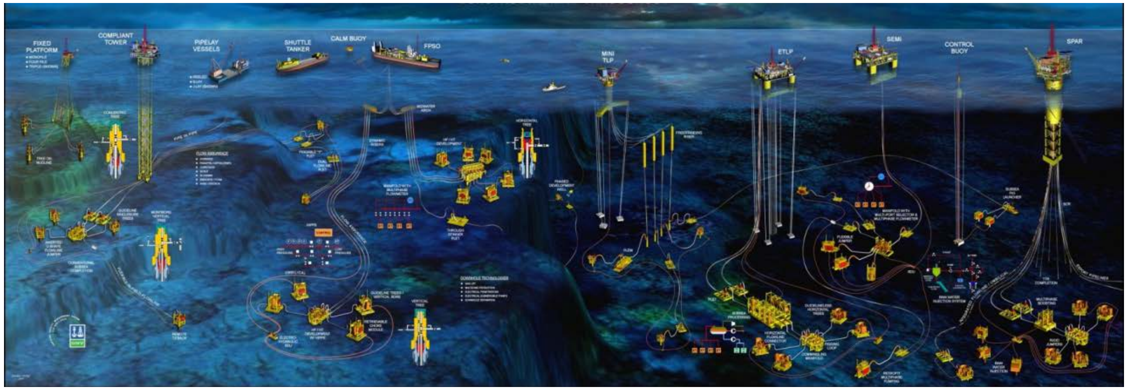
WOOD GROUP
MUSTANG

Introduction to Deepwater Development



Christopher M. Barton

UH Petroleum Industry Expert Lecture Series

Petroleum Technology Program

October 29, 2014

Presentation Overview

- A Historical Perspective
- Why Deepwater?
- Deepwater Solutions
- Field Development Planning
- Floating System Selection
- Technology, Trends and Challenges
- Wrap-up
- Q&A

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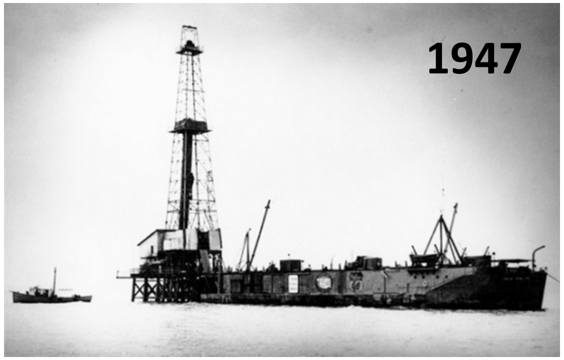
A Historical Perspective

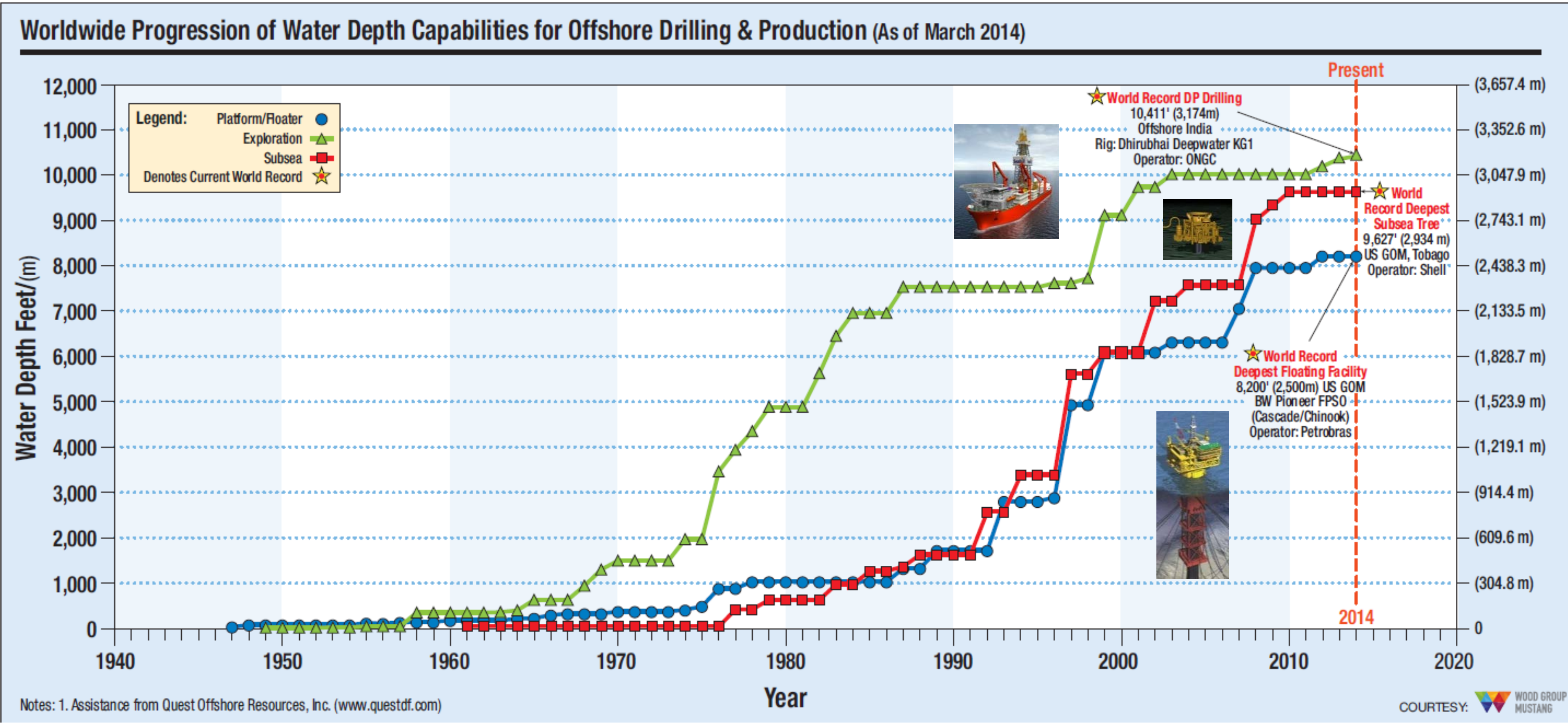
- First well drilled out of sight of land 67 years ago in 21 ft water depth
  - ✓ **Today, we are drilling in depths exceeding 10,000 ft**
- First offshore platform installed in 1947 in 21 ft of water
  - ✓ **Today, platforms are being installed in depths exceeding 8,000 ft**
- World's tallest structure 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.

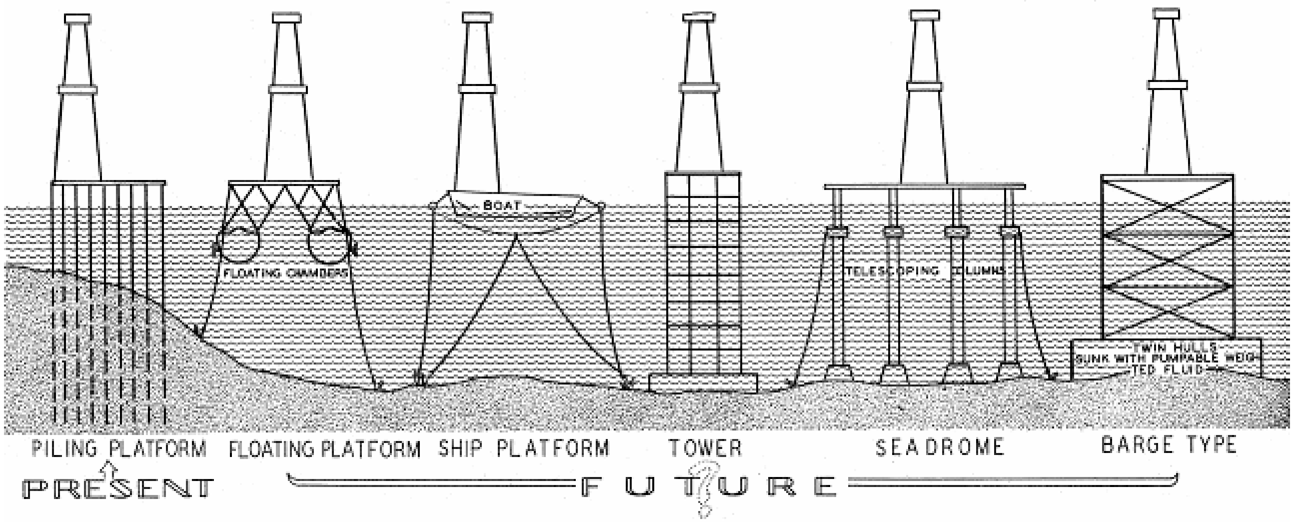
The 50 Year March to Deepwater



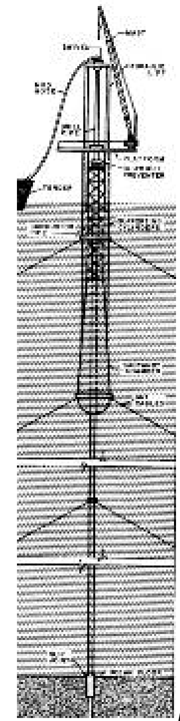
1. The drillers were drilling in deepwater long before we had the production capability.
2. The time and depth gap between drilling and production is closing fast.
3. 10,000’ has been the water depth threshold for almost 10 years.

The Deepwater Vision – Then and Now

June 1947 - Oil & Gas Journal



Feb 1959 - Offshore Magazine



Semi

FPSO

Compliant Tower

TLP

Spar

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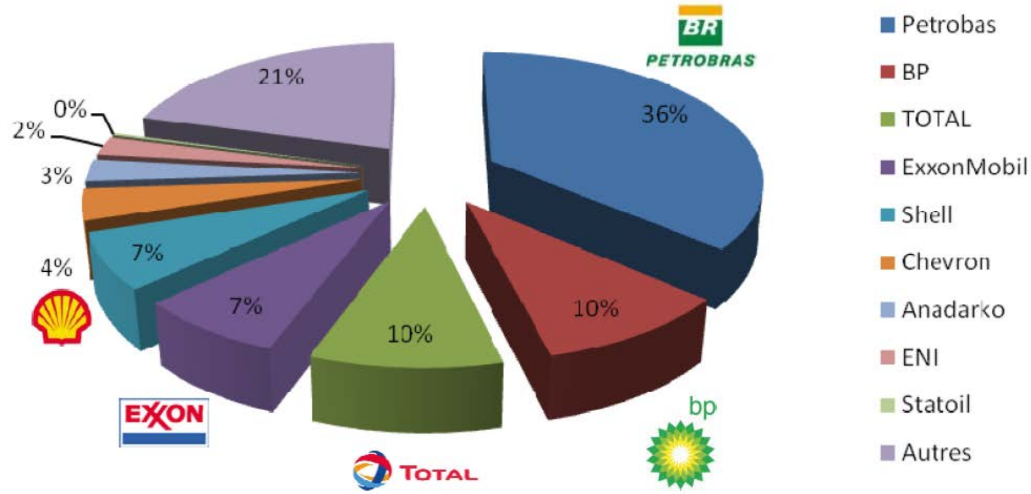
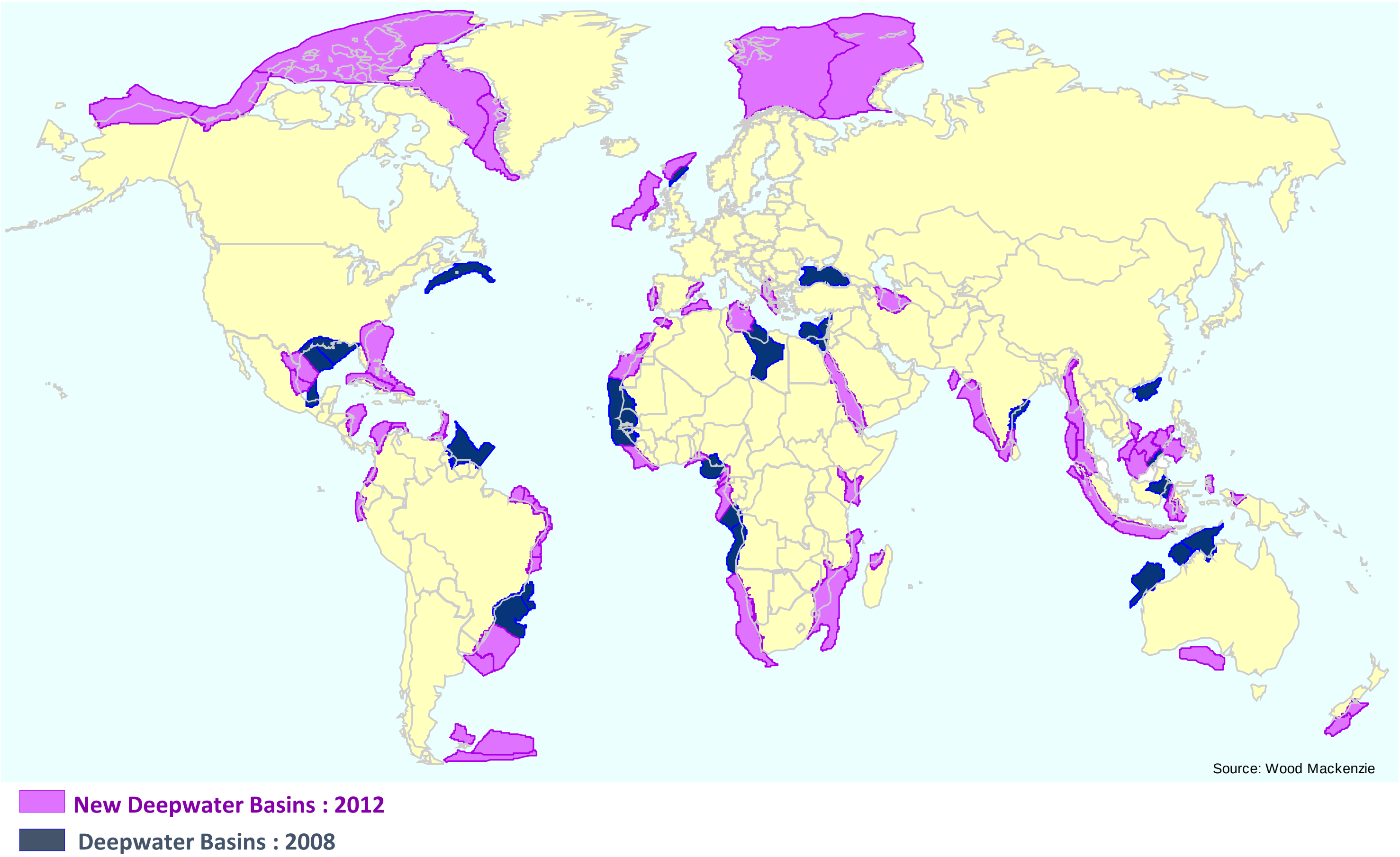
Why Deepwater?

