



Floating LNG

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SNAME UK Collegium 2012

Floating LNG

- Background
- Floating Liquefaction
 - Rules and Standards
 - Design Process & Challenges
 - Safety Approach
 - Cargo Containment system & Size
 - Process Selection
 - Offloading
 - Projects

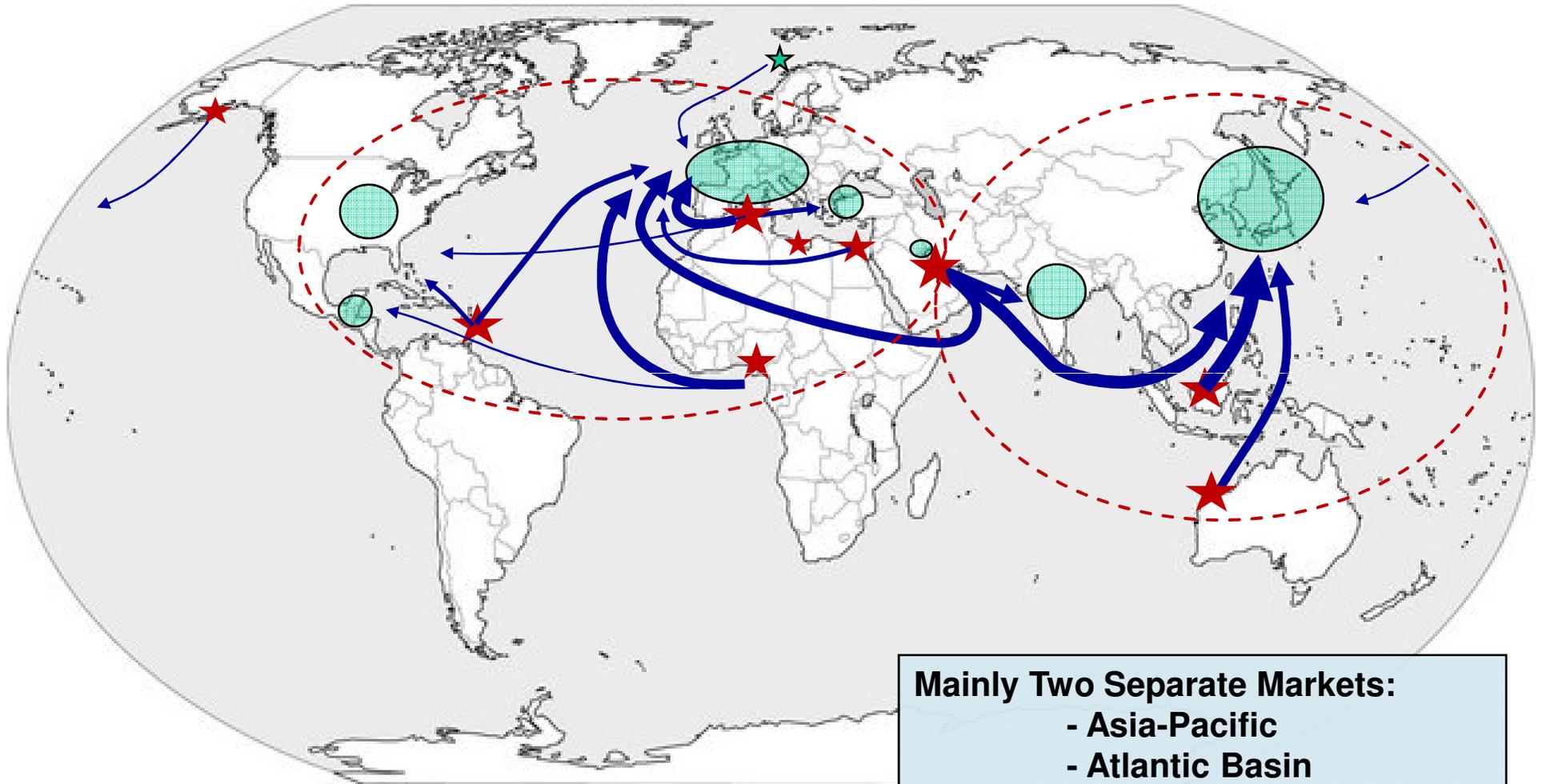
The Era of (Liquid) Natural Gas?



LNG Supply & Demand

- **Natural gas** will be playing a greater role in the global energy mix
 - ...China's ambitious policy for gas use, has commitments to meet growth
 - ...dampened growth of nuclear power
 - ...increase use for transportation and power plants
 - ...environmental drivers when replacing other fossil-fuels
- **Natural gas prices** in the US are significantly less than in Asia
 - ...presenting a significant arbitrage opportunity
- **New shale discoveries** & enhanced recovery techniques are fueling shale gas revolution ...though the extent of US shale gas reserves has been scaled back
- **Increased** demand for LNG in Asia is a the key driver for the shipping sector
 - ...Australia & Angola will both boost exports
- **Australia LNG** production could increase threefold by 2020 with key customers like China and India

LNG Markets – 2005

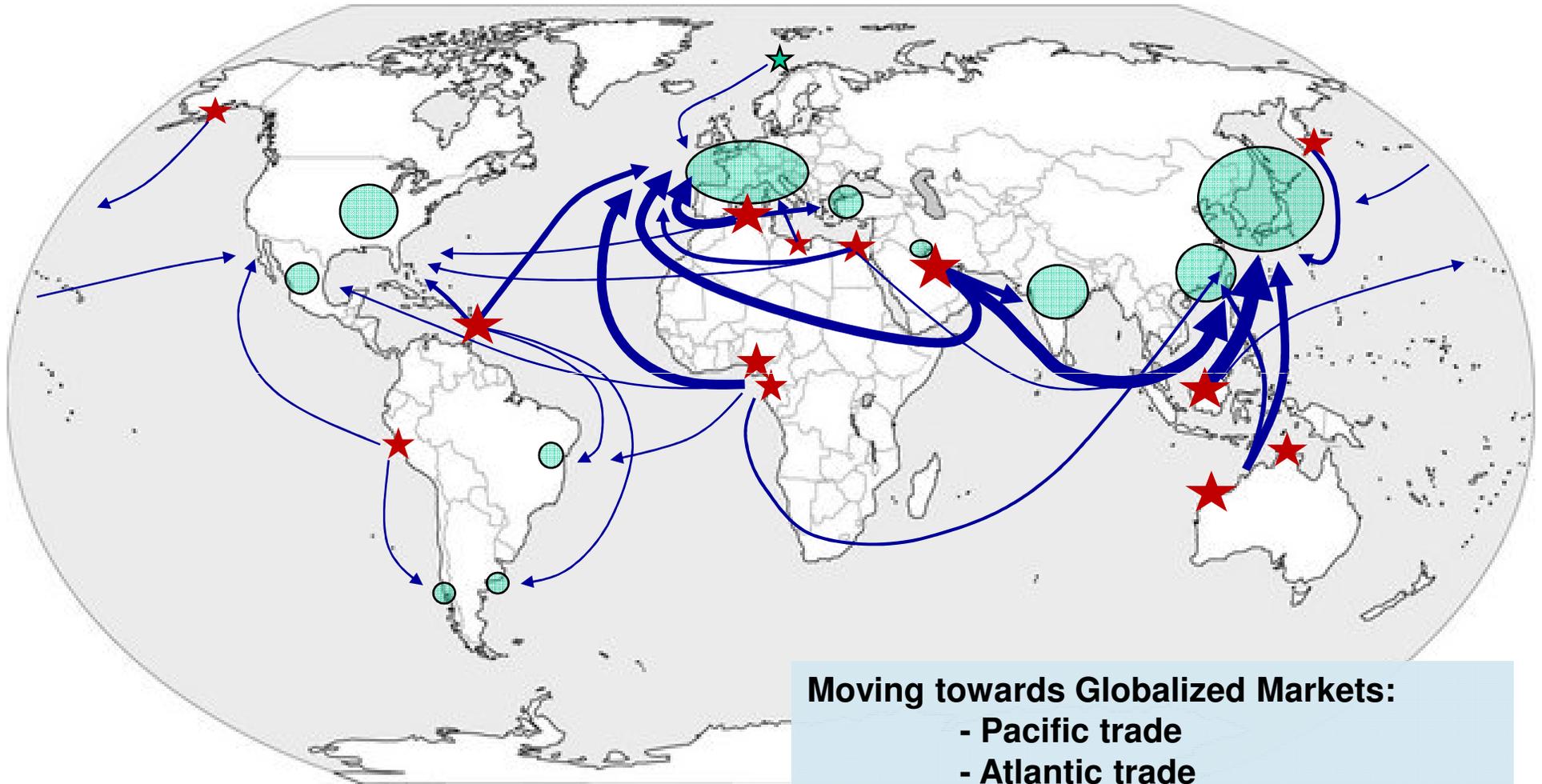


Mainly Two Separate Markets:

- Asia-Pacific
- Atlantic Basin

Middle East: awing supplier

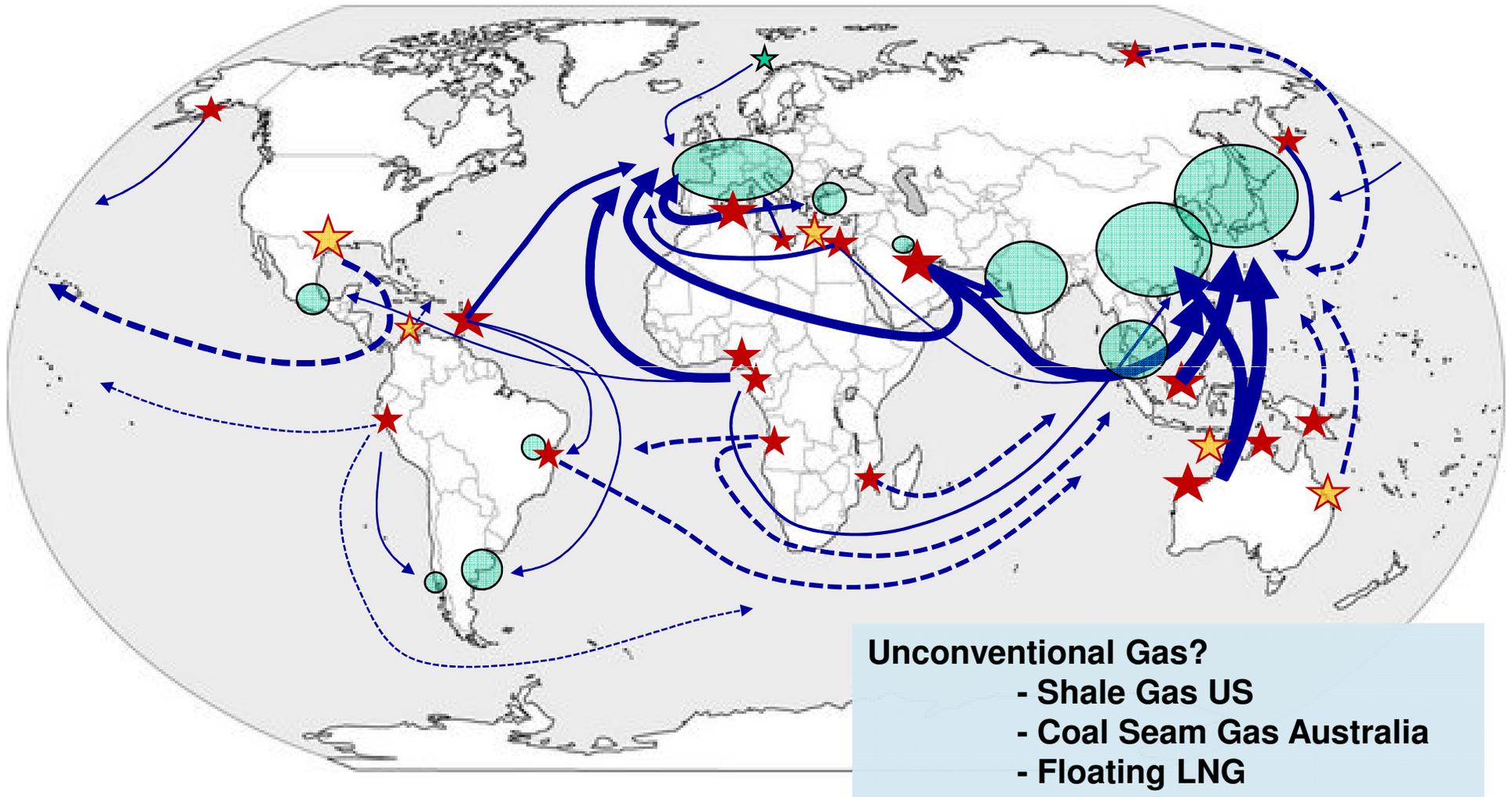
LNG Markets – 2010



Moving towards Globalized Markets:

- Pacific trade
- Atlantic trade
- Expanded Middle East trade?

