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Bulk carrier technologies for the near future – composites, hybrid and LNG

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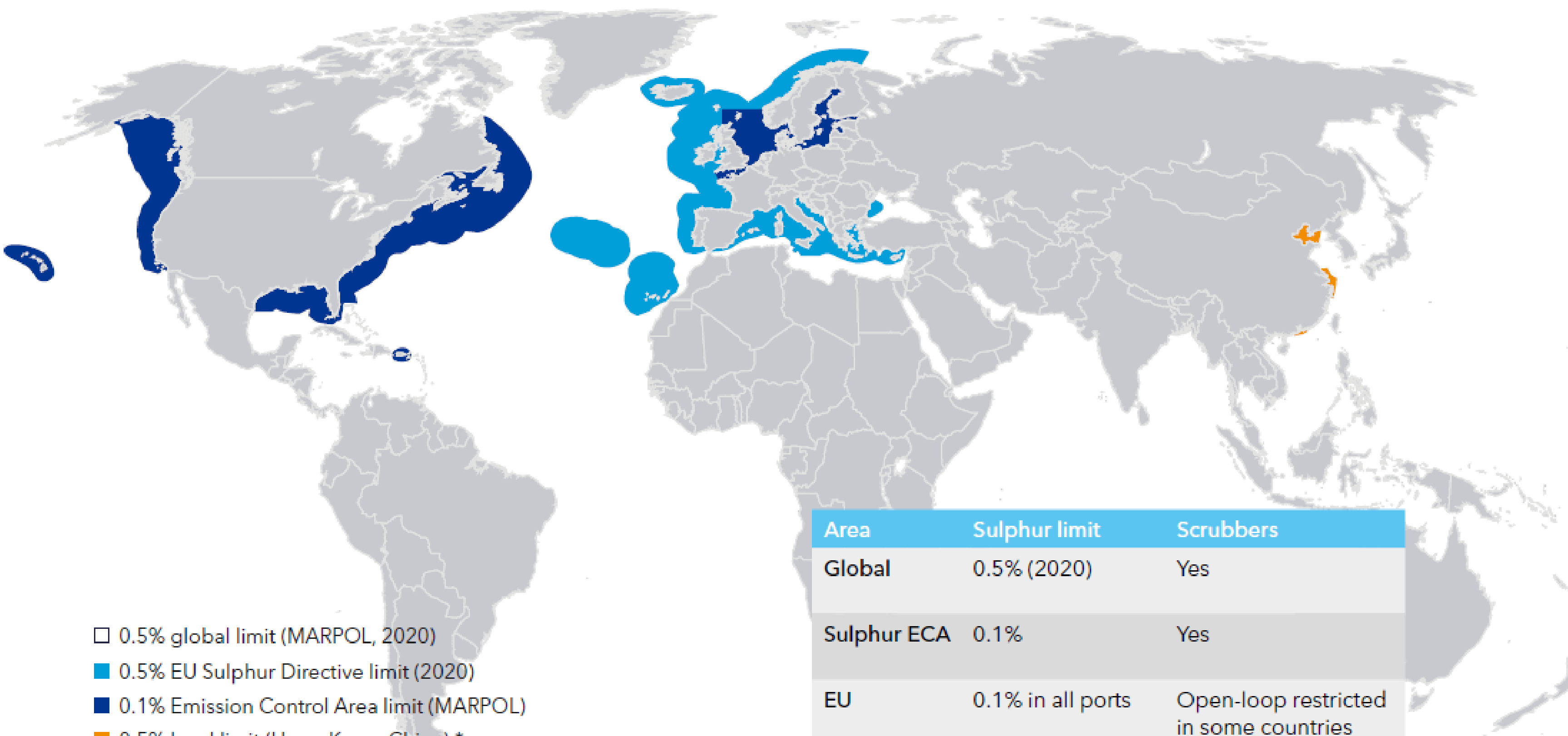
Joint Industry Project "Green Corridor"
- LNG fuelled Bulk Carriers Operating from Western Australia

SAFER, SMARTER, GREENER

Why LNG as fuel for bulk carriers?
- Environmental regulations (1/2)

SOx



Area	Sulphur limit	Scrubbers
Global	0.5% (2020)	Yes
Sulphur ECA	0.1%	Yes
EU	0.1% in all ports	Open-loop restricted in some countries
China	0.5% in selected areas	Yes
California	0.1% within 24 nm	No, only through research exemption

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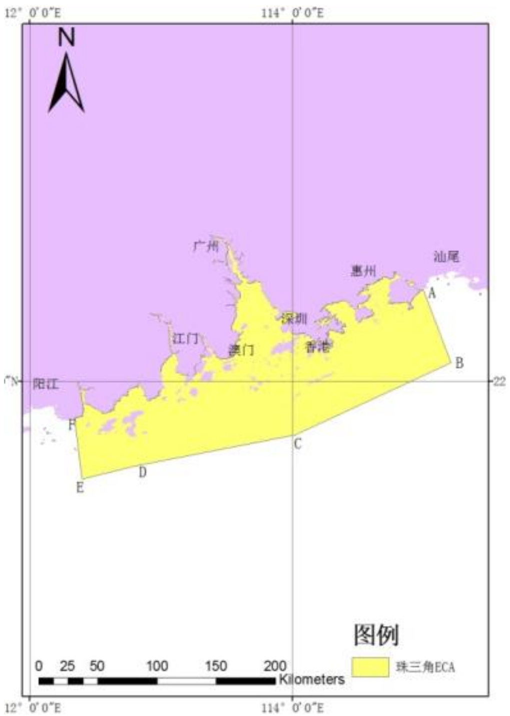
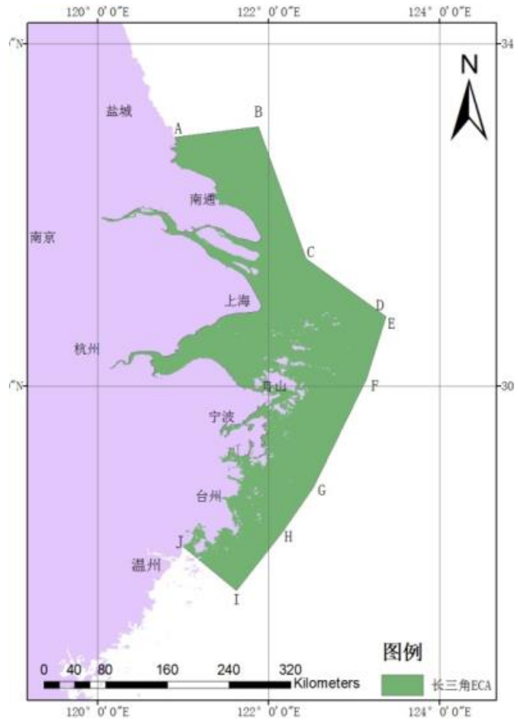
Why LNG as fuel for bulk carriers?
- Environmental regulations (2/2)

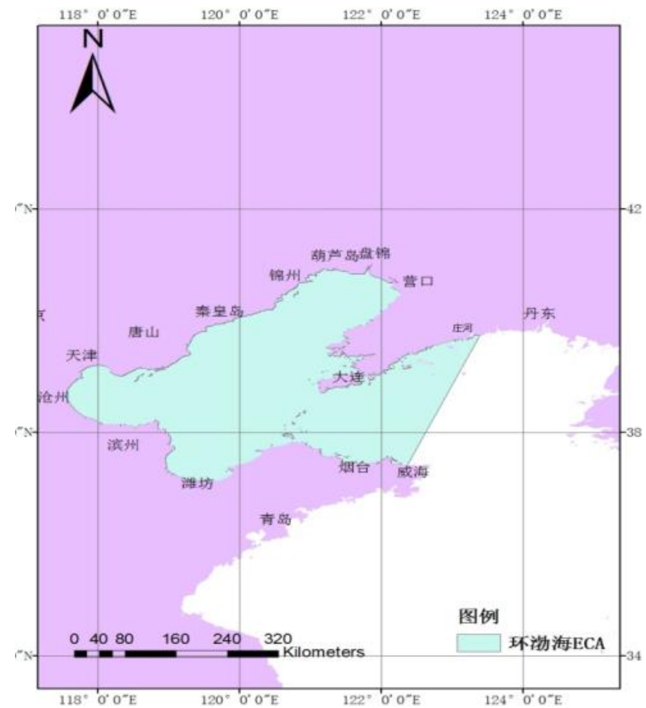
SOx



Hong Kong / Guangzhou



Shanghai



Tianjin / Dalian / Sea of Bohai

Impact:

Outcome:

How “green” is LNG?

The “greenest” alternative with respect to emissions to air:

Emission component	Emission reduction with LNG as fuel	Comments
SOx	100%	▪ Complies with ECA and global sulphur cap
NOx, Low pressure engines (Otto cycle)	85%	▪ Complies ECA 2016 Tier III regulations
NOx, High pressure engines (Diesel cycle)	40%	▪ Need EGR/SCR to comply with ECA 2016 Tier III regulations
CO2	10-25%	▪ Benefit for the EEDI requirement ▪ Contribution on the MRV ranking
Particulate matter	95-100%	▪ No regulations (yet)

Ambition: To develop a sustainable "Green Corridor" – iron ore and coal trade between Western Australia and China

Cargo owners:

BHP

Fortescue
The New Force in Iron Ore

RioTinto

Ship owners:

MOL
Mitsui O.S.K. Lines

U-MING MARINE

Designer:

SDARI

woodside

LNG supplier:

Class:

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Step 1: Overall business case evaluation

What would be more cost-effective – to retrofit LNG onto existing bulk carrier or to build a new dual-fuelled bulk carrier?

