Deepwater Maintenance (EMM 5103)

MSc - Asset Maintenance and Management

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Co-funded by the Erasmus+ Programme of the European Union

Course outline

- Introduction and an overview of offshore structures
- Deepwater Floating Production Systems
- DW Floaters Design Criteria
  - Hydrostatics and Stability
  - Global Response of Floating Structures
- Feature and Concept of Floaters
  - Spar
  - Tension Leg Platform
  - Semi-submersible
  - Floating, production, storage and offloading (FPSO)
  - Sub-Sea Systems

Course outline

- Deepwater challenges
- Mooring line for FPS Systems (Basics, design and Integrity)
- Pipelines and Risers
- Miscellaneous Topics in Floater Systems
  - Geo Hazards
  - A concrete floater concept
  - Deepwater Facility Operations

Learning Objectives

The main objective of the course covers the:

- Definition and concept of offshore structures.
- Difference between shallow water and deep water and the fixed bottom and floating structures
- An overview environmental loading that is necessary for design and maintenance of offshore structure.
- Concept and understanding of hydrostatic and hydrodynamic stability of floating structures

Learning Objectives

- Features and description of various deepwater floating structures i.e. spar, semi-sub, TLP, FPSO and sub-sea installation.
- Concept and description of mooring lines' pipelines and risers.
- Challenges and issues in deepwater

Learning Outcome

At the end of this course, students should be able to:

- Demonstrate the concepts of floating and fixed offshore structures and their application
- Determine the hydrostatic and hydrodynamic stability of floating structures
- Analyze and assess the mooring lines
- Design the fundamental concepts in pipelines and risers

Introduction and an overview of offshore structures
Chapter-1

Introduction

Ocean & Seas: A Hidden Treasure of Resources

Introduction:

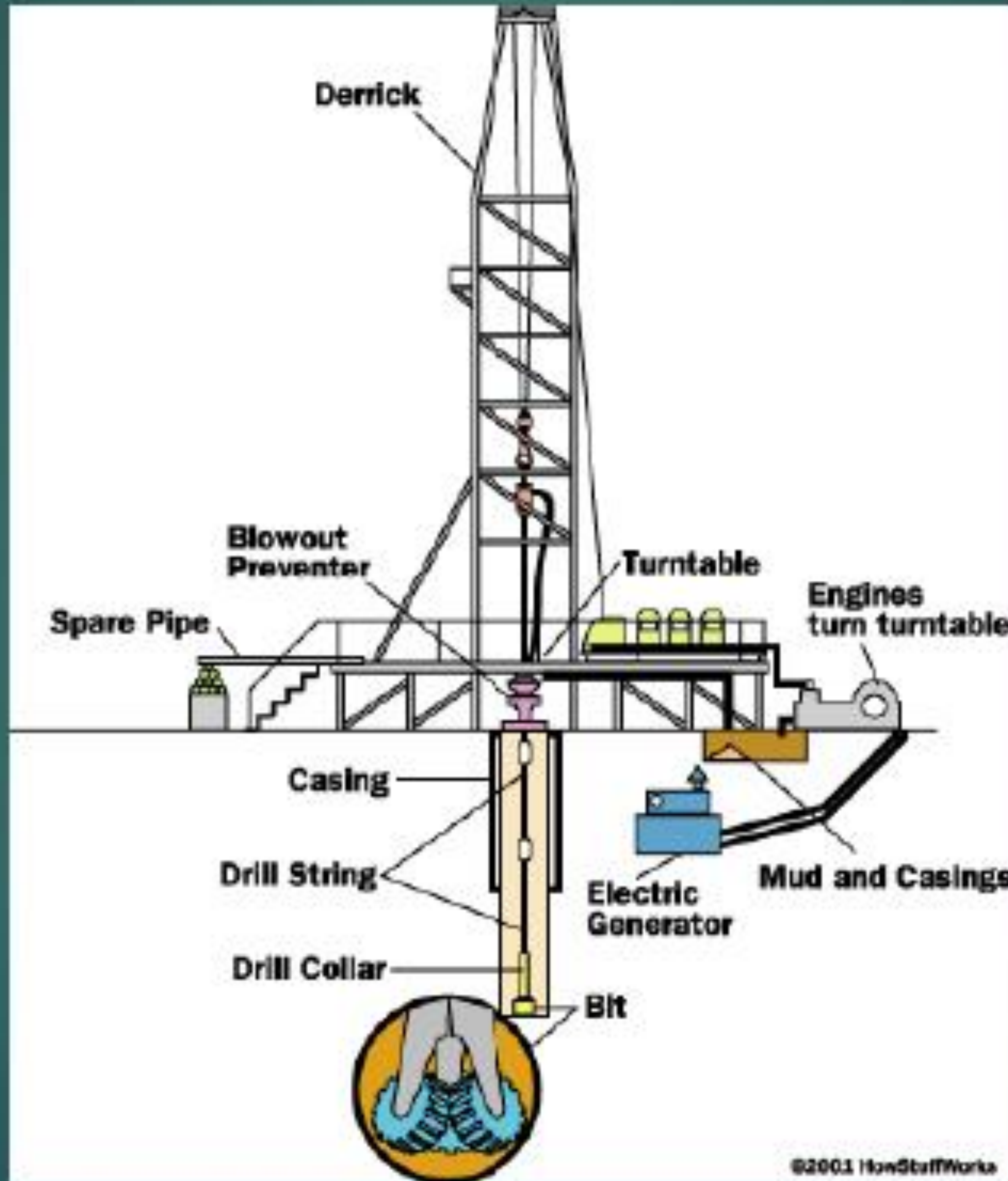
Hydrocarbon a nature gift and a hidden treasure in the oceans and seas

- Hydrocarbons represent the dominant source of energy today.
- 20% of the oil and gas production takes place in offshore areas.
- New reserves to be exploited would increasingly be sought in deeper waters and call for challenging new technologies.

An overview of oil & gas basic

- Oil reserves are the quantities of crude oil estimated to be commercially recoverable by application of development projects to known accumulations from a given date forward under defined conditions.
- The total estimated amount of oil in an oil reservoir, including both producible and non-producible oil, is called oil in place.
  - However, because of reservoir characteristics and limitations in petroleum
  - extraction technologies, only a fraction of this oil can be brought to the surface, and it is only this producible fraction that is considered to be reserves.
  - The ratio of producible oil reserves to total oil in place for a given field is often referred to as the recovery factor, recovery factors vary greatly among oil fields.
  - The recovery factor of any particular field may change over time based on operating history and in response to changes in technology and economics.

Anatomy of an Oil Rig



Drilling Equipment and Terminology

Rotating equipment – *used for rotary drilling*

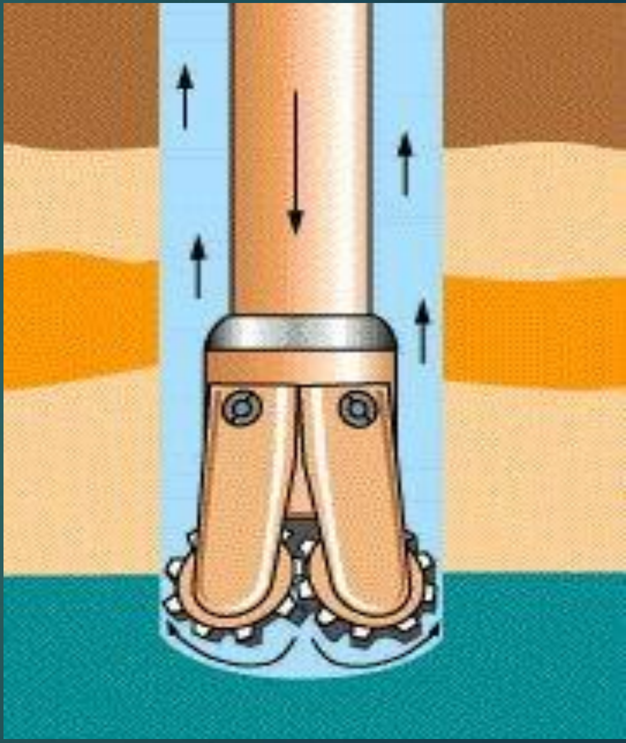
swivel - *large handle that holds the weight of the drill string; allows the string to rotate and makes a pressure-tight seal on the hole*

drill string – *consists of drill pipe (connected sections of about 30 feet (10 meters) and* **drill collars** *(larger diameter, heavier pipe that fits around the drill pipe and places weight on the drill bit)*

turntable or rotary table – *drives the rotating motion using power from electric motors*

Drilling Equipment and Terminology

Drill bit(s) - end of the drill that actually cuts up the rock; comes in many shapes and materials (tungsten carbide steel, diamond) that are specialized for various drilling tasks and rock



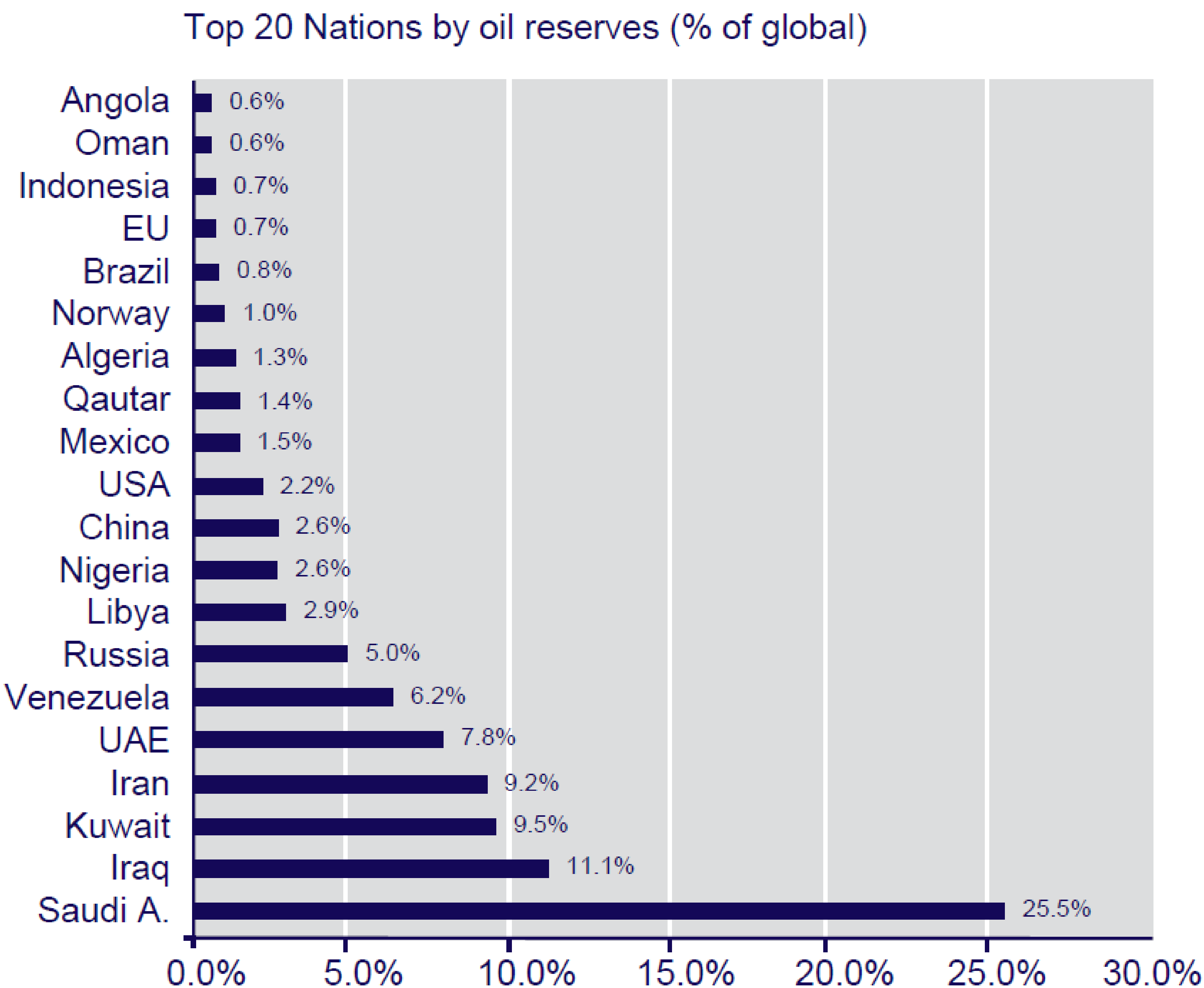
Casing - large-diameter concrete pipe that lines the drill hole, prevents the hole from collapsing, and allows drilling mud to circulate

Drilling Equipment and Terminology

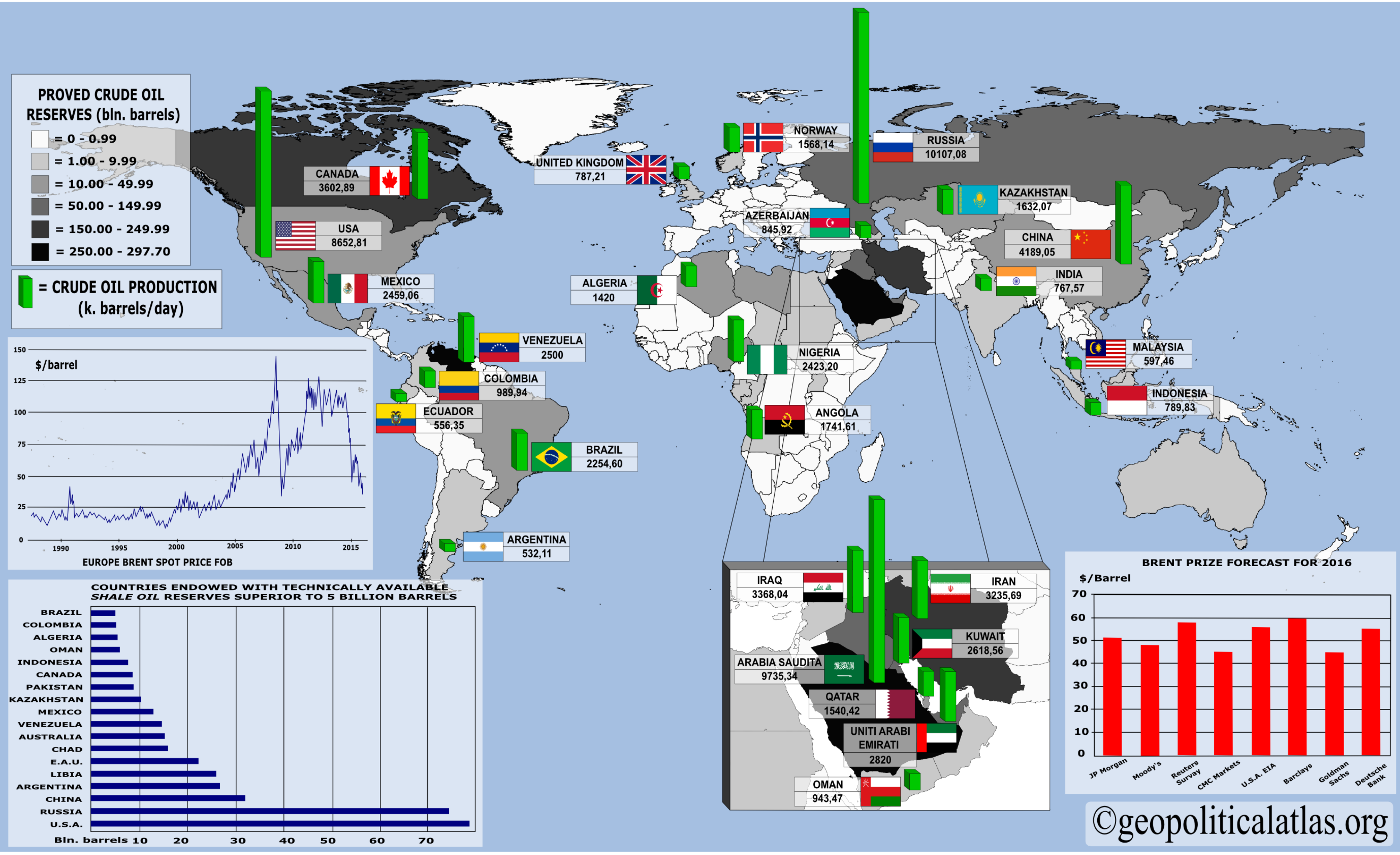
Drilling mud: used to stabilize the excess pressure created due to fluid in the formation used to cool drill bit remove rock chips

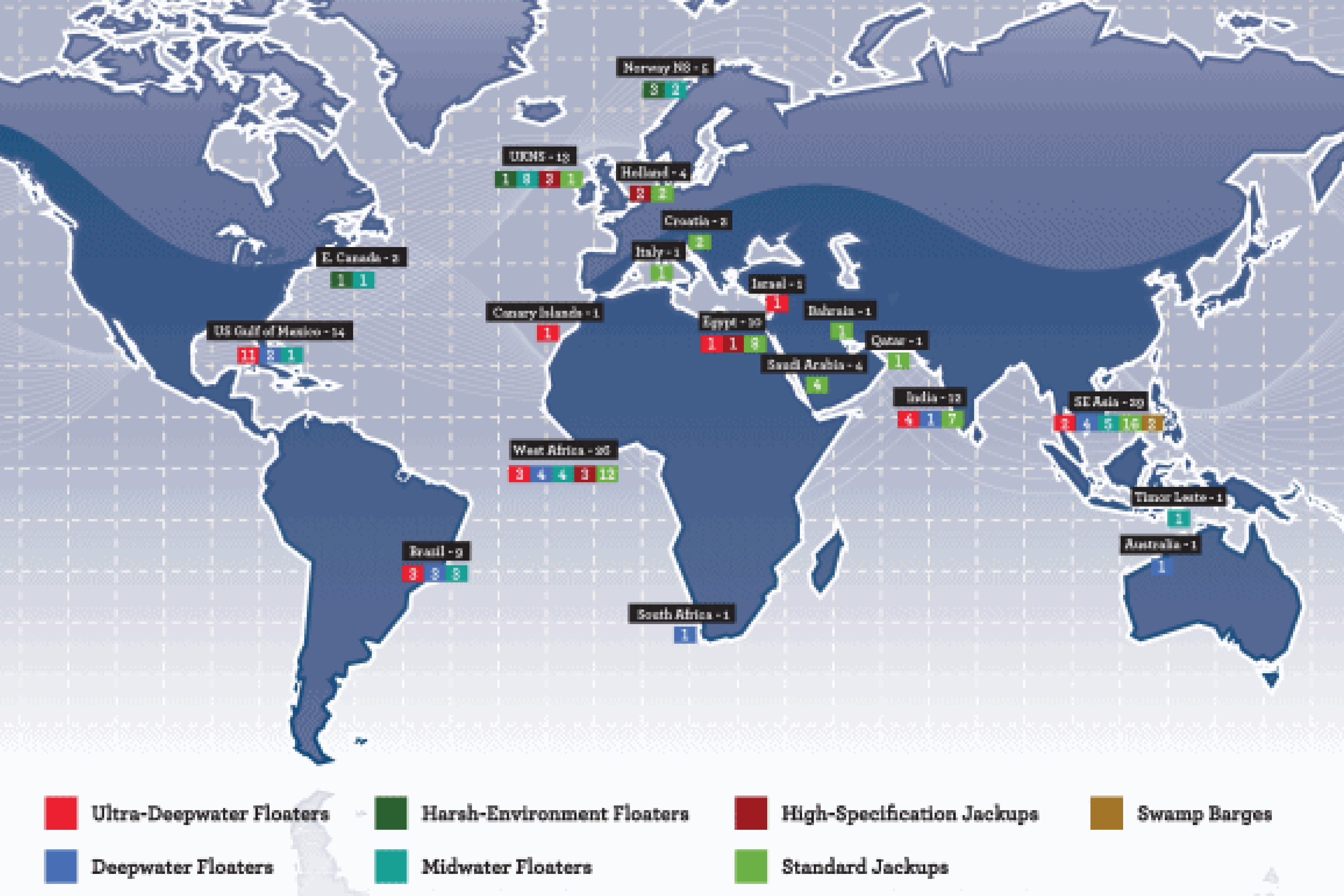
Derrick - support structure that holds the drilling apparatus; tall enough to allow new sections of drill pipe to be added to the drilling apparatus as drilling progresses

Blowout preventer - high-pressure valves (located under the land rig or on the sea floor) that seal the high-pressure drill lines and relieve pressure when necessary to prevent a blowout (uncontrolled gush of gas or oil to the surface, often associated with fire)


Top 20 Nations by oil reserves (% of global)
Angola
Oman
Indonesia
EU
Brazil
Norway
Algeria
Qautar
Mexico
USA
China
Nigeria
Libya
Russia
Venezuela
UAE
Iran
Kuwait
Iraq
Saudi A.
0.6%
0.6%
0.7%
0.7%
0.8%
1.0%
1.3%
1.4%
1.5%
2.2%
2.6%
2.6%
2.9%
5.0%
6.2%
7.8%
9.2%
9.5%
11.1%
25.5%
0.0%
5.0%
10.0%
15.0%
20.0%
25.0%
30.0%

WORLD OIL RESERVES AND MAIN PRODUCERS





Norway NS - 5
3 2
UKNS - 13
1 8 3 1
Holland - 4
2 2
Croatia - 2
2
Italy - 1
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E. Canada - 2
1 1
Israel - 1
1
Canary Islands - 1
1
Bahrain - 1
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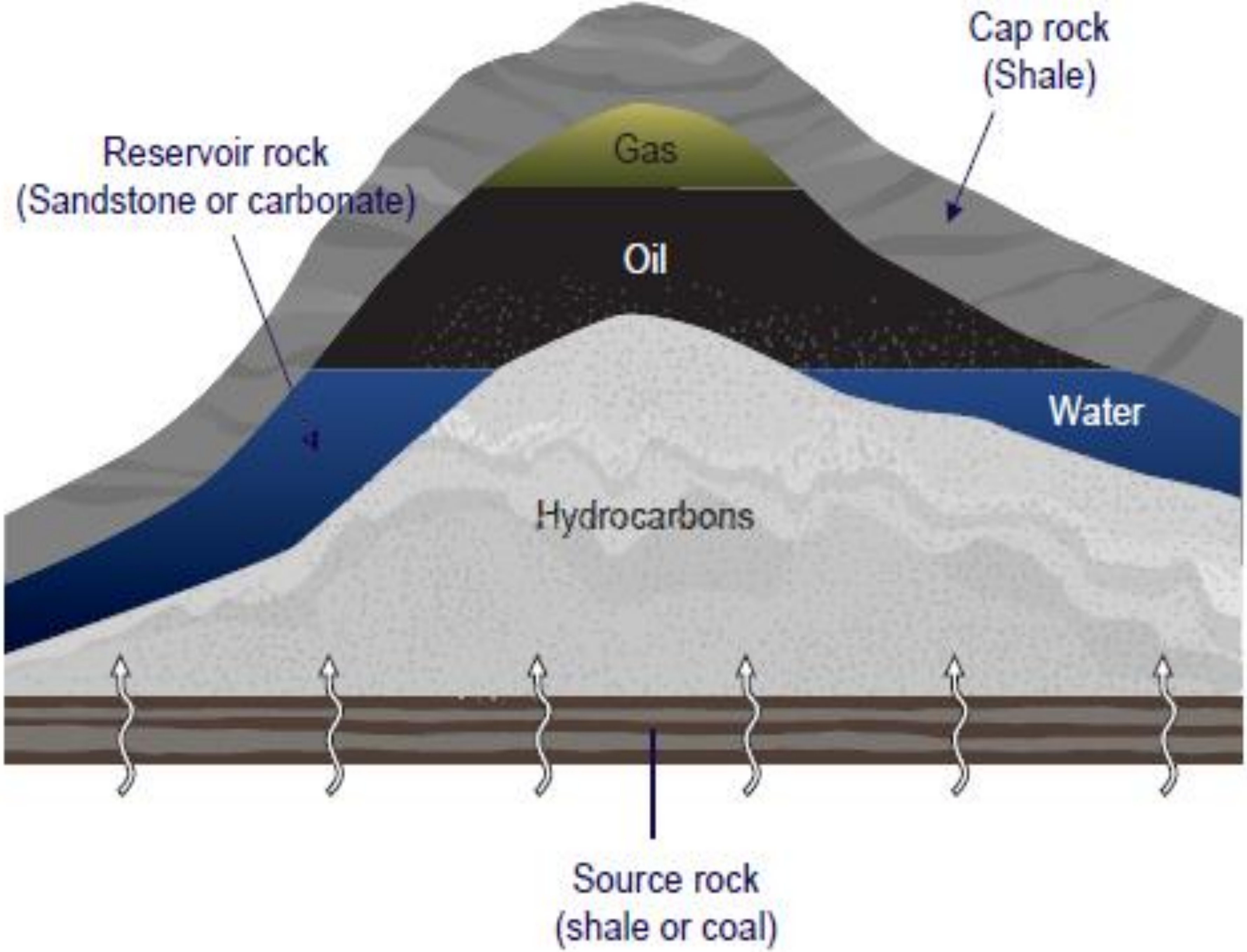
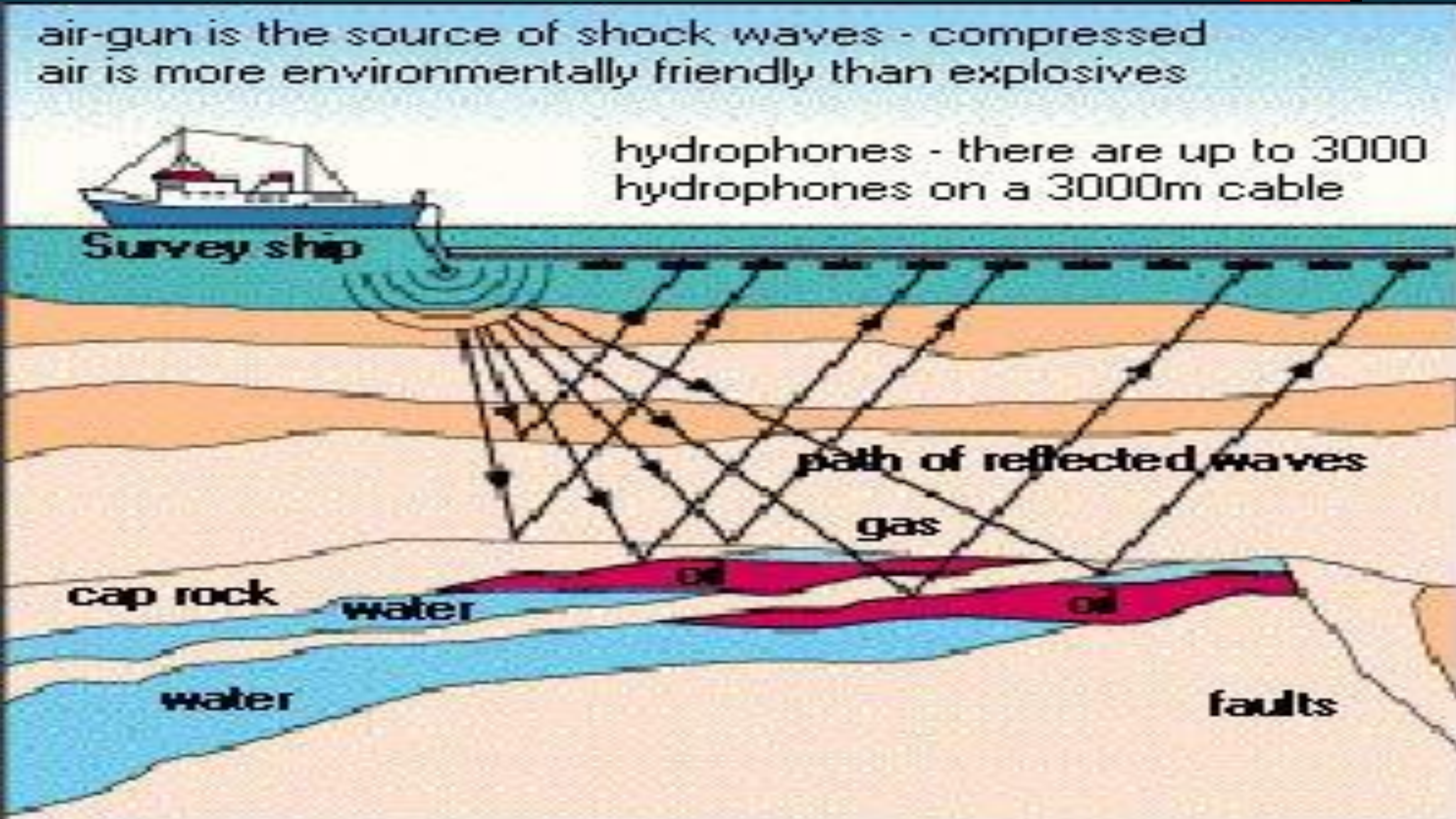
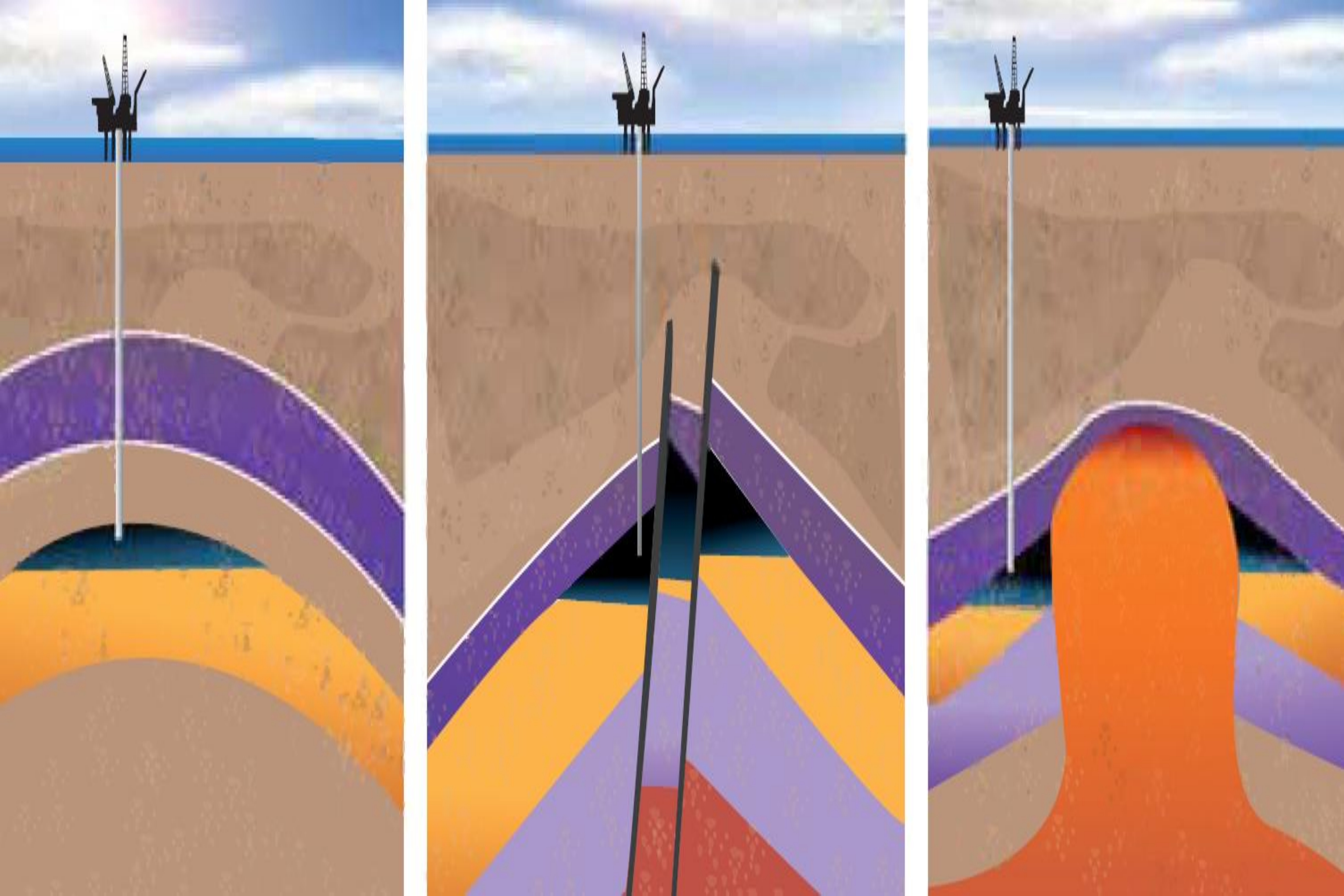
Egypt - 10
1 1 8
Qatar - 1
1
US Gulf of Mexico - 14
11 2 1
Saudi Arabia - 4
4
India - 12
4 1 7
SE Asia - 29
2 4 5 16 2
West Africa - 26
3 4 4 3 12
Timor Leste - 1
1
Australia - 1
1
Brazil - 9
3 3 3
South Africa - 1
1
Ultra-Deepwater Floaters
Harsh-Environment Floaters
High-Specification Jackups
Swamp Barges
Deepwater Floaters
Midwater Floaters
Standard Jackups