LNG Markets – 2015?



Floating LNG: Key Drivers

- Access to stranded gas reserves offshore
- Countries with poor infrastructure and lack of skilled
 - Limited local infrastructure required:
The main asset can be built in a specialized fabrication yard and moved to location upon completion
- Permitting and safety
 - The facility can be located away from local communities (“not in my backyard”)
- Time to market
 - Reduce construction time by building at specialized yard
 - Assets can be built ahead of the project (only local “interface” required) – many LNG RV/FSRUs built on speculation

Floating LNG: Upstream vs Downstream

UPSTREAM

LNG Production

- LNG FPSO
- FLNG
 - (Very) complex projects
 - Huge topsides (15 - 80k ton)
 - High cost/project specific

Complex process combining different industries

- Offshore production
- Onshore LNG production
- LNG marine operations

DOWNSTREAM

LNG Regasification

- LNG RV /SRV
- FSRU
 - (Relatively) simple designs
 - Simple process (“pump and vaporizer”)
 - Low cost / “liquid” asset

Generally build as LNG ships with a regasification plan added on

=> Shipbuilding approach

VERY DIFFERENT PROJECTS!

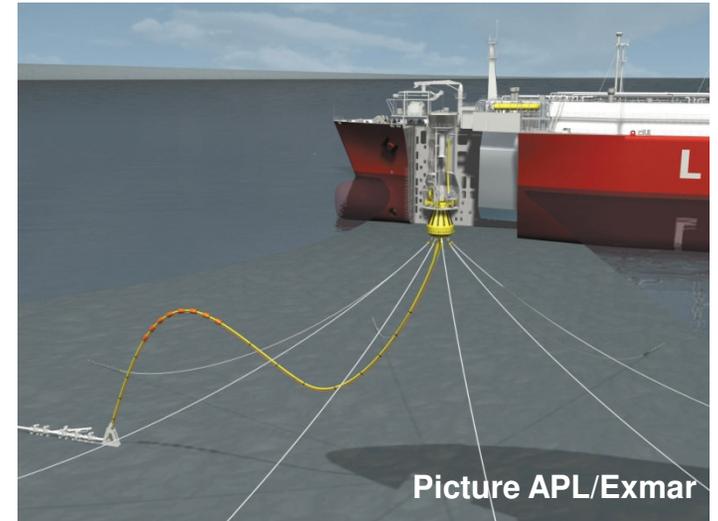
FLOATING REGASIFICATION

Floating Regasification: Introduction

- Main objectives
 - Deliver regasified LNG to the market
 - Tie into existing networks that need increased capacity
 - Develop new markets with minimum local infrastructure
 - Provide seasonal supply
- Main advantages
 - Time to market
 - Can be located away from the shoreline in populated areas
 - Reduces political risks
- Main challenges
 - Motions (offshore)
 - LNG transfer (offshore and at the jetty)
 - Environmental requirements (use of sea water, air emissions, etc.)
 - NG heating value adjustment/odorization

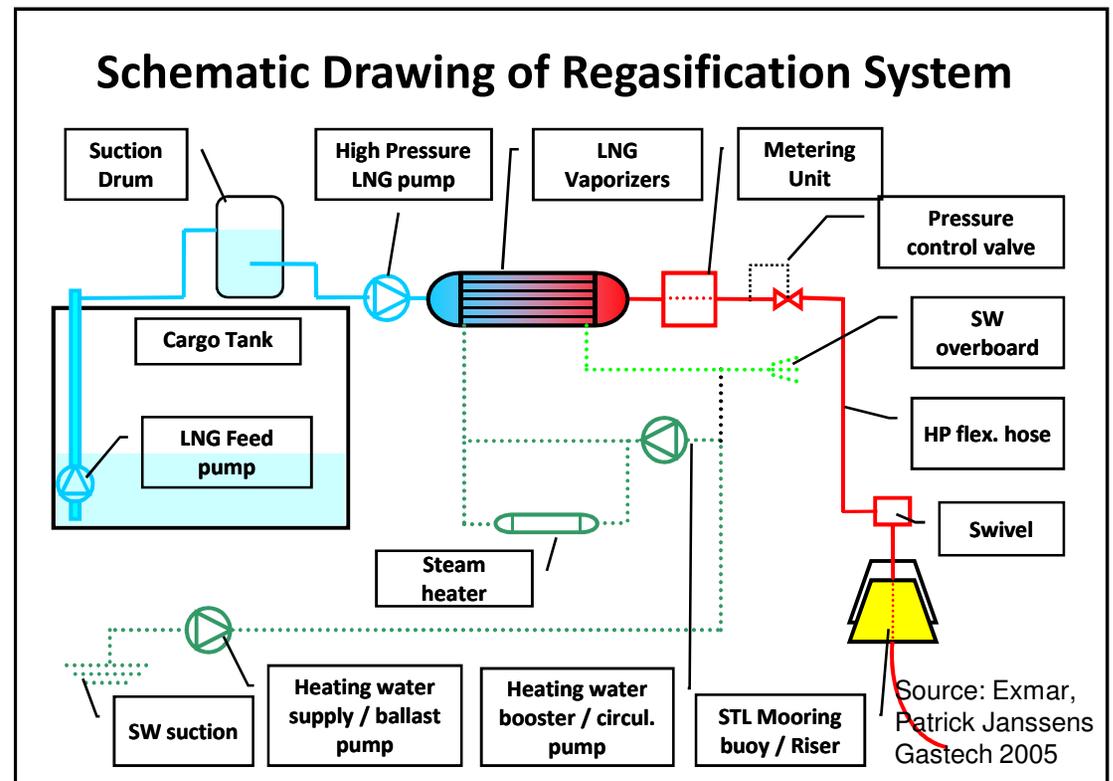
Regasification: Basic Principles

- Mooring system
 - Offshore
 - Turret mooring with a single subsea riser to offload the high pressure gas
 - At a jetty
 - Conventional ship mooring
 - Offloading regasified LNG through high pressure jacksan arm
- LNG transfer
 - Offshore
 - Side by side loading (mild sea states only!!)
 - Flexible hose(s) or marinized LNG jacksan arms
 - Mooring availability depending on metocean conditions
 - At a jetty
 - Side by side (hoses or LNG jacksan arms) or via conventional jetty



Floating Regasification: Basic Principles

- Cargo containment
 - Generally based on existing LNG carrier design.
 - Membrane carriers operating offshore need reinforced cargo containment system to prevent sloshing damage
- Regasification process (typical)



Regasification: Open vs Closed Loop

- **“Open Loop”**

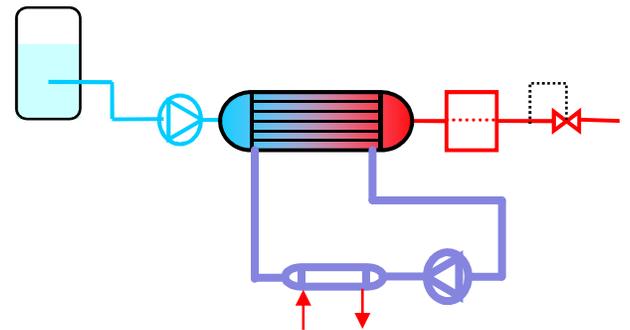
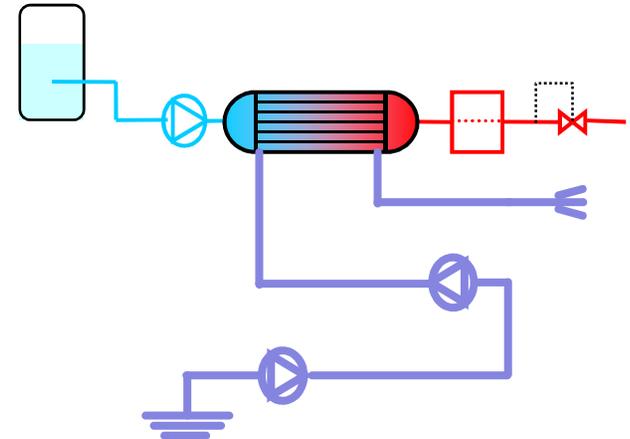
Sea water is used as main heat source for the regasification process

- Large amounts of heating water used
- Most energy efficient/lowest air emissions
- Not suitable for cold areas

- **“Closed Loop”**

Separate heat source used for the regasification process (typically gas or fuel fired steam boilers)

- Limited use of sea water (cooling water for machinery)
- Less energy efficient /increased air emissions



First Project: Exmar/Excelerate LNG RV

- First regas operation (2005) at GOM deepwater port
- First jetty discharge (2007) at Teesside

Operating Mode	Design Capacity
SW Heated (open loop)	Nominal 500 mmscf/d @ 100 bar
	Peak 690 mmscf/d @ 100 bar
Steam Heated (closed loop)	450 mmscf/d @ 100 bar

