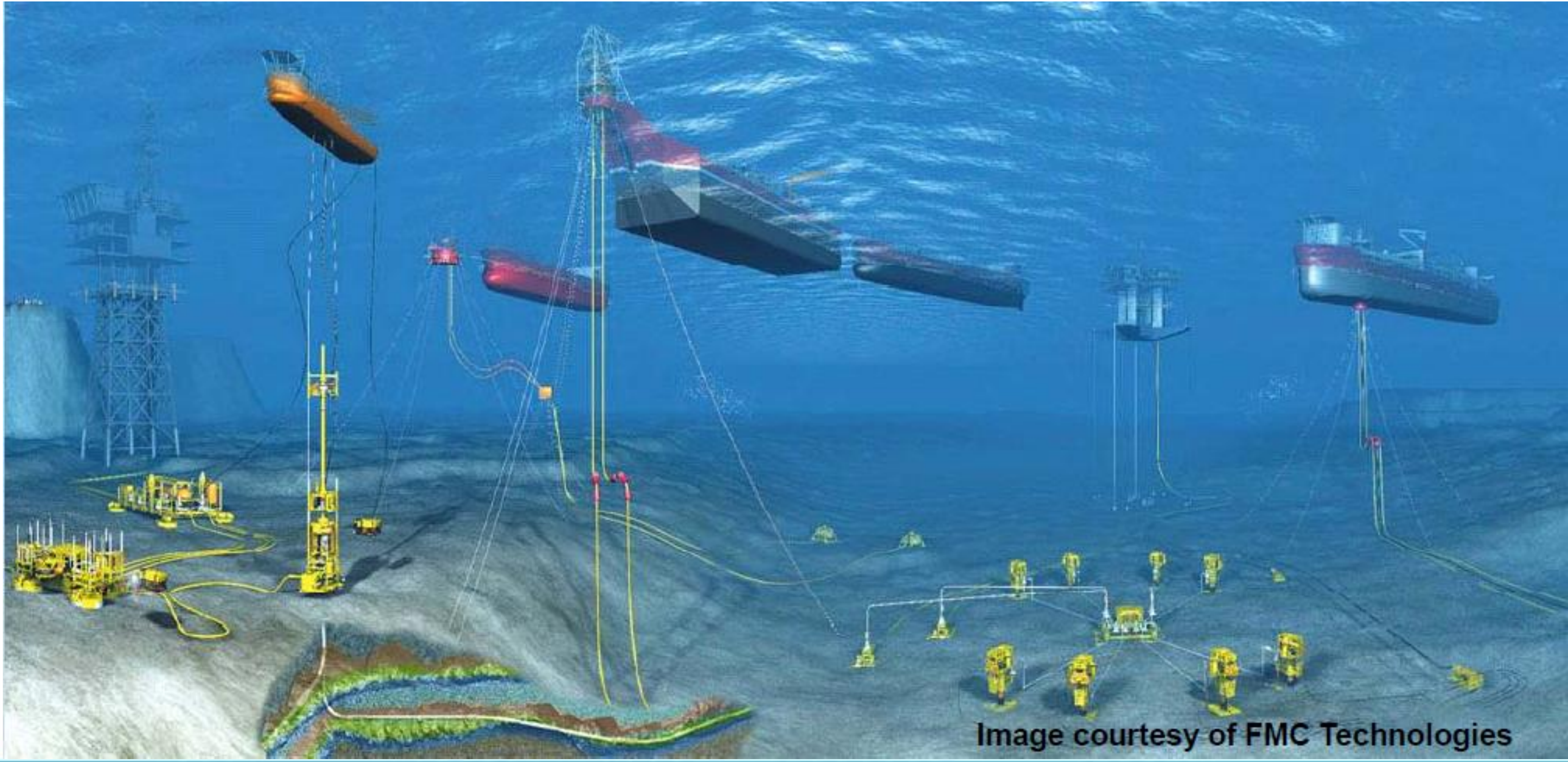


해저 공학

서유택

Lecture plan

1주	해양 유・가스전 개발 및 운전의 이해
2주	해저 생산 시스템과 해양 플랫폼의 주요 구성 요소
3주	해저 생산 시스템 설계 및 운전 특성
4주	신규 해저 생산 시스템: subsea processing
5주	해저 생산 유체의 열역학적 해석
6주	PVT software를 이용한 상평형 분석
7주	해저 파이프라인의 설계 및 설치
8주	중간고사
9주	다상 유동과 해저 파이프라인: 압력 강하 및 liquid holdup
10주	다상 유동과 해저 파이프라인: 열전달과 U-value
11주	해저 생산 시스템과 상부 공정 연결: Slug catcher design
12주	Multiphase flow simulator를 이용한 압력 강하 계산
13주	Multiphase flow simulator를 liquid holdup 계산
14주	Case study: Export compressor rating and liquid holdup calculation
15주	기말고사

Introduction

- The design and operation of offshore production facilities are becoming a critical component as the industry goes to deeper water, longer tiebacks, higher temperature and pressure reservoir.

- Safety and Environment considerations override all other items and should be considered in all design aspects.

- The design of the flow system and the operational procedures should maximize production and minimize down time and flow disruption

- Shutdown and start-up operations are the most critical in terms of implementation and personnel training

Safety and Environment

Piper Alpha

- On 06 July 1988, work began on one of two condensate-injection pumps, designated A and B, which were used to compress gas on the platform prior to transport of the gas to Flotta. A pressure safety valve was removed from compressor A for recalibration and re-certification and two blind flanges were fitted onto the open pipe work. The dayshift crew then finished for the day.

- During the evening of 06 July, pump B tripped and the nightshift crew decided that pump A should be brought back into service. When the pump was operational, gas condensate leaked from the two blind flanges and, at around 2200 hours, the gas ignited and exploded, causing fires and damage to other areas with the further release of gas and oil. Some twenty minutes later, the Tartan gas riser failed and a second major explosion occurred followed by widespread fire. Fifty minutes later, at around 2250 hours, the MCP-01 gas riser failed resulting in a third major explosion. Further explosions then ensued, followed by the eventual structural collapse of a significant proportion of the installation.

- **167 men died on the platform. 59 men survived – most of them badly burned.**

Thunder hose PDQ

- *Thunder Horse PDQ* was evacuated with the approach of Hurricane Dennis in July 2005. After the hurricane passed, the platform fell into a 20 degree list and was in danger of foundering.

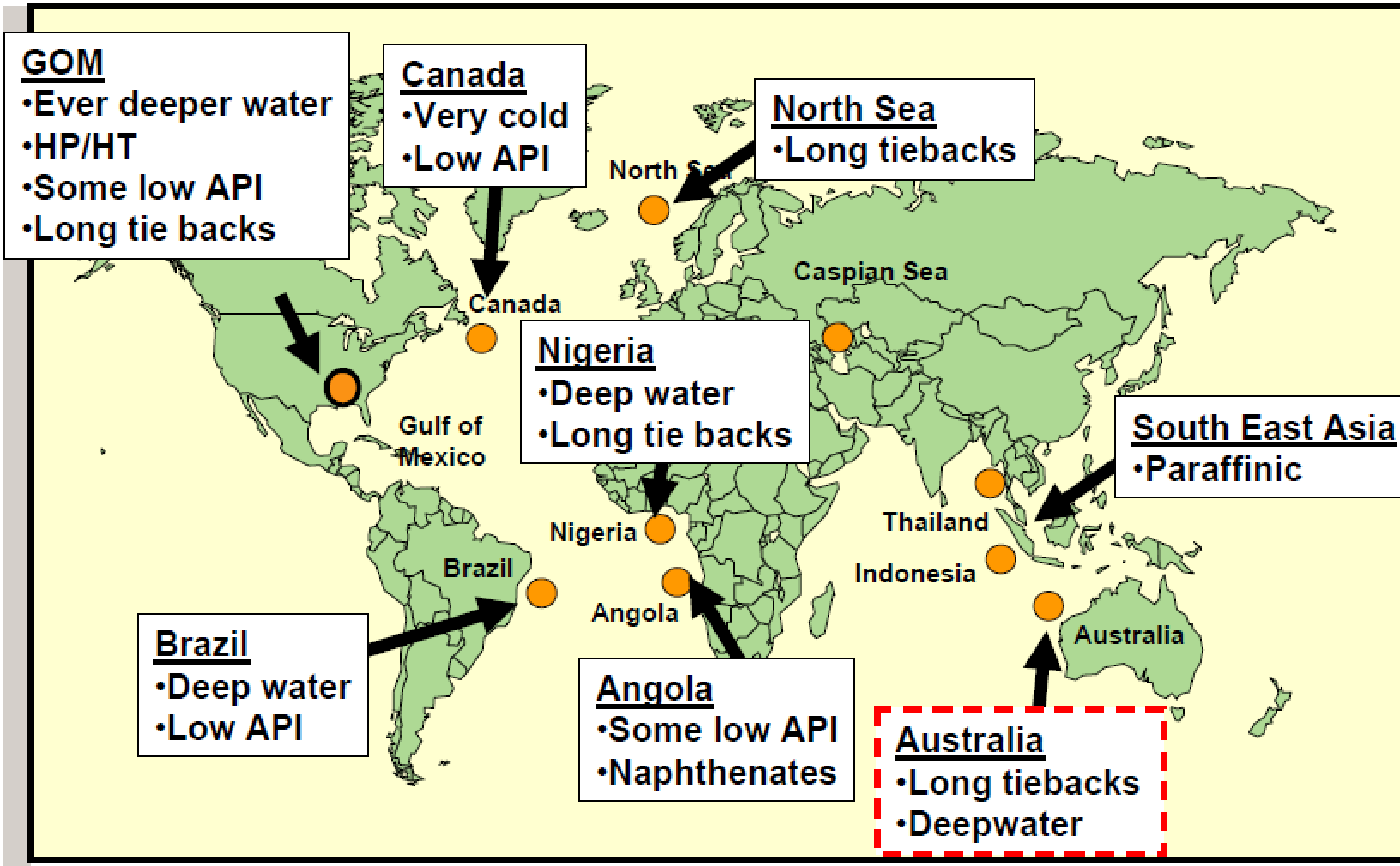
- The platform was designed for a 100-year event, and inspection teams found no hull damage and no leaks through its hull. Rather, an incorrectly plumbed 6-inch length of pipe allowed water to flow freely among several ballast tanks that set forth a chain of events causing the platform to tip into the water.

- The platform was fully righted about a week after *Dennis*, delaying commercial production initially scheduled for late 2005. During repairs, it was discovered that the underwater manifold was severely cracked due to poorly welded pipes. An engineering consultant said that the cracked manifold could have caused a catastrophic oil spill.

- The platform took a nearly-direct hit six weeks later from Hurricane Katrina, but was undamaged.

