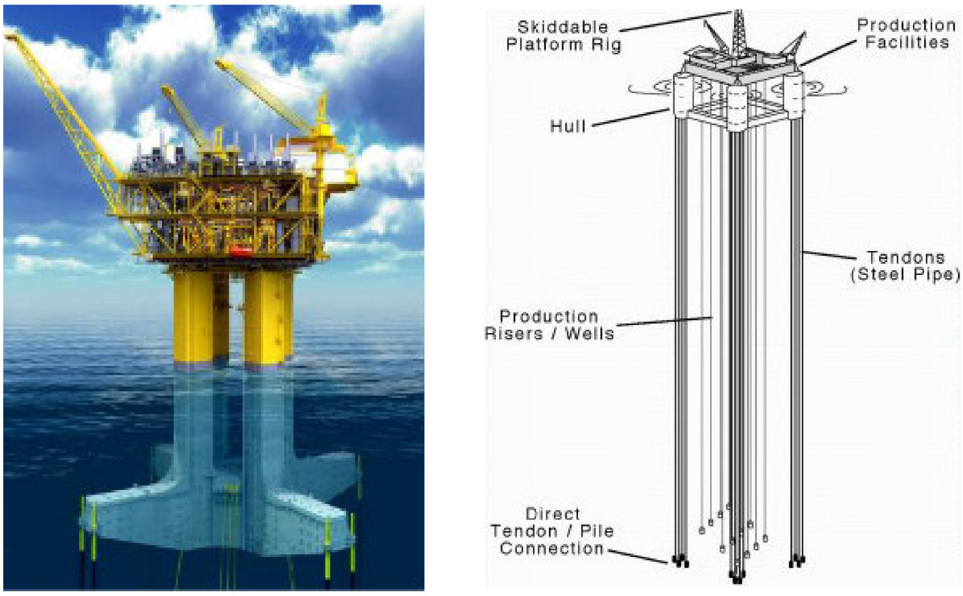
Figure 15. Cross-section of different concepts of compliant towers used in the oil and gas industry, showing (**a**) "dumb" tower, (**b**) compliant piled tower, (**c**) compliant tower with 'mass trap', (**d**) buoyant tower with flex joint, (**e**) guyed tower with flex joint, and (**f**) articulated column.

3.10. Tension Leg Platform and Seastar Platform

The Tension Leg platform is a type of platforms that is held by tendons. The tension leg platform operates on the same principles as the SeaStar platform. Since there is no water chamber to oppose the lateral movement, such a construction is less stable than a SeaStar platform. The Seastar platform is a larger form of the Tension Leg platform. The platform's long, flexible legs are anchored to the seafloor and run up to it. These legs, like the SeaStar platform, allow for a lot of side-to-side movement (up to 20 feet) but very limited vertical mobility. Tension leg platforms are capable of working at depths of up to 7000 feet. SeaStar platforms resemble tension leg platforms in size. The platform is made up of a floating rig, similar to the semi-submersible type (as mentioned in Section 3.5) [299]. When drilling, a lower hull is filled with water, increasing the platform's stability against wind and sea movement. Seastar platforms, in addition to this semi-submersible rig, also include the tension leg system found on larger platforms. Long, hollow tendons that go from the seafloor to the floating platform are known as tension legs. These legs are kept under continual tension and prevent the platform from moving up or down. Their elasticity, on the other hand, allows for side-to-side movement, allowing the platform to endure the power of the ocean and the wind without breaking the legs. When it is not cost-effective to build a larger platform, Seastar platforms are often employed for smaller deep-water reservoirs. They can operate in up to 3500 feet of water.

A floating rig, a lower hull, and tension cables comprise the Seastar platform. A water-filled lower shell boosts the platform's stability against wind and water movement. It also has a tensioned system in addition to the semi-submersible rig. The tension leg, which is made out of high-strength steel cables, is part of the tension system. Tension stress is not a problem with these wires. This construction is vulnerable to high wave and wind pressures, but the water-filled body will mitigate these effects, making the structure more stable. Figure 16 shows an illustration of typical TLP.

The Tension Leg Platform has been used in making notable historical developments in the oil and gas industry. The Heidrun Tension Leg Platform (TLP) was the first platform where a composite riser joint was deployed in 2002. It is also the first platform that composite riser joint was successfully deployed after extensive composite research. The TLP has 56 well slots on the subsea riser template. The Heidrun TLP has a total height of 109 m, a square pontoon having a box cross-section, a pontoon height of 110 m, a pontoon height of 13 m, and eight decks located near each of the four circular columns located at each corner. It is the first and biggest floating TLP with a concrete hull. It is the largest floating structure carrying the largest deck load ever, with a topside weight of 43,000 tons, and a total platform displacement of 288,200 tons. Conoco discovered the Heidrun field in 1985, which lies about 175 km off Norway's coast and north of Kristiansund at a water depth of about 350 m. It produces 65,000 barrels of oil daily, 110,000 barrels of water daily, and 760 m^3 of natural gas. The Heidrun TLP has produced over 944 million oil and gas barrels since October 1995, at 05:37 when the choke valve was opened to become operational. Figure 17 shows the Heidrun Tension Leg Platform (TLP), while Table 10 lists some tension leg platforms constructed with their details.



(a) (b)

Figure 16. Illustrations showing (**a**) the tension leg platform (TLP), and (**b**) a labelled TLP.

Figure 17. Heidrun Tension Leg Platform (TLP). (Courtesy: Statoil.).

Table 10. List of some tension leg platforms constructed.

Platform	Water Depth (m)	Operator	Installation Year	Location
Prince TLP	454 m	EnVen Energy Corp.	2001	GoM, USA
Kizomba TLP	1012 m	Esso Exploration	2004	Angola
Marlin TLP	986 m	BP & Anadarko	1999	GoM, USA
Marco Polo TLP	1311 m	Anadarko Petroleum Corp.	2003	GoM, USA
Ram-Powell TLP	1000 m	Shell	1997	GoM, USA
Magnolia ETLP	1420 m	ConocoPhillips	2003	GoM, USA
Heidrun TLP	350 m	Conoco	1995	North Sea, Norway
Moho Nord TLP	1200 m	Total Energies	2015	Congo
Stampede TLP	1067 m	Hess Corporation	2017	GoM, USA
Shenzi TLP	1333 m	BHP Billiton Petroleum Inc.	2008	GoM, USA
URSA TLP	1204 m	Shell	1999	GoM, USA
Olympus /Mars B	914 m	Shell	2014	GoM, USA
Mars TLP	896 m	Shell	1996	GoM, USA
Auger TLP	872 m	Shell	1993	GoM, USA
Jolliet TLP	536 m	MC Offshore Petroleum & Conoco	1989	GoM, USA
Hutton TLP	148 m	ConocoPhillips	1984	North Sea, UK
Snorre TLP	310 m	Saga Petroleum	1992	North Sea, Norway
Oveng TLP	271 m	Hess	2006	Equatorial Guinea
Okume/Ebano TLP	503 m	Hess	2006	Equatorial Guinea
Brutus TLP	910 m	Shell	2001	GoM, USA
Malikai TLP	500 m	Shell	2014	Malaysia

3.11. FPSO

The acronym FPSO stands for floating production storage and offloading. As the name implies, the FPSO is a production system equipped with processing equipment for the separation and treatment of crude oil and gas together with a large storage hull to store the treated oil for export [260,268–270]. With the continuous push of production activities into deeper waters, the FPSOs have over the years dominated the oil and gas industry mainly due to their attributed advantages which include large storage hulls, and their suitability for application in remote offshore areas [269,270]. The International Maritime Association (IMA) and World Energy Reports (WER) reveal a total of 175 FPSO units in operation as of November 2022, which is equivalent to 68% of the overall floating production systems.

Shuttle tankers are also classified as FPSOs used for offshore production activities, such as with loading and discharging fluid products using (un)loading marine hoses [31–39]. Depending on the environmental condition, FPSOs are either maintained in position using a spread or turret mooring system as illustrated in Figure 18. A spread of FPSOs located in different geological locations is presented in Table 11 and Figure A4 of Appendix A.

