



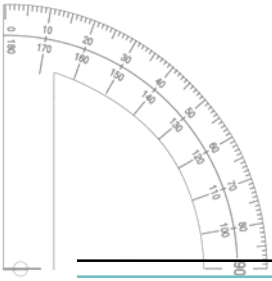
Subsea Separation and Processing of Oil, Gas & Produced Water

Past, Present and Future

Why We Need It Now

Clifford Neal Prescott
Fluor Offshore Solutions, USA
13 January 2012





Acknowledgements

- Rice Global E&C Forum
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- Subsea Technology Suppliers
- Fluor Management
 - FOS / FG
- Fluor Subsea Development Team



Presentation Outline

- Market Trends
- Evolution of Subsea Separation of Oil & Gas
- Current Subsea Separation Technology
- Subsea Technology Under Development
- State of Art Recap / Technology Gaps
- The Future of Offshore

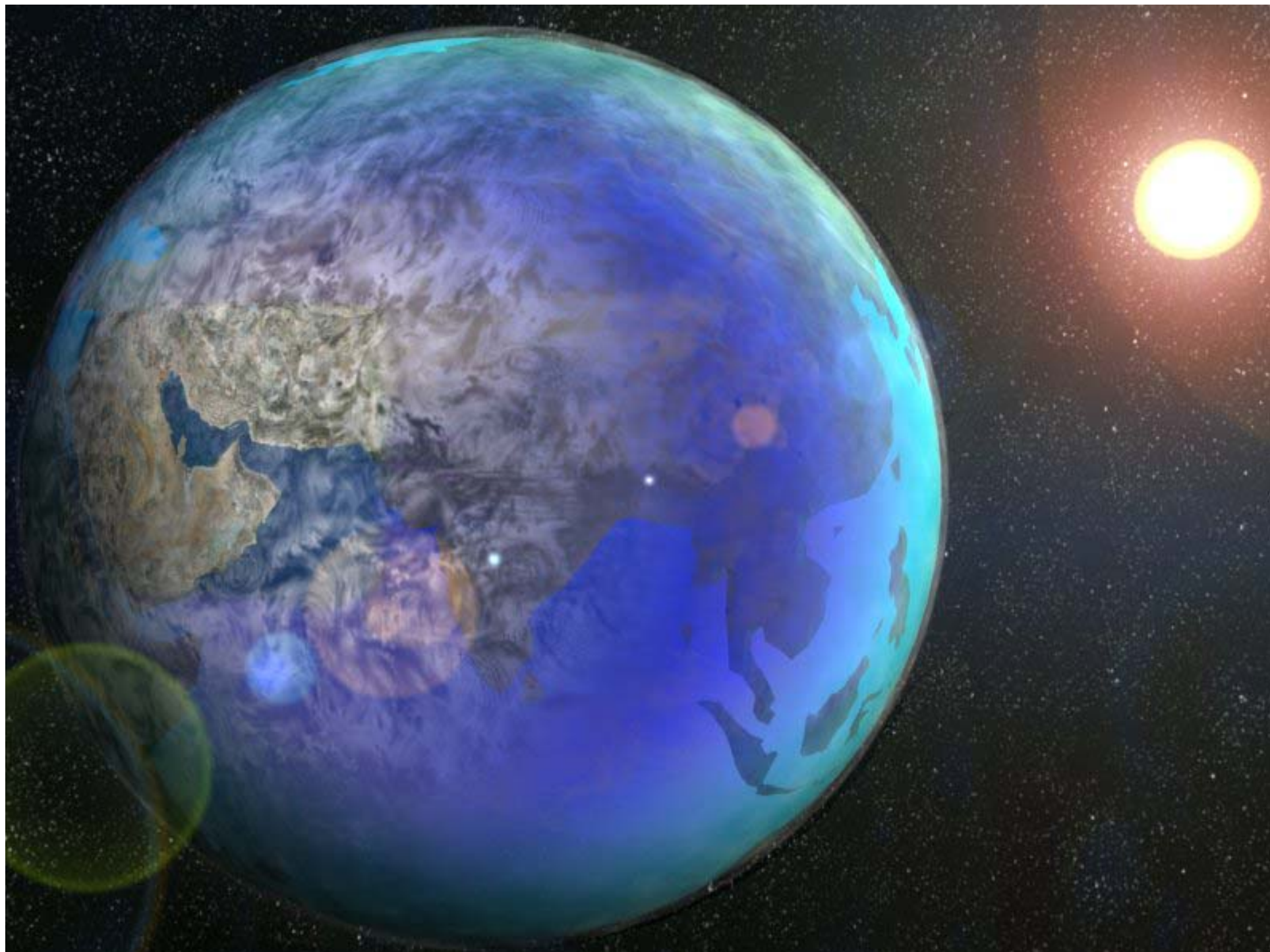


Abstract

- As more offshore fields near the end of easily recoverable hydrocarbons, the associated fields are experiencing an increase in the production of reservoir water and solids (sand, etc.); the industry is becoming one that must address the produced water in order to extract additional reserves.
- Technology advances in handling, cleaning and disposing produced water will eventually allow production increases of hydrocarbons with clean reservoir water that may be injected into the sea without harming the environment.
- This presentation gives an introduction and overview into the Offshore Industry, past to present, and describes the Technologies related to Subsea Separation and Production of Oil & Gas and how the industry is expanding into the future as a result of market demands.



Subsea Separation and Processing of Oil, Gas & Produced Water





Market Trends

	2002	2003	2004	2005	2006	2007	2008	2009
ExxonMobil	2496	2516	2571	2523	2681	2616	2404	2387
BP	2018	2121	2531	2562	2475	2414	2410	2535
PetroChina	2109	2119	2233	2270	2276	2312	2380	2311
Shell	2359	2379	2253	2093	2030	1899	1771	1680
Petrobras	1533	1701	1661	1847	1908	1920	1996	2103
Chevron	1897	1823	1737	1701	1759	1783	1676	1872
Total	1589	1661	1695	1621	1506	1509	1456	1381
ConocoPhillips	891	1237	1242	1447	1698	1644	1367	1615
ENI	921	981	1034	1111	1079	1020	1026	1007
StatoilHydro	1112	1132	1135	1102	1058	1054	1056	1067

Data: Petroleum Review, May 2010

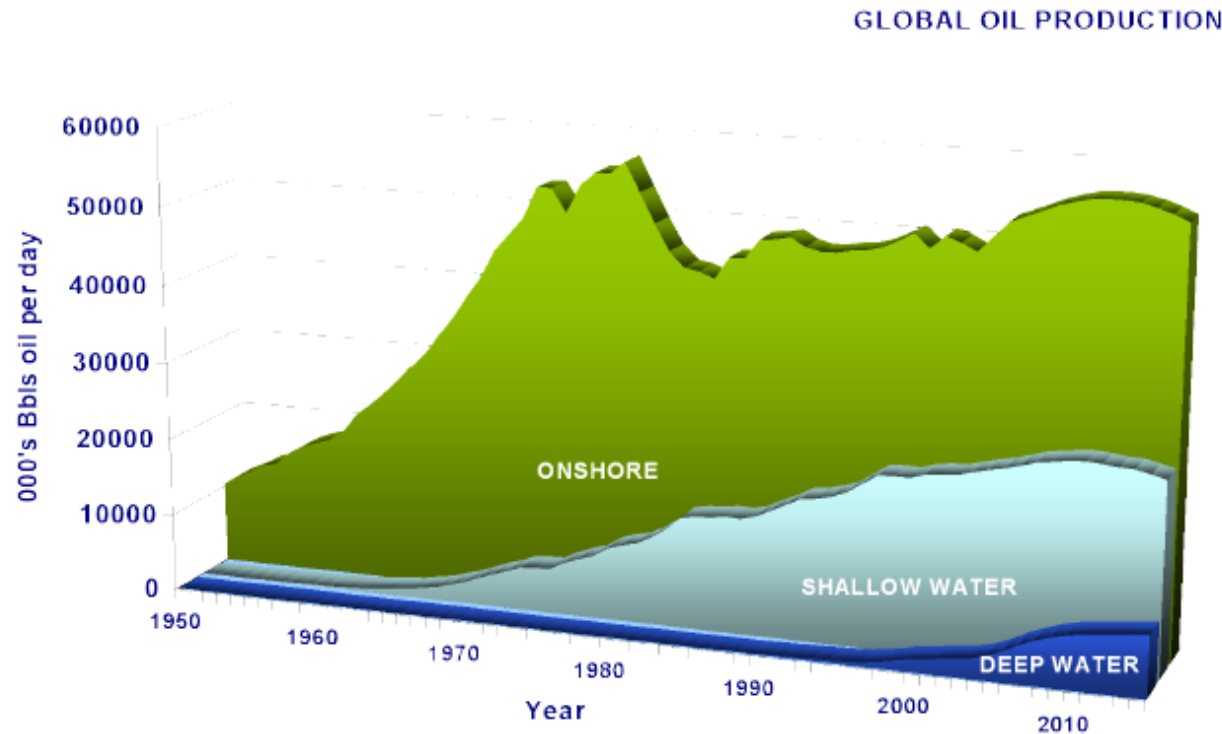
Peak Year?

- Peak oil, the point in time when the maximum rate of global petroleum extraction is reached, after which the rate of production enters terminal decline, is a reality, not just for the majority of the producing countries but perhaps for the majority of the top producers.
- Offshore is one of the few remaining places where the oil majors can increase production





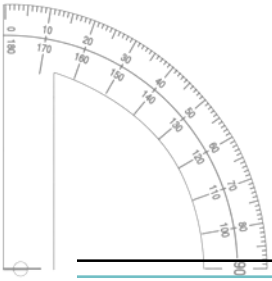
The Importance of Offshore Oil Production



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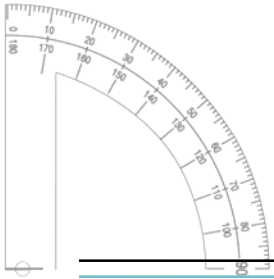
Source: Douglas Westwood

- Offshore 35% of world production
- Deepwater – 3% of production in 2002, 6% in 2007, 10% by 2012
- After 2012, deepwater is the only sector to continue to grow.

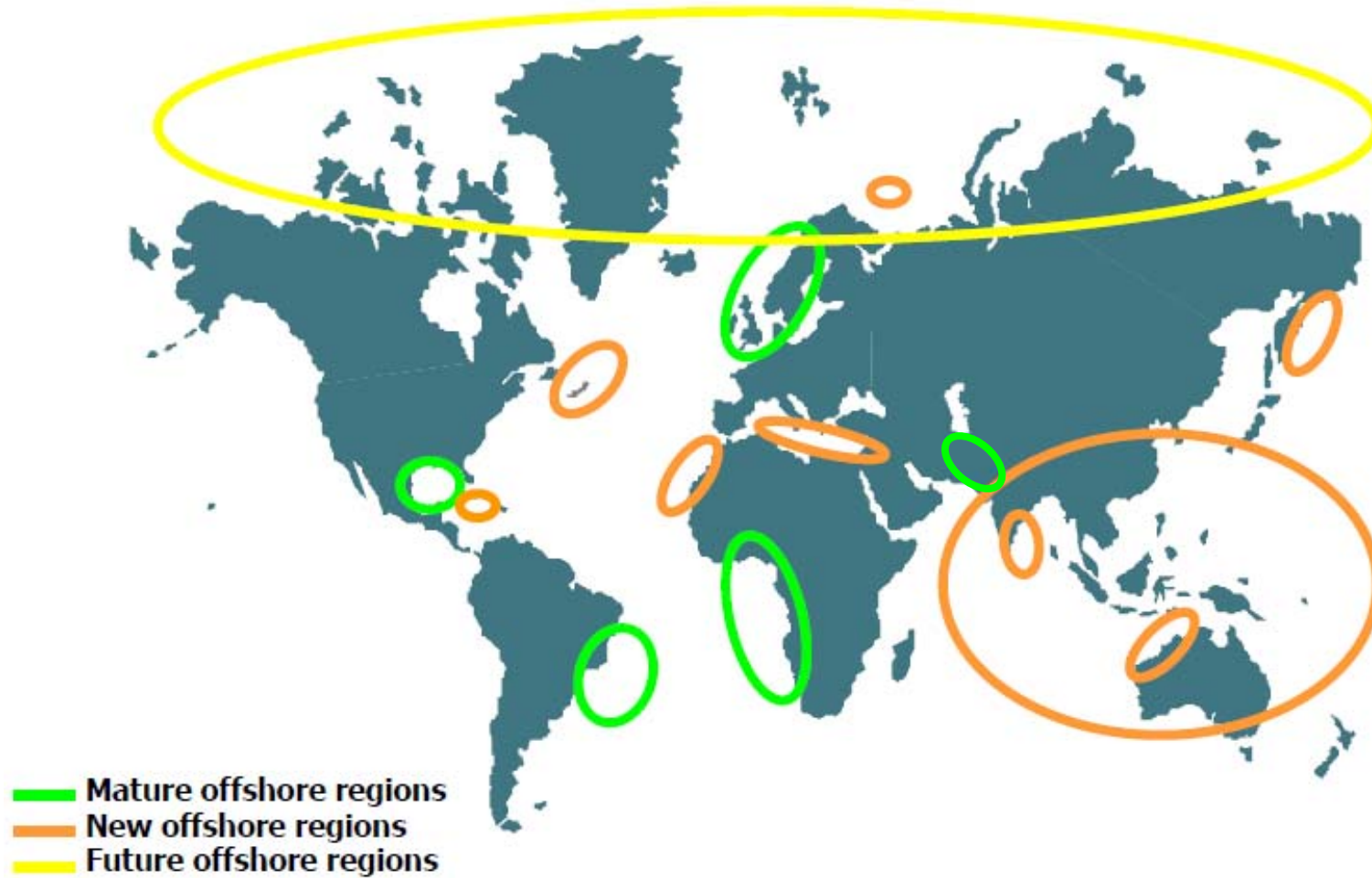


The Push to Find Energy

- There is an increasing demand on crude oil as a source for transportation fuel driven by the rapidly expanding energy needs of countries with expanding economies. There is a close correlation between GDP growth and energy consumption. The push to find energy is moving the offshore market into deeper waters and into Arctic areas not previously explored.
- Offshore locations of hydrocarbons are being developed in deeper waters, from increasingly-remote locations and in extreme metocean conditions. Smaller, more widely scattered reserves, which were in the past uneconomic or too technologically challenging to develop, are now benefiting from higher oil prices and more advanced subsea hardware solutions.