Source: Exmar, Patrick Janssens, Gastech 2005



Picture Exmar

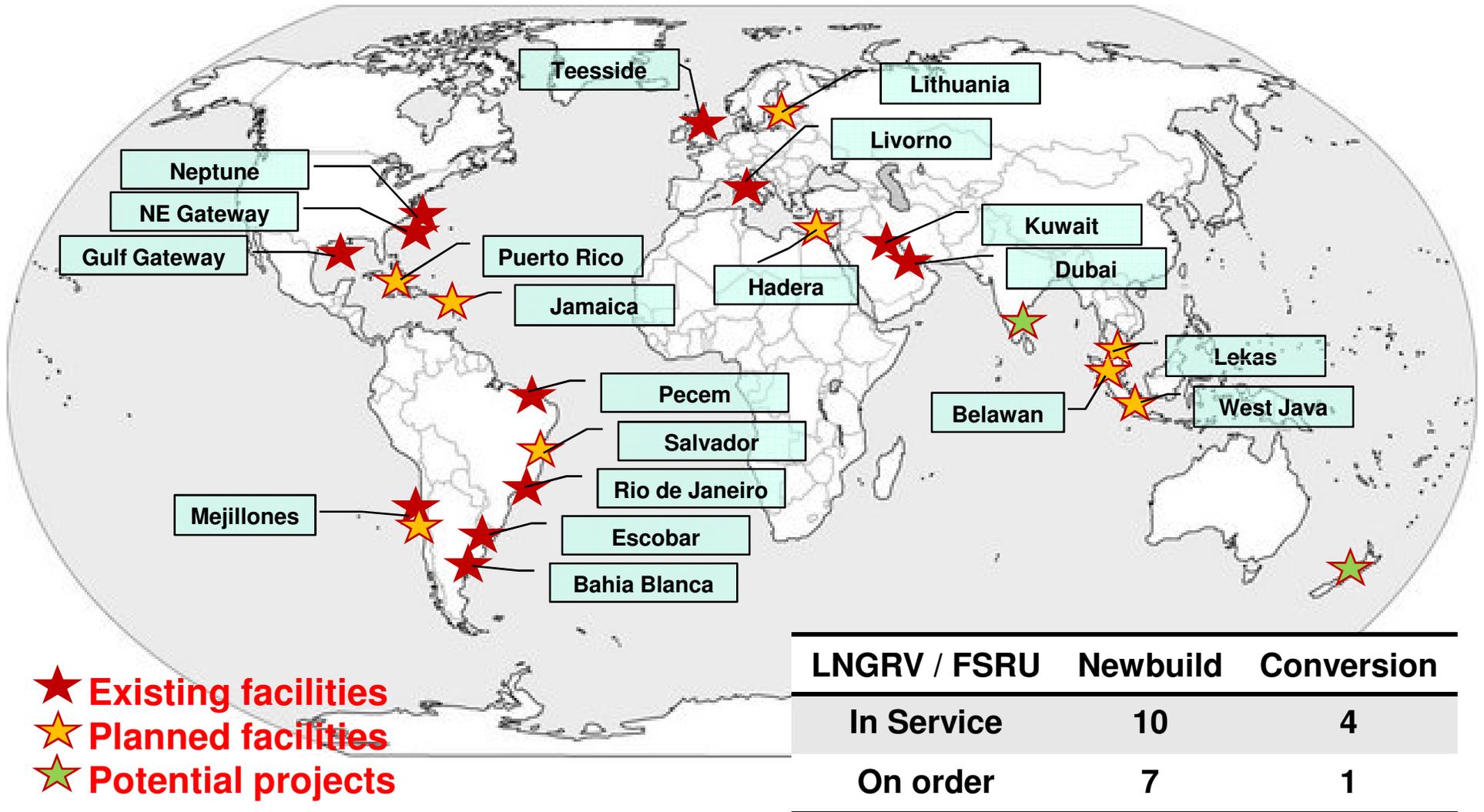


Picture Excelerate

From Novel Technology 2005/2207

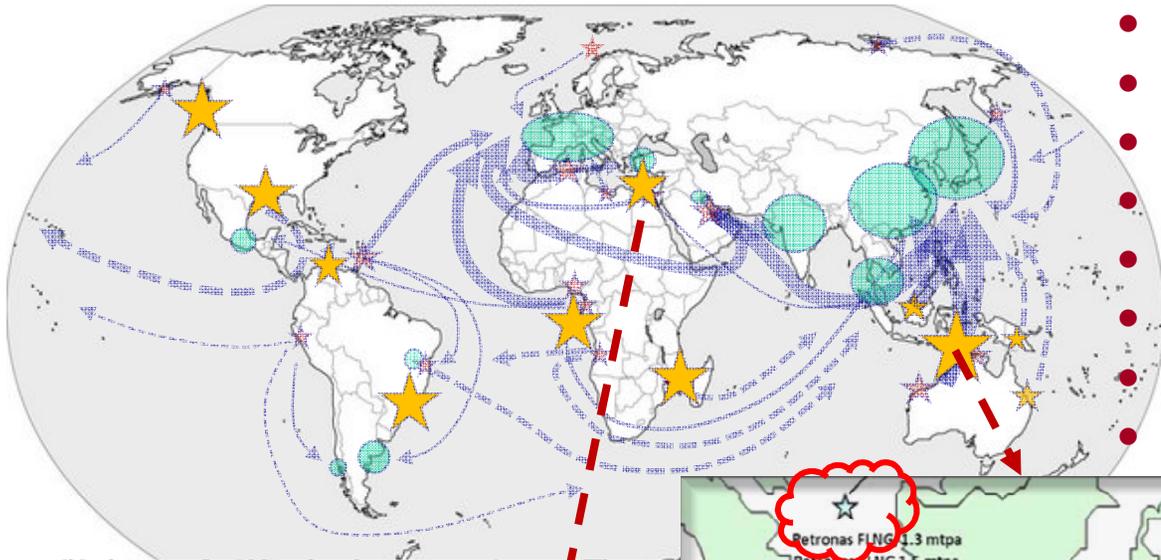


To proven concept



FLOATING LNG PRODUCTION

Floating LNG Production: Opportunities?



- Southeast Asia
- Papua New Guinea (PNG)
- Mediterranean (Tamar, Leviathan...)
- South America (Brazil)
- US/Canada
- Colombia
- West Africa (Nigeria, ...)
- East Africa (Mozambique)



Offshore Gas Experience?

Escravos LPG FSO



First purpose-built
LPG FSO Offshore Nigeria
(classed by ABS)

Offshore Gas Experience?

Sanha LPG FPSO
First LPG FPSO
(classed by ABS)



135,000 m³ storage capacity
Product propane and butane
IHI SPB LPG tanks
Offloading side-by-side or tandem
External turret mooring by SBM
Onboard production of propane and butane
Refrigeration plant

Specific Design Challenges for Floating LNG

- **Establish basis for Rules and Standards**
- **Address FLNG specific Safety Concerns**
 - Potential for gas leaks & explosions (NG, LPG, ...)
 - Cryogenic spills
- **Cargo Containment System**
 - Requirement for unrestricted partial filling
 - Offshore maintenance (No dry-docking)
- **Topside Design**
 - Restricted footprint available
 - Motions and accelerations
 - Marinisation of process equipment
- **Offloading**
 - Side by side offloading
 - Tandem offloading (dedicated ships)