Quantified the actual difference in CAPEX and OPEX for retrofit versus newbuild

Conclusion:

- A retrofit option is possible, but ...
  - Allows less capacity for the LNG fuel tanks, thus less operational flexibility
  - Is significantly more expensive
  - Location of LNG fuel tanks is a key challenge
- A NB seems more attractive and forward looking

Step 2: Design considerations: Fuel tanks – capacity and tank type

- Operational trade routes between Australia and China were analysed
  - ✓ AIS analysis showed that round trip cruising range of 14,000 to 18,000 NM had the highest number of runs
  - ✓ Main focus on iron ore trade, but with flexibility also for voluminous cargo as coal was incorporated
- Bunkering flexibility, operational flexibility and CAPEX
  - Favourable with ability to avoid BOGs handling and bunkering from vessels

- **Conclusion:**
  - ✓ Optimal tank capacity: 6,000 m3

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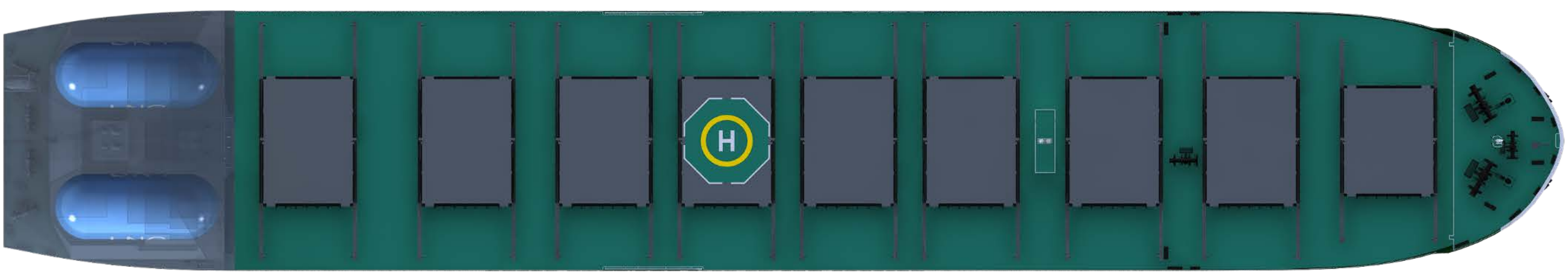
Step 2: Design considerations: Fuel tanks – tank type

Tank type	Pros	Cons or areas to consider
Type C	▪ Allows pressure increase ▪ No need for external BOG handling ▪ No sloshing effect ▪ Simple fuel system ▪ Robust technology ▪ Little maintenance ▪ Easy installation ▪ Good track record on both LNG-fuelled shipping and LNG containment on land	▪ To allow proper protection, a steel shield needs to be considered ▪ Less flexibility on location, and so increased bending moment may result in additional cost (more steel in vessel design) ▪ If located on the aft deck, mooring deck modification may be required (lifeboat, mooring lines, etc). In general, the aft deck is crowded, posing challenges for the arrangement of bunkering station, fuel gas preparation room, ventilation systems, etc. (separation between hazardous area and safe areas).
Type B	▪ Space-efficient ▪ Minimum sloshing effect ▪ Easy to operate in terms of leak detection	▪ Boil-off gas handling required ▪ Pumps needed ▪ Design and approval process much more extensive ▪ If the tank is designed to be midships: much longer double-walled piping ▪ Midships design: the ventilation ducts and openings related to LNG spaces are to be protected from damage due to cargo operations ▪ If located aft of No. 9 cargo hold, it will need a steel shield, water spray and A-60 protection on accommodation forward of the bulkhead; accommodation window to be arranged on side
Membrane	▪ Space-efficient ▪ Low weight ▪ Proven technology in LNGC market	▪ Boil-off gas handling required ▪ Pumps needed ▪ Most complicated in the leak detection operation ▪ Risk of sloshing effect (not known, as no ships in operation yet) ▪ More yard work due to the alignment and welding of hull lines and membrane system ▪ Longer building time, as built with ships' hull, but could be solved by "block" solution

Step 2: Design considerations: Fuel tanks – Location

- Tank location preferably as close as possible to engines:
  - ✓ Reduces the risk induced by long cryogenic pipelines and pressure drop
  - ✓ Reduces the need for additional risk mitigation options (well protected)
  - ✓ Reduces the costs of the cryogenic systems
- Challenge:
  - ✓ Avoid loss of cargo and volume capacity
  - ✓ Stability, and avoid excessive extra steel to compensate for increased bending moment



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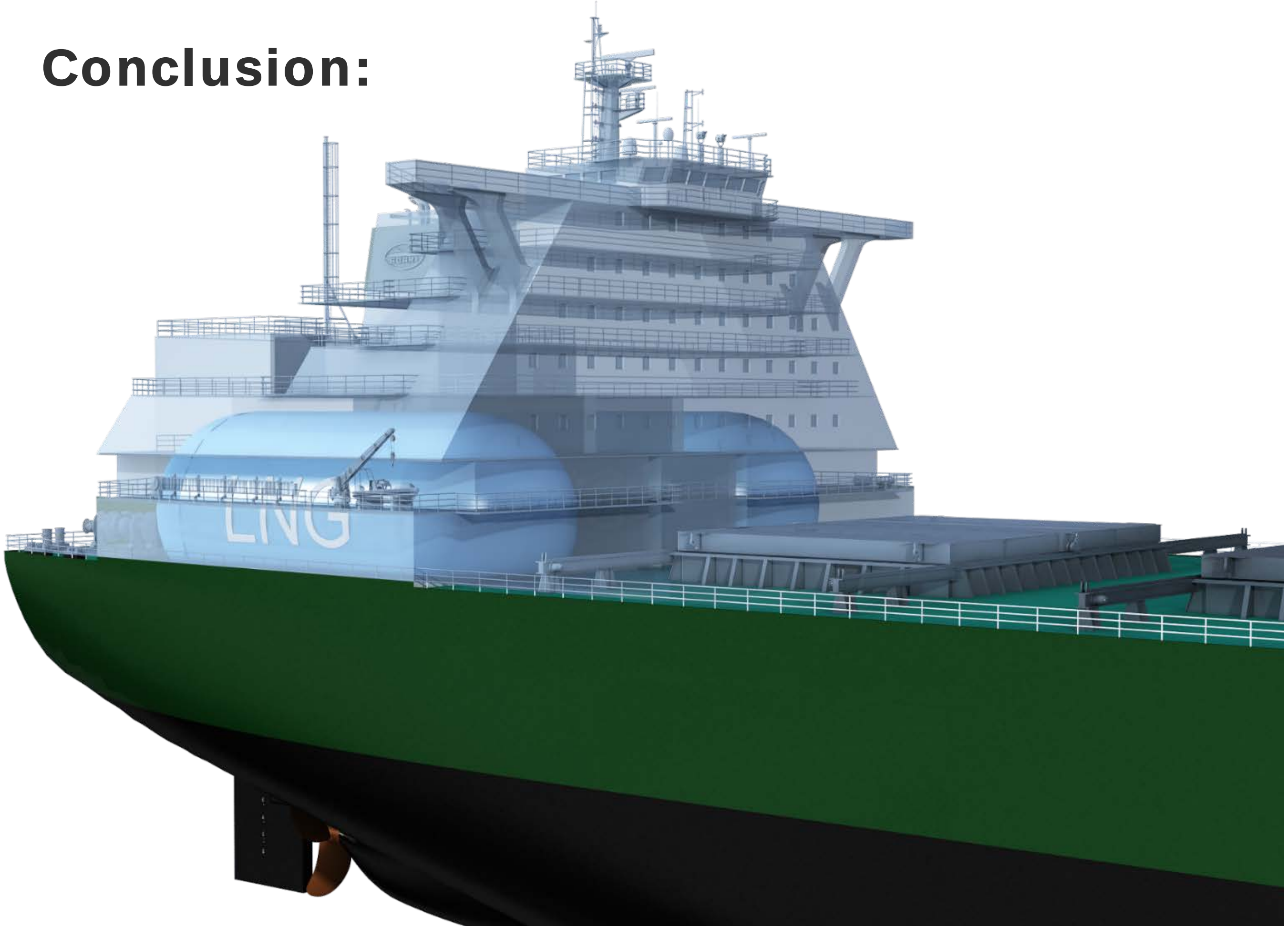
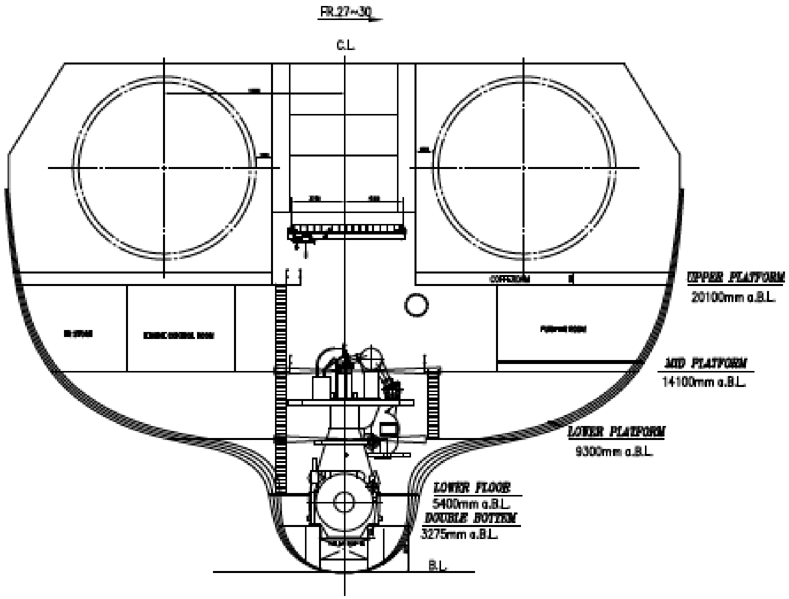
Step 2: Design considerations:
Fuel tanks – Location

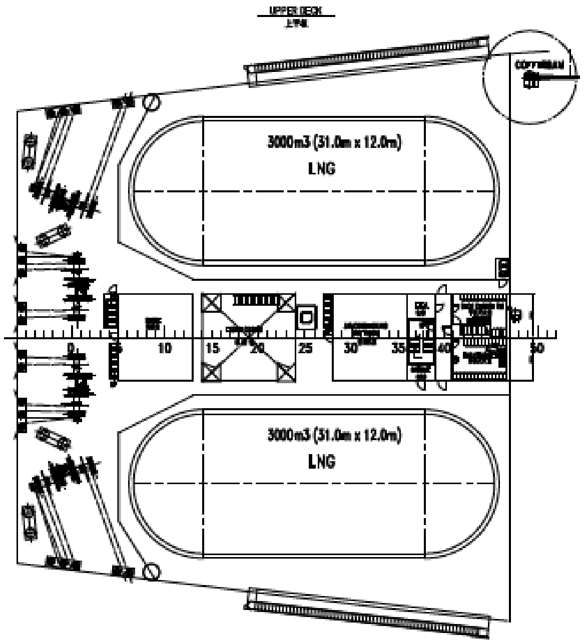
Conclusion:



- ✓ 2x3000m3 LNG fuel tanks
- ✓ Located above the engine room and submerged a few metres below the main deck.