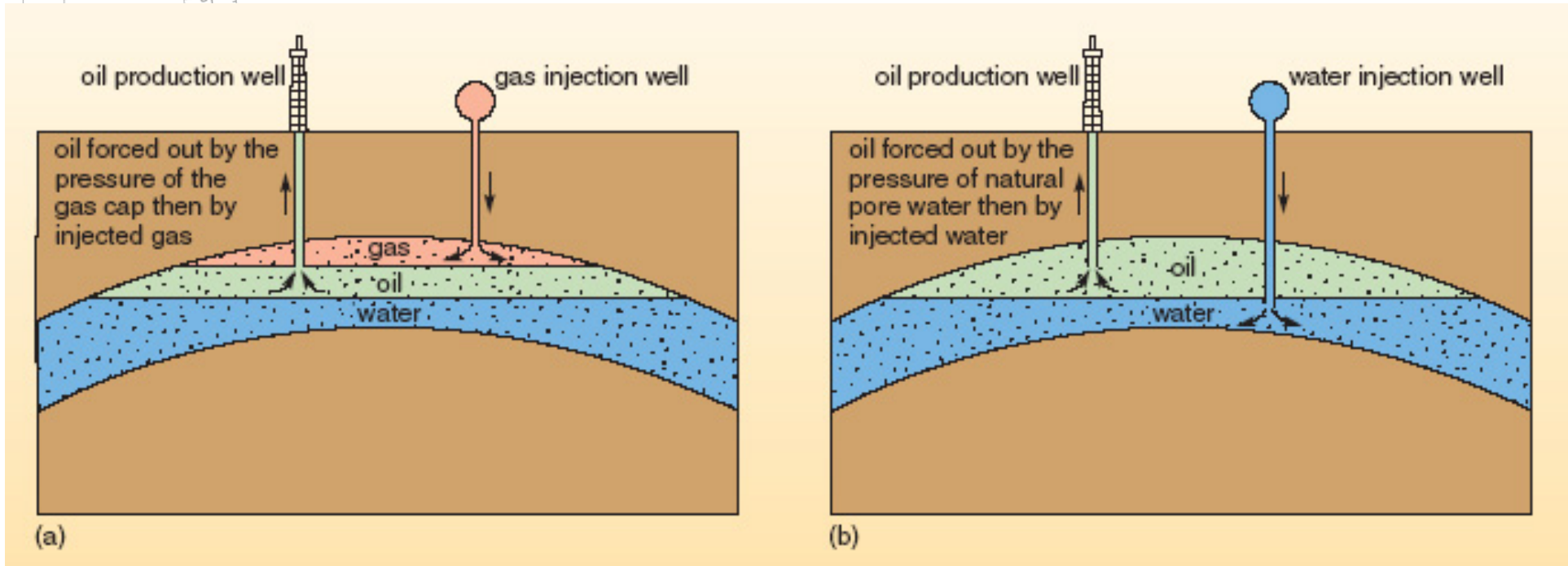


World Offshore Oil & Gas Production Regions



Evolution of Subsea Separation of Oil & Gas

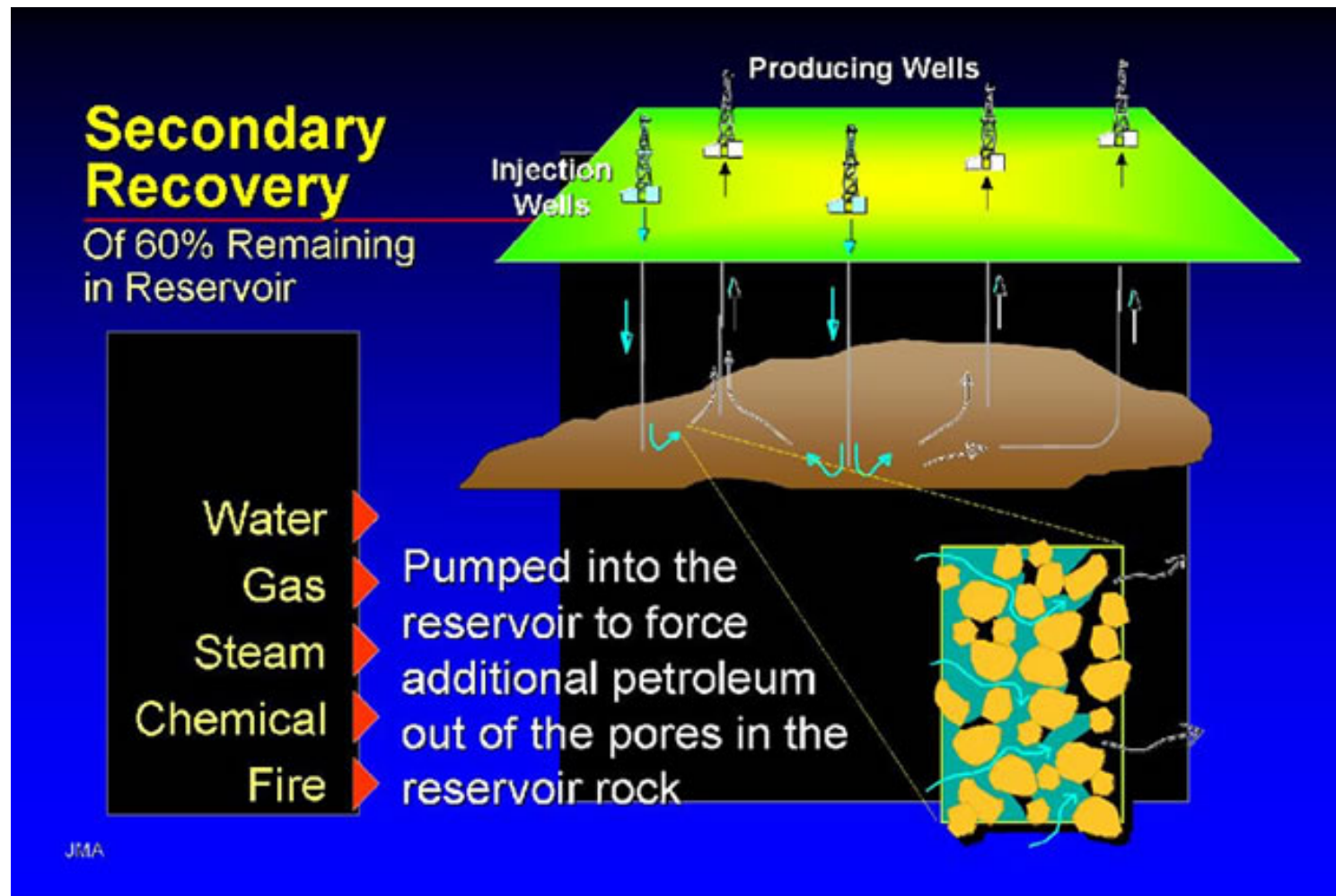
Oil and Gas Production



- All fluid petroleum is confined underground at high pressure, which provides a natural 'drive' for production, rather like artesian water supplies
- During the early stages of production, getting these fluids to the surface safely means allowing a controlled release of fluids under pressure. To prolong extraction later in the life of an oil or gas field, it usually becomes necessary to maintain the pressure underground by injecting pressurized water or gas, or both, into the reservoir.
- When production begins, during primary recovery, pressurized fluids within the reservoir rise up the borehole and reach the surface. As the pressure is released, any gas dissolved in the oil comes out of solution, to rise and escape along with the oil. As production continues, the pressure of the petroleum remaining in the reservoir begins to fall. This fall in pressure and the loss of dissolved gas increases the viscosity of the oil, so that it will not flow so readily. Typically only 5–30% of the petroleum in the reservoir is brought to the surface during the primary recovery stage.

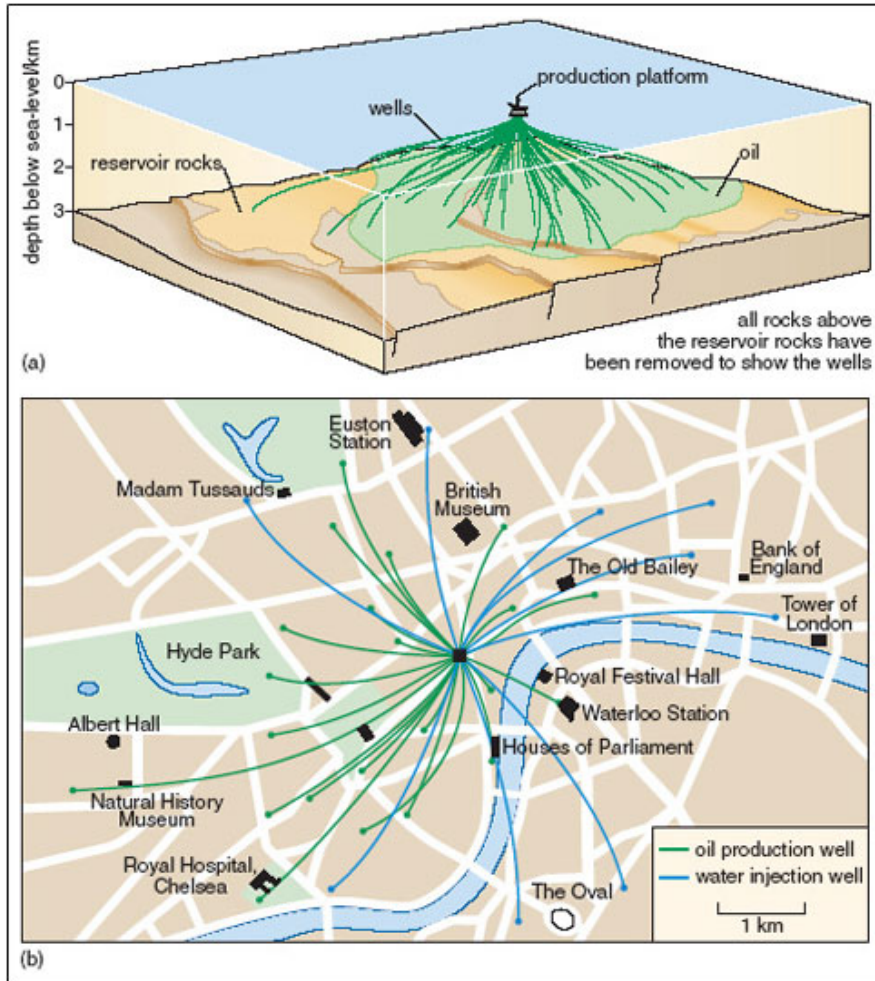


Enhanced Oil Recovery



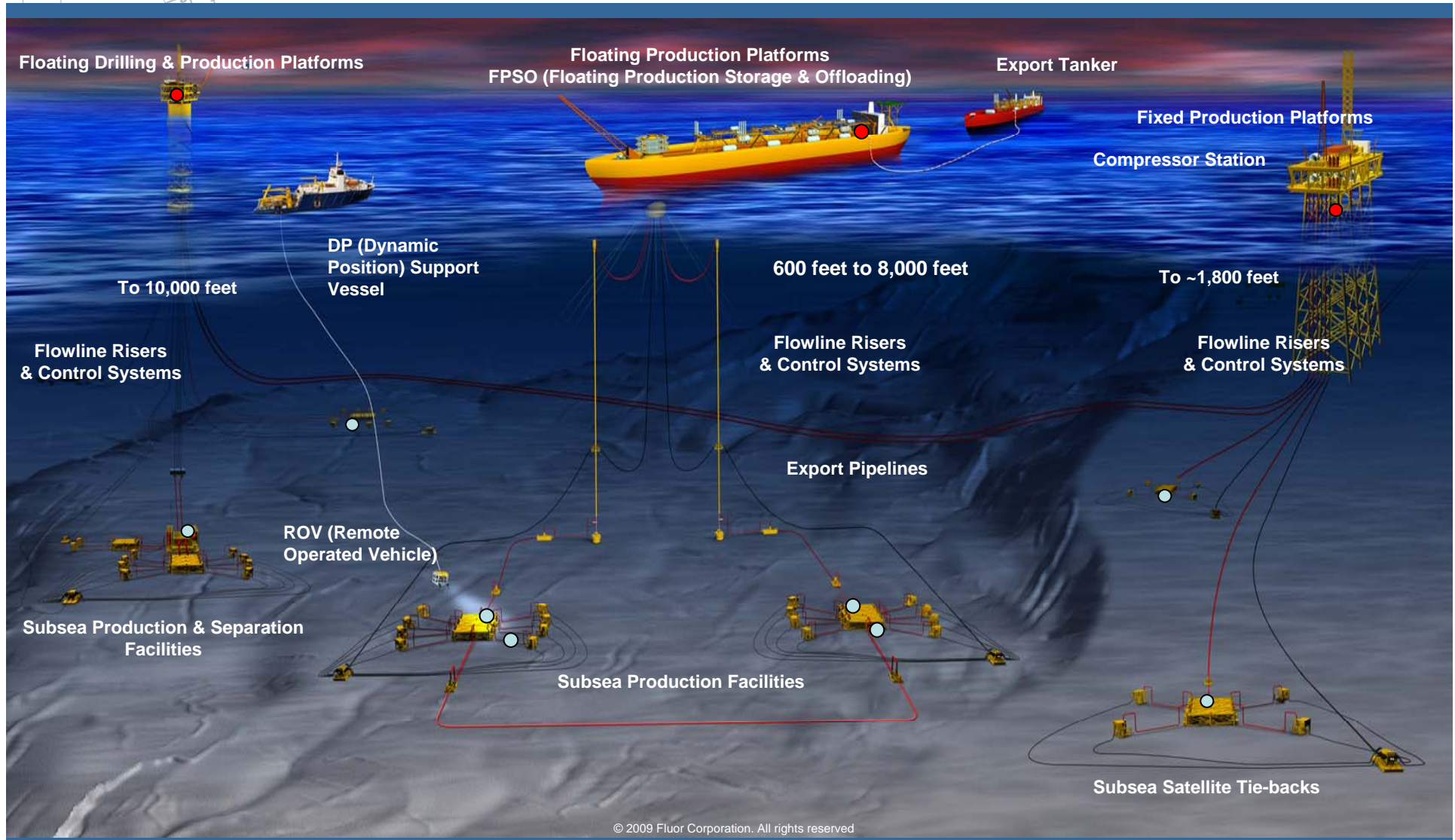


Oil and Gas Production



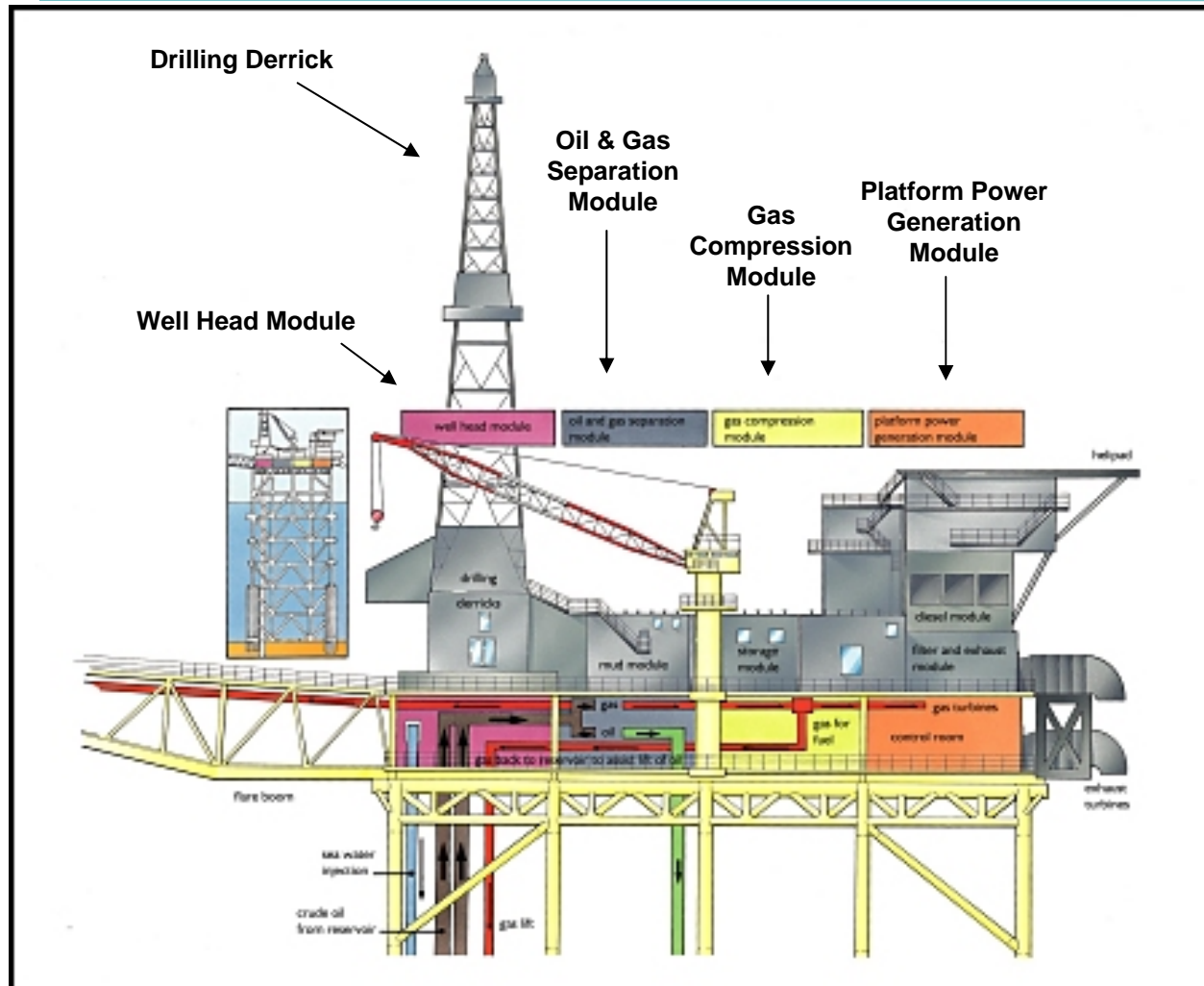
- In order to develop offshore fields economically, numerous directional wells radiate out from a single platform or from several sub-sea wellheads to drain a large area of the reservoir.
- This allows each well to produce as much petroleum as possible at economic rates. Wells which deviate at more than 65° from the vertical and reach out horizontally more than twice their vertical depth are known as *extended reach wells*.
- Where reservoirs are thin or suffer from low permeability it may be appropriate to drill production wells at more than 80° from the vertical and these are called *horizontal wells*. The flow rate from a horizontal well may be more than five times that from a vertical well, thereby justifying the higher cost of drilling a well with a complex geometry.