Rules & Standards

Combination of 3 Industries

**Offshore
Production**



**Floating Offshore
Liquefied Gas
Terminal**

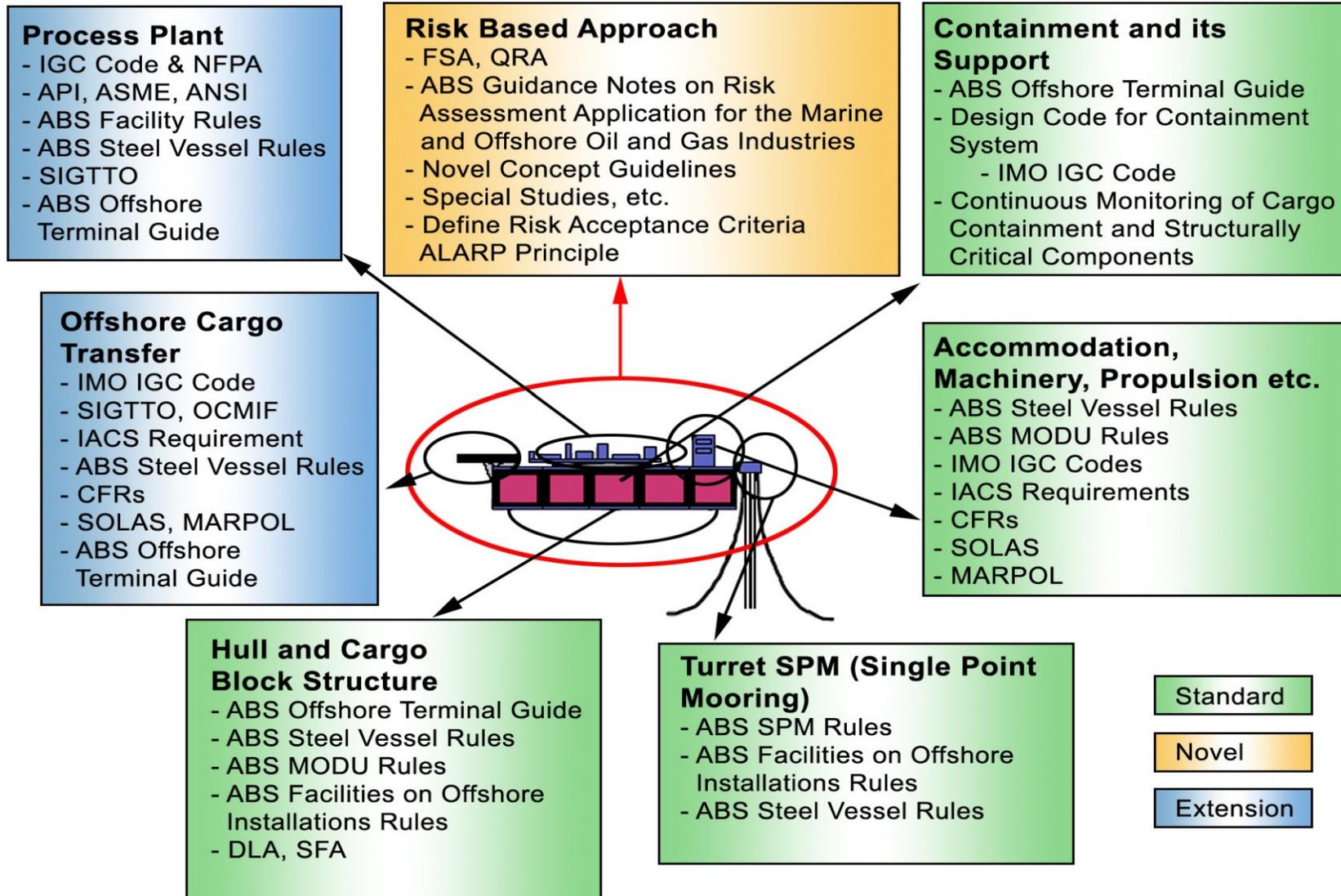


Onshore LNG

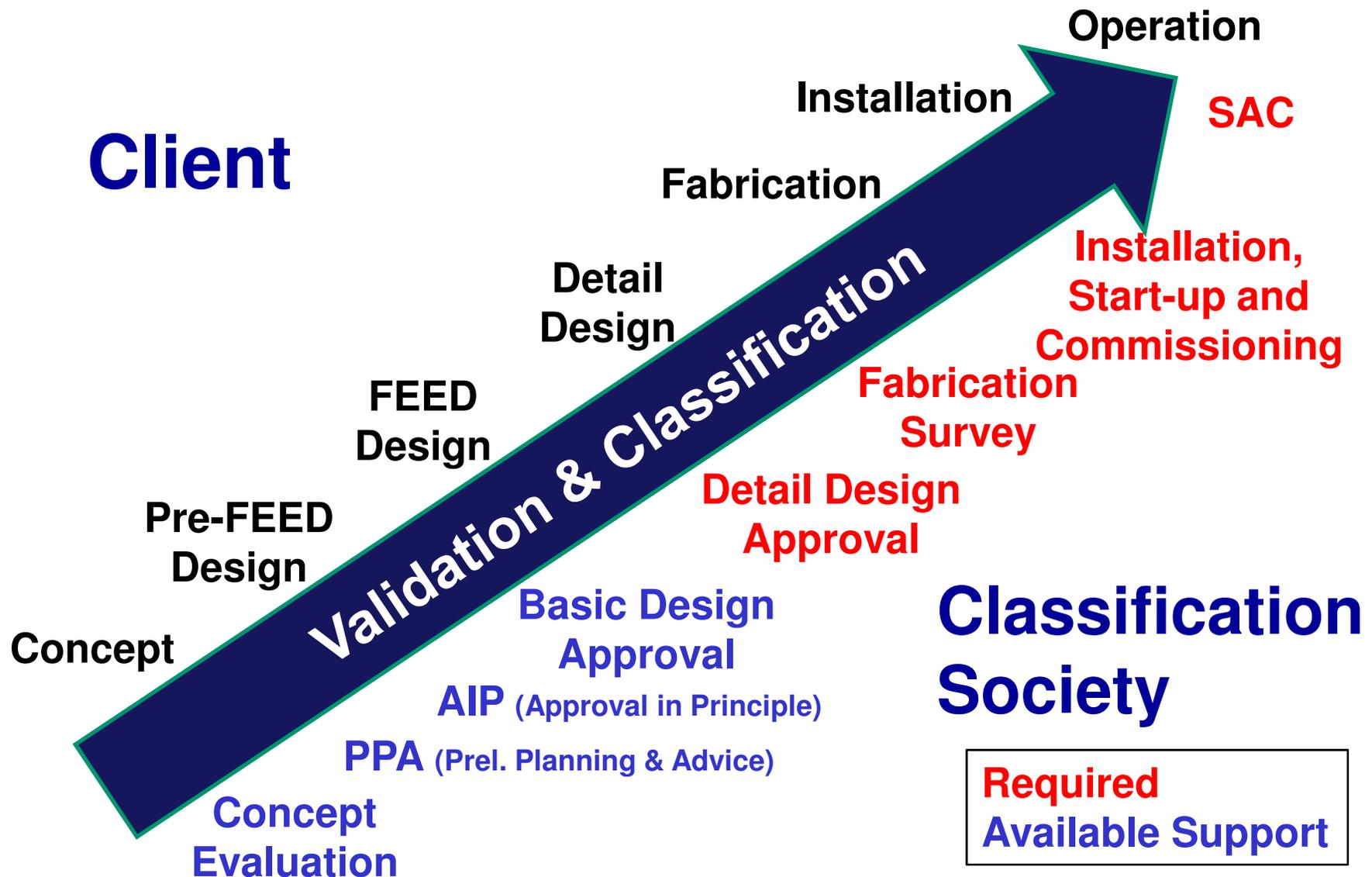


LNG Shipping

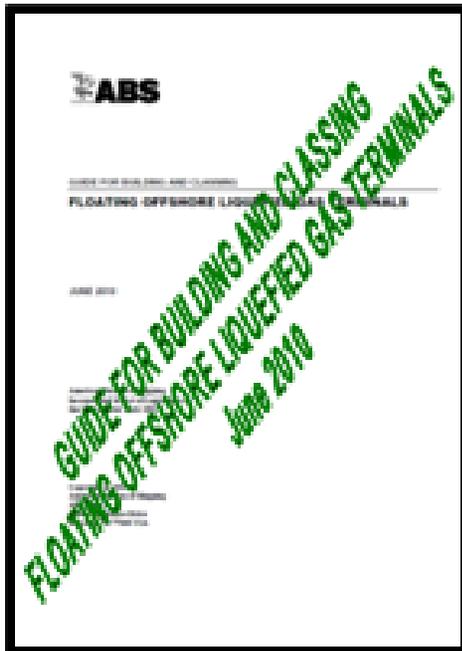
FLNG Rules & Standards



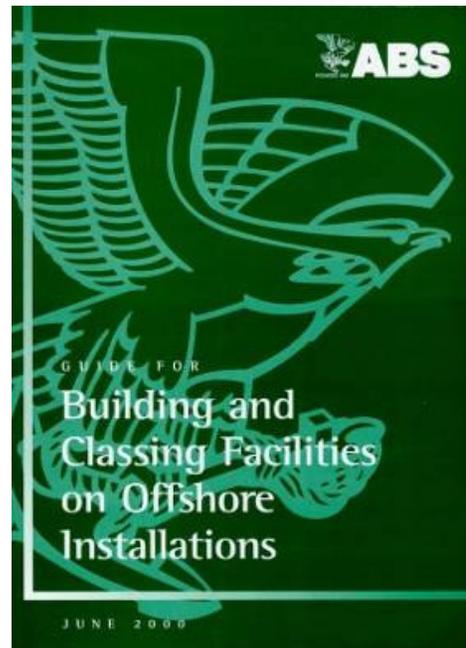
Design Process and Class Role



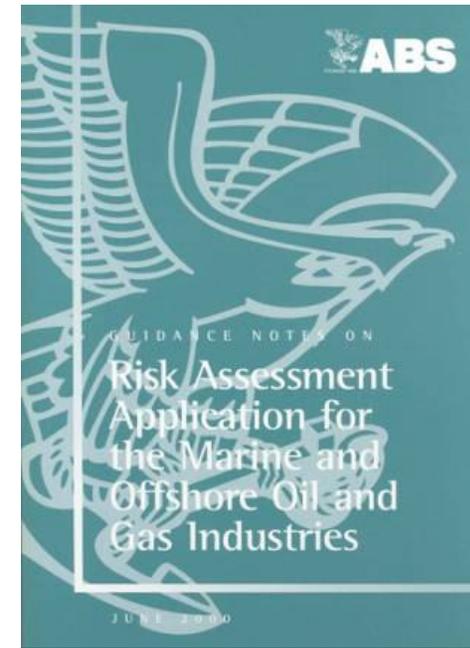
ABS Rules & Guides: Topside Facility



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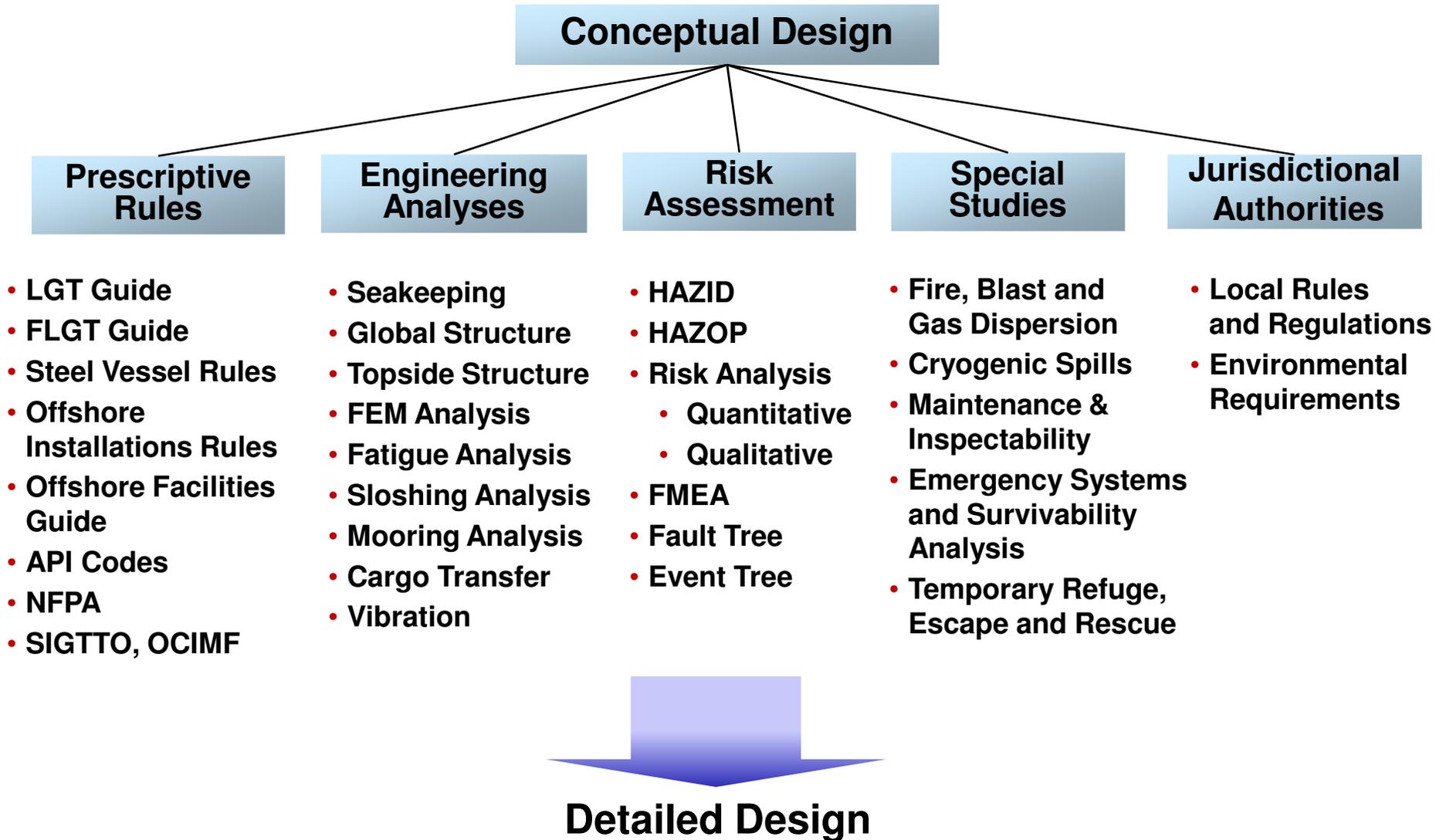
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Industry Standards
API, ASME, NFPA, etc.

Risk-based alternatives

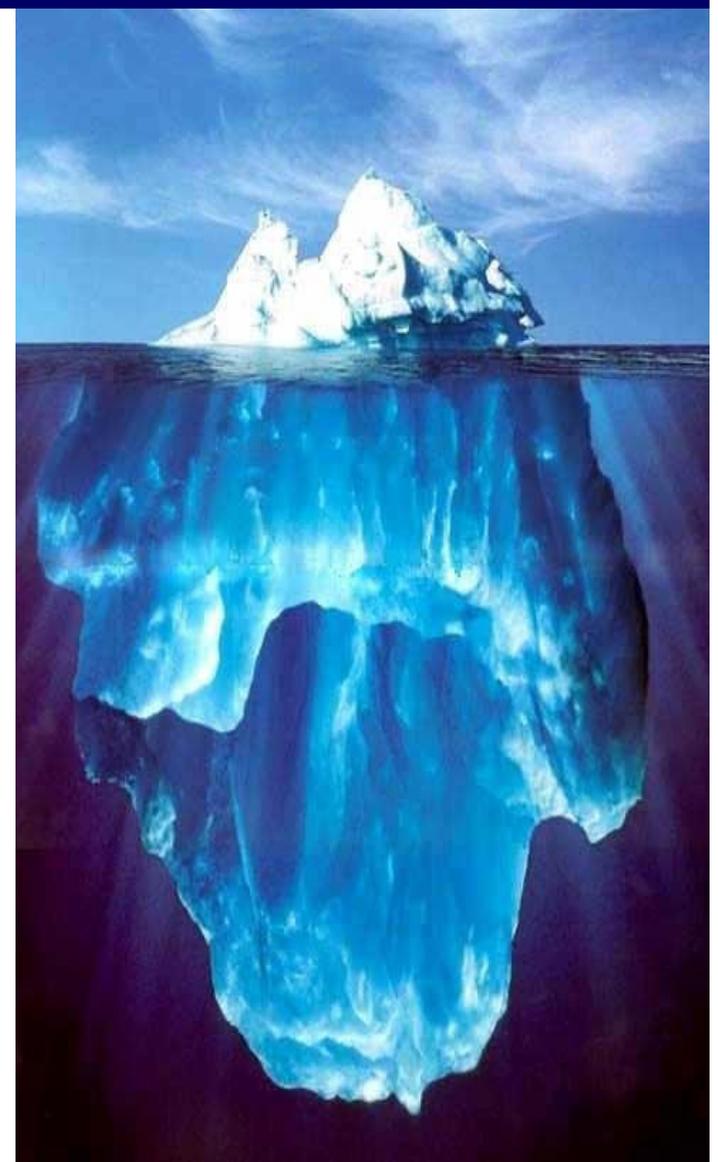
Evaluation & Assessment



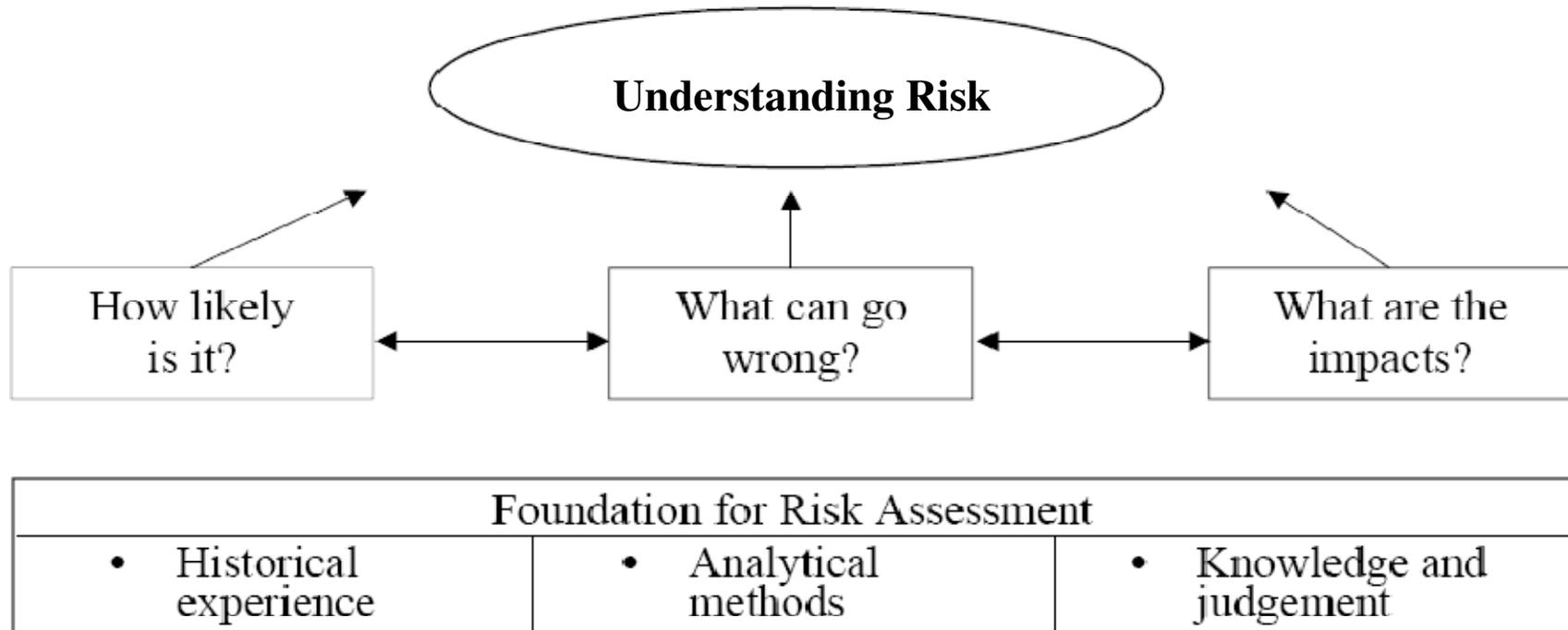
Managing Risk

Can Risks Be Eliminated?

