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The new challenges for LNG chains

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Rueil-Malmaison

22 April 2013

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New challenges for LNG chains

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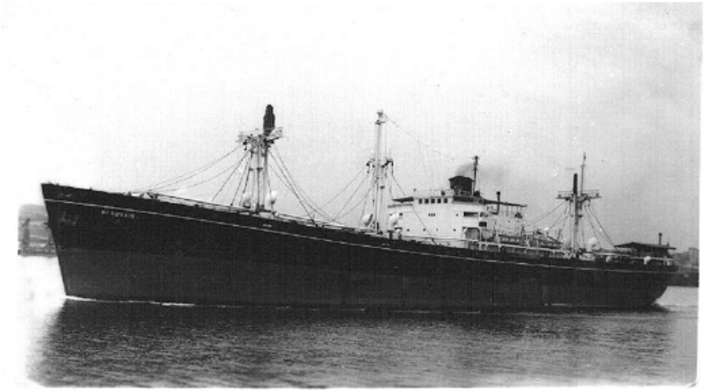
Current market needs driving innovation

- **What are the current market needs and corresponding innovations to develop the LNG market ?**

Needs	Liquefaction	Shipping	Regasification
Feed new markets (low initial capacity, short time to market, first step before onshore regas)			❑ FSRUs ❑ Ship-to-ship transfer
Monetize new gas fields	❑ FLNGs (offshore) ❑ Ship-to-ship transfer ❑ Barges (nearshore / at berth) ❑ Arctic conditions	❑ Ice-breakers	
Reduce costs / impacts	❑ FLNGs (offshore) ❑ Modularization ❑ Efficiency improvements	❑ Size ❑ Propulsion ❑ BOG	❑ BOG management (FSRUs) ❑ Air heating (onshore)

GDF SUEZ experience in developing new LNG technologies

- 50 years in the LNG business and LNG technology development
- First LNG chain to supply Le Havre, France (Gaz de France) and Canvey Island, UK (British Gas) from Arzew (Algeria) in 1964
- 1980: Montoir - First to build membrane full containment tanks
- 2000: Commissioning of a peak-shaving in Shanghai using proprietary CII liquefaction process
- 2001: Partner in Snohvit's innovative liquefaction project in the Arctic
- 2002 : First to order Diesel electric LNG carriers
- Delivery of 2 Shuttle and Regasification Vessels in 2009-2010
- Leverage in-house Research and Development Centre as well as its international partnerships



« Le Beauvais », experimental ship, 1958

GDF SUEZ Neptune, 2010

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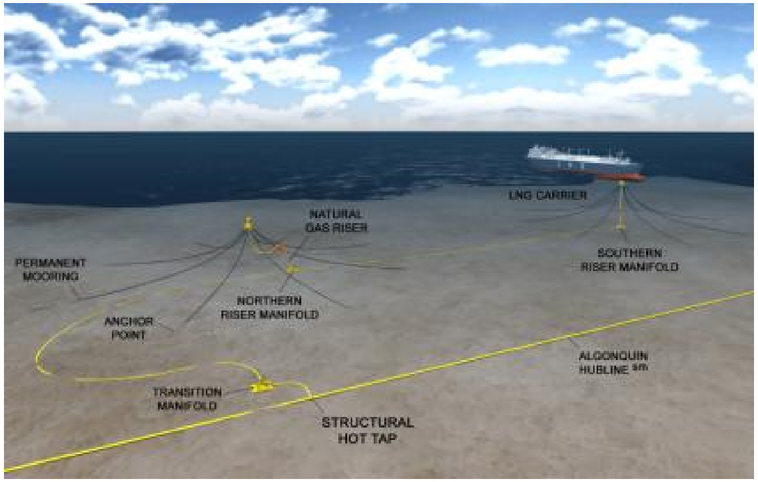
Floating Regasification to feed new markets

- **Initial scheme : Shuttle Regasification Vessels**
  - ➢ to bring an answer if no appropriate site onshore
  - ➢ to ease permitting (located offshore ; connected through a turret)
  - ➢ regasification onboard used part time (when moored)



Neptune (offshore Boston)

- **New scheme : FSRUs**

  (Floating Storage and Regasification Units)
  - ➢ to quickly bring regasified LNG to a new market
  - ➢ to back-up the existing grid during peak periods
  - ➢ “permanently” moored, offshore or in a port (quay, berth)
  - ➢ LNG transfer: ship-to-ship (aerial flexible hoses, articulated arms) or ship-to-jetty-to-ship

Ship-to-jetty-to-ship – Mejillones FSU (Chile)

Reduce Costs / Impacts in Regasification

- **FSRUs :**

  Being regularly used in regasification mode, their efficiency has to be improved and the evolutions are now :

  - ➢ Open-loop (limit fuel consumption)
  - ➢ Recondenser (limit BOG flaring) ; a higher operating pressure of LNG tanks would even more simplify BOG management

Side-by-side transfer (By courtesy of Hoegh LNG)

- **Onshore plants:**

  - ➢ Air heating where air temperature is high enough (first application in Dahej) → no impact on water, provide fresh water, lower costs

Dahej terminal (By courtesy of Petronet LNG)

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New challenges for LNG chains