Offshore Technology for Oil & Gas Production





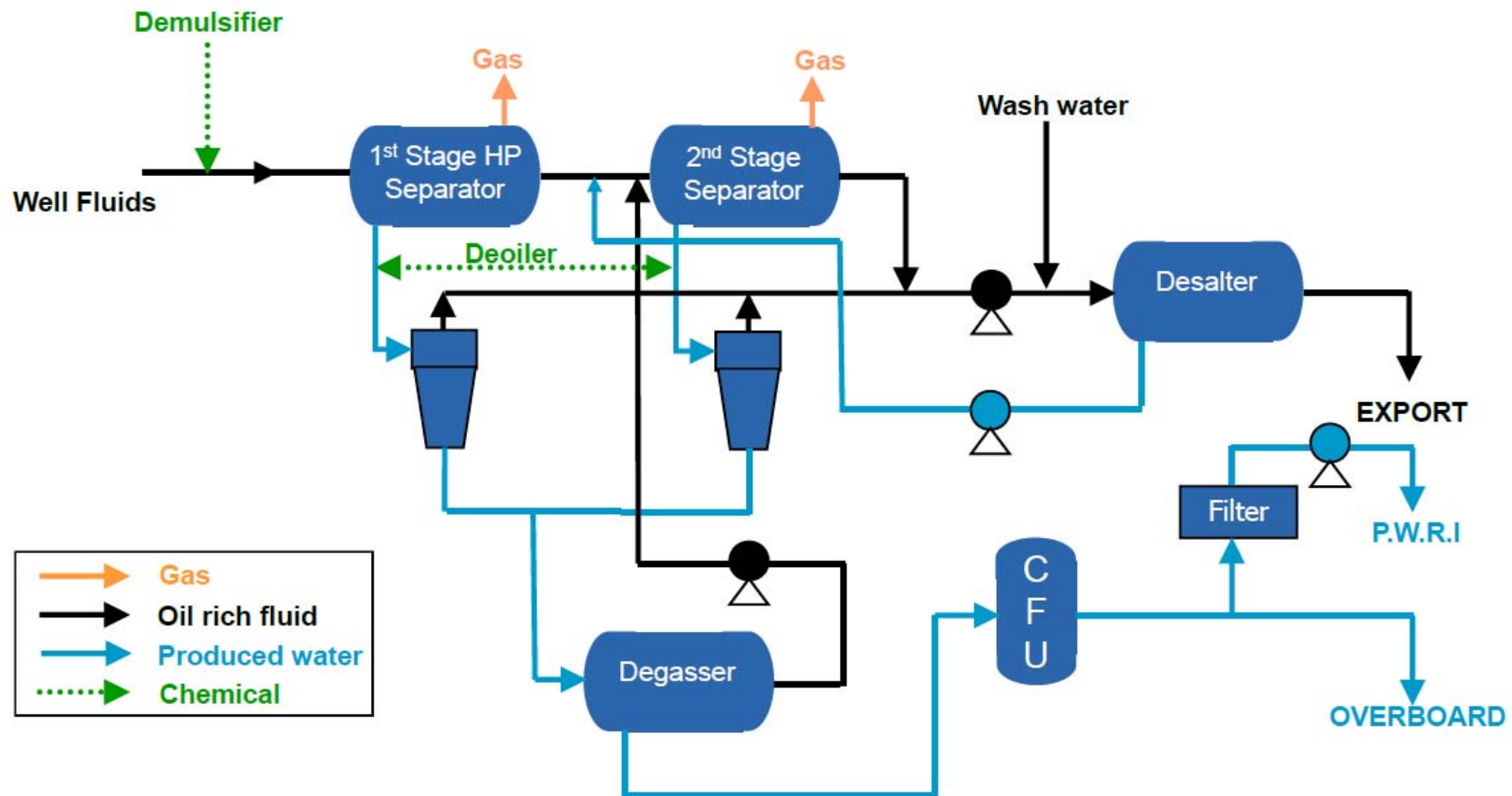
Oil & Gas Production – Offshore Platforms

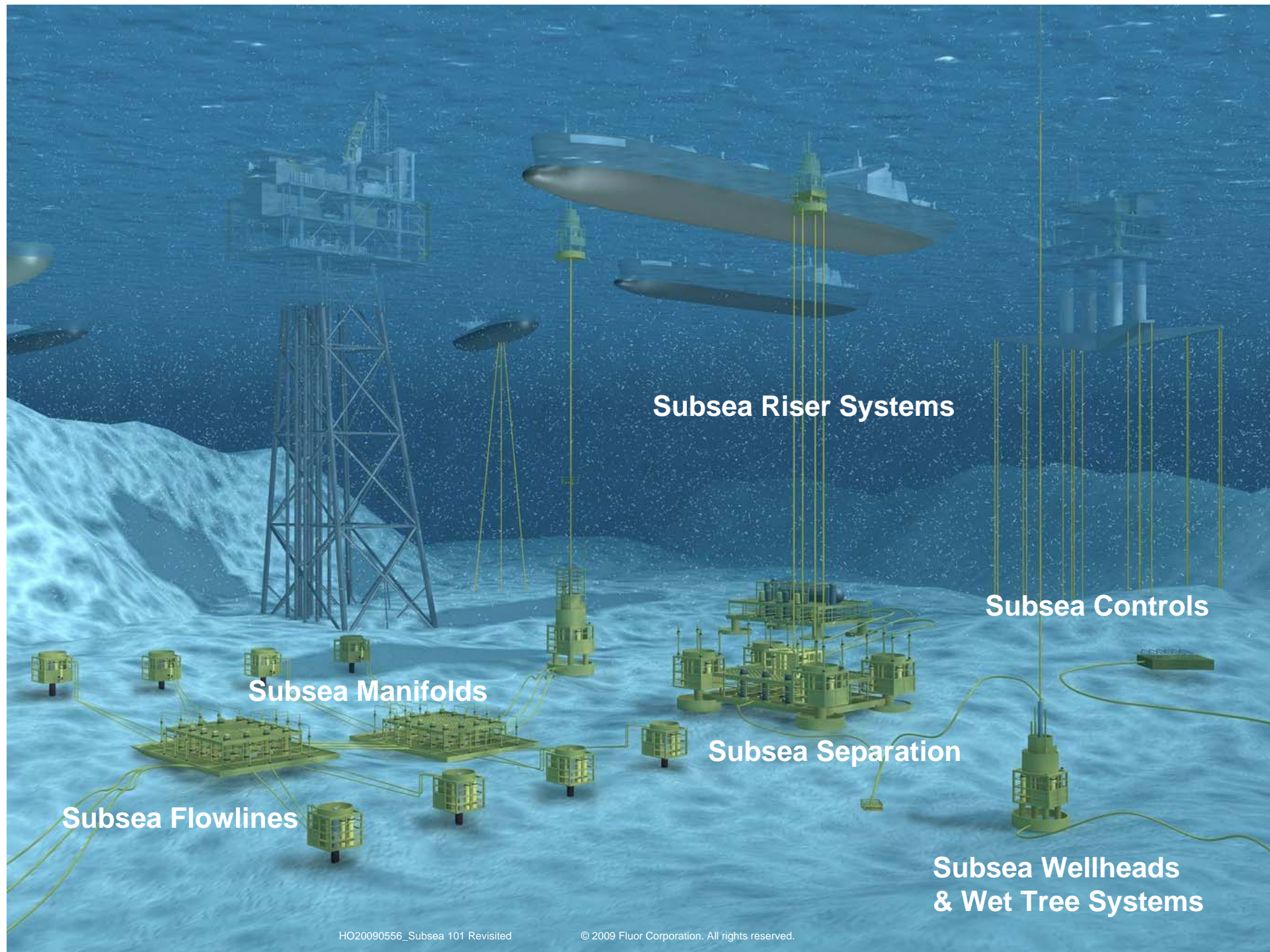


- Oil platforms are an industrial town at sea, carrying the personnel and equipment needed for continuous hydrocarbon production.
- The most important functions are drilling, preparing water or gas for injection into the reservoir, processing the oil and gas before sending it ashore, and cleaning the produced water for disposal into the sea.



Oil Production Process Train





Subsea Riser Systems

Subsea Controls

Subsea Manifolds

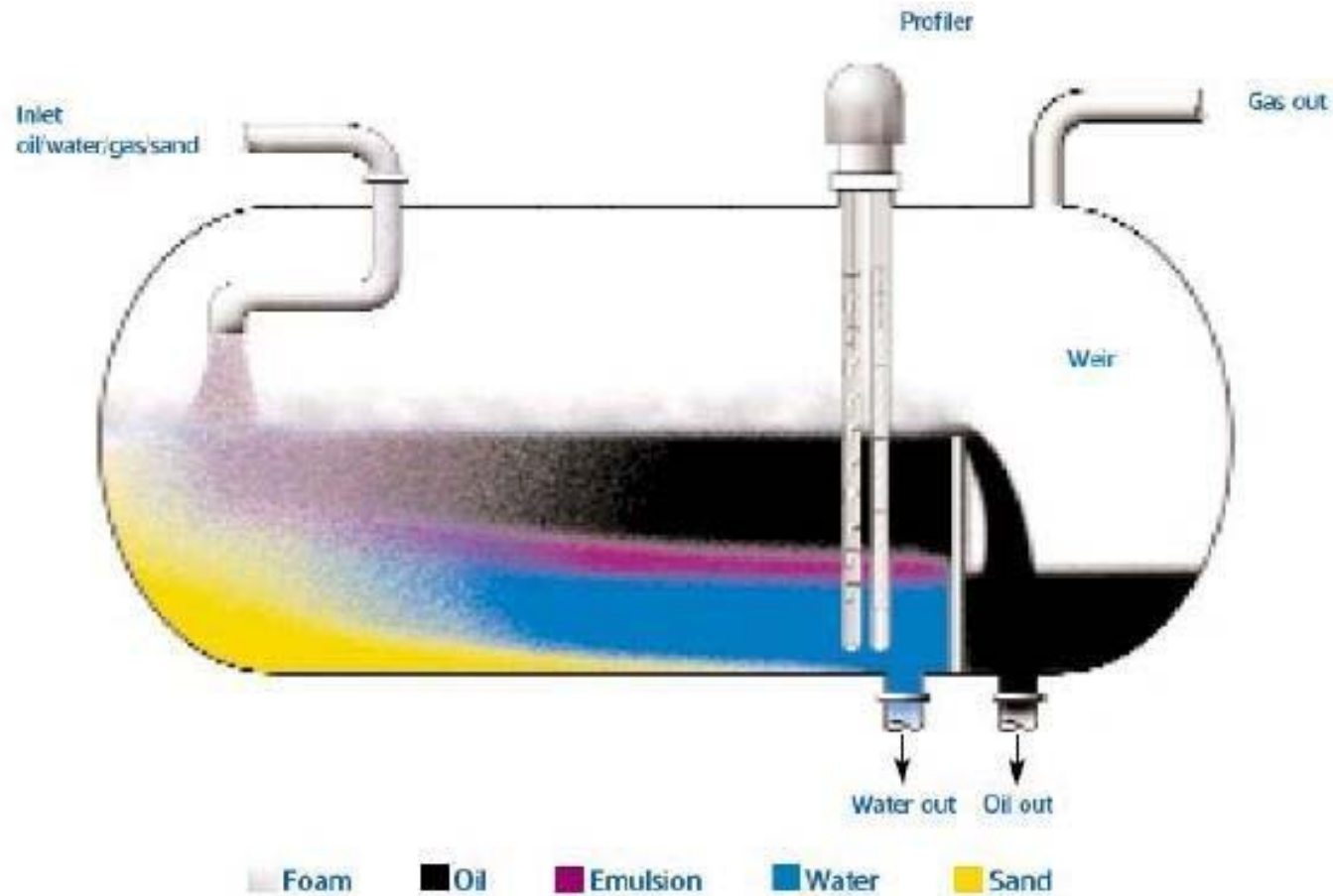
Subsea Separation

Subsea Flowlines

**Subsea Wellheads
& Wet Tree Systems**



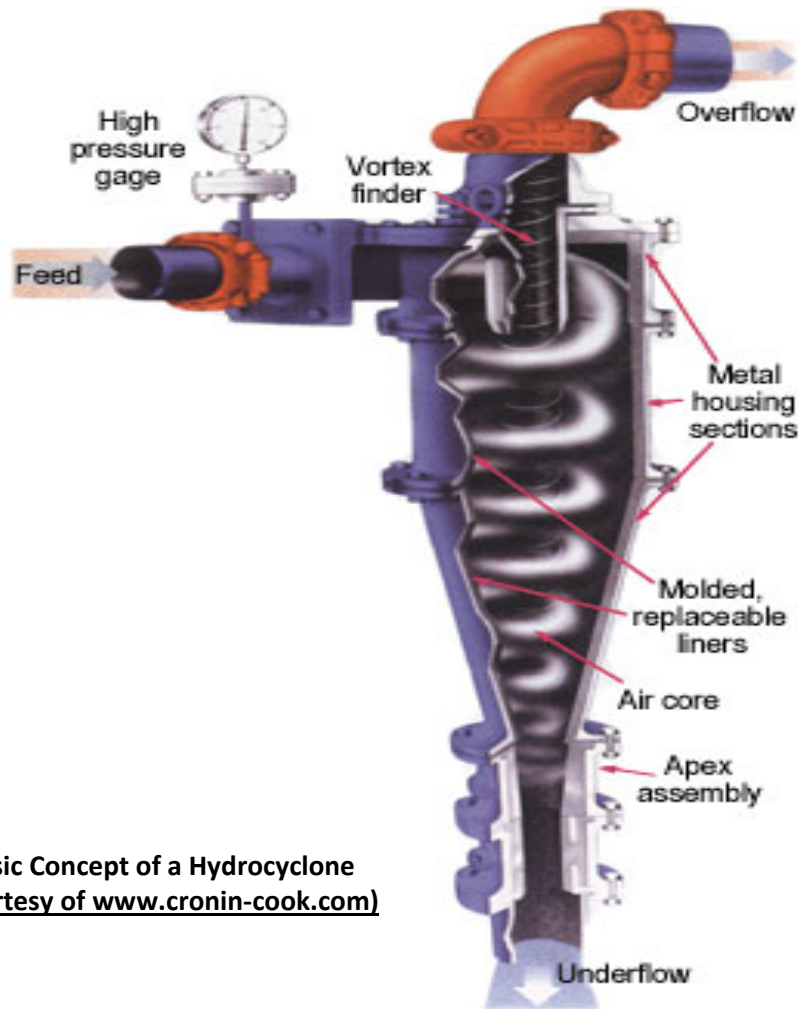
Typical Separator & Profile



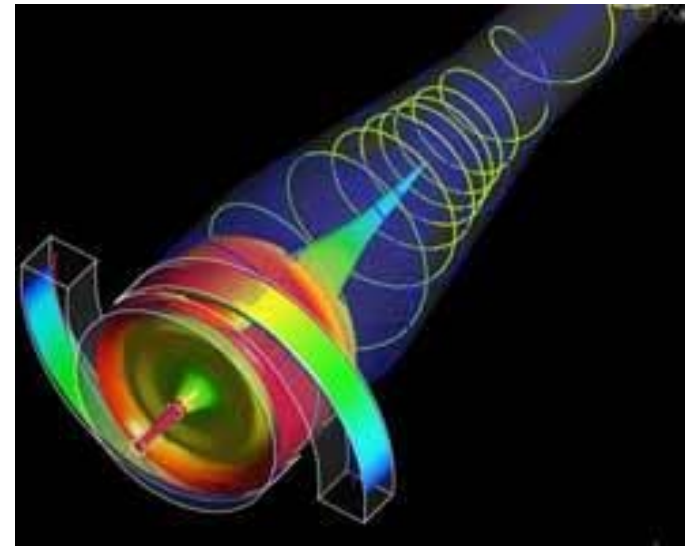
Typical Production Separator and Profile (Courtesy of Produced Water Society)



Hydrocyclones



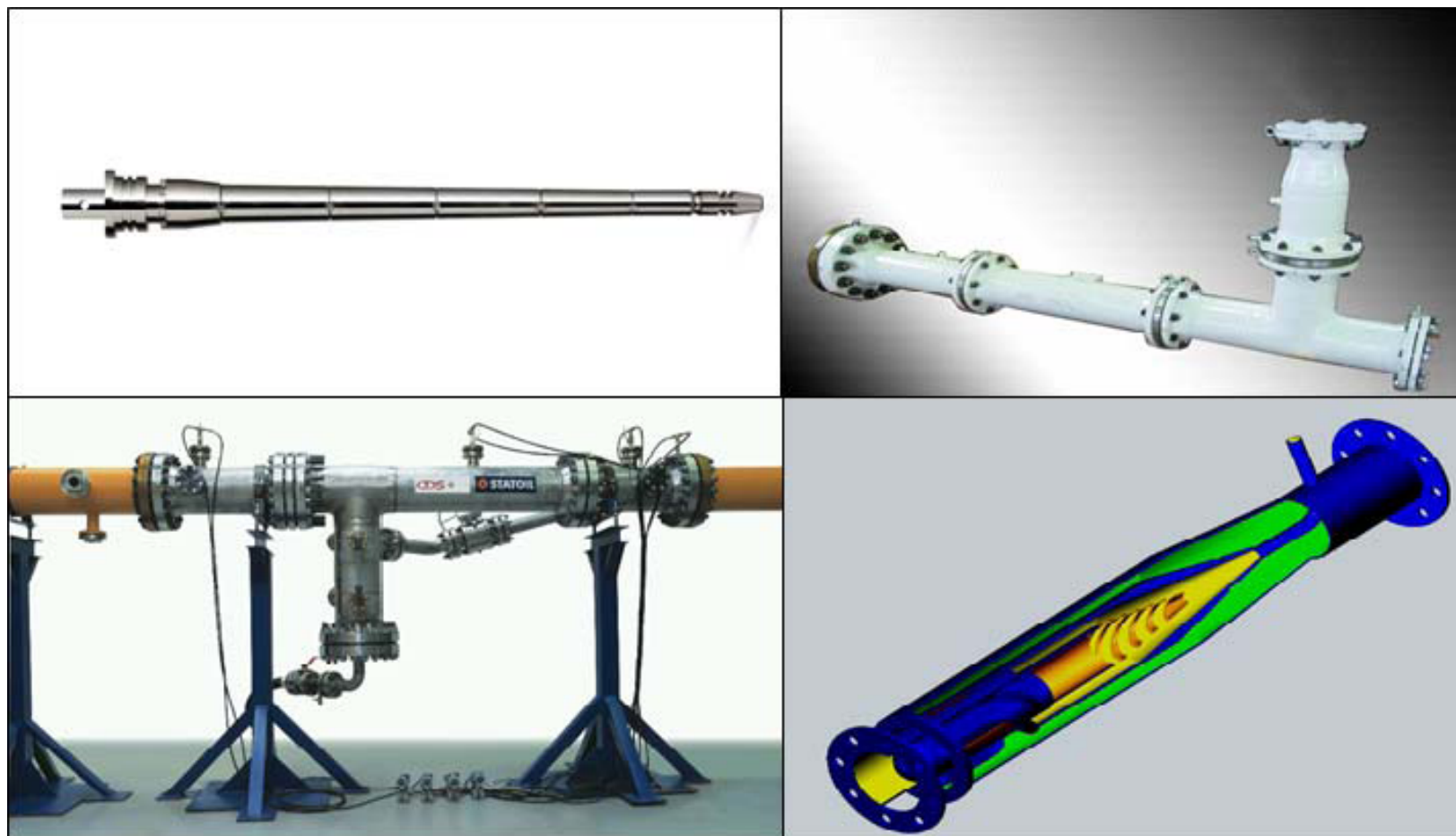
Basic Concept of a Hydrocyclone
(Courtesy of www.cronin-cook.com)



Fluid Modeling for sizing a Hydrocyclone
(Courtesy of FLSmidth)



Sand Handling - Hydrocyclones



Inline Cyclonic Separation Equipment - Clockwise: Liquid-Liquid Separation, Phase Splitter, De-Sander, Deliquidizer, (Courtesy of OTC 20080 paper, 2009)



Sand Handling – De-Sander



Inline De-Sander (Courtesy of FMC Technologies)