BP Thunder Horse Platform

Emerging issues for offshore fields



Four major changes

1993

- Deepwater = 600 m
  : 3 companies, few wells
- Hydrate/Wax apprehension
- Problem magnitude unknown
  : Wax or Hydrate ?
  : Time scale unknown
- Only steady state simulation
  : Transient was uncertain

2003

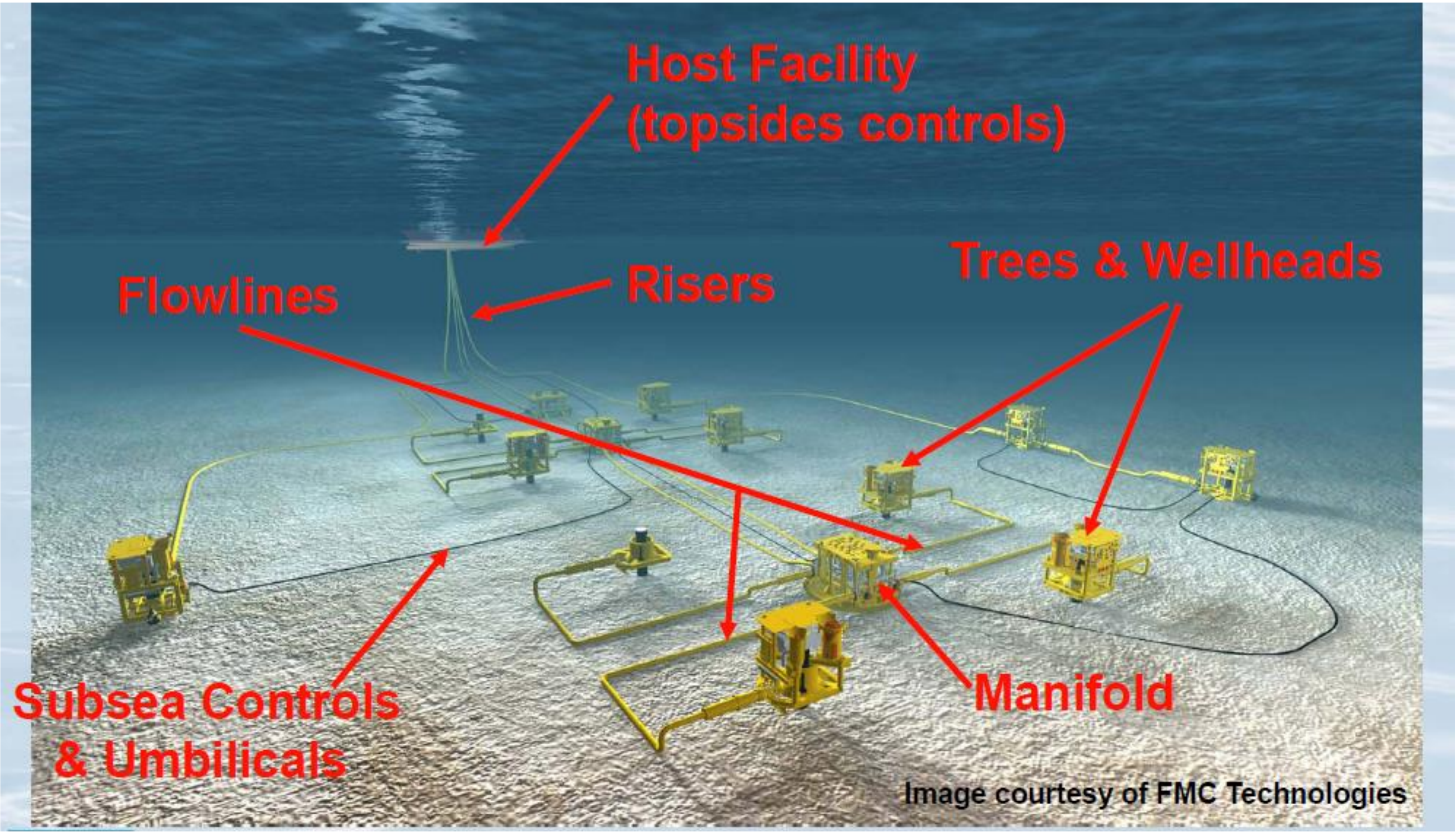
- Deepwater > 2000 m
  : Many companies & wells
- Hydrate/Wax avoidance
- Problem identified
  : Hydrate > Wax > Napthenates
  : Hydrate (min/hr) vs Wax (wks/mths)
- Steady state & Transient simulation

Flowline/Riser/Service line Design

- Reservoir fluid characteristics dominate design
  : Pressure drop and cooling causes separation
    - multiphase regime causes irregular flow and vibration
    - slugging occurs as velocity decays
  : Hydrate may form as P and T changes
  : Waxes may precipitate on cooling
  : Corrosion may occur as water condenses
  : Sand may cause plugging
  : Pigging may be required

- Emergence of “Flow Assurance” as an Engineering discipline

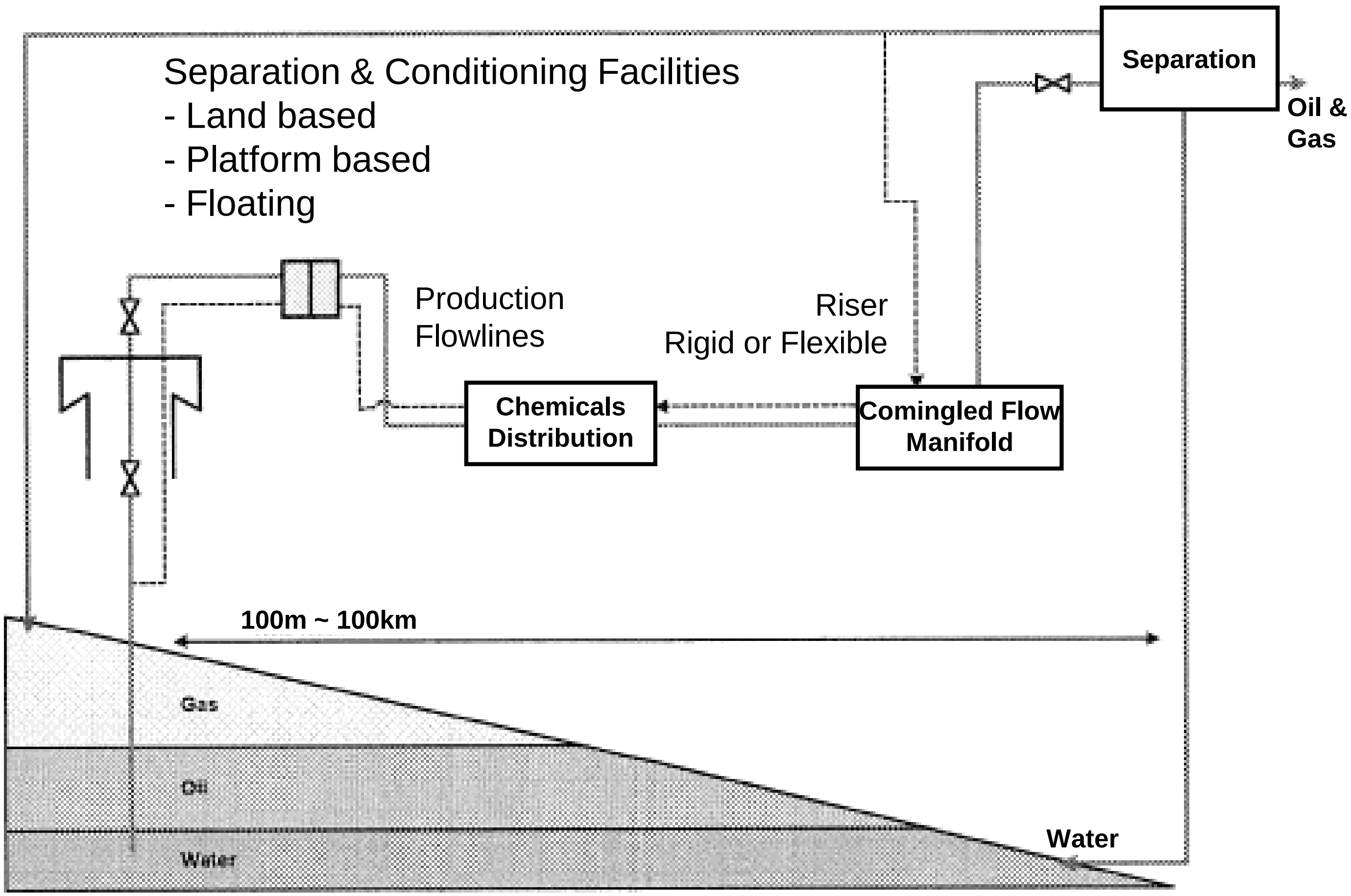
Typical Field Layout



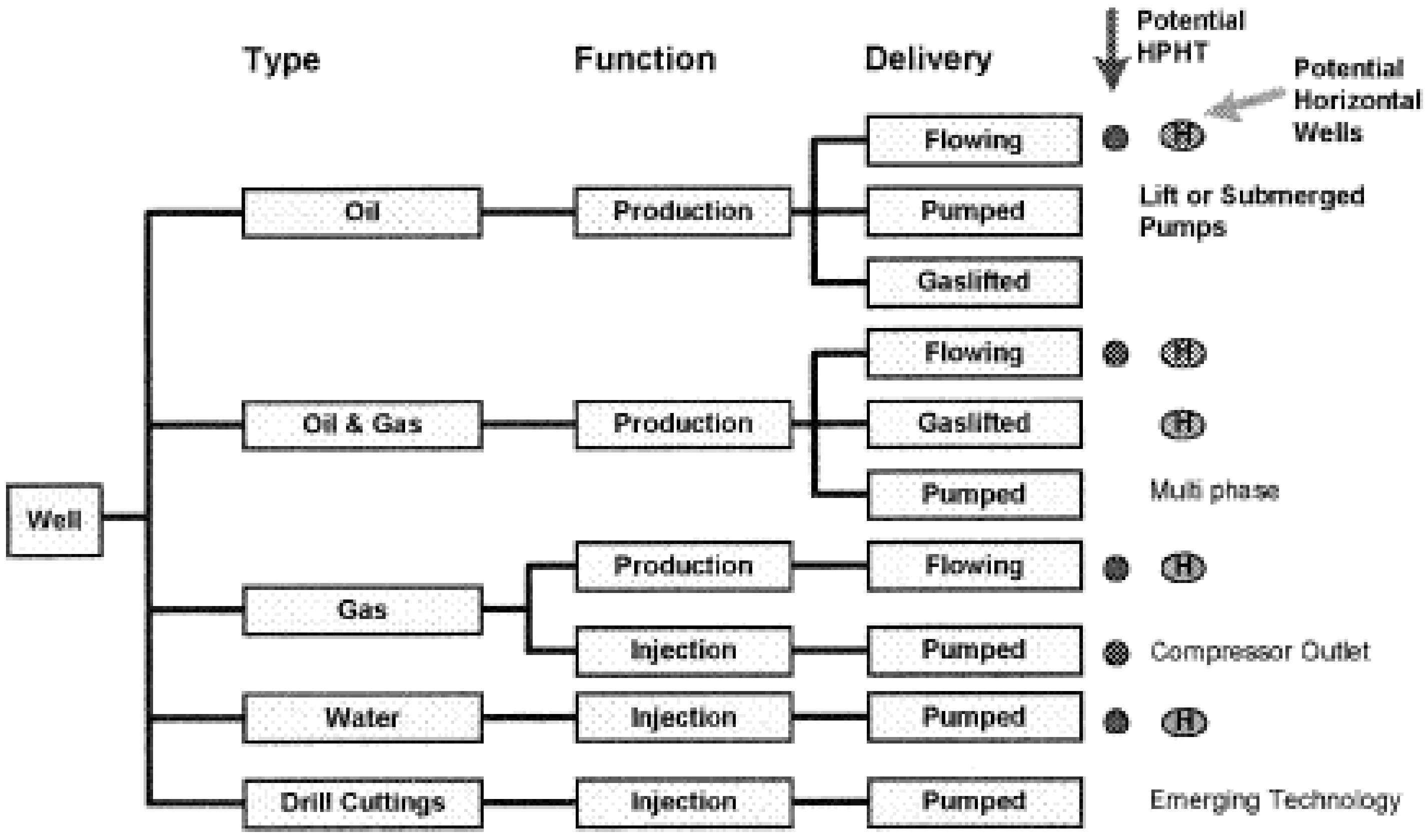
Field Development – The Building Blocks

- Reservoir Considerations
- Hydrocarbon Production Processing
- Subsea Production Options
- Health, Safety, and Environment