Step 2: Design considerations: Fuel tanks – Location



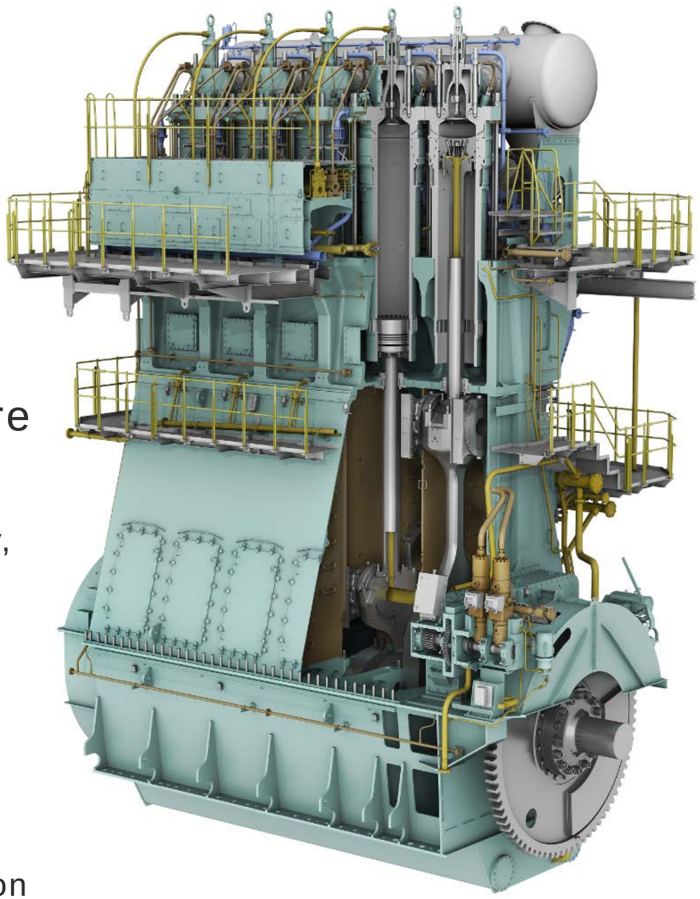


- **Benefits:**
  - ✓ Protection for the fuel tanks
  - ✓ Enhances fire protection
  - ✓ Does not reduce the cargo carrying capacity, even for volumetric cargoes such as coal.

Step 2: Design considerations: Engines

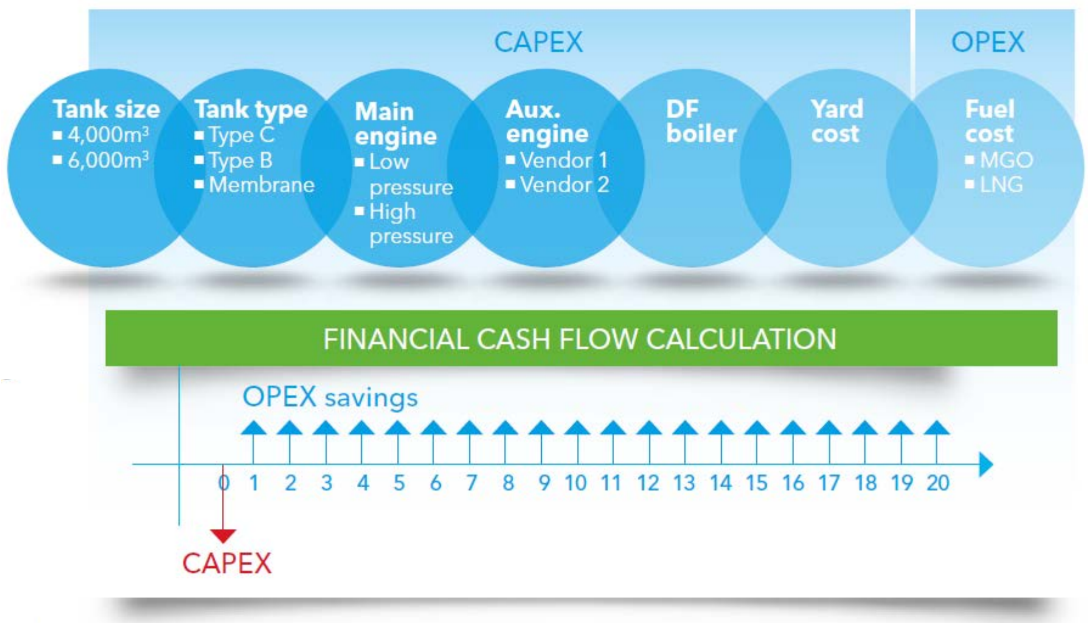
High Pressure dual fuel engine with EGR

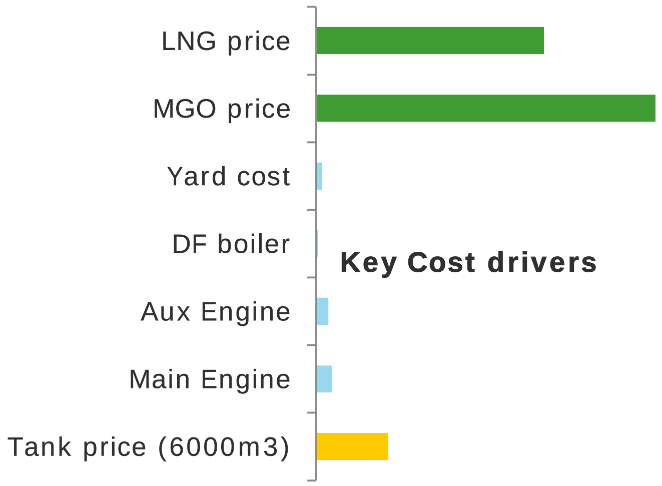
- Duel fuel engines
  - ✓ Offers robustness and sturdiness in operational redundancy
  - ✓ Several suppliers offering mature solutions
- Low and High pressure engines are included
  - ✓ Allows maximum flexibility, since both options have their own pros and cons
- Design is fully NOx Tier III compliant
  - ✓ High pressure engine option is fitted with an exhaust gas recirculation (EGR) system



Low Pressure dual fuel engine

Step 3: Detailed business case evaluation, including sensitivity analysis





Inflation	2.5%
Discount rate	8%
Vessel lifetime	20 years

- Detailed cost estimation based on request to multiple suppliers
- Monte Carlo simulation to establish sensitivities on CAPEX and fuel prices
- Estimation of pay-back time for various fuel price scenarios, including what LNG price would be required for a pay-back time of 5, 8 and 12 years respectively

Step 3: Breakeven fuel prices for NB, payback / TC period 12 years

No.	Scenario	MGO cost 1 ($ / mt)	LNG cost 1 ($ / mmBtu)	Payback period 1 (yr)	MGO cost 2 ($ / mt)	LNG cost 2 ($ / mmBtu)	Payback period 2 (yr)
1	NB-4000 TGE tank (C), Wartsila	480	10.0	12	700	15.7	12
2	NB-6000 GH tank (C), MAN	480	9.3	12	700	15.0	12
3	NB-6000 GH tank (C), Wartsila	480	9.7	12	700	15.4	12
4	NB-6000 TGE tank (C), MAN	480	9.4	12	700	15.1	12
5	NB-6000 TGE tank (C), Wartsila	480	9.8	12	700	15.5	12
6	NB-6000 LNGPac (C), Wartsila	480	9.4	12	700	15.1	12
7	NB-6000 SPB (B), MAN	480	7.7	12	700	13.5	12
8	NB-6000 GTT (membrane), Wartsila	480	8.9	12	700	14.5	12
9	NB-8000 SPB (B), MAN	480	7.4	12	700	13.1	12
10	NB-8000 GTT (membrane), Wartsila	480	8.8	12	700	14.5	12

Step 3: Detailed business case evaluation, including sensitivity analysis

- **Main conclusions:**
  - Reinforced the belief in LNG as marine fuel for the vessels operating in the Green Corridor
  - A robust business model for both ship operators and the LNG bunkering supplier is feasible

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Step 4: Detailed, technical risk considerations …

- A high-level hazard identification (Hazid) exercise was carried out
  - Key hazards due to on-board LNG storage and operations were identified
  - Inputs from all partners proved very useful to share a common understanding of the challenges at hand and what technical solutions could mitigate the risks
- A list of actions for major incidents mapped out were tabulated
  - Design updated based on action items
- The refined design is now in the process of a thorough review according to Class rules and applicable regulations, expected to result in an Approval in Principle by end of June.

Conclusion:
The new, innovative Newcastlemax design developed in the “Green Corridor” JIP, offers unique solutions for cost-efficient, safe and flexible operations and is ready to serve as the outline specification for newbuilding orders already in 2017.

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Newcastlemax concept design

- An evolutionary approach was undertaken to make SDARI's highly energy-efficient Green Dolphin design - LNG fuelled
- One of the key innovations involved in this design was the position of the Type C tanks.
  - ✓ Through several iterations, it was identified that two tanks, each placed above the engine room but submerged from the main deck, would give an optimal balance between cost, operational flexibility and safety.