Cap rock
(Shale)
Reservoir rock
(Sandstone or carbonate)
Gas
Oil
Water
Hydrocarbons
Source rock
(shale or coal)

Searching for oil over water using seismology





An overview of oil & gas basic: Types of Reserves

Proved Reserves

- Proved reserves are those quantities of petroleum that - by analysis of geological and engineering data - can be estimated with reasonable certainty to be commercially recoverable, from a given date forward, from known reservoirs and under current economic conditions, operating methods, and government regulations.
- If deterministic methods are used, the term reasonable certainty is intended to express a high degree of confidence that the quantities will be recovered. If probabilistic methods are used, there should be at least a 90% probability that the quantities actually recovered will equal or exceed the estimate.

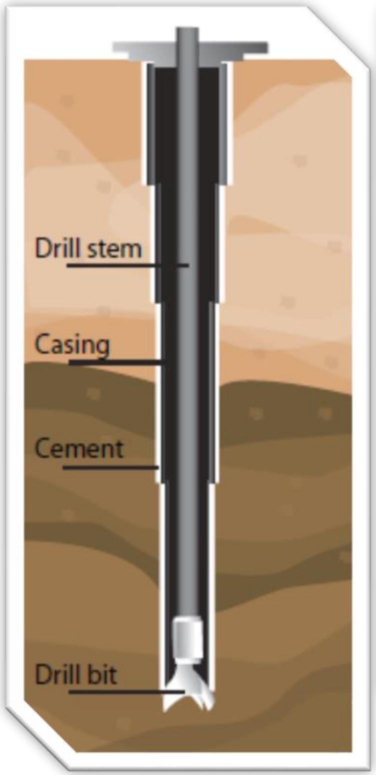
An overview of oil & gas basic: Types of Reserves

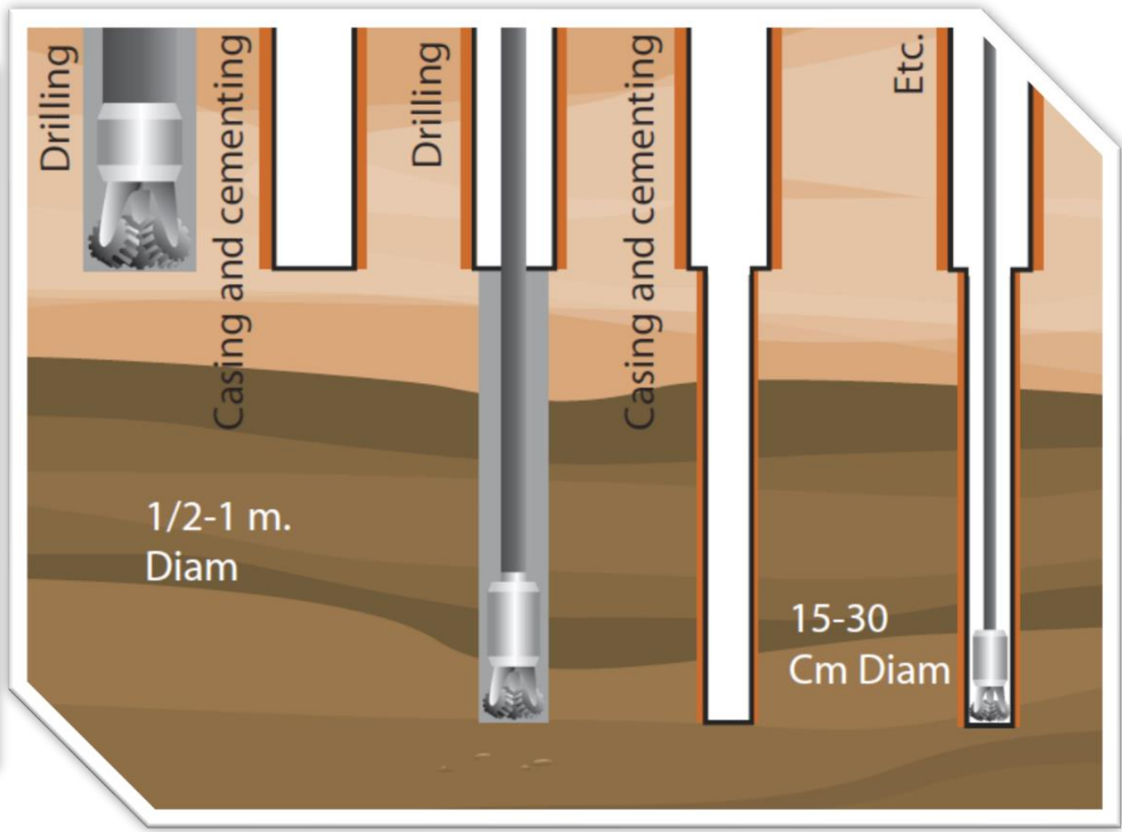
Unproved Reserves

- Unproved reserves are based on geologic and/or engineering data similar to that used in estimates of proved reserves; but technical, contractual, economic, or regulatory uncertainties preclude such reserves being classified as proved.
  - Unproved reserves may be further classified as probable reserves and possible reserves.
  - Unproved reserves may be estimated assuming future economic conditions
  - different from those prevailing at the time of the estimate.
  - The effect of possible future improvements in economic conditions and technological developments can be expressed by allocating appropriate quantities of reserves to the probable and possible classifications.

An overview of oil & gas basic: Drilling

- The largest and most critical investment for any oil company is that of drilling and intervening in wells.
- The creation and life of a well can be divided into 5 stages:
  - **Planning**
  - **Drilling**
  - **Completion**
  - **Production**
  - **Abandonment**





An overview of oil & gas basic: Well Types

- Wildcat wells - when a well is drilled, based on a large element of hope, in a frontier area where very little is known about the subsurface.
  - In many areas oil exploration has reached a very mature phase and the chances of finding oil simply by drilling at random are very low.
  - Therefore, a lot more effort is placed in exploration and appraisal wells.
- Exploration wells - when they are drilled purely for exploratory (information gathering) purposes in a new area.
- Appraisal wells - when they are used to assess characteristics (e.g. flow rate) of a proven hydrocarbon reservoir.
- Production wells - when they are drilled primarily for producing oil or gas, once the producing structure and characteristics are established.

Offshore Structures: An Overview

- Offshore structures are large platforms that primarily provide the necessary facilities and equipment for exploration and production of oil and natural gas in a marine environment.
  - During the initial prospecting phase, jack-up or alternatively floating rigs are used to drill exploration wells, and if the drilling operation proves successful, a permanent production platform may be placed at the site.
  - Initially the exploration well is drilled to determine, whether any oil or gas is present within a given area.
  - Once the decision to initiate an oil production has been taken, a production facility will be placed at the site.

Offshore Structures: An Overview

- The platform may consist of 1 or several platforms, or 1 integrated production platform.
- Depending on the site, location and water depth, the production facilities are either floating platforms or platforms placed direct on the seabed.
- Generally, oil platforms are located in shallow waters on the continental shelf.
- However, as the demand for oil and gas increases and reserves are found in increasingly deeper waters, facilities and equipment must be located either directly on the bottom of the sea or on floating vessels.
- A typical wellhead platform in the North Sea is equipped with 12 - 24 wellheads, and in a few cases up to 30 - 40 wellheads.

Offshore Structures: An Overview

  - Directional drilling allows the reservoirs to be accessed at different depths and at remote positions of up to 5 to 8 km from the platform.
- In general offshore structures may be used for a variety of reasons:
  - **Oil and gas exploration**
  - **Production processing**
  - **Accommodation**
  - **Bridges and causeways**
  - **Loading and off loading facilities**

Offshore Structures: An Overview

- In the steel platform category, there are various types of structures, depending on the use, and depending on the water depth in which the platforms operate.
  - The development of offshore oil and gas fields has played an essential role in the total oil production worldwide, as oil prices in the 1970’s and again from 2005 encouraged increased development in order to attain self sufficiency.
  - The design of offshore structures used for oil and gas exploitation has evolved since then, with national and international standards and regulations assuring that all platforms are designed to withstand a certain wave and wind load and to a high safety level.
  - In most cases platforms are designed to last 25-30 years with respect to material fatigue as well as to withstand impact with boats and dropped objects.
  - Finally to ensure the safety and integrity of existing structures, advanced inspection, monitoring systems and advanced analysis have been activated.

Types Offshore Structures

Types Offshore Structures

- Offshore platforms are used for exploration of Oil and Gas from under Seabed and processing.
- The First Offshore platform was installed in 1947 off the coast of Louisiana in 6M depth of water.
- Today there are over 7,000 Offshore platforms around the world in water depths up to 1,850M

Types Offshore Structures

- Platform size depends on facilities to be installed on top side eg. Oil rig, living quarters, Helipad etc.
- Classification of water depths:

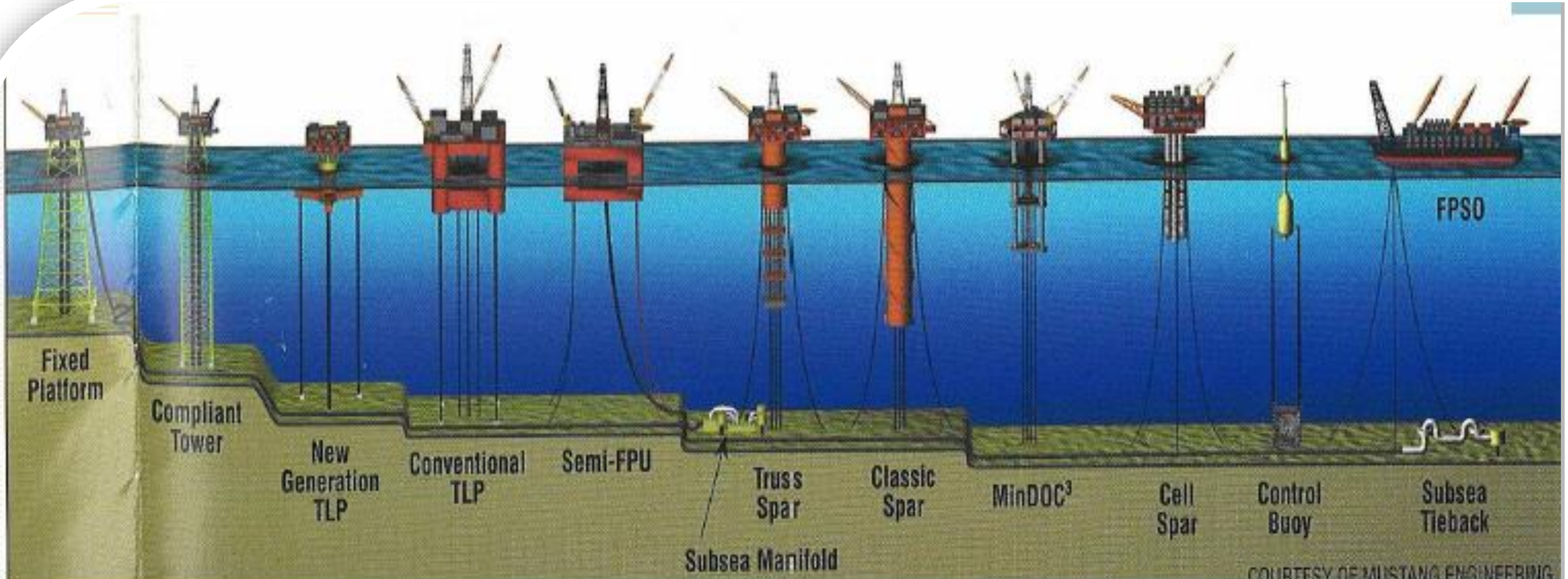
  < 350 M- Shallow water

  < 1500 M - Deep water

  > 1500 M- Ultra deep water

  US Mineral Management Service (MMS) classifies water depths greater than 1,300 ft as deepwater, and greater than 5,000 ft as ultra-deepwater.

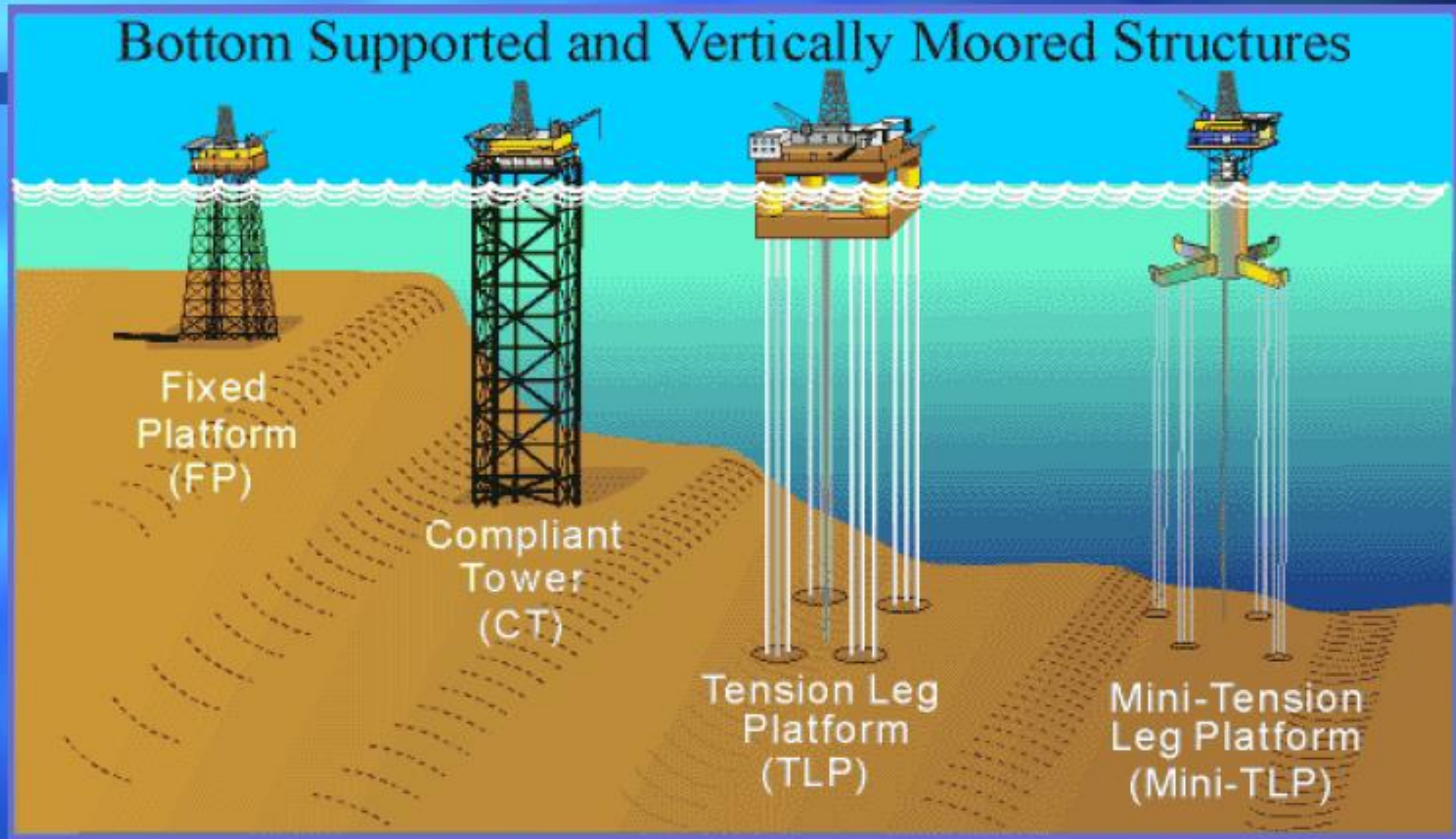
Types Offshore Structures



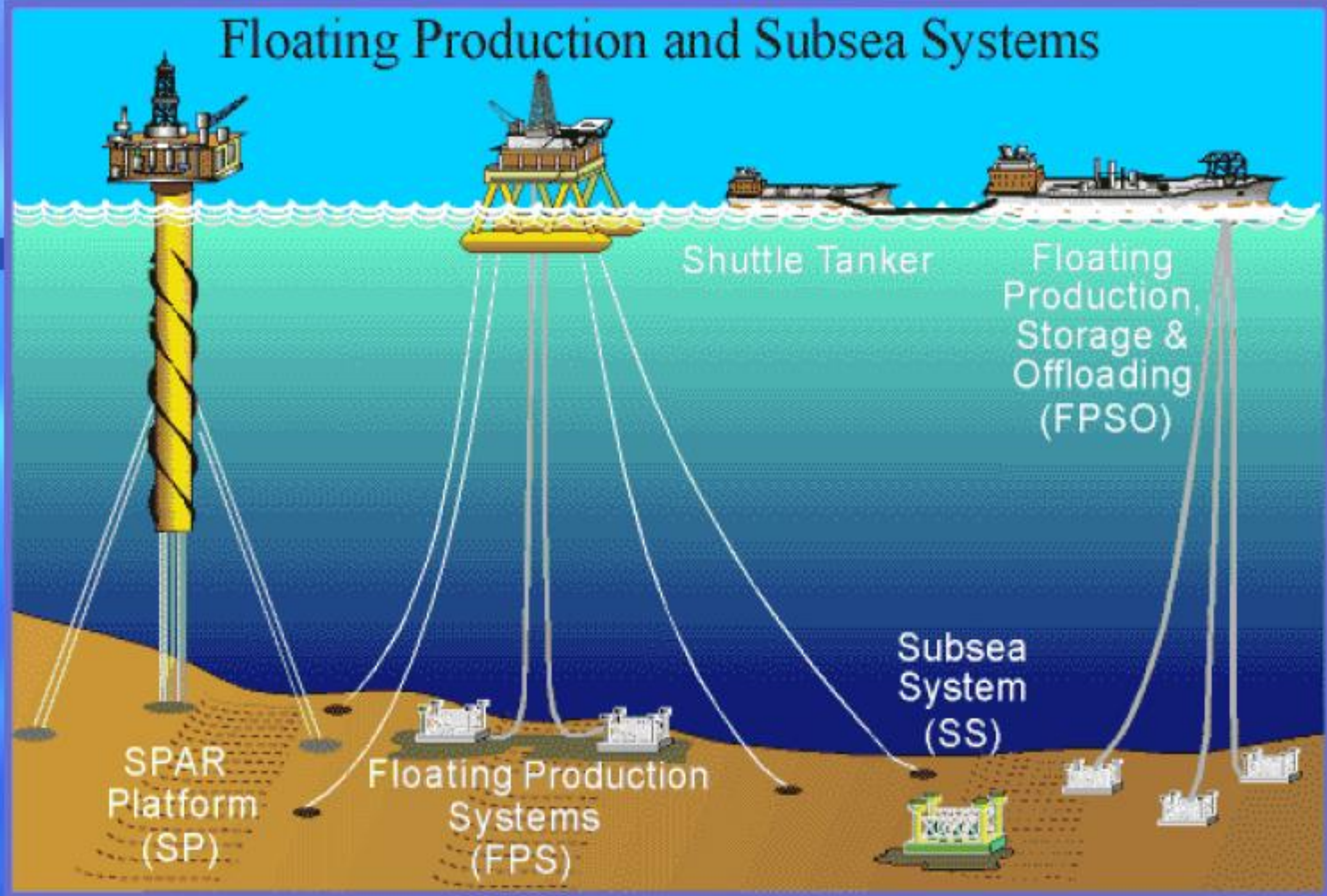
Industry Acronyms

CB	Control Buoy
CGT	Compliant Guyed Tower
CPT	Compliant Piled Tower
CPU	Caisson Production Unit
CT	Compliant Tower
DCU	Dry Completion Unit
DDCV	Deep Draft Caisson Vessel
DDF	Deep Draft Floater
DDS	Deep Draft Semi
FDPSO	Floating Drilling, Production, Storage and Offloading System
FPDSO	Floating Production, Drilling, Storage and Offloading System
FPSO	Floating, Production, Storage and Offloading
FPU	Floating Production Unit
MinDOC³	Cross between a semi-submersible and a truss spar (Keppel Fels and Tex BASS)
SCF	Single Column Floater
Semi-FPU	Semi-Submersible Floating Production Unit
TLP	Tension Leg Platform

Offshore platforms can broadly categorized in two types



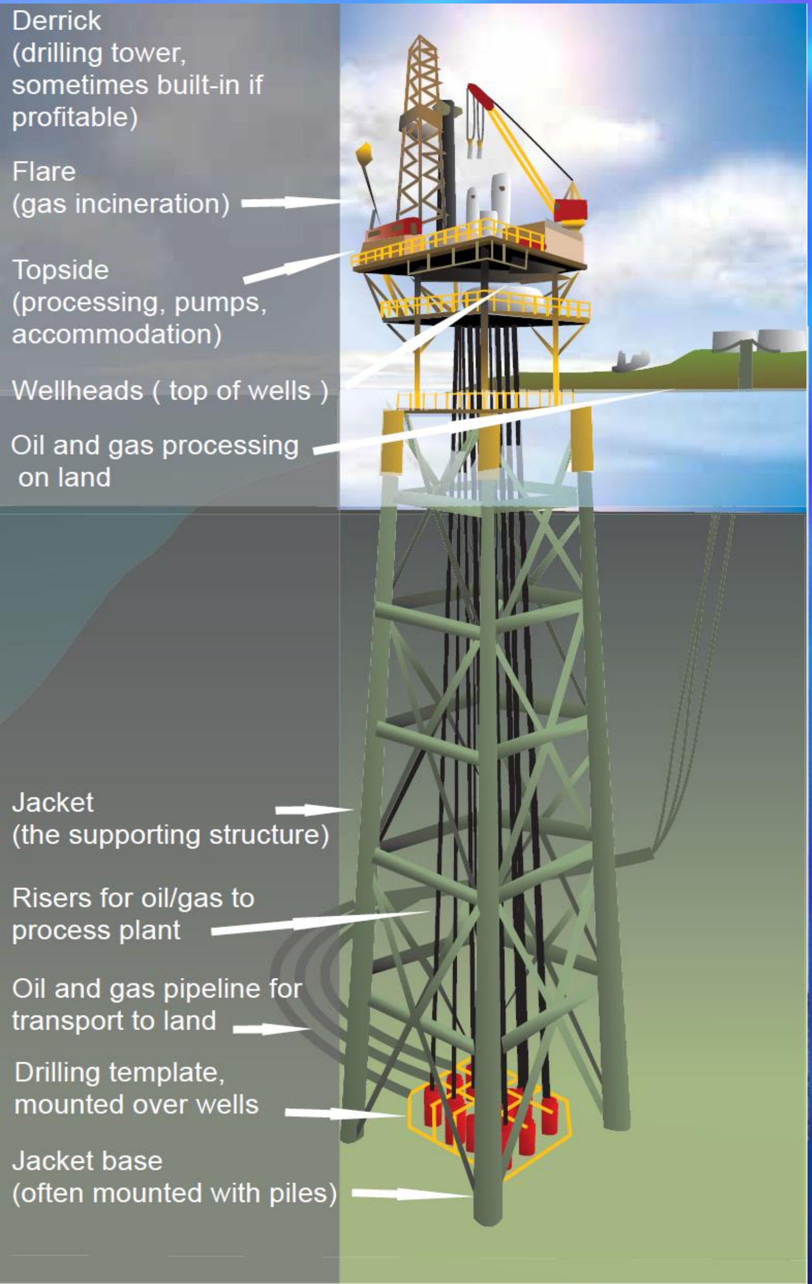
- Fixed structures that extend to the Seabed.
  - Steel Jacket
  - Concrete gravity Structure
  - Compliant Tower