- 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

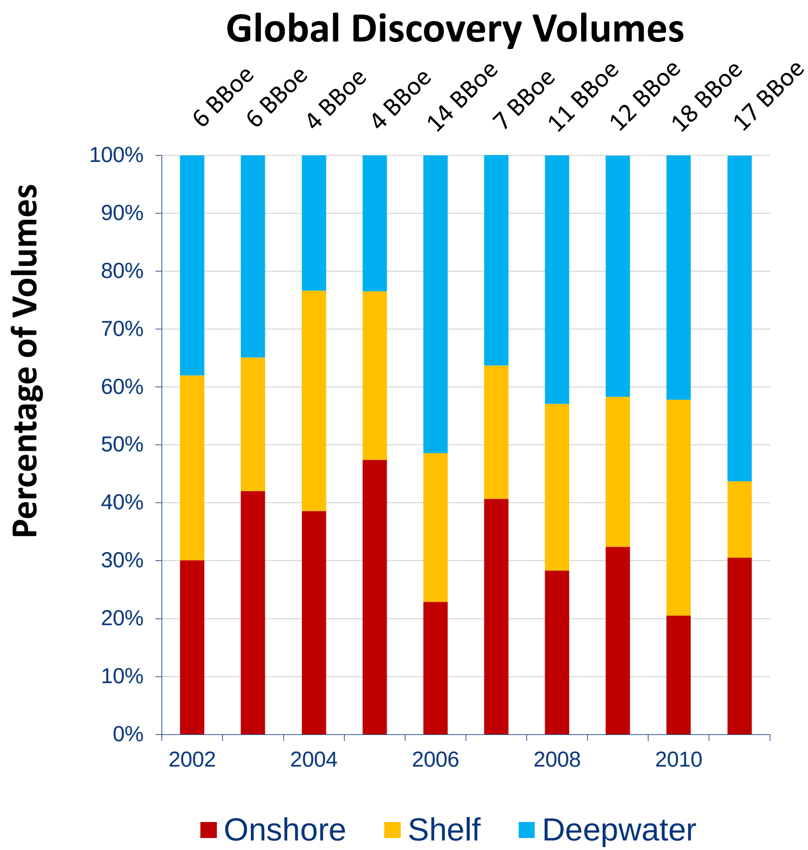


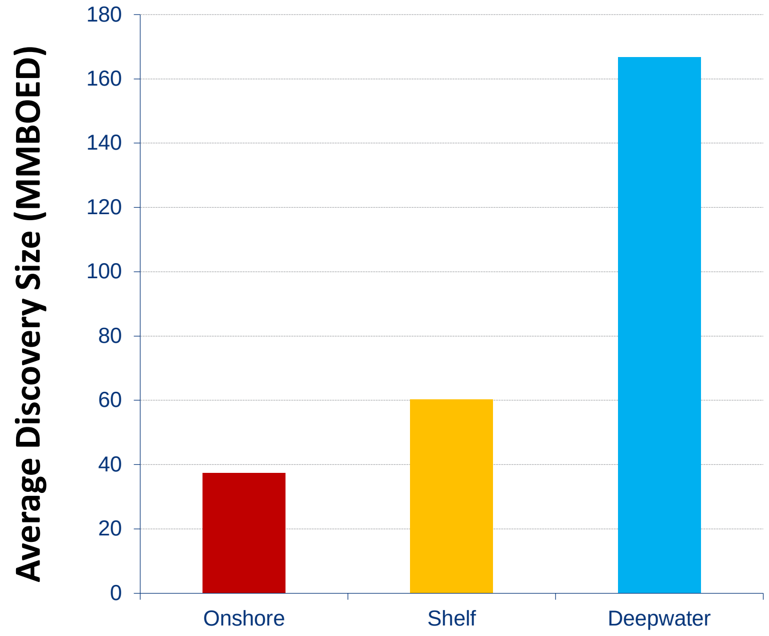
Deepwater Drilling is Rapidly Expanding



- 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

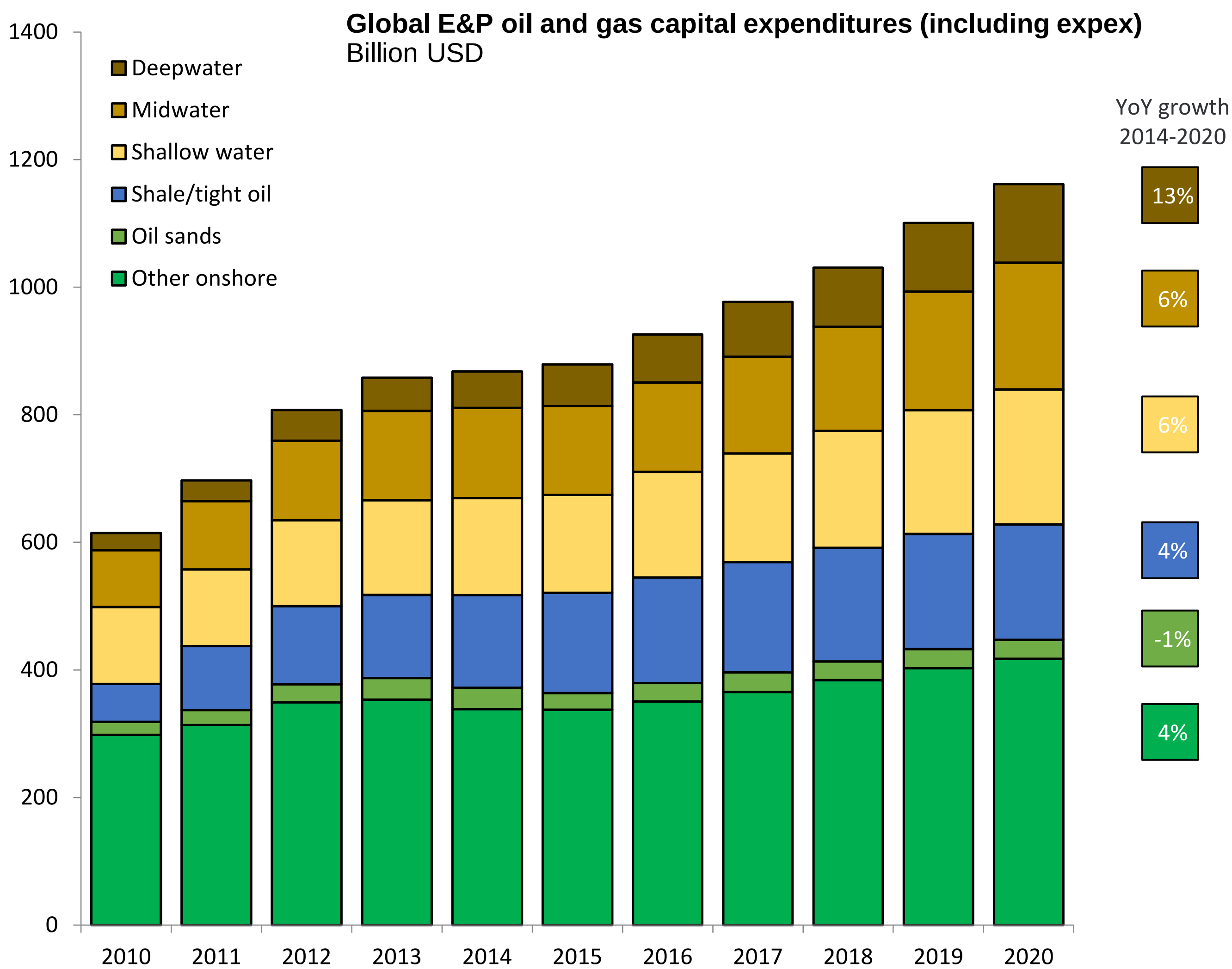




Larger average field sizes and more cumulative volumes discovered in deepwater than onshore or shelf

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

Long-term Investment Outlook is Good



Source: Rystad

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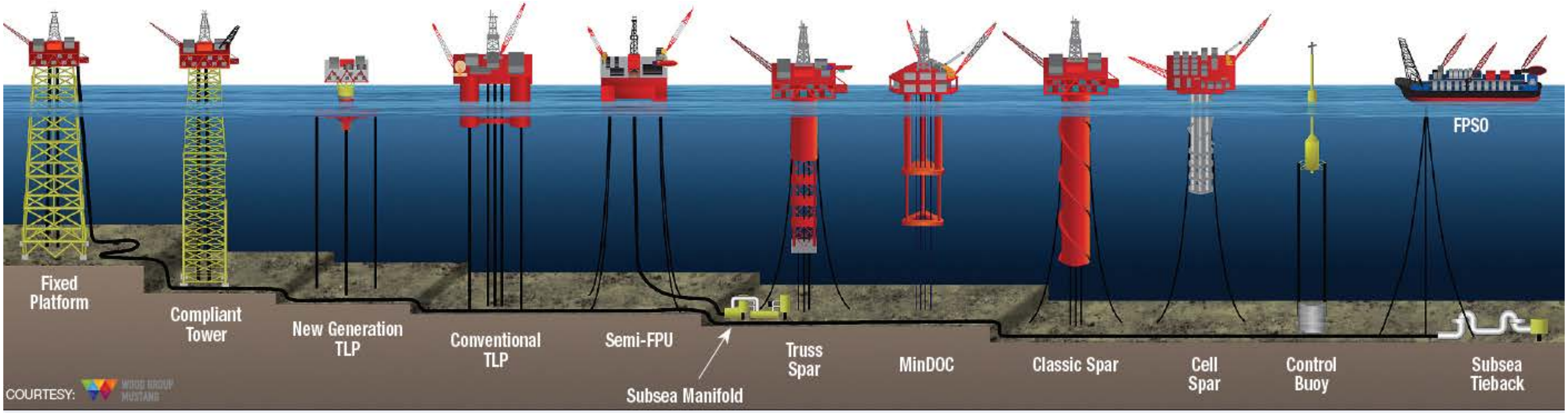
Deepwater System Types Currently in Use

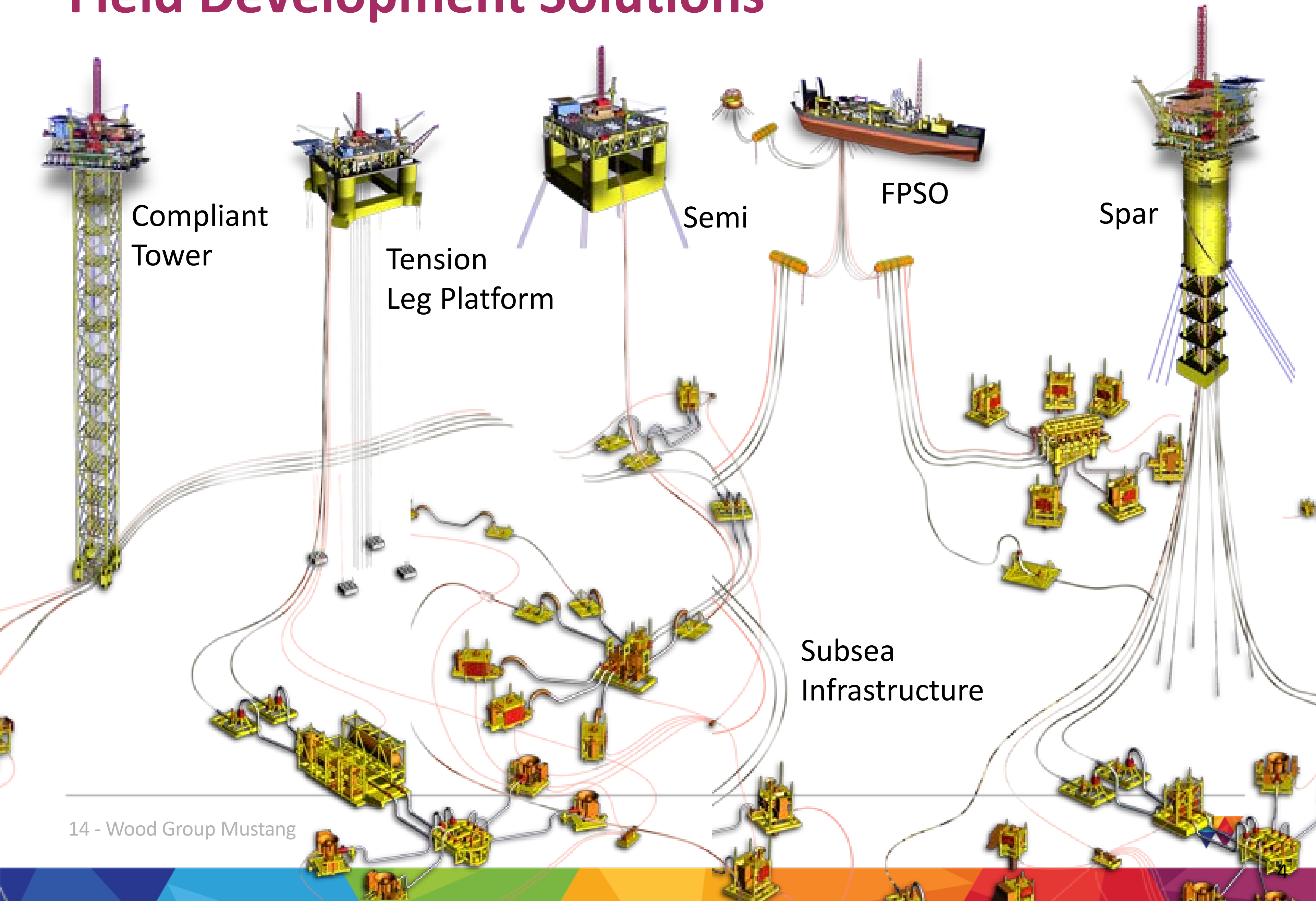


Source: Mustang Engineering & Offshore Magazine Deepwater Poster – May, 2013; Go to www.offshore-magazine.com/maps-posters.html