VESSEL SPECIFICATIONS

Main particulars
- Length overall: 300.0 m
- Breadth: 50.0 m
- Depth: 25.2 m
- Scantling draught: 18.5 m
- Deadweight at scantling draught: 210,000 t
- Cargo holds volume: 225,000 m^3
- LNG tank volume: 6,000 m^3
- Number of cargo holds: 9 cargo holds
- kind of cargo: grain, coal, ore

Machinery
- Main engine: WINGD 6X72 DF MAN B&W 6G70ME-C9.5-GI

Speed
- Service speed at design draught and CSR with 15% sea margin 14.4 k

EEDI
- 35% below IMO reference line for bulk carriers, complies with EEDI PHASE 3

Class notation
- DNVGL, +A1 BULKCARRIER ESP BC-A GRAB[35] CSR, Holds 2, 4 ,6 and 8 may be empty, COAT-PSPC(B) GAS FUELLED

DESIGN FEATURES

Dual-fuel system
- Dual-fuel system of LNG and HFO to be applied for main engine, auxiliary engines and boiler
- Endurance of 18,000 nm in GAS Mode

Fuel- and energy-efficient
- Hull lines optimized for an operating profile including ballast, design and scantling draughts and speeds in the range of 10-15 kn
- No-bulb concept for a flexible design with improved overall performance, including operation in realistic sea states
- Added resistance in waves calculated numerically and compared to tank test results

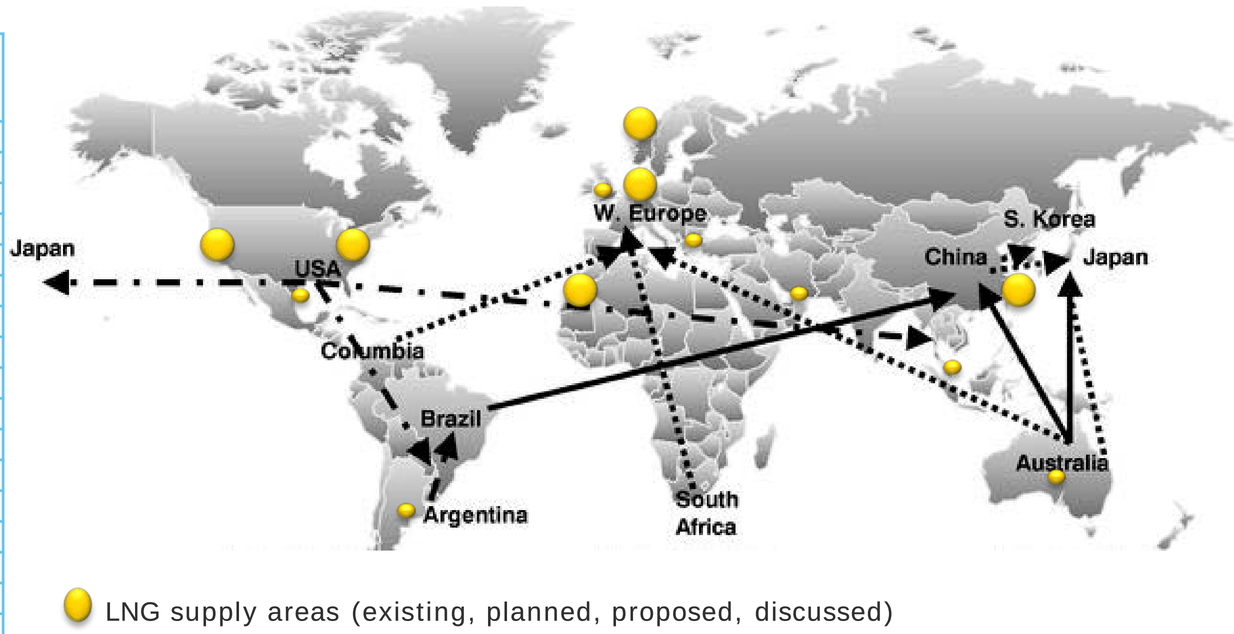
Environmentally friendly
- Designed to comply with current and future expected local and global emission regulations
- Efficient main engine with low fuel consumption and emission levels, IMO NO_x Tier III-compliant
- No SO_x or PM emission in GAS Mode
- GHG emission 20% less in GAS Mode

Can LNG also be applied for global trade routes for coal and grain?

Coal

Grain

From Area	To Area	Shipments	Average of Distance
USA (Gulf)	China (North)	14	12,365
Brazil (South)	China (North)	44	11,370
Brazil (South)	China (South)	11	10,185
Brazil (South)	Iran	10	8,393
USA (North)	China (North)	12	7,399
South Africa	Italy	12	6,690
Brazil (South)	Netherland	10	5,322
Australia	India (East)	40	5,102
USA (North)	Brazil (South)	22	4,873
Australia	China (North)	13	4,657
Australia	Japan (North)	15	4,581
USA (Gulf)	UK	9	4,549
South Africa	India (West)	18	4,491
Australia	Taiwan	45	4,229
Australia	Japan (South)	232	4,127
Indonesia	India	12	3,783
USA (North)	Netherland	29	3,505
South Africa	Brazil (South)	24	3,343
USA (North)	UK	10	3,242
Indonesia	Japan (South)	100	2,821
Indonesia	South Korea	18	2,738
Indonesia	India (East)	14	2,500
Indonesia	Hong Kong	20	1,876
Indonesia	Taiwan	44	1,730
Russia	UK	24	1,721
Argentina	Brazil (South)	23	1,121
Russia	Japan (South)	14	910



- **Vessel category:** Panamax/Kamsarmax
- **Popular trade routes:** 27 based on shipments

Kamsarmax design by Oshima, AiP by DNV GL

Key challenges:

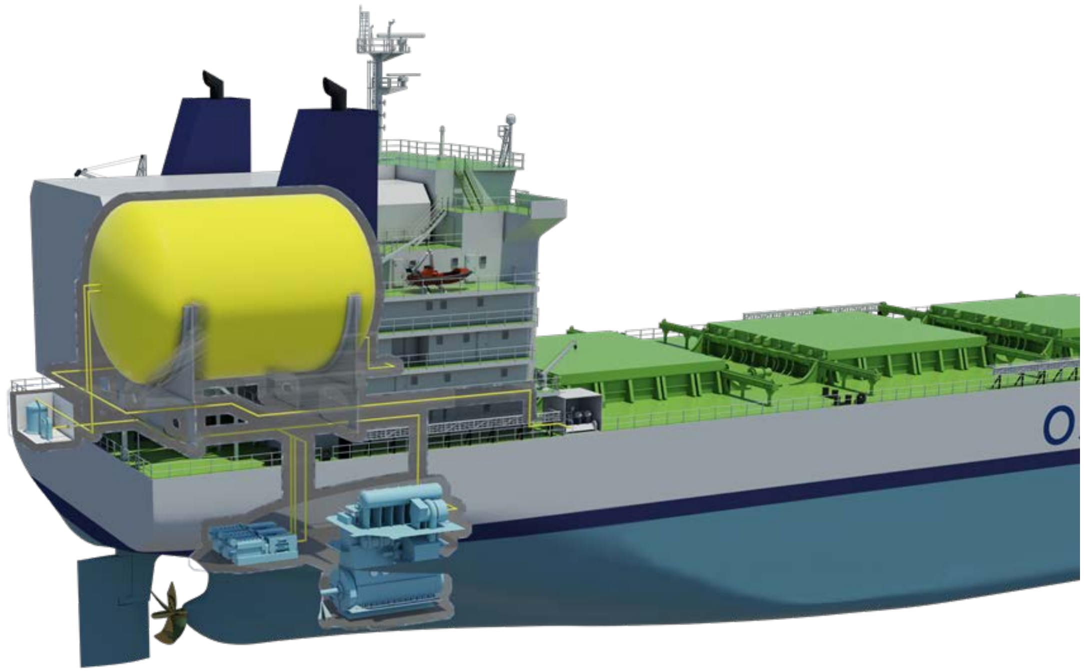
- Keep the same cargo capacity
- Limited space on deck
- Accommodate up to 3,000m^3 of LNG

Solution:

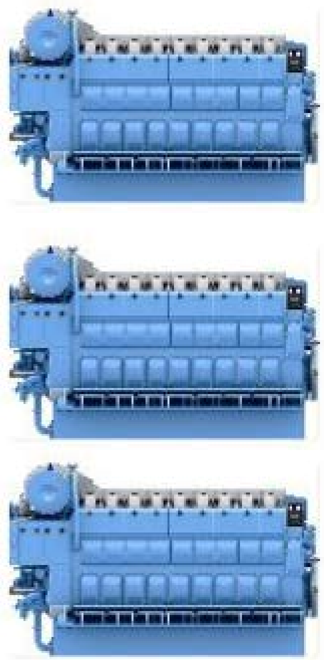
- Unique U-shaped superstructure
- LNG tank protected by a steel cover forming a box which is part of the hull structure and provides additional safety

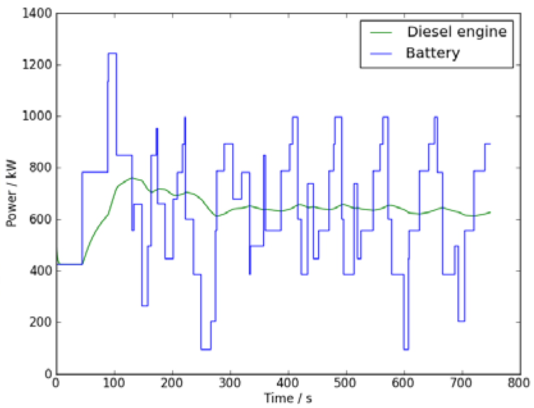
LNG system installation on board

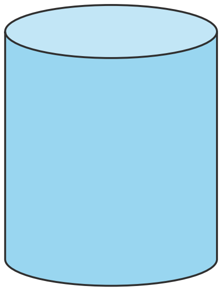
- Both LNG tank type C and type B can be installed in the same dedicated space
- Can accommodate any LNG volume requirement up to about 3,000 m^3 by type-B tank installation
- Also the arrangement is suitable design for retro-fit after the delivery.