Structures that float near the water surface- Recent development

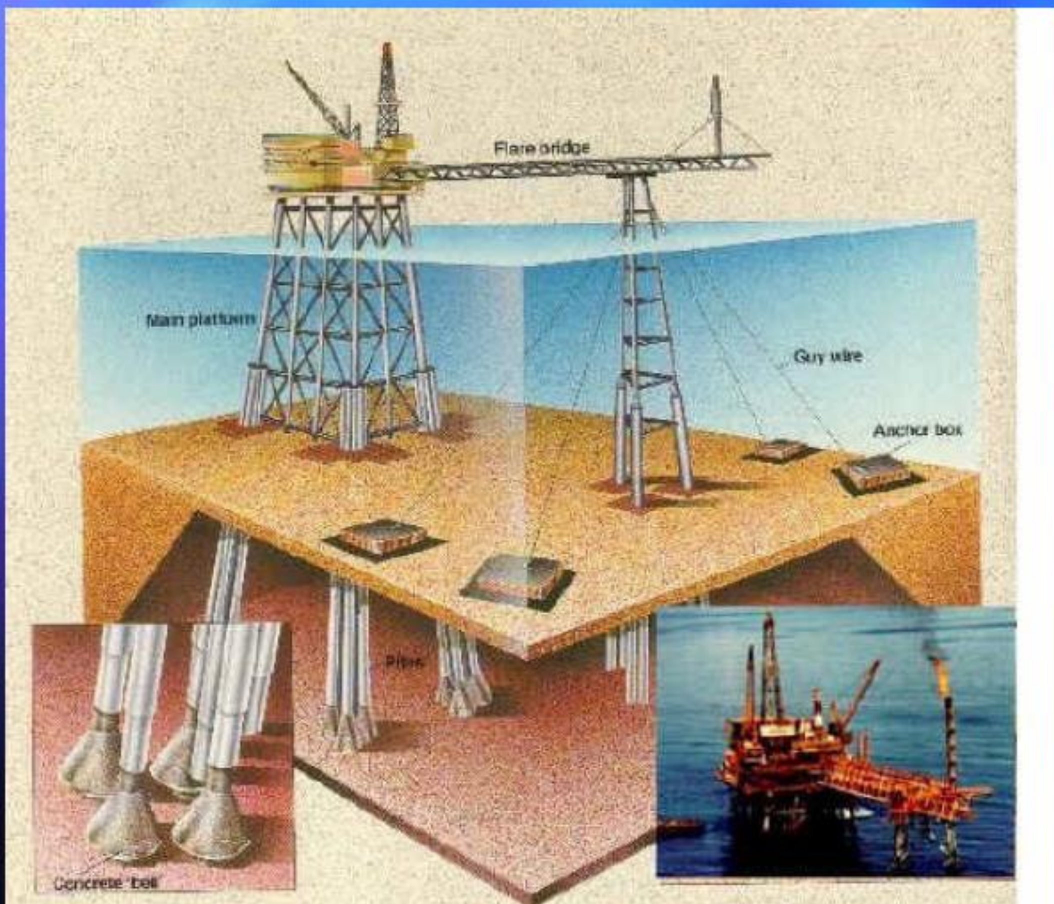
- Tension Leg platforms
- Semi Submersible
- Spar
- Ship shaped vessel (FPSO)

TYPE OF PLATFORMS (FIXED)



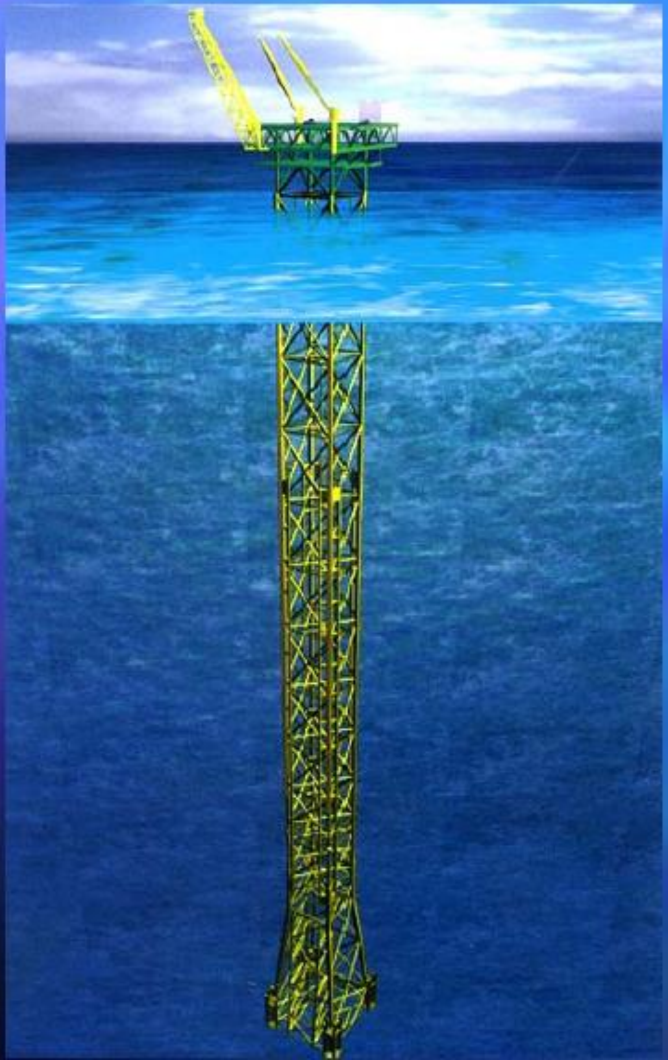
- JACKETED PLATFORM
  - Space framed structure with tubular members supported on piled foundations.
  - Used for moderate water depths up to 400 M.
  - Jackets provides protective layer around the pipes.
  - Typical offshore structure will have a deck structure containing a Main Deck, a Cellar Deck, and a Helideck.
  - The deck structure is supported by deck legs connected to the top of the piles. The piles extend from above the Mean Low Water through the seabed and into the soil.

TYPE OF PLATFORMS (FIXED)



- JACKETED PLATFORM (Cont.)
  - Underwater, the piles are contained inside the legs of a "jacket" structure which serves as bracing for the piles against lateral loads.
  - The jacket also serves as a template for the initial driving of the piles. (The piles are driven through the inside of the legs of the jacket structure).
  - Natural period (usually 2.5 second) is kept below wave period (14 to 20 seconds) to avoid amplification of wave loads.
  - 95% of offshore platforms around the world are Jacket supported.

TYPE OF PLATFORMS (FIXED)

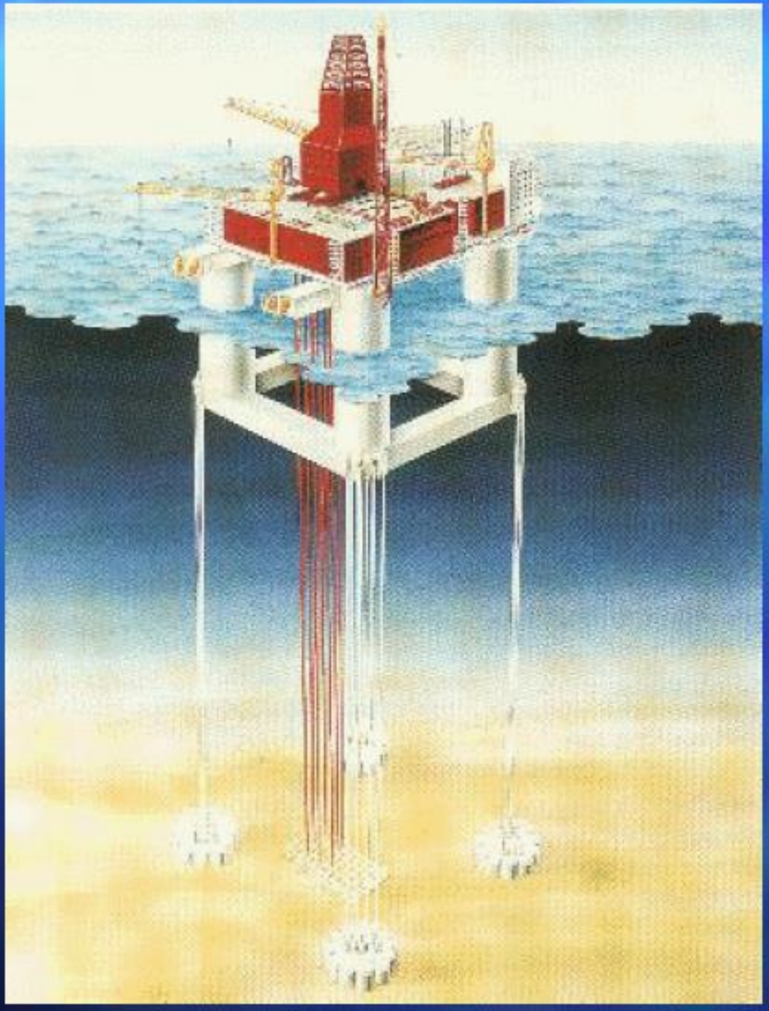


- COMPLIANT TOWER
  - Narrow, flexible framed structures supported by piled foundations.
  - Has no oil storage capacity. Production is through tensioned rigid risers and export by flexible or catenary steel pipe.
  - Undergo large lateral deflections (up to 10 ft) under wave loading. Used for moderate water depths up to 600 M.
  - Natural period (usually 30 second) is kept above wave period (14 to 20 seconds) to avoid amplification of wave loads.

TYPE OF PLATFORMS (FIXED)

- CONCRETE GRAVITY STRUCTURES:
  - Fixed-bottom structures made from concrete
  - Heavy and remain in place on the seabed without the need for piles
  - Used for moderate water depths up to 300 M.
  - Part construction is made in a dry dock adjacent to the sea. The structure is built from bottom up, like onshore structure.
  - At a certain point , dock is flooded and the partially built structure floats. It is towed to deeper sheltered water where remaining construction is completed.
  - After towing to field, base is filled with water to sink it on the seabed.
  - Advantage- Less maintenance

TYPE OF PLATFORMS (FLOATER)



- Tension Leg Platform (TLP)
  - Tension Leg Platforms (TLPs) are floating facilities that are tied down to the seabed by vertical steel tubes called tethers.
  - This characteristic makes the structure very rigid in the vertical direction and very flexible in the horizontal plane. The vertical rigidity helps to tie in wells for production, while, the horizontal compliance makes the platform insensitive to the primary effect of waves.
  - Have large columns and Pontoons and a fairly deep draught.

TYPE OF PLATFORMS (FLOATER)

- Tension Leg Platform (TLP)
  - TLP has excess buoyancy which keeps tethers in tension. Topside facilities , no. of risers etc. have to fixed at pre-design stage.
  - Used for deep water up to 1200 M
  - It has no integral storage.
  - It is sensitive to topside load/draught variations as tether tensions are affected.

TYPE OF PLATFORMS (FLOATER)

- SEMISUB PLATFORM
  - Due to small water plane area , they are weight sensitive. Flood warning systems are required to be in-place.
  - Topside facilities , no. of risers etc. have to fixed at pre-design stage.
  - Used for Ultra deep water.
  - Semi-submersibles are held in place by anchors connected to a catenary mooring system.

TYPE OF PLATFORMS (FLOATER)

- SEMISUB PLATFORM
  - Column pontoon junctions and bracing attract large loads.
  - Due to possibility of fatigue cracking of braces , periodic inspection/ maintenance is prerequisite

TYPE OF PLATFORMS (FLOATER)

- SPAR:
  - Concept of a large diameter single vertical cylinder supporting deck.
  - These are a very new and emerging concept: the first spar platform, *Neptune*, was installed off the USA coast in 1997.
  - Spar platforms have taut catenary moorings and deep draught, hence heave natural period is about 30 seconds.
  - Used for Ultra deep water depth of 2300 M.
  - The center of buoyancy is considerably above center of gravity , making Spar quite stable.
  - Due to space restrictions in the core, number of risers has to be predetermined.

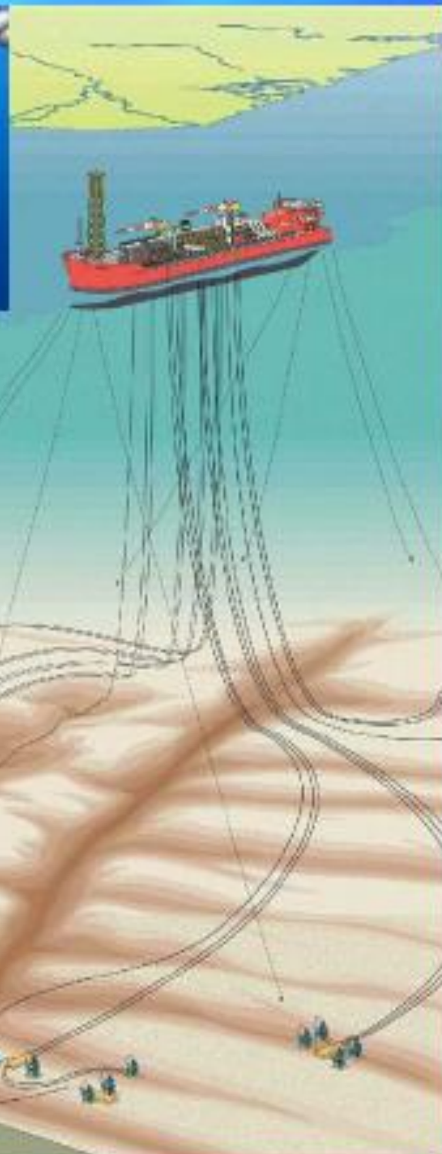
TYPE OF PLATFORMS (FLOATER)

- SHIP SHAPED VESSEL (FPSO)
  - Ship-shape platforms are called Floating Production, Storage and Offloading (FPSO) facilities.
  - FPSOs have integral oil storage capability inside their hull. This avoids a long and expensive pipeline to shore.
  - Can explore in remote and deep water and also in marginal wells, where building fixed platform and piping is technically and economically not feasible
  - FPSOs are held in position over the reservoir at a Single Point Mooring (SPM). The vessel is able to weathervane around the mooring point so that it always faces into the prevailing weather.

PLATFORM PARTS

- TOPSIDE:
  - Facilities are tailored to achieve weight and space saving
  - Incorporates process and utility equipment
    - Drilling Rig
    - Injection Compressors
    - Gas Compressors
    - Gas Turbine Generators
    - Piping
    - HVAC
    - Instrumentation
  - Accommodation for operating personnel.
  - Crane for equipment handling
  - Helipad

PLATFORM PARTS

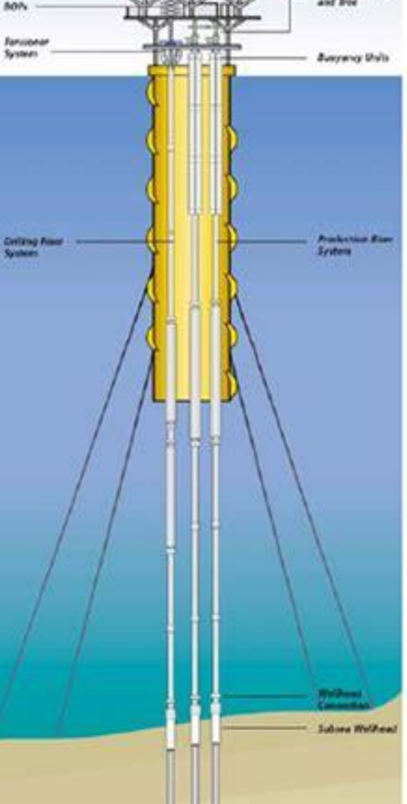
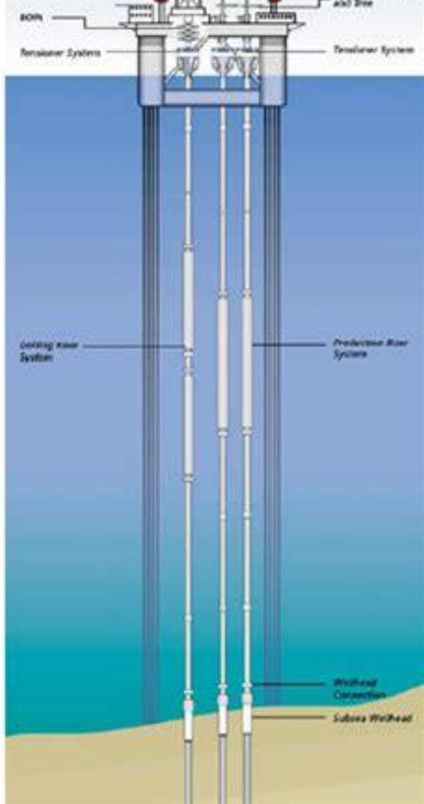


- MOORINGS & ANCHORS:
  - Used to tie platform in place
  - Material
    - Steel chain
    - Steel wire rope
      - Catenary shape due to heavy weight.
      - Length of rope is more
    - Synthetic fiber rope
      - Taut shape due to substantial less weight than steel ropes.
      - Less rope length required
      - Corrosion free

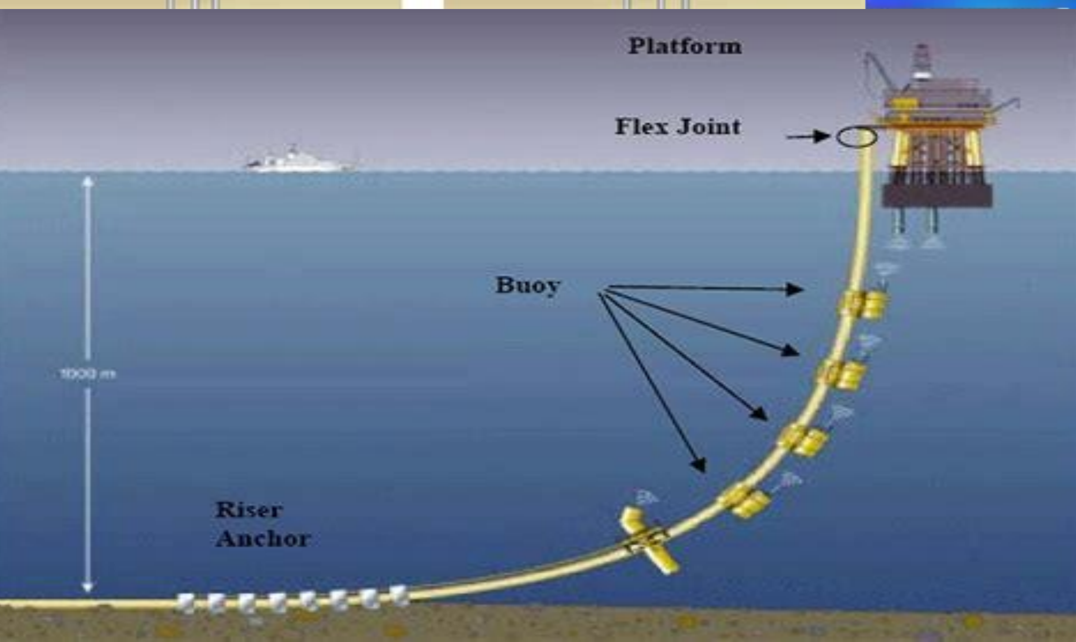
PLATFORM PARTS

- RISER:
  - Pipes used for production, drilling, and export of Oil and Gas from Seabed.
  - Riser system is a key component for offshore drilling or floating production projects.
  - The cost and technical challenges of the riser system increase significantly with water depth.
  - Design of riser system depends on filed layout, vessel interfaces, fluid properties and environmental condition.

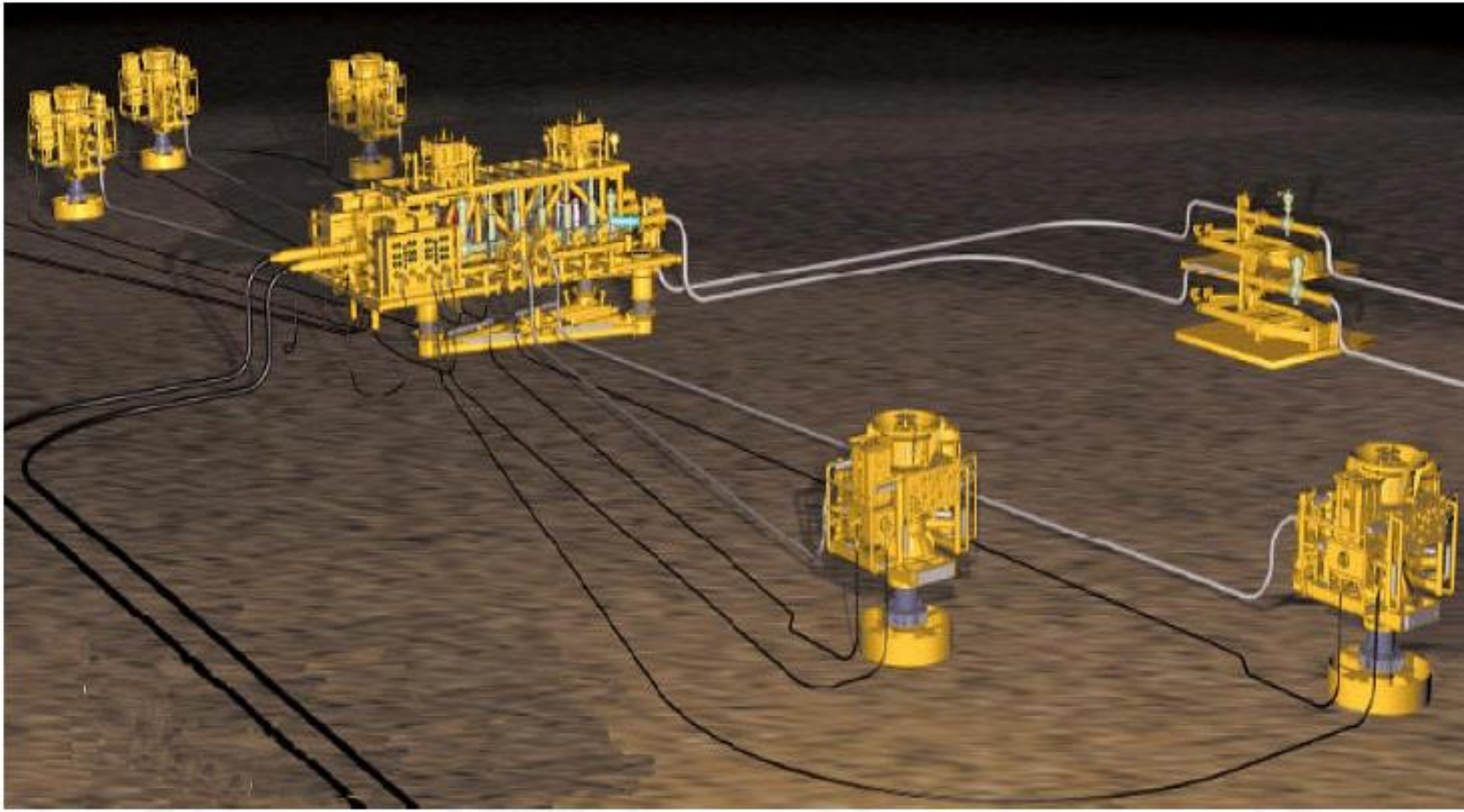
PLATFORM PARTS

- RISER:
  - Remains in tension due to self weight
  - Profiles are designed to reduce load on topside. Types of risers
    - Rigid
    - Flexible - Allows vessel motion due to wave loading and compensates heave motion
      - Simple Catenary risers: Flexible pipe is freely suspended between surface vessel and the seabed.
      - Other catenary variants possible



SUBSEA SYSTEMS



SUBSEA SYSTEMS

- Used in wells located on the seafloor to transport extracts via riser / pipelines to existing production platform.
- Moveable rigs are used to drill wells, allowing for a platform to serve many wells over large area.
- Used in waters up to 2,100m deep.

MOBILE OFFSHORE DRILLING UNITS

- Drill ships
- Jack-ups
- Tender-assisted drilling

DRILL SHIPS

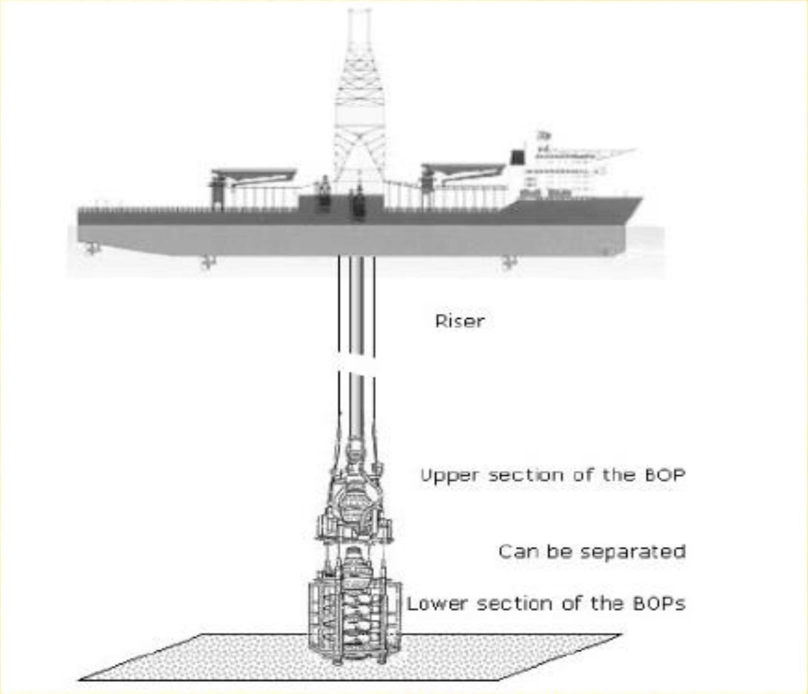
DRILL SHIPS.

Drill Ship are for ultra deep water and have worked waters up to 10000 feet. Riser drilling technology is used for drilling from a floating vessel. A large diameter Riser Pipe is used to connect the rig to the Subsea BOP's on the seabed and provide a conduit for running the drill string to the stata below the seabed.

DRILL SHIPS

The Riser Pipe is a steel pipe of a diameter of approximately 50 cm, and is equipped with attached line and floating buoyant material (partially).

The floating buoyant material acts to reduce weight in water. This Riser Pipe receives, in addition to self weight, other forces such as bending, tension or compression caused by motion of the vessel. In order to provide sufficient strength against these forces, high-tension steel will be used. BOP is provided at the bottom end of the Riser Pipe on seabed.



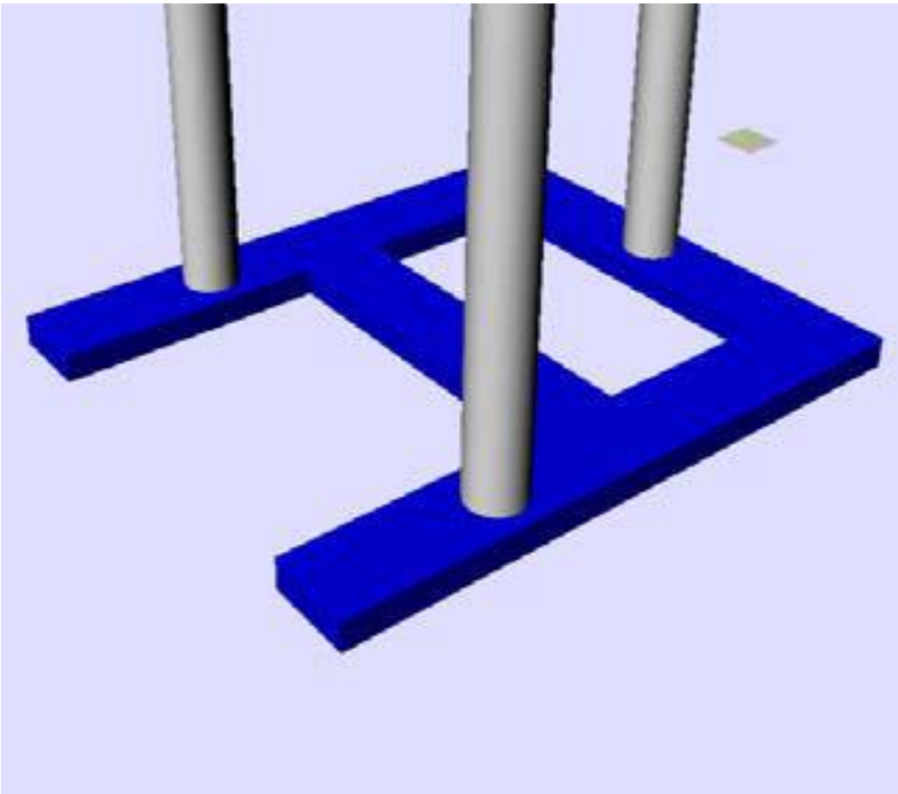
This is a safety unit that closes the borehole to prevent any fluid (liquid such as oil or water, gas such as natural gas or hydrogen sulfide) contained in the strata from rising up to Drill Ship through Drill Pipe or Riser Pipe when the Drill Pipe reaches abnormally high-pressure strata.