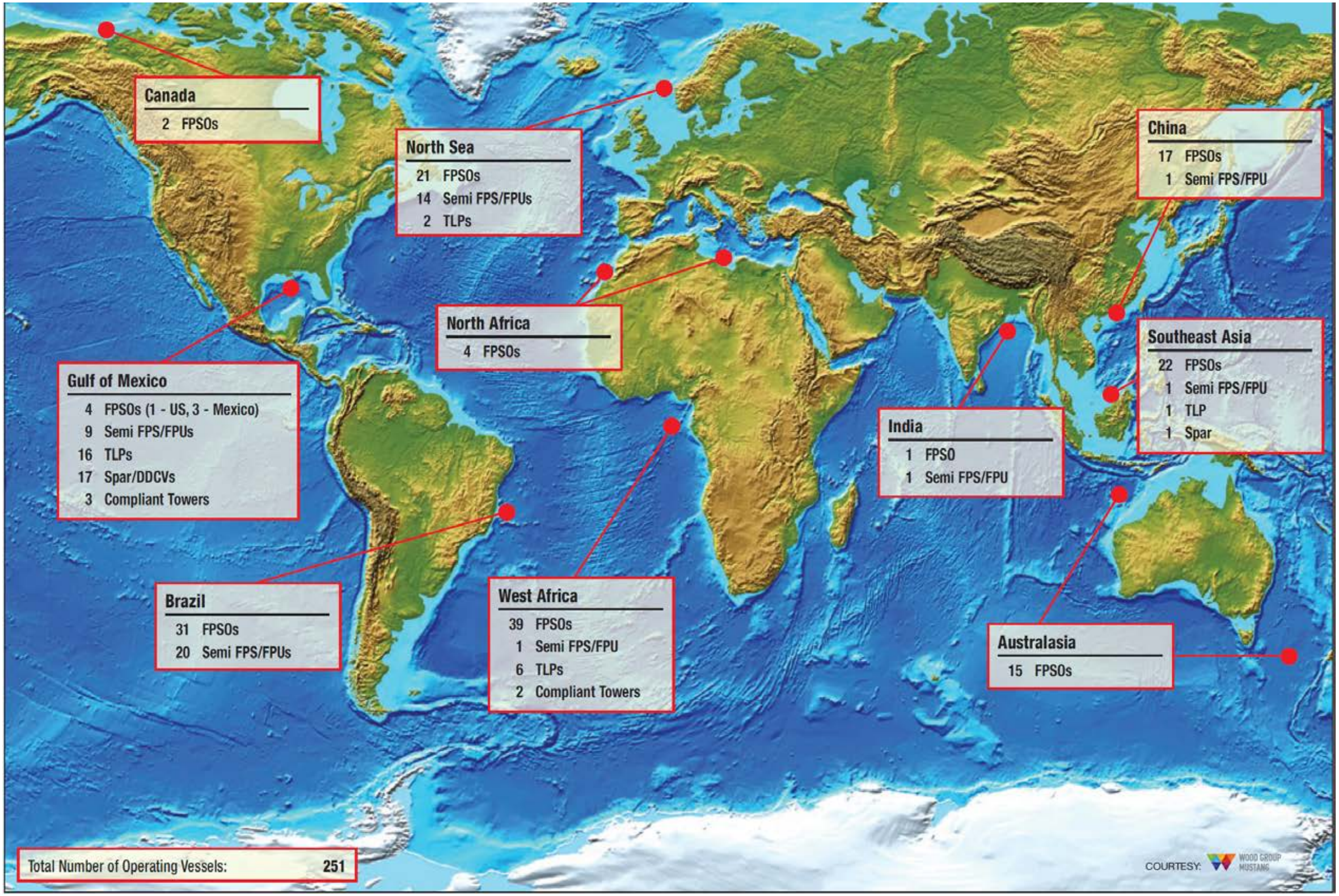
Three Deepwater System Groups:

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

Field Development Solutions



Deepwater Systems Global Distribution

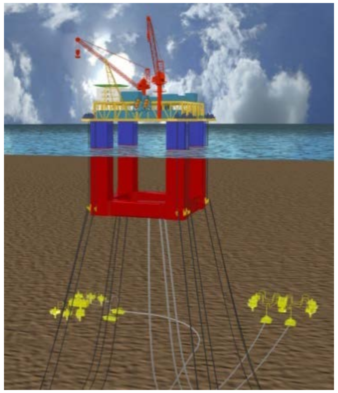


Predominant Floater Types

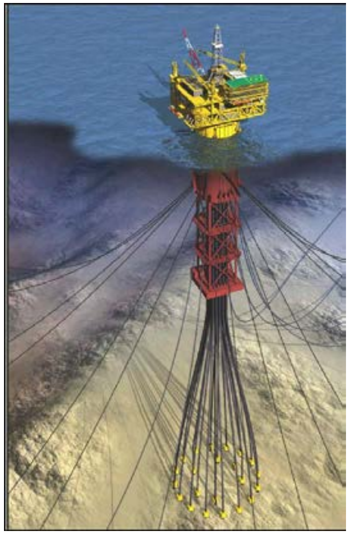
There are four primary industry recognized floating production solutions, accepted because:

- ***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

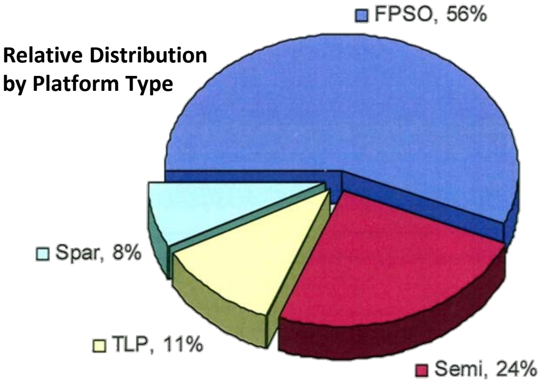


Semi-submersible (Semi)



Spar

FPSO

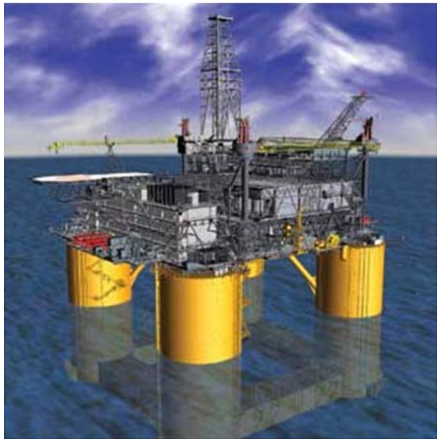


Fundamental Concept Differentiators

- Functionality
- Scalability
- Integration
- Installation
- Flexibility

Semisub (Wet trees)

Spar (Dry or Wet trees)



TLP (Dry or Wet trees)

FPSO (Wet trees)

Semisubmersible Platform – Variants and Differentiators

- **Functionality**
  - Wet trees
  - Subsea BOP drilling, completion, intervention
- **Scalability Constraints**
  - Limited envelope of SCR applicability
- **Installation, Integration**
  - Quayside integration
  - Relatively simple installation
- **Flexibility**
  - Ease of decommissioning, relocation and future expansion

Conventional Draft

Deep Draft

Tension Leg Platform – Variants and Differentiators

- **Functionality**
  - Dry or Wet trees
  - Subsea BOP drilling, completion, intervention
- **Scalability Constraints**
  - Tendons limit w.d. to about 5,000 ft
- **Installation, Integration**
  - Quayside or offshore integration
  - Installation relatively complex
- **Flexibility**
  - Limited flexibility for decommissioning, relocation

Classic (Aker)

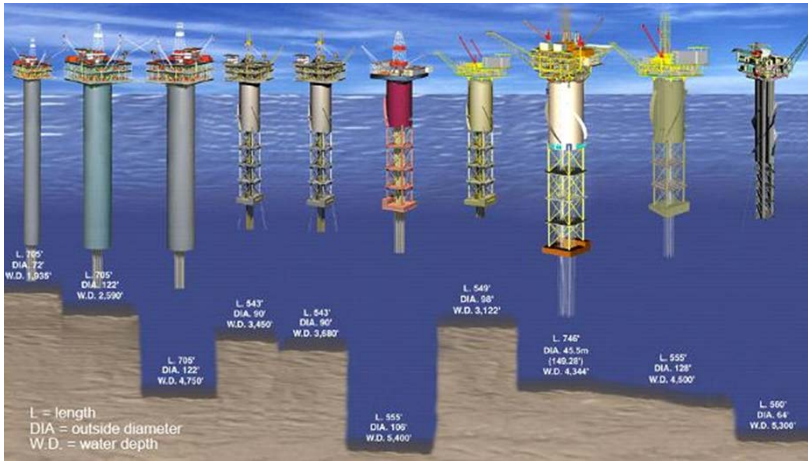
ETLP (FloaTEC)

MOSES (Modec)

SeaStar (Atlantia)

Spar Platform –
Variants and Differentiators

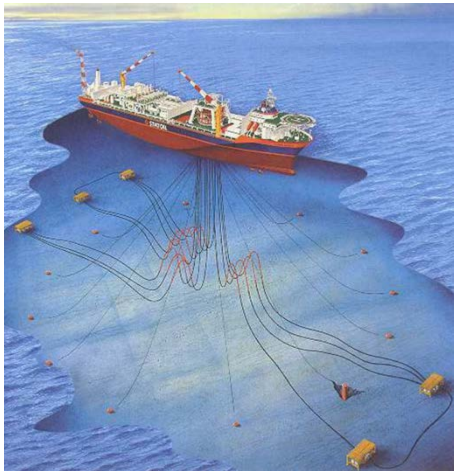
- **Functionality**
  - Dry or Wet trees
  - Subsea BOP drilling, completion
- **Scalability Constraints**
  - Dual barrier production riser with increasing depth and pressure
  - Very large payloads (>25,000 tons)
- **Installation, Integration**
  - Offshore deck installation
- **Flexibility**
  - Limited flexibility for decommissioning, relocation, expansion



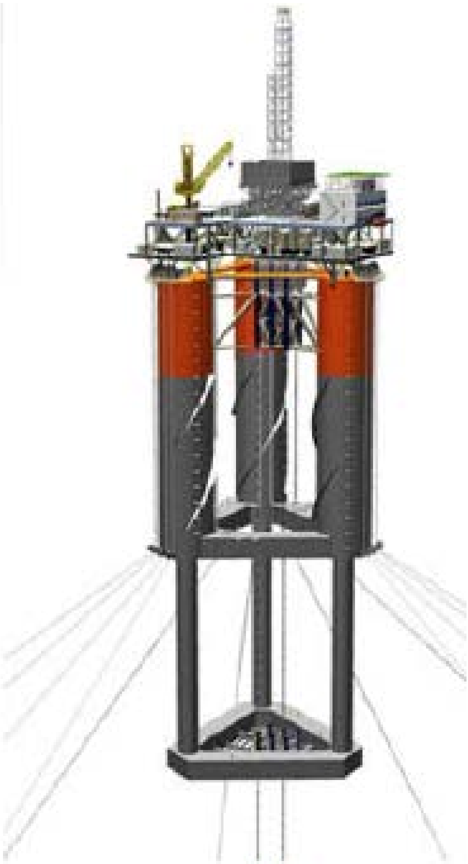
Classic, Truss and Cell Spars

Floating Production, Storage & Offloading – Variants and Differentiators

- **Functionality**
  - Wet trees
  - Subsea BOP drilling, completion, intervention
- **Scalability Constraints**
  - No water depth constraints
  - Riser constraints in deeper waters
  - Very large payloads (>25,000 tons)
- **Installation, Integration**
  - Shipyard integration
  - Suitable for harsh and remote locations
- **Flexibility**
  - Good flexibility for decommissioning, relocation, expansion