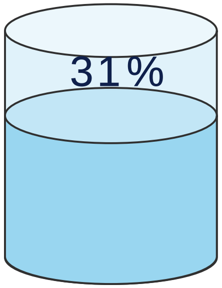
Hybrid operation of cranes may provide significant fuel savings on geared bulk carriers







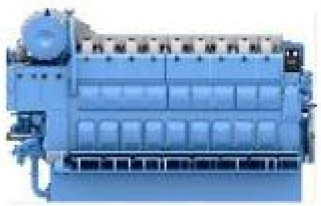
313 tons used

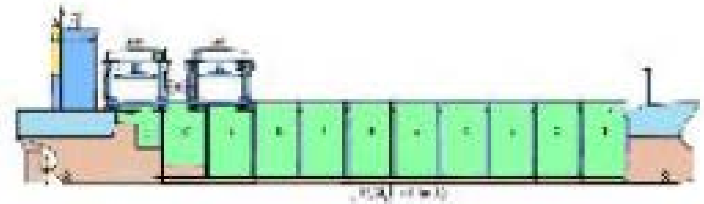


217 tons used

Principle: The Diesel generators run at optimal load while the battery handles all the dynamics (peak shaving): Batteries discharge when power demand is greater than the engine output and charges when the power demand is less

Hybrid operation of cranes
- a power oriented battery system is best suited





Hotel load	375 kW

Operational data	
Days of operation per year	105
Hours of operation per day	14
Total operation hours per year	1470

Peak power demand:

Crane Cycle GLE7526-MLC-6030-2		
1 Load on	60 s	20 kW
2 Hoisting of load 15m	45 s	372 kW
3 Luffing in + hoisting 5m	14 s	475 kW
4 Slewing 75 deg	27 s	80 kW
5 Lowering 10m	27 s	-212 kW
6 Load off	10 s	20 kW
7 Hoisting empty grab 5m + Slewing 75 deg	15 s	125 kW
8 Luffing out + Lowering empty hook 15m	30 s	-89 kW

Example battery configuration replacing one genset

Rack of 5 modules, each 24 kWh (energy):

Continuous power:
- 5*80kW = 400kW

Peak power (<30s):
- 5*160 Kw = 800 kW

Weight:
- 5*470 kg = 2.350 kg

Footprint:
- ~ 1m2

- Minimum floor space required is ~2m2

- plus space for installations needed in addition to the battery modules (cooling manifold, circulation pump, heat exchanger, inverter)

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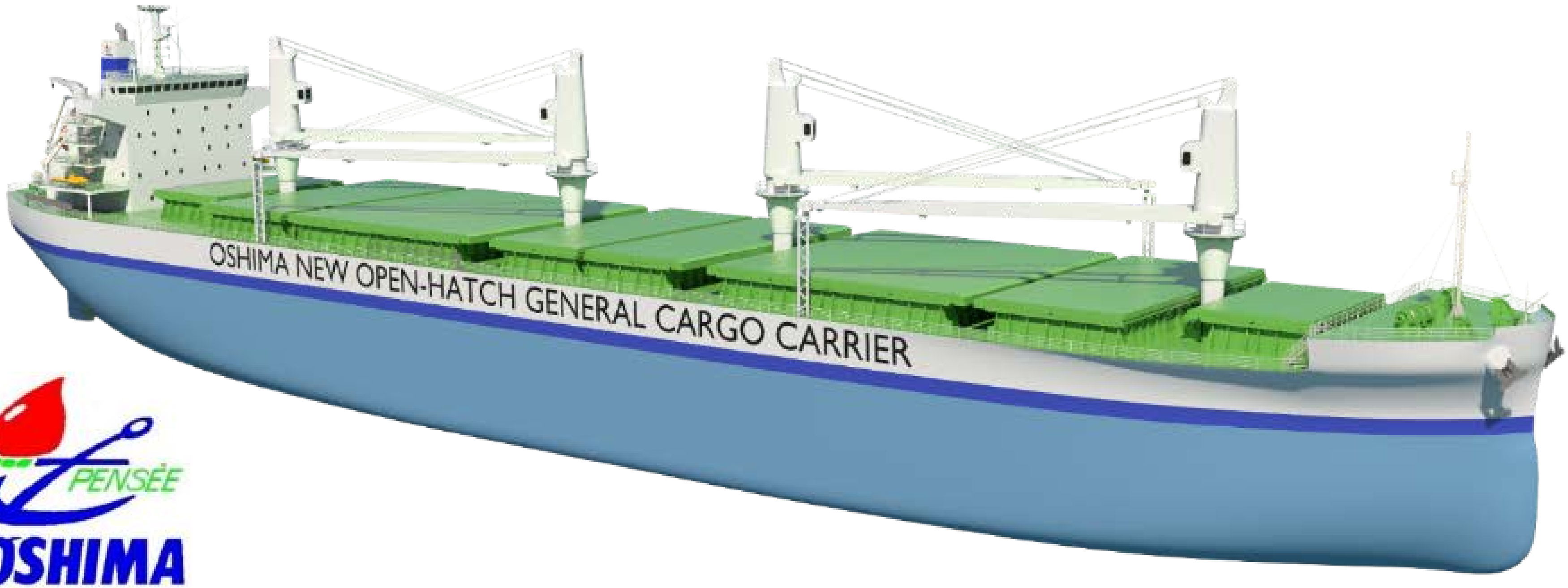
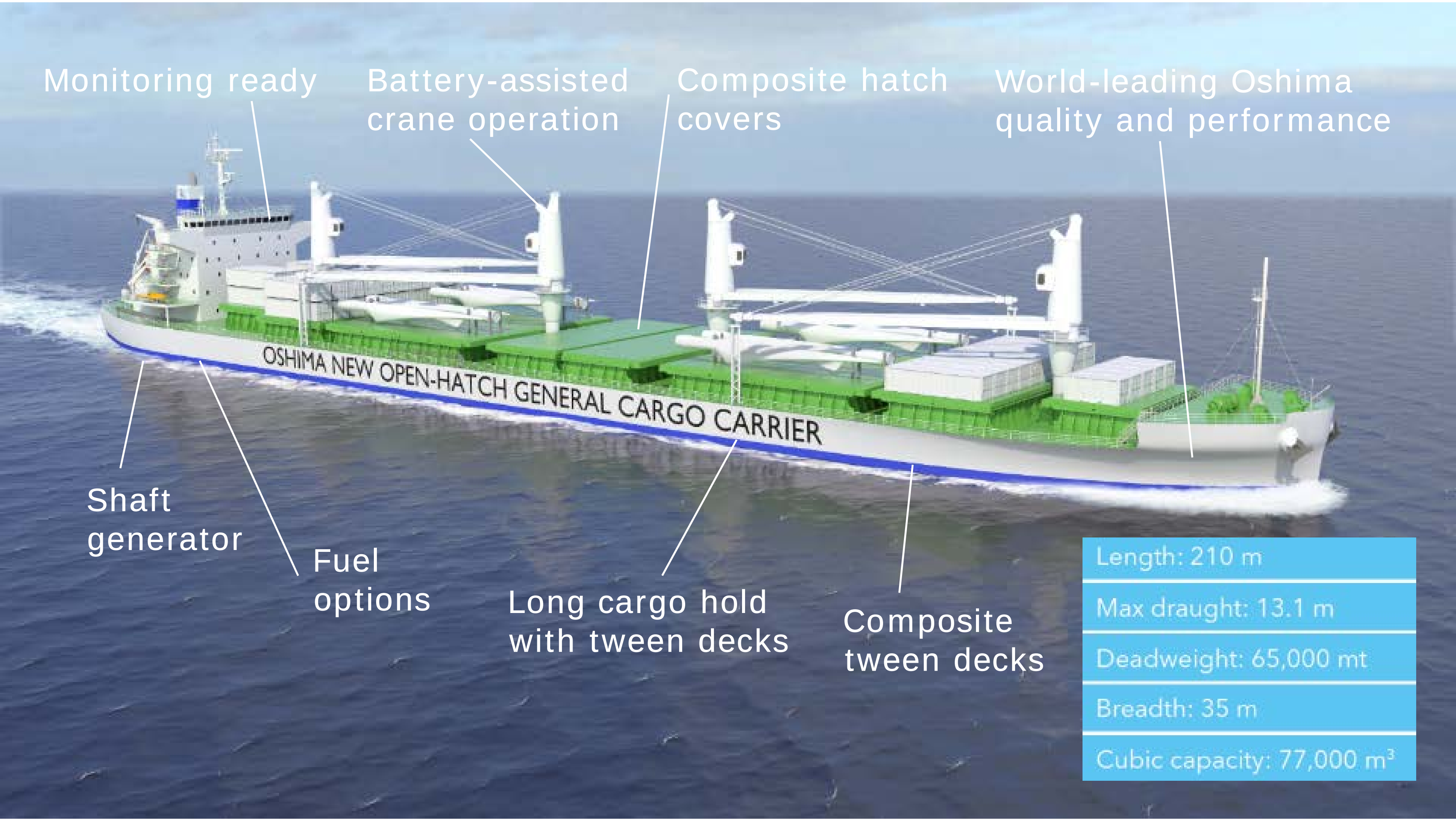