Monetizing stranded gas fields : FLNGs

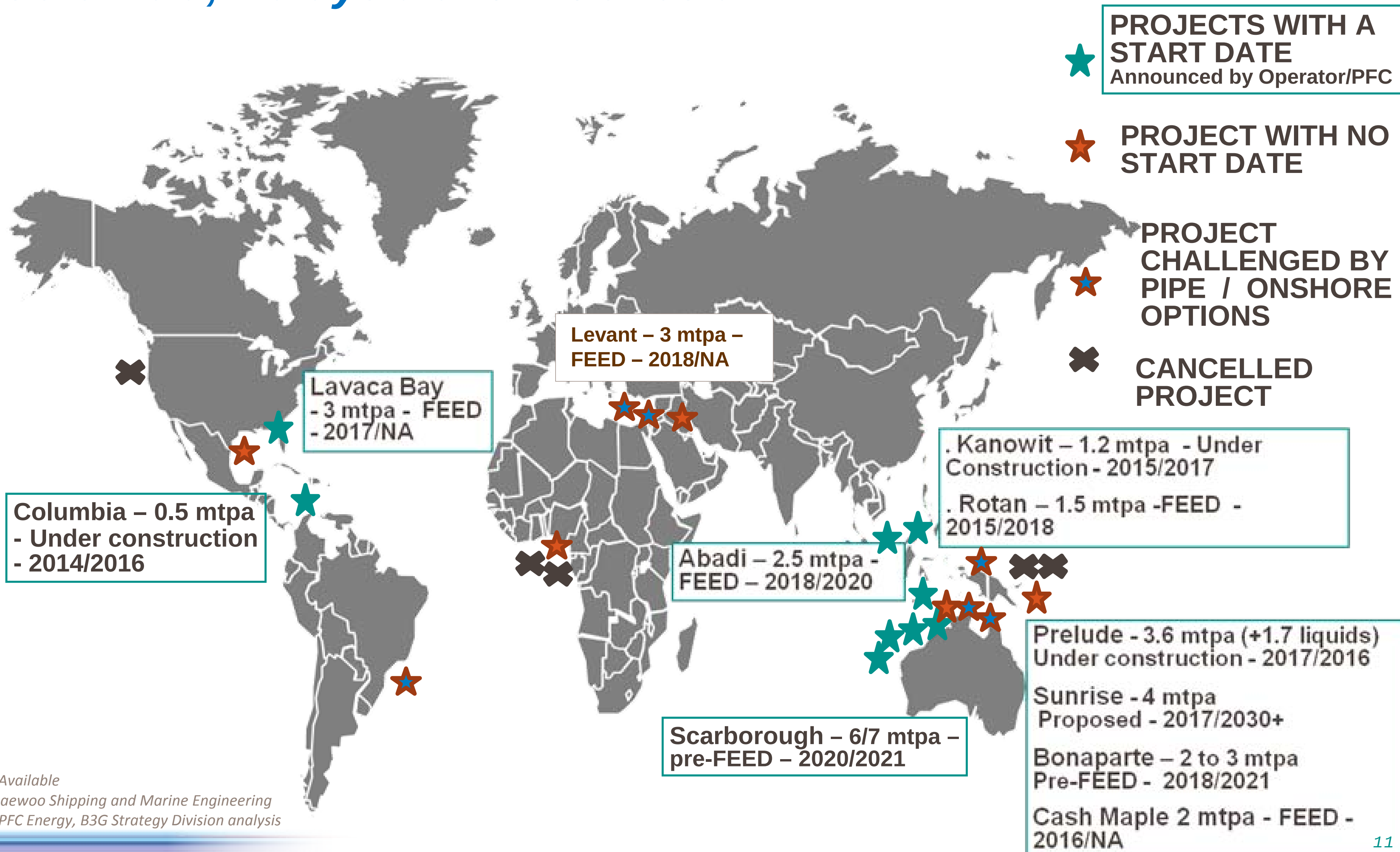
~ 8,500 offshore oil & gas fields with >1.5 Tcf commercial reserves or technical resources around the world (Source Wood Mackenzie)

FLNGs are an option to monetize remote medium-sized gas fields

- Reduced environmental footprint : no need to compress the gas for transmission purposes, to lay down long pipelines to shore, to dredge, to build a jetty and an onshore LNG plant
- Can be cost-effective versus onshore options (for remote gas fields, high local labor costs, lack of appropriate onshore sites,…)
- Can limit execution risks (construction controlled in a shipyard, limited soil quality issues)

Overview of FLNG projects in the world

- ***The most advanced projects are located in Western Australia, Colombia, Malaysia and Indonesia***



NA: Non Available
DSME= Daewoo Shipping and Marine Engineering
Sources: PFC Energy, B3G Strategy Division analysis

FLNG Developments and players

- 11 FLNG projects worldwide with an announced start date (average capacity 2.4 mtpa, excluding Scarborough 6-7 Mtpa)
  - Only 3 under construction (3.6 mtpa + Shell Prelude, 1.2 mtpa Petronas Kanowit , 0.5 mtpa Pacific Rubiales)
  - Some other projects are challenged by pipe or on-shore options (Brazil, Timor Leste, Papua New Guinea, East Mediterranean)
- Economics are heterogeneous and need to be confirmed, but FLNG could compete with on-shore projects
- Shell, Petronas, Inpex and Exmar are the most advanced promoters
- EPCIC companies : front-runners are Technip, Samsung, DSME but a lot of others are involved:
  - KBR, JGC, SAIPEM, Toyo, CB&I,
  - HHI, IHI,
  - Modec, BW, Hoegh LNG, etc