- Not generally
- But risks can be **controlled**:
 - Mitigate hazards
(**inherently safe design**)
 - Reduce likelihood of occurrence
(**risk prevention**)
 - Reduce consequence
(**risk mitigation**)



Managing Risk

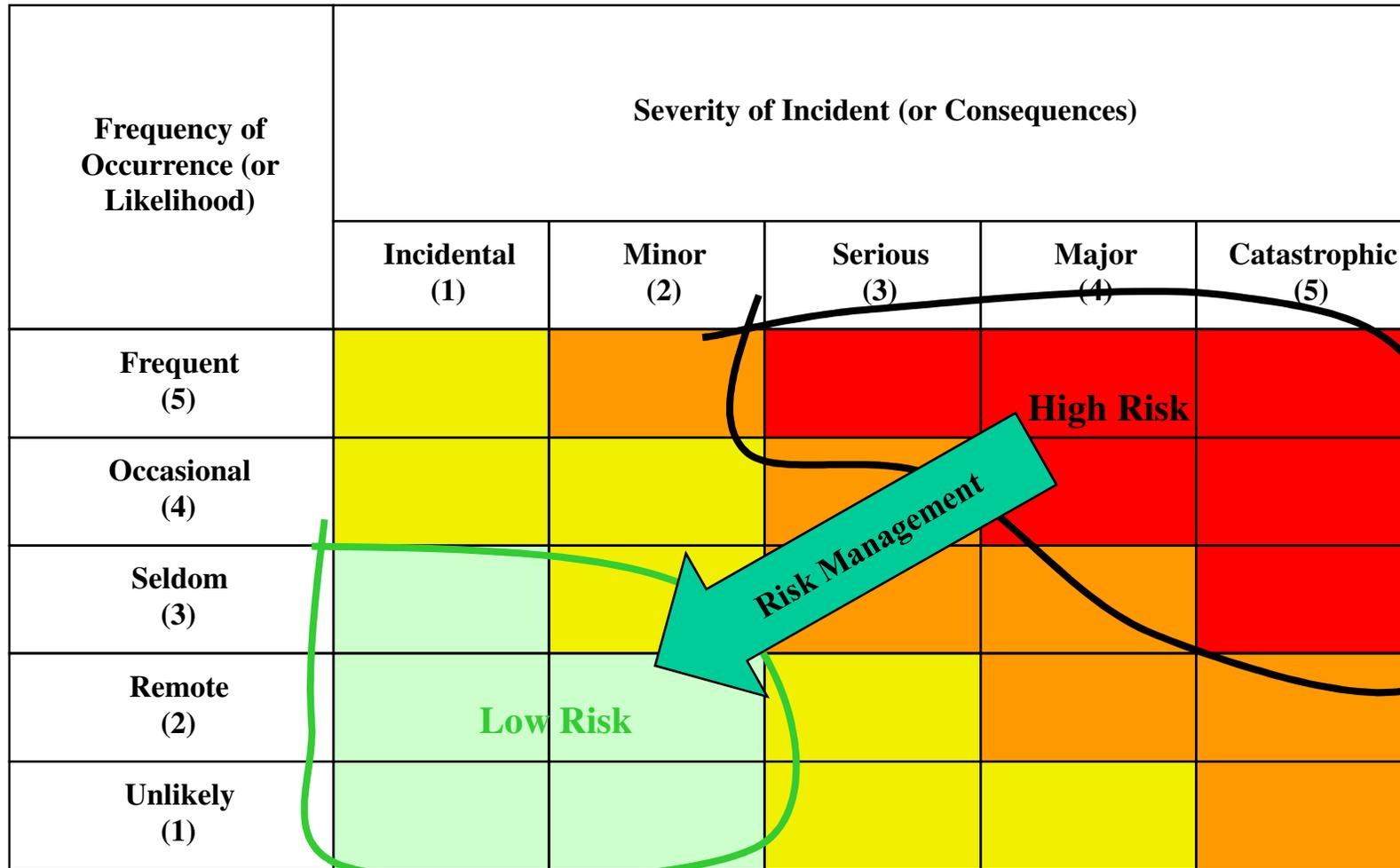


RISK = Frequency x Consequence

How are Risks Controlled?

Qualitative Risk Ranking Matrix

Frequency of Occurrence (or Likelihood)	Severity of Incident (or Consequences)				
	Incidental (1)	Minor (2)	Serious (3)	Major (4)	Catastrophic (5)
Frequent (5)				High Risk	
Occasional (4)					
Seldom (3)					
Remote (2)	Low Risk				
Unlikely (1)					



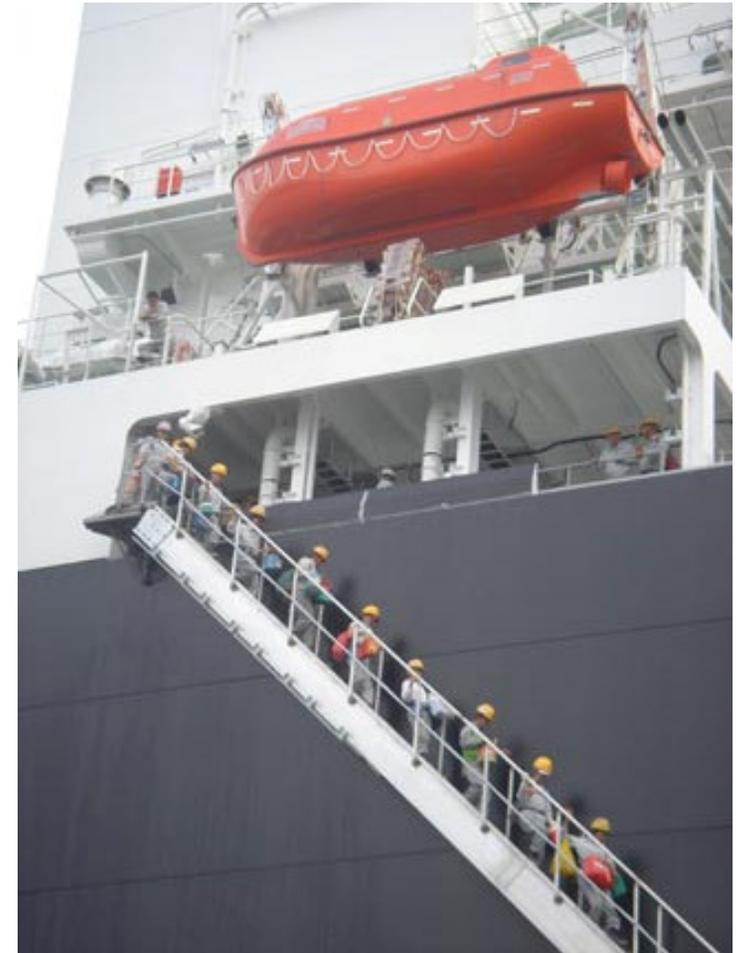
Note: Highest risk is in top right corner. Risk decreases with shading from right to left (shading is for illustrative purposes only)

Layout Objectives

- To minimize
 - Likelihood of uncontrollable releases of hydrocarbon to the environment
 - Possibility of hazardous accumulations
 - Probability of ignition
 - Spread of hazardous liquids and gases
- Rapid removal of any accumulations that occur
- Separation of fuel and ignition source as far as practical
- Separate areas – non-hazardous and hazardous
- Separation of Modules (by distance or blast walls)
- Prevent fire escalation and equipment damage

Layout Objectives

- Minimize the consequences of fire and explosions
- Provide safe escape and evacuation
- Facilitate effective emergency response
- Create safe environment for personnel and operations
- Minimize dropped objects hazards to personnel, equipment and structure (facility and subsea)



Cargo Containment

Cargo Containment Systems for LNG carriers

IMO Classification of LNG Vessels

Independent Tanks

Integrated tanks

Type A

$p < 700$ mbar
Full secondary barrier

Type B

$p < 700$ mbar
Partial Secondary barrier

Type C

$p > 2000$ mbar
No Secondary barrier

Membrane Tanks

$p < 700$ mbar
Full secondary barrier

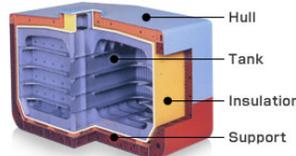
Spherical (Moss)



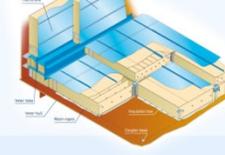
Cylindrical



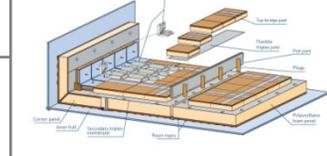
Prismatic (IHI SPB)



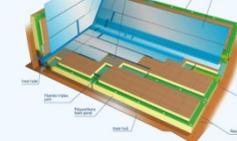
GTT No 96



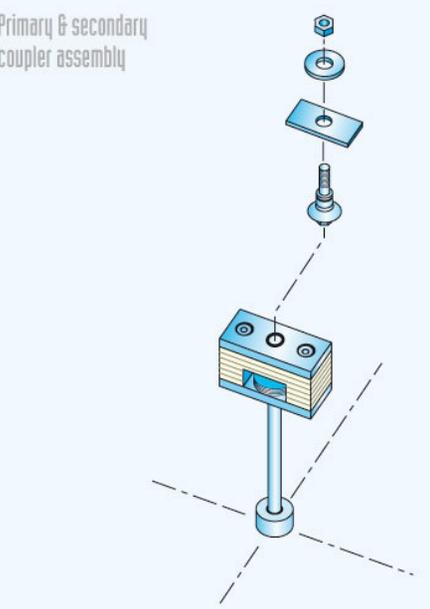
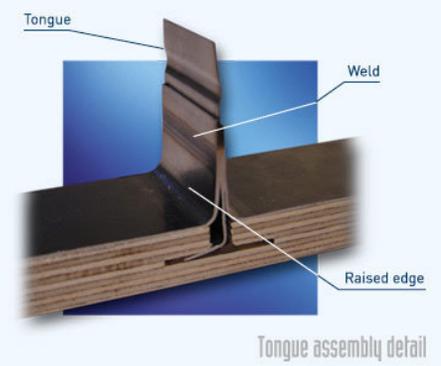
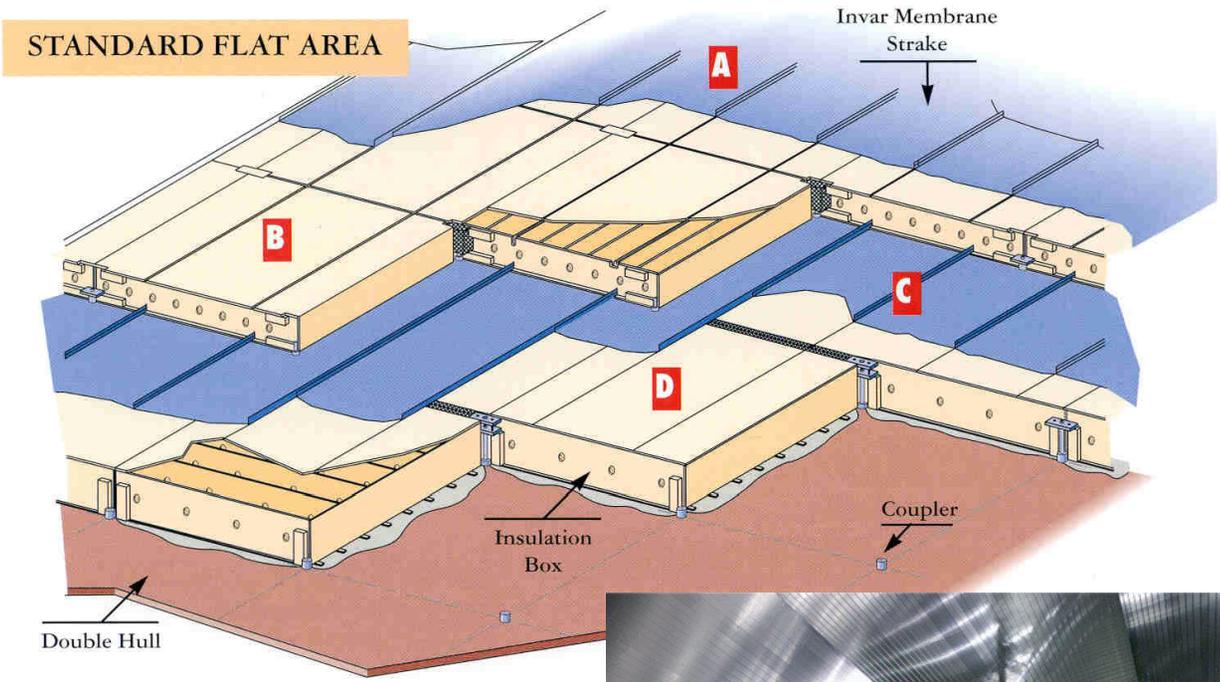
GTT Mark III