Figure 18. FPSO mooring system: (**a**) Internal turret (**b**) external turret, and (**c**) spread mooring system.

Table 11. List of some FPSOs globally used on oil and gas facilities.

FPSO	Water Depth (m)	Vessel Length (m)	Storage Capacity (Barrels)	Operator	Owner	Year	Fields
Stones (or Turritella FPSO)	2914 m	247 m	800,000	Shell	SBM Offshore	2016	GoM, USA
Bonga FPSO	~1800 m	295 m	2,000,000	Shell	Shell & NNPC	2005	Niger Delta, Nigeria
Agbami FPSO	~1463 m	319.99 m	2,150,000	Chevron	Chevron & NNPC	2007	Agbami, Nigeria
Parque das Conchas (BC-10)	~1800 m	330 m	2,000,000	Shell	Shell	2010	Brazil
Kikeh FPSO	~1350 m	337 m	2,000,000	MDPX Sdn Bhd	MDFT Labaun	2007	Malaysia
Peregrino FPSO	100 m	332.99 m	1,600,000	Statoil	Maersk	2010	Brazil
Sevan Piranema FPSO	1100 m	66 m (dia.)	300,000	Petrobras	Teekay	2008	Brazil
Goliat FPSO	420 m	112 m (dia)	1000,000	Eni & Statoil	Eni	2015	Barents Sea, Norway
Polvo FPSO	160 m	340.6 m	1,266,000	HRT	BW Offshore	2007	Brazil
Frade FPSO	1128 m	337.06 m	1,550,000	Chevron	SBM Offshore	1976, 2009	Brazil
Cidade de Vitoria FPSO	1386 m	337 m	1,900,000	Petrobras	Saipem	2007	Brazil
Marlim Sul FPSO	1670 m	342.99 m	1,000,000	Petrobras	SBM Offshore	2004	Brazil
Terra Nova FPSO	100 m	292.25 m	960,000	Suncor	Suncor	2001	Canada
Aquila FPSO	1233 m		700,000	Eni	Eni	2013	Adriatic Sea, Italy
Triton FPSO	95 m	244 m	630,000	Dana	Dana	2000	UK
Gryphon FPSO	112 m	257.6 m	540,000	Total Energies	Maersk	1993	UK
Äsgard A FPSO	300 m	276 m	910,000	Statoil & Eni	Statoil	1998	Norway
Alvheim FPSO (converted Odin)	112 m	285 m	560,000	Marathon & Det Norske	Statoil/Marathon	2008	North Sea, Norway
Firenze FPSO	815 m	268 m	700,000	Eni	Saipem	2011	Adriatic Sea, Italy

3.12. Concrete Gravity-Based Structure (GBS)

A support structure maintained in place by gravity is referred to as a "gravity-based structure," most prominently offshore oil rigs. Due to their protected area and adequate depth, fjords are frequently used to build these structures. The basis of construction for the Concrete Gravity-Based Structure was the application of reinforced concrete. The base's design incorporates vacuum spaces or caissons to provide the structure with natural buoyancy, allowing it to be floated to a field development site. Once on site, the blank spaces on the seabed are flooded, and the topside modules are hauled into place. The vacant holes were then filled with permanent iron ore ballast or utilized as crude oil storage compartments. Due to the sheer massive weight of concrete structures, foundation piles are not required, thus the name gravity base structure [299–307]. Figure 19 illustrates a typical GBS, showing Troll A concept.

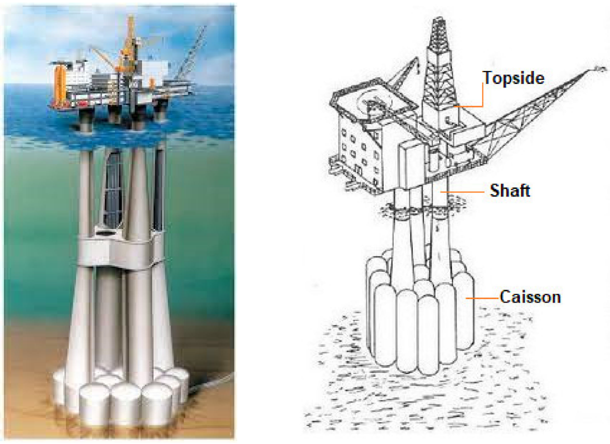
An example of a concrete gravity-based structure is the Troll A platform (as shown in Figure 20), which exists off the west coast of Norway, in the Troll gas field. This offshore structure was built in 1996, and it is recorded as the largest structure ever moved and dropped into the ocean [301,307]. Table 12 and Figure A5 of Appendix A show different GBS platforms with their details.

Table 12. Installation of different concrete gravity-based structures.

Installation	Water Depth (m)	Type	Location	Year	Operator
Troll A	303 m	Condeep, 4 shafts	North Sea, Norway	1995	Norske Shell
Beryl A	120 m	Condeep, 3 shafts	North Sea, UK	1975	Mobil
Brent B	140 m	Condeep, 3 shafts	North Sea, UK	1975	Shell

Table 12. *Cont.*

Installation	Water Depth (m)	Type	Location	Year	Operator
Brent D	140 m	Condeep, 3 shafts	North Sea, UK	1976	Shell
Frigg TCP2	104 m	Condeep, 3 shafts	North Sea, Norway	1977	Elf
Stratfjord A	146 m	Condeep, 3 shafts	North Sea, Norway	1977	Mobil
Stratfjord B	146 m	Condeep, 4 shafts	North Sea, Norway	1981	Mobil
Stratfjord C	146 m	Condeep, 4 shafts	North Sea, Norway	1984	Mobil
Gullfaks A	135 m	Condeep, 4 shafts	North Sea, Norway	1986	Statoil
Gullfaks B	142 m	Condeep, 3 shafts	North Sea, Norway	1987	Statoil
Oseberg A	109 m	Condeep, 4 shafts	North Sea, Norway	1988	Norsk Hydro
Gullfaks C	216 m	Condeep, 4 shafts	North Sea, Norway	1989	Statoil
Draugen	251 m	Condeep, 1 shaft	North Sea, Norway	1993	Shell
Sleipner A	82 m	Condeep, 4 shafts	North Sea, Norway	1993	Statoil



(**a**) (**b**)

Figure 19. Illustrations showing (**a**) the concrete gravity base structure (GBS), and (**b**) a labelled GBS.

Figure 20. The Troll A concrete gravity base structure (Courtesy: Statoil).

4. Applications of Offshore Platforms

There are a variety of applications for offshore platforms, with the advantages presented in this section.

4.1. Advantages and Disadvantages of Offshore Platforms

This study presented different fundamentals of the main types of offshore structures (fixed and floating) in Sections 2 and 3. The design considerations have also shown that these offshore structures have unique capacities. Each offshore platform is designed for specific purpose, however some offshore platforms such as drilling submersibles could have general application for drilling different well sites. Hence, the applications of these concepts in the offshore platforms are dependent on the functionalities which lead to their advantages. Offshore platforms have a variety of uses in the marine industry. For example, oil or gas platforms might provide storage facilities for oil and gas before being transported to refineries. The advantages have been reported on a variety of offshore structures [299,300]. The design and development of these structures have been identified in a variety of literature on CGBS [300–312], FPSOs [313–329], compliant platforms [330–344], fixed jacket platforms [345–369] and SPARS [370–389]. Another well-known application of offshore platforms is for generating energy via offshore wind farms [390–400].

Although, offshore platforms are subjected to a variety of strong forces (such as ocean waves, wind, and currents), and the materials used to construct them must withstand these forces. Based on platform design, steel and concrete are the most common offshore construction materials, although most concrete based structures are not very popular in recent times due to their limitations. The advantages and disadvantages of different offshore platforms are summarized in Table 13. Figures A6 and A7 of Appendix A show the location of most of the deep water offshore structures in the Gulf of Mexico.