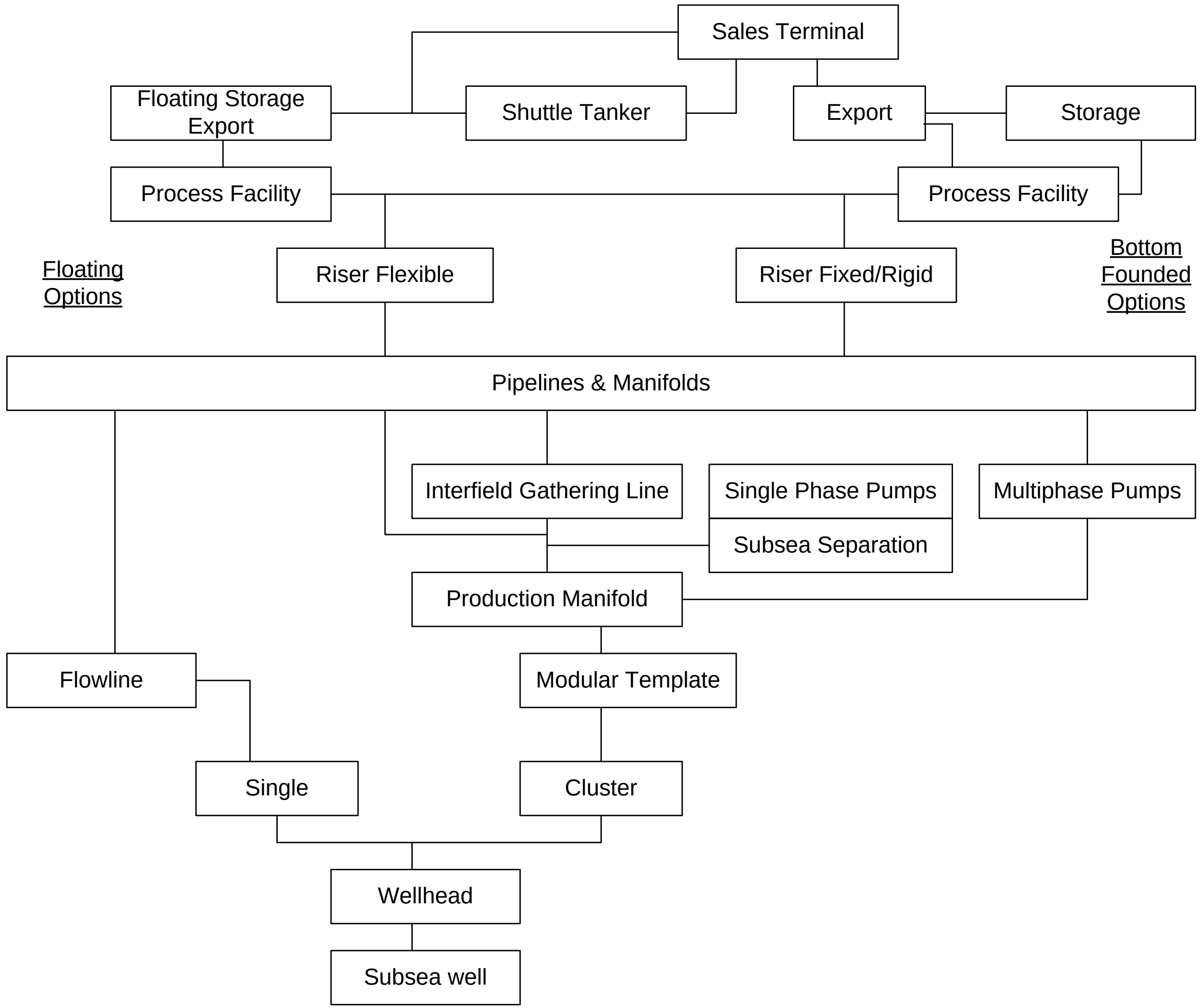
Hydrocarbon Production Processing



Subsea Production Options



Subsea Production Options



Reservoir

Fluid type	API gravity	GOR (scf/STB)	C1 mol%	Character
Black oil	< 30	< 2000	< 60	Liquid oil composed of various chemical species
Volatile oil	< 40	2000 ~ 3000	60 ~ 70	Fewer heavy molecules but more C2~C6; release of large amount of gas
Condensate	40 ~ 60	3300 ~ 50,000*	70 ~ 80	Gas at reservoir; Retrograde behavior yield light oil
Wet gas	40 ~ 60	> 50,000	80 ~ 90	Gas at reservoir; Two phase mixture in a flowline
Dry gas	NA	No liquid at STP	90 ~ 100	Primarily methane; solely gas under all conditions

* Retrograde gas can go as high as 150,000 scf/STB

Main Petroleum Components

Note:
Paraffin wax= 20<n<40

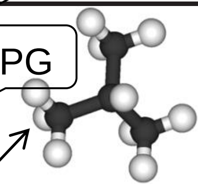
Paraffin = Alkane (C_nH_{2n+2})

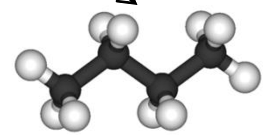
Naphthene = Cycloalkane

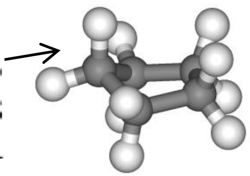
Component	Formula	Boiling Temperature at 1 atm (°C)	Density at 1 atm and 15°C (g/cm^3)
		Paraffins	
Methane	CH_4	−161.5	–
Ethane	C_2H_6	−88.3	–
Propane	C_3H_6	−42.2	–
i-Butone	C_4H_{10}	−10.2	–
n-Butane	C_4H_{10}	−0.6	—
n-Pentane	C_5H_{12}	36.2	0.626
n-Hexane	C_6H_{14}	69.0	0.659
i-Octane	C_8H_{18}	99.3	0.692
n-Decane	$C_{10}H_{22}$	174.0	0.730
Naphthenes			
Cyclopentane	C_5H_{10}	49.5	0.745
Methyl cyclo-pentane	$CH_3C_5H_{10}$	71.8	0.754
Cyclohexane	C_6H_{12}	81.4	0.779
Aromatics			
Benzene	C_6H_6	80.1	0.885
Toluene	C_7H_8	110.6	0.867
o-Xylene	C_8H_{10}	144.4	0.880
Naphthalene	$C_{10}H_8$	217.9	0.971
Others			
Nitrogen	N_2	−195.8	—
Carbon dioxide	CO_2	−78.4	—
Hydrogen sulfide	H_2S	−60.3	—

LNG

LPG







Sweet corrosion

Sour corrosion

Natural Gas Compositions

Component	Pluto (mol %)	NWS (mol %)	Gorgon (vol. %)	Jansz (vol. %)	Browse (mol %)	Ichthys (mol %)
N_2	8.1	0.8	2.0	2.3	0.5	0.4
CO_2	1.9	3.0	14.0	0.3	9.8	8.5
CH_4	83.0	85.3	76.7	91.5	79.3	70.0
C_2H_6	3.9	5.8	3.2	3.8	5.6	10.3
C_3H_8	1.4	2.2	0.9	1.1	2.1	4.2
C_4H_{10}	0.7	1.0	0.3	0.4	0.9	1.9
C_5+	1.4	1.9	0.1	0.6	1.8	4.4

Reservoir fluids

- Oil and gas reservoirs formed in porous sedimentary rock many millions of years ago.
- Some reservoirs are close to the earth’s surface whilst others are deep in the formation.
- Some have very high pressure and temperatures whilst other do not.
- The range of hydrocarbons varies, as does their concentration.

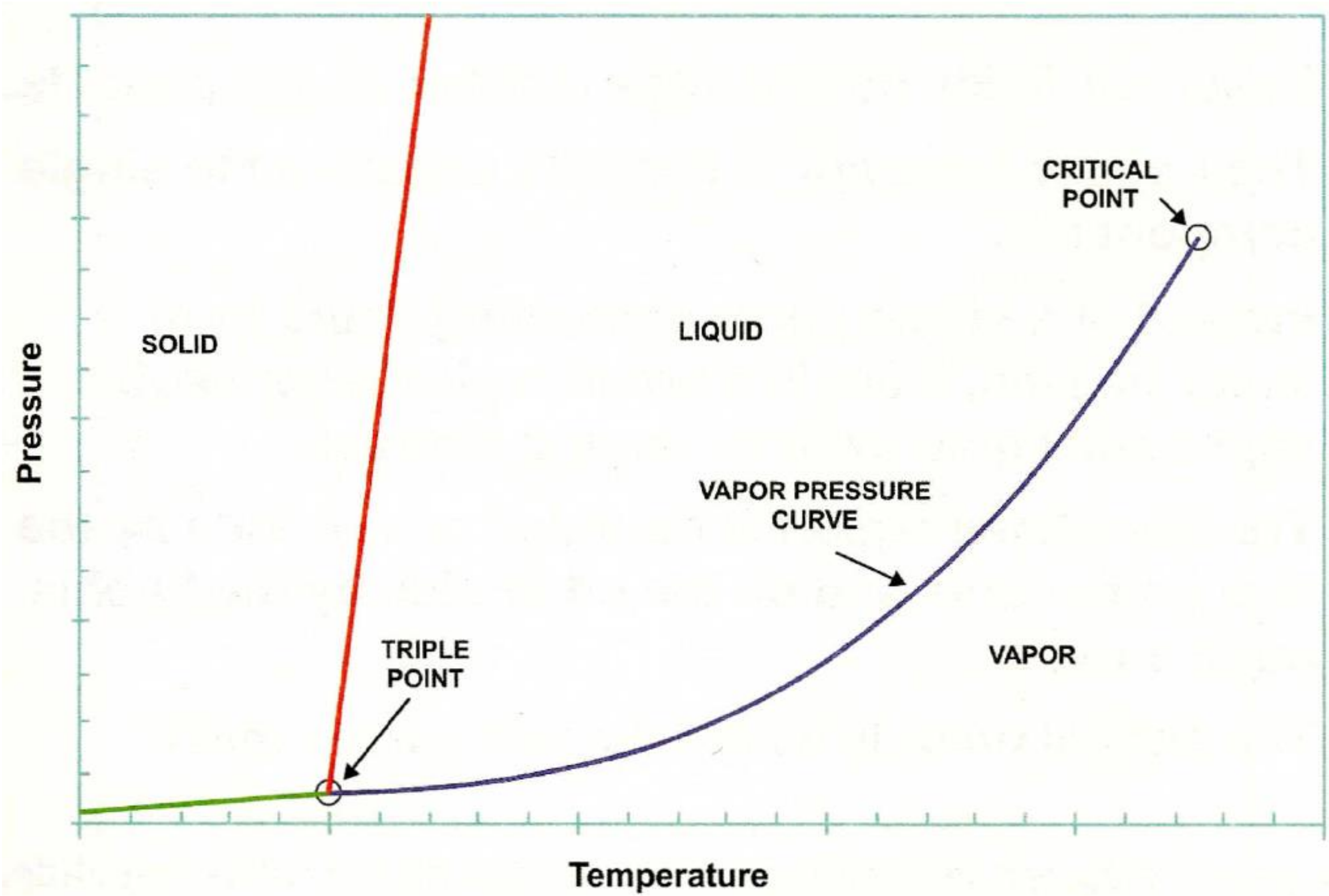
- Need to classify !!