Sand Handling – Hammer Mill



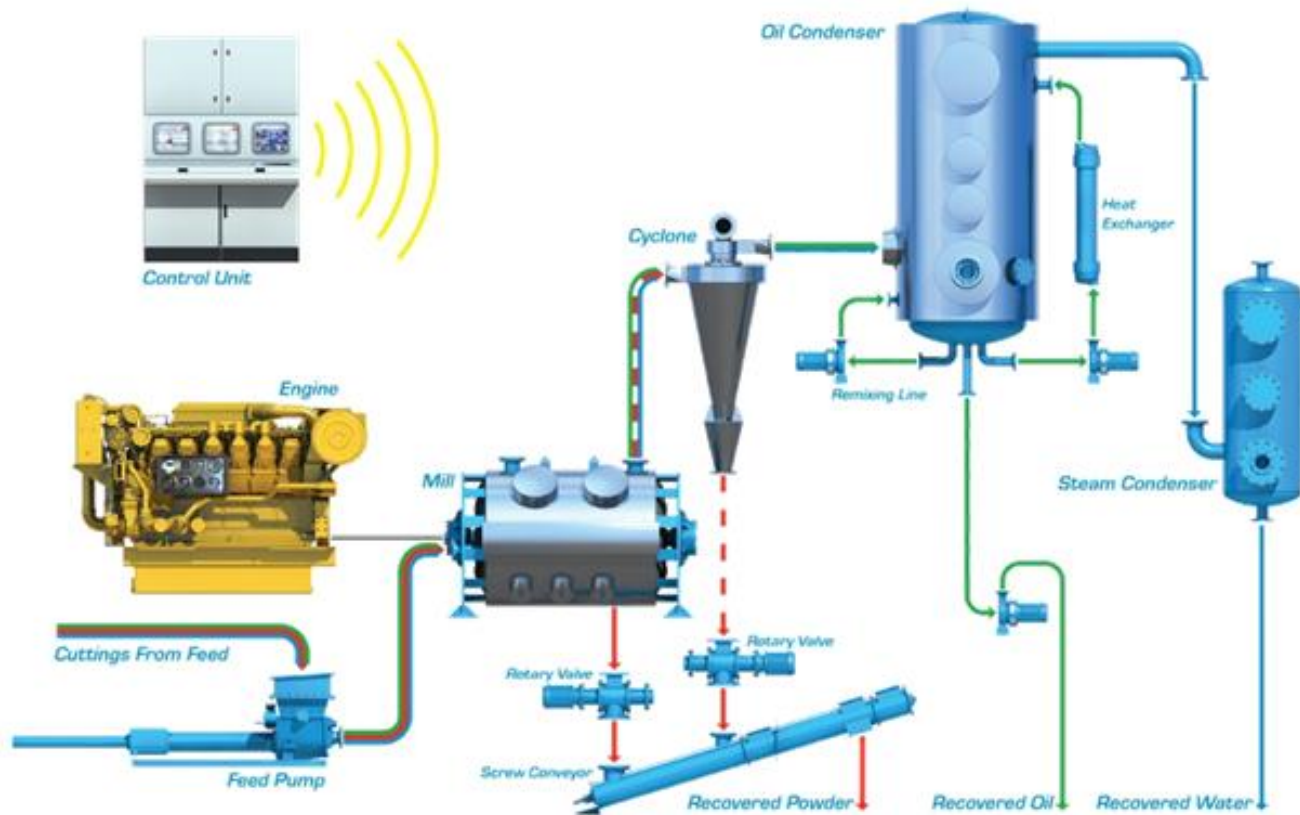
- Based on direct mechanical heating through the use of a pounding mill's action on the cuttings.
- The combination of high mechanical shear and *in-situ* heat generation creates an environment that promotes flash evaporation of water and hydrocarbons.

Process Flow of TWMA Hammer Mill (Courtesy of TWMA Ltd Website)





Sand Handling – Hammer Mill

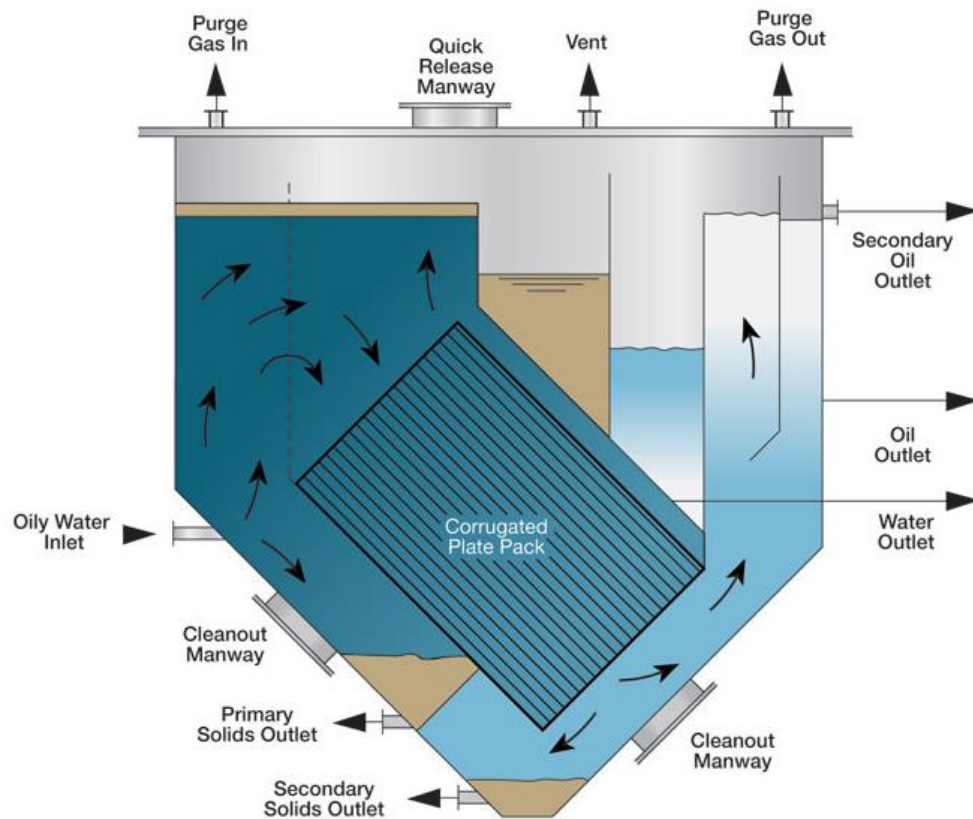


Process Flow of TWMA Hammer Mill (Courtesy of TWMA Ltd Website)



Coalescing Plate Interceptor

Corrugated Plate Interceptor

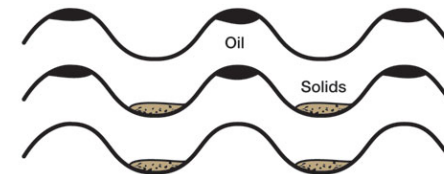


CPI typical layout

Gravity separator, contains closely spaced corrugated plates, uses Stoke's Law for successful operation.

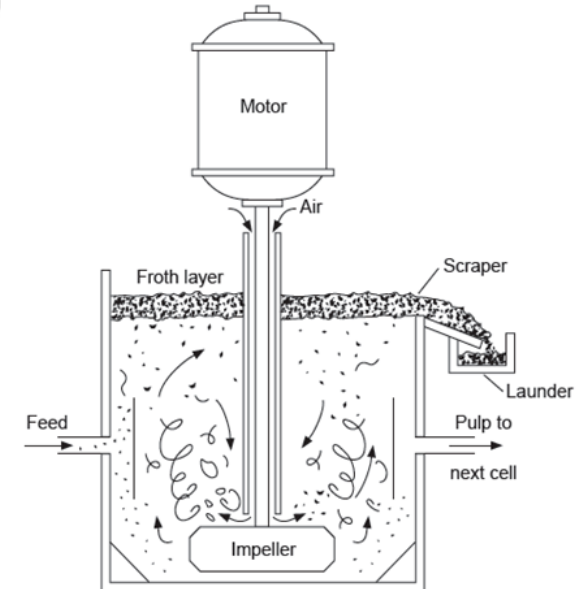
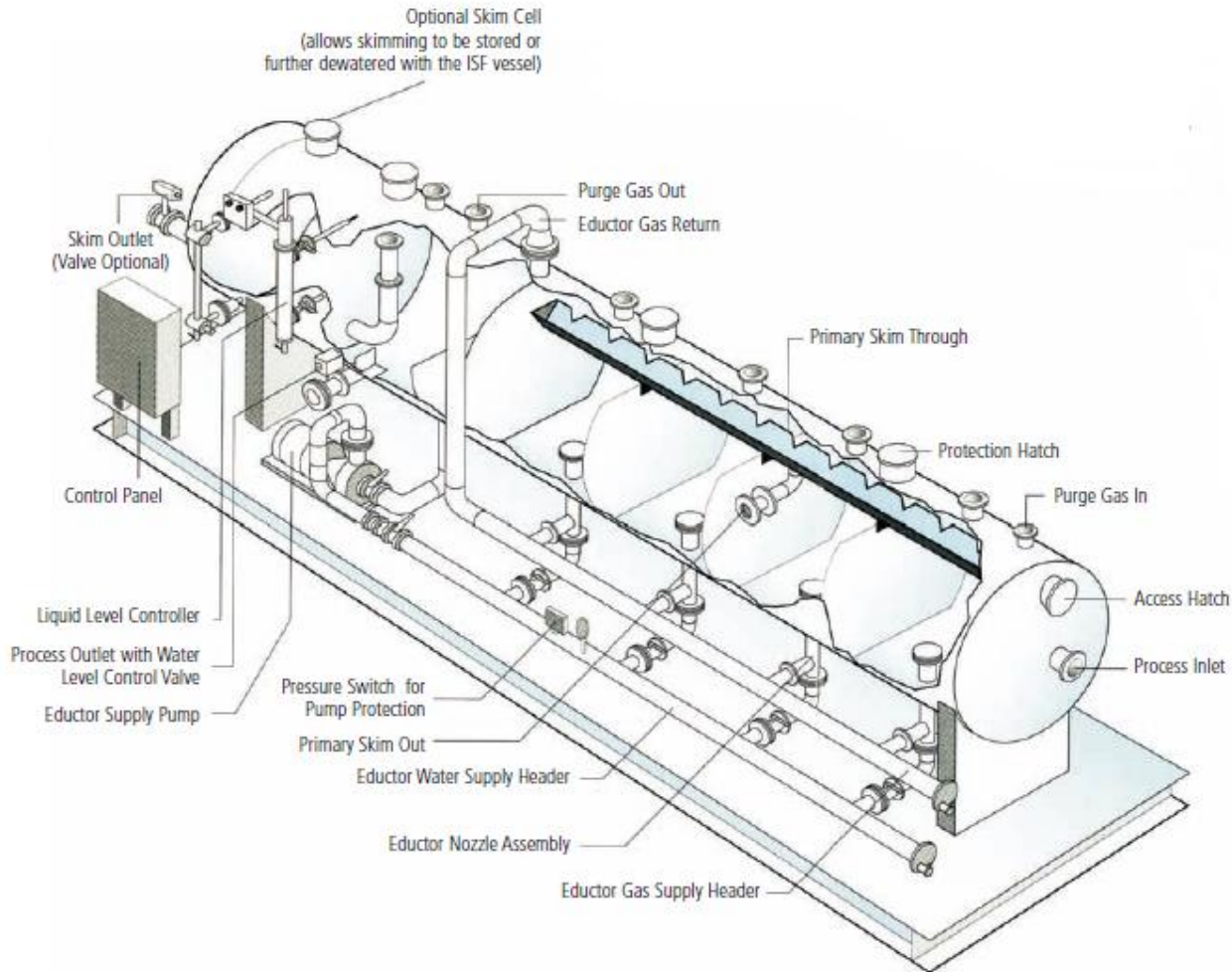
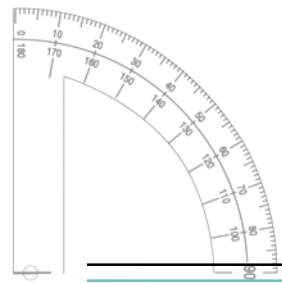
Benefits are:

- No Power Requirement
- No Moving Parts
- Low Capex and Opex
- Low Maintenance Cost



Visual Function of plates

Gas Floatation Cells





Filtration



Modern Walnut Shell Filtration Package (Courtesy of Produced Water Society)





Advanced Filtration

- **2010 SPE Spotlight on New Technology Awardee.**
- **Clean Water Technology for Produced Water Treatment**
- **Declared advantageous over traditional carbon bed filtration and acid injection**
- **Currently deployed for removal of emulsified oils and water-soluble organics (WSO) in DW offshore platforms to meet overboard discharge requirements.**





Advanced Subsea Separation



FMC Pazflor SS Gas/Liquid Separation & Boosting, Courtesy of FMC



FMC Tordis Subsea Separation System, Courtesy of FMC



Advanced Subsea Separation

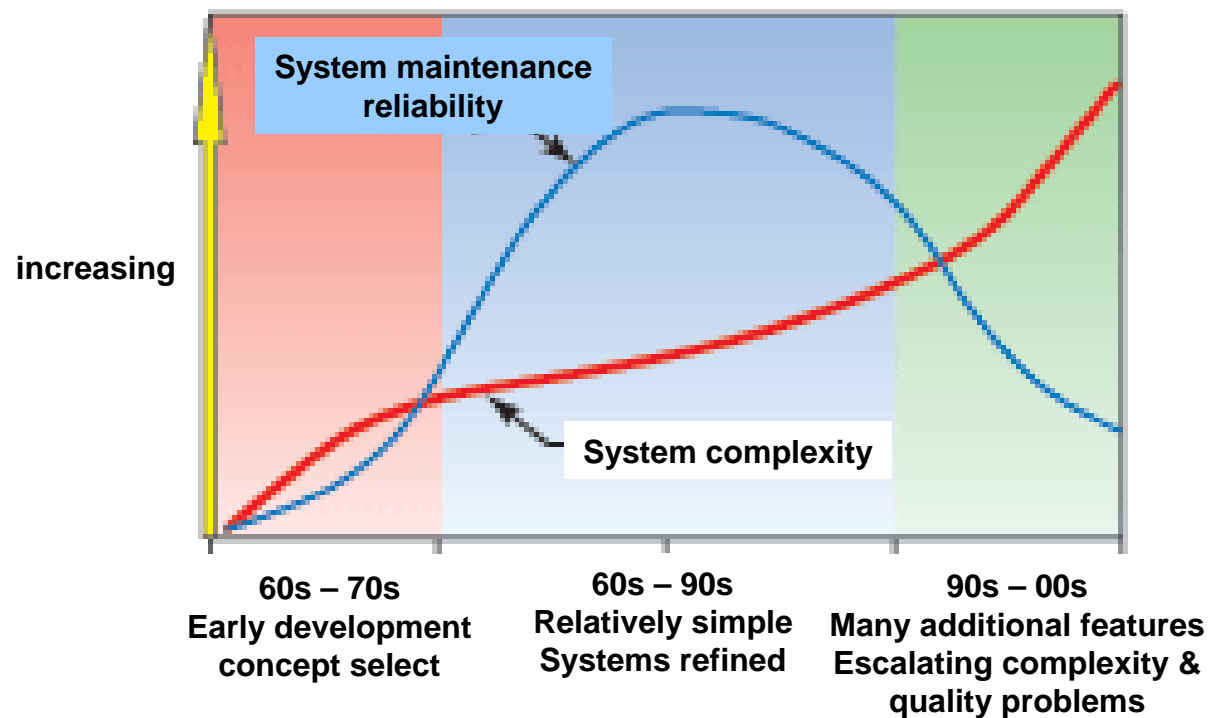


Pipe Separator (Courtesy of FMC Technologies)



Evolution of Subsea Production Technology

Trends of subsea systems

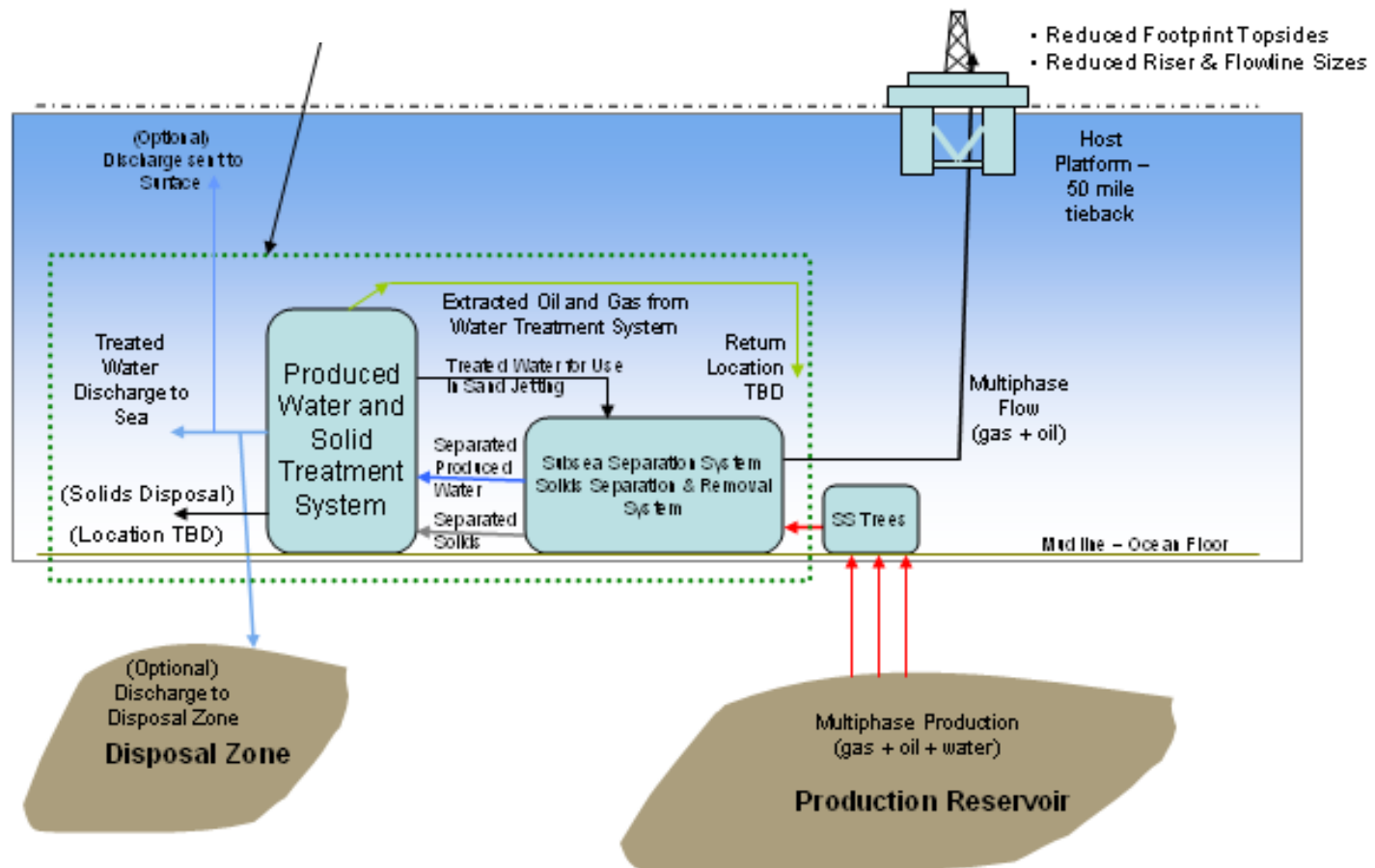


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Basis of Design

Study focus area



Production Wastes

- Produced Water
- Produced Sand
- Drilling Fluids
- Drill Cuttings



What is Produced Water?