Table 13. Advantages and Disadvantages of offshore platforms.

Platform	Advantages	Disadvantages
Jacket Platform	• Can handle significant topsides weights • Good motion characteristics • Suitable for drilling/workover operations	• Mating of jacket structures • Weight increases as water depth increases • Requires heavy lift, Derrick Barge • Requires offshore hook-up • Limited water depth range
Gravity Platform	• construction onshore for transport; • towing to the site of installation; • quick installation by flooding; and • use of traditional methods and labor for installation.	• unsuitability for sites with poor soil conditions; • long construction periods delaying the start of production; • natural frequencies falling within the range of significant power of the input wave spectrum.
Compliant Tower	• Good motion characteristics • Suitable for drilling/workover operations • Dry tree • Robust relative to payload changes • Lighter than fixed jacket platforms • Installation flexibility	• Requires heavy lift Derrick Barge • Requires offshore hook-up • Limited water depth range
SPAR	• Superior stability • Dry trees • Accommodates payload changes • Friendly to offset drilling • Passive hull system • Low maintenance cost • low heave and pitch motion compared with other platforms • use of dry trees (i.e., on the surface); • ease of fabrication; • unconditional stability because the center of gravity is always lower than the center of buoyancy, resulting in a positive GM; and • derives no stability from the mooring system and hence does not list or capsize even when completely disconnected from its mooring system.	• Topside lift at the installation site • Large derrick barge required for topsides installation • Difficulty of installation because the hull and the topsides can only be combined offshore after the spar hull is upended; • Little storage capacity, which brings along the necessity of a pipeline or an additional FSO; and • Lack of any drilling facilities.

Table 13. *Cont.*

Platform	Advantages	Disadvantages
TLP	• Dry tree • Dry wellheads • Quayside topsides-hull integration • deep water capability; • Low maintenance cost; • mobility and reusability; • low-cost increase with the increase in water depth; and • stability, because the platform has minimal vertical motion.	• Sensitive to deck payload change • Active hull system • Not friendly to offset drilling • Tendon fatigue • high initial cost; • fatigue of tension legs; • high subsea cost; • little or no storage; and • difficult maintenance of subsea systems.
Semisubmersible	• A large number of flexible risers possible • Good motion response • having better stability in harsh environments, • large deck area; and • higher mobility	• Wet tree only • High maintenance cost • Fatigue motion unfriendly to risers • Limited topside weight capacity • No oil storage facility
FPSO	• Early production • Providing field storage • Extensive deck area of a large tanker provides flexibility in process plant layout • Less weight sensitive than other types of floating production systems • Ability to utilize aging or surplus tanker hulls for conversion to an FSPO vessel; • low cost; • mobility and reusability; • reduced lead time; • quick disconnecting capability which can be useful in iceberg-prone areas; • little infrastructure required; and • turret mooring system enables FPS (converted ship type) to head into the wind/waves reducing their effect.	• The subsea tiebacks connected with FPSOs typically result in increased well maintenance expenses. • limited to small fields; • low deck load capacity; • damage to risers due to motion; • poor stability in rough seas; and • little oil storage capabilities.

4.2. Exploratory Application of Offshore Platforms

This study presented various exploratory applications of offshore structures (fixed and floating) used in the oil and gas industry. Due to the orientation of the superstructure, the foundation of this semi-submersible in deeper waters needs high payload integration for minimized motion responses across every degree of freedom (DoF). During production on the platform, the oil and gas are separated and transferred to shore via pipelines or tankers. To achieve these, proper planning must be conducted for the lifting, transportation, installation, design, fabrication, and commissioning of these offshore petroleum platforms. Among the exploratory applications are (un)loading hose applications via shuttle tankers (or FPSO) and single point mooring (SPM) buoys. Other applications are ocean monitoring buoys, breakwater and wave energy devices. However, larger exploratory applications are seen as presented in recent luxury semisubmersibles, semisubmersible crane vessels (SSCV), offshore support vessels (OSV), and rocket launch pads.

4.2.1. Luxury Cruise

Due to the obvious level of stability that semisubmersibles can provide through reconfiguration, deep-draft semisubmersibles are the wave of the future for ocean engineering. Various press publications, ranging from a Cable News Network (CNN) article to an exclusive Forbes article, New York Times, Huffington Post, The Sun News, and Yatch World review made reviewed this Kokomo Ailand [400–407]. These journalists published articles covering the event on a novel kind of luxury cruise that was fashioned after a mini-island in September of 2015 [390]. Migaloo Private Submersible Yachts designed the floating system by using he column stabilized semisubmersible concept to construct the hull of the floating mini island. This hull would have an exceptionally high level of stability in order to operate as a yacht or luxury cruise ship [254]. The type and extent of deck support integration were the main advantages it provided over traditional cruise ships [400–407]. Recent years have seen some rather bizarre ideas in yacht design, from Lego-inspired vessels to futuristic craft that resemble Concorde jets on water [400]. Different rendered views of the super yacht are given in Figure 21.

Figure 21. Views of the Mini Island Semisubmersible—Migaloo's Kokomo Ailand, showing (**a**) isometric view and (**b**) front view (Adapted/Reused with permission from Christian Gumpold, CEO of Migaloo Private Submersible Yachts and Migaloo Submarines. Courtesy: Migaloo).

According to Migaloo [401], the Kokomo Ailand is a private floating habitat based on semi-submersible platforms with an overall length of 117 m, a beam of 78 m and a draft between 20.5 m to 9.7 m. However, it is still safe to say that nothing compares to Kokomo Ailand, an 80-m-tall private floating island with two beach clubs, a waterfall, and a shark feeding station. The fact that Kokomo is a real place is arguably the most amazing of all. In reality, the project's designers, Migaloo, presented their ideas at the 'Monaco Yacht Show', and they already had "quite strong" expressions of interest from clients all around the world, at the time of its design [400]. The structure gives a better look at the stunning layout of a super yacht as well as a semisubmersible. The untrained eyes may mistake the ship for an upscale oil rig, despite the fact that it is much more opulent. The futuristic floating island has two elevators, a jacuzzi with a glass bottom, and a penthouse that is 80 m above sea level. However, to transport large, hefty vessels would require time and movement at a speed of eight knots using eight (8) Azipods [402]. It is simply a piece of floating land, yet it is designed like an island that was influenced by nature. It can be supported by specially made support vessels, which are currently popular in the yachting and shipping sectors. Thus, it functions as an offshore primary base or hideaway from which one may travel anyplace. However, the design is also inspired by owners demands and the need to evolve from conventional designs. In a recent article by Migaloo [401], it depicted the evolution of the floating structure (submersible yacht) as a result of the impact of sustaining technological changes with disruptive concepts using the model by Professor Christensen C.M. [408], as seen in Figure 22.