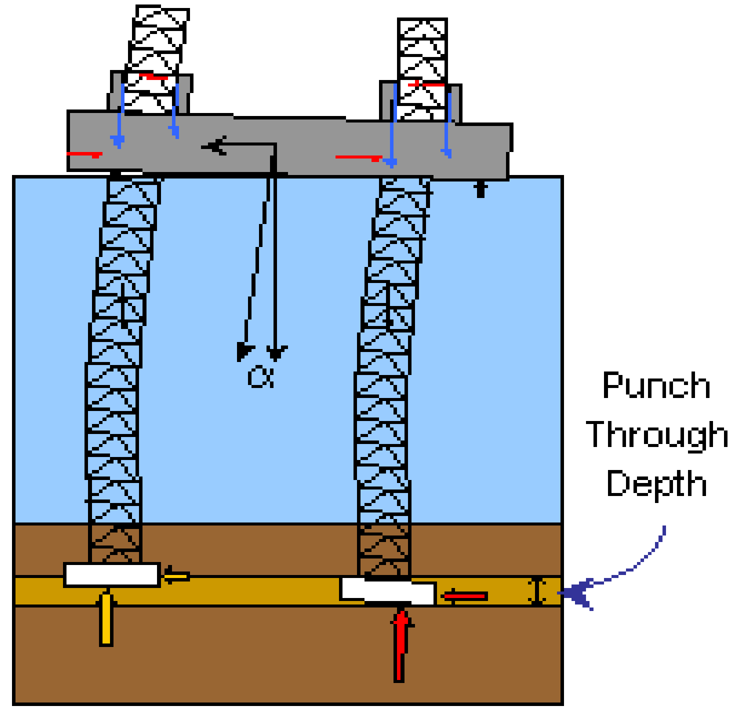
Jack- up

JACKUPS

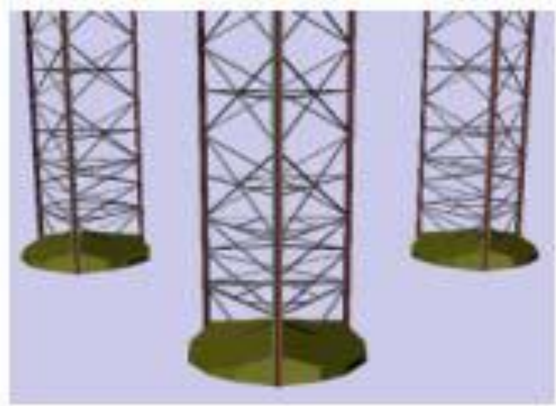
- Usually towed to shallow locations and anchored using jack-like legs.
- Legs lowered to seabed and hull jacked-up clear of the sea surface.
- Used in waters of depths up to 160m.

Jack-up footings

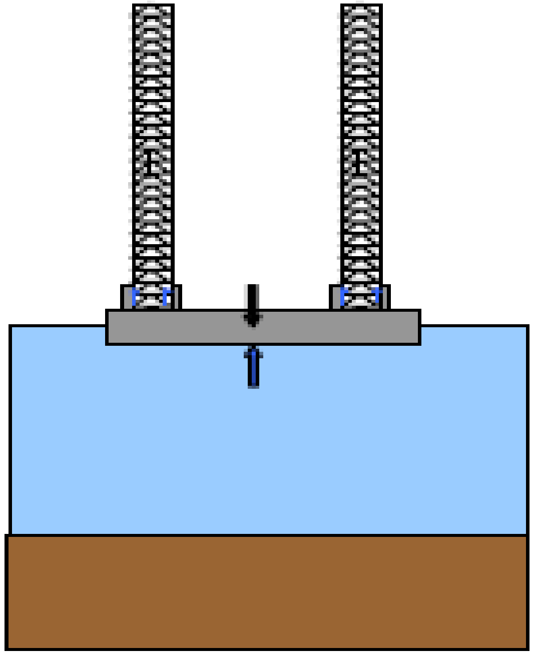




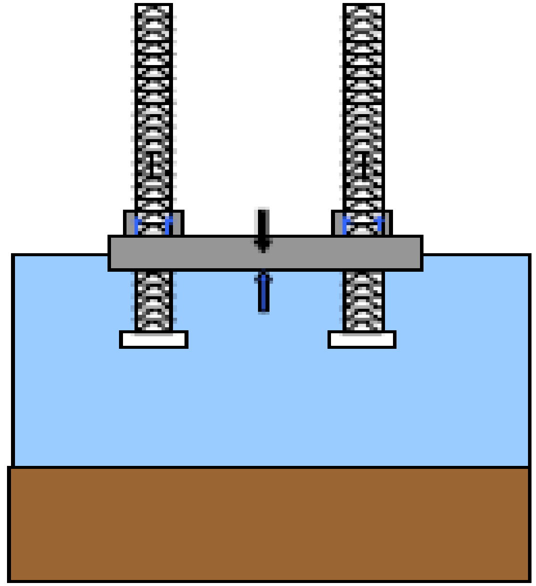
Punch Through



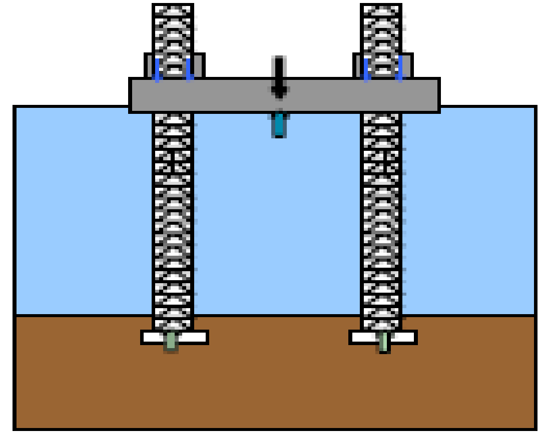
Typical profile of a Spudcan



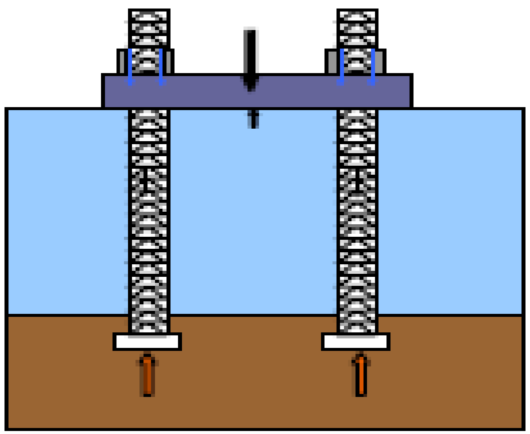
Arriving on Location



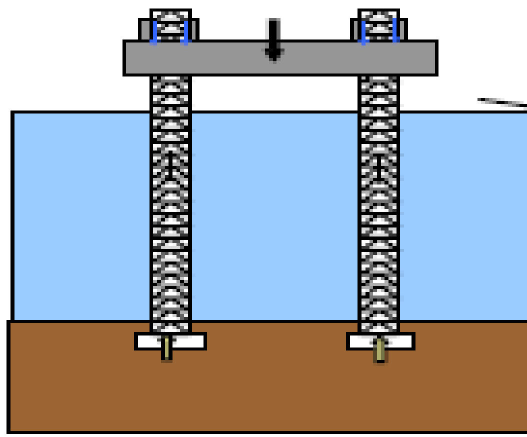
Lowering Legs



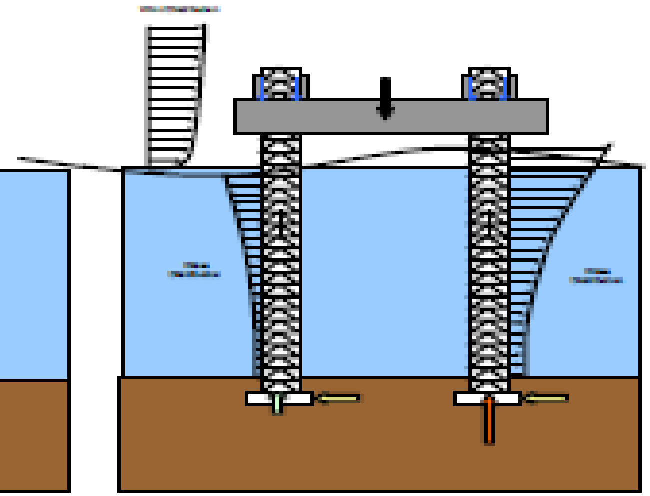
Coming Out of the Water



Preloading



At Full Airgap



With Environmental Loads

TENDER ASSISTED DRILLING

TENDER SUPPORT.

Smedvic T-7 tender Rig

This tender is a purpose built self-erecting drilling tender barge with a flat bottom, raked stern and raked bow hull shape.

The Self-Erecting Tender Rig (SETR) is designed especially as a cost efficient and very flexible drilling system for development scenarios involved multiple well slot, fixed offshore platforms. Whereby the rig moves from platform to platform using its own Drilling Equipment Set (D.E.S) which is lifted on by its own crane.

Lifting operations can be made onto platforms up to a height of 65 feet above mean sea level.

TENDER ASSISTED DRILLING

- Features self-erecting drilling units and tender support vessels.
- Used in fields with relatively few wells and restrictions on topside weights.
- Semi-submersible rigs are increasingly used in TAD to reduce platform topsides and jacket weight / cost.

PLATFORM DERRICKS

Platform derricks are designed to maximises the operation and/or limitations of the installation. Many of today's Platform derricks are designed to meet the demanding specifications required for North Sea due to the adverse weather condition.

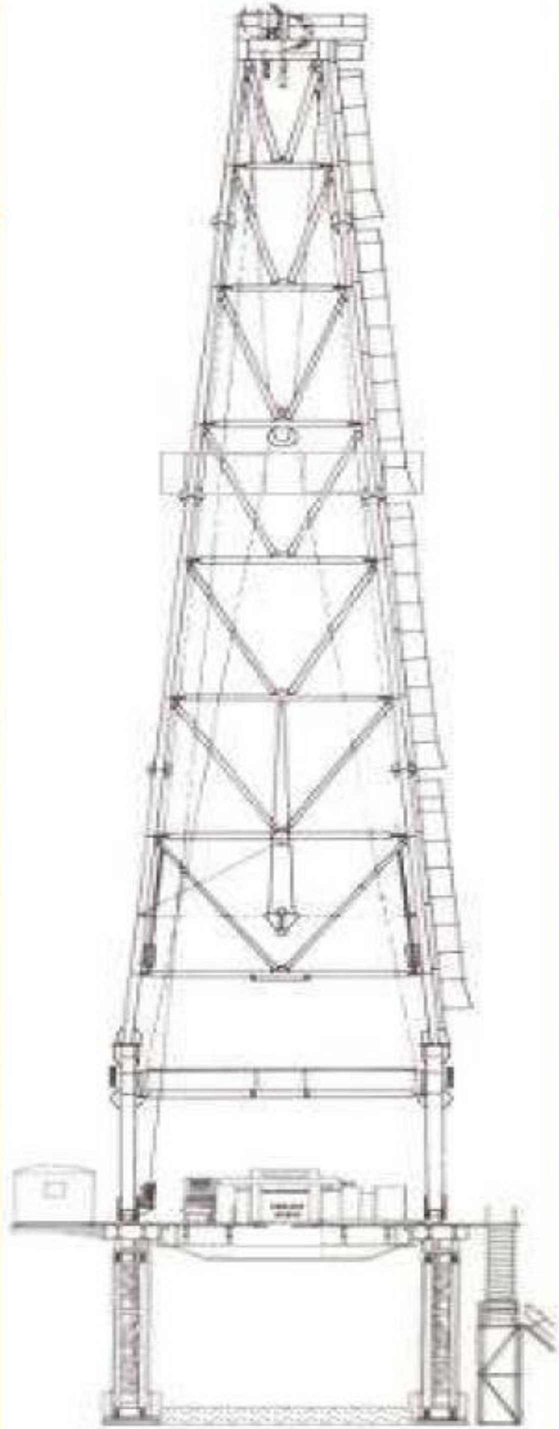
With the demand for deep water drilling many derrick accommodate a diverse range of specifications, that can include the crown mounted compensators, vertical pipe handling systems and harsh motion and environmental criteria.

DERRICKS

Standard Derrick: is a bolted structure that must be assembled part by part, usually used on offshore platforms.

• Derrick installed on floating rigs are designed to withstand extra dynamic stresses due to rolling, pitching, heaving and stresses from wind.

• The space available between the rig floor and the crown block must be higher to handle the wave- induced vertical movement of the floating support.



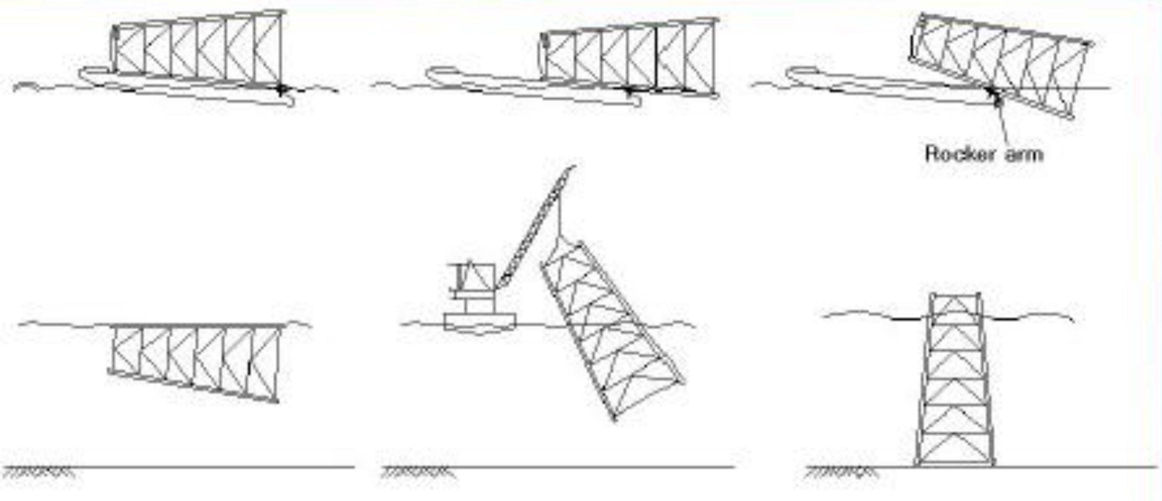


Figure 5 Launching and upending sequences of a platform jacket

PLATFORM INSTALLATION

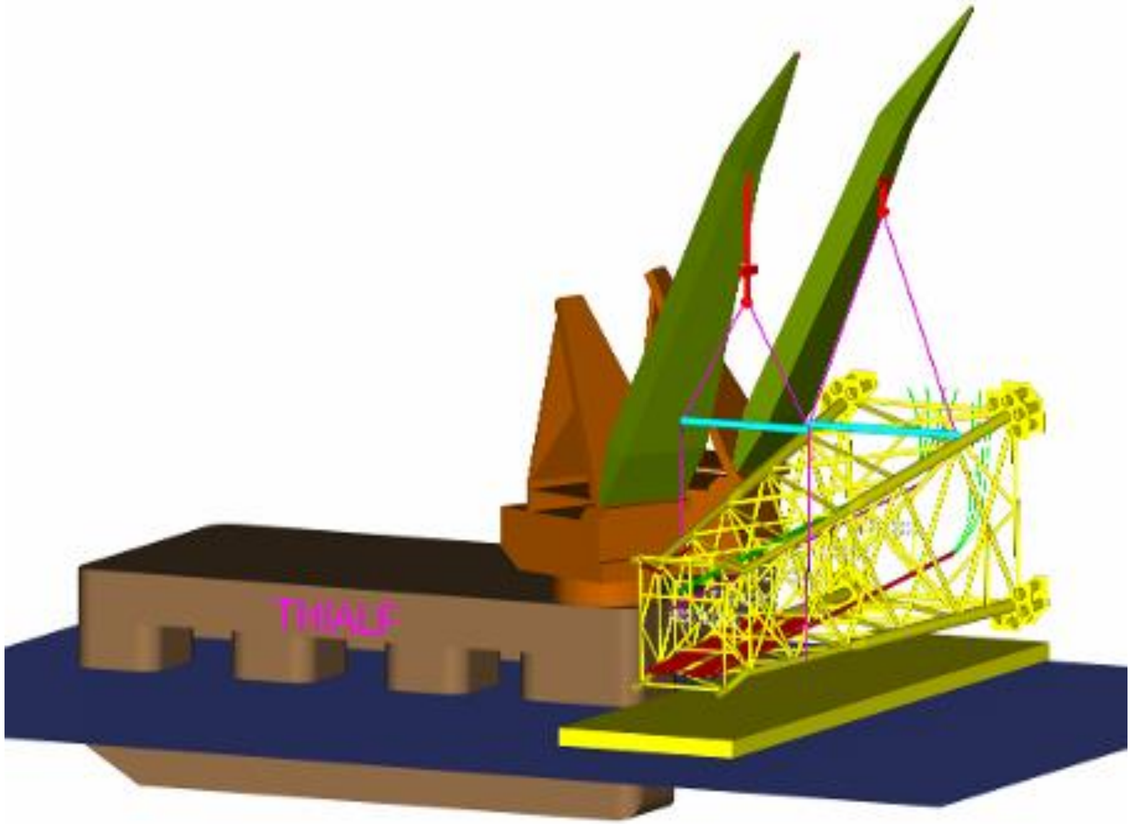
BARGE LOADOUT:

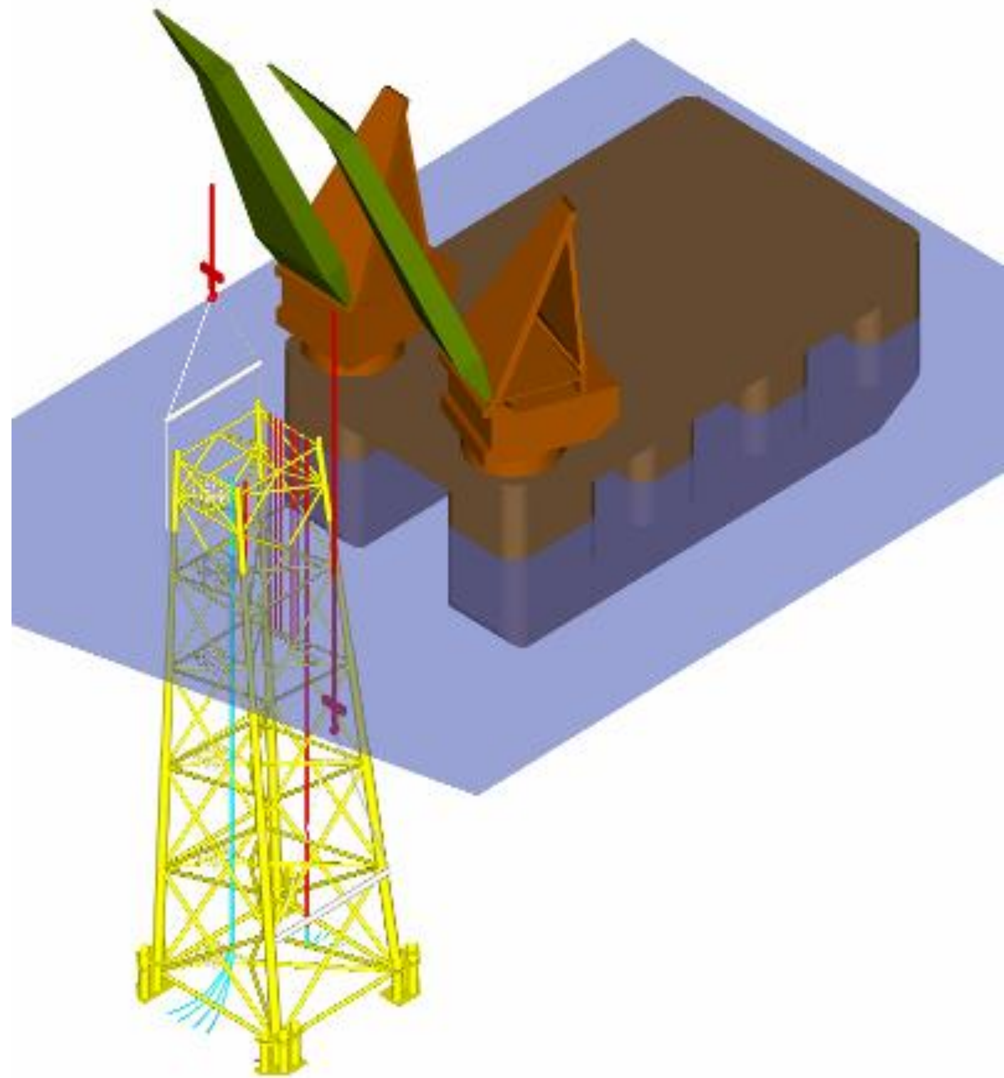
Various methods are deployed based on availability of resources and size of structure.

- Barge Crane
- Flat over - Top side is installed on jackets. Ballasting of barge
- Smaller jackets can be installed by lifting them off barge using a floating vessel with cranes.

– Large 400’ x 100’ deck barges capable of carrying up to 12,000 tons are available

Jacket installation: crane lift





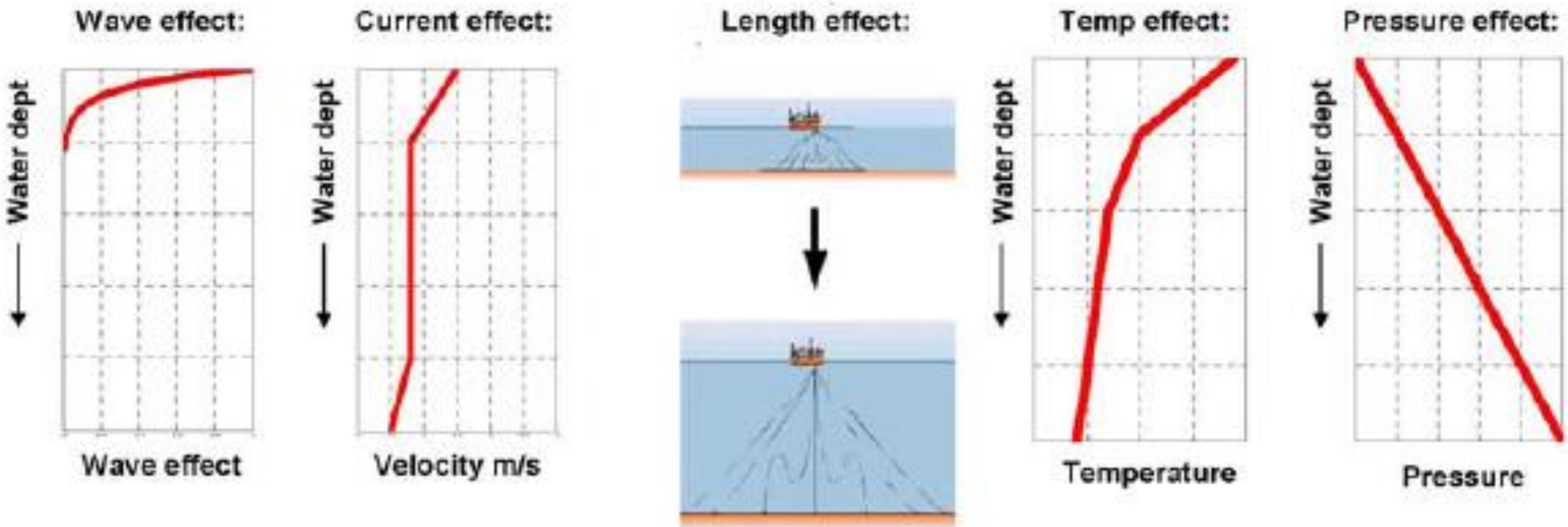
Jacket installation,- final phases

- Jacket in upright position?
  - Ballast in jacket legs
- Transit to set-down point. Several 100 meters
- Further ballasting and lowering by crane
- Landing
- Release crane
- On-bottom stability in temporary phase?
- Piling

Offshore Installation Risks

- The offshore installation risks are mainly centered on the lifting operations and weather.
- Offshore installations, especially fixed platforms, are badly effected by weather and can be delayed from travelling to location due to bad forecasts.
- Upon reaching location the installation is again weather dependent with almost calm conditions required to final position and lift.
- The whole of the offshore installation of the Jacket & Topsides lifts require near perfect conditions.
- Once the lifting operations are complete the jackets/topsides secured then there is very little follow-on work which is at risk.
- Final Commission and start-up requires checking for transport damage, loosening of bolts, pipe joints etc. before commencing.

Change of physical effects with increasing water depth



Effect from waves not chainging with water depth.

New and complex substructure shapes - hydrodynamics

Current acting through the whole water column – increased importance

Strong and complex current profiles (x,t)

Increased importance of current load & load effects (viv).

Increased weights and loads on sub systems.

Increased hang off loads

Increased "system" flexibility.

Complex installation & retrieval operations

Low ambient temperature, below 0°C may occur.

Increased risk of hydrate formation. Mitigation and remediation important.

Increased external pressure – collapse of risers and pipelines

Water intrusion in electrical and hydraulic systems

Depressurerisation access limited

Introduction to Deepwater Development Chapter-1

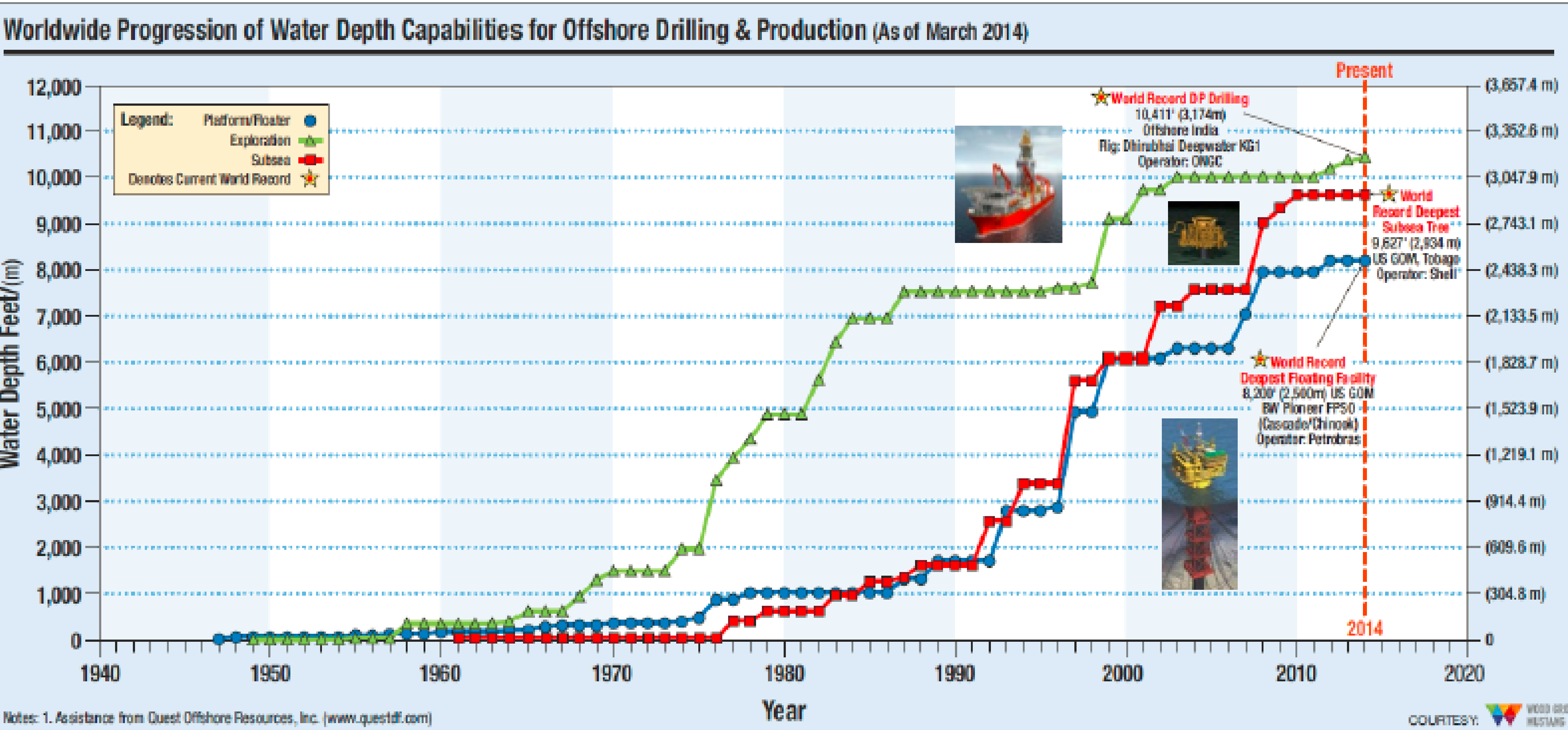
A Historical Perspective

- First well drilled out of sight of land 67 years ago in 21 ft water depth
    - ✓ **Today, we are drilling in depths exceeding 10,000 ft**
- First offshore platform installed in 1947 in 21 ft of water
    - ✓ **Today, platforms are being installed in depths exceeding 8,000 ft**
- World's tallest structure was installed offshore in 1979 in 360 ft of water
    - ✓ **Today, a fixed platform stands in excess of 1,800 ft of water**
- First subsea tree installed in early 1960's in less than 320 ft of water
    - ✓ **Today, subsea trees are being installed in depths exceeding 9,500 ft of water**

Kerr-McGee's drilling platform, Kermac Rig No. 16, was the first offshore rig in the Gulf of Mexico that was out of sight of land. It was installed in 1947 in 20 ft of water, 10 miles at sea.