Regarded as a **WASTE** stream in oil and gas production

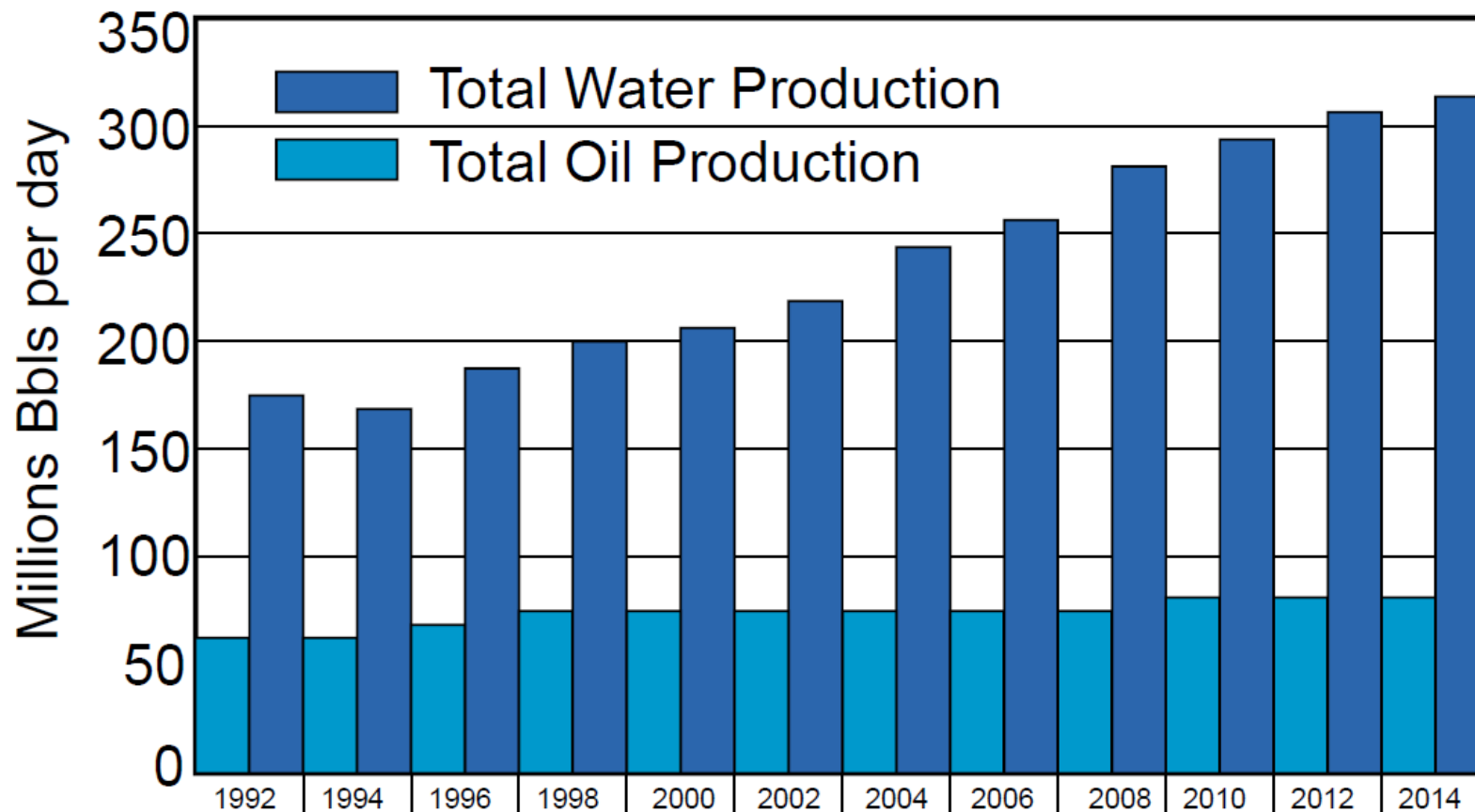
May include:

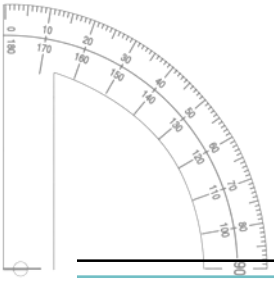
Formation Water	Saline formation brines in the reservoir
Condensation Water	Water vapour condensing during production
Returned injection water	Water injected to boost the reservoir pressure
Water used for de-salting	Washing the crude with clean water and removing



Global Oil & Water Production

For every 1 barrel of oil, ≈ 4 barrels of Water!



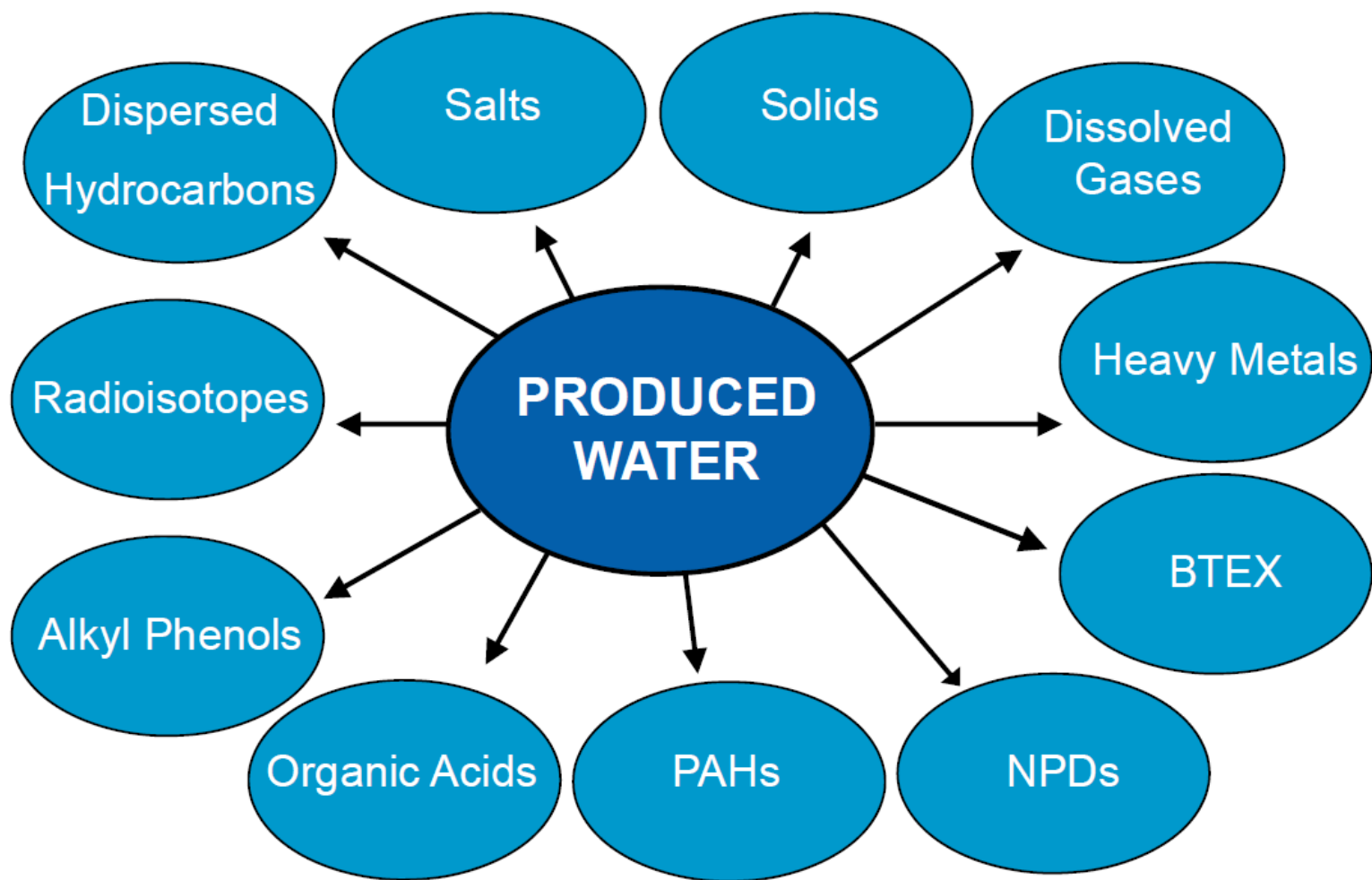


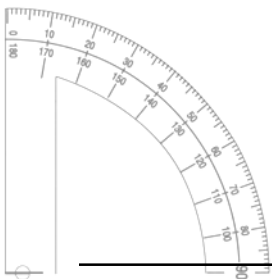
Produced Water Situation in USA

- Produced water: 21 billion bbl in 2007 or 57.4 million bbl / day
- 20% of world total
- Average w/o ratio: 7:1
- Many older wells: w/o ratio > 50

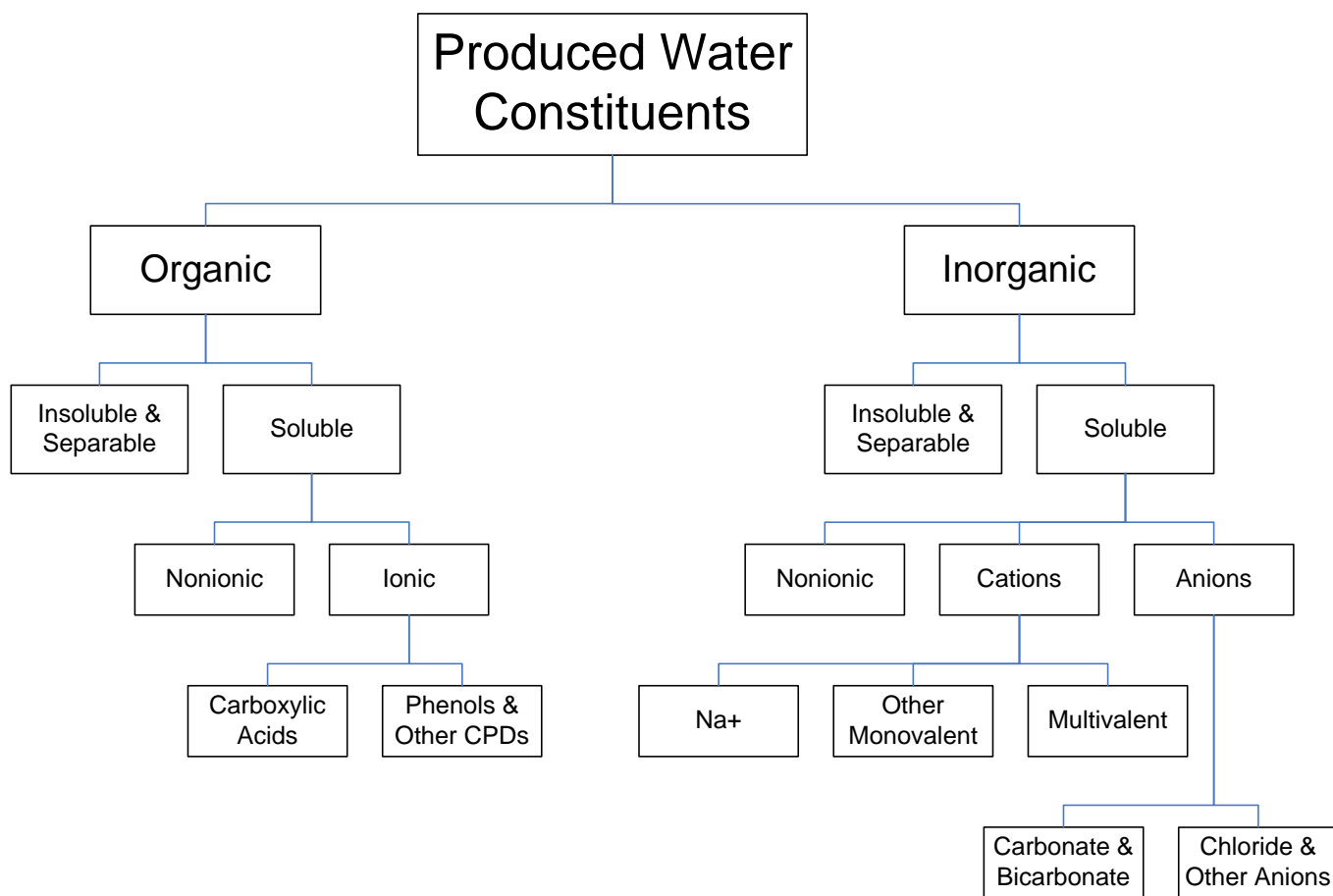


Produced Water Composition





Produced Water Composition



Produced Water Constituents (Hayes, 2004)



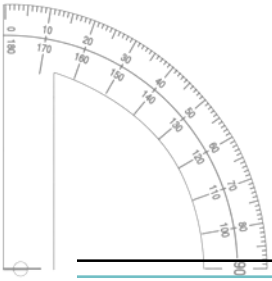
Produced Water Summary

- Produced Water is complex and many of its compositions can cause harm to the environment
- Large amount of water currently produced
- Largest waste stream
- Water production is increasing worldwide
- Substantial amount of oil wasted
- Discharge strictly regulated
- Regulations are getting increasingly more stringent



Baltic Sea Convention & Helcom





Baltic Sea Convention & Helcom

- **Philosophy - Use of Best Environmental Practices and Best Available Technologies**
- **Additional measures shall be taken if the consequent reductions of inputs do not lead to acceptable results**
- **200 Recommendations made since its creation in 1972**
- **Oil in Water Limits set at 15 mg/L monthly average, max 40 mg/L per day**
- **Region has seen a drastic improvement to the water quality**



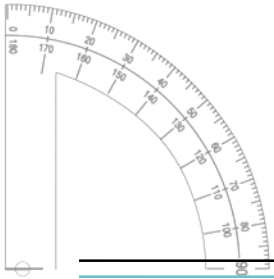
Barcelona Convention (Mediterranean Sea)





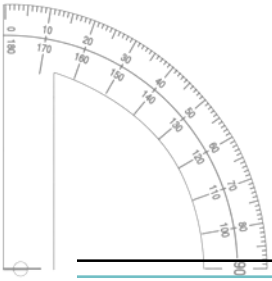
Barcelona Convention (Mediterranean Sea)

- Established in 1975, currently has 22 countries focused on the Protection of the Mediterranean Sea
- Main objectives:
 - Assess and control marine pollution,
 - Protect the natural and cultural heritage of the area
 - Contribute to the improvement of the quality of life
- Oil in Water Limits set at 40 mg/L monthly average, max 100 mg/L per day (under further review)



Kuwait Convention (Red Sea)





Kuwait Convention (Red Sea)

- Established 1978 to prevent, abate, and combat pollution of the marine environment in the Red Sea
- A high priority on combating hydrocarbon pollution
- Review of all types of discharges
- No sand discharge
- Oil in Water Limits set at 40 mg/L monthly average, max 100 mg/L per day (under further review)



OSPARCOM (North Sea)