FLNG economics

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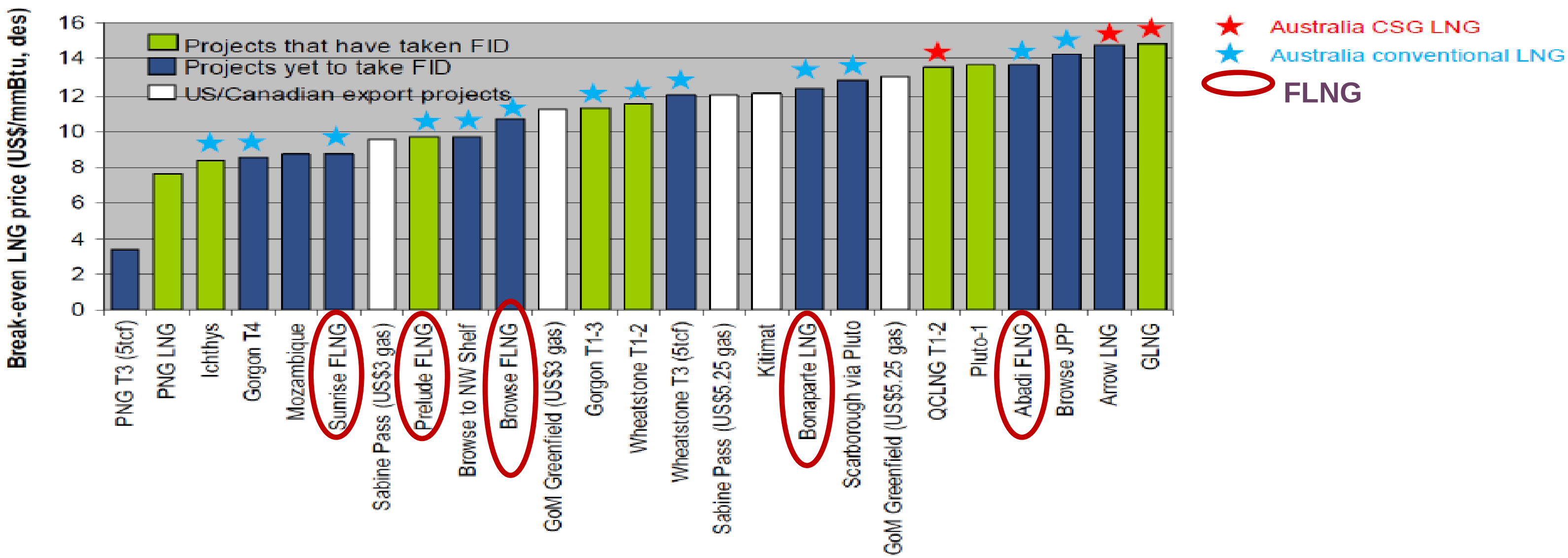
FLNG projects can challenge other LNG projects *(Source: Citi Research)*



Nearshore barges to liquefy onshore gas

- Attempt to decrease CAPEX when a protected area is available near shore or at berth/quay to liquefy gas
- Potential simplifications : no thrusters, no turret, no living quarters, limited LNG storage (FSU can be added), power can come from the grid
- One 0.5 mtpa project developed off Columbia by Pacific Rubiales / Exmar, with regas facilities in case of redeployment (FLRSU)

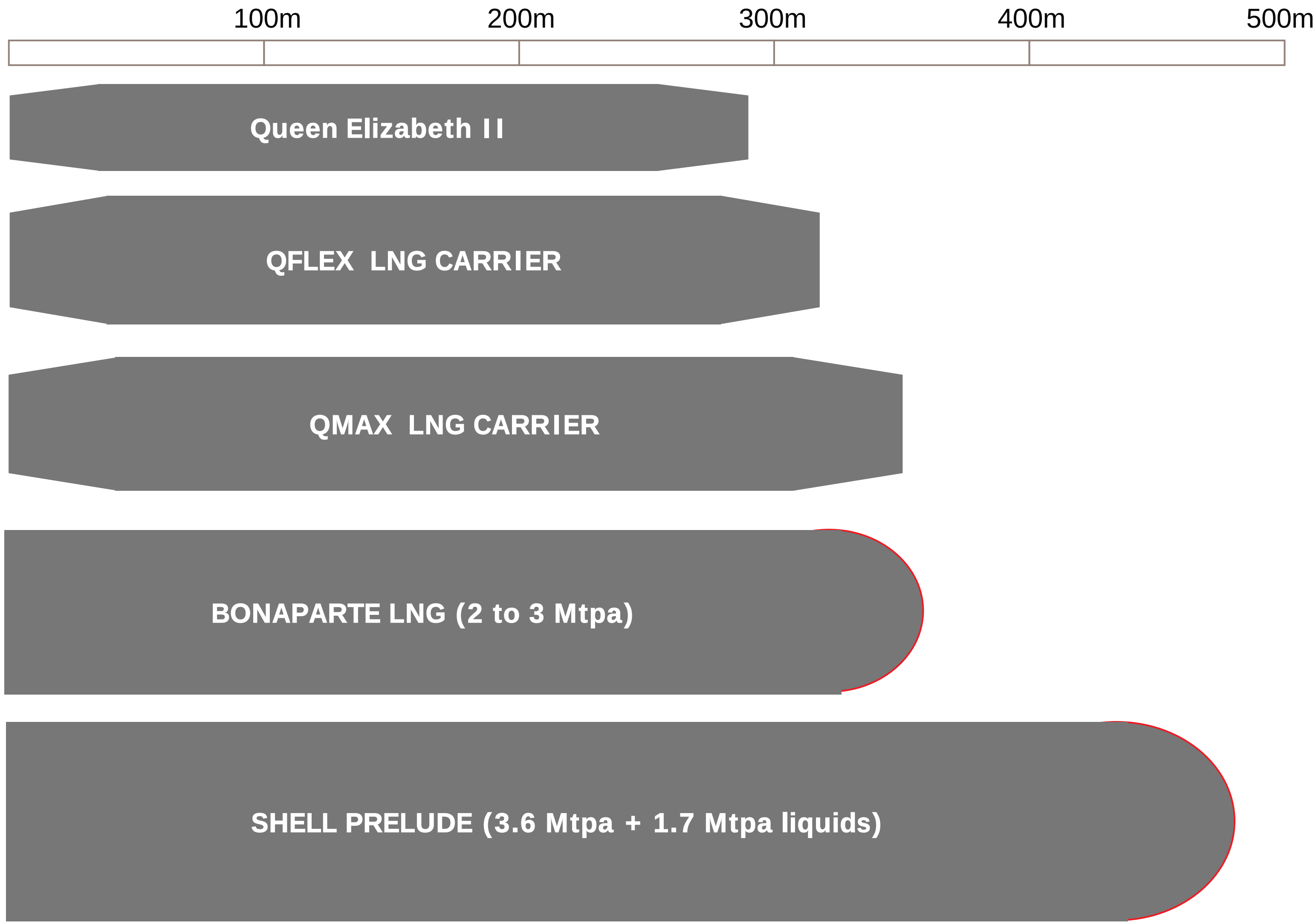
Pacific Rubiales FLRSU (By courtesy of Black and Veatch)

Key challenges for FLNG design

- Metocean constraints (berthing, cyclones)
- Hull (remain compatible with shipyard facilities)
- Turrets (efforts, safety)
- Topsides :