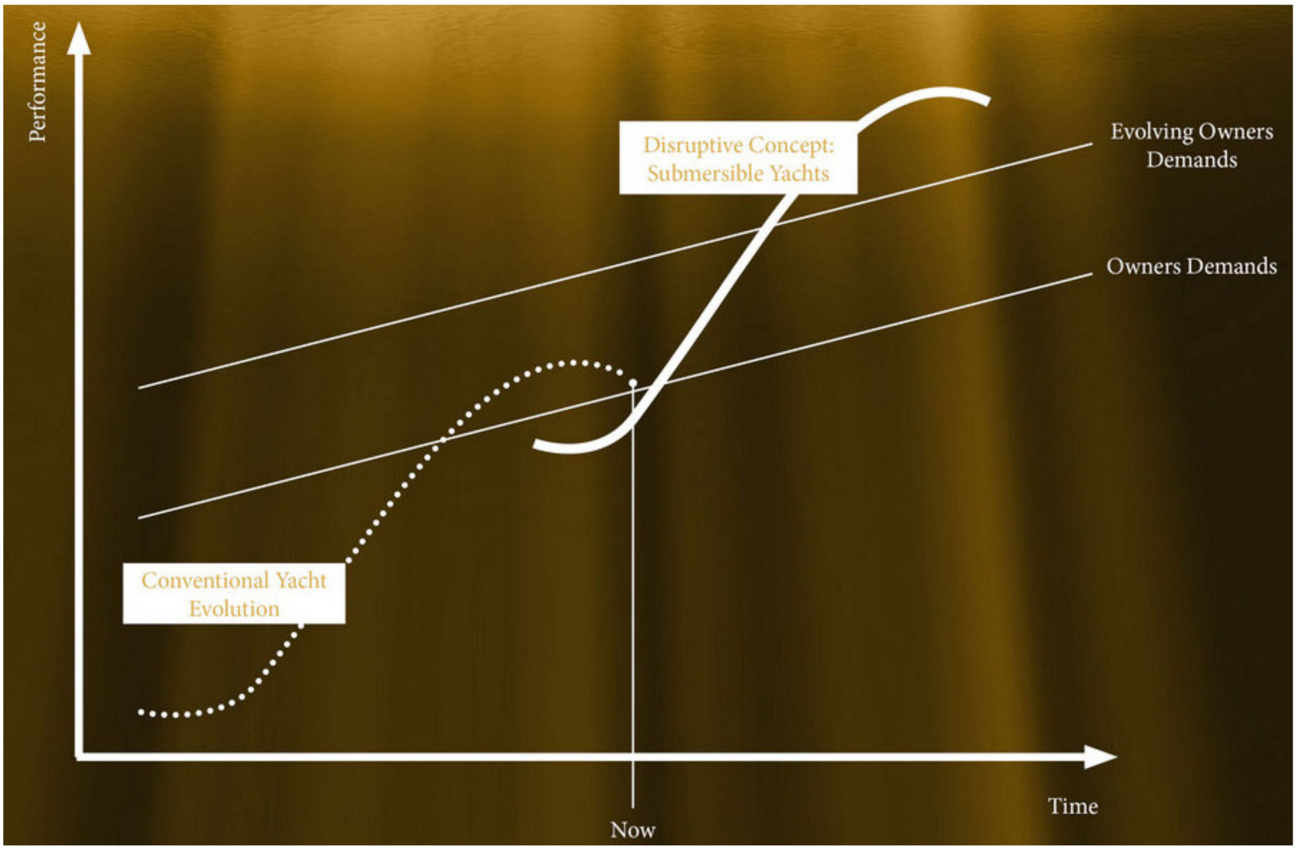
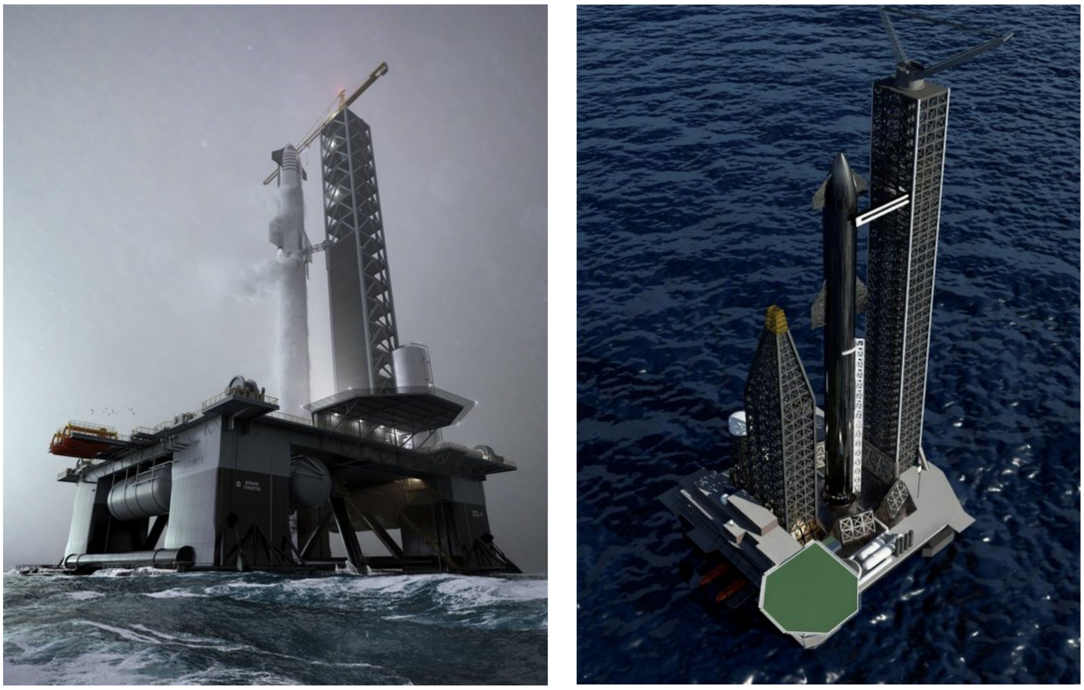


Figure 22. The impact of evolution and sustaining technological changes with disruptive concepts to meet market demands and product performance (Courtesy: Migaloo).

4.2.2. Offshore Rocket Launch and Landing Platform

Another application is an offshore rocket launch and landing platform. Space Exploration Technologies (SpaceX) is investigating the potential use of modified semi-submersible oil drilling rigs for the launch and landing of their new completely reusable rocket Starship on a specific Starship offshore platform [409–417]. SpaceX has acquired two old offshore oil drilling rigs as the ENSCO/Valaris 8506 offshore model, which is a specified destination for the Starship spaceship. The two floating spaceports—Phobos and Deimos, were given them the names as the named after the moons of Mars. However, launch pads can also be used in other ways. A semi-submersible drilling rig called Ocean Odyssey has been modified to use as a rocket launcher. The drilling platforms were essentially identical when they were built and when Elon Musk, the owner of SpaceX, purchased them under the names ENSCO/Valaris 8500 and 8501, respectively. As part of a six-month effort, Phobos was relocated from the Port of Galveston to Pascagoula, Mississippi, in January 2021 to start the retrofit of the rig for Starship operations. The majority of the outdated equipment on the rig's deck has been removed as of July 2021. Since one of the platforms was supposed to be substantially operational by the end of 2021 and that Starships would fly out to sea and land on the platform later in 2022 to be carried to the platforms, refitting had also started around January 2021 on Deimos at the Port of Brownsville, USA. At the time of this publication, the Deimos platform was still under development. Figure 23 shows Deimos ocean offshore spaceport which is an offshore launch platform.



(a) (b)

Figure 23. Rendering views of the Deimos rocket launch platform to be completed in 2022/2023, showing (**a**) the starship fueling up before liftoff on its offshore launch platform, and (**b**) the aerial view of ocean offshore spaceport Deimos (Courtesy: SpaceX).

4.2.3. Converted Offshore Structures

In recent times, the use of converted offshore structures has been seen to have increasing advantages in exploratory, drilling and production activities. For floating offshore units, there are eight (8) distinct hull types to choose from [418]. These converted offshore structures include Mobile offshore drilling units (MODU), Service Offshore Vessels (SOV), and Offshore support vessels (OSV). The ship-shaped monohull is the most prevalent kind of vessel, such as the use of the Floating Storage and Offloading unit (FSO) P-47 which was converted from a former Very Large Crude Cargo (VLCC).

The offshore energy market is subject to frequent fluctuations, which also affect the demand for installation tools, floating structures, and support vessels [419]. The cost of new construction is high, and it frequently takes too long to reap the benefits of an opportunity when it arises. Another option is to upgrade or convert an existing unit. There are different tiers of capability growth when converting or upgrading existing equipment. With each level come higher complexity, hazards, and rebuilding expenses. Options include extending the life and modernising an older ship, temporarily converting it, increasing its capacity, adding features, altering its current function, and finally, completely converting an older merchant cargo ship into a brand-new offshore unit. If a major vessel conversion project is properly planned and managed, it is possible for it to be competitive with newbuilding choices. There are a lot of excellent prospects for upgrades and conversions within the sizable pool of current commercial and offshore vessels, both ageing and new vessels. This new lease on life broadens their operational and financial horizons and assists the offshore industry in making extraordinary strides in the performance of transport, building, and installation [418–422].