The Perdido spar is the deepest floating oil platform in the world at a water depth of about 8,000 ft. It was installed 200 miles from shore and is operated by Shell in the Gulf of Mexico.

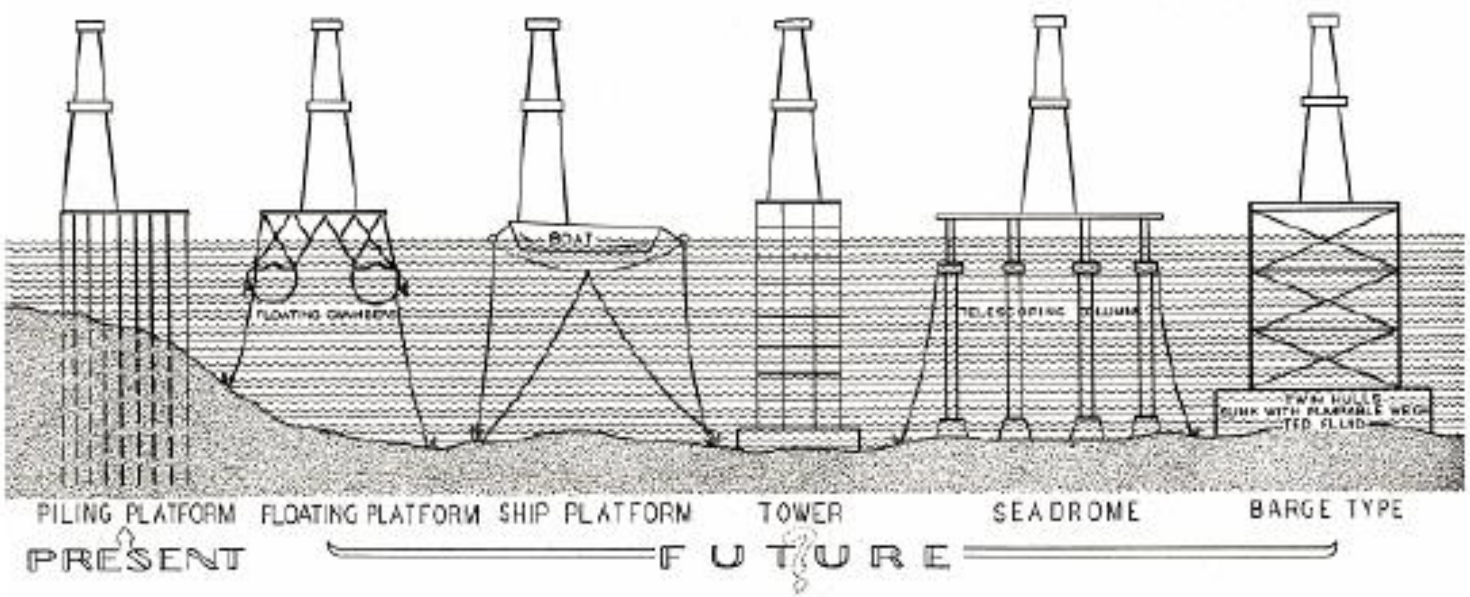
The 50 Year March to Deepwater



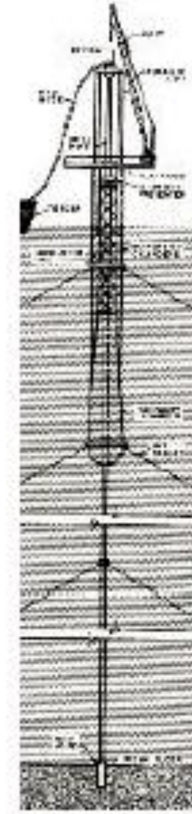
1. The drillers were drilling in deepwater long before we had the production capability.
2. The time and depth gap between drilling and production is closing fast.
3. 10,000' has been the water depth threshold for almost 10 years.

The Deepwater Vision – Then and Now

June 1947 - Oil & Gas Journal



Feb 1959 - Offshore Magazine

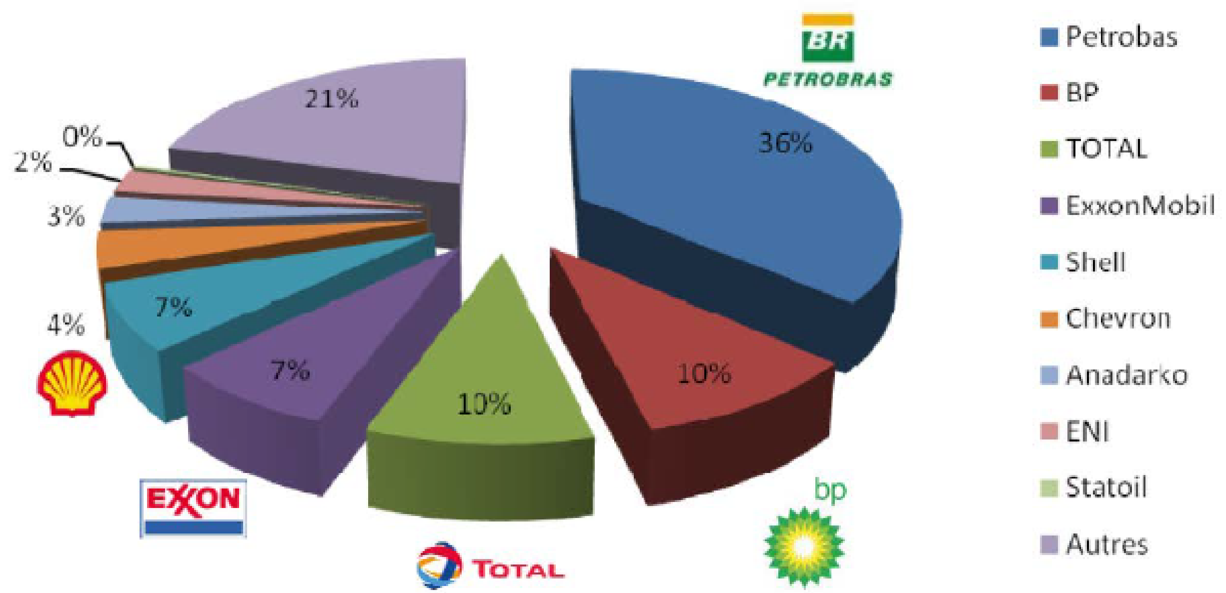


Semi **FPSO** **Compliant Tower** **TLP** **Spar**

Why Deepwater?

- Future oil demand will remain strong
- Deepwater is where the remaining big reserves are located
- Deepwater will account for 25% of global offshore production by 2015, compared to just 9% now
- Innovative technologies will allow economic developments in deep and ultra-deepwater

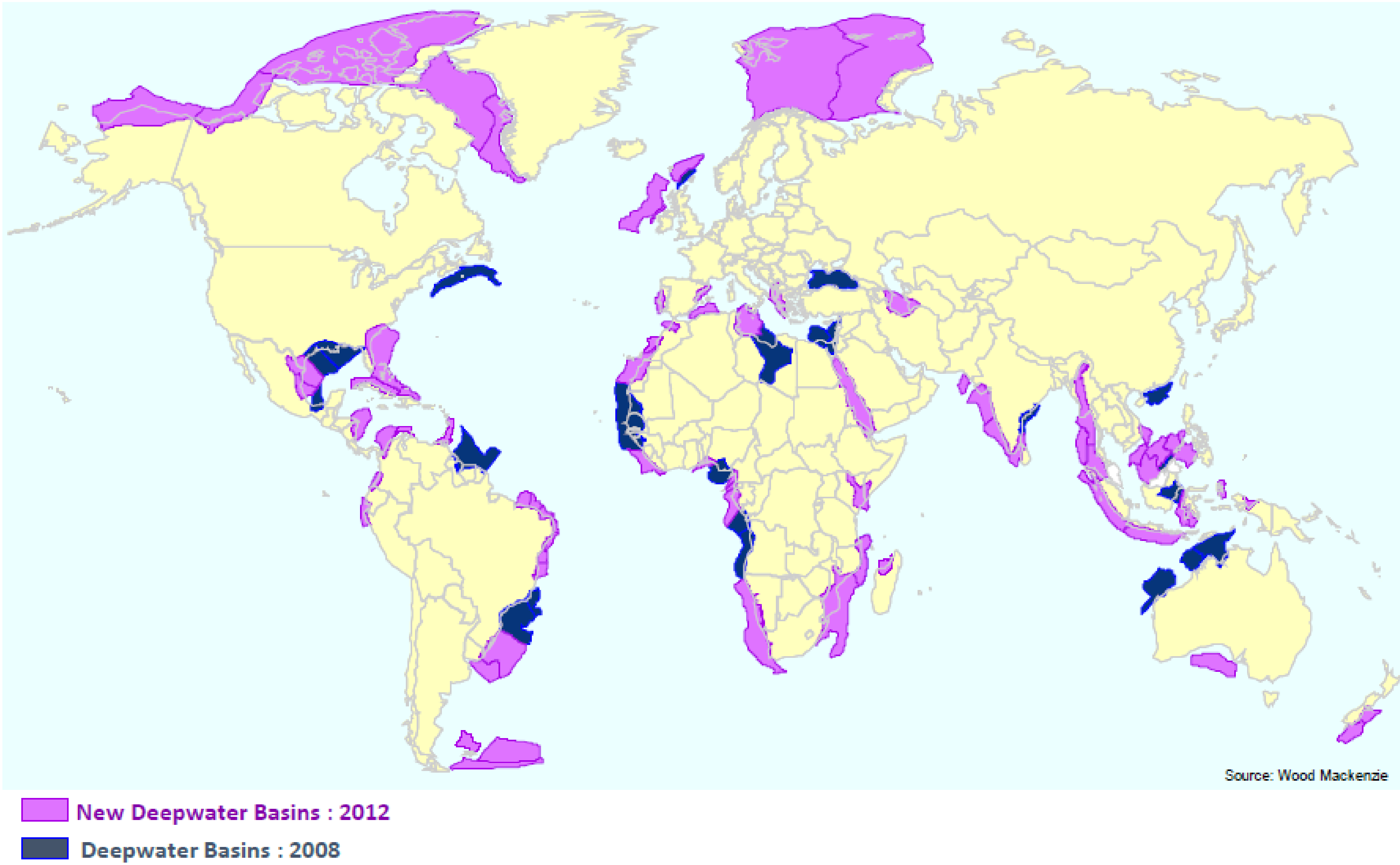
Relative Deepwater Well Activity in 2013



FACTORS DRIVING DEEPWATER RUSH

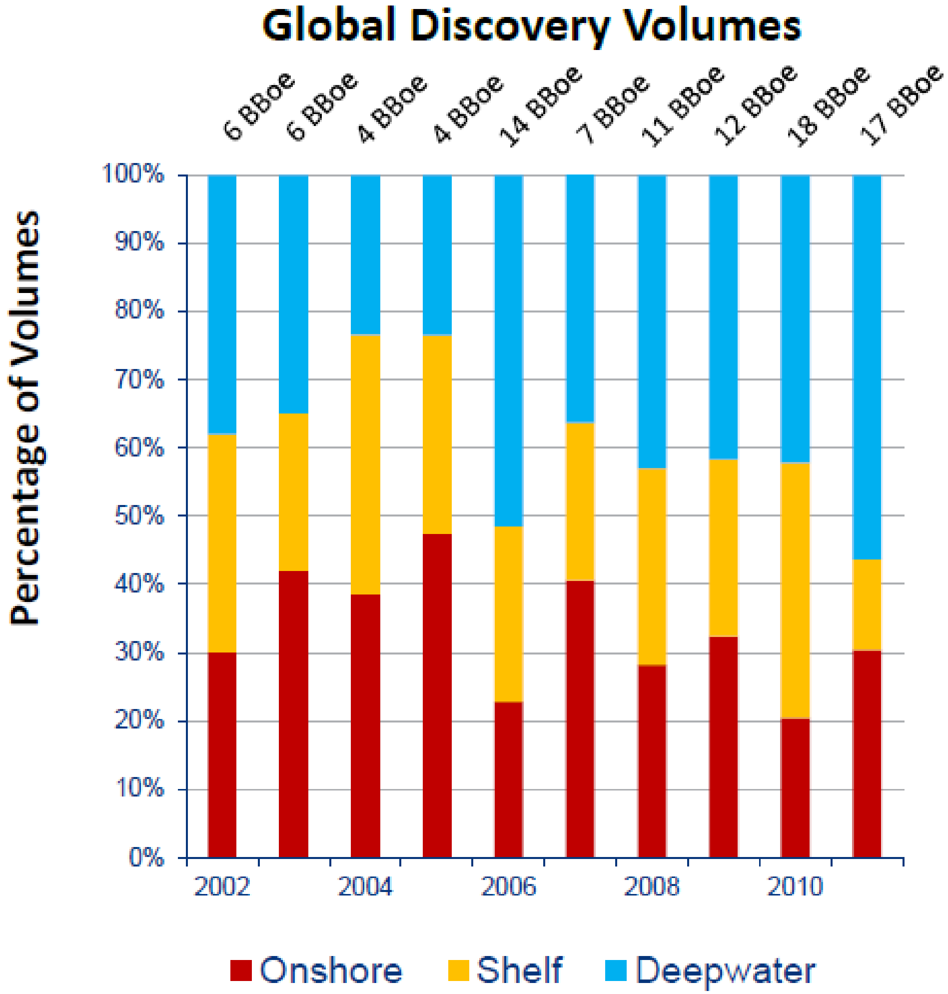
- Growing global demand for energy.
- Traditional fields fast exhausting.
- Declining production & reserves.
- Oil supply jitters.
- Pressure to diversify supply.
- Energy economics.
- Technological advent.

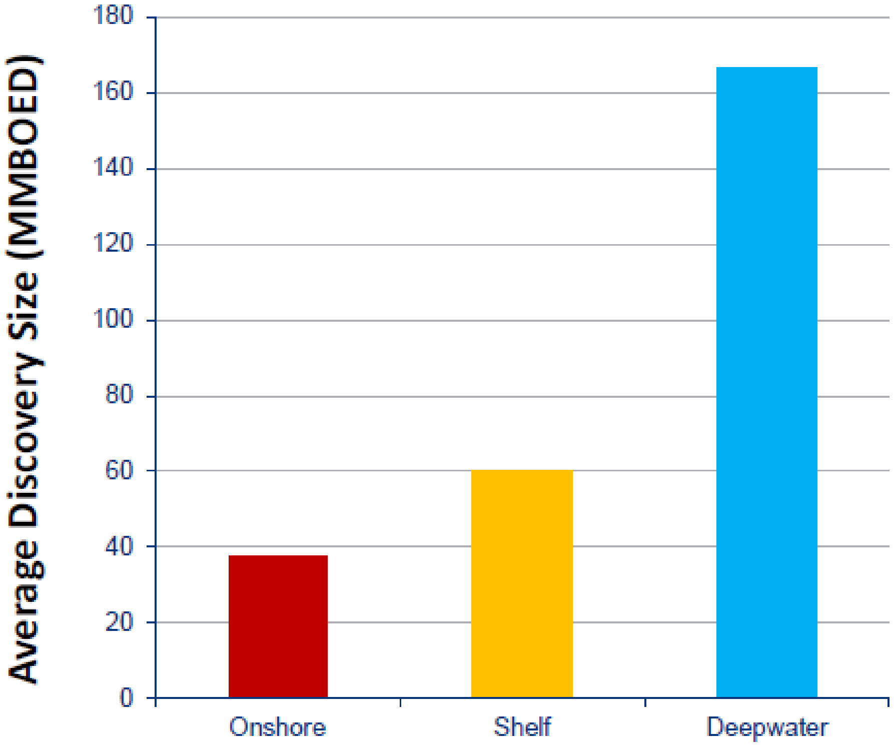
Deepwater Drilling is Rapidly Expanding



- New deepwater basins are being identified at a rapid pace
  - Expansion will be further enabled by the significant additions to the floating rig fleet over the next several years

Deepwater Has High Potential

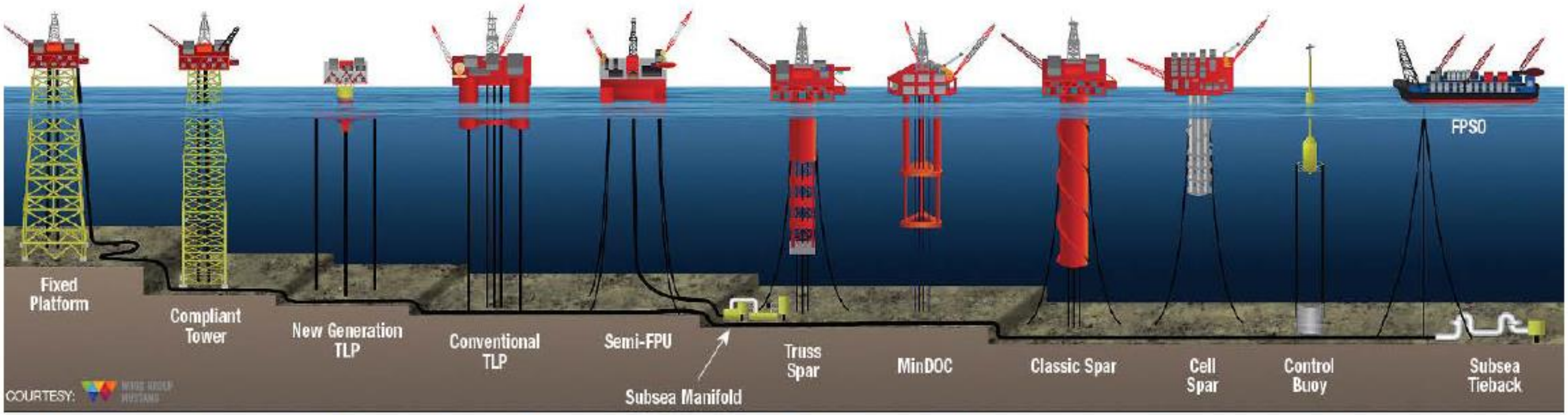




Larger average field sizes and more cumulative volumes discovered in deepwater than onshore or shelf

Source: Wood Mackenzie. Deepwater defined as >400m and ultra deep as >1,500m

Deepwater System Types Currently in Use

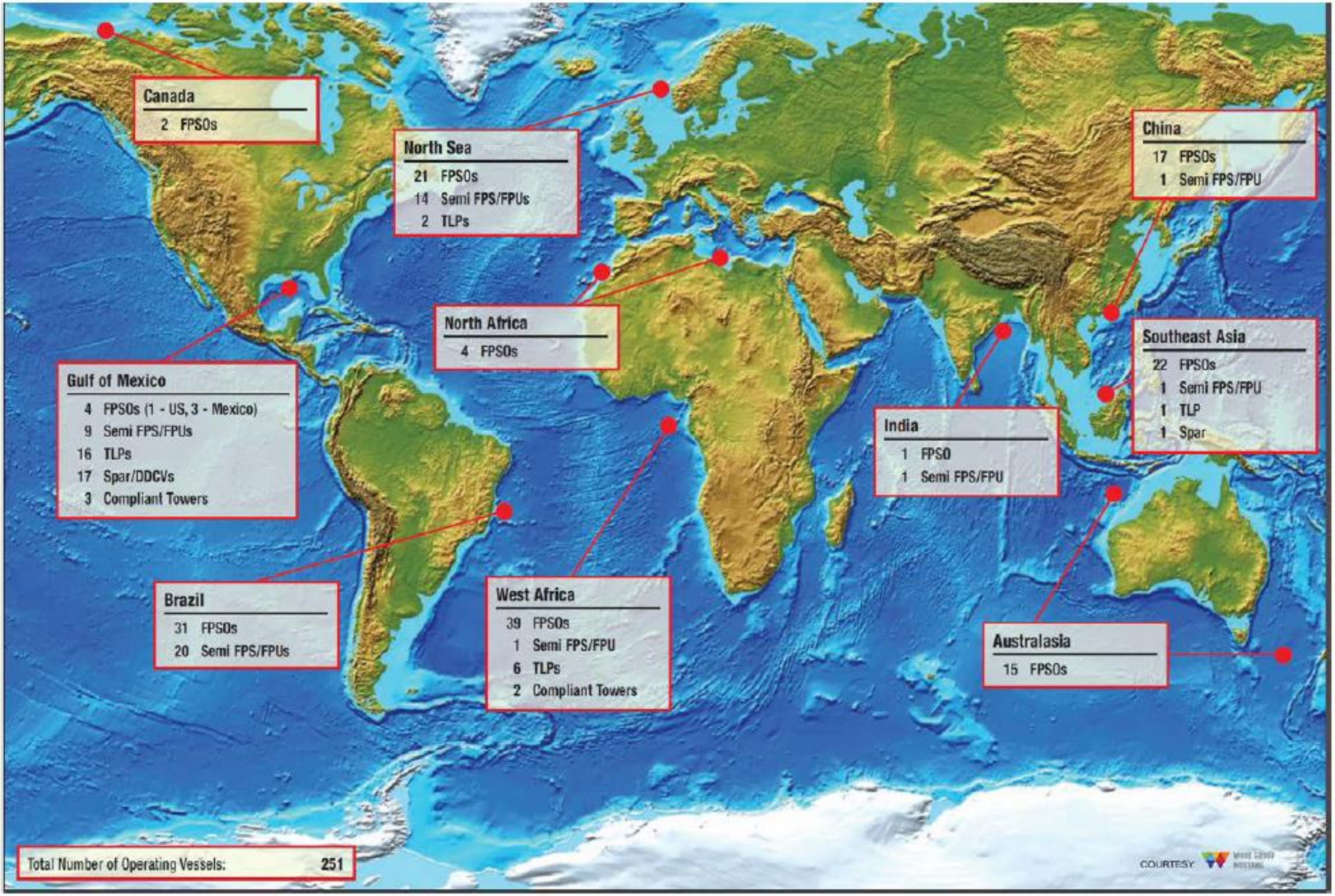


Source: Mustang Engineering & Offshore Magazine Deepwater Poster – May, 2013; Go to www.offshore-magazine.com/maps-posters.html

Three Deepwater System Groups:

1. Dry Tree Systems – Fixed Platform, Compliant Tower, TLP, Spar
2. Wet Tree Systems – New Gen. TLPs, Conventional TLPS, FPSOs, Cell Spar, Control Buoy, SS Tiebacks, Semi-FPS
3. Mixed Dry / Wet Tree Systems – Fixed Platforms, New Gen. TLP, Conventional TLP, Spar

Deepwater Systems Global Distribution

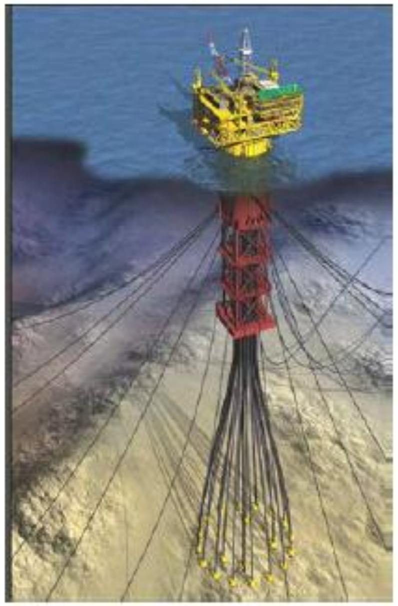


Predominant Floater Types

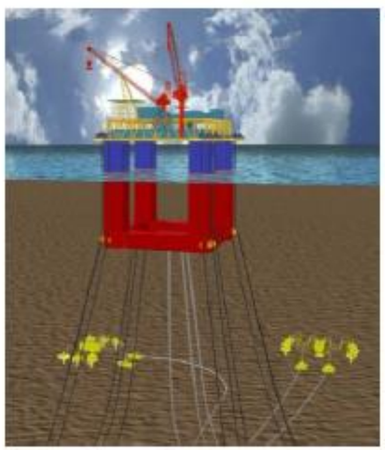
There are four primary industry recognized floating production solutions, accepted because:

- ***Proven*** - Many years of Operating history
- ***Functional*** - Used for a large variety of functions, wet or dry tree
- ***Scalable*** – Wide range of topsides payloads
- ***Adaptable*** – Applications worldwide

Tension Leg Platform

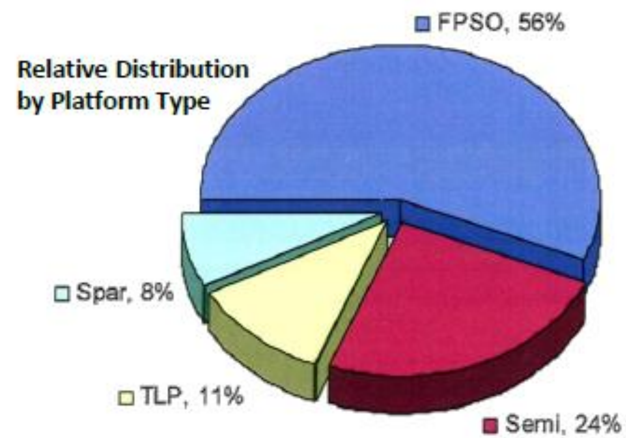


Spar



Semi-submersible (Semi)