- Weight : to be strictly monitored (weight of topsides can be equivalent to the weight of a standard LNG carrier, supported by a hull three times heavier)
- Congestion : constructability, safety issues
- Motions : qualification of gas/liquid heat exchangers (distribution of liquids), columns (structural), rotating equipment (efforts, three-point support, marine environment, use of aero-derivative GT as mechanical drive), sloshing in LNG storage

FLNG hull size compared to other ships



Key points to be validated in FLNG design

Gas liquefaction process and mechanical drivers:

(N2 expansion, SMR, DMR)

Comparison and prequalification of liquefaction processes and technologies to drive the compressors (Gas Turbines, Electric Motors, Steam Turbines)

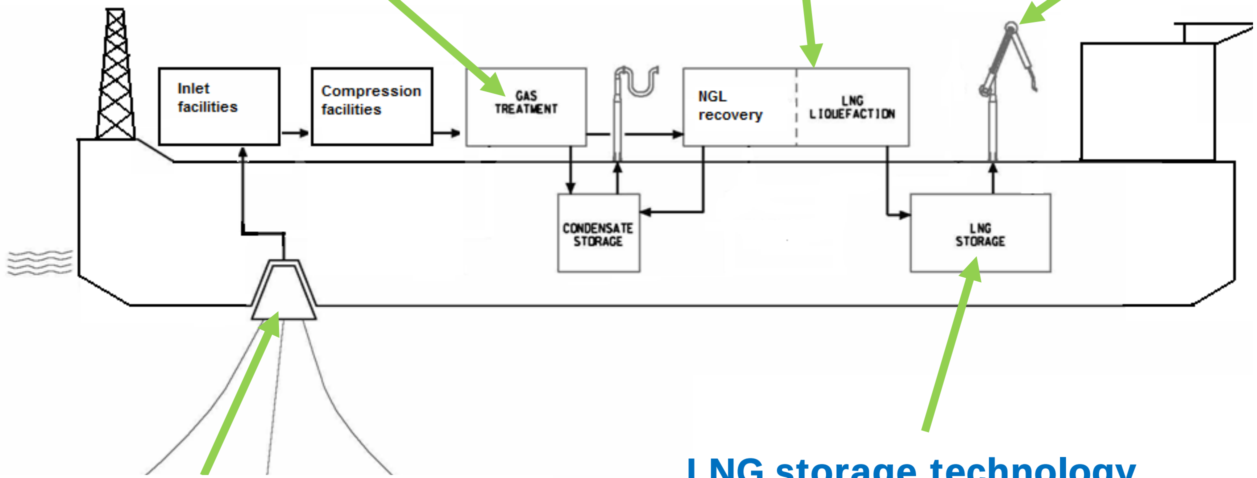
Gas treatment processes

(AGRU, Dehydration, Hg removal)

Selection of processes and technologies, qualification of motion sensitive equipment

Offloading system:

- Validation of side by side transfer using marinized loading arms according to metocean conditions (wind, waves, currents) and safety constraints
- Qualification of equipment
- Definition of operational limitations
- Survey of Tandem systems development as alternate solution if required



Turret

disconnectable or not disconnectable

FLNG sails away when cyclones alert or permanently moored and designed to face 10,000 years return period Metocean event

LNG storage technology

Membrane (GTT) or SPB (IHI)

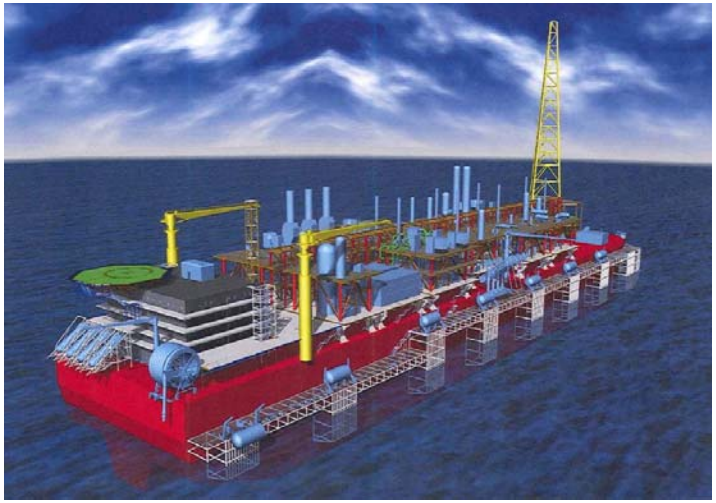
Qualification of containment system to afford sloshing meeting high reliability and safety criteria and high availibility level

Bonaparte FLNG : Validated key points

Stay on station or Sail away ?

- The location is a cyclone origin area, resulting in frequent warnings with little time to determine likely severity
- Improving the design from 100 years (winter storms) to 10,000 years (cyclonic storm) not significantly more onerous ; owing to short distance for wave height development even in high severity cyclones
- Sailing away leads to significant loss in production as every event results in a disconnect

Permanently moored station is selected



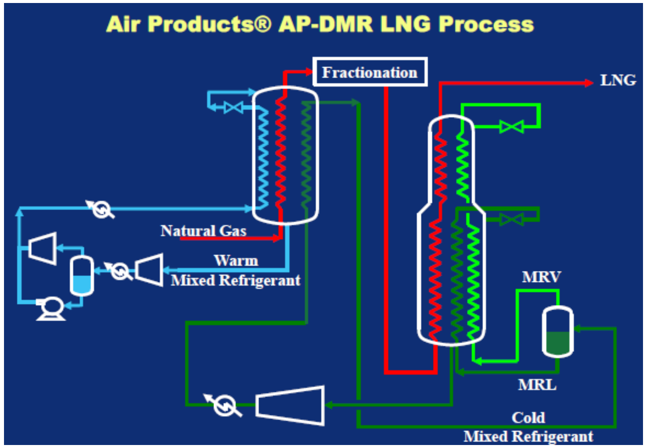
Gas treatment processes :

- **Acid Gas Removal Unit :** this is the most challenging equipment as the removal of CO_2 down to 50 ppm is usually done onshore through high columns (amine absorber and regenerator) whose efficiency could be affected by motions. Nevertheless, thanks to physical models, some vendors are able to guarantee separation efficiency with MDEA for motions (roll, pitch) which will be very rarely obtained on this site. **MDEA process is selected.**
- **Dehydration, Mercury removal :** Standard technologies used onshore, not sensitive to motions as solid adsorbers, will be selected here (molecular sieves for dehydration, sulphur impregnated carbon for mercury removal).