GTT CS1



Membrane Tank: GTT No 96



Insulation

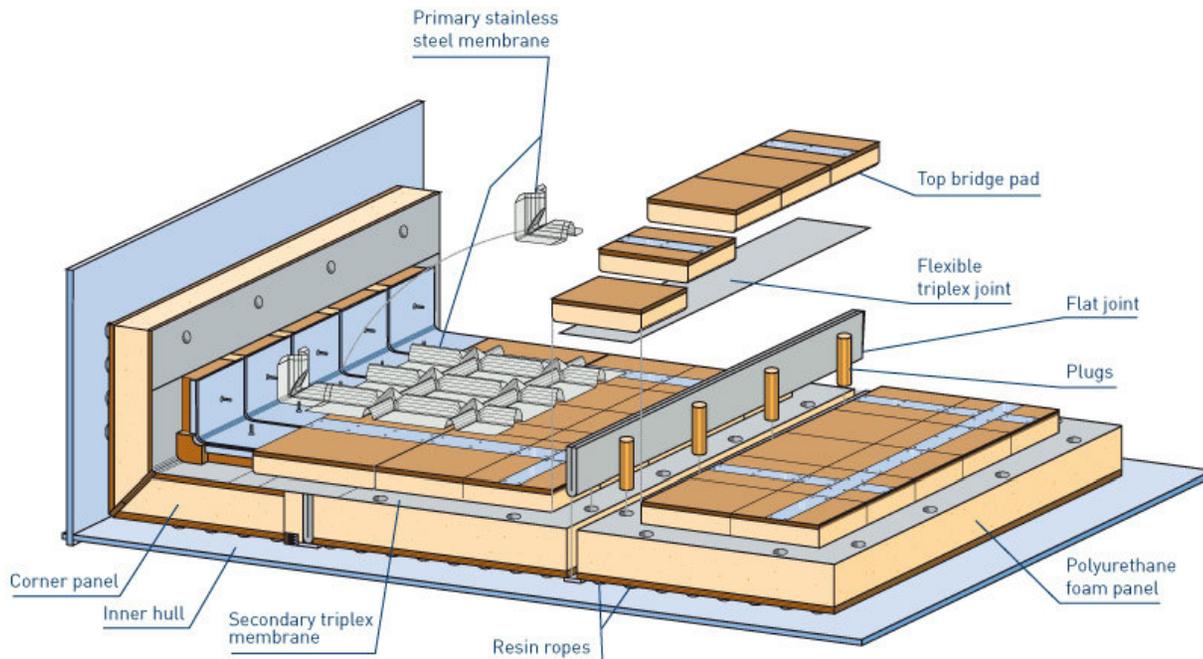
- Thickness: 530 mm
- Plywood/perlite
- Typical BOR: 0.15%

Membrane

- 0.7 mm Invar

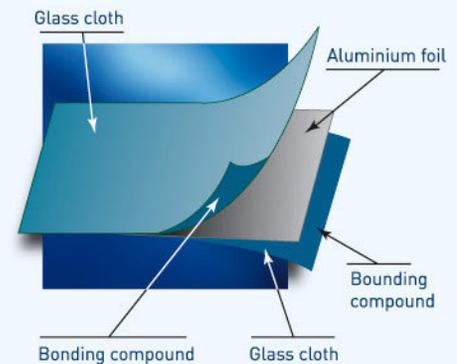


Membrane Tanks: GTT Mark III



Stainless steel membrane

Triplex membrane

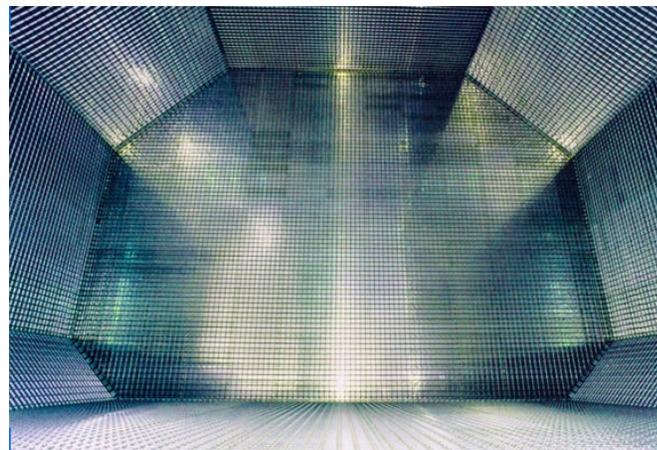


Insulation

- Thickness: 270 mm
- Reinforced PU foam
- Typical BOR: 0.15%

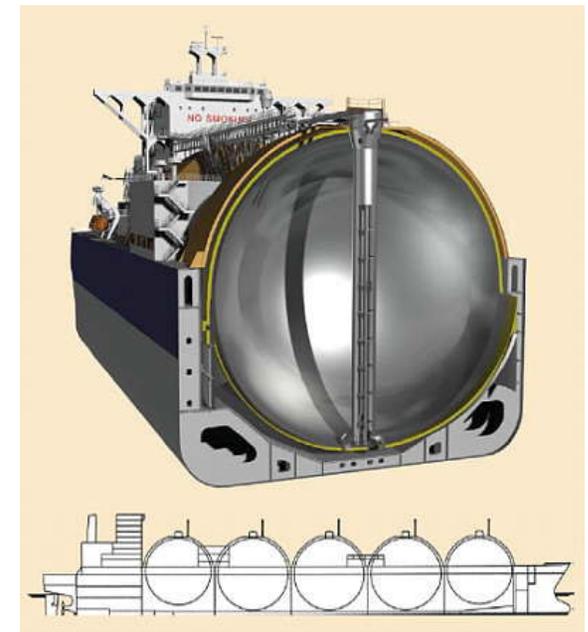
Membrane

- 1.2 mm SUS (primary)
- Triplex (Secondary)



Type B: Spherical Tanks – MOSS

- Historically spherical tanks dominant as first choice of Japanese shipyards



Type B: Prismatic Tanks – IHI SPB

- Independent prismatic type B (IHI SPH)
- Strong and robust system, but expensive
- So far only 2 ships built (ABS class)



Cargo Containment Systems for FLNG

Containment System Main Concerns	<p style="text-align: center;">MOSS</p> 	<p style="text-align: center;">SPB</p> 	<p style="text-align: center;">Membrane Single Row</p> 	<p style="text-align: center;">Membrane Double Row</p> 
Partial Filling (Sloshing)	<ul style="list-style-type: none"> • Very Robust • Tank shape prevents sloshing 	<ul style="list-style-type: none"> • Very Robust • Centreline bulkhead prevents sloshing 	<ul style="list-style-type: none"> • Limited impact resistance • Full width tanks prone to sloshing 	<ul style="list-style-type: none"> • Centreline bulkhead prevents sloshing
Topside Support	<ul style="list-style-type: none"> • Very Limited Deck Space available 	<ul style="list-style-type: none"> • Plenty deck space • Full width Modules only 	<ul style="list-style-type: none"> • Plenty deck space • Full width Modules only 	<ul style="list-style-type: none"> • Excellent deck space • Centreline bulkhead can support modules
Maintenance on site		<ul style="list-style-type: none"> • Excellent accessibility to tank structure 	<ul style="list-style-type: none"> • Poor accessibility inside tanks • Requires staging 	<ul style="list-style-type: none"> • Poor accessibility inside tanks • Requires staging
Other	<ul style="list-style-type: none"> • >100 ships in service • Mainly Japanese Shipyards 	<ul style="list-style-type: none"> • 2 ships in service • 1 Supplier (IHI) • Expensive 	<ul style="list-style-type: none"> • > 230 ships in service • Many yards 	<ul style="list-style-type: none"> • Long. Cofferdam heating required

CCS – Double Row Membrane



Containment Size

LNG Storage Capacity

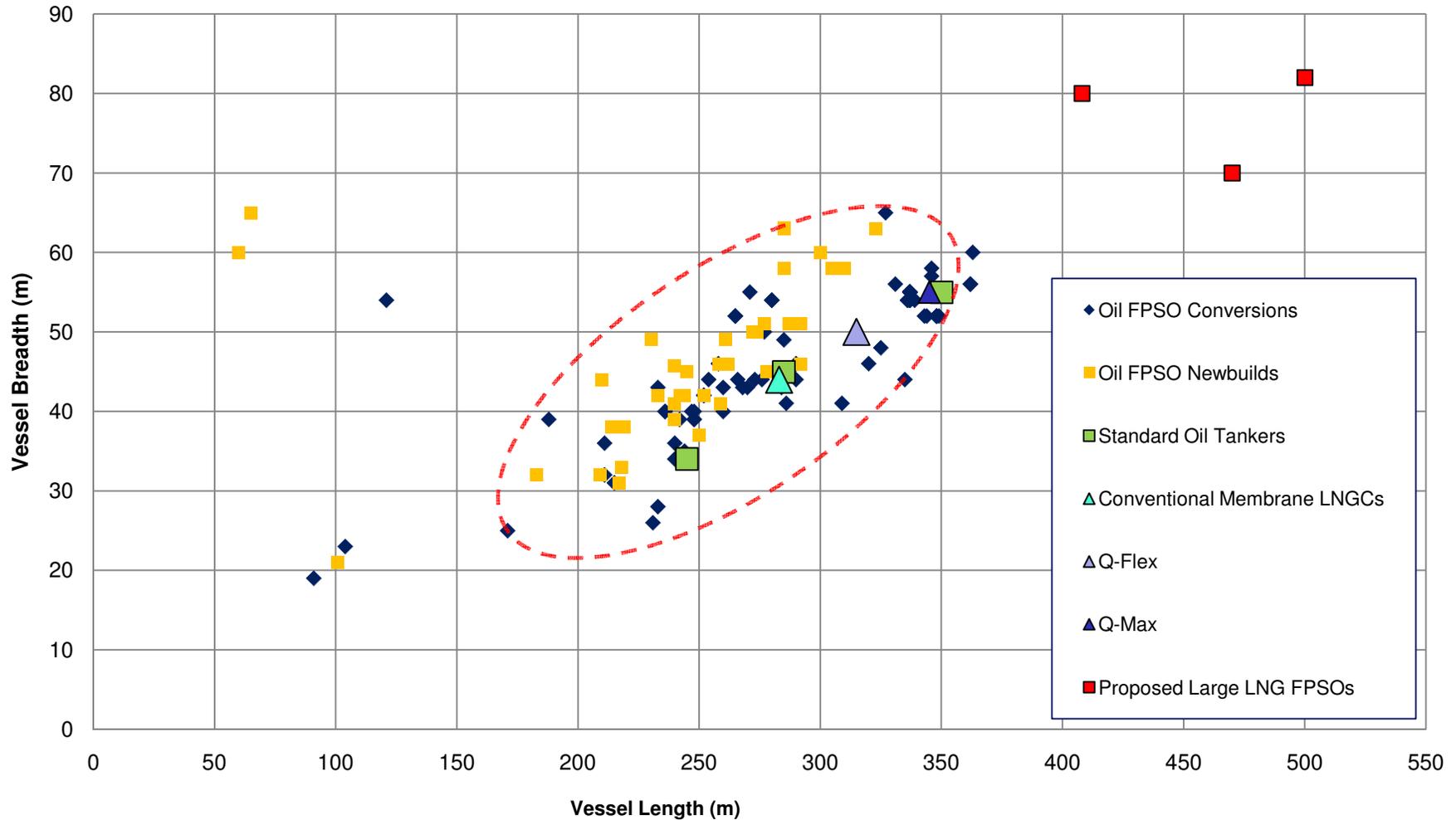
- **Production Capacity**
 - Projects ranging from 0.5 mtpa to over 5 mtpa
- **Size of LNG Carriers considered**
 - Typically 155.000 – 170.000 m³ range
- **Buffer storage required**
 - Offloading availability
 - Metocean Conditions
 - Choice of offloading system



Projects typically 170,000 m³ up to 300,000 m³ range

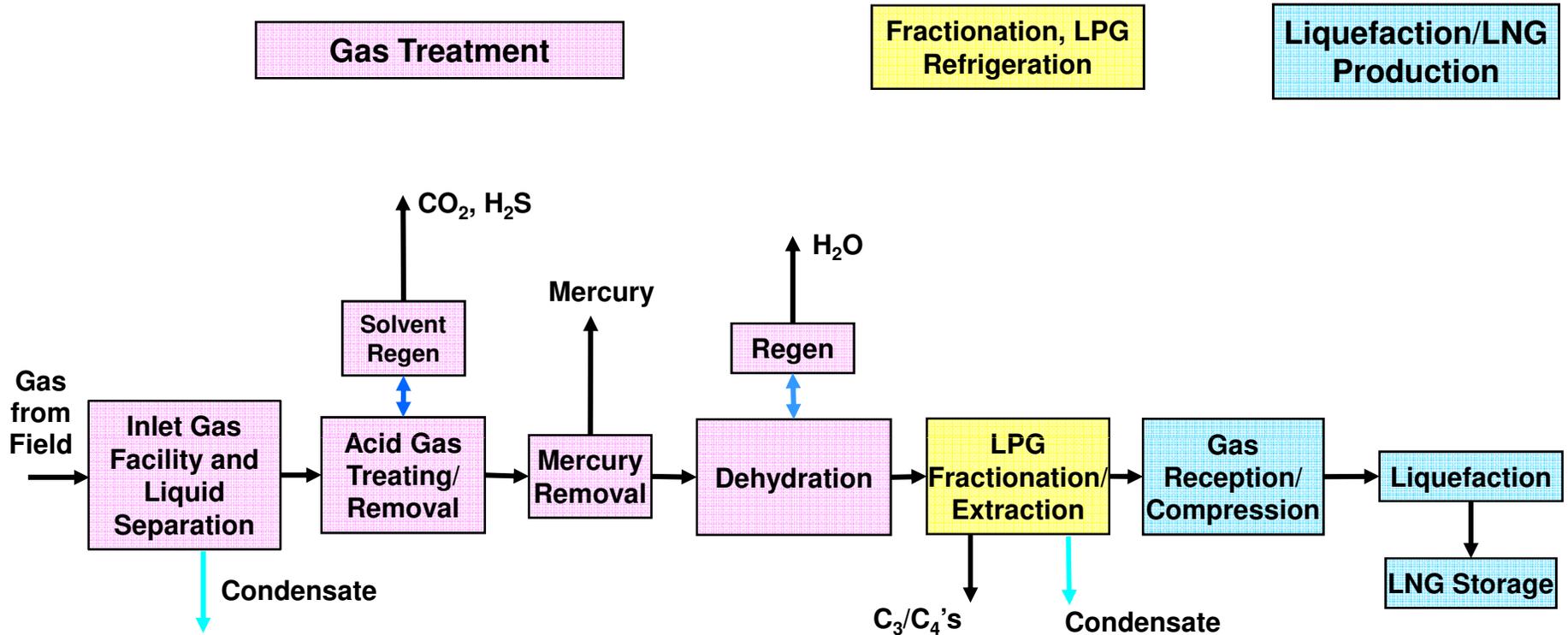
FLNG Hull Size – Present Projects

Hull Size Comparison of hull dimensions (length and breadth)