OSHIMA

NEW OPEN-HATCH GENERAL CARGO CARRIER

A CONCEPT DESIGN USING COMPSITE MATERIALS AND HYBRID POWER GENBERATION

CONCEPT OVERVIEW



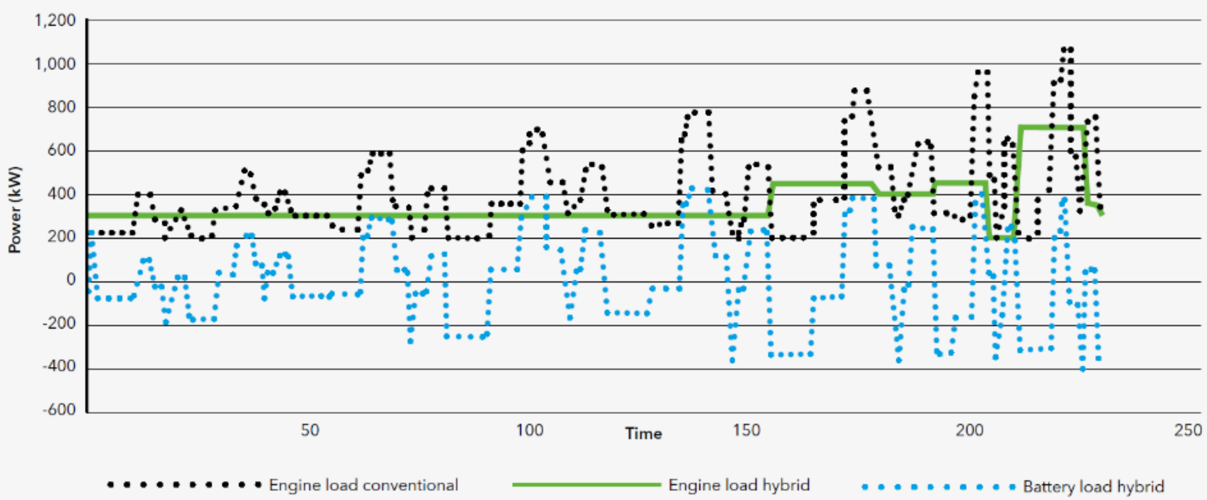
BASED ON MARKET DEMANDS

- Input from major ship owners
- Fleet profile research – existing and orderbook
- Assessment of trades, ports and cargoes

Trade patterns analysed for determination of ship particulars and operating profiles

BATTERY HYBRID

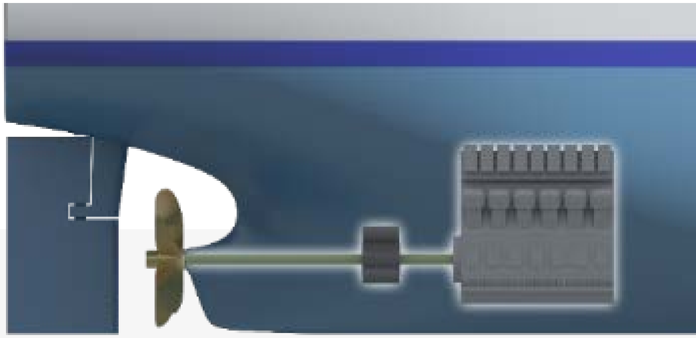
- Battery-supported crane operations
- Payback time 6–9 years, according to DNV GL feasibility study
- Benefits
  - Stable power supply
  - 20% reduction in crane operations annual fuel cost
  - Reduced maintenance – engine running hours -50%
  - Energy regeneration and storage when lowering cargo

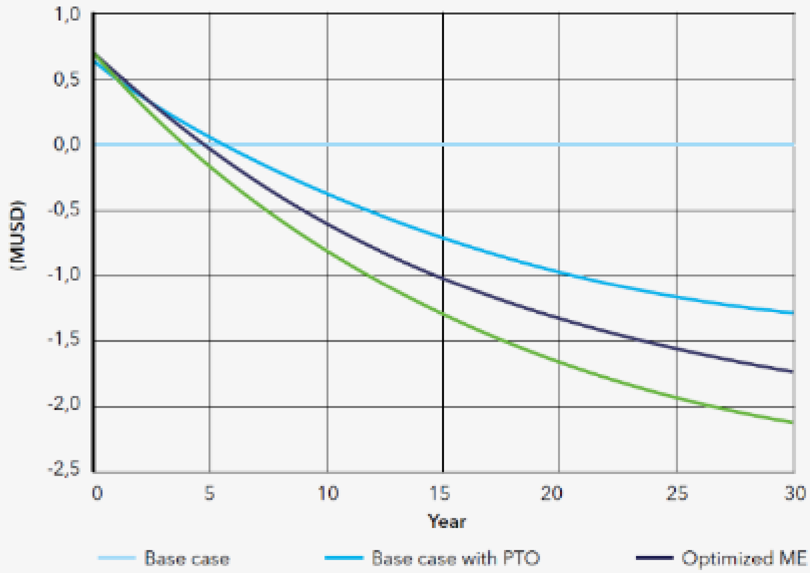


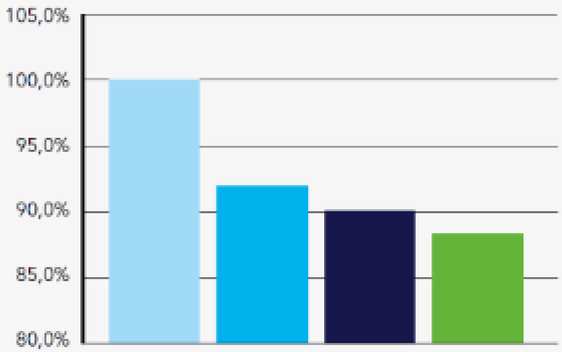
Genset load profile – conventional and hybrid

SHAFT GENERATOR

- PTO/PTI shaft generator and optimized main engine
- Payback time 4–8 years, according to DNV GL feasibility study
- Benefits
  - Up to 10% (11.5%) reduction in annual fuel cost
  - More than 30% reduction in maintenance costs



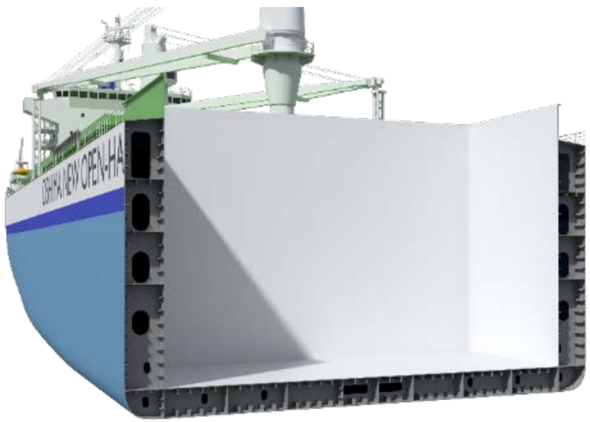


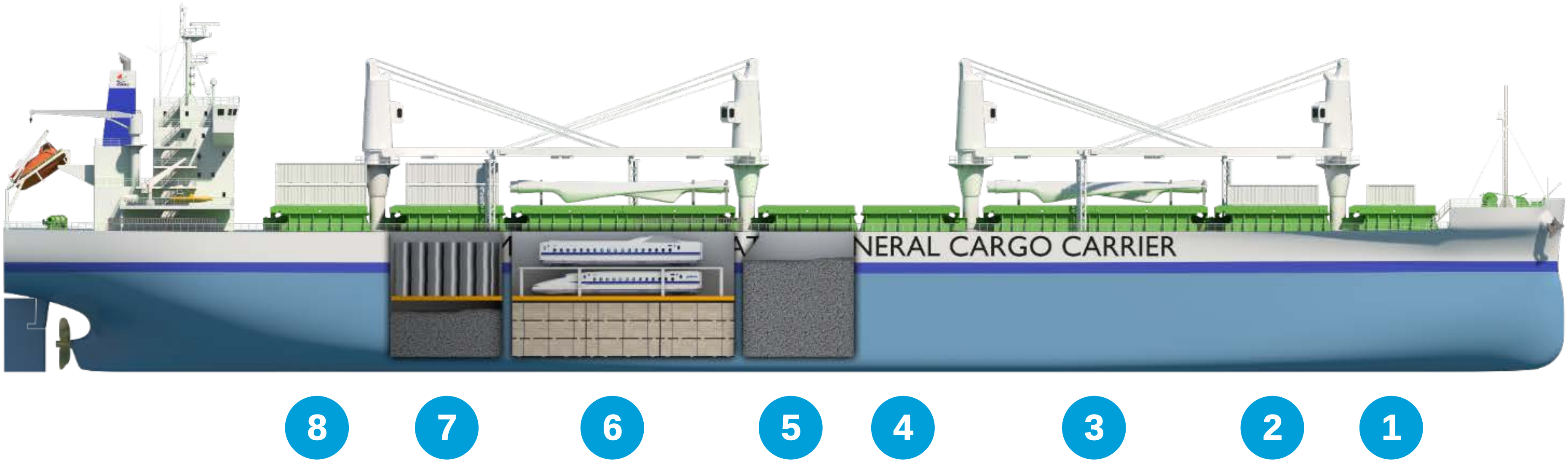


Fuel cost per year compared to conventional system

CARGO FLEXIBILITY

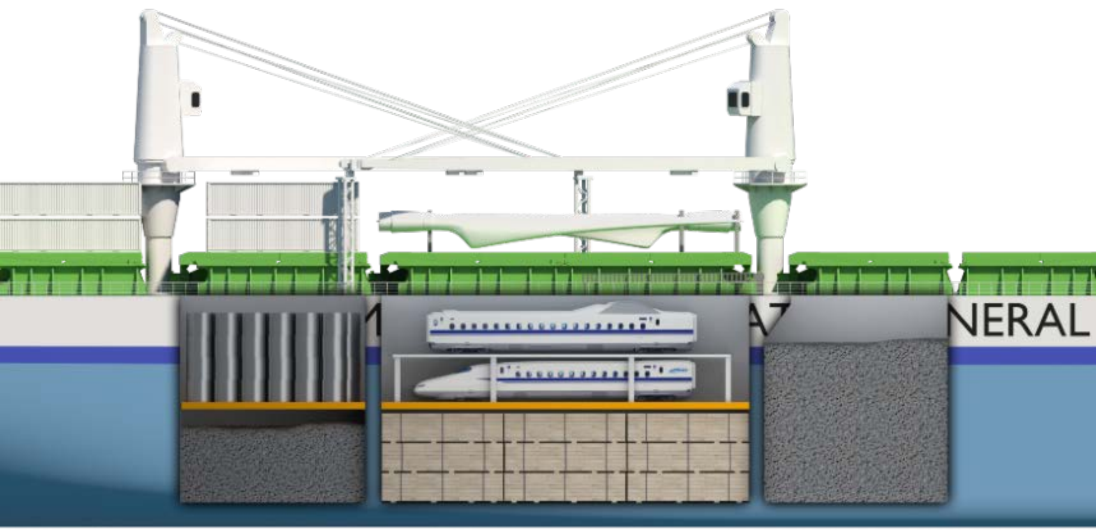
- Tween deck adapted design
  - Flexible loading
  - High cargo hold utilization
- Designed for wide range of cargoes
- Box-shaped holds, full-width openings
- Two long cargo holds (no. 3 & 6)