The considerations for the selection of offshore platforms are very important also for converting offshore structures from one purpose to another [419]. Purpose-built production semi-submersible platforms were created when the oil industry expanded into harsher regions and deeper waters. ‘Deepsea Saga’ was converted on Agyll oil field, as Agyll FPF semi-submersible which was later converted to Deepsea Pioneer. The Transworld 58 was the first purpose-built semi-submersible production platform used on the Balmoral field in the UK North Sea, was built in 1986 and later converted. There were various platforms that were converted, though [235,423–432]. The Spirit of Columbus drilling rig was converted into Petrobras 36, which sank in 2001. Another offshore vessel that was renovated as part of a joint venture between BP and BHP was the Atlantis PQ. However, the largest converted semi-submersible platform for Production-Drilling-Quarters purpose is Thunder Horse PDQ with GVA40000 design.

Due to their excellent stability, wide deck areas, and variable deck load, semi-submersibles are particularly well suited for some operations which the offshore support vessel can perform [249,433–442]. Some vessels have two (2) build dates because the second one represents the date they were rebuilt. However, the latest dates are mostly considered, because it represents the current qualification class and classification for the vessel or offshore structure. These vessels include the offshore multiservice vessel Q4000 which was built in 2002 for Caldive. The Transocean Marianas which is a 1979-built Offshore Safety Support Vessel was later transformed into a drilling vessel. While Sedco/Phillips SS was the first vessel built in accordance with Red Adair's suggestions, Iolair, an offshore safety support vessel, was built for BP in 1982. After being decommissioned, offshore production platforms have also been transformed into other offshore constructions [443–453]. Drilling semi-submersibles were modified for use as integrated drilling and production platforms when oil fields were initially created offshore. The Transworld 58 drilling semi-submersible was converted into the Argyll FPF, the first semi-submersible floating production platform, in 1975 for the Hamilton Brothers North Sea Argyll oil field. These vessels provided incredibly reliable and affordable platforms, such as the recent Norwind Breeze SOV converted by VARD for Norwind Offshore in 2022 [454–456]. Table 14 shows the list of some converted vessels and offshore platforms with conversion/delivery date.

Table 14. List of some converted vessels and offshore platforms with conversion/delivery date.

Conversion Name	Former Platform Name	Owner	Location	Conversion /Delivery Date
Atlantis PQ	Atlantis PQ	BP and BHP	GoM, USA	2007
Thunder Horse PDQ (Production, Drilling, Quarters)	Thunder Horse PDQ	BP and ExxonMobil	GoM, USA	2005
Transocean Marianas semi-submersible drilling unit	Tharos from 1979 to 1994, Polyportia from 1994 to 1996, and P. Portia from 1996 to 1998.	Chevron	GoM, USA; Offshore West Africa (OWA)	1979
Greater Stella FPF 1	FPF1 (2017), AH001 (2012), Sedco/Phillips SS (1986)	Petrofac Facilities Management	Stella Field, North Sea	2017
Transworld 58 drilling semi-submersible	Transworld 58 Floating Production semisubmersible (1975), North Sea Pioneer, Norscot Producer, drilling semi-submersible, Duncan FPF semi-submersible (1985)	Hamilton Brothers Oil and Gas	North Sea	1975
Deepsea Pioneer FPF semi-submersible	'Deepsea Saga'-converted Agyll FPF semi-submersible (1971–1975), Deepsea Pioneer (1984)	Hamilton Brothers Oil and Gas	Agyll Field, North Sea	1983
Petrobras P-36 semi-submersible	Spirit of Columbus drilling rig (1984–1994), P-36 (1997–1999)	Petrobras	Roncador Oil Field,	1995
West Defender jack-up	Offshore Defender jack-up	Scorpion Offshore	-	2007
Mr. Demp jack-up	later Loosbrock Sun, Songa Sun, Achilles, RBF 192, THE 192, Blake 505, GPS Producer 1, Mopu Sepat	Marine Drilling	-	1981
Vanguard I jack-up	Later Dual Rig 41, Ensco 51, Deepsea Fossil	Huthnance Drilling	-	1982
Ulstein Service Operations Vessel (SOV)	Ulstein PX121 Platform Supply Vessels (PSV)	Ulstein	North Sea	2022
Norwind Breeze SOV (2022)	Skandi Responder Offshore Tug/Supply Ship (2015)	Norwind Offshore	North Sea	2015/2022
FSO Africa	Hellespont Metropolis (2002), TI Africa (2004), FSO Africa (2010)	-	Persian Gulf	2010
FSO Asia	Hellespont Alhambra (2002), TI Asia (2004), FSO Asia (2009)	-	Persian Gulf	2010

Table 14. *Cont.*

Conversion Name	Former Platform Name	Owner	Location	Conversion /Delivery Date
Transworld Rig 64 jack-up	Later Noble Rig 64, Johnnie Hoffman, Noble Johnnie Hoffman, Paragon 8301	Transworld Drilling	-	1976
Pool Rig 53	Later Well Services Rig 53	Pool Company	-	1982
Zephyr I semi-submersible	Later Ocean Zephyr, now Atlantic Zephyr	Odeco	-	1973
Pat Rutherford Sr.	Later Dixilyn-Field 95, Sonat D-F 95, Boss Prithvi, Seadrill, Odin Neptune	Viking Offshore A/S	-	1974

5. Conclusions and Recommendations for Future Research

The manuscript presents a comprehensive review on different offshore structures—fixed and floating offshore platforms to examine some sustainable design approaches. It gives very interesting data and provides a valuable tool in support the general understanding, design and management of these structures, certainly in accordance with the industry design guidelines. The manuscript includes an introduction with a description of the state-of-art of the different types of offshore facilities and their purpose, classification of different types of these applications, with their advantages and disadvantages. Part II of this review [5] presents an in-depth review on considerations of most relevant parameters influencing the design process, a section focused on considerations regarding the management of the offshore facilities and the need for future research.

In this paper, the comprehensive review included the state-of-the-art on various offshore platforms and achievements made in the industry. Suitable types of offshore platforms for various seawater depths are offered for long-term operations, high productivity, high serviceability and sustainability. From this review, it has been identified that these platforms are divided into numerous sorts based on their functionality, and application and the depths of water where they operate. Therefore, it is evident that each offshore platform is different, as this review shows their variabilities and unique applicability. Although these platforms are subjected to somewhat large changes as a result of widespread wave activity. These platforms also remain extremely robust in a severe ocean environment, with a large portion of their structure submerged. An example of such platforms is the semisubmersible, as different oil and gas corporations have taken notice of its adaptable but durable properties.

In general, this type of platform is favored due to its ability to produce oil and gas as well as its cost effectiveness. However, other types of offshore platforms are also utilized based on their respective unique applications. Drilling rigs and Semisubmersible platforms were found to be the most promising design in the review study, and they are a viable choice for offshore exploration and production. These designs are also carried out in a variety of geographic locations and environmental conditions. Fixed jacket platforms have been seen in the North Sea and Persian Sea, as these areas do not require offshore structures with ultra-deep drafts, and the weather are not very extreme as most locations in the Gulf of Mexico. Furthermore, the efficient factors required to thoroughly improve the service life and failure patterns of these offshore structures should be considered. In more recent designs, there are exploratory applications of new concepts, production facilities and related devices such as wave energy and breakwater devices. Hence, new and sustainable design approaches have been applied as these techniques are more adaptable to these devices, and aid faster design of offshore structures. However, adequate validation to verify each design is recommended. In a nutshell, this review presents types of application, benefits and challenges of offshore structures. The solutions from these different technologies can aid in the design and construction of offshore structures by presenting a reference data source. This review also sheds more light towards the understanding of offshore structures to enable designers with more innovative concepts that are more resilient, efficient, durable and sustainable in the industry.