Liquefaction Process

Typical Process Block Flow Diagram

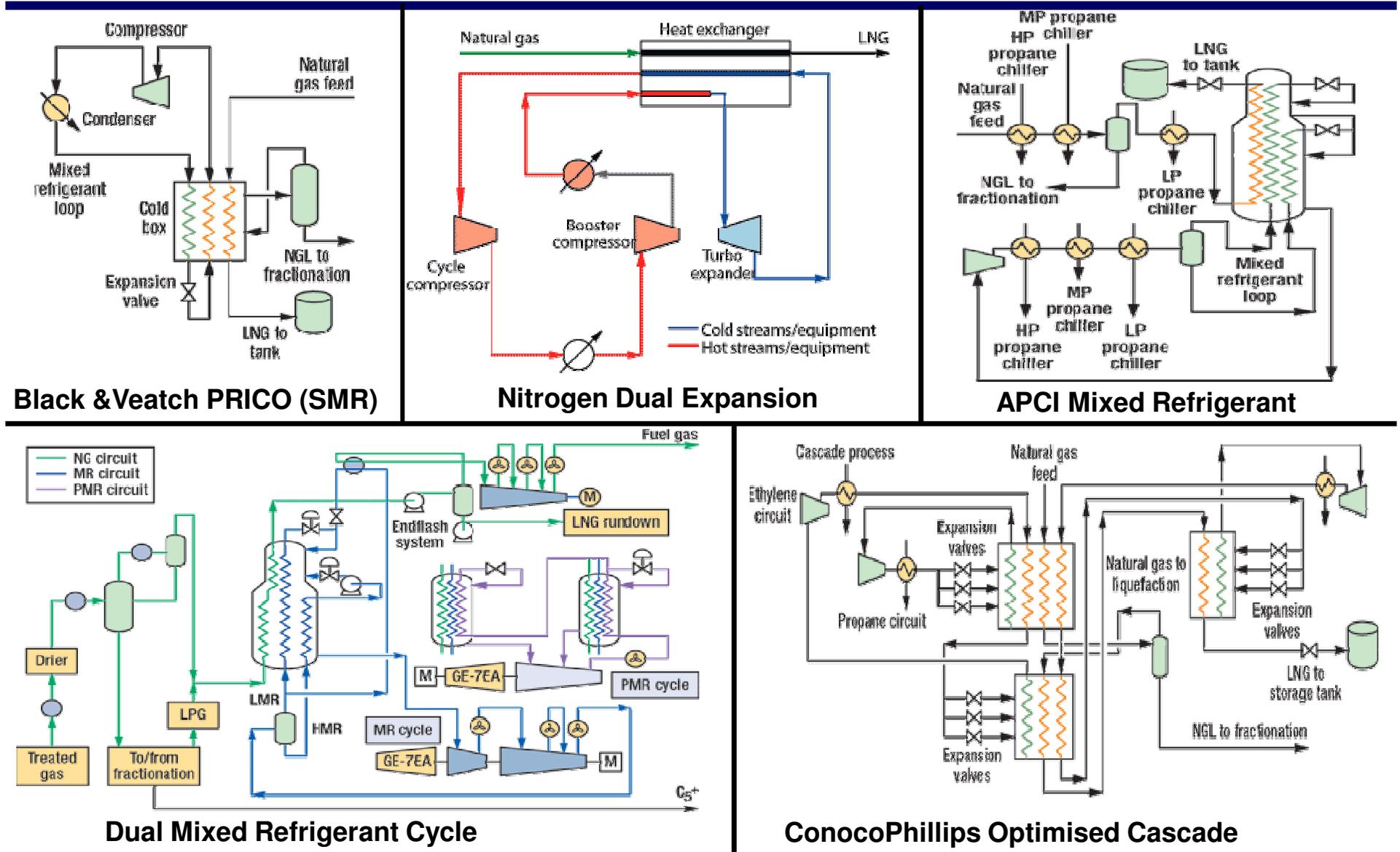


- Utility Production**
- Power Plant
 - Cooling Water
 - Water Treatment
 - Steam
 - Nitrogen Generation
 - Fresh Water
 - Fire Fighting Systems
 - Flare

Liquefaction Process Selection – Main Drivers

- Main Considerations
 - Overall Efficiency
 - Cost
 - Simplicity (Equipment count/Ease of operation)
 - Motion sensitiveness
 - Maintainability
 - Availability
 - Safety
- Main Challenges
 - Moving land based technology to an offshore environment
 - Design accelerations (Transit often dimensioning)
 - Motion sensitive process equipment
 - Restricted Footprint

Liquefaction Process Selection



Black & Veatch PRICO (SMR)

Nitrogen Dual Expansion

APCI Mixed Refrigerant

Dual Mixed Refrigerant Cycle

ConocoPhillips Optimised Cascade

Liquefaction Technology Selection

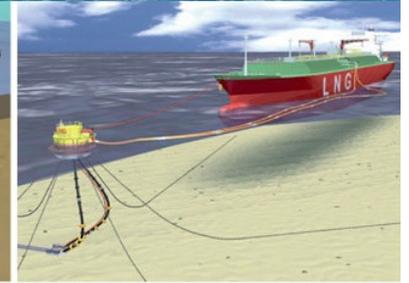
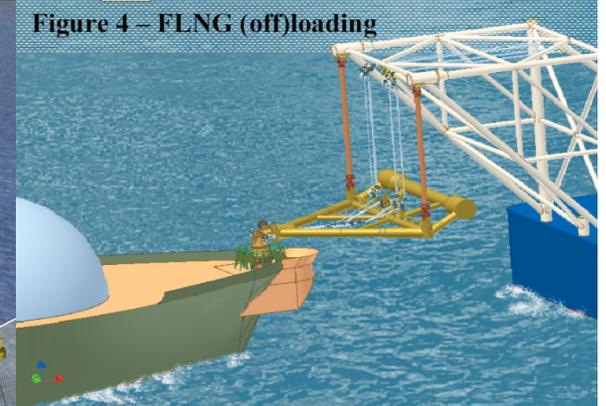
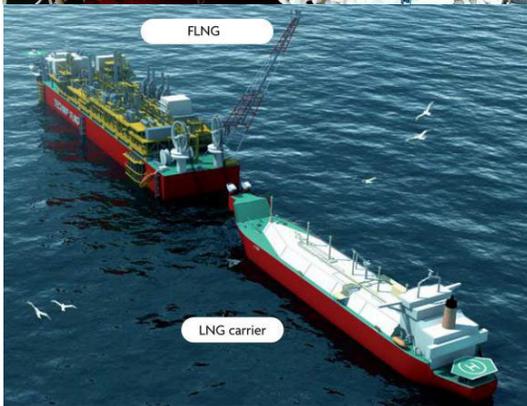
Criteria	Cascade	Mixed Refrigerant	Methane/N2 Cycle	Dual Nitrogen Expander
Uses proven technology	Yes	Yes	No	Yes
Overall space required	High	Moderate	Low	Low
Refrigerant storage hazard	Yes	Yes	No	No
Requirement for Refrigerant Import and/or Storage	Yes	Yes	No	No
Explosion/BLEVE Hazards	High	High	Low	Low
Sensitivity to vessel motion	Moderate	Moderate	Low	Low
Simplicity of operation	Moderate	Moderate	Moderate	High
Process Efficiency	High	High (DMR) Low (SMR)	Low/Moderate	Low
Flare Capacity	High	High	High	Low
Expected Offshore Availability	Low	Low	Moderate/High	High
Total Capital Cost	High	Moderate	Low	Low

Liquefaction Process Selection

- Small and Medium capacity Plants (0.5 – 2 mtpa)
 - Generally Dual N₂ Expansion and SMR favoured
 - Maximum capacity per train about 1 mtpa
 - Low Equipment count/easy to operate
- Larger capacities requires multiple trains (> 2.5 mtpa)
 - Generally Mixed refrigerant and Cascade process (single train)
 - Higher efficiency
 - Some projects still favour multiple train N₂ or SMR

Offloading

LNG Transfer Systems



Eurodim and Bluewater patents pending

Hydrocarbon Transfer – Industry Experience

Installation	Oil	LPG	LNG
Onshore Terminal (Jetty)	✓	✓	✓
Ship to Ship (Lightering)	✓	✓	±
Side by Side (Moored F(P)SO)	✓	✓	×
Tandem	✓	✓	×
CALM Buoy	✓	±	×

✓ - Many references proven in design and operation

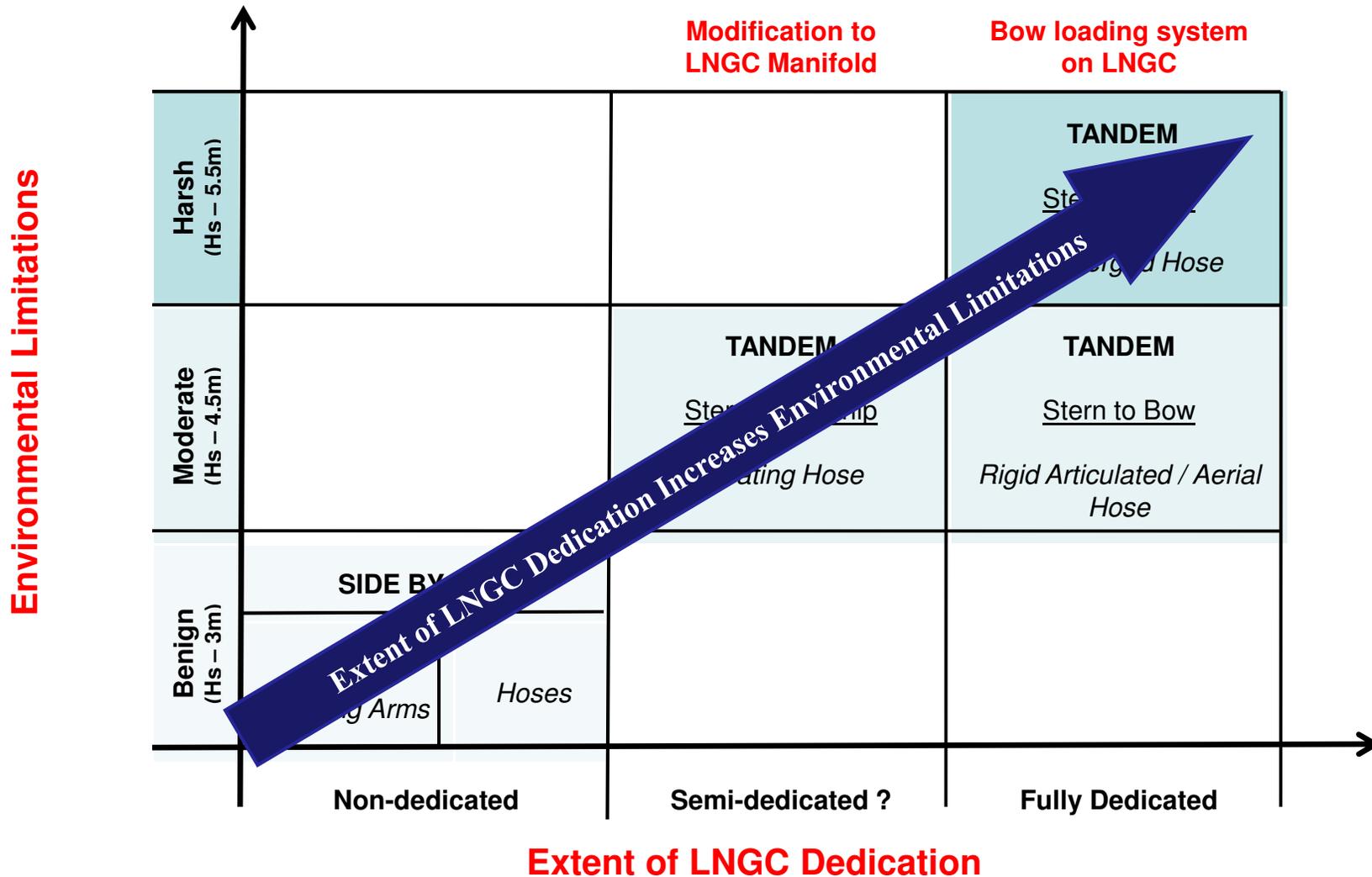
± - Limited references

× - No references, unproven in design and operation

LNG Transfer System Conceptual Options

Installation	Transfer Options / Enabling Technologies	Offloading System Components Type Approved	Proven in Operation	Dedicated LNGC Required	Environmental Limitations	Loading System Technology Availability
Side by Side	Loading Arms	✓	±	✗	Benign	Available
	Aerial Hoses <10” (Midship to Midship)	✓	✓	✗	Benign	Available
	Aerial Hoses >10” (Midship to Midship)	±	✗	✗	Benign	Further engineering & integration work
Tandem	Aerial Hose (Stern to Bow)	±	✗	✓	Benign to Moderate	Under development
	Submerged Hose (Stern to Bow)	✗	✗	✓	Benign through to Harsh	> Future
	Floating Hose (Stern to Midship)	✗	✗	±	Benign to Moderate	
	Rigid Articulated System	✓	✗	✓		
LNG CALM Buoy	Floating Cryogenic Flexible & Cryogenic Riser & Cryogenic Swivel	✗	✗	✓	Benign to Moderate	