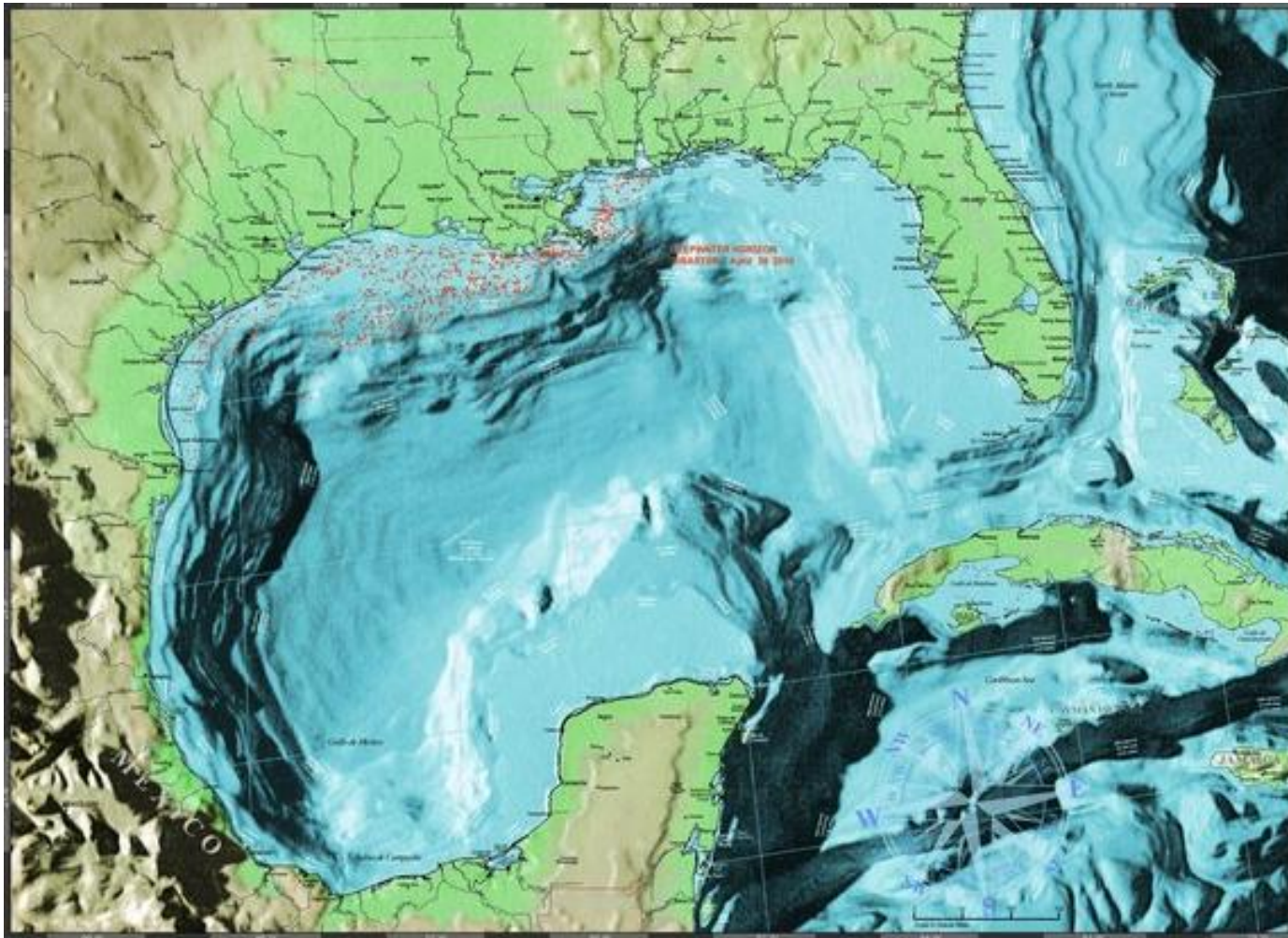


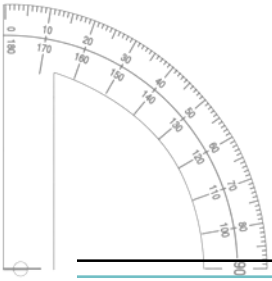
OSPARCOM (North Sea)

- Established in 1992, Treaties of Paris and Oslo, went in effect , 1998
- Oil discharges w/ PW down by 20% , set reduction targets for discharge, PW > increase
- Drilling fluids, cuttings pile pollution reduced. Moves to cessation of discharges, emissions and losses of hazardous substances by 2020
- Ultimate aim, achieve near background values for naturally occurring substances and close to zero for man-made substances
- 30 mg/L oil in PW, < 2012, focus on reducing toxicity of Individual components contributing to final effluent



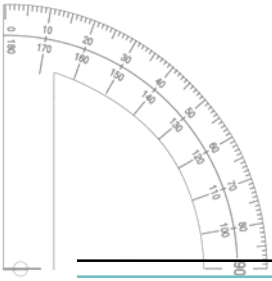
Gulf of Mexico - Seafloor





US Regulations (Gulf of Mexico)

- **Philosophy of Whole Effluent Toxicity Testing**
- **Limits set at 29mg/L monthly average, 40 mg/L daily maximum**
- **No free oil discharged - Visual sheen method on the surface of the receiving water. Monitoring done daily**
- **Observed sheens must be recorded on NPDES permit**
 - US Environmental Protection Agency – Office of Wastewater Management - National Pollutant Discharge Elimination System
- **No discharge of sand**



US Regulations (Gulf of Mexico)

- **Toxicity test required, ASTM 1664 Method**
 - American Society for Testing and Materials
 - **7-day avg minimum for the test effluent to be diluted and placed in 8 different test replicas, each containing at least 5 organisms of mysid shrimp**
- **½ must remain alive for the 7 day test**
- **A No Observable Effect Concentration (NOEC) => specified critical dilution concentration**
- **Dilution rates set on discharge pipe diameter and water depth from the seafloor**



Marine Life and Seabed Effects

- Marine life is sensitive to changes in temperature and salinity.
- Decreases in Salinity effect some marine life by causing them to swell and explode.
- Increases in Salinity effect some marine life by causing them to shrink or implode.

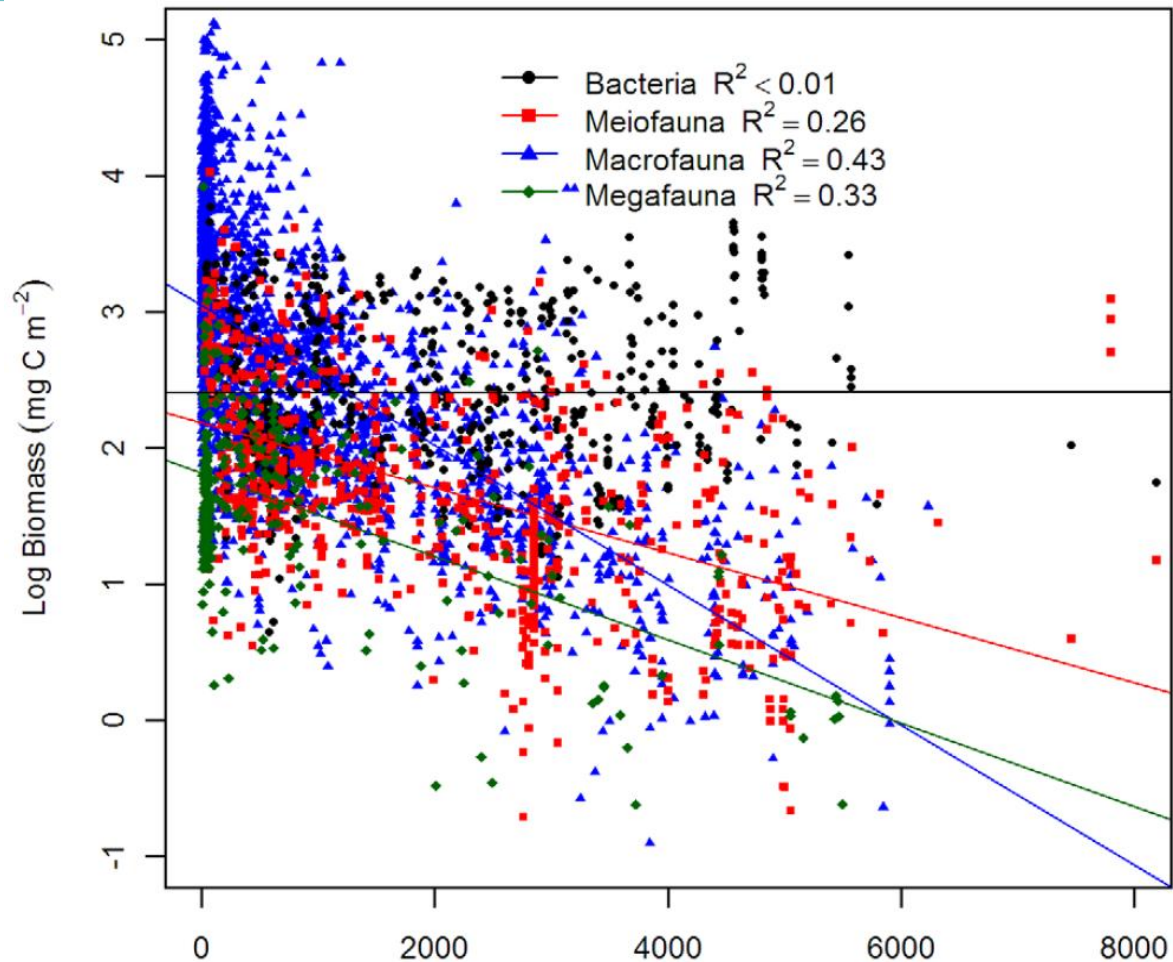
A swimming shrimp at over 9000 feet water depth in the Gulf of Mexico

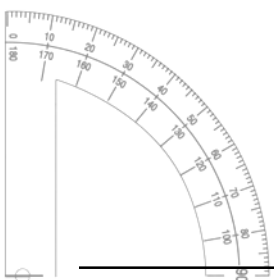




Marine Life and Seabed Effects

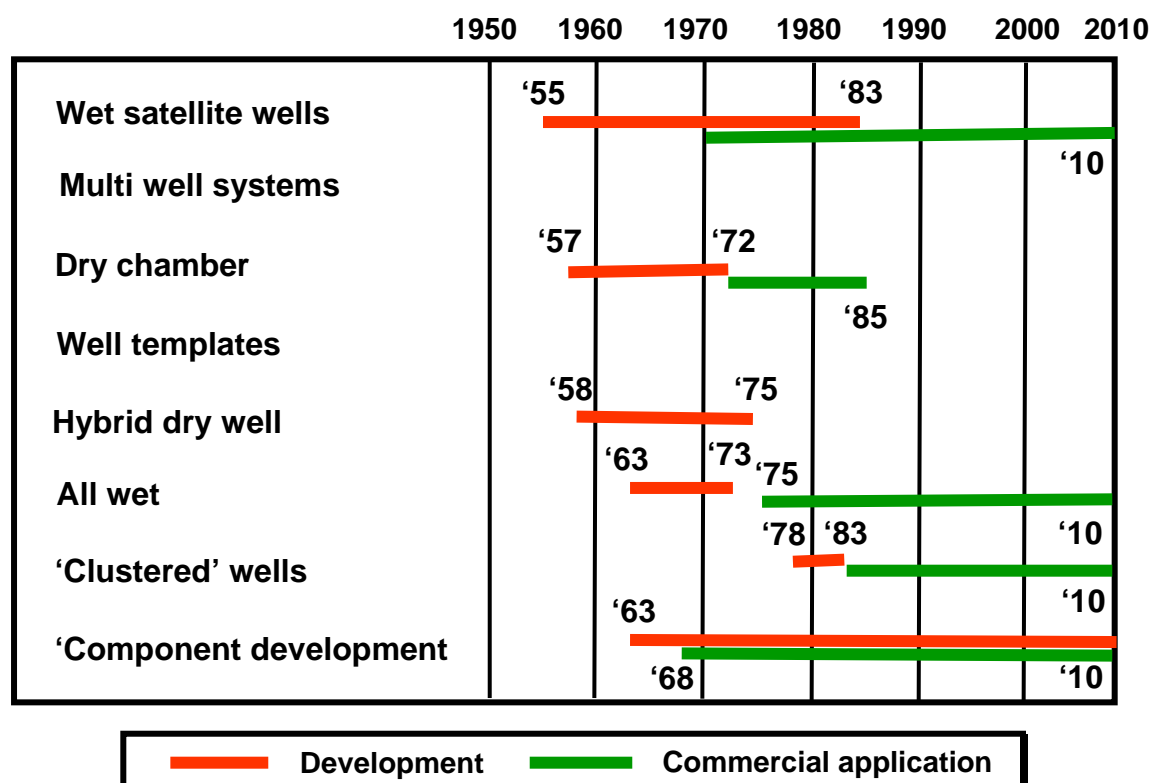
- **Bacteria is a key component**
- **All throughout the world's oceans in all depths biomass varies.**
- **Except the quantity of bacteria – It's constant!**





History of Subsea Production

Evolution of seafloor well technology



- Lockheed Petroleum Services – July, 1972 – First Subsea Chamber – Main Pass – Gulf of Mexico
- Exxon Company of USA – Developed first prototype of subsea “template”, 1975
- Fluor Corporation (Deep Oil Technology) – Developed one of first concepts for Subsea Production. – 1968 – 1975.

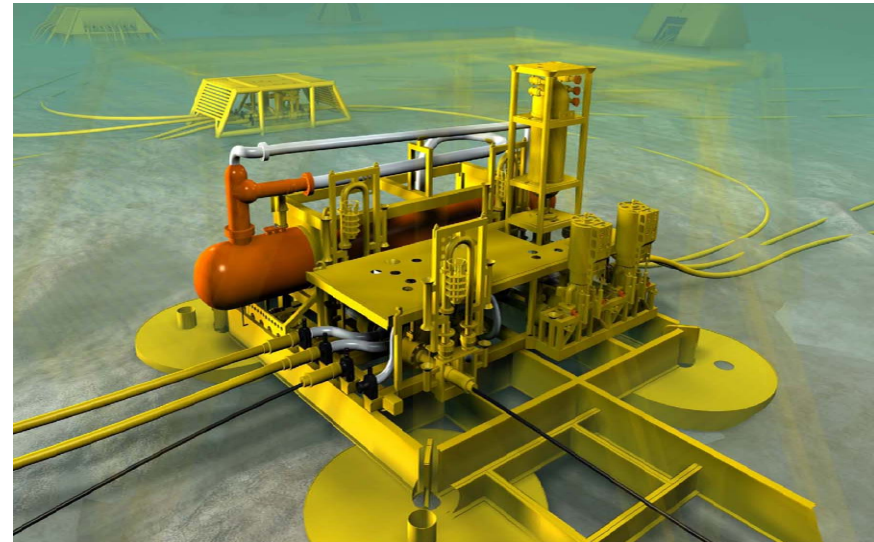
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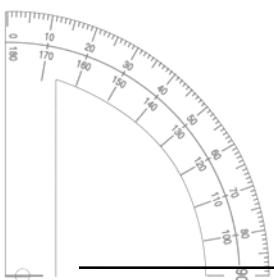




Subsea Processing – The Beginnings

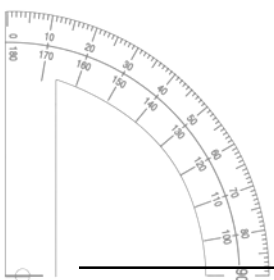
- Zakum Subsea Process System 1969, OTC 1083
- GoM Submerged Processing System 1975
- Highlander Subsea Slug Catcher 1985
- BOET Argyll Subsea Separator 1988, OTC 5922 1990 OTC 6423
- GA-SP Goodfellows Statoil 1991 carried into Alpha Thames work
- Kvaerner Subsea Booster Station 1992
- GLASS Bardex 1993 OTC 7245
- VASPs Petrobras 1990 – 1998
- DEEPSEP MAI & Petrobras 1995
- ABB COSWAS 1997 – 2001
- Troll Pilot





Recent Subsea Separation Installations

OPERATOR / YEAR	FIELD NAME	TECHNOLOGY USED	TECHNOLOGY TYPE	TECHNOLOGY SUPPLIER	WATER DEPTH ft
Statoil 2001	Troll C	Horizontal SUBSIS	Separator	GE /Framo	1,116
Petrobras 2001	Marimbá	VASPS	Separator & ESP	Saipem	1,265
Statoil 2007	Tordis	Horizontal	Separator	FMC/CDS	689
Shell 2009	BC-10	Caisson	Separator & ESP	FMC/CDS	6,562
Shell 2010	Perdido	Caisson	Separator & ESP	FMC/CDS	9,600
Petrobras 2011	Marlim	Inline	Separator	FMC	2,881
Total 2011	Pazflor	Vertical Separator	Separator	FMC/CDS	2,625
Petrobras 2012	Congro	VASPS	Separator & ESP	FMC	
Petrobras 2012	Malhado	VASPS	Separator & ESP	FMC	
Petrobras 2012	Corvina	VASPS	Separator & ESP	FMC	
Petrobras TBA	Canapu	Inline Supersonic	Separator	FMC Twister	5,579



Subsea Separation – Statoil Troll

- Horizontal separator; water for re-injection
- Measured Oil-in-Water is 15 to 600 ppm
 - Sample with 15 ppm was at 100% design flowrate

Design parameters for the Troll C subsea separation station

Total liquid capacity:10,000 cu m/day (~ 63,000 b/d)

Water capacity:6,000 cu m/day (~ 38,000 b/d)

Oil capacity:4,000 cu m/day (~ 25,000 b/d)

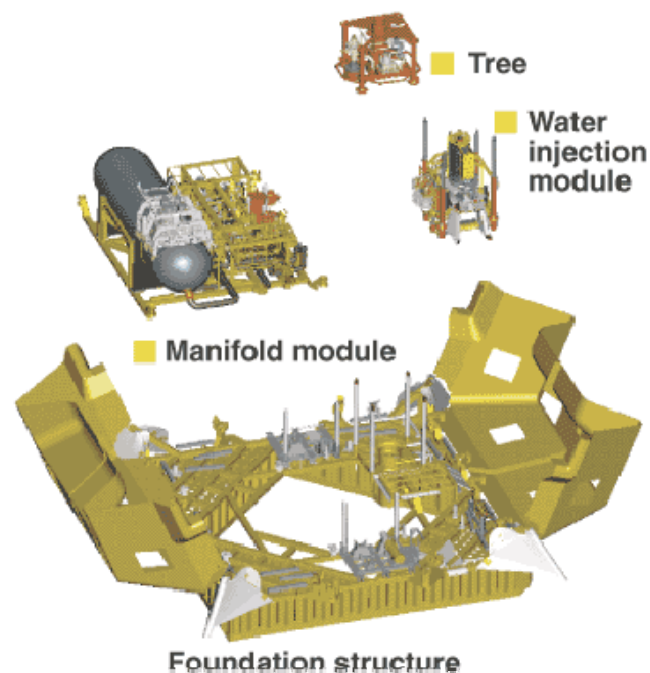
Gas capacity:800,000 cu m/day (~28 MMcf/d)