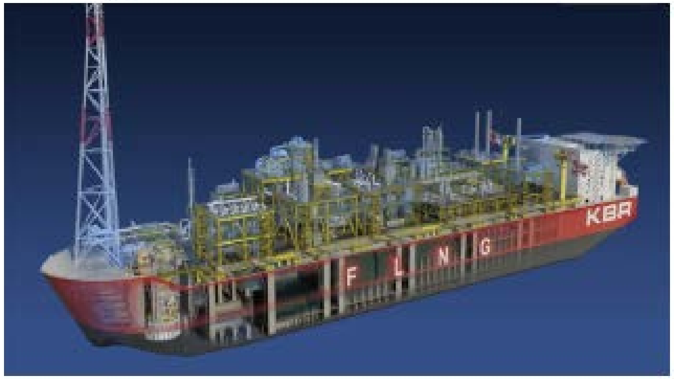
Emerging Deepwater Floating Platforms



MinDOC 3™
(dry tree, worldwide)

Sevan, MonoBR
Circular FPSO
(wet tree, worldwide)

FPSO with drilling
(mild, directional seas)



Floating LNG
(wet tree, worldwide)

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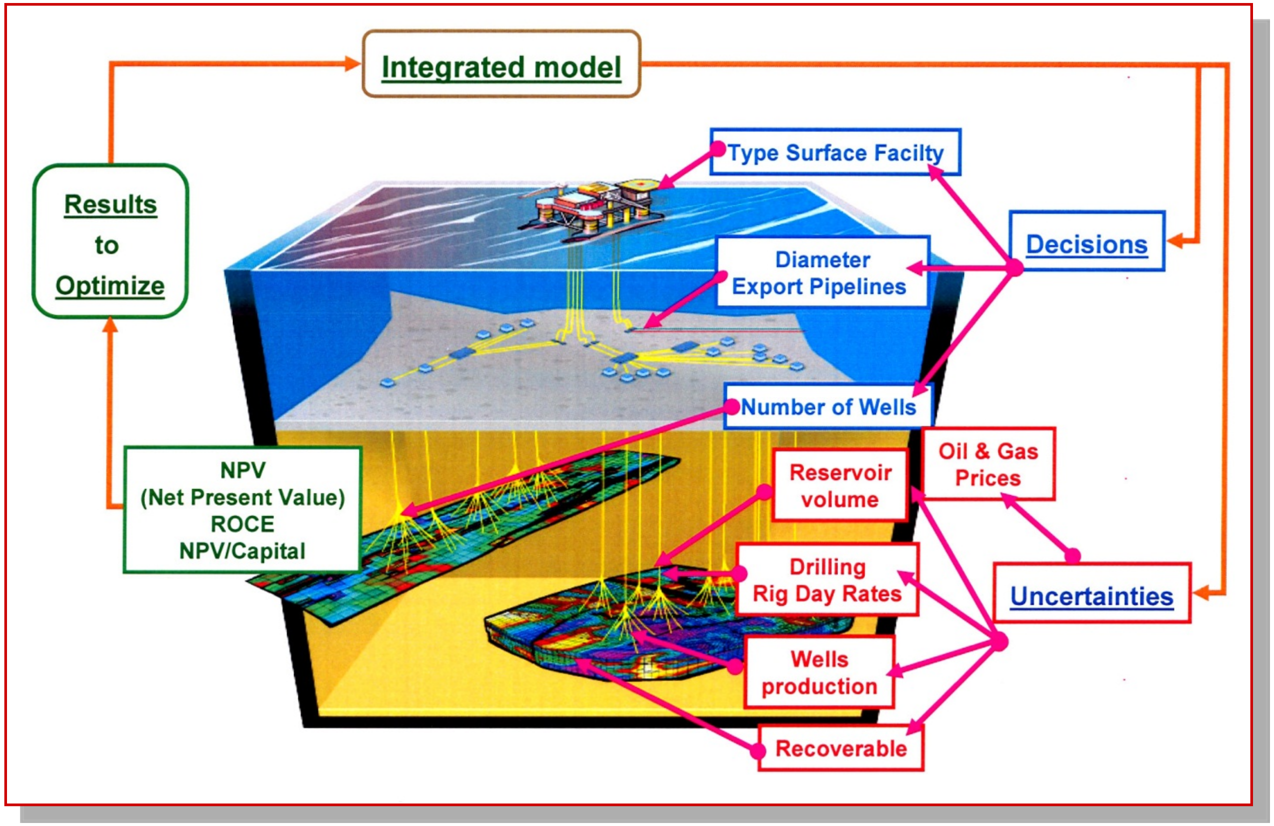
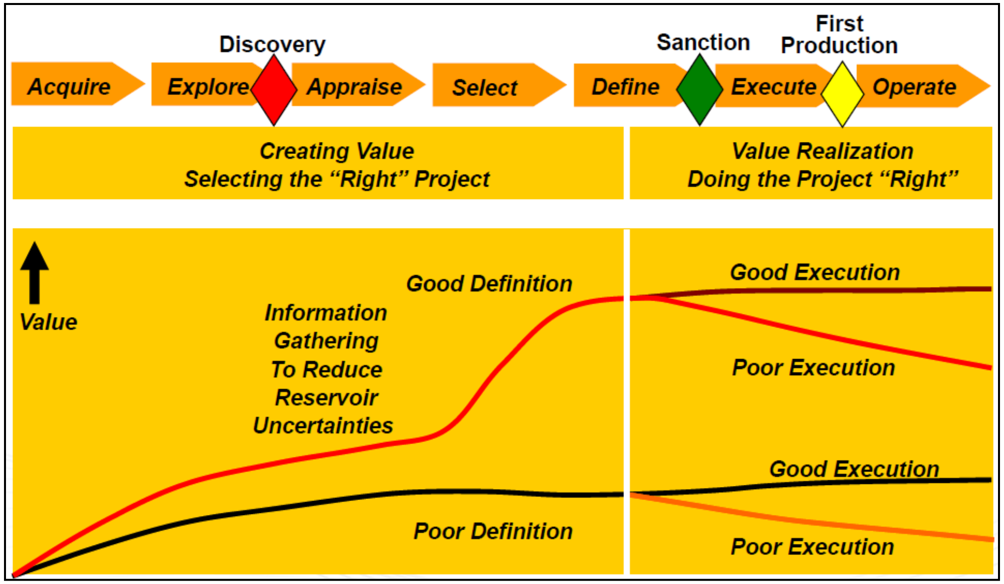
Field Development Planning Process

- 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



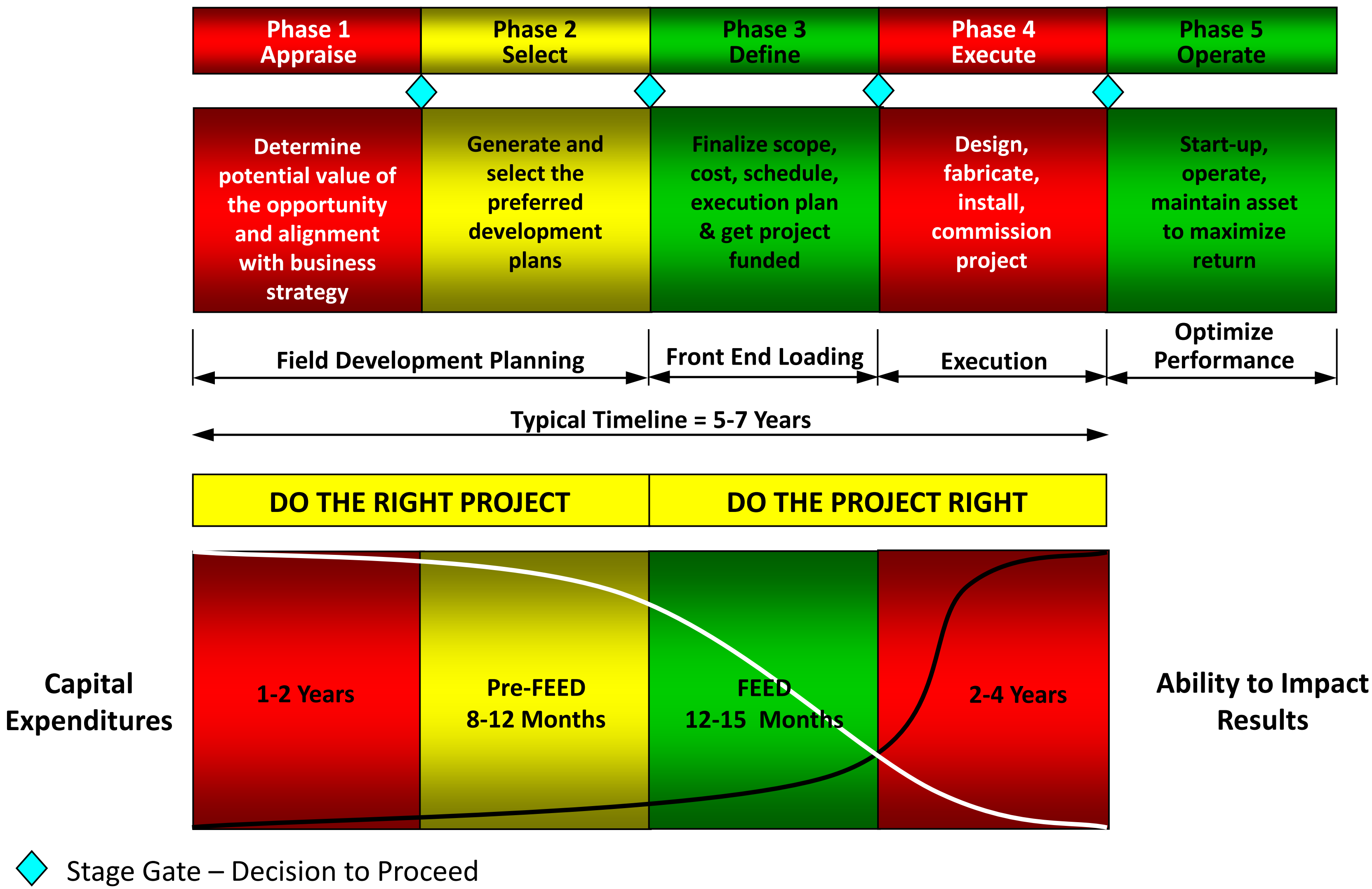
Early Planning Creates the Greatest Value

- 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



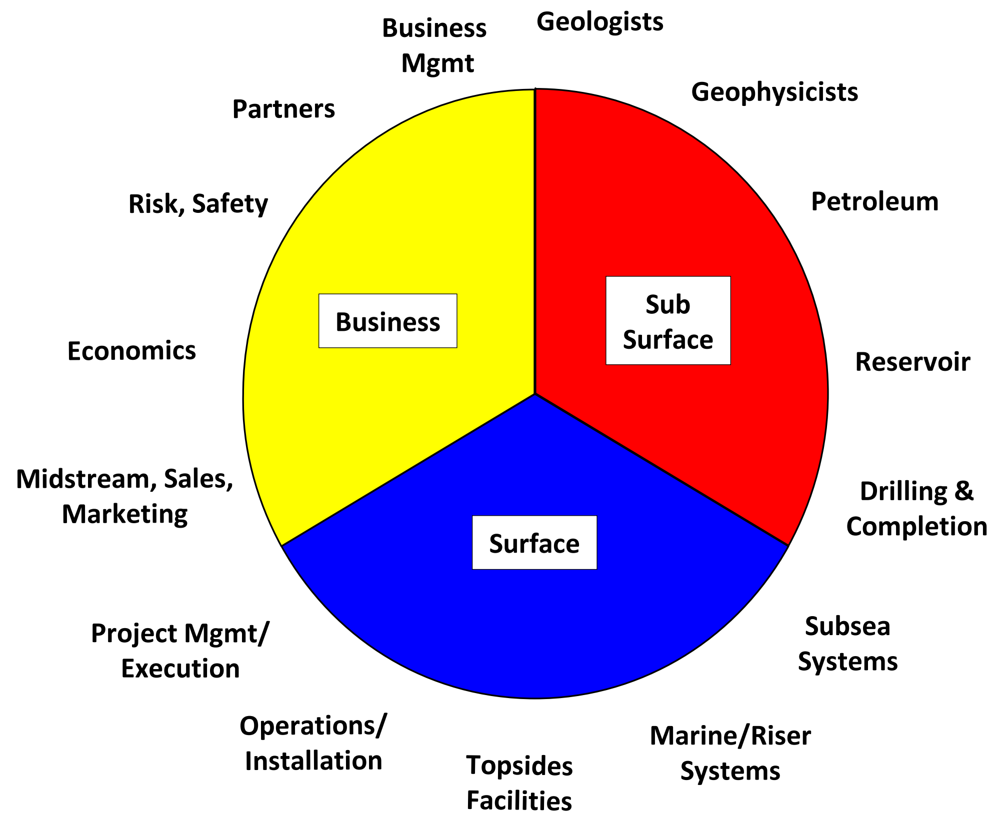
- The **spend in these phases is generally a small percentage of total development spend** but provides substantial added value to the project