  - Phase behavior: compositions

  - Fluid properties: API gravity

  - Reservoir flow characteristics: Productivity index

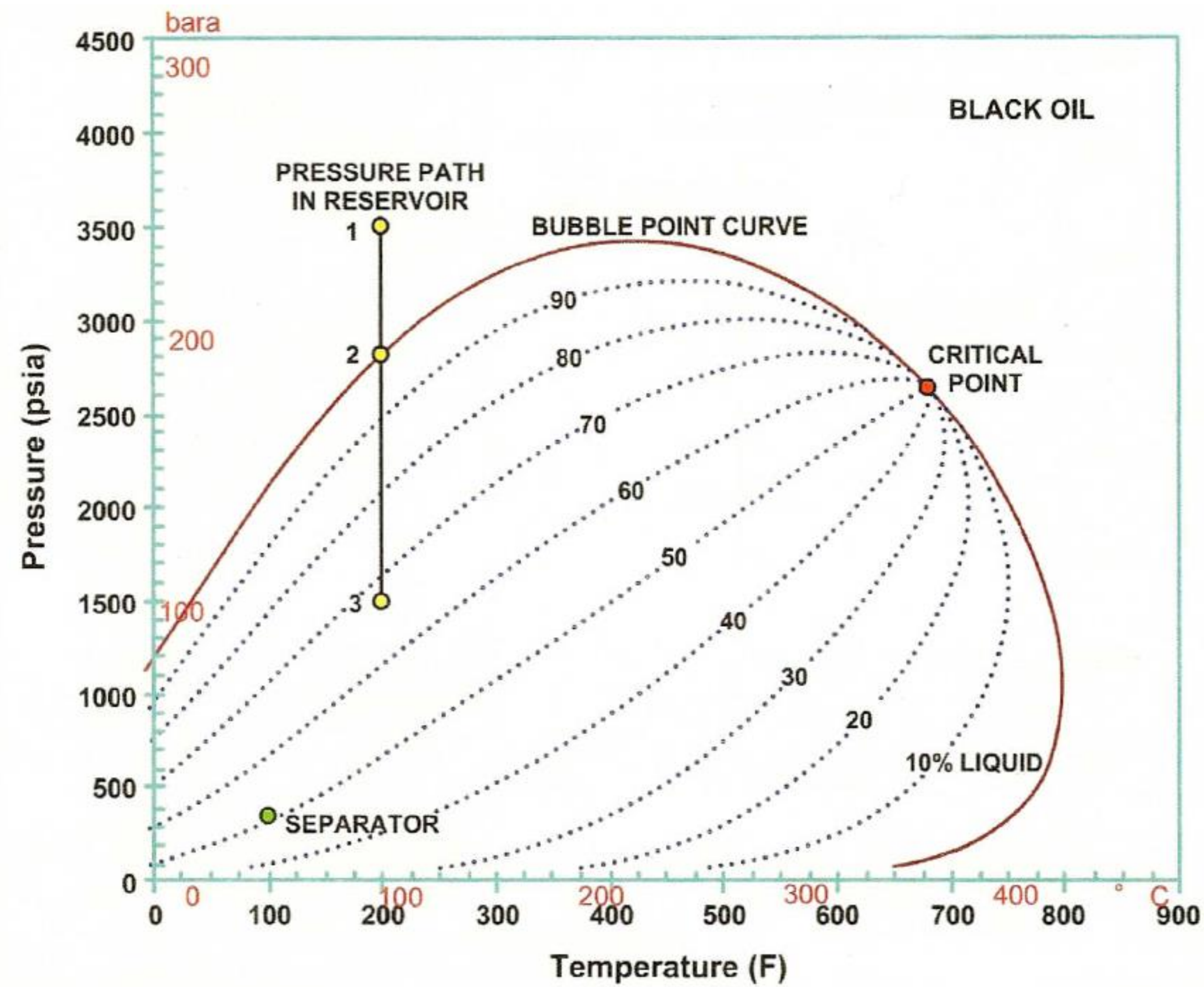
Phase behavior – Pure component



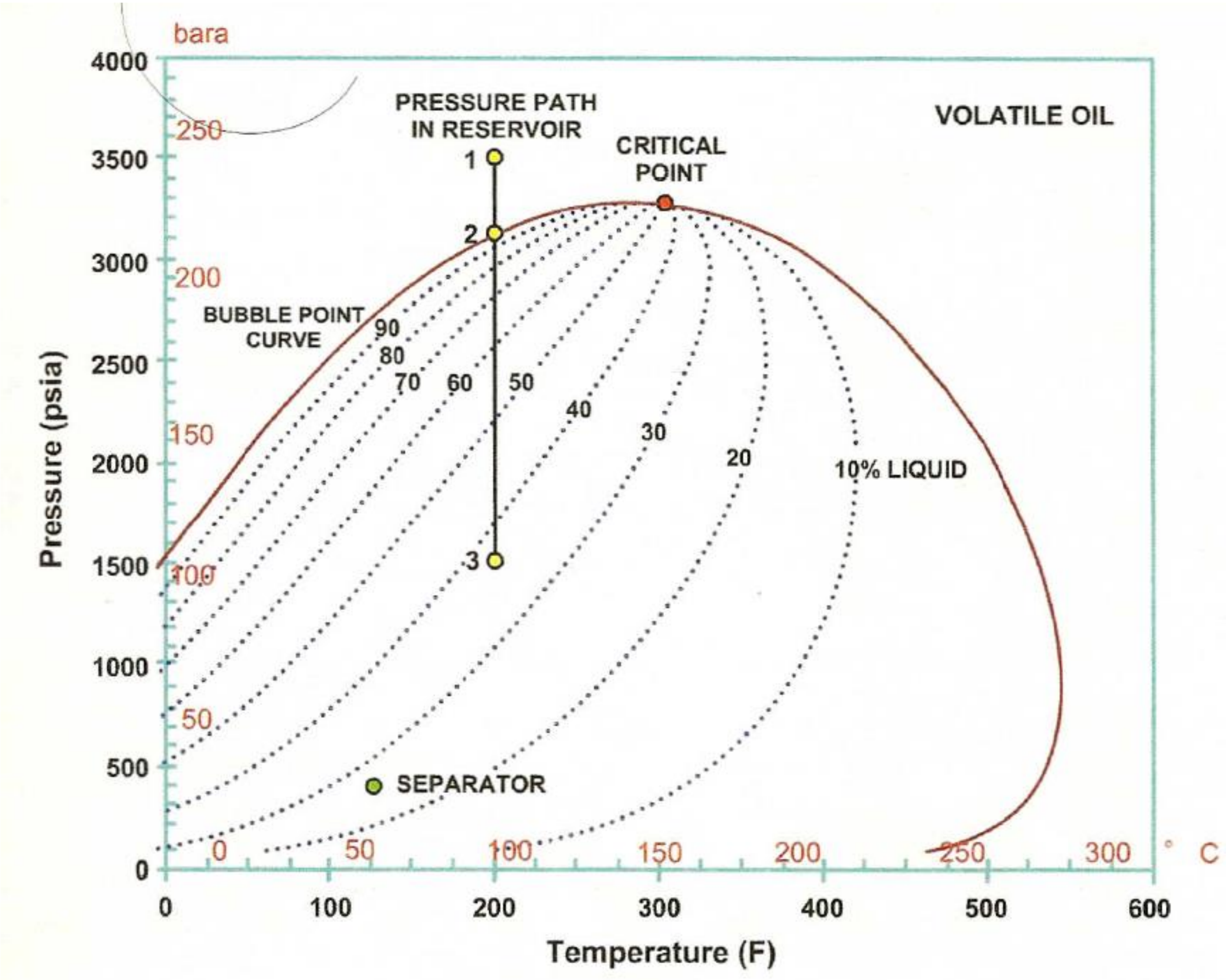
Phase behavior - Multicomponents

- Reservoir fluids have a huge number of components.
- Their phase behavior is complex compared to single components.
- Instead of a single curve separating liquid from vapor phases, there is a broad region where both vapor and liquid exist .
- The two-phase region is bounded on one side by the dew point curve and on the other side by the bubble point curve.
- The critical point is where the two curves meet