FPSO



Fundamental Concept Differentiators

- Functionality
- Scalability
- Integration
- Installation
- Flexibility

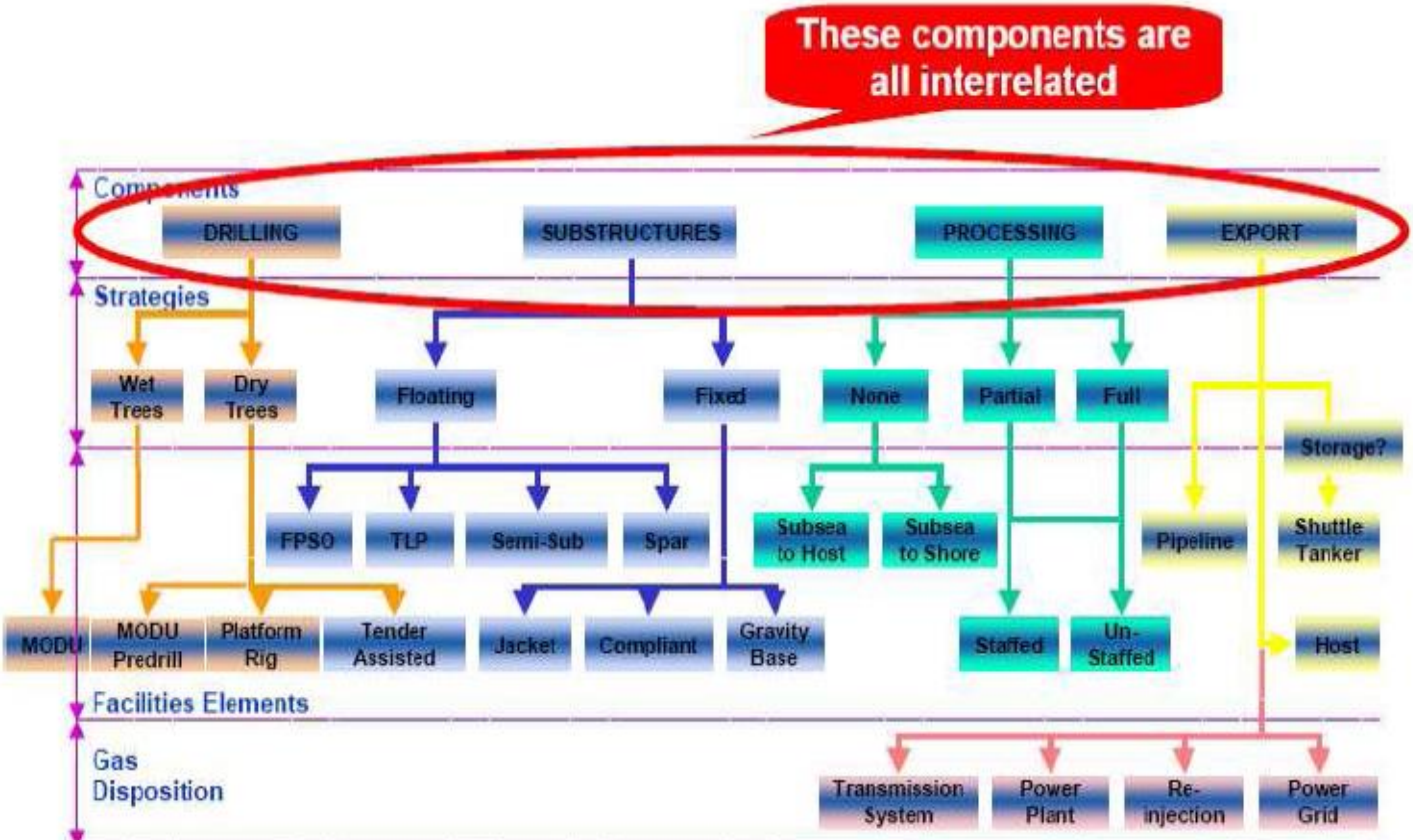
Semisub (Wet trees)

Spar (Dry or Wet trees)

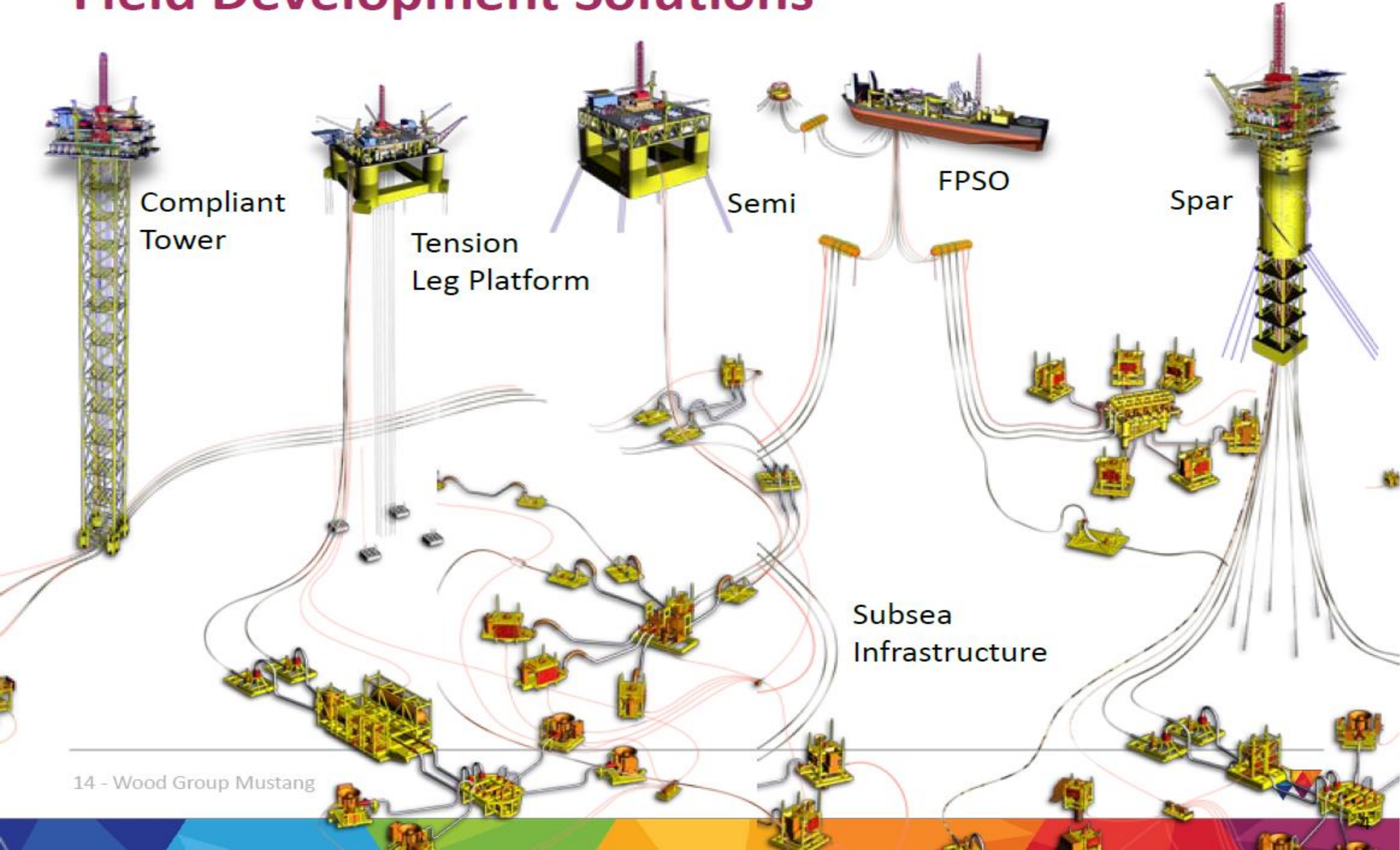
TLP (Dry or Wet trees)

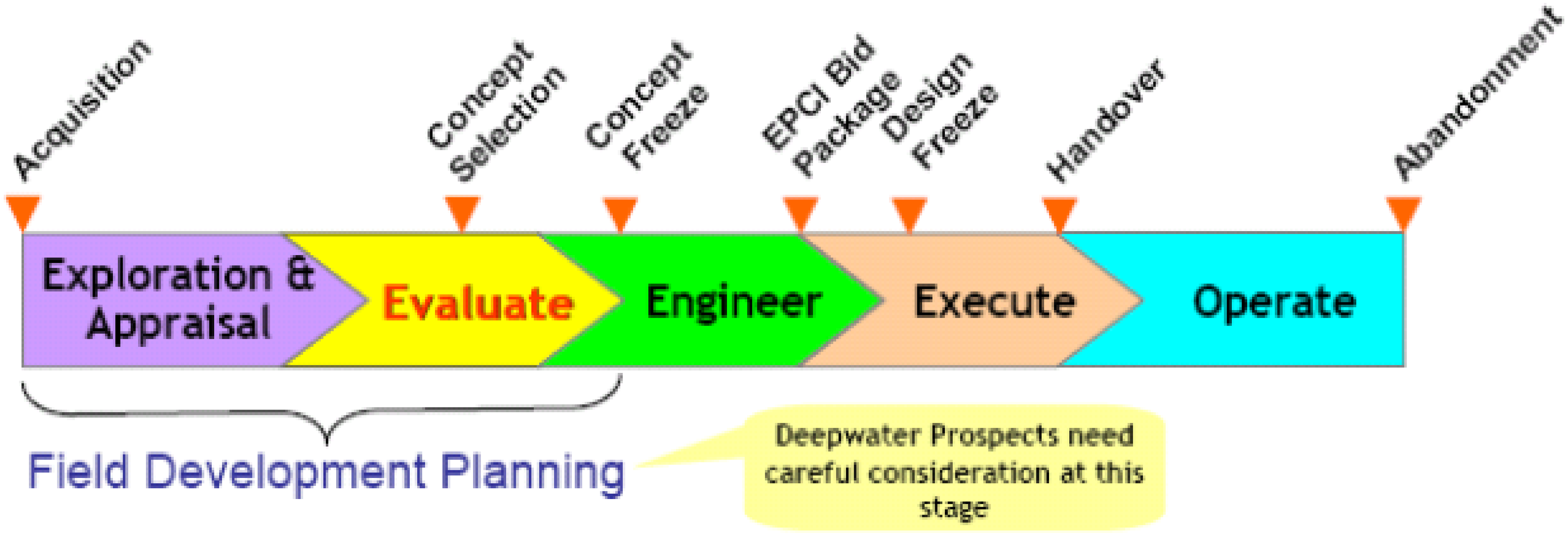
FPSO (Wet trees)

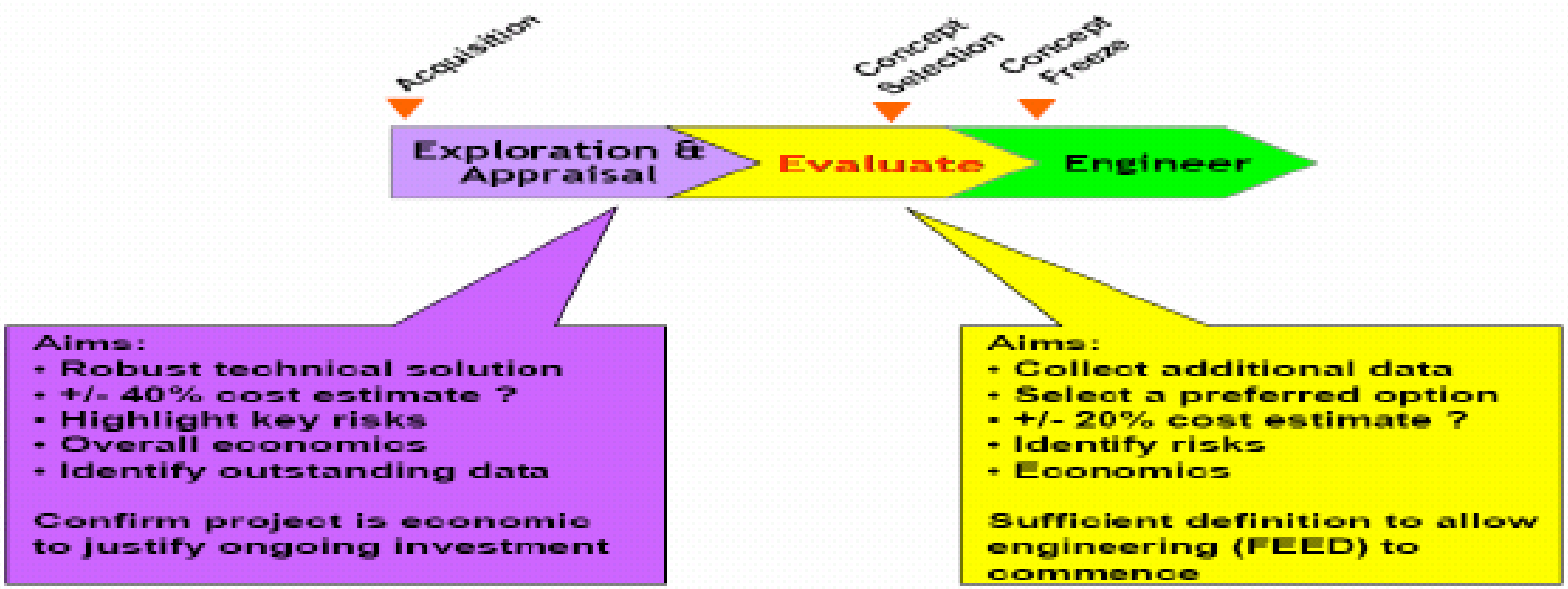
Scope and Components of Offshore Project



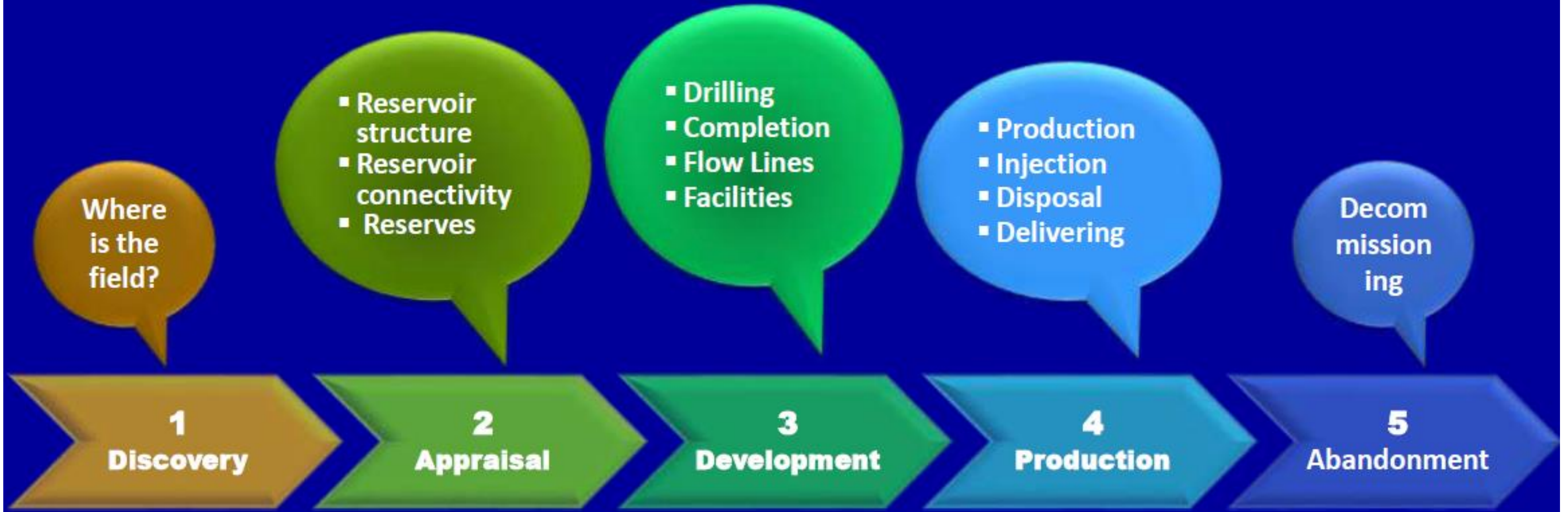
Field Development Solutions




Acquisition
Concept Selection
Concept Freeze
EPCI Bid Package
Design Freeze
Handover
Abandonment
Exploration & Appraisal
Evaluate
Engineer
Execute
Operate
Field Development Planning
Deepwater Prospects need careful consideration at this stage


Acquisition
Concept Selection
Concept Freeze
Exploration & Appraisal
Evaluate
Engineer
Aims:
• Robust technical solution
• +/- 40% cost estimate ?
• Highlight key risks
• Overall economics
• Identify outstanding data
Confirm project is economic to justify ongoing investment
Aims:
• Collect additional data
• Select a preferred option
• +/- 20% cost estimate ?
• Identify risks
• Economics
Sufficient definition to allow engineering (FEED) to commence

Oil or gas field life cycle



1-3 years

- Geologic structure
- No of Flow units
- Rock Properties
- Fluids Properties
- Driving Mechanism
- No Producing wells
- No of Injection wells
- Expected workovers

1-5 years

- Drilling & Completion
- Well Testing
- On line reservoir model updating and fine-tuning
- Flow Lines
- Surface Facilities for produced and injected fluids: Separators, Compressors, Pump stations, Measuring System

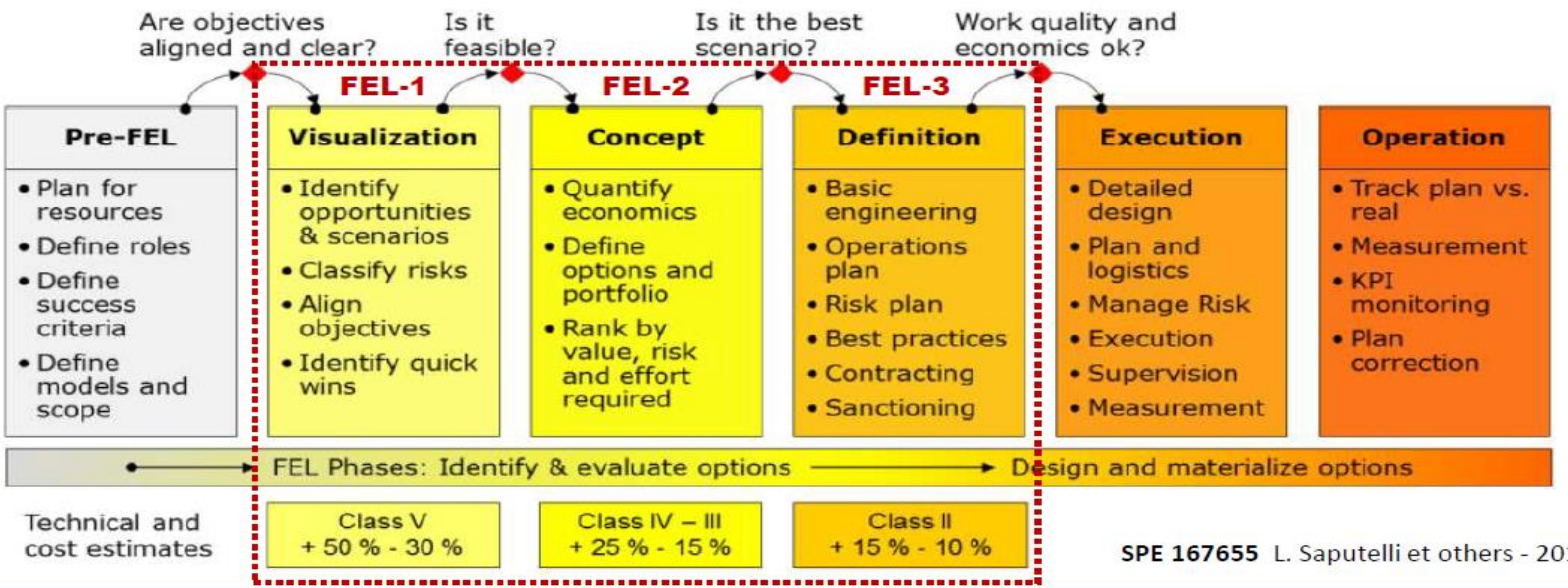
10-50 years

- Production System Surveillance
- Downhole Data Acquisition
- Asset Management

Front-End-Loading (FEL) Process [1]

- Front-end-loading (FEL) should be considered as a **sound field development practice** that **allows the optimum allocation of capital and human resources, reduces the uncertainty** of key information and ensures a holistic view to all field development plan decisions.

- Front-end-loading methodology is a 3-step capital project planning process:
  - **FEL 1: The prefeasibility stage;**
  - **FEL 2: The feasibility stage, and;**
  - **FEL 3: The basic engineering and development stage.**

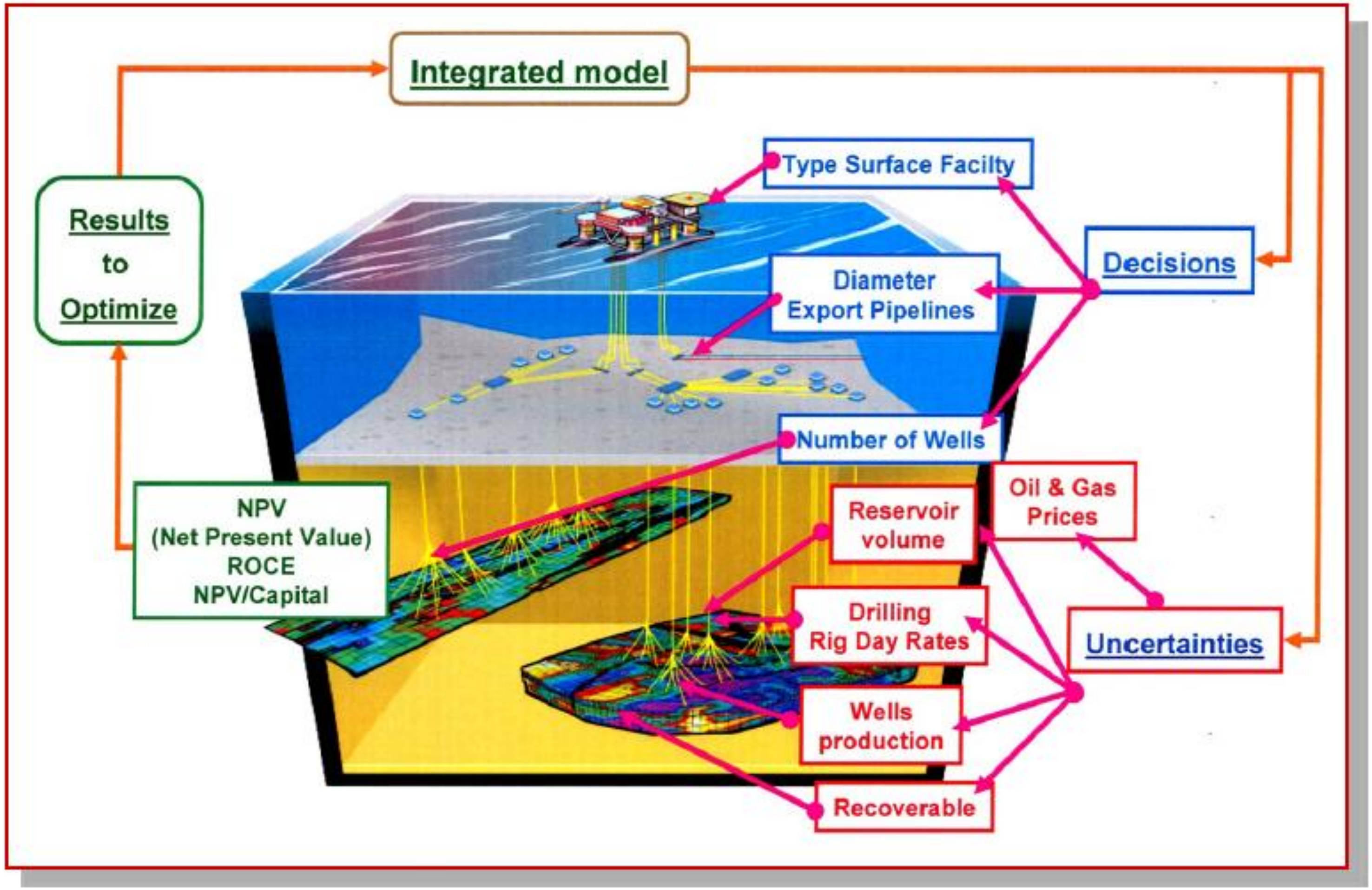


SPE 167655 L. Saputelli et others - 2013

Field Development Planning Process

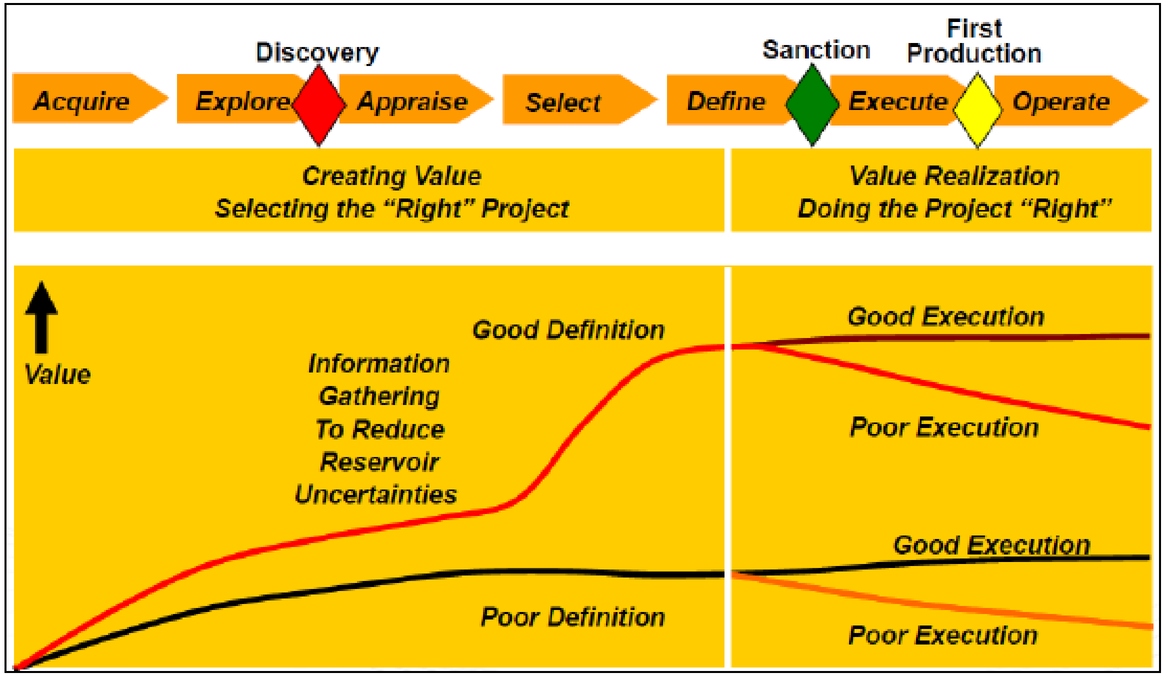
- To define an **optimum reservoir depletion** and **compatible facilities development plan** that has a high probability of meeting an Operator's major business drivers

- **It occurs in early project phases** when reservoir information is limited and uncertainty of key decision variables is high