Project Phases Have Distinct Objectives

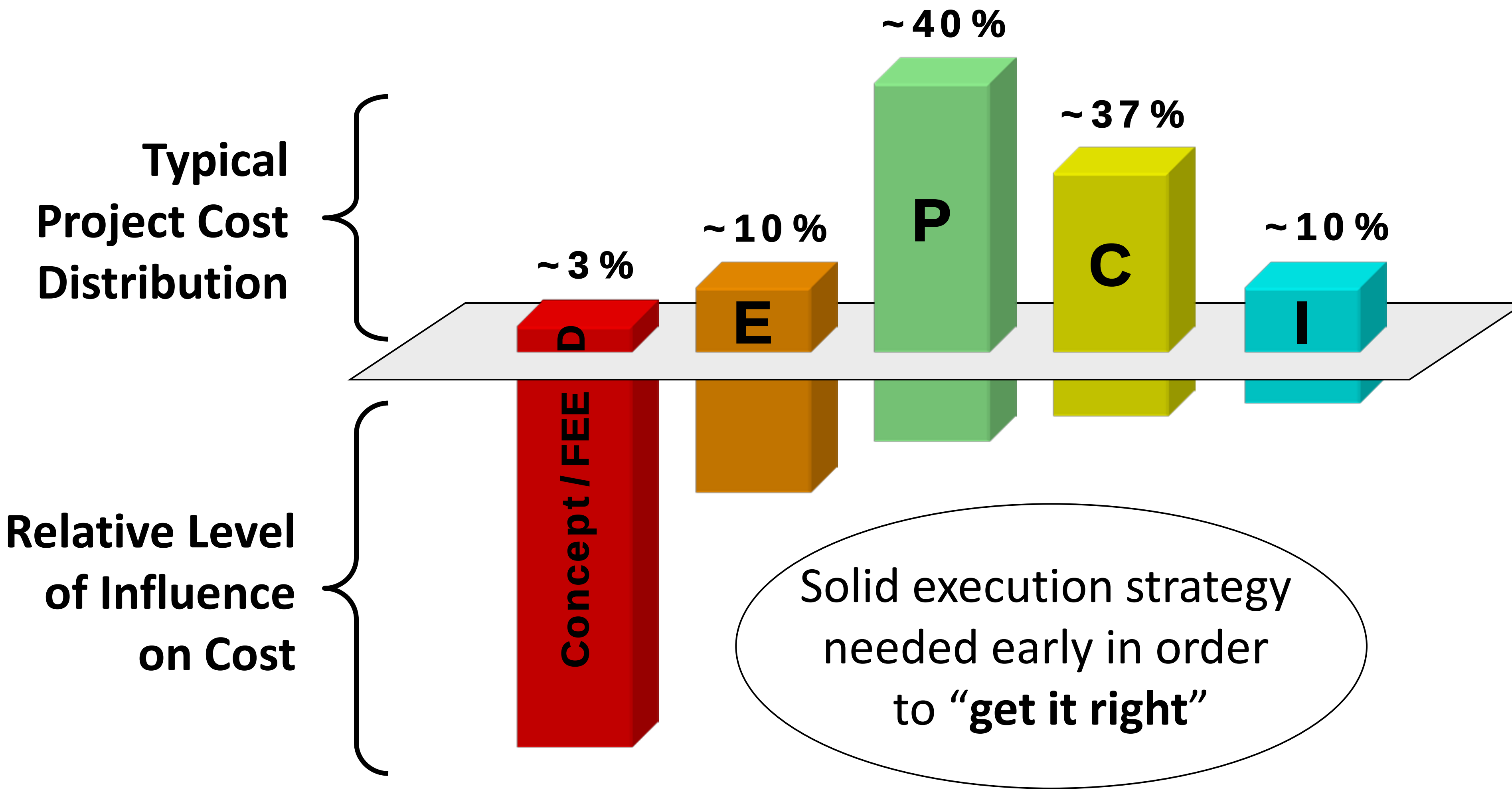


Planning is a Collaborative Process

- 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

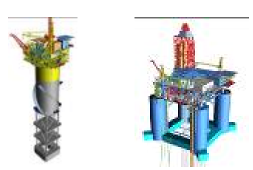


Proper Planning is Critical to Success

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

<u>Feasibility Studies</u>

- Identify alternatives
- Determine technical feasibility
- Determine Commercial Viability



<u>Concept Studies</u>

- Screen alternatives
- Select development concept

<u>FEED</u>

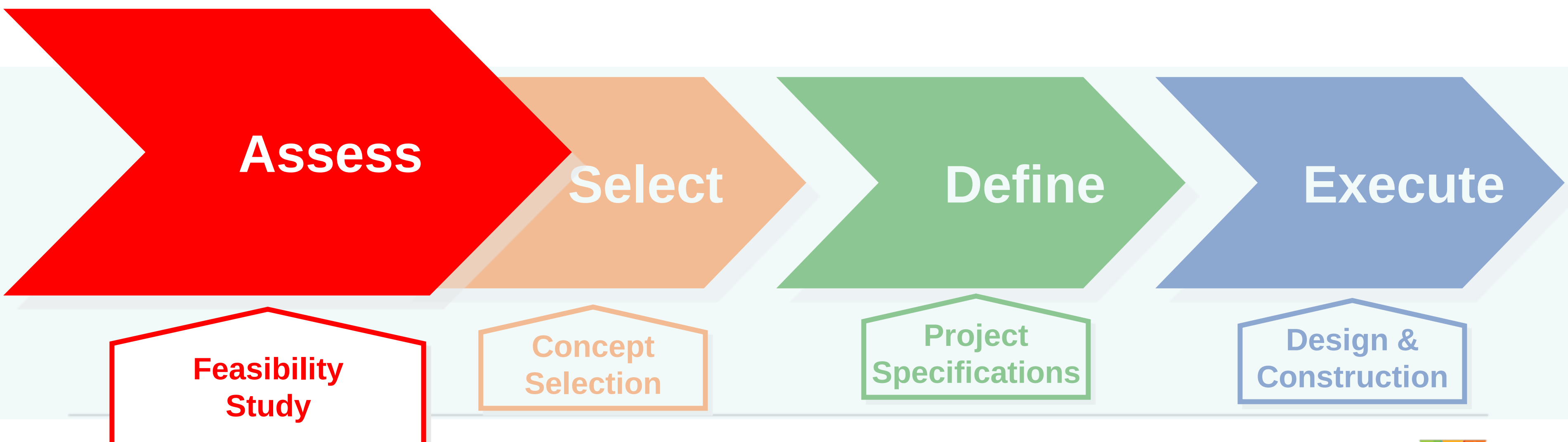
- Define development concept
- Design basis
- Cost
- Schedule
- Execution Plan

<u>Execute EPCI</u>

- Detail design
- Construction
- Installation
- HUC

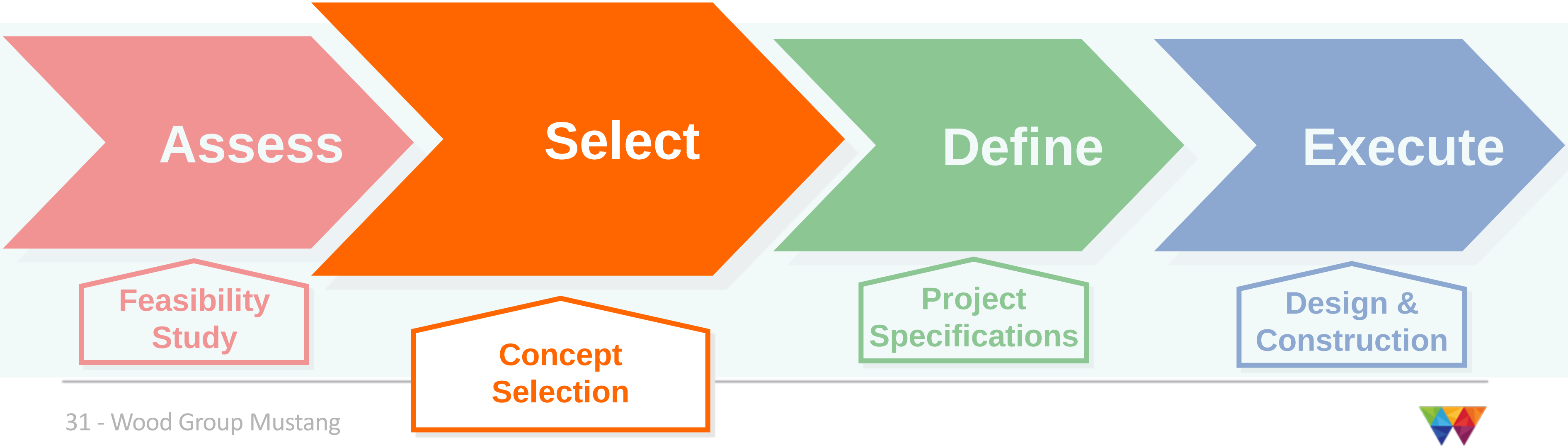
Planning for Success – Feasibility Phase

- 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?



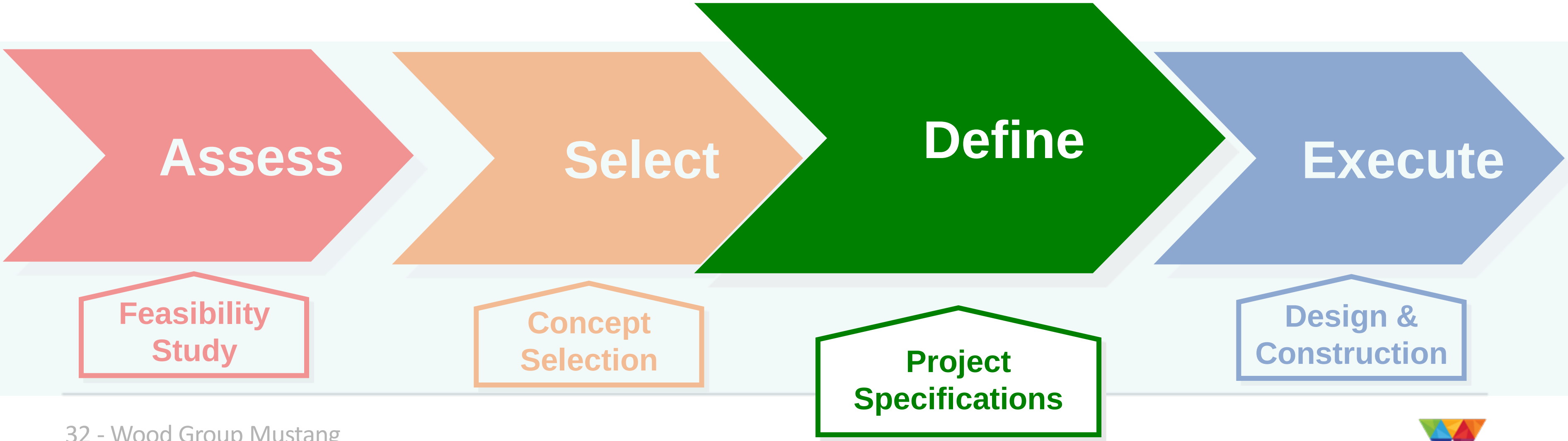
Planning for Success – Concept Selection