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Abbreviations

2D	Two-Dimensional
3D	Three-Dimensional
AISC	American Institute of Steel Construction
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
BOEM	Bureau of Ocean Energy Management
BOP	Blowout Preventer
CFD	Computational Fluid Dynamics
CEV	Carbon Equivalent Value
CNN	Cable News Network
CPU	Central Processing Unit
CT	Compliant Tower
DD	Semi Deep Draft Semisubmersible
DDCV	Deep-Draft Caisson Vessel
DNV	Det Norske Veritas
DoF	Degree of Freedom
DTS	Dry-Tree Semisubmersible
FDPSO	Floating Drilling Production Storage and Offloading
FLNG	Floating Liquid Natural Gas
FOWT	Floating Offshore Wind Turbine
FPS	Floating Production Systems
FPSO	Floating, Production, Storage and Offloading
FPU	Floating Production Units
FSU	Floating Storage Units
FSO	Floating Storage and Offloading
GBS	Gravity Base Structure
GoM	Gulf of Mexico
IMA	International Maritime Association

MET-INT	Metocean Interim
MODU	mobile offshore drilling unit
MOPU	Mobile Offshore Production Unit
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
OSV	Offshore Support Vessel
PSV	Platform Service Vessel
RAO	Respond Amplitude Operator
RP	Recommended Practice
SCR	Steel Catenary Risers
SOV	Service Offshore Vessel
SpaceX	Space Exploration Technologies
SPAR	Single Point Anchor Reservoir
SPM	single point mooring
TLP	Tension Leg Platform
TTR	Top Tension Riser
U.A.E.	United Arab Emirates
U.S.A.	United States of America
VIV	Vortex Induced Vibration
VLCC	Very Large Crude Carrier
WEC	Wave Energy Converter
WER	World Energy Report

Appendix A

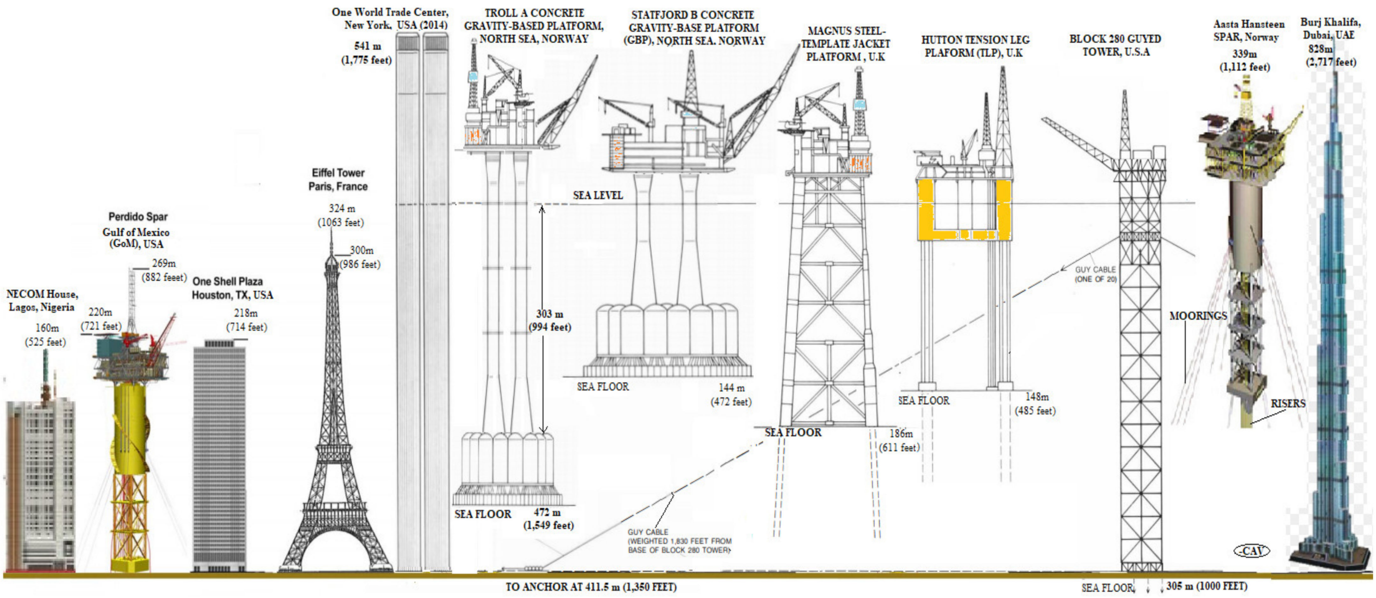

Figure A1. Offshore oil platforms compared to tallest building structures [Credit: Author 1—C.V.A.].

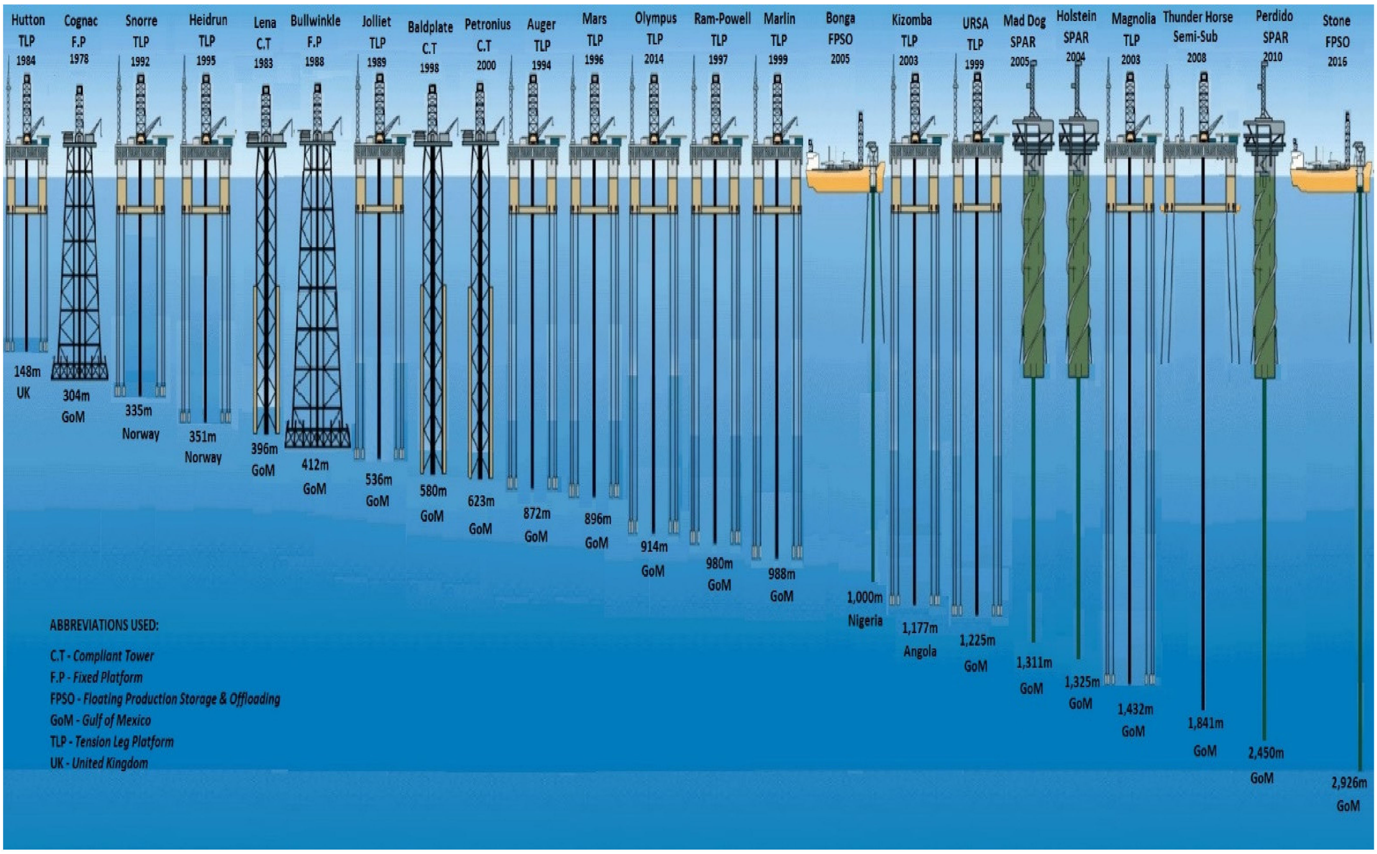

Figure A2. History of Offshore Deep water platforms showing different offshore platforms, their water depths and installation years [Image Credit: Author 1—C.V.A.].