Bonaparte FLNG : Liquefaction process

An extensive comparison of suitable processes has been conducted during Concept Selection

- Selection among 13 processes, based on gas (flammable or not) expansion or liquid hydrocarbon refrigerant
- Deeper comparison, involving process licensors and equipment vendors, made for 7 processes against Open art nitrogen expansion,
- At this stage, **APCI DMR is selected** as the base case for the next phase of this project



APCI Dual Mixed Refrigerant

Selection criteria applied to DMR:

- **Safety** : preliminary QRA shows a risk level similar to N2 expansion (higher risk from explosion but lower risk of fatalities due to unignited leaks; limited contribution to the global IRPA anyway)
- **Environment :** lower CO2 emissions due to higher efficiency
- **Technical robustness / Operability** : limited number of equipment (one train for 2 to 3 mtpa), heat exchangers proven onshore and not much affected by motions, support from an experienced licensor
- **CAPEX / NPV :** overall CAPEX/NPV should be similar (similar CAPEX, lower availability but better efficiency)

Bonaparte FLNG : Mechanical drivers

Comparison of drivers for liquefaction compressors has been conducted as well

- Availability of such drivers with the appropriate power is key for the design of liquefaction trains
- Steam turbines discarded first due to higher CAPEX, number of equipment, space requirements, and operation issues
- Study of Gas Turbine-drive versus Electric motor-drive carried out with an external consultant, including inputs from vendors
- At this stage, **GT-drive is selected** as the base case for the next phase of this project

Selection criteria :

- **Safety :** some advantage to E-drive but with a very limited contribution to the global IRPA anyway; in case of E-drive, power is also produced by Gas Turbines
- **Environment :** some advantage to GT-drive in terms of CO2 emissions (avoid power losses in the distribution system) but not very significant
- **Technical robustness / Operability**: similar level with pro and cons for each technology (lack of offshore references for the largest drivers)
- **CAPEX / NPV :** better NPV for GT-drive due to lower CAPEX and OPEX (lower number of equipment, weight and footprint) and better efficiency, despite lower availability

Bonaparte FLNG : Offloading systems

Availability issue : Need for a system able to carry out the whole LNG loading process in a safe manner within an expected 24 h window from approach to departure of LNG carrier.

Options :

Base case studied

Side by Side through rigid arms or flexible hoses

Pros: existing technologies, existing LNG carriers fleet
Cons: metocean limitations for operation

Alternative case

Tandem through flexible hoses

Pros: Increased operational windows (metocean)
Cons: lack of experience, need for specific LNG carriers

Taking into account Full bridge simulations, basin tests and numerical simulations carried out for the Triton FSRU project, and preliminary QRA, downtime studies and FLNG/LNGC side by side moored dynamic simulations specific to Bonaparte, **Side-by-side is selected for this site** (mooring limitations not reached 98.8% of the time)

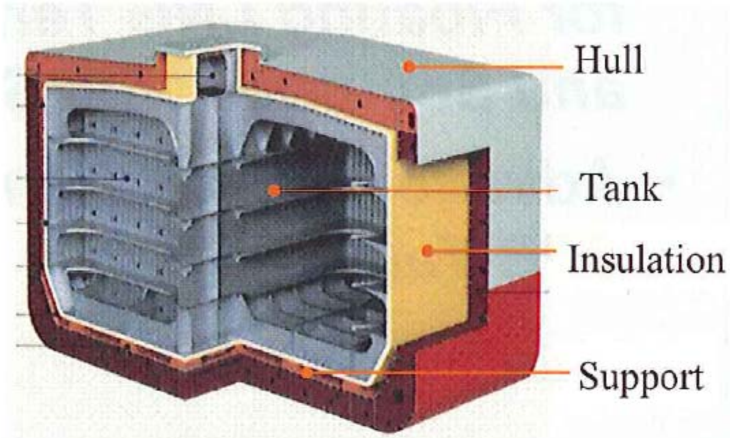
Bonaparte FLNG : LNG cargo containment system

- **Issues :**

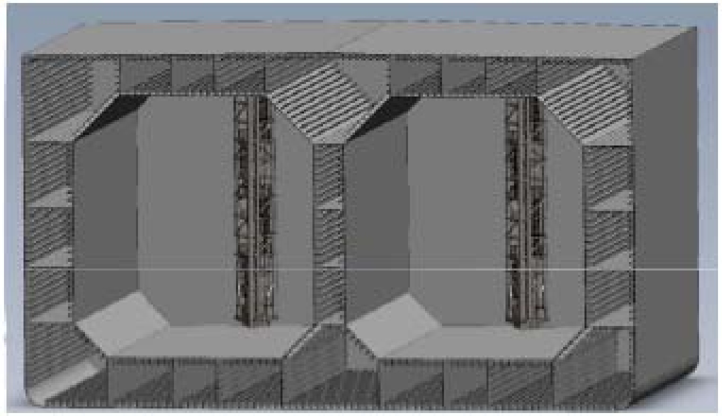
Design : tank size, hull shape vs capacity, integration below deck bearing topsides, construction timeline

Operation : partial filling capability considering sloshing aspects, cargo and boil off handling, offshore maintenance and repair (impact on availability), operational feedback