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



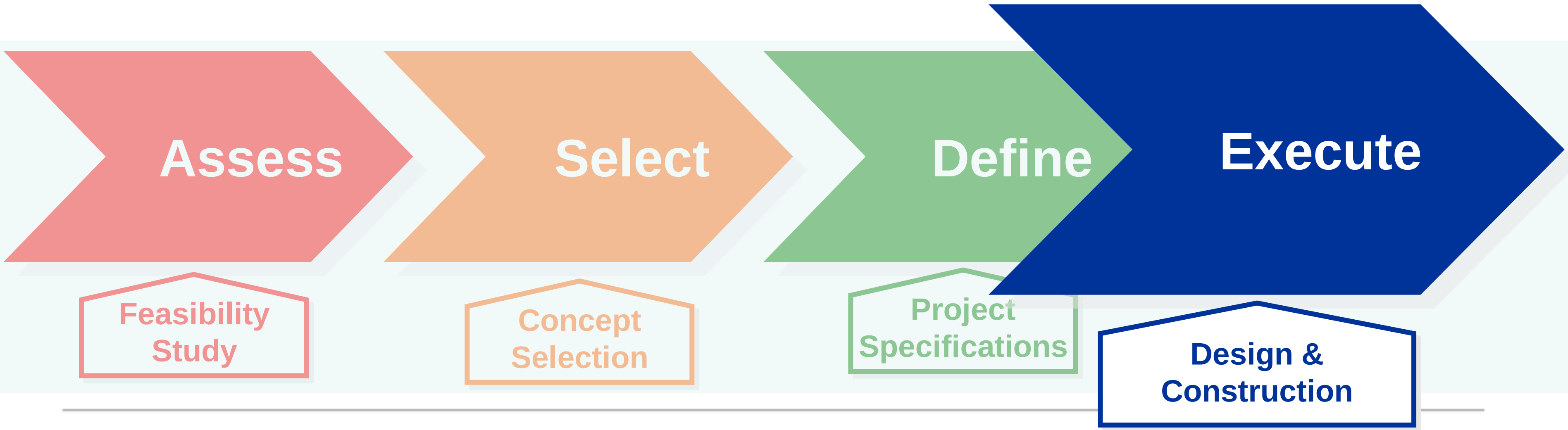
Planning for Success – FEED Phase

- 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



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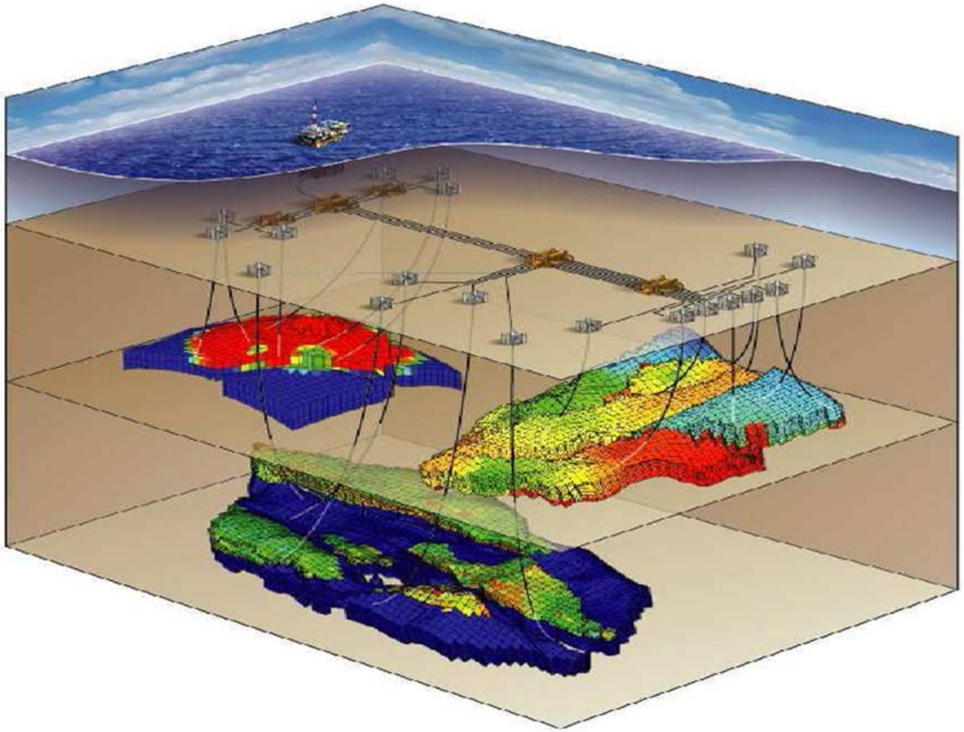
Floating System Selection Factors

- **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

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:

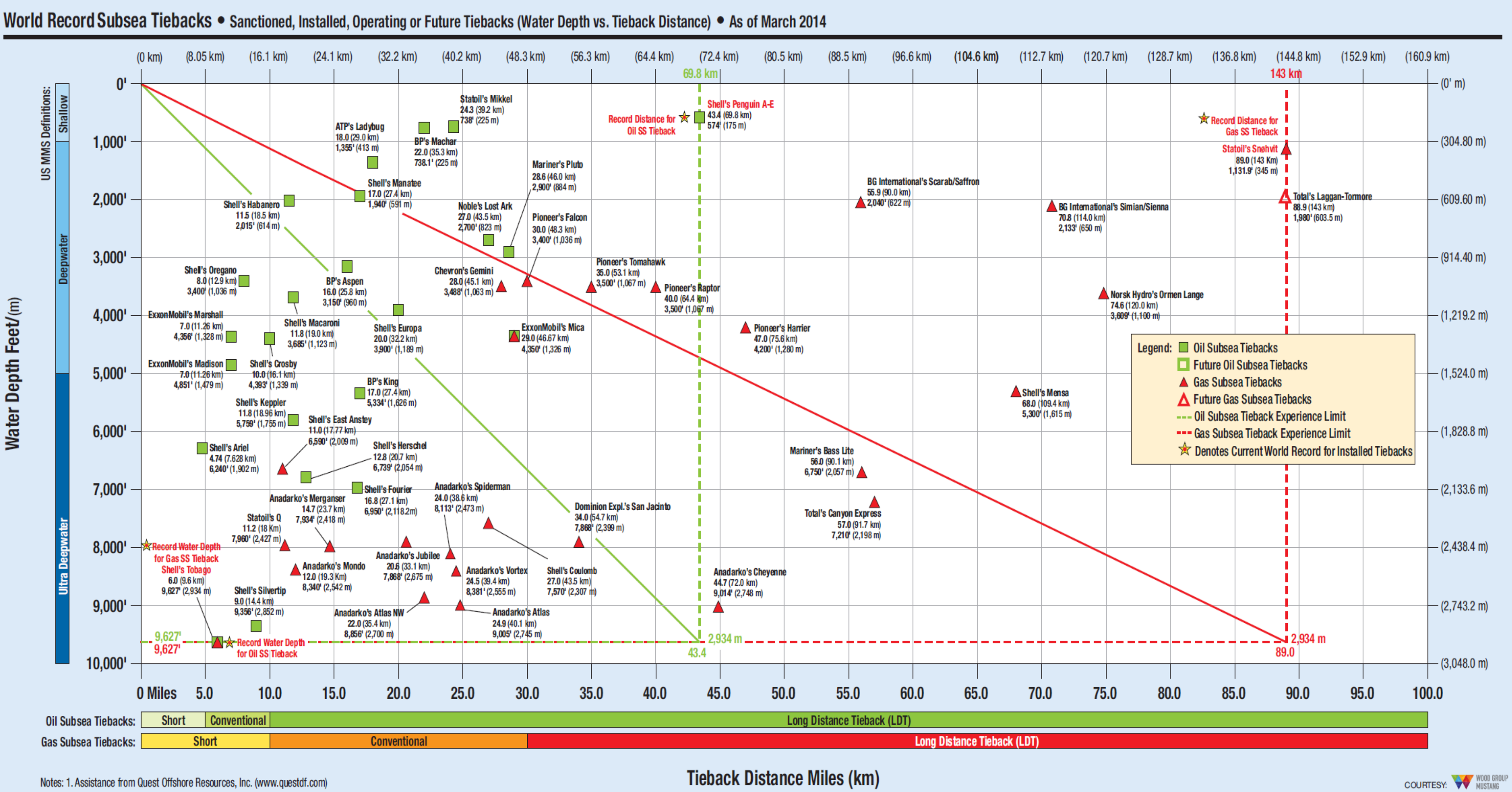
Field Proven ●

Qualified ○

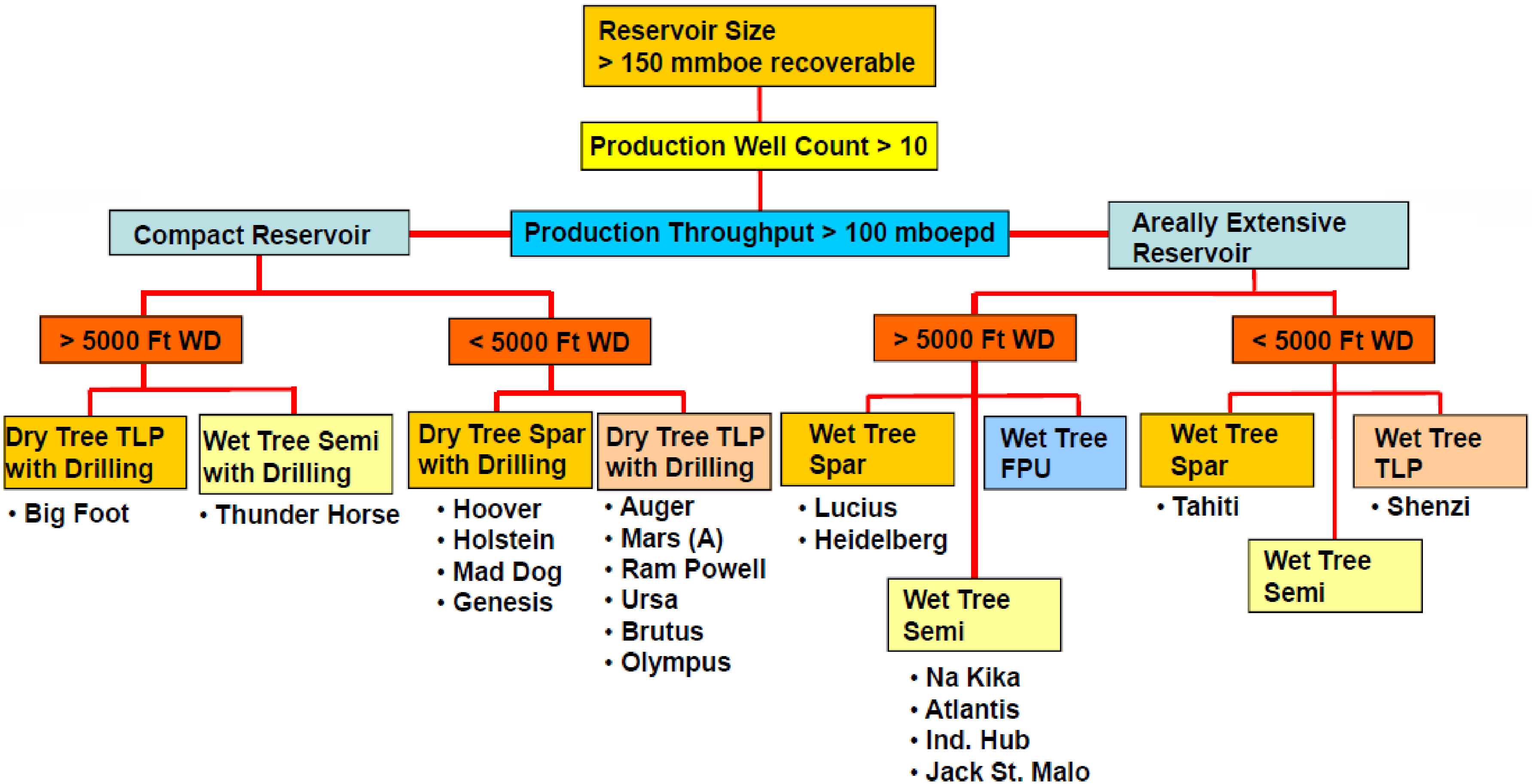
* "Unconventional" FPSOs include Sevan SSP, Petrobras MonoBR, Global SSP SSP320 & SSP PLUS.

		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')	●	●	●		See Water Depth Range Comparison Graph		●		●	●		●	See Well Capability by Deepwater Production Type Graph	●		●	●	●	○	●	○		●	○	●	●
Compliant Towers	●	●	●				●		●	○		●		●		●	●	●	○	●	○		●		○	○
FDPSOs	●	●	●	●			○	●			●	○		○	○		●	○		○	●	○		●	○	○
FPSOs																										
Spread Moored	●	●		●			○	●	●	●	●				●		●			●	●			●	●	●
Turret Moored	●	●		●			○	●	●	●	●				●			●	●	●	●			●	●	●
Unconventional*	●	●	○	●			○	○	○	○	○	○			○	○	○	○	○	●	●	○	○	○	○	○
Conventional TLPs	●	●	●					●	●		●	●		●	●	●	●	●	●	●	●	●	●	●	●	○
Proprietary TLPs	●	●	●			●	●	●	●	●	●	●		●	●	●	●	●	○	●	●	●	●	○	●	○
Spars																										
Dry Tree	●	●	●			●	●	○	●			●		●	○	●	●	●	○	●	●	●	●	●	●	○
Wet Tree	●	●	●			○	●	○	○		●			●	○	●	○	●	○	●	○	○	●	○	○	○
Semi-FPUs																										
Conventional	●	●	○					●	○	●	●	○		●			●	●	●		●		●		●	○
Deep Draft Wet Tree	●	●	○			○	○	●	●	○	●			●	○	○	●	●	○	●	●	○	●	○	●	○
Deep Draft Dry Tree	○	○	○			○	○	○	○	○		○		○	○	○	○	○	○	○	○	○	○	○	○	○
Subsea Tiebacks	●								●	●	●			●			●	●	●							

Technology Enables Longer Gas Tiebacks



Typical Decision Tree for Screening Floating Platforms – Large Multiple Reservoirs