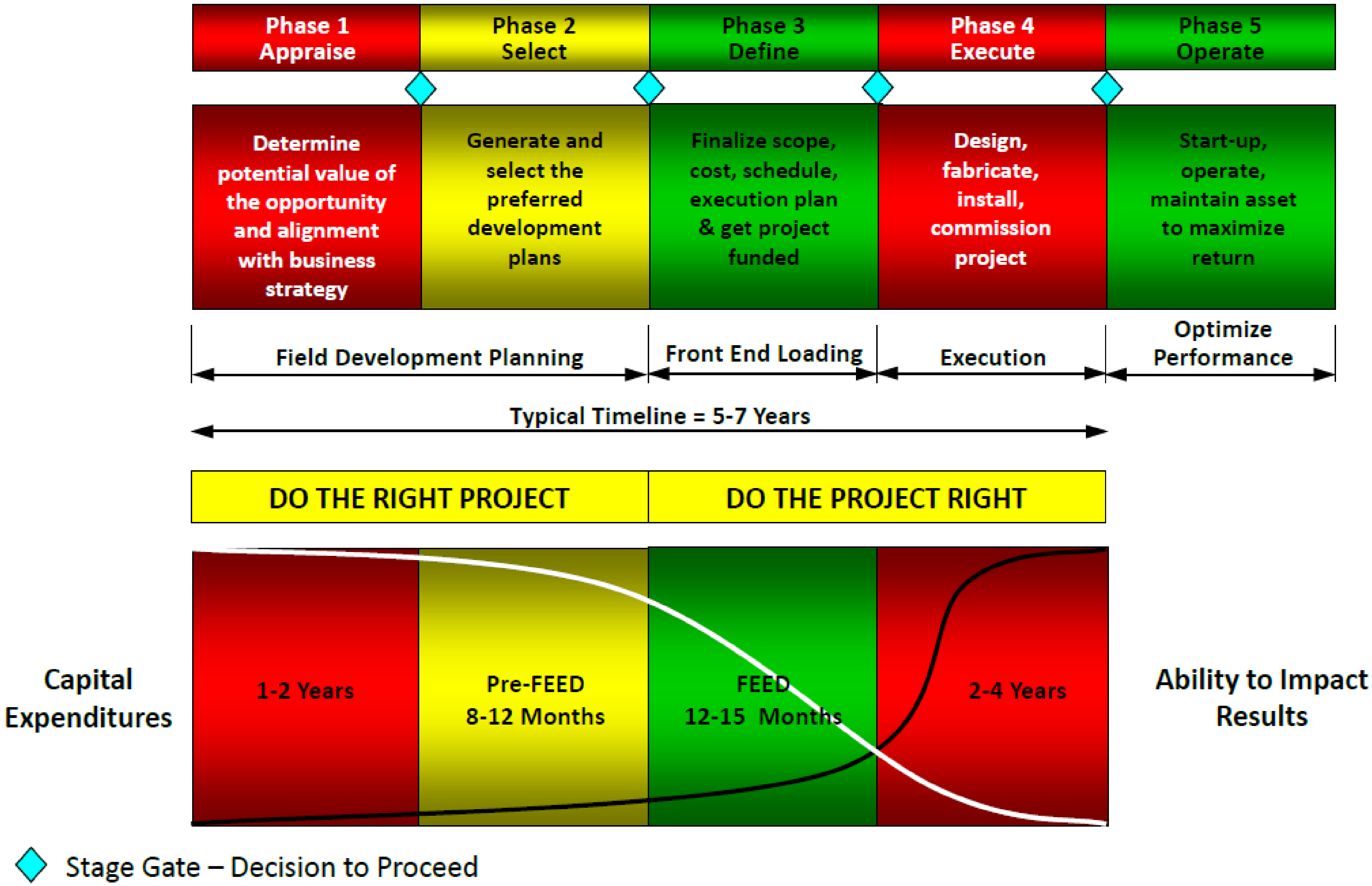
Early Planning Creates the Greatest Value

- The **greatest value to a project is created in the Appraise and Select phases** which involve:
  - Developing a robust **reservoir model** and depletion plan
  - Optimizing the **drilling program** (greatest recovery with fewest wells)
  - Minimizing **well performance** uncertainty
  - Selecting the right **surface facility** plan



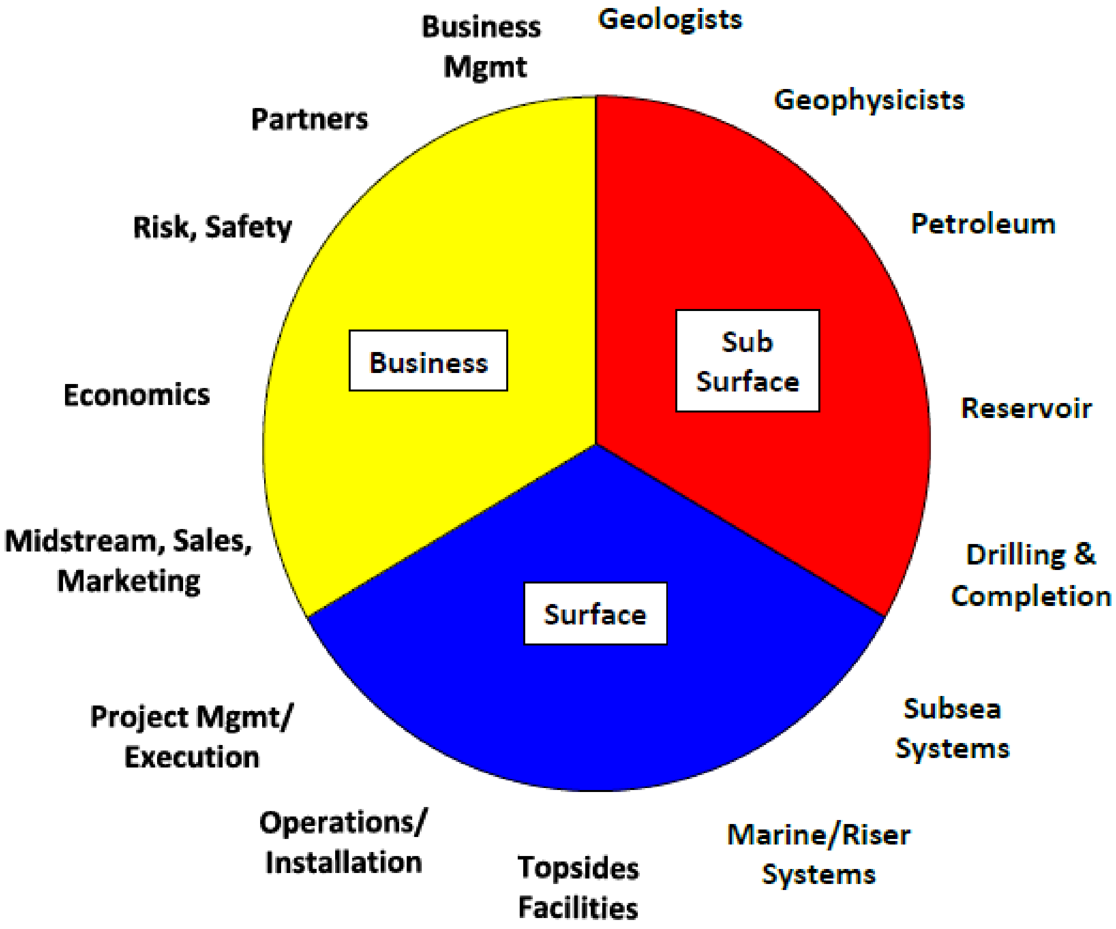
- The **spend in these phases is generally a small percentage of total development spend** but provides substantial added value to the project

Project Phases Have Distinct Objectives

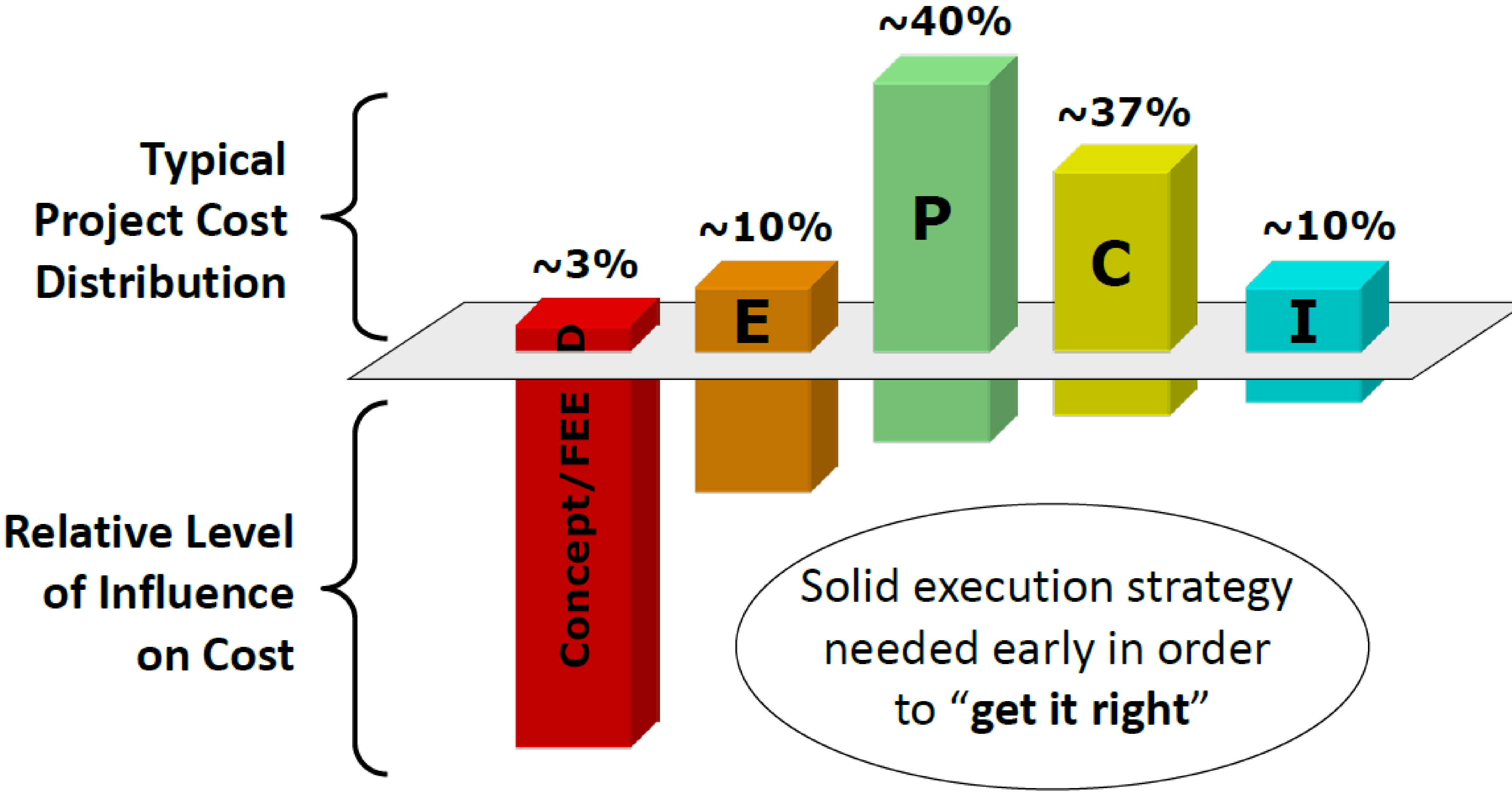


Planning is a Collaborative Process

- Objective is to **select a development plan that satisfies** an Operator's commercial, strategic and risk objectives
- It involves a **continuous interaction** between key elements:
    - Subsurface
    - Surface
    - Business
- The process **requires continuous and effective collaboration and alignment** between reservoir, well construction, surface facilities and commercial teams



Relative Influence on Cost



Proper Planning is Critical to Success

Assess	Select	Define	Execute
Feasibility Study	Concept Selection	Project Specifications	Design & Construction

Feasibility Studies

- Identify alternatives
- Determine technical feasibility
- Determine Commercial Viability

Concept Studies

- Screen alternatives
- Select development concept

FEED

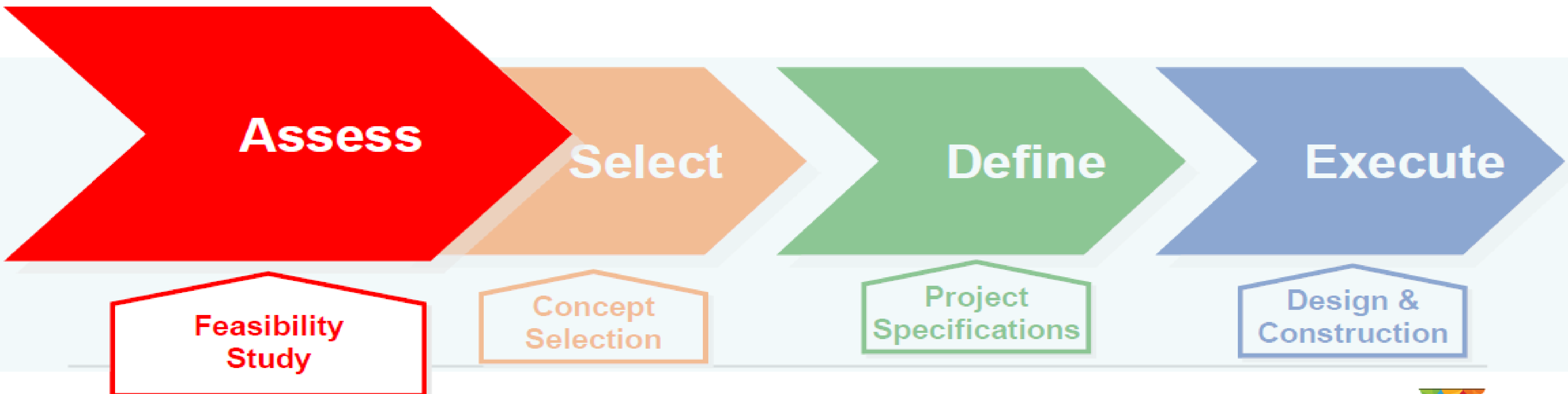
- Define development concept
- Design basis
- Cost
- Schedule
- Execution Plan

Execute EPCI

- Detail design
- Construction
- Installation
- HUC

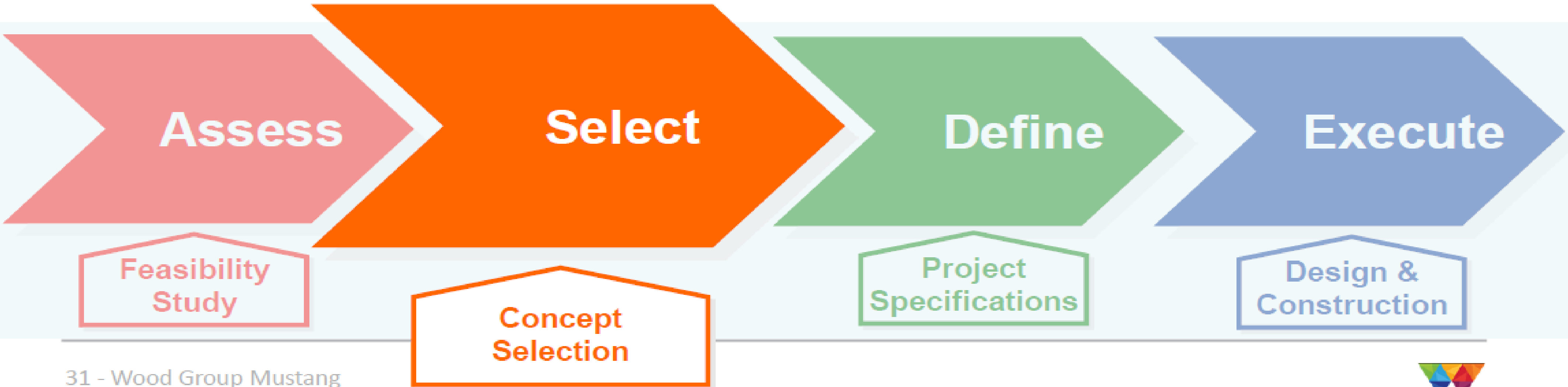
Planning for Success – Feasibility Phase

- Does the technology exist?
- Is it technically feasible?
- Can it be built to the required size?
- Can it be installed?
- Do the risks appear manageable?



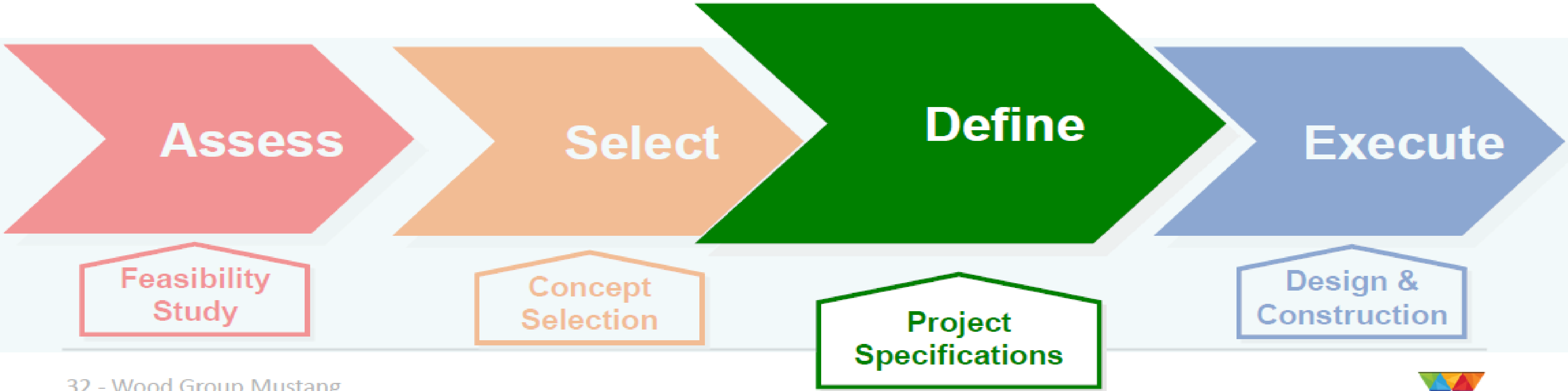
Planning for Success – Concept Selection

- Which concept will have the highest NPV?
- Constructability and install ability issues
- First-of-a-kind issues
- Site conditions
- Potential contracting constraints
- Risk analysis



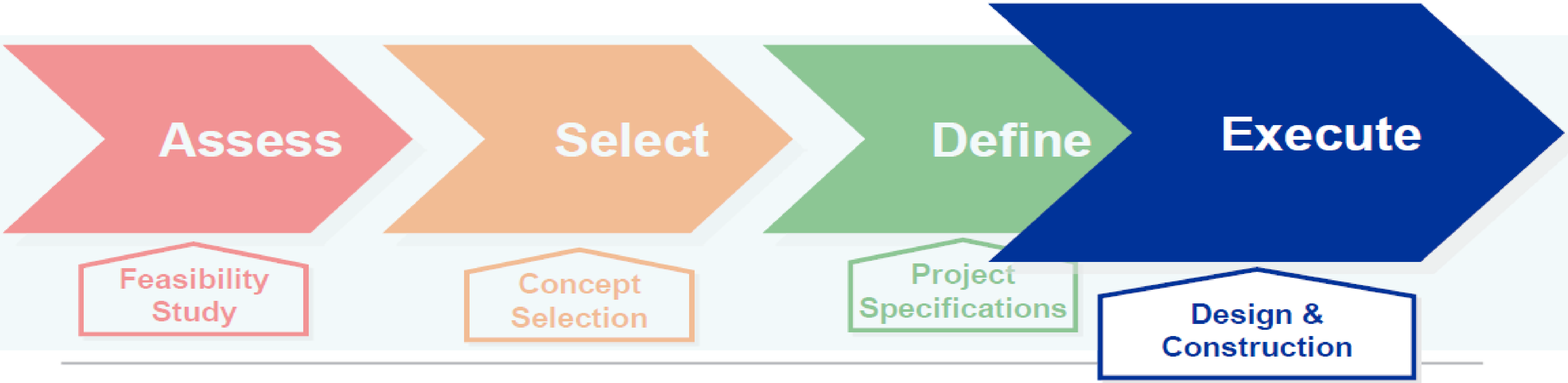
Planning for Success – FEED Phase

- Strive for a fabrication friendly design
- Strive for an installation friendly design
- Identify risks and develop mitigation plans
- Develop a manageable contracting strategy
- Develop a realistic cost estimate and schedule



Planning for Success – EPCI Phase

- Reflects pre-sanction planning
- Focus becomes ‘work the plan’
- Inadequate planning leads to serious problems
- Recovery is expensive



Floating System Selection Factors

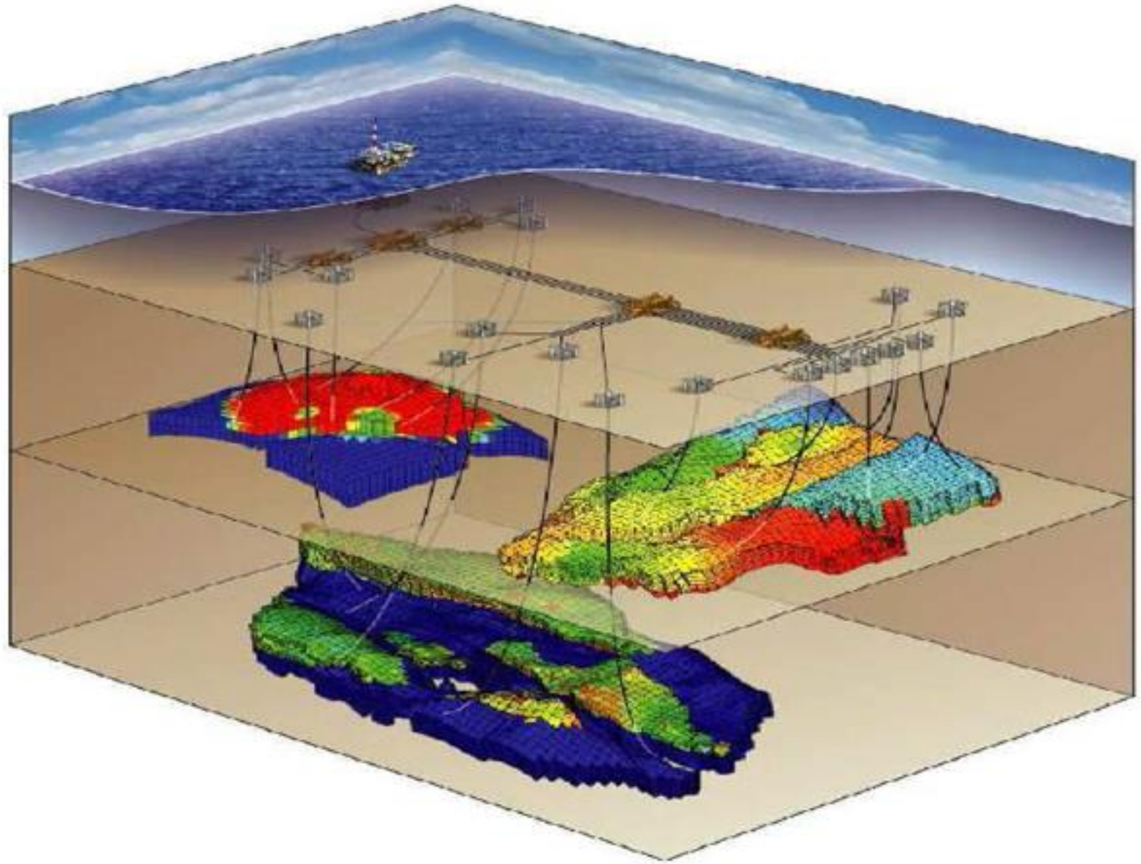
- **Functional**
  - Dry/Wet trees; drilling, workover
- **Technical**
  - Water depth; Metocean; Shut-in pressure; risers
- **Execution**
  - Topsides integration, installation and commissioning
- **Operations**
  - Safety; reliability; availability
- **Flexibility**
  - Contracting; future expansion; relocation
- **Commercial**
  - Capex, Opex and schedule

System Selection Criteria

- Location of drilling activity.
- Depth of water, seabed features & lateral force at location for offshore drilling.
- Deck requirements.
- Size of field and location of wells.
- Transport of oil requirements.
- Type of drilling i.e. active site drilling, ‘wildcat’ well drilling, scientific drilling

Key Drivers for Floating System Selection

- **Reservoir** characteristics drive everything
- **Field architecture** and layout / future expandability
- **Riser** options / platform motions
- **Metocean** criteria
- **Topsides** requirements
- **Local content** requirements
- **Drilling & completion** strategy
- **Risk** issues & mitigating measures
- **Execution** plan and delivery model



Completion Strategy Drives Floater Selection

Criteria	**Total Subsea** (wet-tree)	**Surface** (dry-tree)
CAPEX Cost	Lower	Higher
DRILEX Cost	Higher	Lower
OPEX Cost	Higher	Lower
Production Reliability	Lower	Higher
Reservoir Mgmt and Productivity	Lower	Higher

Deepwater Concept Qualification Matrix

Deepwater Field Development Concept Selection Matrix

COURTESY: WOOD GROUP MUSTANG

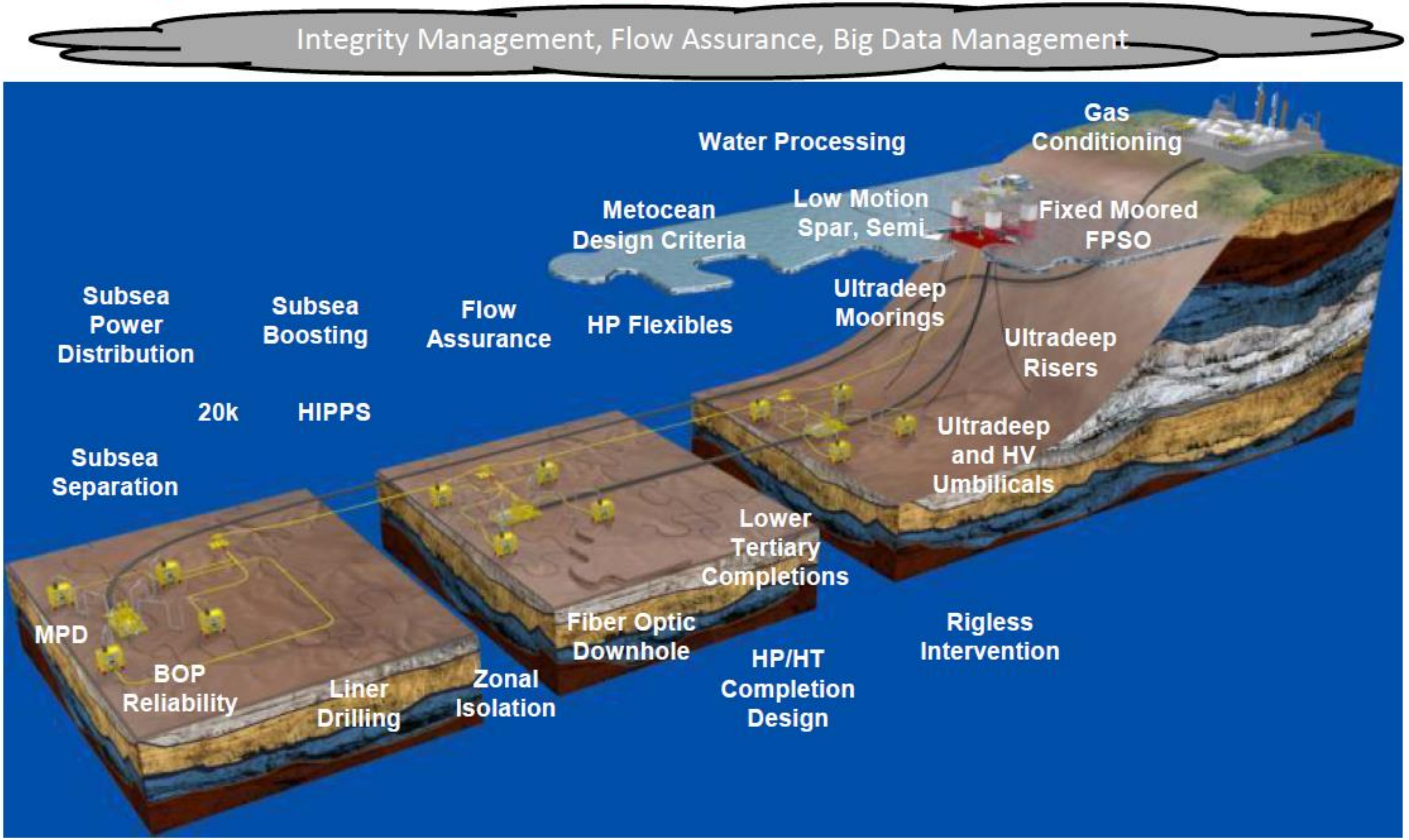
Legend:

- Field Proven
- Qualified

* "Unconventional" FPSOs include Sevan SSP, Petrobras MonoBR, Global SSP SSP320 & SSP PLUS.