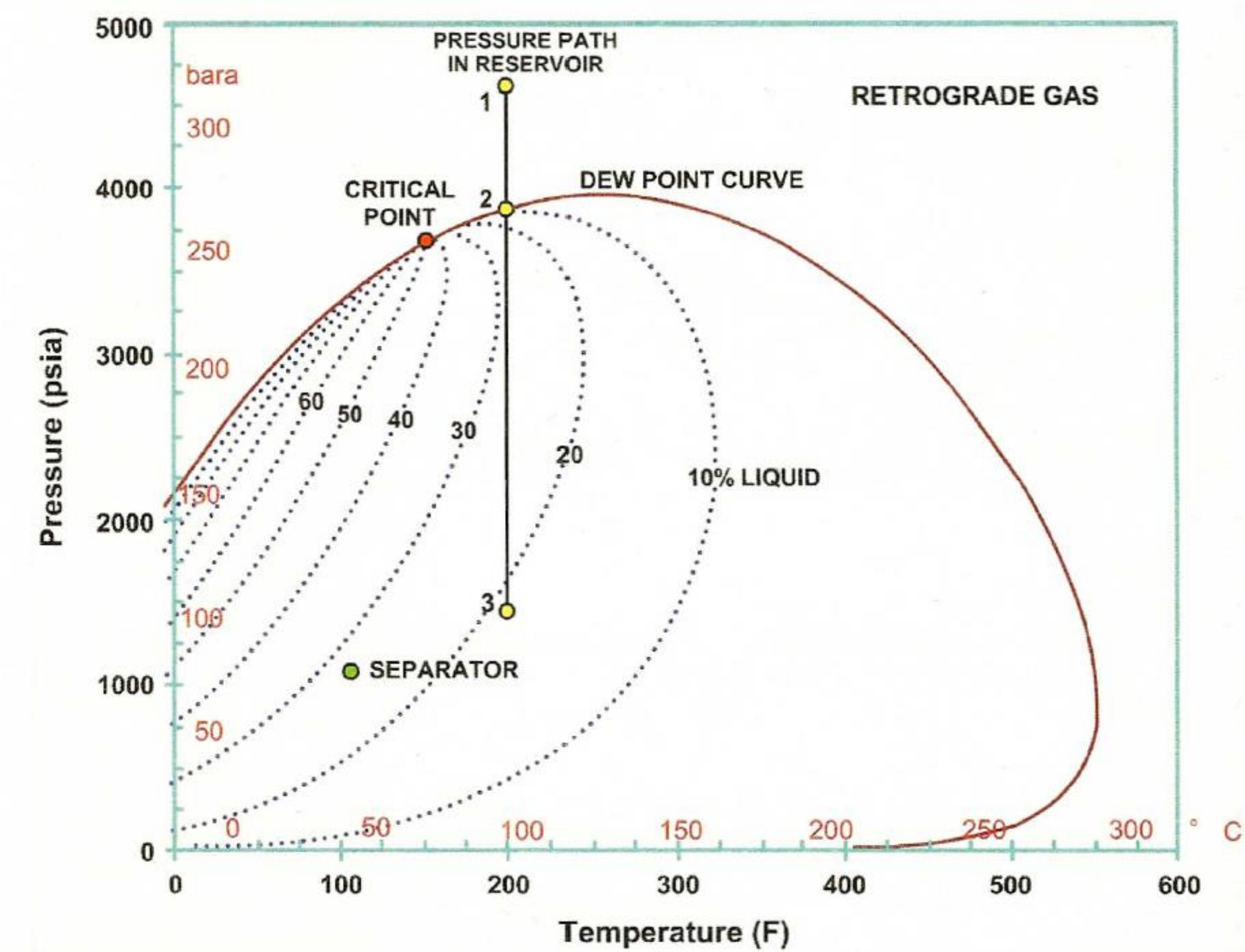
Black oil phase diagram



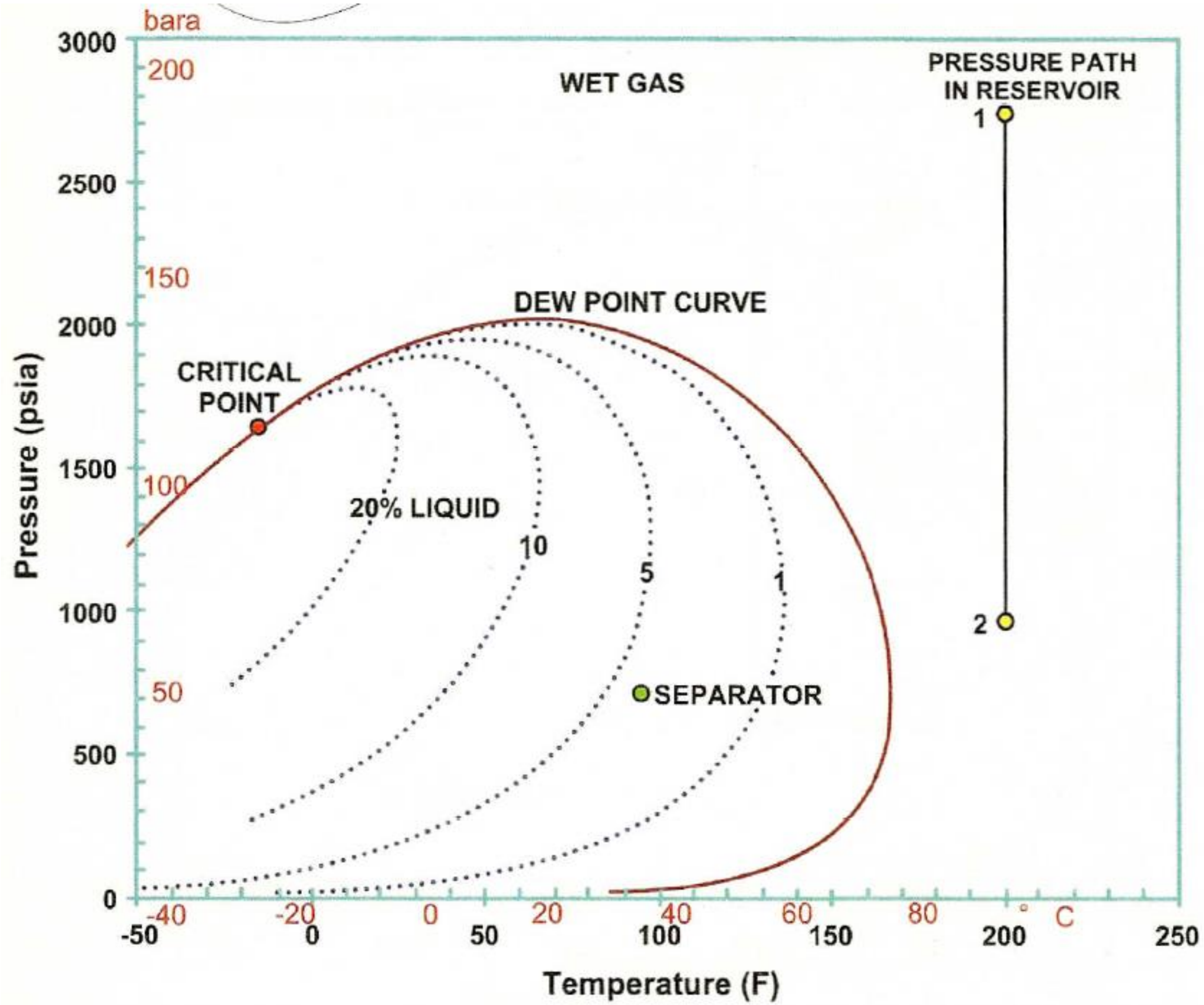
Volatile oil phase diagram



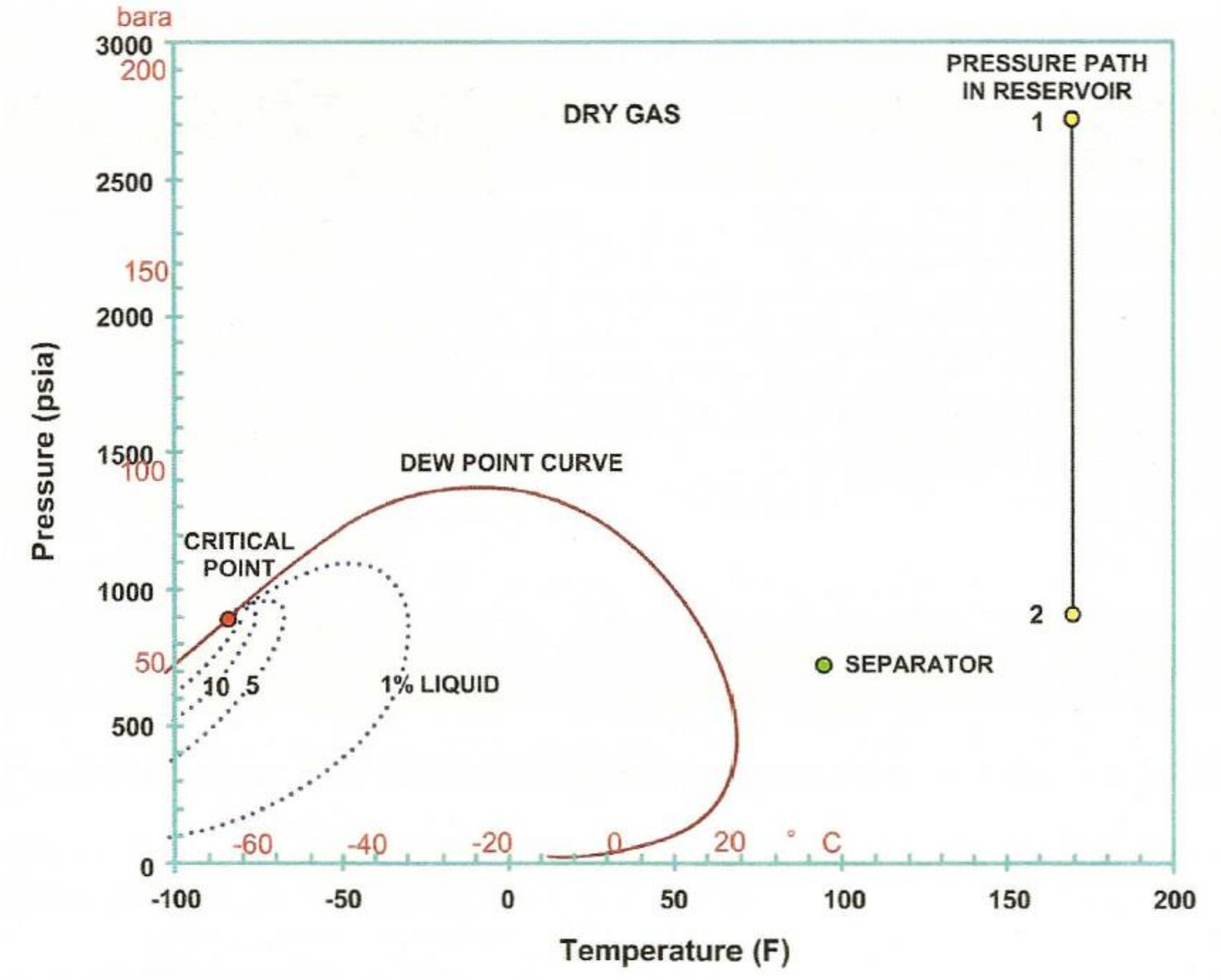
Condensate phase diagram



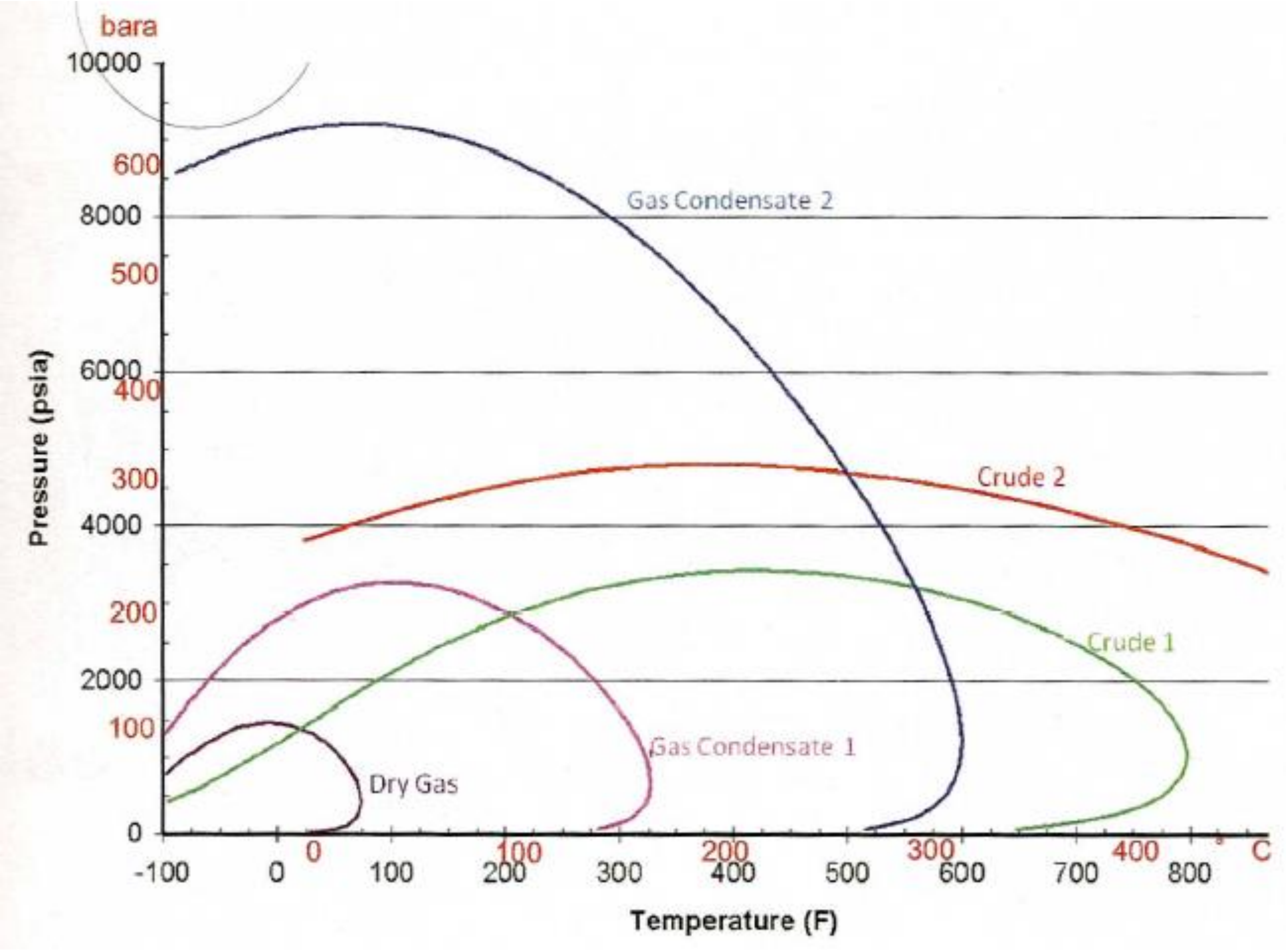
Wet gas phase diagram



Dry gas phase diagram



Two phase envelops for various fluids



Reservoir flow characteristics

- Pressure is the main driving force for a reservoir and this will decay with time.
- The initial pressure and subsequent pressure profile of the reservoir will determine how reservoir flows and how it will produce.
- Above the bubble point pressure, all the gas is in solution and will remain in solution until the bubble point pressure is reached.

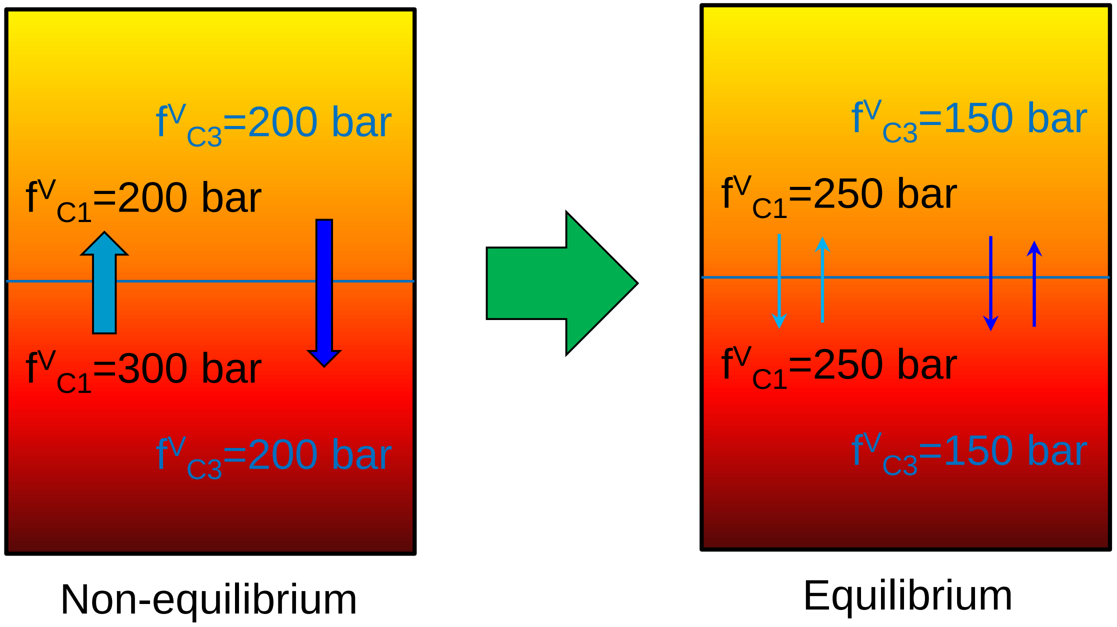
  : The reservoir produces under “solution” drive.

  (only 5~25% recovery of available reserves)
- At or below the bubble point pressure, the gas comes out of solution and forms a gas cap above the oil. The fluid is in the two-phase region and at equilibrium.

  : The reservoir produces under “gas” drive. (20~40% recover)
- Once the well bottom pressure is equal to the reservoir pressure, the reservoir pressure can no longer support production.