Max water cut:90%

Key performance requirements for the Troll C subsea separation station

Max oil in water (re-injection product):1,000 ppm

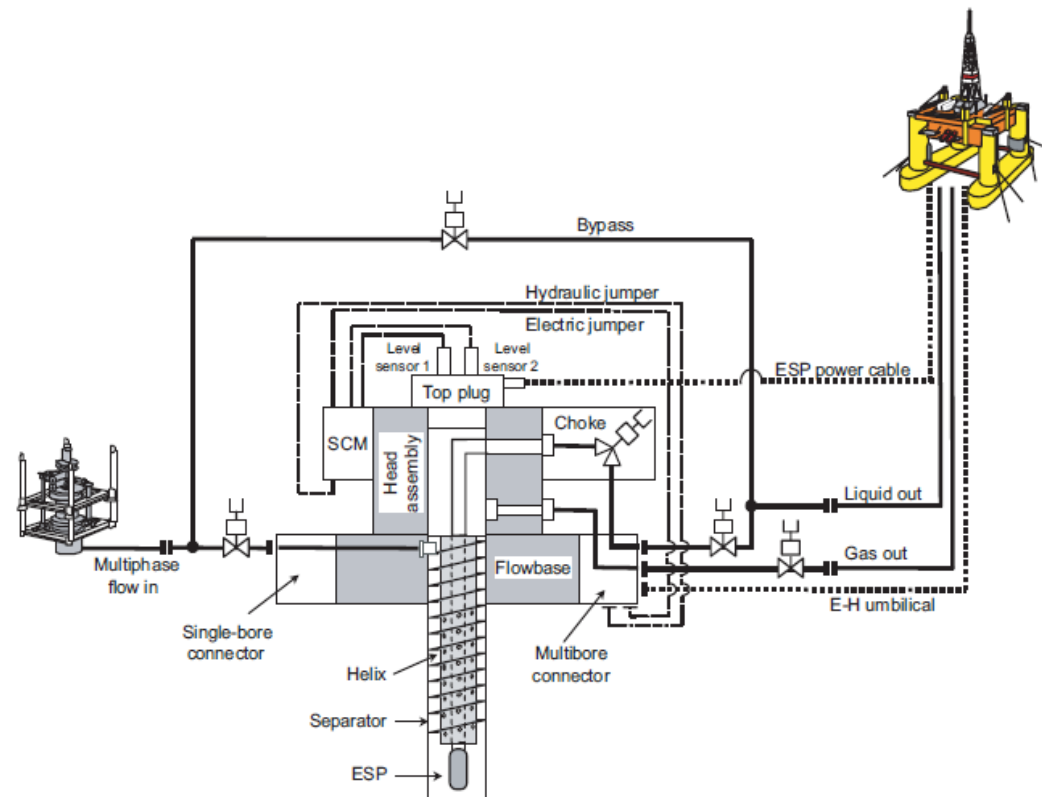
Max water in oil (produced to host):10%





Petrobras Marimba

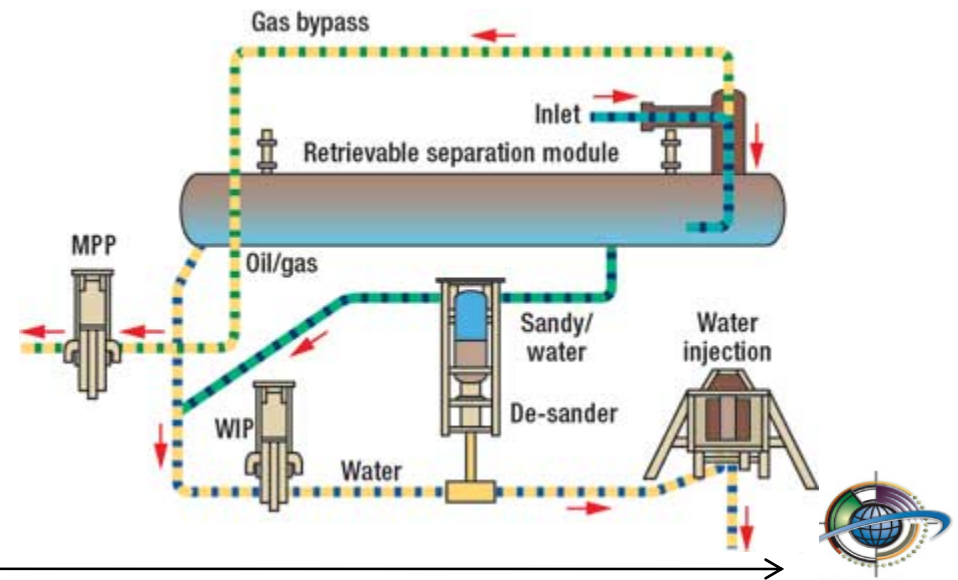
- Gas-Liquid Separation
- Oil and Water Not Separated





Subsea Separation – Statoil Tordis

- Horizontal separator; water for re-injection
- Design Spec
 - 1000 ppm oil-in-water; observed performance of 500 ppm
- 17 m Long, diameter 2.1 m; liquid retention time 3 minutes
- Capacity 100 KBWPD, 50 KBOPD
- Sand was disposed with water to injection well, then surface facility
- Lessons learned
 - Sand jetting was required more often than designed.





Statoil Tordis – Sand Management

- A CDS Sand Jetting system as the primary sand removal
- A cyclonic sand removal system as a back-up
- The removed sand is transported to a desander and sand accumulator vessel in batches.
- The accumulated sand is pressurized and transported to the discharge side of the water injection pump.
- All the separated sand is injected with the water.

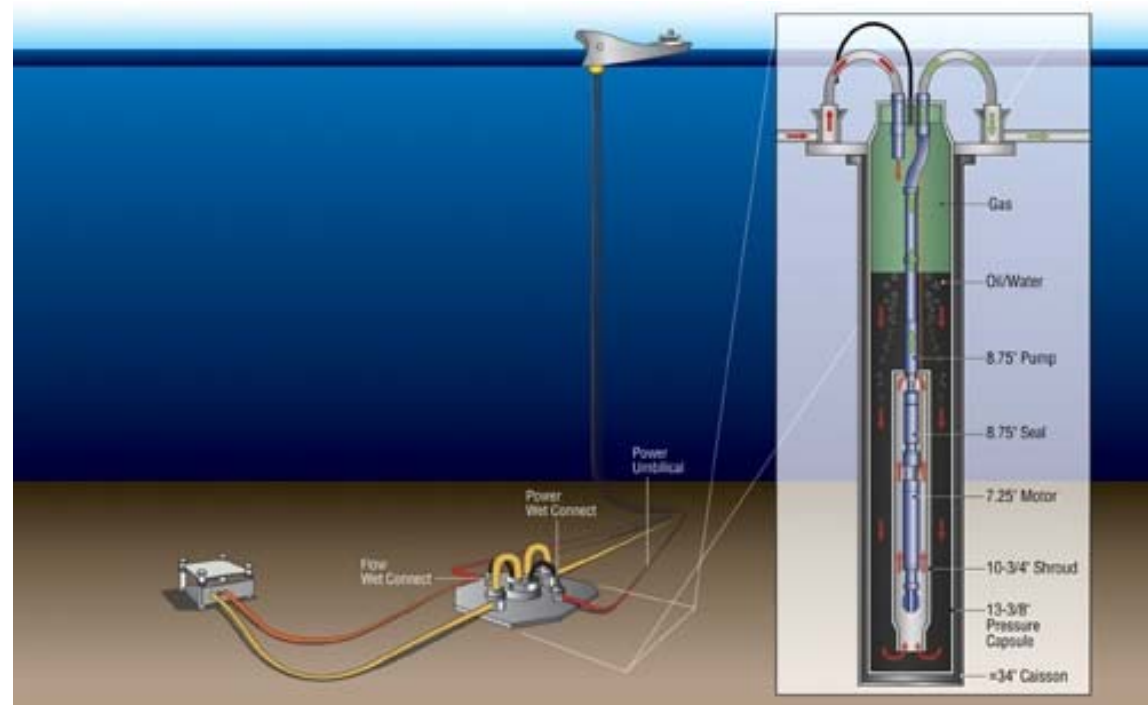


FMC Tordis Subsea Separation System, Courtesy of FMC



Shell BC-10 and Perdido

- Gas-Liquid Separation Only
- Oil and Water Not Separated
- Sand Collected in Caisson Bottom and Removed when ESP is Serviced





Total Pazflor

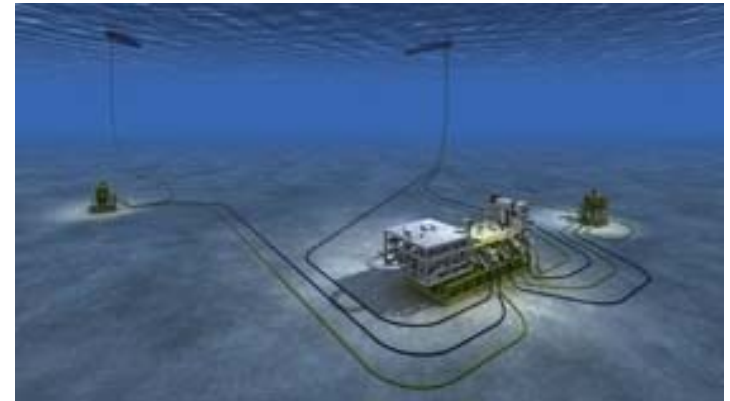
- Vertical Gas-Liquid Separation
- Purpose is to reduce gas volume fraction to enable multiple pump use
- Vessel design including curved lower section to prevent sand accumulation
- A sand handling system including sand flushing is installed as a back-up solution to remove sand build-up





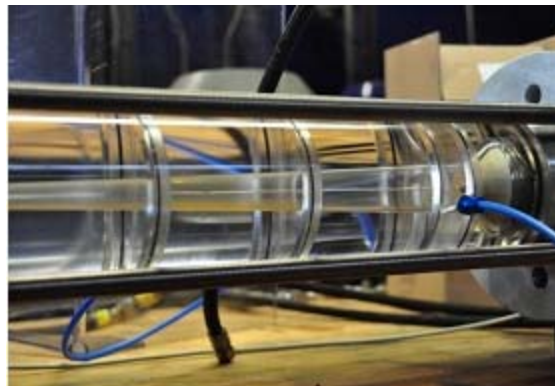
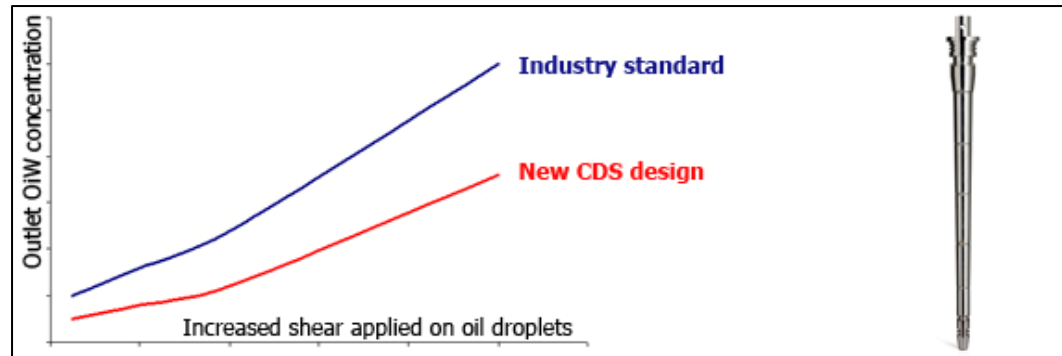
Petrobras Marlim

- The water is separated from the well-stream and re-injected back into the reservoir for pressure maintenance
- Subsea Separation System
 - PipeSeparator concept for the separation of the water from the well stream
 - Water treatment system using InLine HydroCyclones.
 - Sand handling system
 - An InLine DeSander at the inlet of the separation system
 - A dual redundant Sand Jetting System in the outlet section of the PipeSeparator,
 - An InLine DeSander for removal of the particles in the water stream from the separator to protect the re-injection well and reservoir.
 - The separated sand is routed with the oil up to the topside facility.





Petrobras Marlim – Subsea Separation System Components



Inline HydroCyclone



Inline Desander



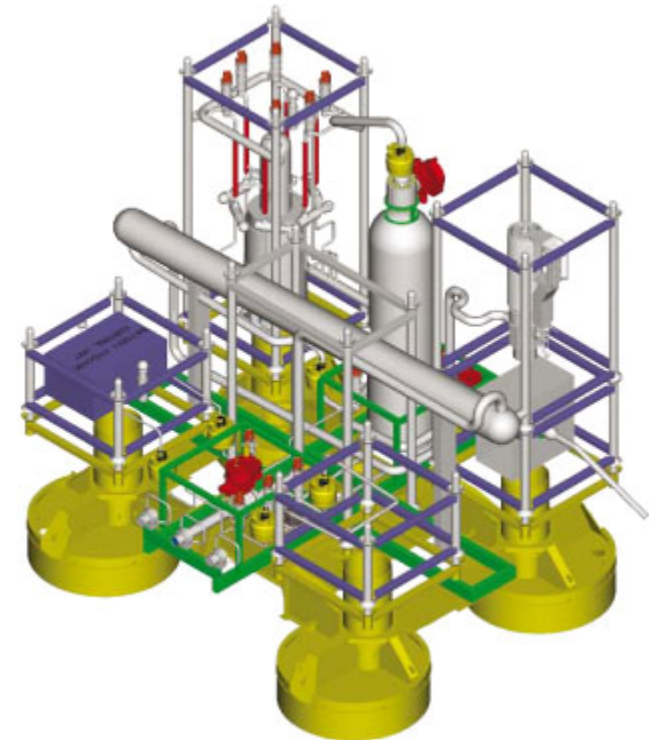
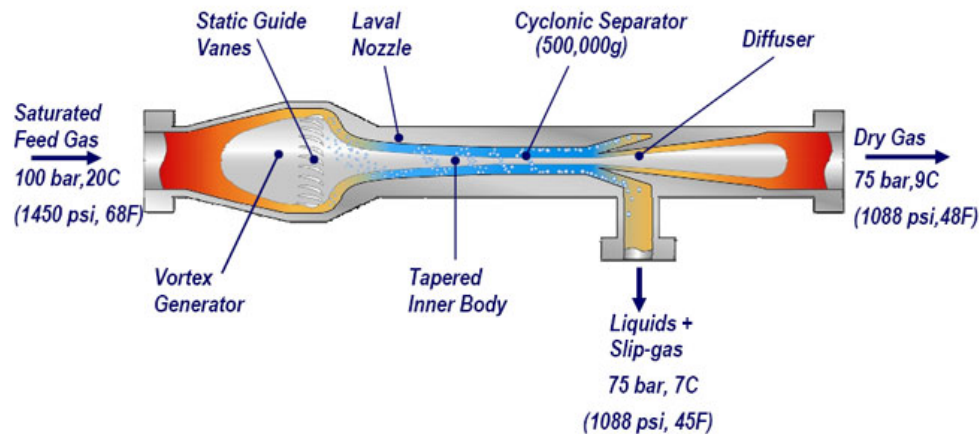
Petrobras Congro, Malhado & Corvina

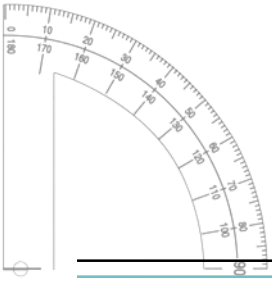
- VASPS (vertical annular separation and pumping system) with Horizontal ESP (electrical submersible pump)
- According FMC's pressure release, the control system incorporates an innovative subsea robotics technology, designed by Schilling Robotics, to operate the manifold and separation station valves.