- **Options :**



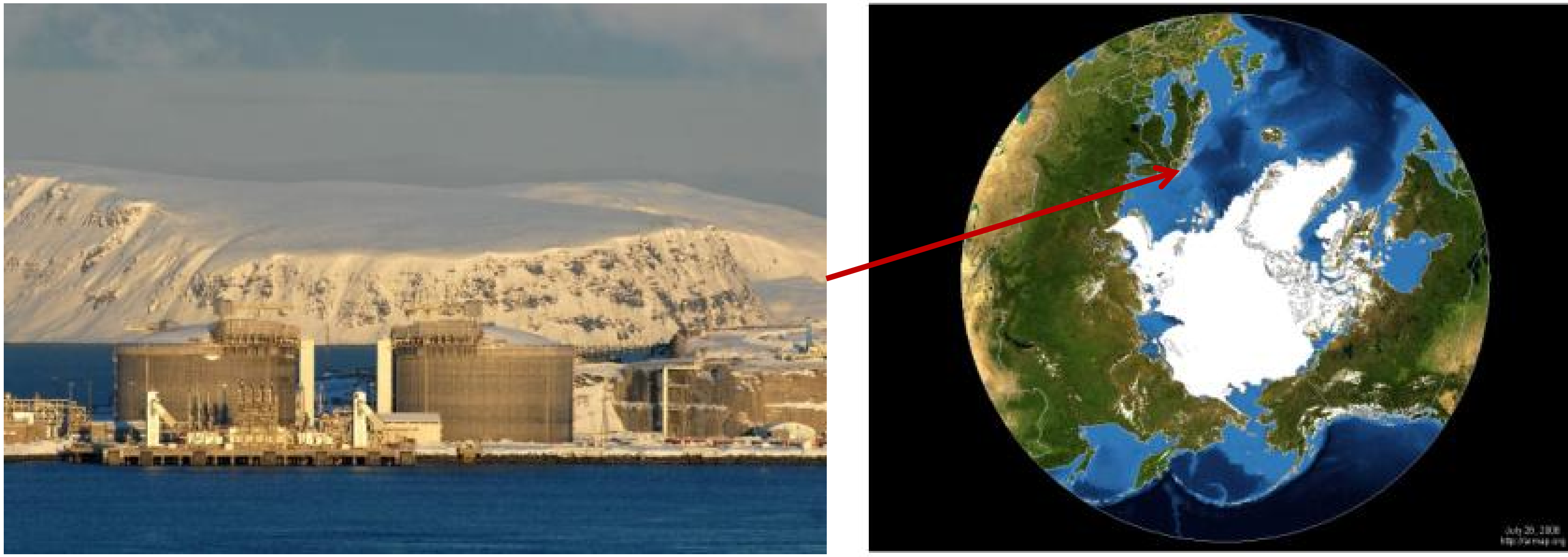
Semi Prismatic type B (IHI)



Double row membrane concepts (GTT)

Taking into account the elements provided by the vendors, **both technologies are qualified for the next step.** NPV might be the decisive element after a call for tenders.

Arctic – a new Eldorado for LNG?



- A large share of the world's oil & gas reserve is located far North, in cold Arctic regions.
- In 2007, Snøhvit LNG plant (Snow White) was the first LNG plant located in this area (70 degrees north) and the first LNG plant in Europe.
- Previously developed to supply the North American and the European markets, Arctic projects in Norway and in Russia are now boosted by additional LNG demand in Asia Pacific.

Arctic projects locations

Yamal LNG T1-3
16.5 Mtpa

Pechora LNG – 2.5 Mtpa

Shtokman LNG – 15 Mtpa

Snøhvit LNG T1 – 4.2 Mtpa

- Existing
- In FEED
- Proposed
- Stalled

Arctic LNG: key projects risks

- **Challenges: severe constructing and operating conditions, ice-bound shipping lanes, high costs and distance from markets make them one of the most expensive LNG projects in the world.**

- **Financial Risk price tag is likely to be high due to the technological challenges associated with the projects.**

- **Geopolitical and Environmental Risk:**
  - Arctic is an environmentally sensitive area, and projects could face pressure from environmental groups; intervention in case of oil spill difficult
  - Ice melting may redefine frontiers

Picture - Source: courtesy of Yamal LNG

Arctic LNG: key projects risks - Construction

Possible construction techniques

- **Onshore / Stick building = standard piece by piece site construction.**
  - Climatic conditions and weather delays
  - Skilled labor cost and large workforce on site
  - Very low productivity (3:1 vs Gulf Cost) and approximately 2 months/ year interruption of construction work
  - Welding

- **Near shore / Barge = dry dock construction of a fully equipped barge .... sunk on foundations / piles at the final place.**
  - Frozen soil to be excavated for dock preparation
  - Permafrost damage
  - Draft (dredging)
  - Piling system

Arctic LNG: key projects risks - Construction

Possible construction techniques

- Onshore / Modularization = yard construction of a fully equipped module. Modularization is a reasonable technique for the process units in Northern Arctic and harsh contexts, with very tight planning

- Pros
  - Construction in a fabrication yard in much better productivity conditions
  - and lower unit cost than on site (particularly in very harsh conditions),
  - Better welding conditions, ...

- Cons
  - Versus traditional stick building, significant steel additional cost
  - More imbricated construction; needs compact and simple shapes,
  - Connections between modules need high tolerances,
  - Foundations must be accurate and ready when modules arrive on site, ...

- Full coordination between module fabrication and site/civil contractor is of paramount importance

Arctic LNG: Winterisation

- ***"Winterisation" : protective measures to be implemented for constructing, operating and maintaining the plant in relation with the harsh climatic conditions.***