Phase equilibrium

- At equilibrium all components will have the same fugacity (f_i) in all phases.
- Fugacity may be understood as effective partial pressures taking into account non-ideal interactions with other molecules



Components of subsea and topside systems

Primary elements

- Tree & Wellheads
- Manifolds
- Flowlines & Risers
- Control systems
- Umbilicals
- Subsea processing
- Surface facilities

Topside controls
- Master control station
- Electrical power unit
- Hydraulic power unit
- Topside umbilical junction boxes
- Chemical injection skie

Subsea Well head

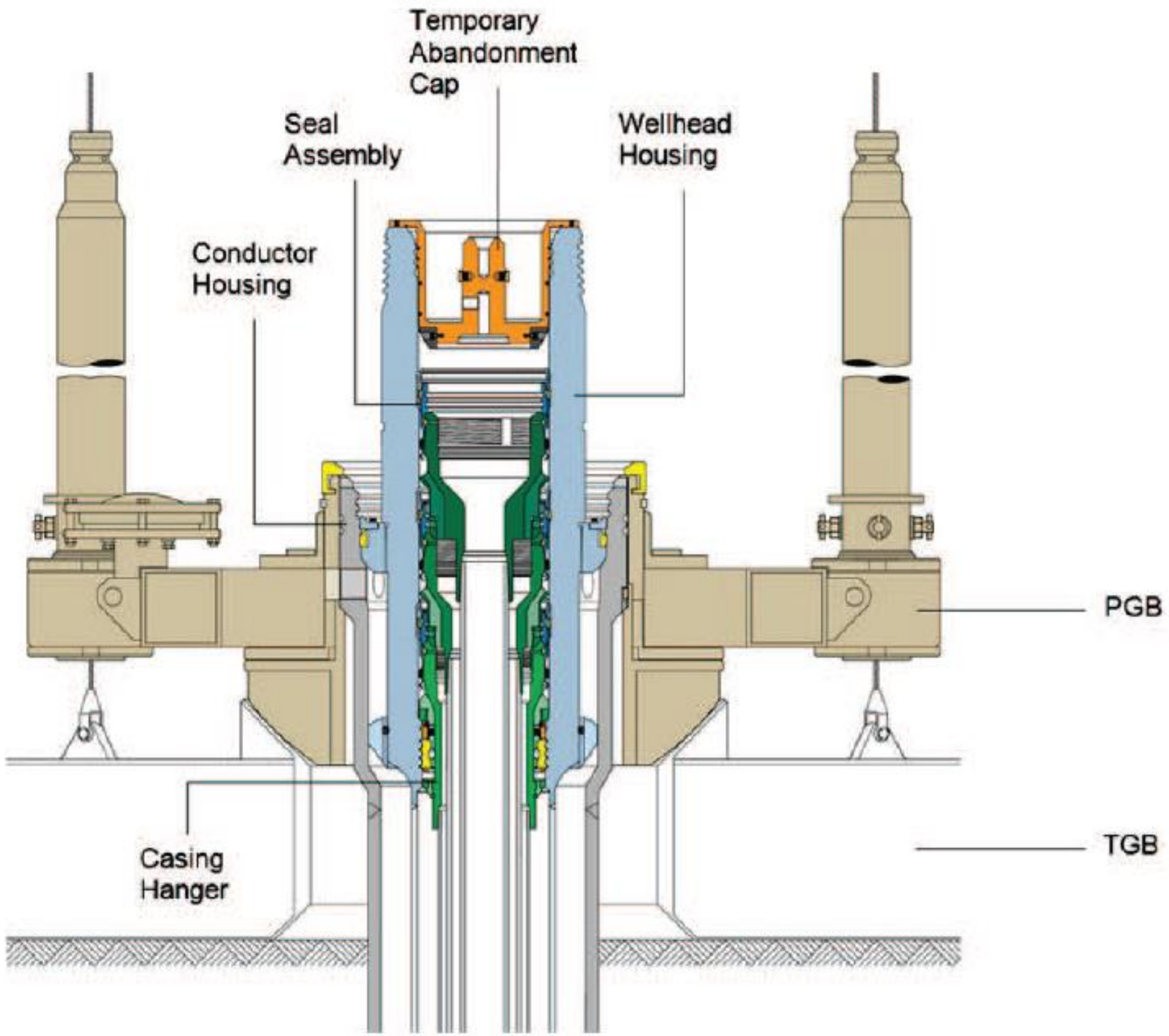
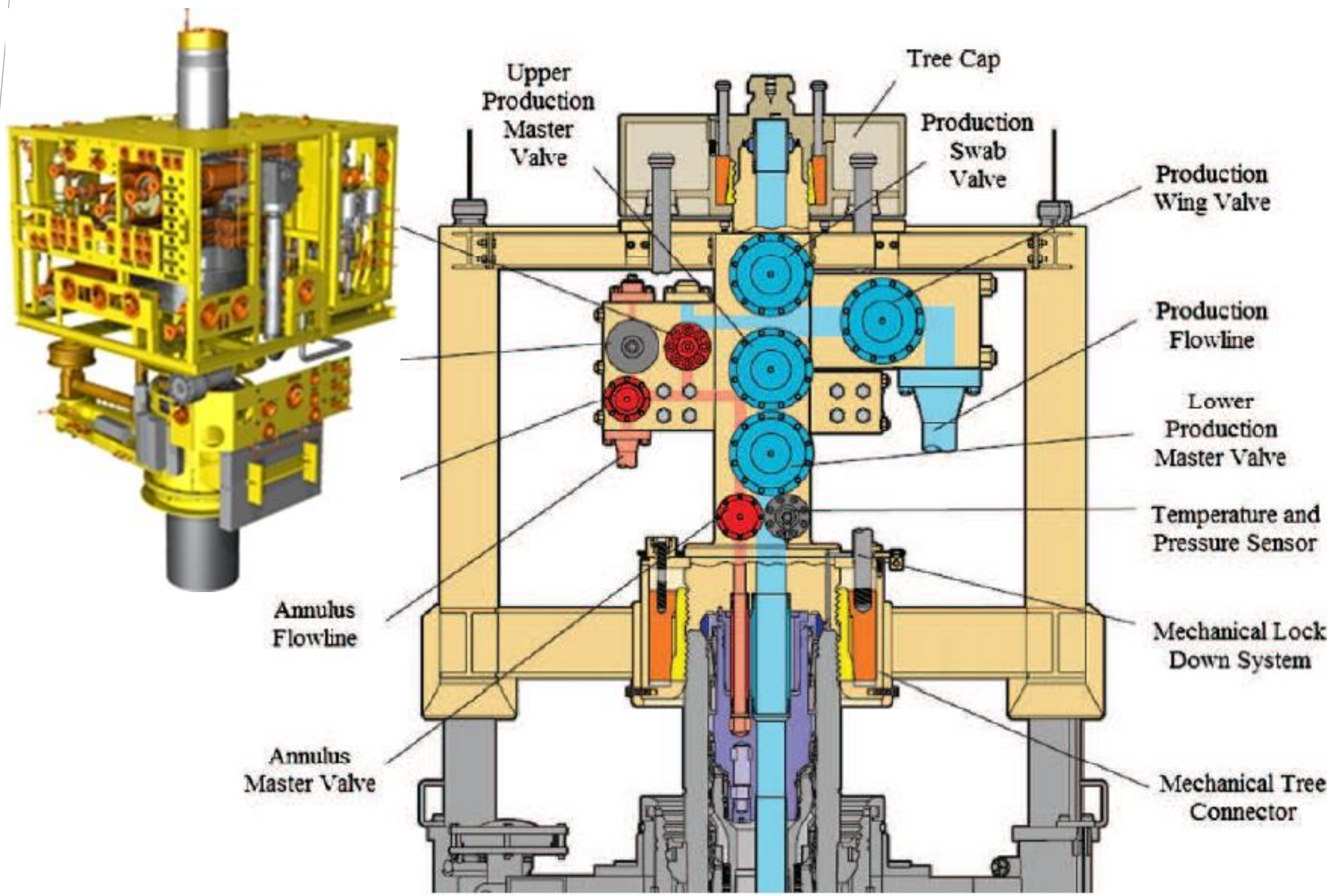
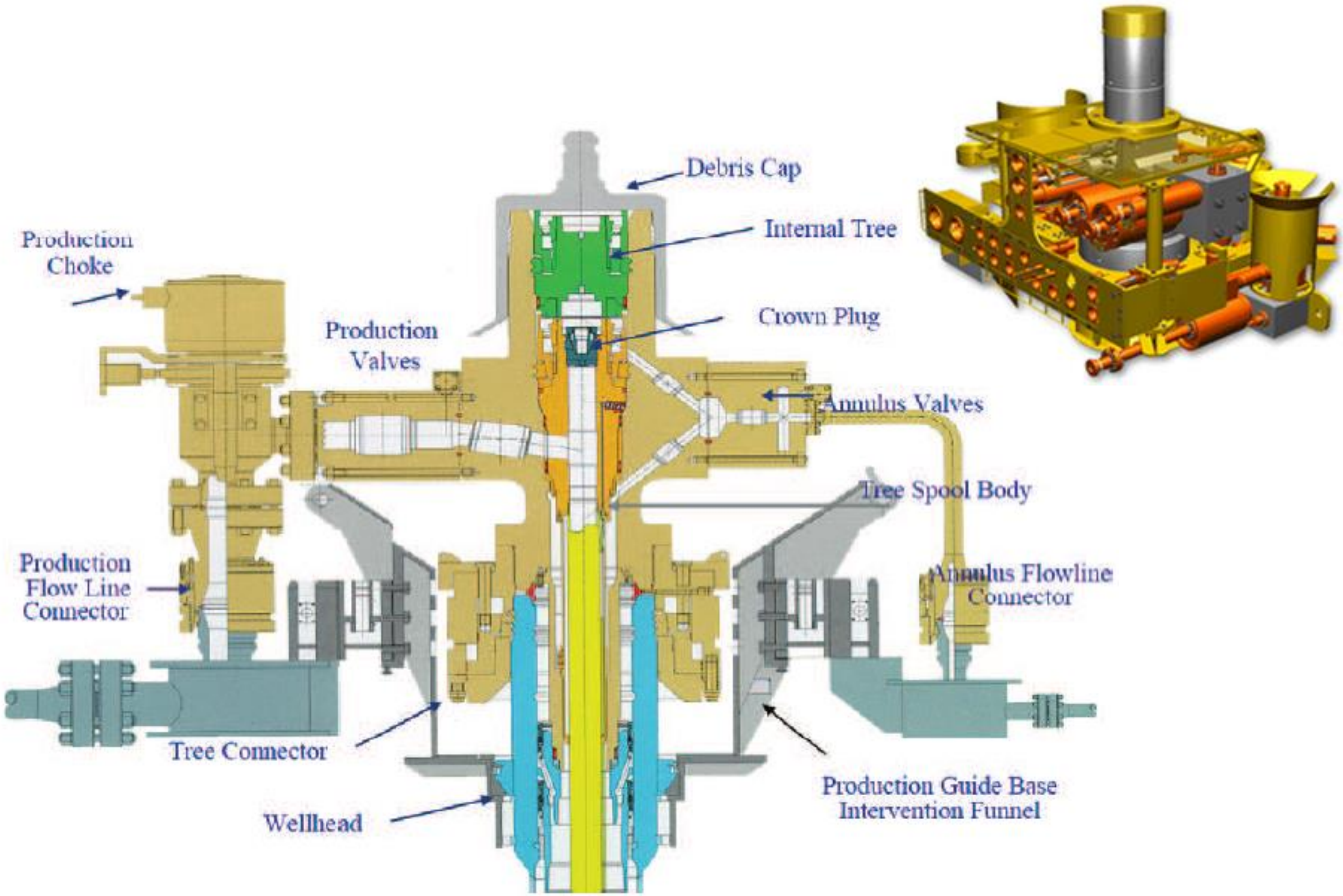


Figure 22-5 Typical $18^{3}/_{4}$-in.Subsea Wellhead System *(Courtesy of Dril-Quip)*