Petrobras Canapu

- Twister BV. In-line supersonic
- Process steps in a compact, tubular device
 - Expansion
 - Cyclonic gas/liquid separation
 - Re-compression
- Dehydrate gas and removes heavy hydrocarbon components
- Technology is not applicable to oil-water separation





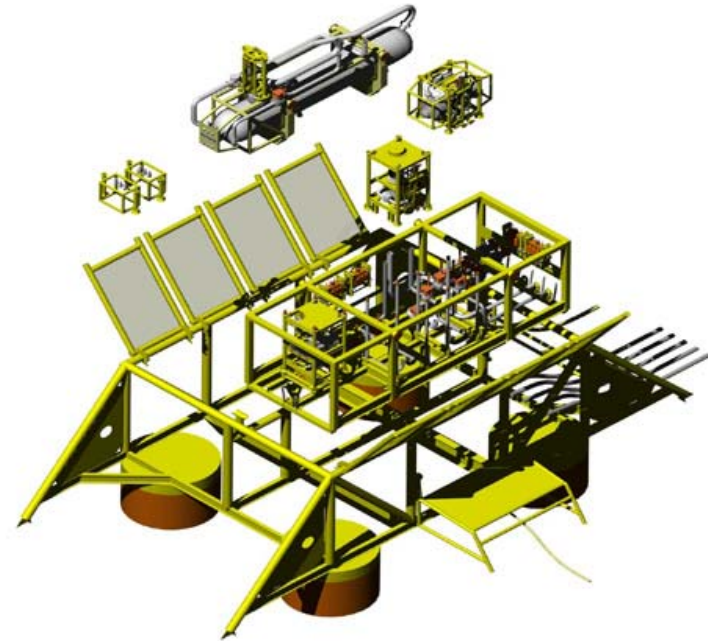
Subsea Technology Under Development

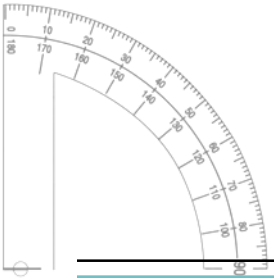
- **Aker Solutions DeepBooster with Subsea Separation**
- **Cameron Compact Separator**
- **Cameron Compact Separator with ESP**
- **FMC InLine ElectroCoalescer**
- **FMC InLine DeWaterer**
- **GE Separator with Electrostatic Coalescers**
- **Saipem COSSP (2-Phase Gas/Liquid Separation & Boosting System Concept)**
- **Saipem Subsea 3-Phase Separation Module**



Aker Solutions DeepBooster with Separation System Flexsep

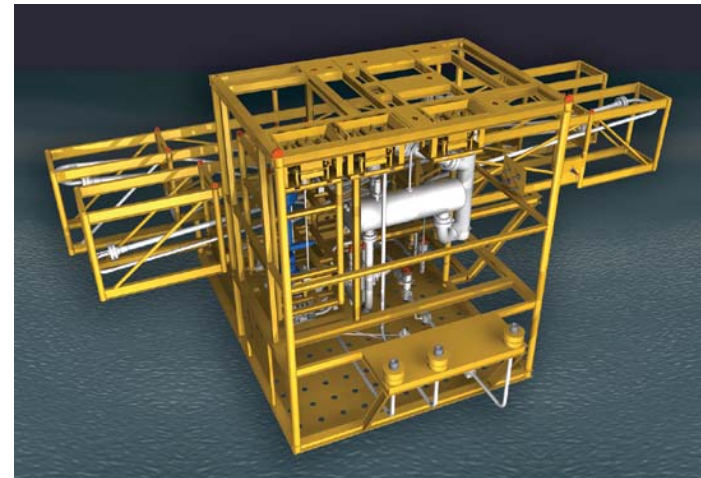
- Compact degassing and scrubbing as a first separation stage
- Compact Electrostatic Coalescer, CEC
 - Technology is qualified and has several topside applications
- Compact separator due to the CEC
- Cyclonic Separation, Multistage cyclonic separation
 - Reduces oil content in water down to 40-100 ppm.
- Liquidbooster: Multistage centrifugal pump concept





Cameron Compact Subsea Separators

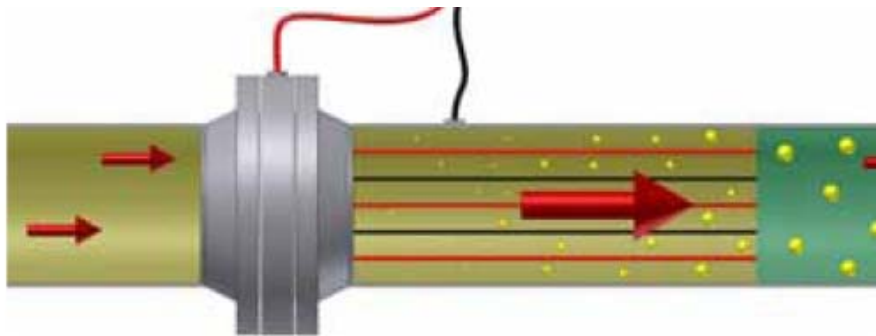
- Without ESP (electric submersible pumps)
- With ESP
- Using Electrostatic Method?





FMC InLine ElectroCoalescer

- Uses electric fields to promote water-in-oil droplet growth and emulsion breakdown to facilitate effective oil-water separation
- Designed to be fitted into pipe spool upstream of the separator
- High voltage power system

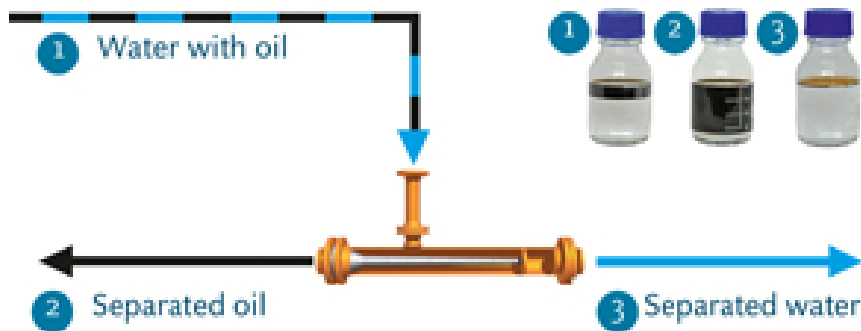




FMC InLine DeWaterer

- Axial flow cyclone design
- Specially designed swirl element - low energy loss and shear.
- An oil core is formed by the oil droplets
- The separated oil is removed through a reject (overflow) opening
- The clean water leaves the cyclone through a water outlet (underflow)

InLine DeWaterer Operating principle

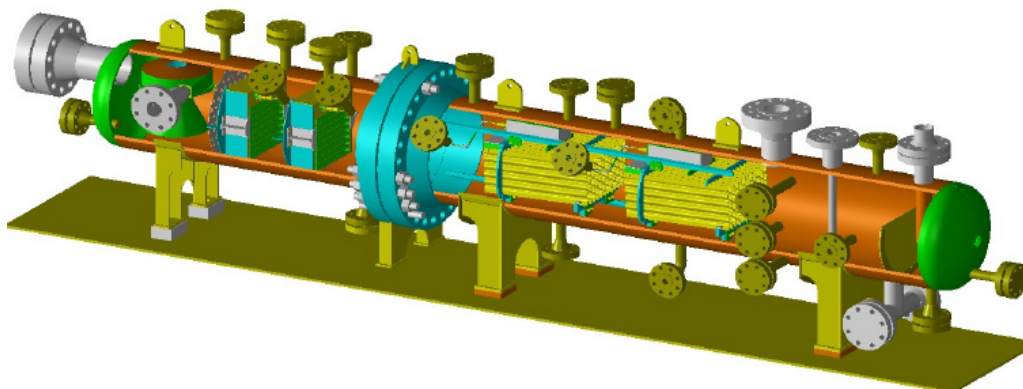


Criteria	Results
Oil in Water at inlet	1 - 50 %
Oil in Water after separation	200 - 2000 ppmv
Gas Volume Fraction at inlet	0 - 50 %
Total Flow rate at inlet	10 - 40 m ³ /h
Water removal efficiency	< 95 %
Pressure Drop reject (from inlet to oil outlet)	0.3 - 2.5 Bar
Pressure Drop underflow (from inlet to water outlet)	0.1 - 2.0 Bar



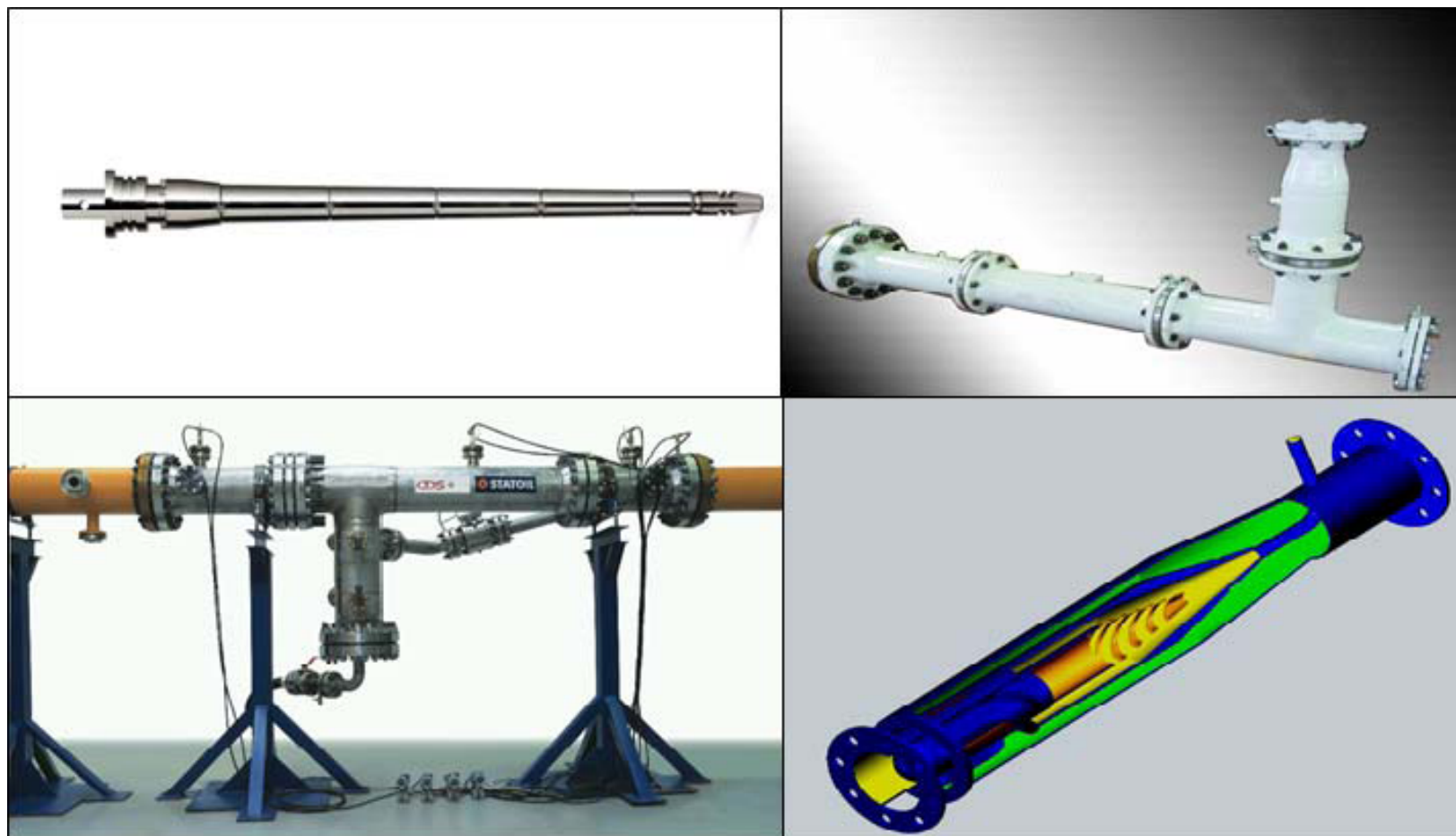
GE Nu-Proc Test Separator With Electrostatic Coalescers

- **GE**
- **DEMO 2000 – 2004**
- **Made to fit Norsk Hydro's test loop**
- **Length: 5200 mm**
- **Diameter: 630 mm**
- **Capacity: 6000 BL/day (as test loop)**
- **Max Pressure: 100 Bar (as test loop)**
- **Max Temp: 120 C (as test loop)**
- **Dual VIECS, Dual LOWACCS**

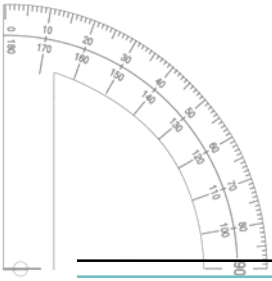




Sand Handling - Hydrocyclones



Inline Cyclonic Separation Equipment - Clockwise: Liquid-Liquid Separation, Phase Splitter, De-Sander, Deliquidizer, (Courtesy of OTC 20080 paper, 2009)



Main Findings from State of Art Review

- Topsides Water Treatment Generally Requires Tertiary System
 - CPI separator (coalescing plate interceptor) / Hydrocyclones / Skimmer
 - Induced Gas Flotation
 - Filtration is sometimes required to achieve low oil and grease concentrations
 - Membrane filtration is sometimes required to remove dissolved organics
- Subsea Separation Technologies Have Focused on
 - Two-phase gas liquid separation
 - Water separation for injection use
 - Much higher oil in water content than discharge limitations
 - De-sanders and/or filters to remove suspended solids to sizes small enough for injection



Main Findings from State of Art Review

- Compact Subsea Oil/Water Separators and Desanders for Deepwater
 - Have been developed and to be installed in the near future
 - Multiple technologies in this area are under development
- Currently Subsea Oil/Water Separation Systems Do Not Meet Discharge Limitations on Oil and Grease Concentrations
 - They can achieve oil in water concentration of several hundred ppm, which is about 10 times the discharge limit.



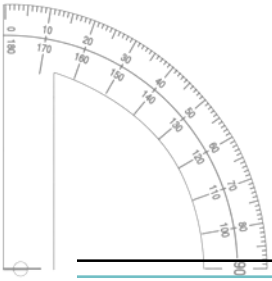
State of the Art Review – Perspectives on Seabed Discharge

- Monitoring and sensing will need to be sufficient to allow for proper control.
- System will need to include capacity for equilibration and up set overflow.
- Use of Desanders and Hydrocyclones will be important to add in concepts.
- Control System Module will be included.
- Architecture for Discharge Diffusion should be considered.
- Options should consider minimal use of moving parts.
- Process flow should consider dual trains for double 100% capacity.
- Hysys Modeling to be done on process stream



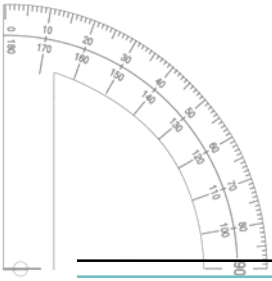
Major Technology Gaps

- Current Subsea Technology Can Not Meet Oil and Grease Limitation for Discharge
 - Installed systems
 - Planned systems
 - Technology under development
- Subsea equipment design to withstand collapse pressure
 - Large volume vessels required in current water treatment technology
- Potentially have to pump water for discharge
 - High volume
 - Large pressure differential
 - High power requirement
 - Pump technology is mature since only water is discharged
- Accurate Monitoring of Discharged Water
 - Oil and Grease
 - Sampling for measurements in laboratory of oil and grease, toxicity etc
- Handling of Start-Up and Upset Conditions
 - Storage Issues



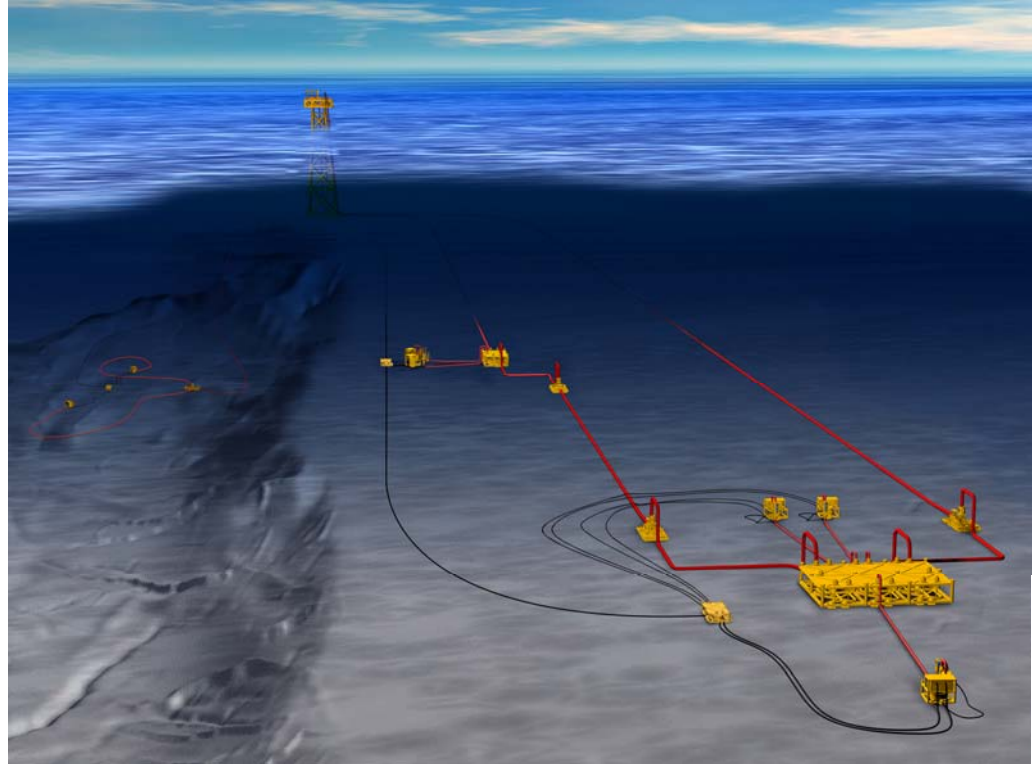
Hot Topics & Challenges to Consider

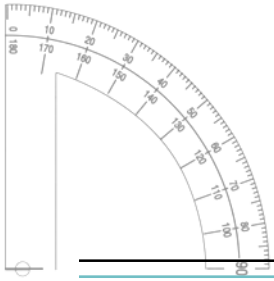
- Final lowest limits reached by Hydrocyclones and filtration
- RO (Reverse Osmosis Membranes) not successful in oil industry due to oil clogging filters
- Compact Coalescers hold promise for solution
- Discharge of sand prohibited in most areas
- Need for high reliability
- Control and Measurement Key Requirements
- Verification to Regulators



The Future of Offshore

- There is a massive 79% forecast for growth in the deepwater sector's capital expenditure to US\$ 206 billion for the 2011-2015 period compared to the previous five years.
- In addition, drilling and completion expenditure for offshore is expected to be more than double the previous five-year period, with subsea equipment expected to see 70% rises over the same period.
- Production expenditure is expected to be concentrated in West Africa, Brazil and the US Gulf of Mexico due to strong deepwater sectors.
- Seabed processing expenditure is expected to grow as the industry becomes more comfortable with the technology.





Thank You!



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