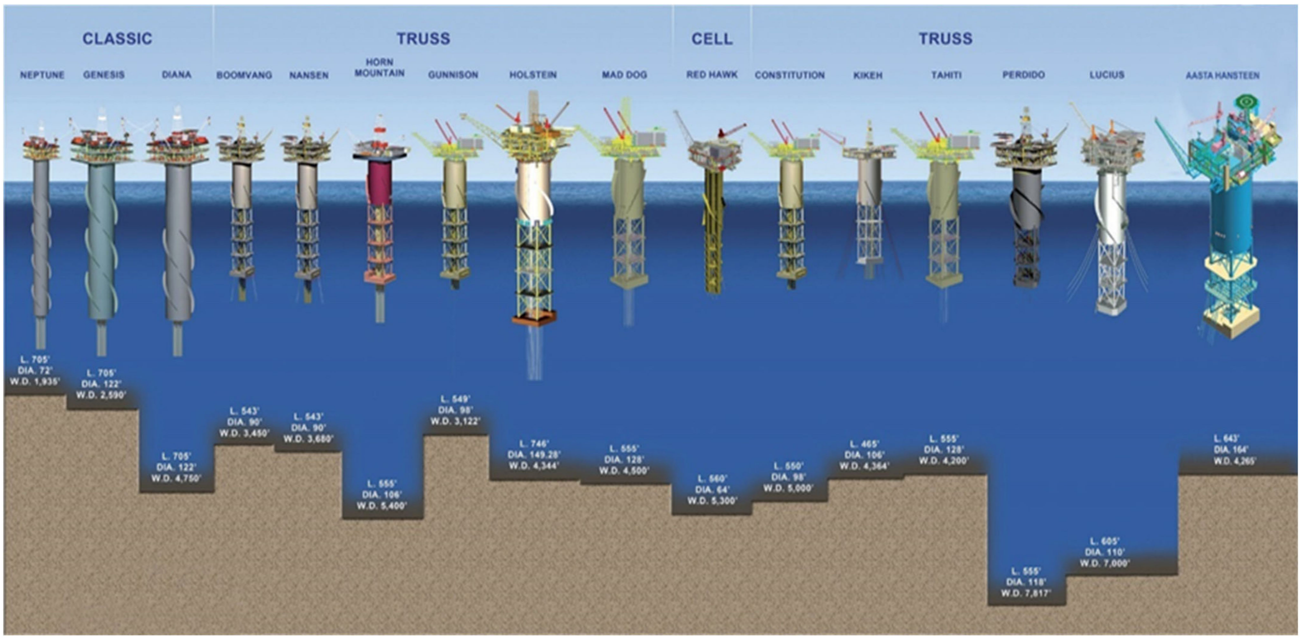

Figure A3. Historical development of SPAR platforms (Courtesy: Technip).

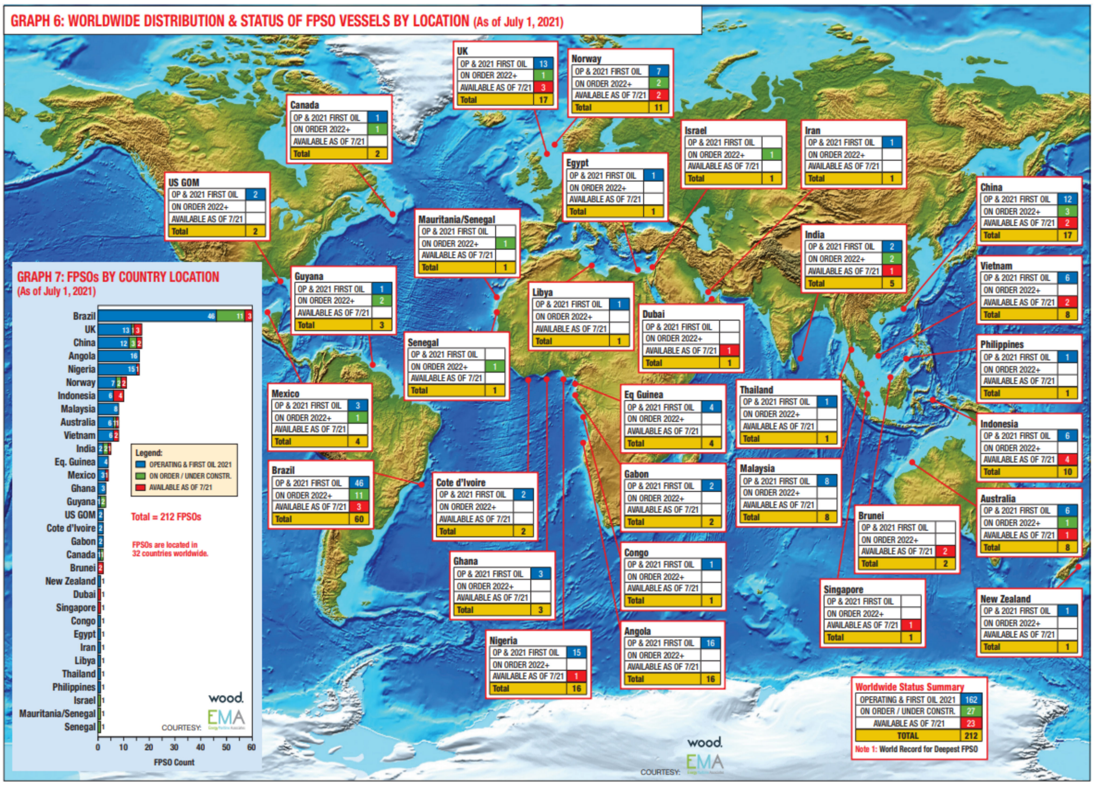

Figure A4. Worldwide distribution and location of floating production, storage and offloading (FPSO) vessels (Courtesy: Offshore magazine, Wood & EMA.).