Comparison of Different Offloading Methodologies



FLNG Projects

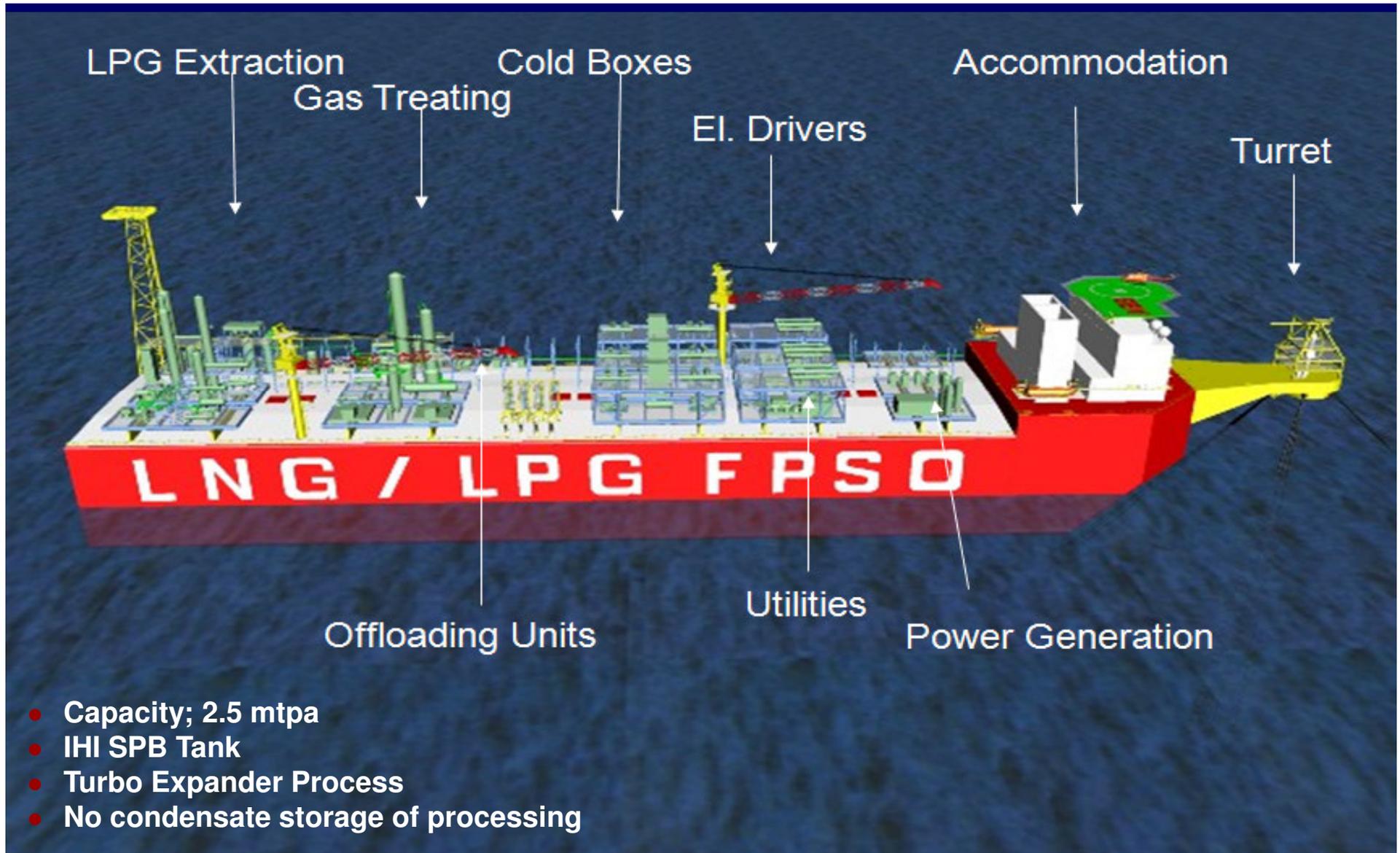
Floating Production: Main Project Parameters

- Production capacity (related to field size)
- Shipping Requirements
- Location
 - Water Depth
 - Metocean conditions
- Feed gas composition
 - Pre-treatment requirements (CO₂, H₂S, Mercaptanes, ...)
 - Products (LNG, LPG, Condensates)
- Shelf State

Floating Production: Main Design Choices

- Unit Size (Storage Capacity, incl. Buffer capacity)
- Cargo Containments System(s)
- General Layout
- Liquefaction process selection (N₂, SMR, DMR, ...?)
 - Simple and robust
 - complex and efficient
- Mooring concept
 - Turret mooring
 - spread mooring
 - quay side
- Offloading
 - Side by side
 - tandem offloading

CBI & ABB Niche LNG & LPG FPSO Topsides



SBM & Linde LNG, LPG & Condensate FPSO



LNG FPSO: Wide Range of Concepts

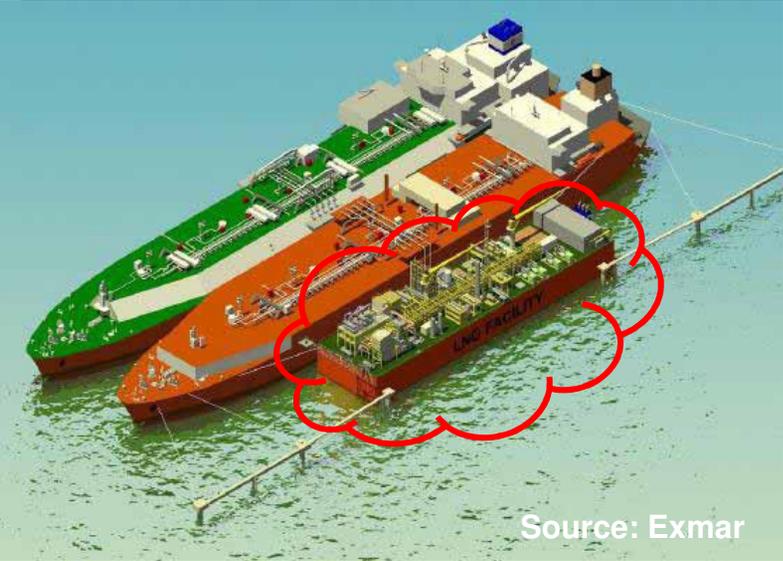
- **Production rate:** 0.5 MTPA to 5 MTPA
- **LNG storage capacity:** 14,000 m³ to 300,000 m³
- **Process plant:** N₂ expander, SMR, DMR, etc.
- **Feed gas:** rich to lean and without/with contaminants
- **Hull size:** >100 m to 500 m length
- **Topside:** 5,000 ton to nearly 100,000 ton
- **Power:** 30 MW to 300 MW
- **Steam:** 100 T to 600 T/d
- **Environment:** mild to harsh
- **Water depth:** shallow to deep
- **Mooring:** spread, turret, quay side

Wide Range of Projects



**From XXL
(Shell Prelude)**
3.6 mtpa LNG
0.4 mtpa LPG
1.3 mtpa Condensates

**To XS
(Exmar – Columbia)**
0.5 mtpa LNG



Source: Exmar

Sanctioned Projects

- Shell FLNG – FID May 2011
 - EPCIC awarded to Technip-SHI consortium
 - Prelude gas field
 - Production capacity:
 - 3.5 mtpa of LNG
 - 0.4 mtpa of LPG
 - Storage tanks:
 - Two-row GTT MarkIII (220,000 m3 LNG)
 - Two-row GTT MarkIII (90,000 m3 LPG)



Dimensions

- Length 488m
- Wide 74m
- Draught 17-20m
- Weight 600,000 ton fully ballasted; 260,000 ton dead weight



MAJOR AWARDS SO FAR

SBM Offshore:
Turret mooring system

Kawasaki Heavy Industries:
Marine boilers

GE Oil & Gas:
Steam turbine-driven compressors

Air Products:
Cryogenic coil-wound LNG heat exchanger

GTT:
Tank containment system

FMC:
Main subsea hardware

LNG Unlimited, 14/10/2011



- Petronas FLNG 1 – FID June 2012

- EPCIC awarded to Technip-DSME consortium
- Kanowit gas field
- Production capacity:
 - 1.2 mtpa of LNG
- Storage tanks:
 - Two-row GTT NO96 (177,000 m3 LNG)

Exmar –FID March 2012

- EPCIC Wison Heavy Industries
- Production capacity
 - 0.5 mtpa
 - Regas capability
- Storage tanks
 - Type C - Bilobe (14,000 m3 LNG)



Present Projects

LEADER (CONSTRUCTOR)	TOPSIDES LIQUEFACTION	LNG MTPA	HULL CONTAINMENT	STORAGE m3	PROJECT STATUS
Shell (Samsung)	Technip Shell DMR	3.5	Barge Membrane	220,000 LNG 90,000 LPG 126,000 Condensate	Prelude Sanctioned , EPC in progress Sunrise next? Inpex partner (Abadi) 4 projects planned
Petronas (DSME)	Technip/Linde MR	1.2	Barge Membrane	???	FEED completed end 2011 Sanctioned March 2012 Second unit bidding
Exmar (Wilson Offshore & Marine)	Black & Veatch SMR	0.5	Barge Type C	14,000 Part of value chain	Pacific Stratus Energy Colombia Sanctioned
Flex LNG (Samsung)	Costain/Kanfa /WParsons Dual Nitrogen	2.0	Ship SPB	170,000+ 50,000 LPG/Cond	Generic FEED 2009 Interoil PNG FEED 2011
Höegh LNG (DSME)	KBR Niche (Methane/N2)	2.0	Ship Membrane	190,000+ 20,000 LPG+ 19,000 Cond	Petromin FEED Generic FEED Tamar, Israel pre-FEED
SBM/Linde	Linde MR	2.5	Barge SPB??	180,000+ 25,000 LPG+ 25,000 Cond	PTTEP Australia Cogee FEED
GDF Suez/Santos	Doris	2.0	TBA Studies	Studies	Bonaparte Conceptual Design

Present Projects

LEADER (CONSTRUCTOR)	TOPSIDES LIQUEFACTION	MTPA	HULL	STORAGE M3	STATUS
Excelerate EBLV	Black & Veatch SMR	3.0 (3x1.0)	Barge Membrane	250,000 (incl. LPG)	Concept FEED in 2012 Lavaca Bay FEED
Petrobras (3 Bidders)	SBM/Chiyoda MODEC/Technip/JGC Saipem	2.7	Barge SPB		FEED submitted end 2010 Shelved – pipeline selected
Inpex	JGC Mixed Refrigerant	4.5	Barge		Feasibility Now with Shell
Aker/Statoil	Aker Mixed Refrigerant	5.8	Barge		FEED Shelved
BW Offshore	Mustang Nitrogen	1.0	Ship SPB/Moss		Concept
Hamworthy	Hamworthy Nitrogen	0.5-2.2	Ship Field Specific	Field Specific	Studies
TGE Marine (CMIC China)	TGE Mixed Refrigerant	0.4-1.5	Ship Type C		Concept
ConocoPhillips	ConocoPhillips Optimised Cascade	5.0	Barge	350,000	Concept Review in 2012
Sevan Marine	Kanfa Nitrogen	1.5	Circular FPSO Tank	200,000	Concept



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