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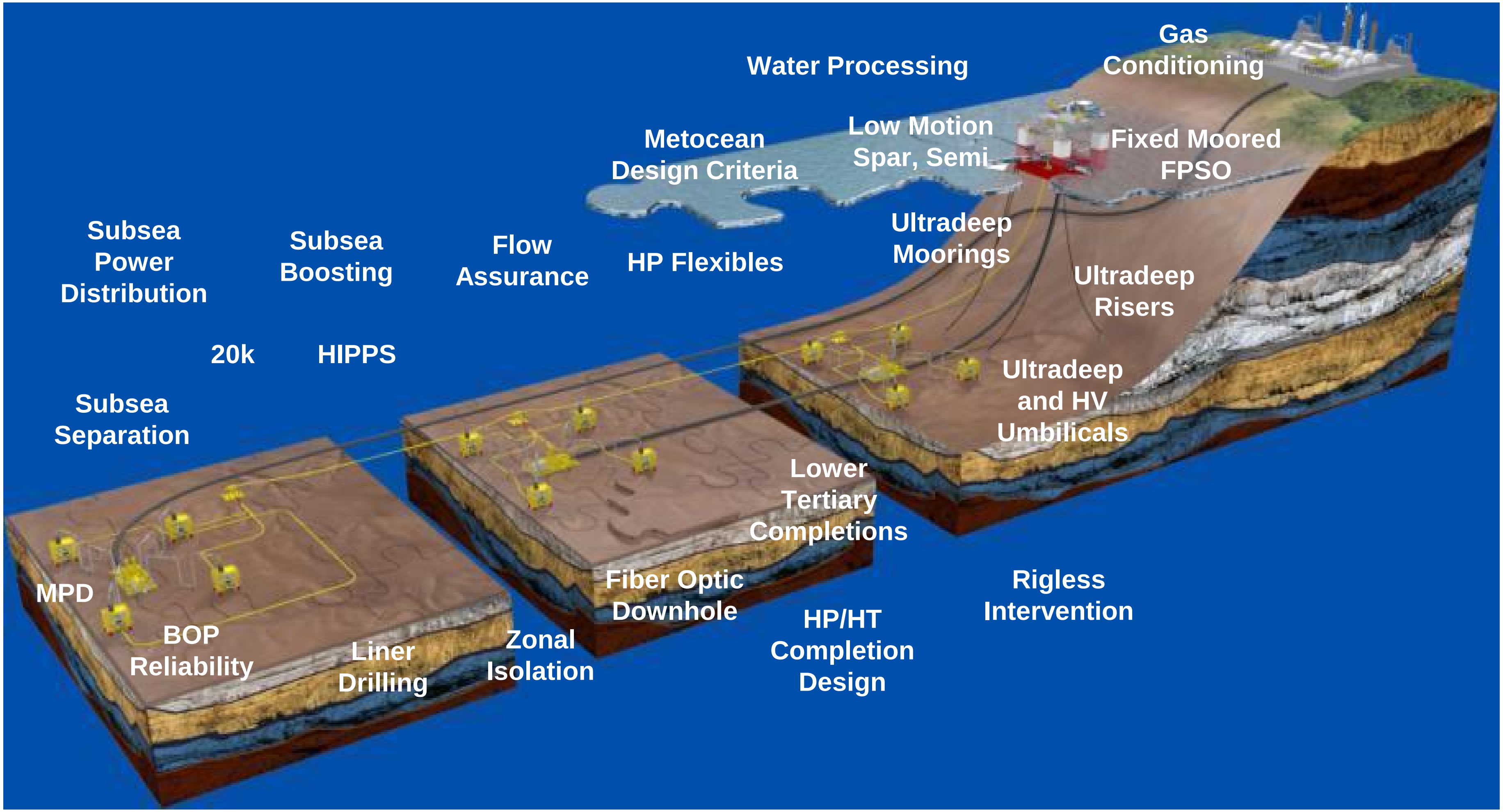
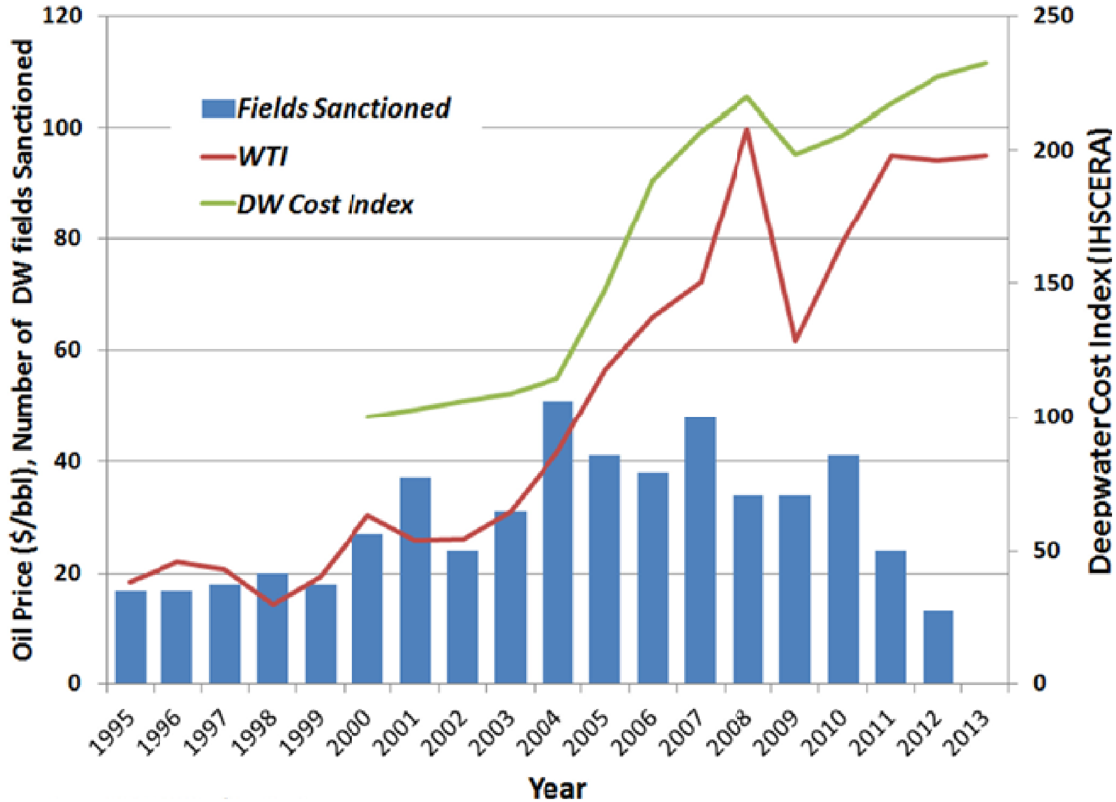
Deepwater Technology Needs

Integrity Management, Flow Assurance, Big Data Management



Deepwater Development Trends

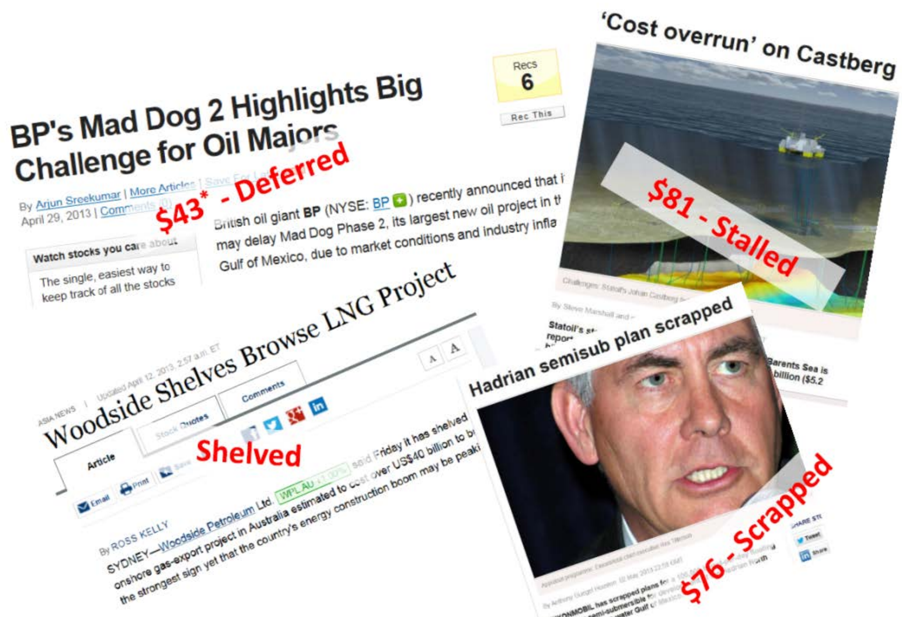
- Capex inflation outpacing oil & gas price inflation
- Most deepwater projects are now “Mega-Projects”
- Industry struggling to achieve acceptable commercial results
- Geographic, geologic and geopolitical trends are root causes



Source: HIS CERA, Wood MacKenzie

Recent Macro Trends in Deepwater Projects

- **Trends**
  - Increasing project complexity – geology, geography, geopolitics
  - Project Capex escalation outstripping oil/gas price escalation
- **Consequence**
  - Many greenfield projects deferred, cancelled, recycled
  - More redevelopment/expansion projects
  - Greater project execution uncertainty
- **Mitigation**
  - Increased emphasis on FEL
  - Faster qualification/adoption of enabling and EOR technologies
  - Bridge skills gap



* Goldman Sachs calculated economic breakeven oil price; Mad Dog breakeven price for Phase I and II together

Putting Field Development Costs in Perspective

GoM – Exxon Hoover - $1.2bn
Installed 2000

GoM – BP Horn Mountain $650M
Installed 2002

GoM – BP – Thunderhorse - $5bn
Installed 2005

GoM – Anadarko I-Hub - $2bn
Installed 2007

GoM – Chevron Tahiti - $2.7bn
Installed 2009

GoM – Chevron JSM - $7.5bn
Installed 2014

Quantifying Impact on a Surface Facility

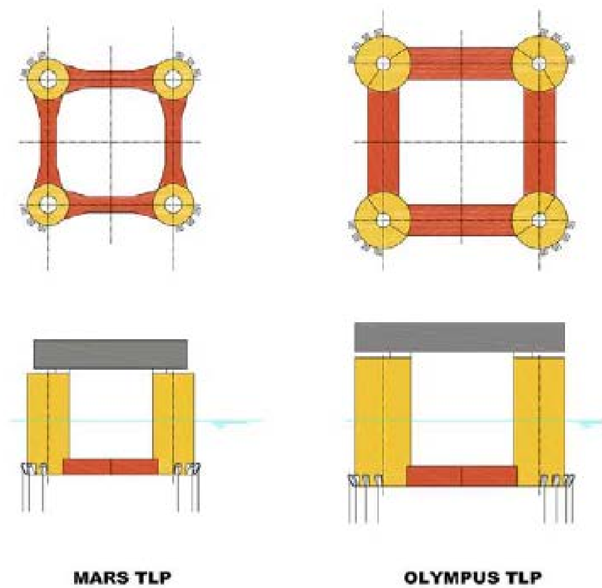
Item	Units	Mars A TLP	Olympus TLP
Sanctioned	-	Sep-93	Sep-10
Water Depth at Floater	ft	~ 2,940	3,028
Functions	-	Full Drilling & Production	Full Drilling & Production
Trees	-	Dry	Dry
Production TTRs	-	24	24
Topside Design Basis			
Peak Oil Rate	mbopd	100 (220 after debottlenecking)	100
Peak Gas Rate	mmscfd	110 (220 after debottlenecking)	180
Water Injection	mbwpd	Yes	Yes
Quarters	-	160	190
Drilling Rig Hook Load	pounds	1 million	2 million
Development Cost		**~ $1 bn**	**Unknown**

Quantifying Impact on a Surface Facility

Olympus TL P is more than twice as 'big' as Mars TL P

- Olympus weighs over 120,000 tons; heavier than 300 Boeing 747 Jumbo Jets
- Base of Hull to Top of Derrick is 406 ft tall (approximately 1.5 x Height Superdome)
- Olympus combined deck area = 342,000 ft^2 (greater than total floor Superdome @ 269,000 ft^2).
- Olympus column spacing = 250 feet (c to c) – similar footprint to One Shell Square

Item	Units	Mars A TLP	Olympus TLP
Hull			
Freeboard	ft	75	100
Draft	ft	87	105
Column Diameter	ft	66.5	90
Column Length	ft	162	205
Column c/c Spacing	ft	200	250
Pontoon (width x height)	ft x ft	27.5 X 24.7	50 X 31.5
Tendons			
Number (corner x #)	-	4 x 3	4 x 4
Outer Diameter x Wall Thickness	in x in	28 x 1.2	38 x 1.44
Tendon Weight	st	6,200	13,000



Quantifying Impact on a Surface Facility

Impact on Olympus TLP

Topsides – 50% greater operating load

- Heavier process equipment for HP reservoir
- Larger drilling rig for deeper reservoir
- Greater Water Injection capacity to increase well recovery

Riser Tension – 2.8 times greater

- Heavier production risers for HP reservoirs
- Greater tension factor for higher metocean loads