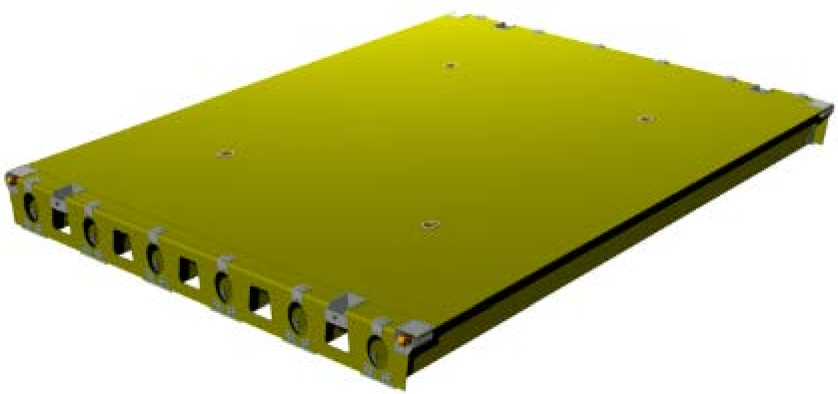
TWEEN DECKS

- Used to effectively segregate different cargoes
- Improves hold utilization and loading flexibility
- Size limited by crane lifting capacity

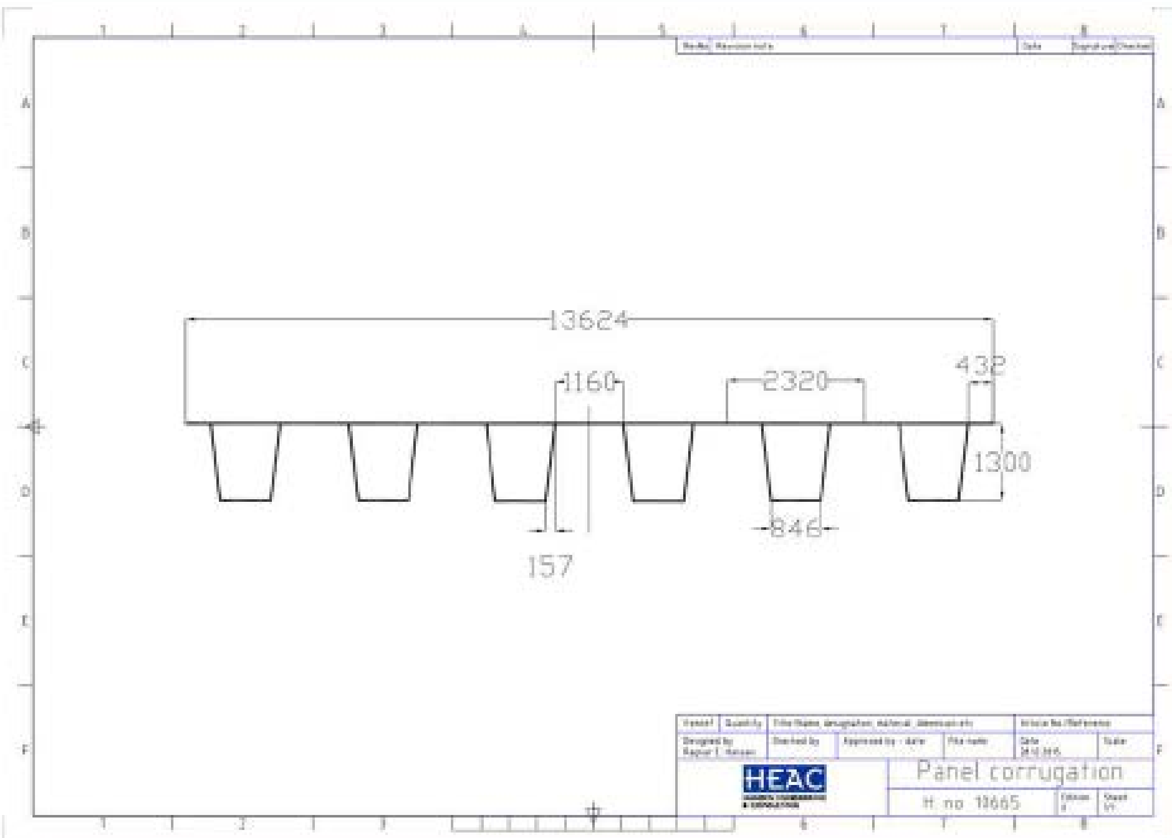


COMPOSITE TWEEN DECK

- Design, production and testing of a full-scale prototype
- DNV GL Approval in Principle (AiP)
- Main benefits
  – 50% weight reduction compared to steel
  – Shorter port handling time
  – Reduced maintenance cost
  – Simple and cost-effective production