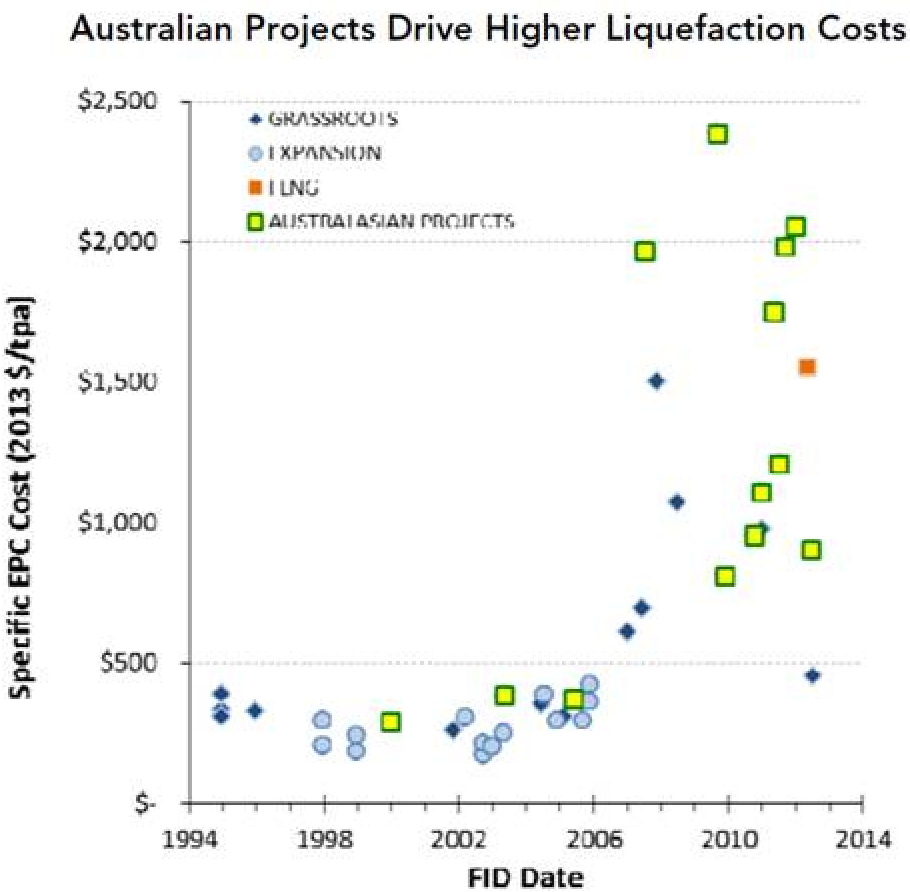
- ***Process/Piping:***
  - **Above ground lines at 1.5m elevation, heat traced and lagged**
  - **Buried lines at least 1m below surface and kept frozen at <-2°C**
- ***Civil/Construction***
  - **Direct contact of sources of heat with permafrost avoided by piling and/or subcooling of ground**
  - **Some construction works, for instance welding, cannot be made in very adverse climatic conditions (low visibility, wind, cold temperatures, fog, blizzard or snowfalls)**
- ***Planning***
  - **Difficult access / logistics by sea during winter and by land during summer**

Controlling Liquefaction costs / impacts

➢ **Cost increase driven by Australian projects** (availability and cost of materials, skilled labour and services, environmental constraints)

➢ **Modularization** is an option to limit cost increase in high labour cost countries (build modules elsewhere and assemble onsite)

➢ **Improving the economics through a better efficiency** : use of aeroderivative gas turbines, replacement of JT valves by Liquid or 2-phase expanders for end flash



Source: Poten & Partners

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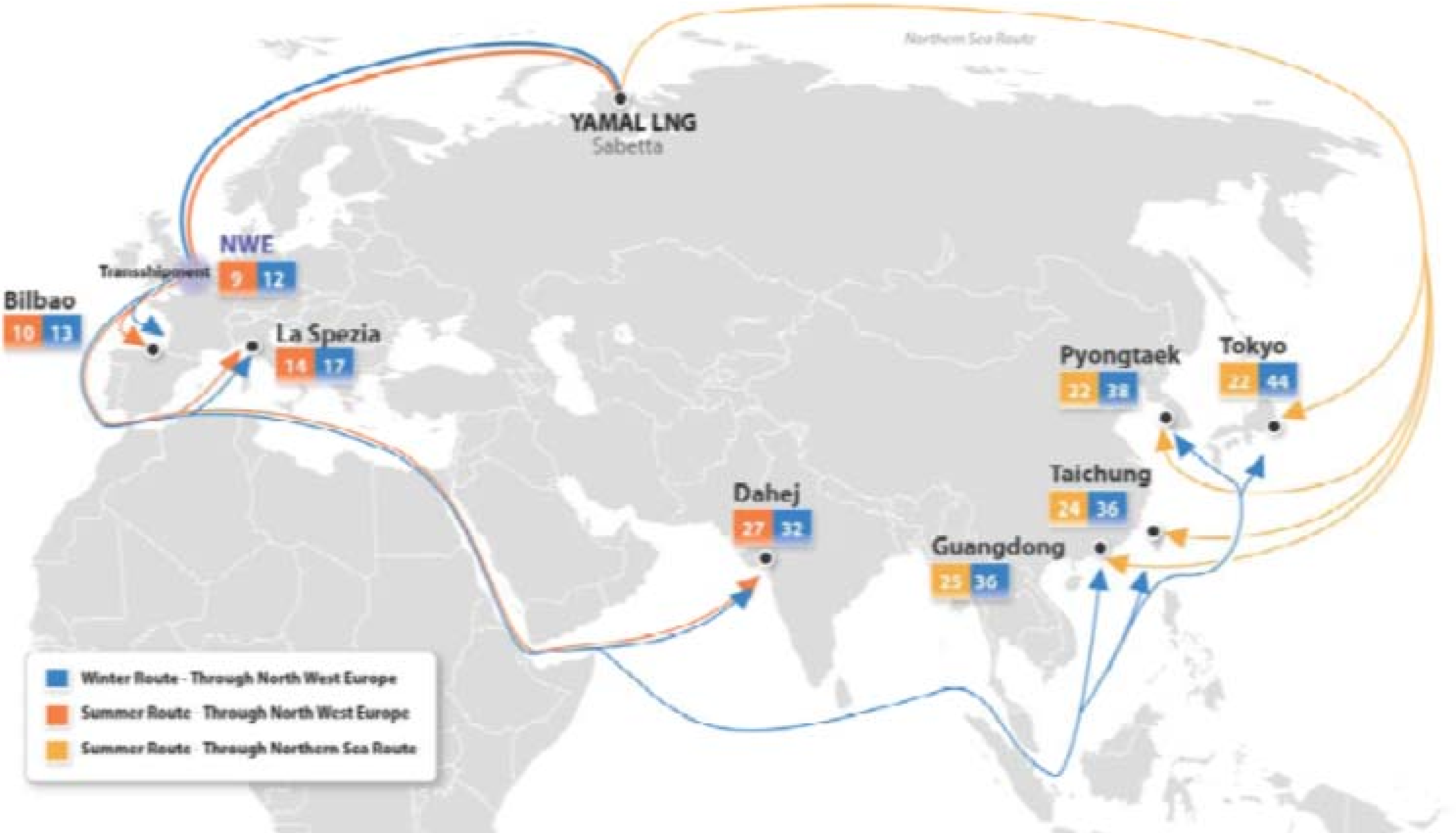
Monetizing arctic fields : also a shipping issue