Subsea tree - Vertical

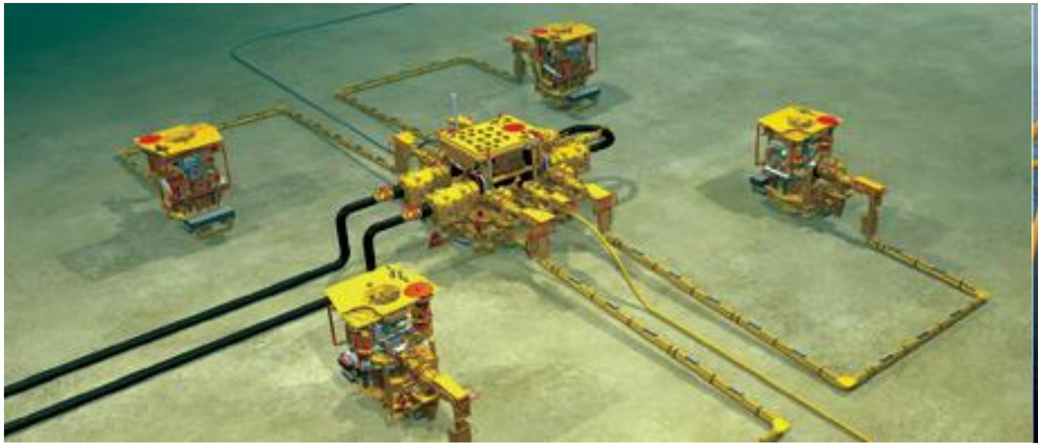


Subsea tree - Horizontal



Subsea Manifolds

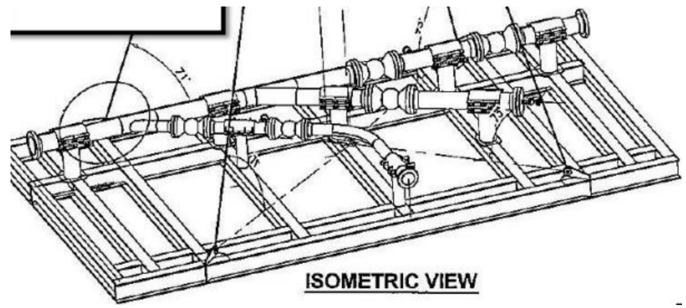
- Subsea manifolds have been used to simplify the subsea system, to minimize the use of subsea pipelines and risers, and to optimize the fluid flow of production in the system.
- The manifold is an arrangement of piping and/or valves designed to combine, distribute, control, and often monitor fluid flow.
- Subsea manifolds are installed on the seabed within an array of wells to gather produced fluids or to inject water or gas into wells.



PLEM/PLET

- PLEM (Pipeline End Manifold)

  : Used to comingle 2 or more pipelines together and eliminate the need for additional risers

- PLET (Pipeline End Termination)

  : Used to link manifold to the production pipeline


Flowline

- Transport reservoir fluid to processing facilities
- Pipelines

  : horizontal transfer from wellhead

  : these may be very long

  : may be rigid or flexible pipe

  : commonly called flowlines

Concrete coated pipeline

Riser

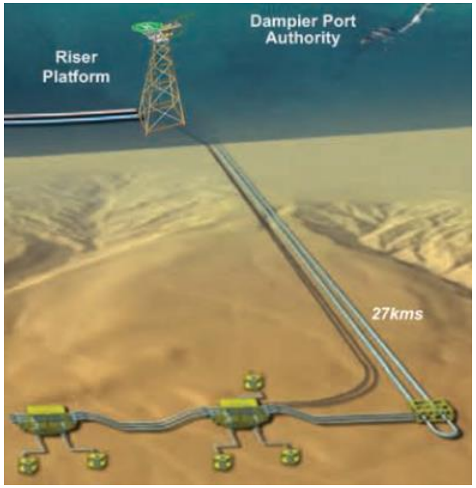
- Vertical transfer to above surface processing facilities
- Either Rigid or Flexible
- Rigid risers normally for fixed platforms

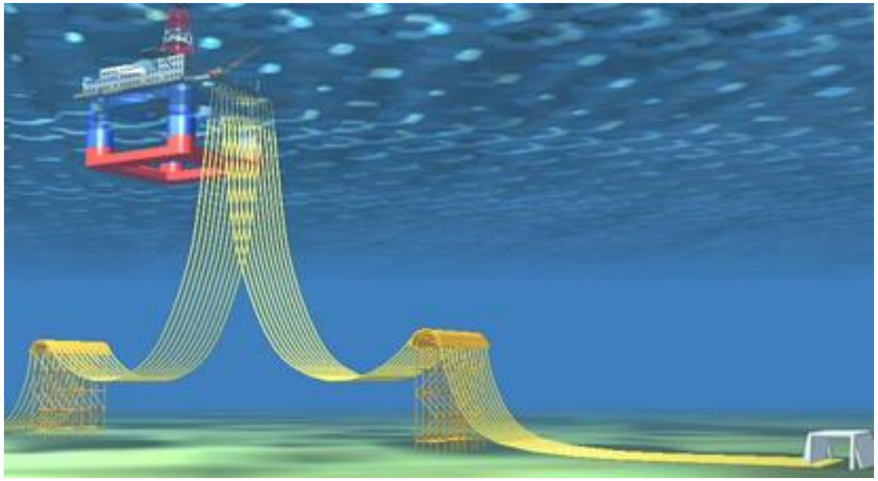
  : pre-installed inside jacket frame

  : cost effective and added riser protection
- Flexible risers mainly for floating production system

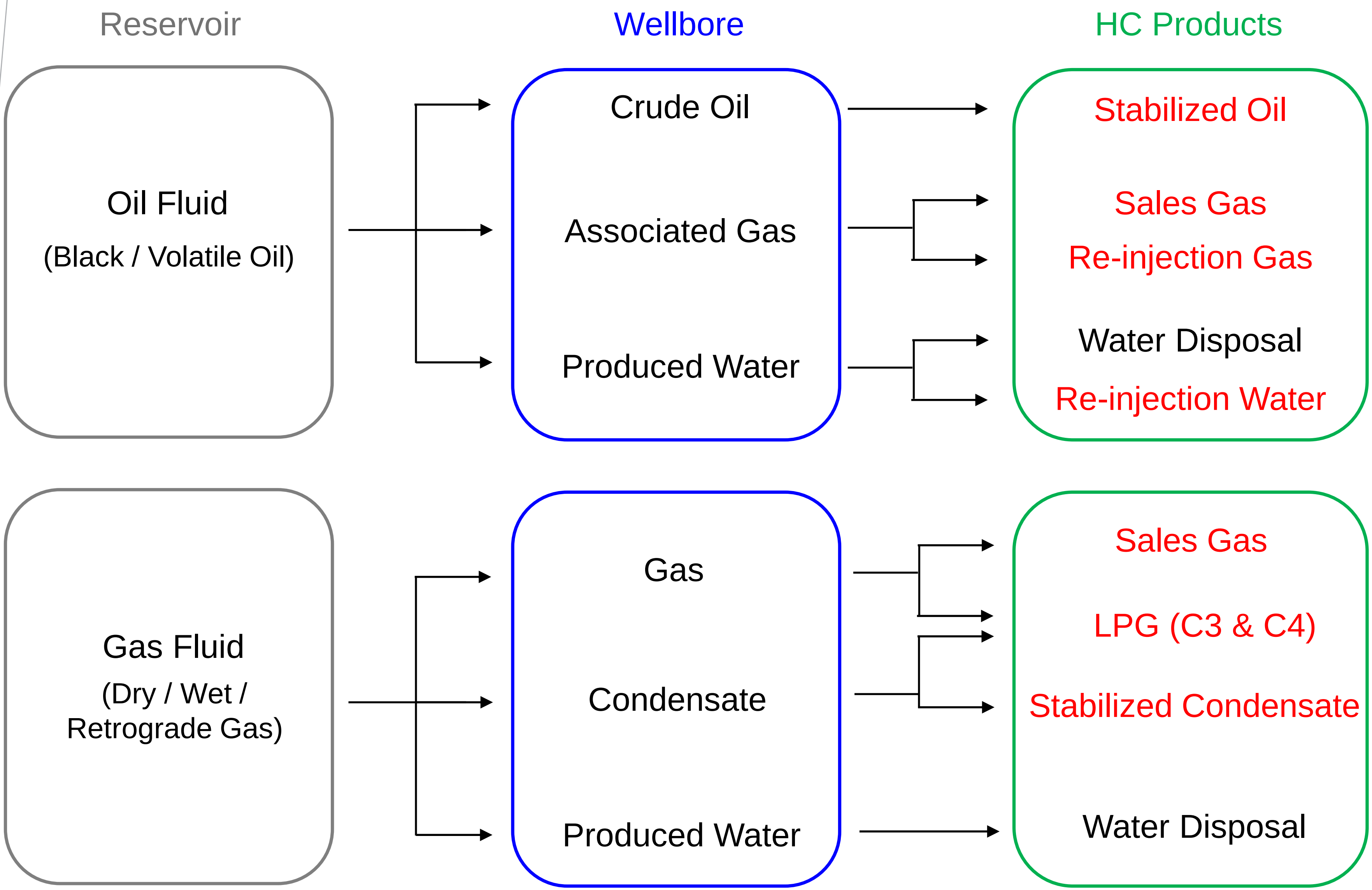
  : Flexibility and reliability

  : Easy and rapid installation





Value chain from reservoir

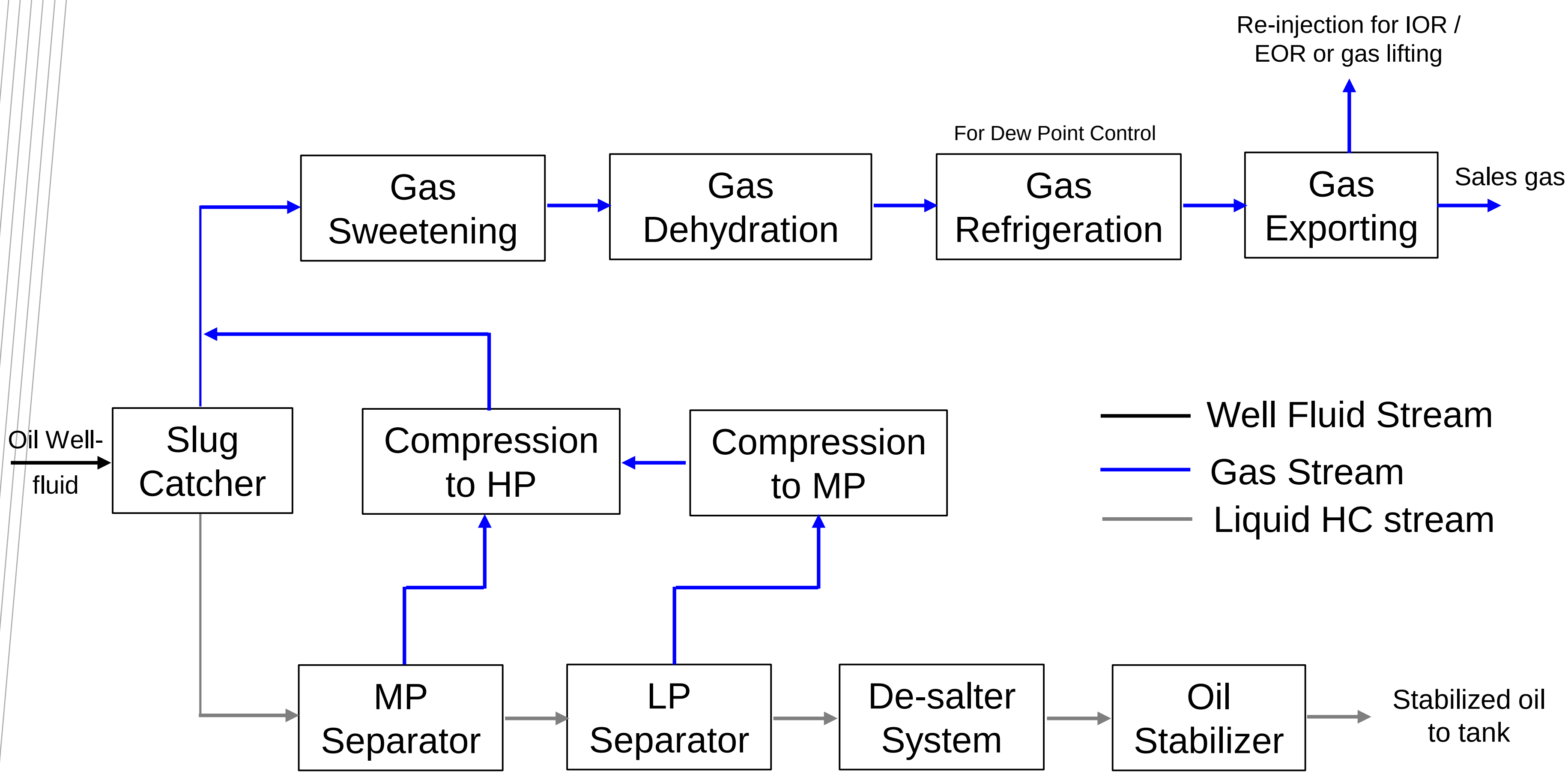


Oil field development

- Processing hydrocarbons received from local production wells i.e. from a platform or subsea template
- Well stream is processed & stored on the vessel, offloaded to a shuttle tanker or exported via a pipeline