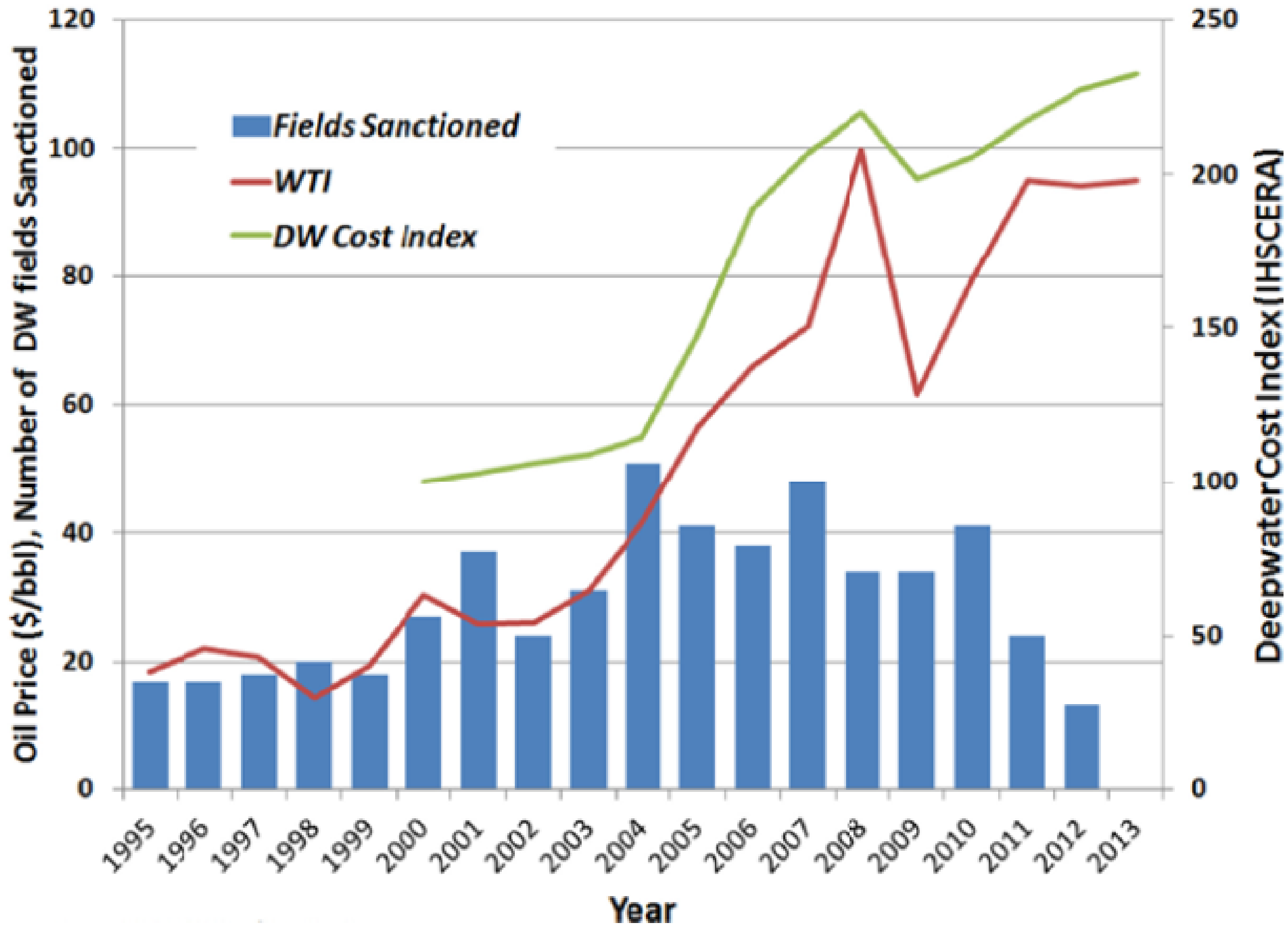
Deepwater Field Development Concept Selection Matrix		MAJOR CAPABILITY					INSTALL		RESERVOIR INFO. – ARIAL EXTENT		TREE TYPE			LOCATION APPLICATION			ENVIR. CONDITIONS			RISERS			EXPORT			
	FIELD APPLICATION EXPERIENCE	PRODUCTION	DRILLING	STORAGE	WATER DEPTH RATING	PAYLOAD SENSITIVE	DECK/HULL MATING OFFSHORE	DECK/HULL MATING @ FABRICATION YARD	SMALL AREA	LARGE AREA	WET TREE	DRY TREE	WELL COUNT	NEARBY INFRASTRUCTURE	REMOTE	SMALL FOOTPRINT (Mooring System)	CALM	AREA WITH HURRICANES/TYPHOONS	HARSH	STEEL CATENARY RISER (SCR) CAPABLE	FLEXIBLE PIPE CAPABLE	TOP TENSIONED RISER	OIL PIPELINE EXPORT APPLICATION	SHUTTLING APPLICATION	GAS PIPELINE	GAS REINJECTION
Conventional Fixed Platform (>1,000')	Field Proven	Field Proven	Field Proven		See Water Depth Range Comparison Graph		Field Proven		Field Proven	Field Proven		Field Proven	See Well Capability by Deepwater Production Type Graph	Field Proven		Field Proven	Field Proven	Field Proven	Qualified	Field Proven	Qualified		Field Proven	Qualified	Field Proven	Field Proven
Compliant Towers	Field Proven	Field Proven	Field Proven				Field Proven		Field Proven	Qualified		Field Proven		Field Proven		Field Proven	Field Proven	Field Proven	Qualified	Field Proven	Qualified		Field Proven		Qualified	Qualified
FDPSOs	Field Proven	Field Proven	Field Proven	Field Proven			Qualified	Field Proven			Field Proven	Qualified		Qualified	Qualified		Field Proven	Qualified		Qualified	Field Proven	Qualified		Field Proven	Qualified	Qualified
FPSOs																										
Spread Moored	Field Proven	Field Proven		Field Proven			Qualified	Field Proven	Field Proven	Field Proven	Field Proven				Field Proven		Field Proven			Field Proven	Field Proven			Field Proven	Field Proven	Field Proven
Turret Moored	Field Proven	Field Proven		Field Proven			Qualified	Field Proven	Field Proven	Field Proven	Field Proven				Field Proven			Field Proven	Field Proven	Field Proven	Field Proven			Field Proven	Field Proven	Field Proven
Unconventional*	Field Proven	Field Proven	Qualified	Field Proven			Qualified	Qualified	Qualified	Qualified	Qualified	Qualified			Qualified	Qualified	Qualified	Qualified	Qualified	Field Proven	Field Proven	Qualified	Qualified	Qualified	Qualified	Qualified
Conventional TLPs	Field Proven	Field Proven	Field Proven					Field Proven	Field Proven		Field Proven	Field Proven		Field Proven	Field Proven	Field Proven	Field Proven	Field Proven	Field Proven	Field Proven	Field Proven	Field Proven	Field Proven	Field Proven	Field Proven	Qualified
Proprietary TLPs	Field Proven	Field Proven	Field Proven			Field Proven	Field Proven	Field Proven	Field Proven	Field Proven	Field Proven	Field Proven		Field Proven	Field Proven	Field Proven	Field Proven	Field Proven	Qualified	Field Proven	Field Proven	Field Proven	Field Proven	Qualified	Field Proven	Qualified
Spars																										
Dry Tree	Field Proven	Field Proven	Field Proven			Field Proven	Field Proven	Qualified	Field Proven			Field Proven		Field Proven	Qualified	Field Proven	Field Proven	Field Proven	Qualified	Field Proven	Field Proven	Field Proven	Field Proven	Field Proven	Field Proven	Qualified
Wet Tree	Field Proven	Field Proven	Field Proven			Qualified	Field Proven	Qualified	Qualified		Field Proven			Field Proven	Qualified	Field Proven	Qualified	Field Proven	Qualified	Field Proven	Qualified	Qualified	Field Proven	Qualified	Qualified	Qualified
Semi-FPUs																										
Conventional	Field Proven	Field Proven	Qualified					Field Proven	Qualified	Field Proven	Field Proven	Qualified		Field Proven			Field Proven	Field Proven	Field Proven		Field Proven		Field Proven		Field Proven	Qualified
Deep Draft Wet Tree	Field Proven	Field Proven	Qualified			Qualified	Qualified	Field Proven	Field Proven	Qualified	Field Proven			Field Proven	Qualified	Qualified	Field Proven	Field Proven	Qualified	Field Proven	Field Proven	Qualified	Field Proven	Qualified	Field Proven	Qualified
Deep Draft Dry Tree	Qualified	Qualified	Qualified			Qualified	Qualified	Qualified	Qualified	Qualified		Qualified		Qualified	Qualified	Qualified	Qualified	Qualified	Qualified	Qualified	Qualified	Qualified	Qualified	Qualified	Qualified	Qualified
Subsea Tiebacks	Field Proven								Field Proven	Field Proven	Field Proven			Field Proven			Field Proven	Field Proven	Field Proven							

Deepwater Technology Needs



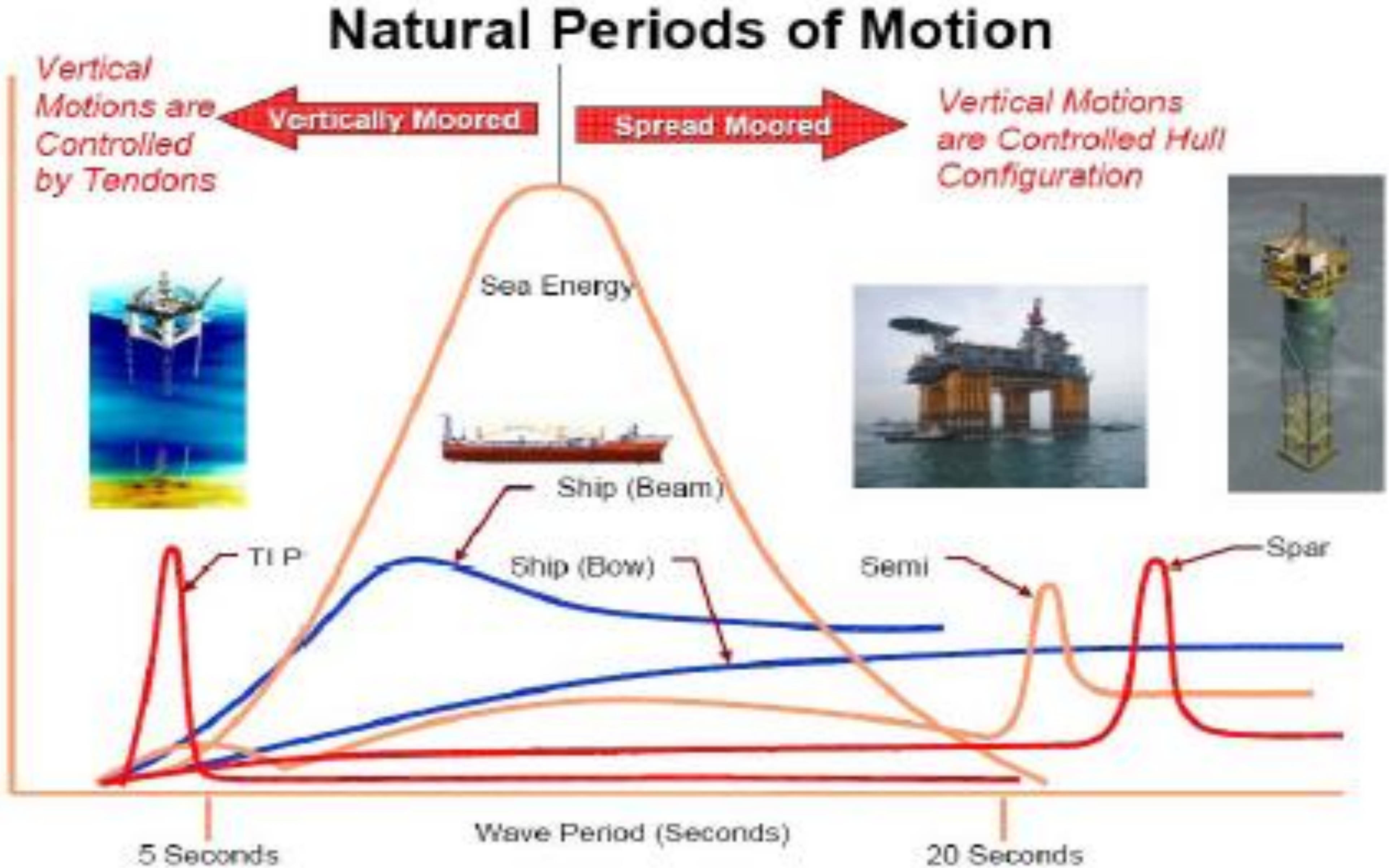
Deepwater Development Trends

- Capex inflation outpacing oil & gas price inflation
- Most deepwater projects are now "Mega-Projects"
- Industry struggling to achieve acceptable commercial results
- Geographic, geologic and geopolitical trends are root causes

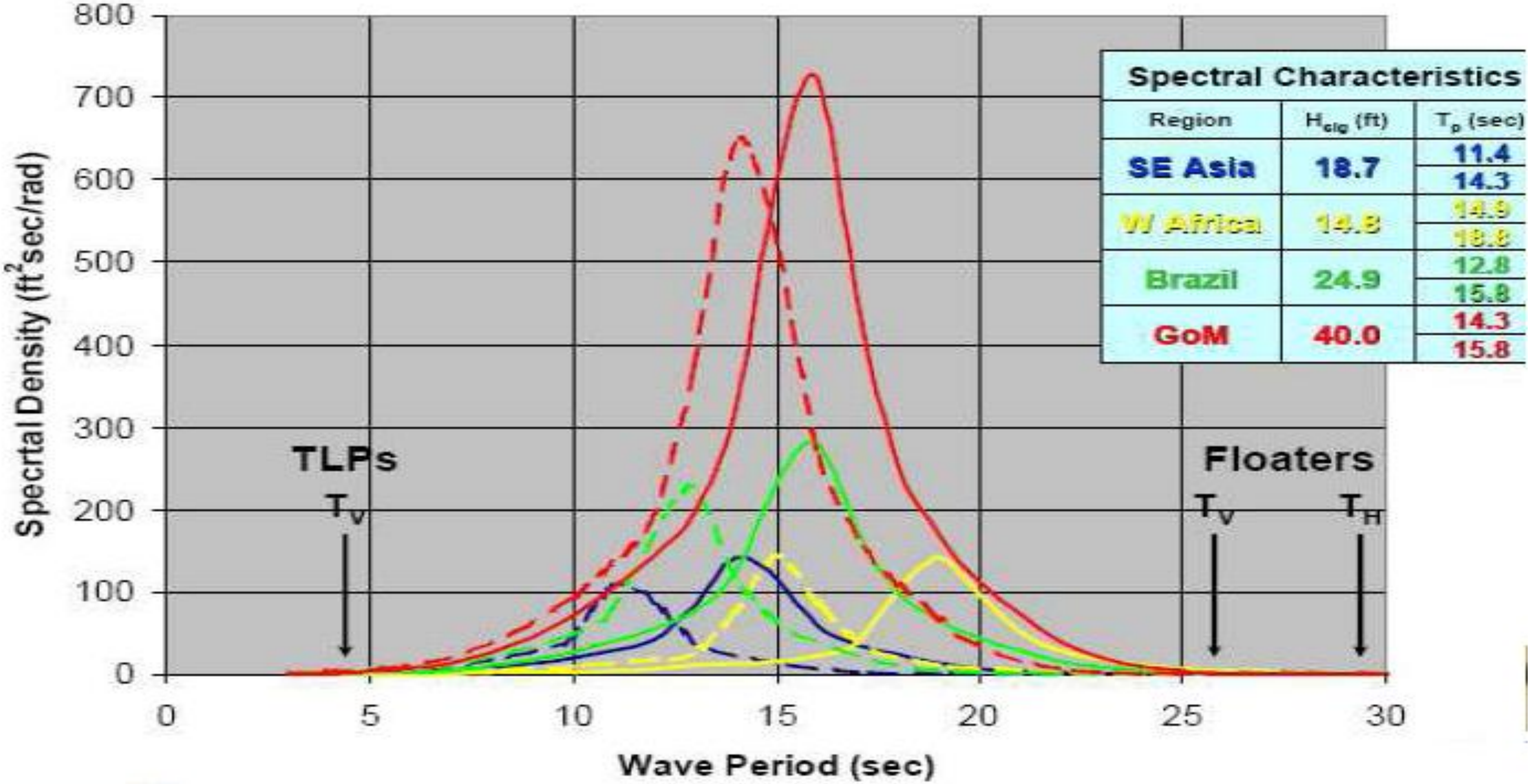


Source: HIS CERA, Wood MacKenzie

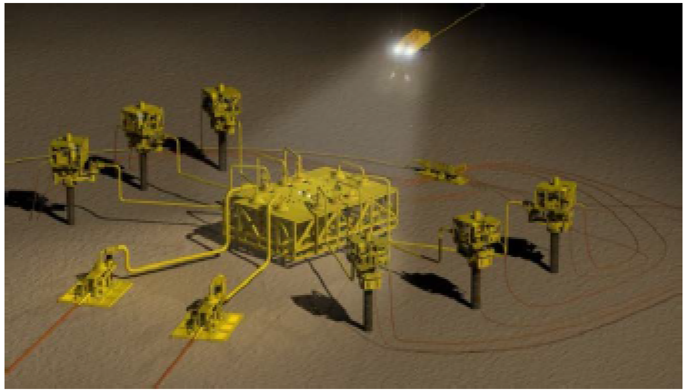
Some Deep Offshore R&D Challenges


Natural Periods of Motion
Vertical Motions are Controlled by Tendons
Vertically Moored
Spread Moored
Vertical Motions are Controlled Hull Configuration
Sea Energy
Ship (Beam)
Ship (Bow)
TLP
Semi
Spar
Wave Period (Seconds)
5 Seconds
20 Seconds

Comparison of Global Design Wave Spectra

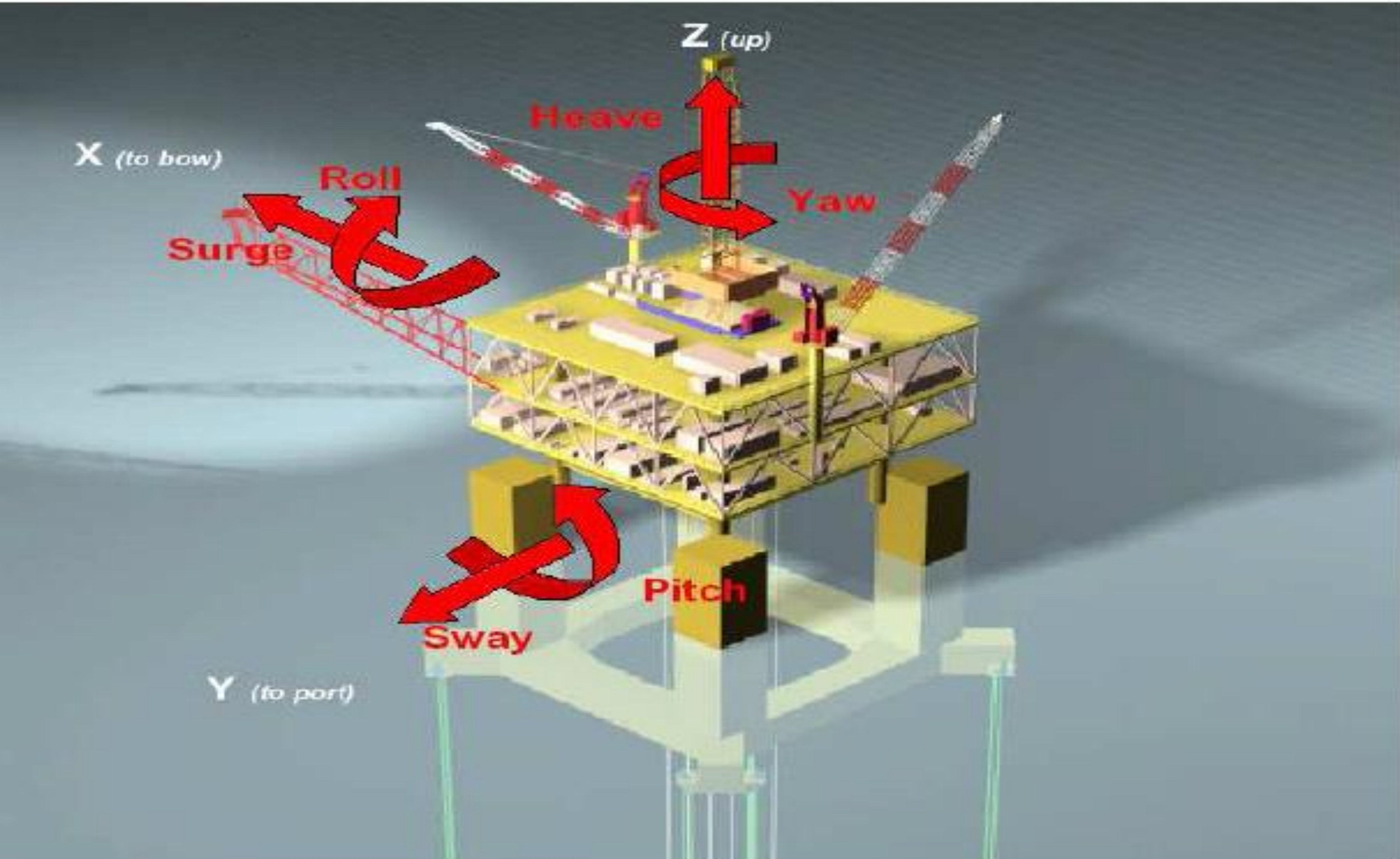


The Deepwater Game is Changing

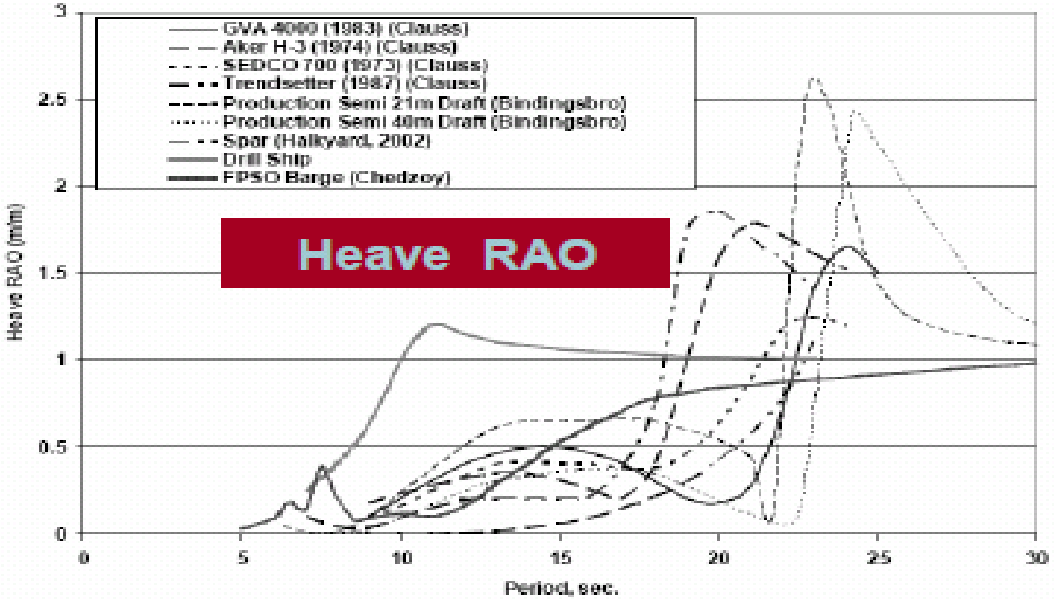


- **Development opportunities are more challenging**...deeper water, more complex reservoirs; sub-economic accumulations; ultra-deepwater and remote locations; viscous oil, low energy drive
- **Capex/risk exposures are large**...cost exposure in the billions; high cost drilling & infrastructure
- **Pressure to shorten schedule and reduce cost continues**... longer cycle times; standardization; technology development vs rapid deployment
- **Lack of local logistics/service industry**...affects project delivery
- **Competent/skilled staffing shortages**...demand still exceeds supply; building local capability can be difficult

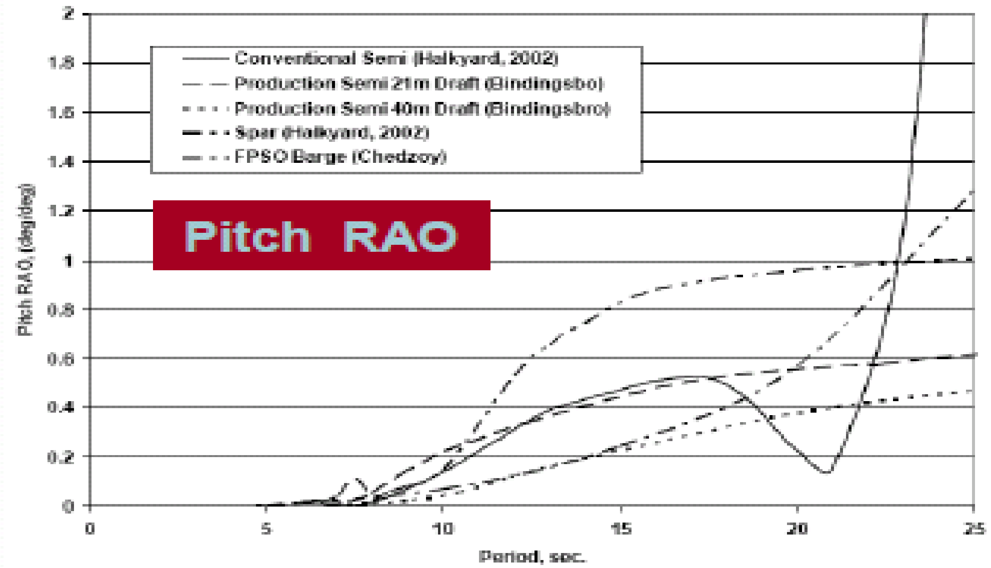
6 DOF Motion Definition (Rigid Body)

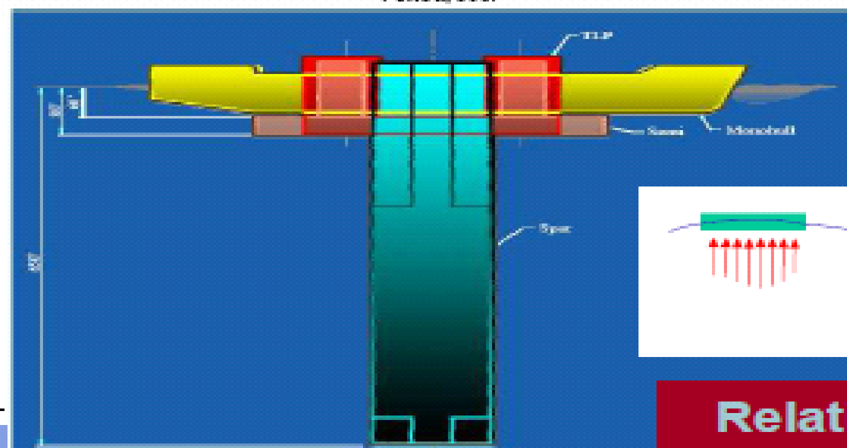


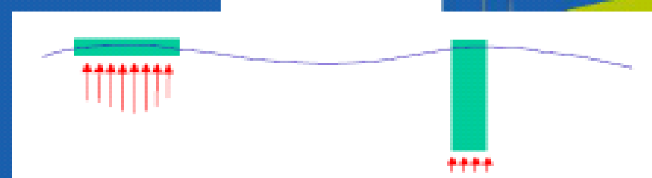
Heave RAO

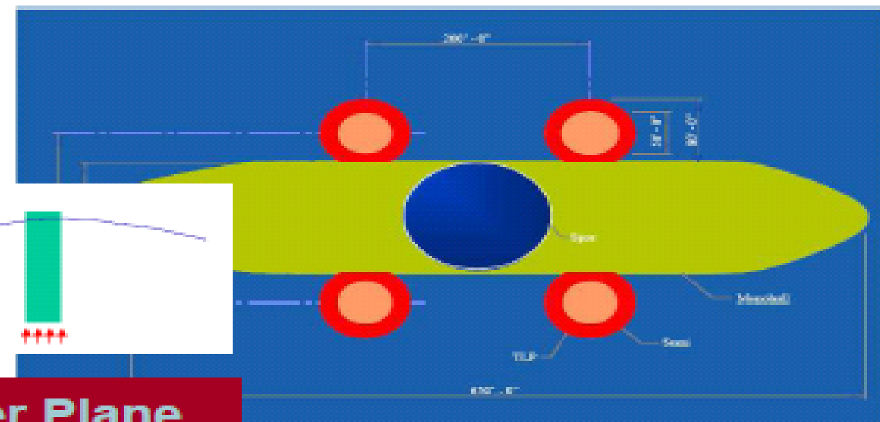


Pitch RAO









Relative Water Plane Area


THANK YOU!
QUESTIONS?