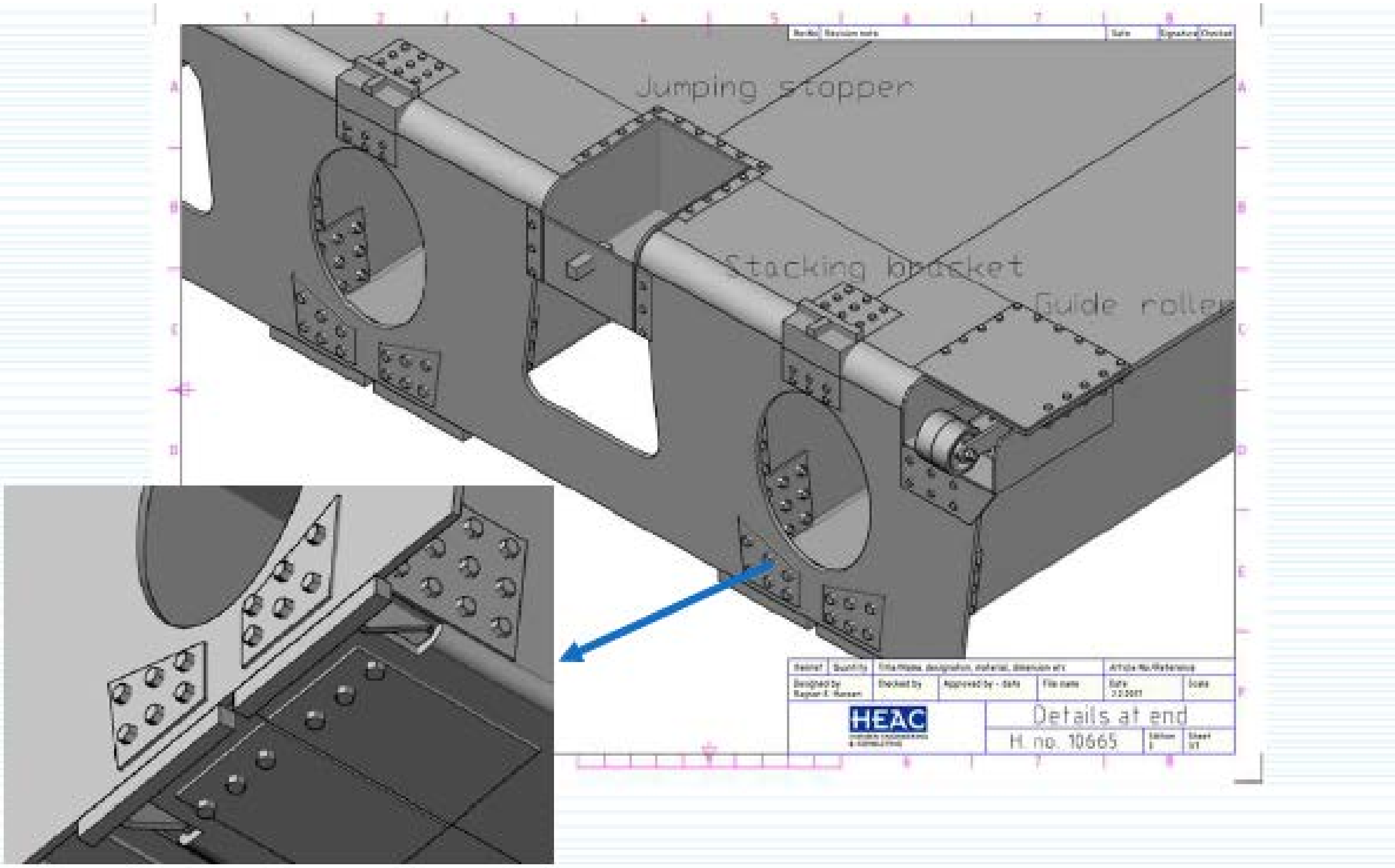
COMPOSITE TWEEN DECK



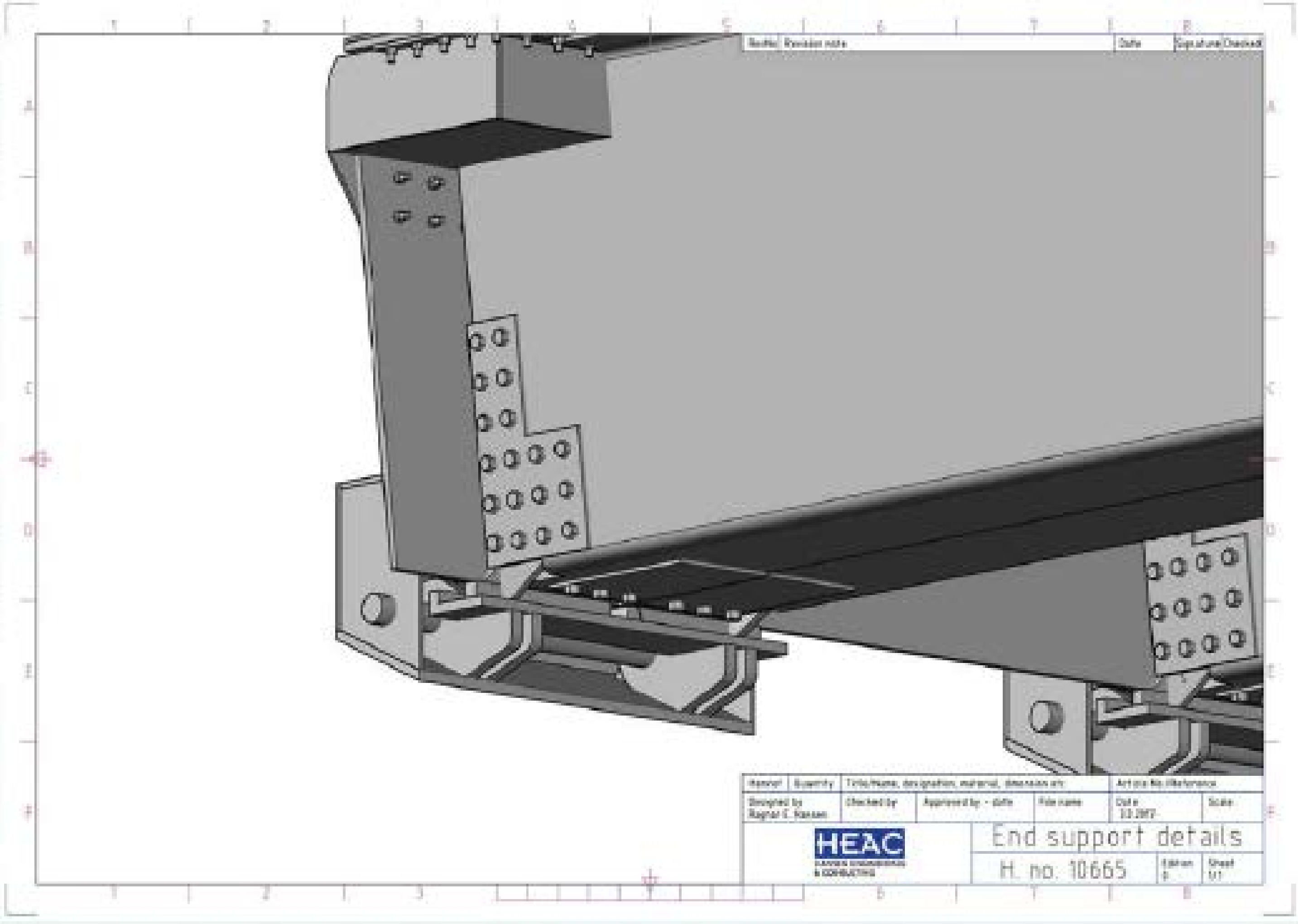
6 equal beams attached to the top plate

Each beam is supported at ends

COMPOSITE TWEEN DECK

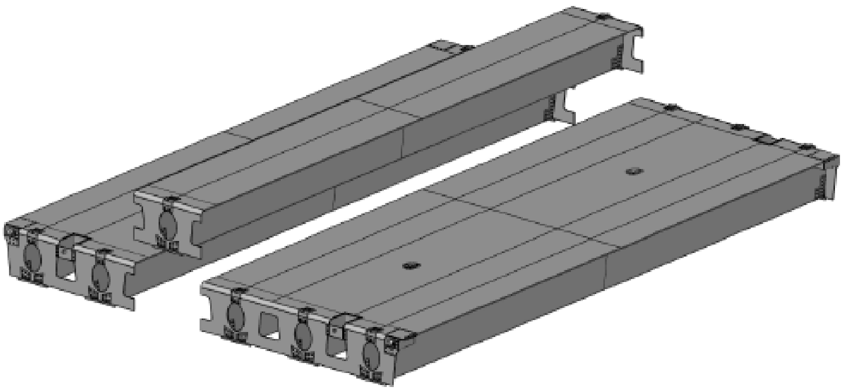


COMPOSITE TWEEN DECK

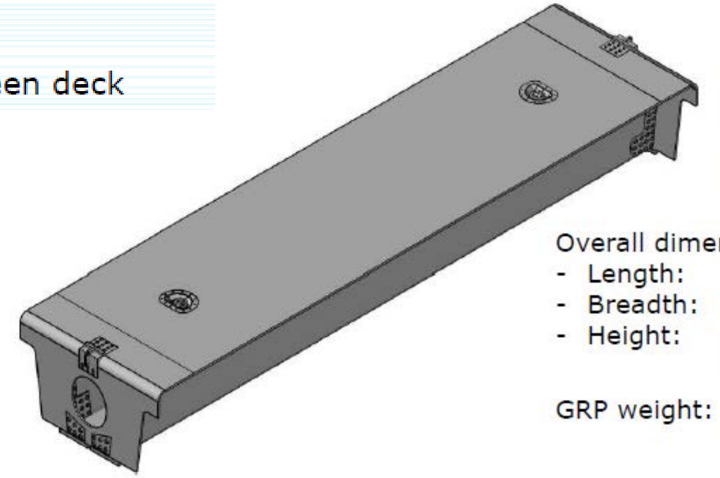


COMPOSITE TWEEN DECK

IKNOW
IKNOW MACHINERY
COMPOCEAN
COMPOSITE SOLUTIONS
PENSÉE
OSHIMA



Prototype extent:
- One corrugation «beam» – half span, i.e 9.1m
- Steel brackets at ends
- Lifting brackets
- Laminate design and thickness as full scale tween deck

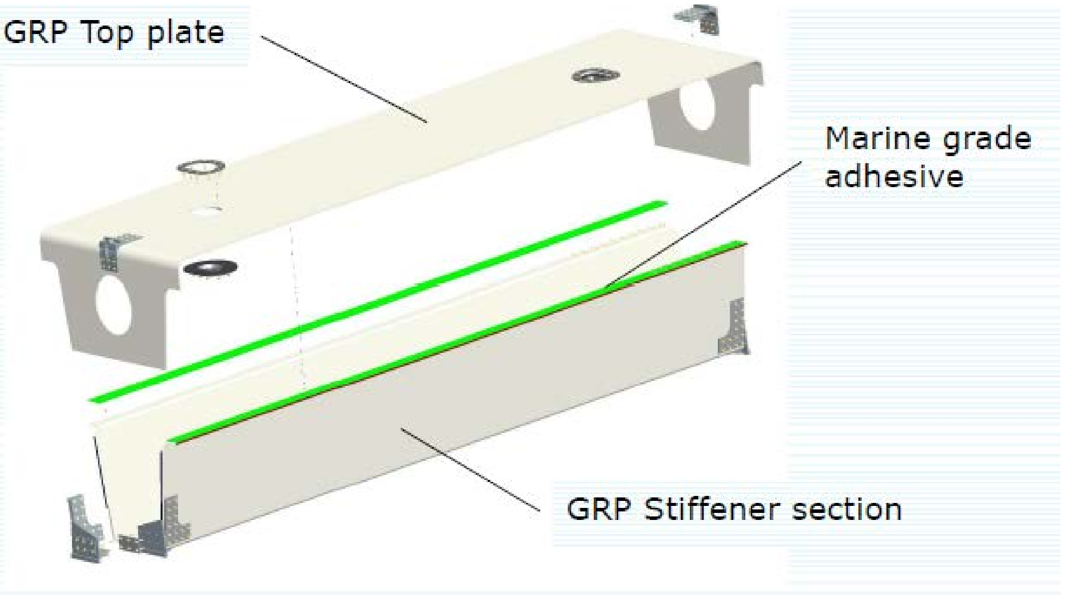


Overall dimensions:
- Length: 9.1 m
- Breadth: 2.32 m
- Height: 1.325m

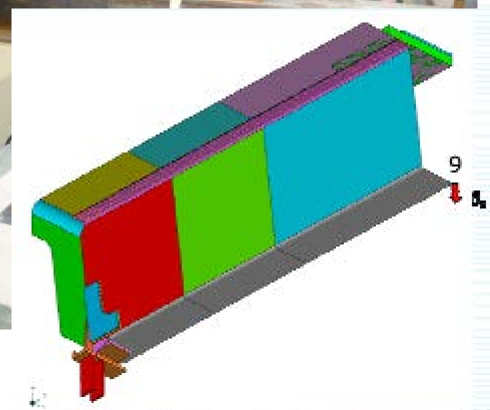
GRP weight: 2,700 Kg

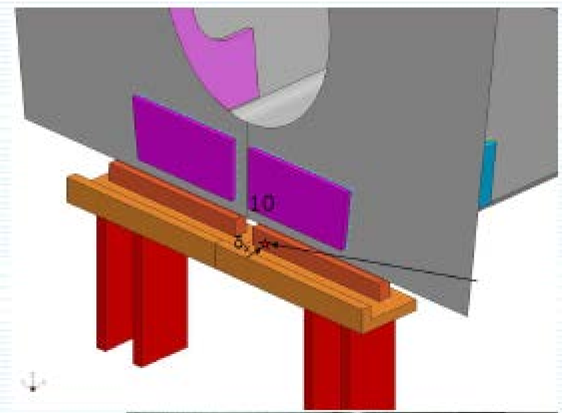
COMPOSITE TWEEN DECK

- Development activities
  - HAZID workshop
  - Design
  - Testing of material properties
  - Prototype construction
  - Static strength testing
  - Impact testing



COMPOSITE TWEEN DECK





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COMPOSITE TWEEN DECK – easy repair!

The small damage from drop tests were repaired, see video

COMPOSITE TWEEN DECK

All objectives of the prototype JIP have been met

- Material properties better than assumed
- Calculations compare well with measurements
- Production method proven
- Impact strength is excellent
- Design verified by 2^{nd} party
- AiP from DNV GL
- Simple repair method documented

- This new design has created interest in the maritime market

OSHIMA NEW OPEN-HATCH GENERAL CARGO CARRIER

Trade and cargo flexibility

- Ship size and cargo-hold arrangement adapted to market demands for trades and cargoes
- Application of new technologies and materials little used for general dry cargo ships
- High cargo utilization and flexible loading with tween decks

Energy efficiency

- Fuel efficient operations with new propulsion configuration
- Energy efficient crane operations with hybridization

Fuel alternatives

- Several options for emission compliance

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