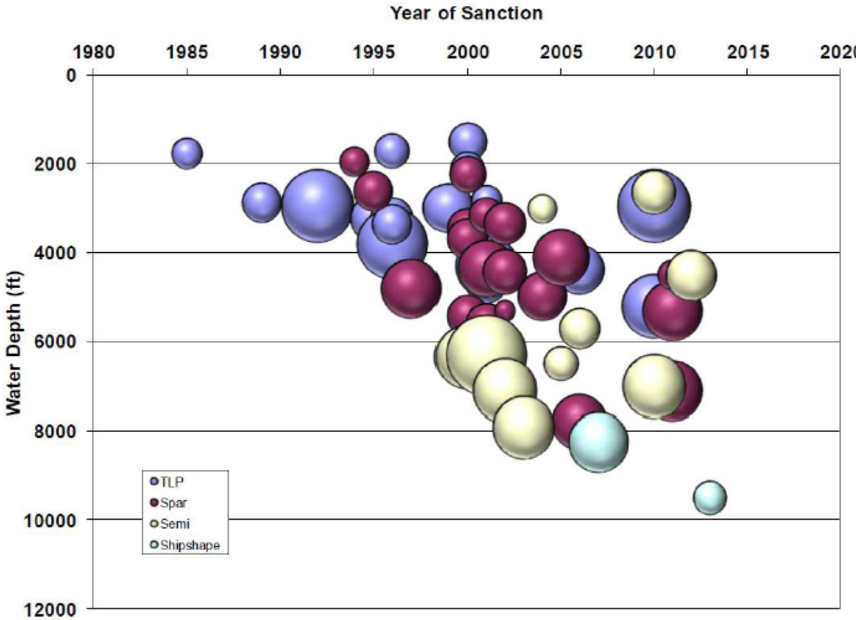
Tendon Pretension – 3.5 times greater

- Design and survival case loads for 2INT-MET metocean basis

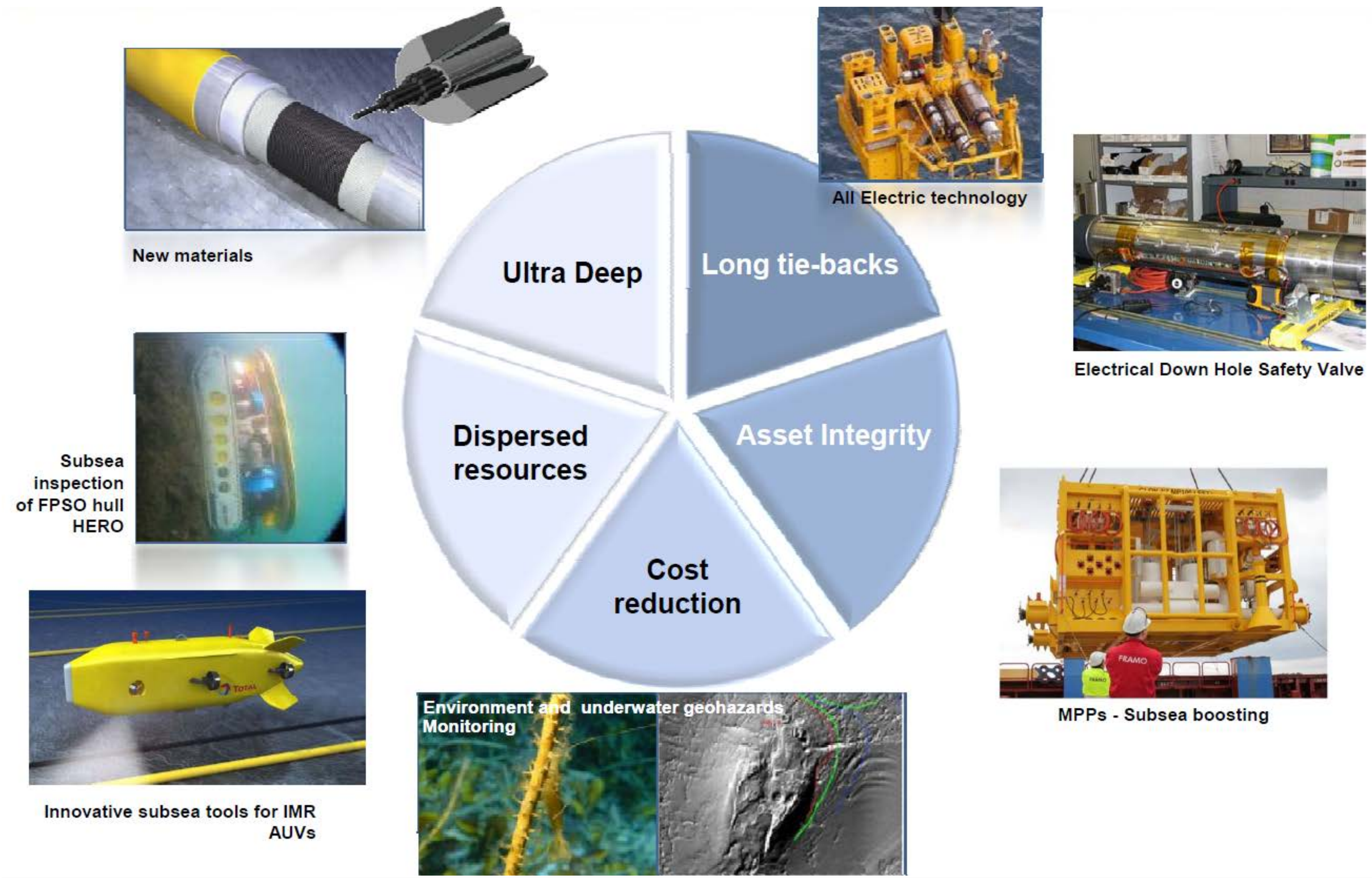
Item	Units	Mars A TLP	Olympus TLP	Factor
Topsides – Operating (no Risers)	st	18,500	27,500	1.49
Riser Payload	st	4,000	11,000	2.75
Topsides – with Riser Payload	**st**	**22,500**	**38,500**	**1.71**
Hull Steel & Outfitting	**st**	**15,600**	**35,800**	**2.29**
Ballast	st	3,600	10,700	2.97
Hull – Including Ballast	st	19,200	46,500	2.42
Pre-Tension	st	9,800	34,000	3.47
Displacement	**st**	**51,500**	**119,000**	**2.31**

Challenges: Stretched Supply Chain

- Massive surge in demand on supply chain started in the year 2000
- Supply chain overwhelmed by this surge
- Created industry-wide skills shortage and dilution of Contractor capabilities



Some Deep Offshore R&D Challenges

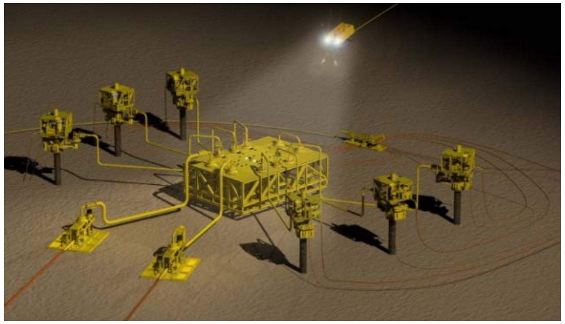


Presentation Overview

- A Historical Perspective
- Why Deepwater?
- Deepwater Solutions
- Field Development Planning
- Key Drivers for Floating System Selection
- Technology, Trends and Challenges
- **Wrap-up**
- Q&A

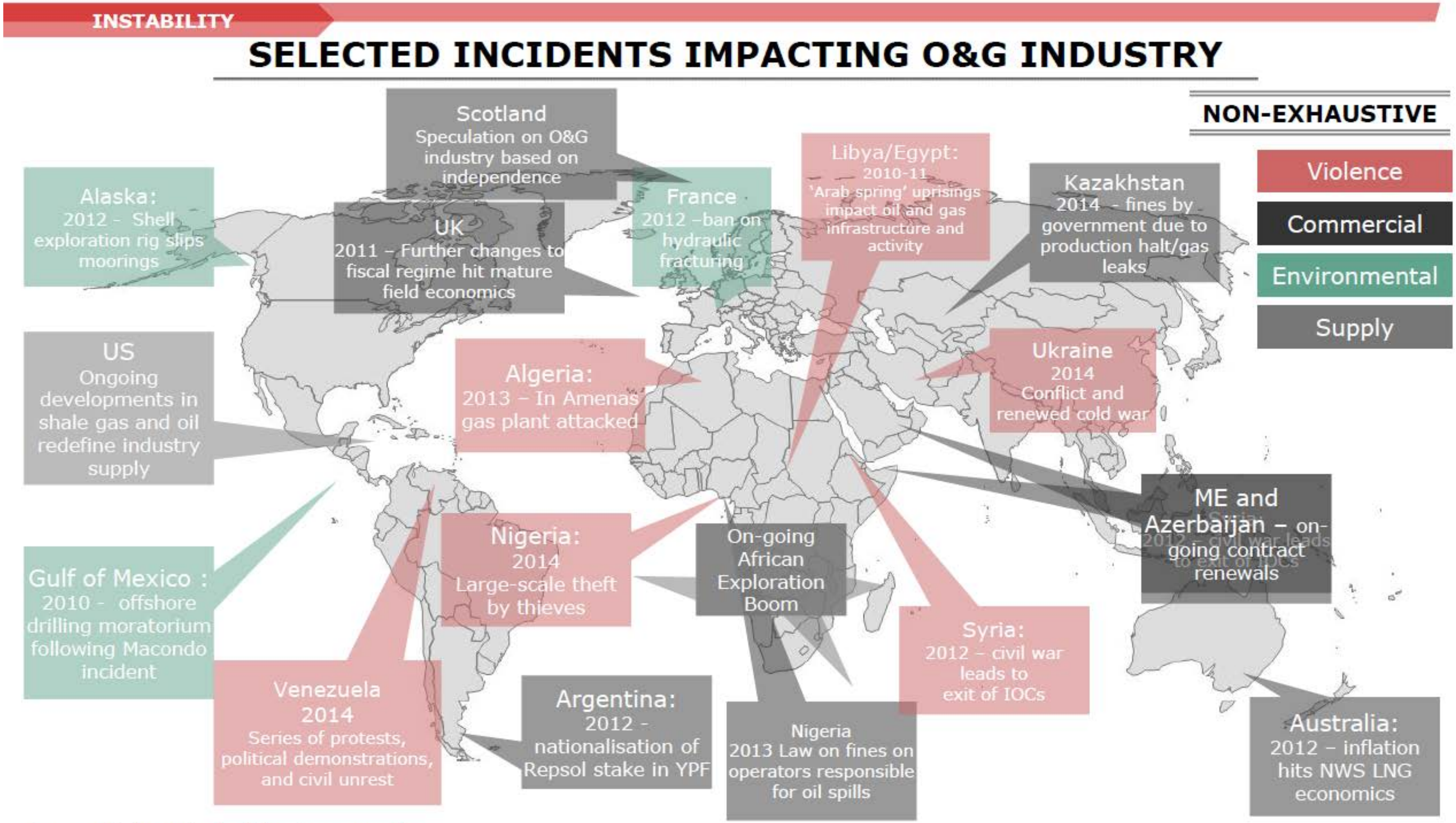
The Deepwater Game is Changing

- **Development opportunities are more challenging**...deeper water, more complex reservoirs; sub-economic accumulations; ultra-deepwater and remote locations; viscous oil, low energy drive



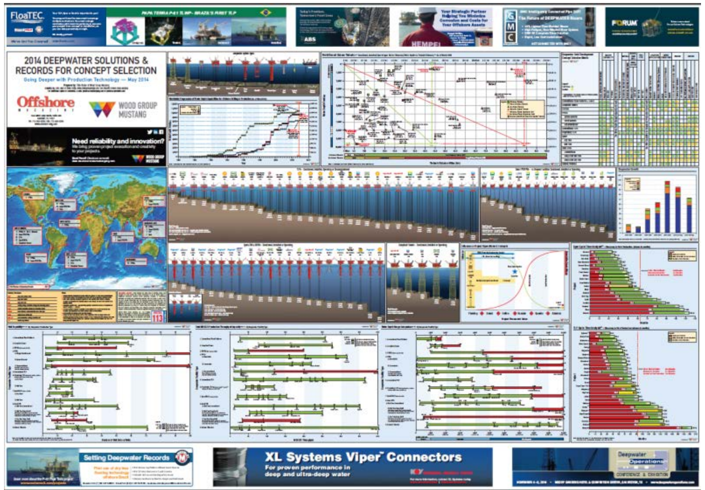
- **Capex/risk exposures are large**...cost exposure in the billions; high cost drilling & infrastructure
- **Pressure to shorten schedule and reduce cost continues**... longer cycle times; standardization; technology development vs rapid deployment
- **Lack of local logistics/service industry**...affects project delivery
- **Competent/skilled staffing shortages**...demand still exceeds supply; building local capability can be difficult

Instability and Change Also Impact the Industry



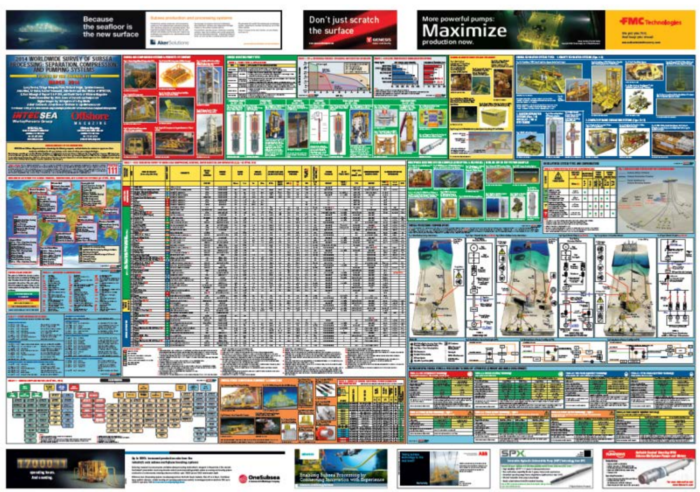
Source: Bain analysis, Literature search

Offshore Magazine Posters



May 2014 Wood Group Mustang Deepwater Solutions Poster

Oct. 2013 U of H Deepwater Mooring Poster



March 2014 IntecSea Subsea Processing Poster

For additional information about Deepwater go to Offshore Magazine's Website:
www.offshore-magazine.com/maps-posters.html

Useful Industry Websites

- www.offshore-mag.com
- www.Oilpro.com
- www.offshore-technology.com
- www.upstreamonline.com
- www.ogjonline.com
- www.rigzone.com
- www.oilonline.com

Advice to Early Career Engineers

- Information is what you need to make money in the short term
- Knowledge is a deeper understanding of how things work and is attained by:
  - Long and arduous study
  - Setting aside profit motive
  - Having intrinsic desire just to know

- **Choose KNOWLEDGE over INFORMATION!**

Summary

- Current trend of increasing CAPEX and recycling projects is unsustainable
- Unconventionals competing for Capital allocation
- Geologic, geographic & geopolitical trends & increased demand on supply chain fundamental drivers
- Solutions include managing reservoir uncertainty, improving capital efficiency, investment in technology, rationalizing local content and bridging skills gap

Questions?

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