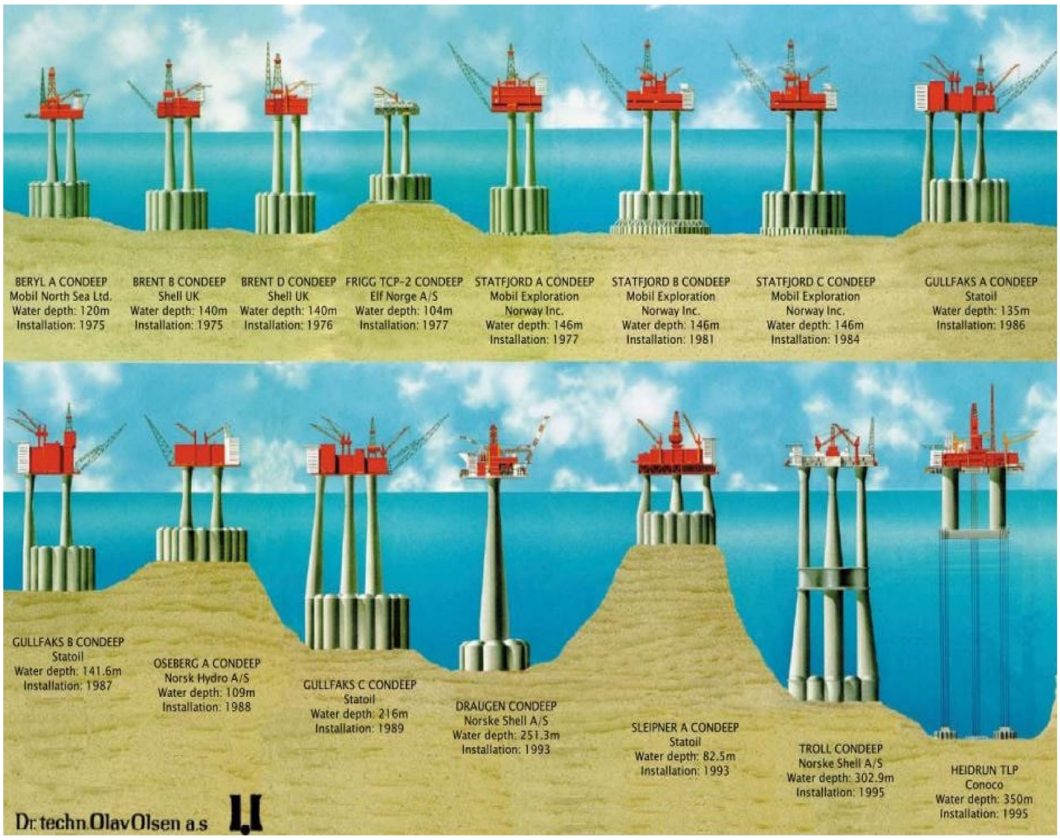

Figure A5. Different Condeep concepts of gravity based structures in the North Sea (Courtesy: Dr.techn, OlavOlsen A.S).

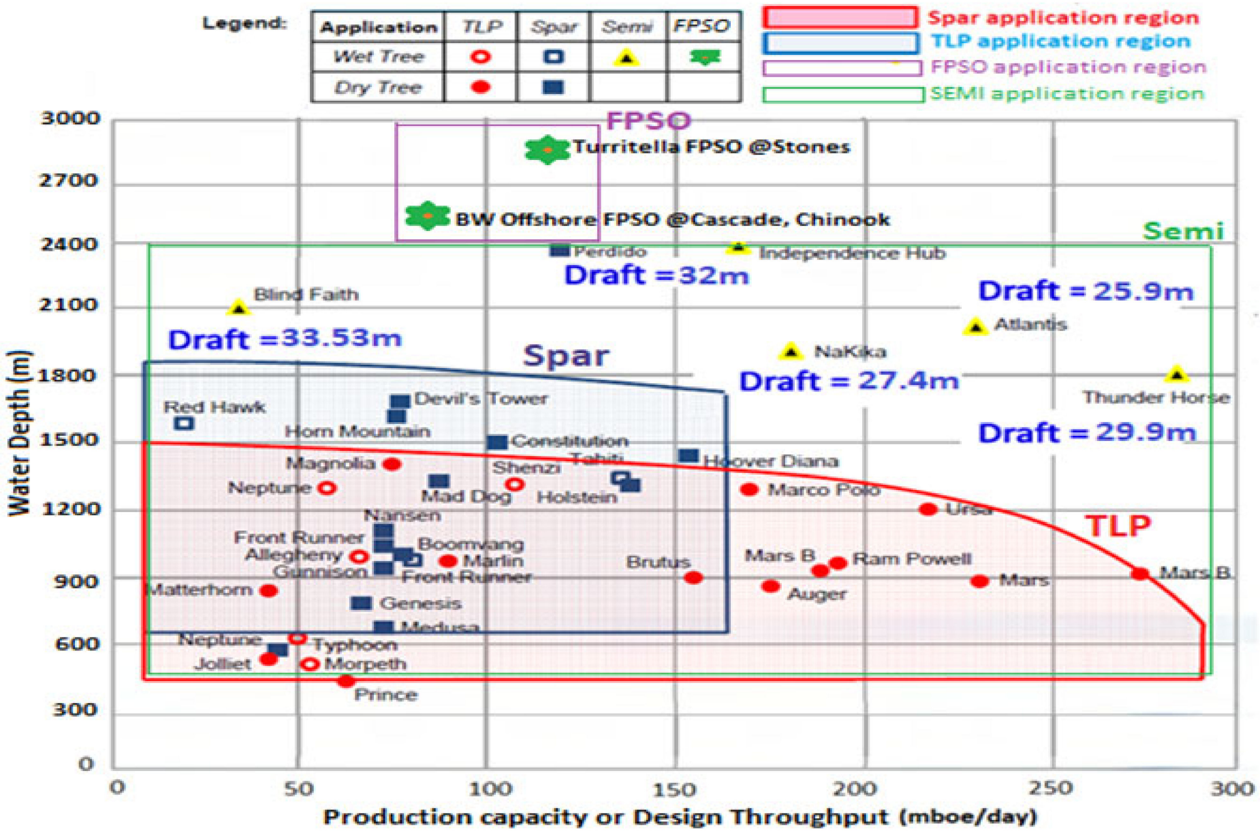

Figure A6. Map of breakdown of Application envelopes for deep-water platforms in the Gulf of Mexico {Illustrated by: Author 1—C.V.A.}.

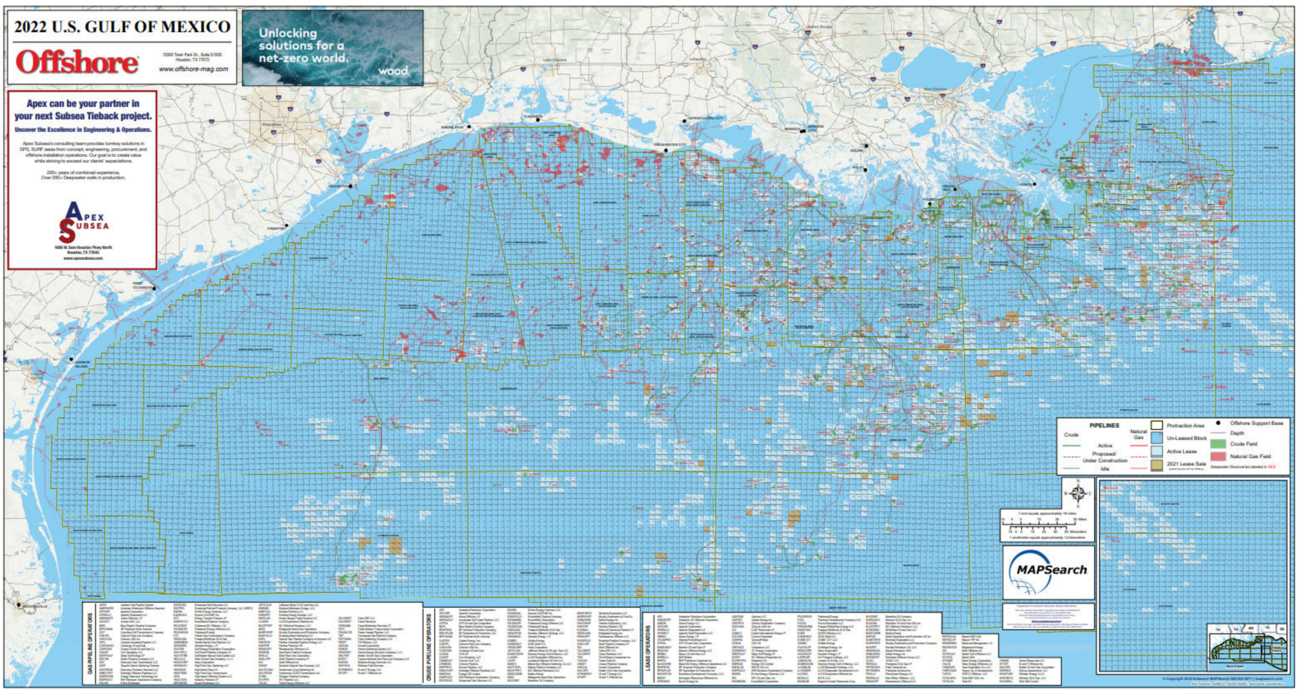

Figure A7. Map of Gulf of Mexico showing Deep water explorations as at 2020 (Courtesy: QuestOffshore and Offshore Magazine).

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