- **Route from Yamal to Asia are free of ice for only two months per year.**
- **Novatek shipped ~600,000tonnes of condensate over 9 cargoes in 2011 .**
- **In October 2012, Gazprom successfully navigated 147,000m3 LNGC Ob River in ballast through the northern route to Montoir.**

Voyage time from Yamal LNG – Summer and winter



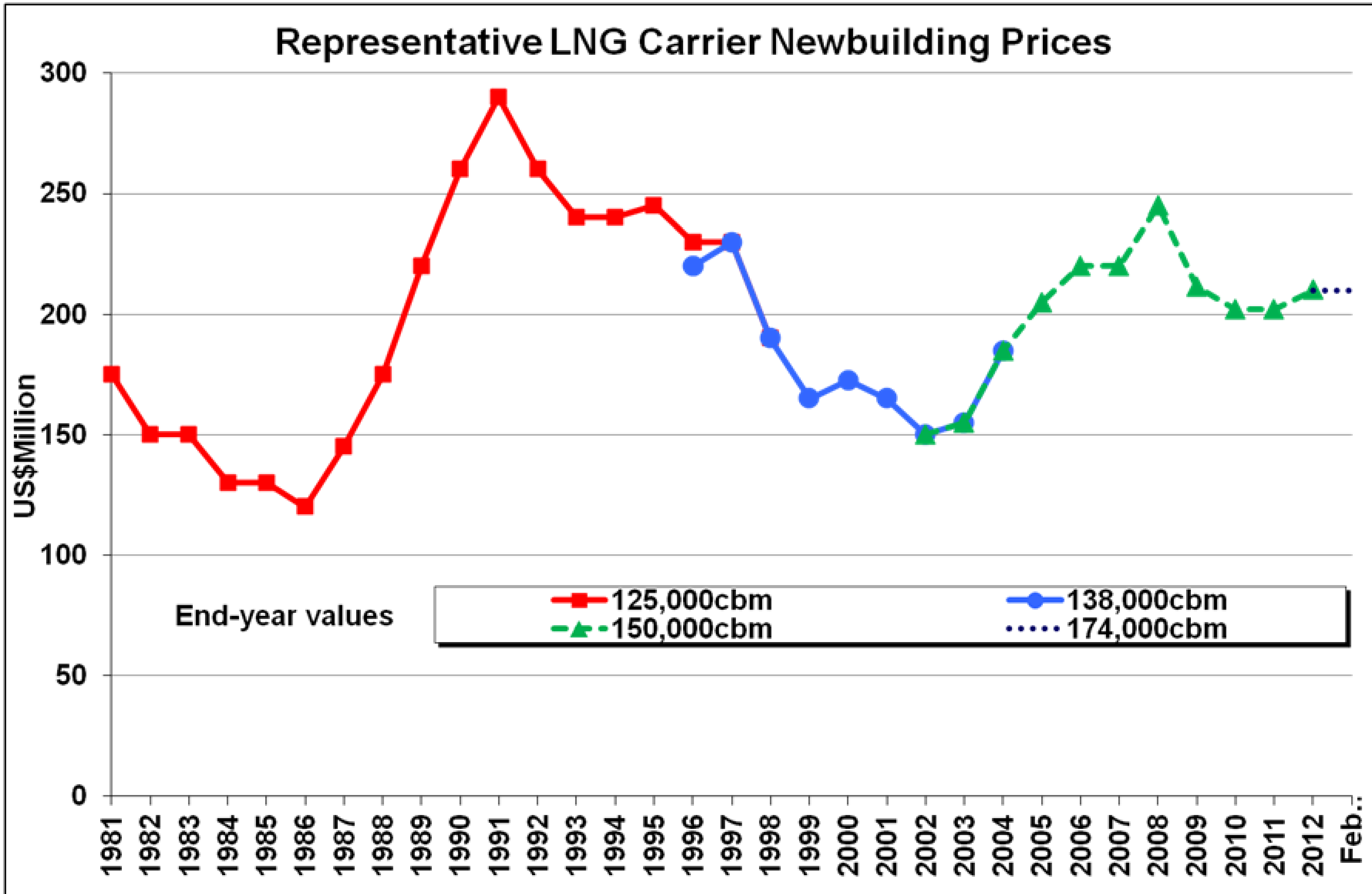
Source: Yamal LNG Presentations, Poten & Partners

Ice class LNG vessels for Yamal LNG project

Picture - Source: courtesy of Yamal LNG

- *Ice class LNG vessels would be used to ship through Kara Sea at all times, to Europe and to Asia through the Northern Route.*
- *Ice class ARC7 (Russian classification).*
- *Capacity: 170,000 m3.*
- *From 12 to 16 ice breaking LNG vessels would be used by Yamal LNG.*
- *Ships would cost between US $300 to $350 million each.*

Prices of newbuilt LNG carriers (Source Simpson Spence & Young) :
mainly linked to shipyard workload and market conditions



Reducing shipping costs

- **Increasing the size of LNG carriers ?**

➢ Qatar switched abruptly from 150,000 to a fleet of 215,000 / 265,000 m3 LNGc (43 built between 2005 and 2009)

➢ Many current orders (around 90) now focus on 170,000 – 180,000 m3 (compatible with most of export/import terminals and with the new Panama channel dimensions)

- **Propulsion and Boil-Off Rate**

➢ Many newbuilds moved away from conventional steam turbine to more efficient Dual Fuel/Tri- Fuel Diesel Electric engines, or enhanced steam turbines

➢ This induces a request to reduce the BOR (from 0.15 to 0.10%/day)

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