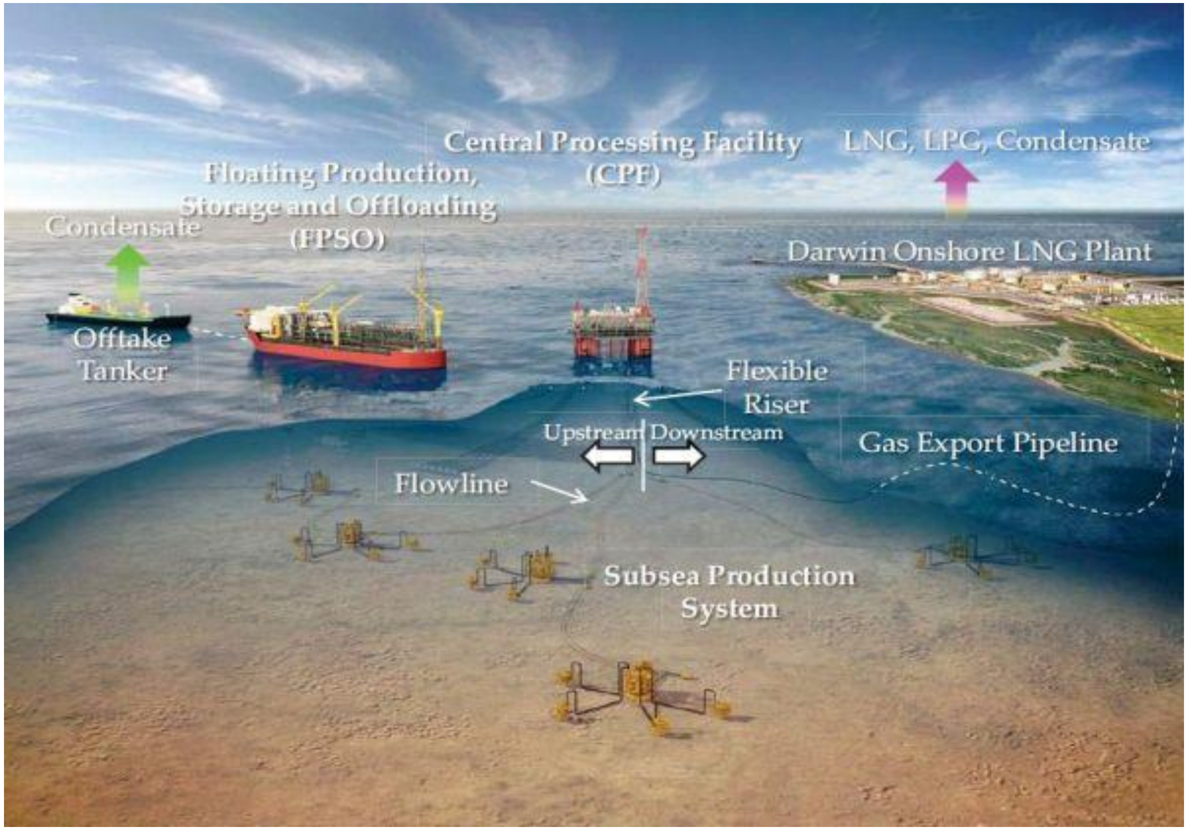
FPSO for Pazflor

CPF for oil field

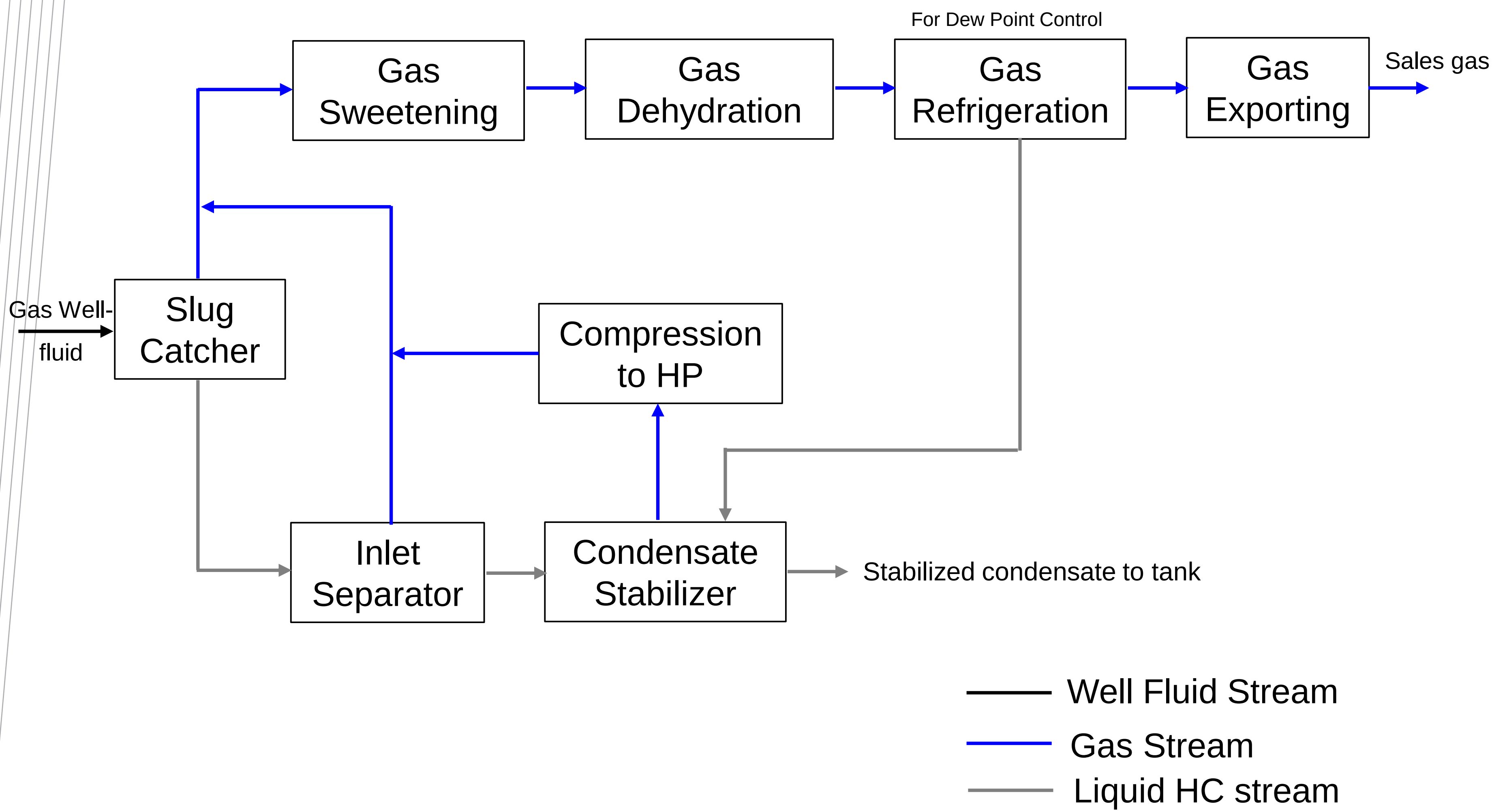


Gas field development

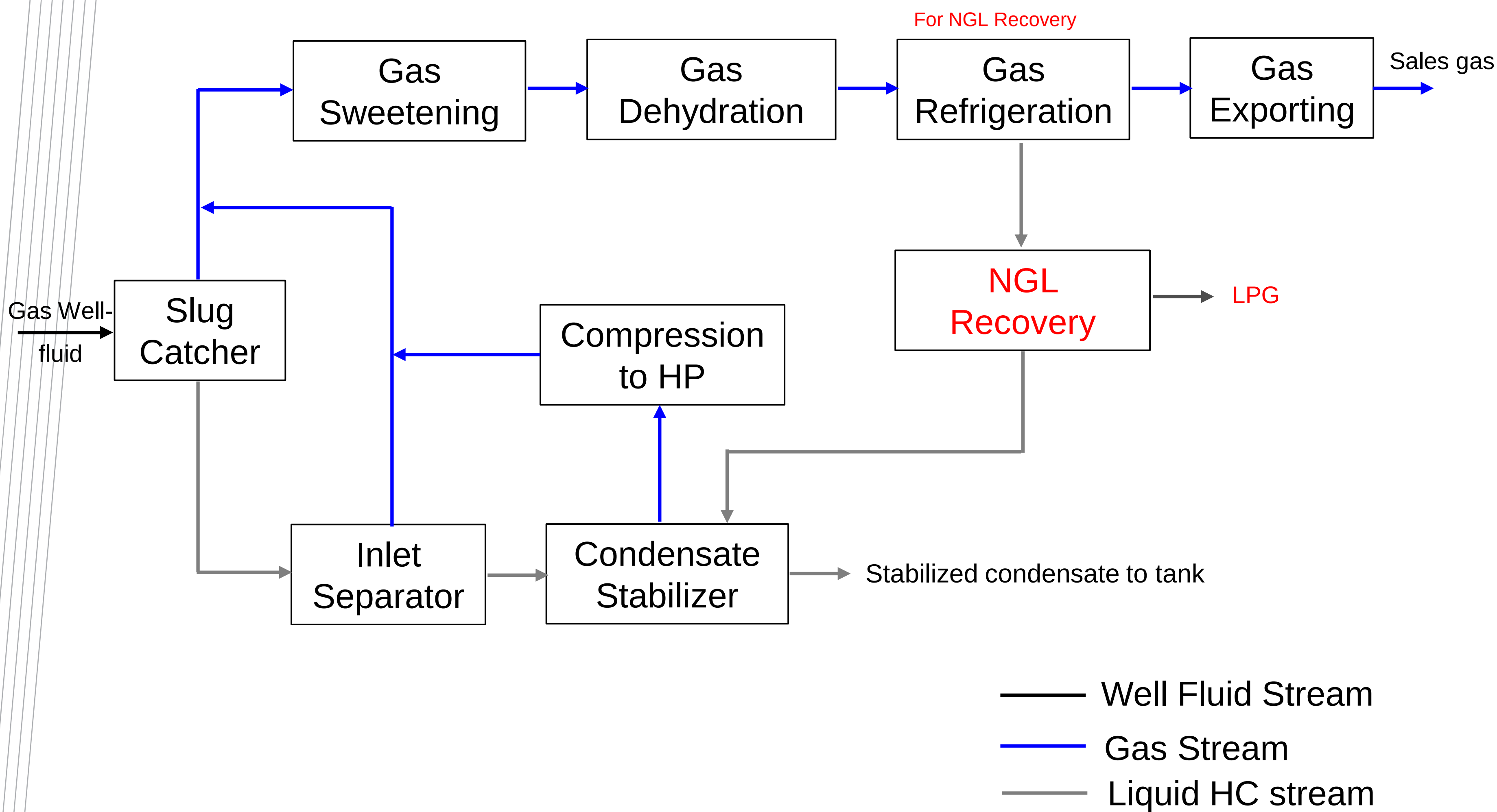
- Processing hydrocarbons received from local production wells i.e. from a platform or subsea template
- Well stream is processed & stored on the vessel, offloaded to a shuttle tanker or exported via a pipeline / or producing LNG



CPF for gas field (1)



CPF for gas field (2)



What happens if something goes wrong

Flowline failure
(Operated below min. pressure limit)

Tree failure
(Sand erosion damage)

Contact: Yutaek Seo

Email: Yutaek.Seo@snu.ac.kr

Thank you