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A Pre-Combustion Carbon Capture System Applied to a Modern LNG Carrier

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Wärtsilä

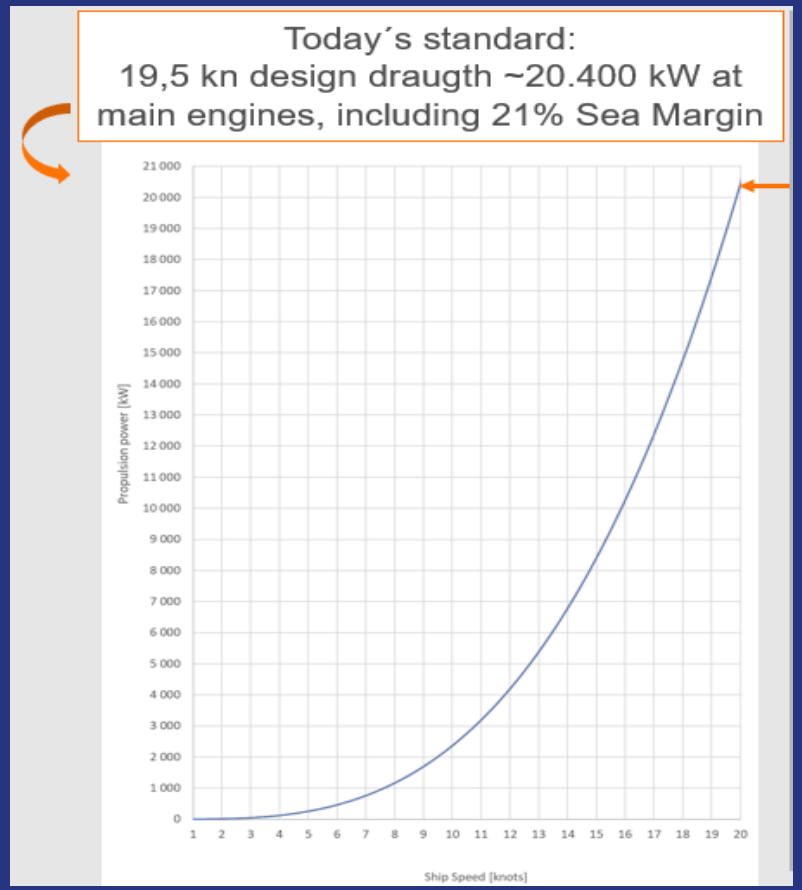
Introduction

Goal: To investigate the pre-combustion carbon capture system from Rotoboost applied in a LNG carrier

Joint study between Rotoboost , Wärtsilä and ABS

Todays standard design:

- 174 000 m3 LNG Carrier
- Design speed 19. 5 knots
- GTT cargo containment system with a BOR of 0.08% per day
- Propulsion system 2 x 2-stroke LP DF engine MCR x RPM (2 x 10.2 MW @ 69)
- Gensets 4 x 4-stroke DF delivering ~ 3 MW each
- 2 x 6-stage Cryostar cryogenic gas compressors



Source: Wärtsilä

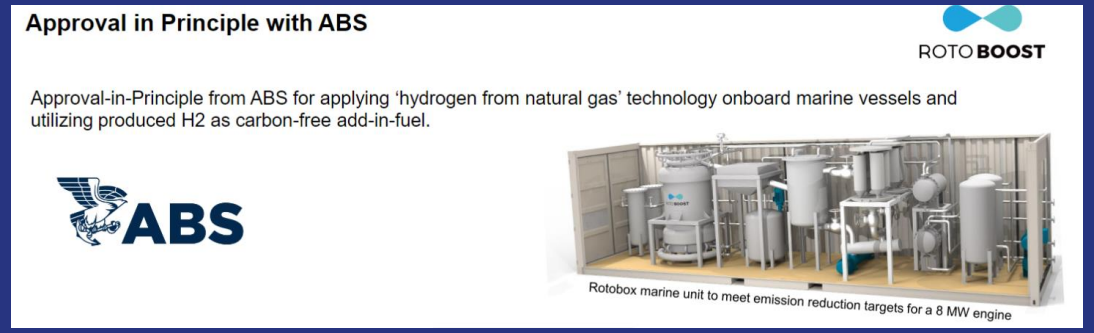
Rotoboost

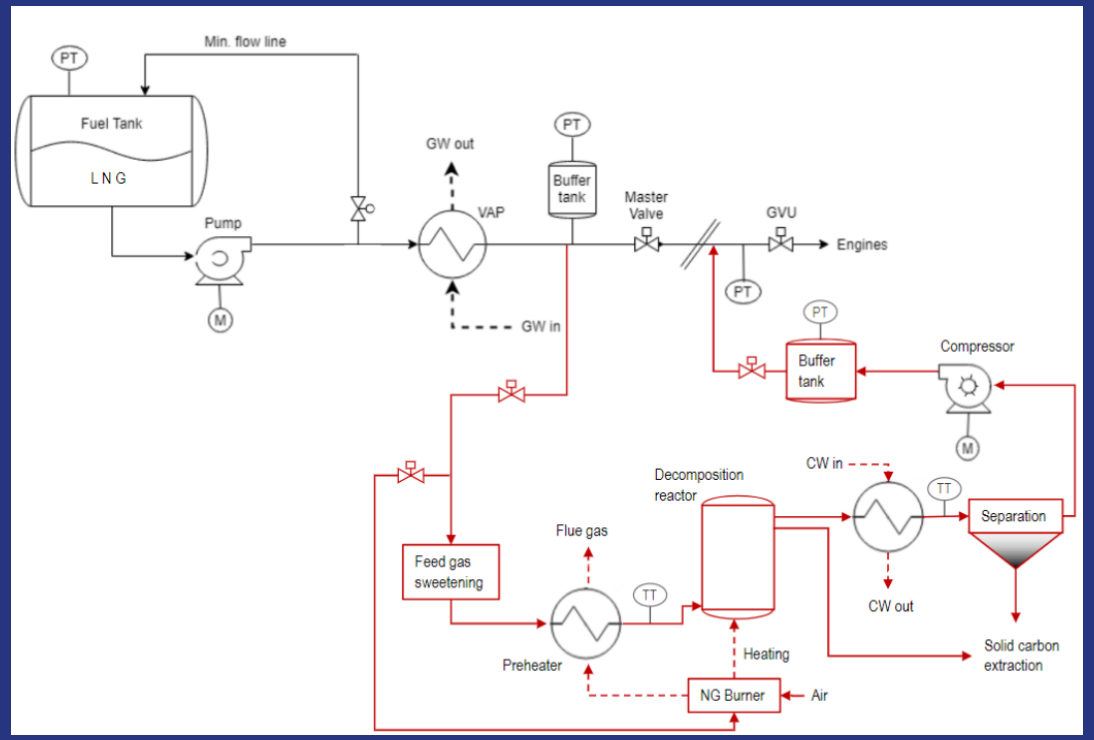
Onboard LNG Decomposition

Principle of Operation

- Natural gas converted into H2 rich decomposition gas (89 mol % hydrogen & 11 mol % unreacted NG) onboard with solid carbon as a byproduct
- H2 used as add-in-fuel for engine together with natural gas
- Vessel continues to bunker only regular LNG fuel, but CO2 emissions are reduced significantly-> better Environmental Index Value, lowered well-to-wake emissions
- Produced solid carbon has sales value (~graphite) -> additional revenue

Compatible Fuels: LNG





Source: Rotoboost

ABS Novel Concepts Review Process

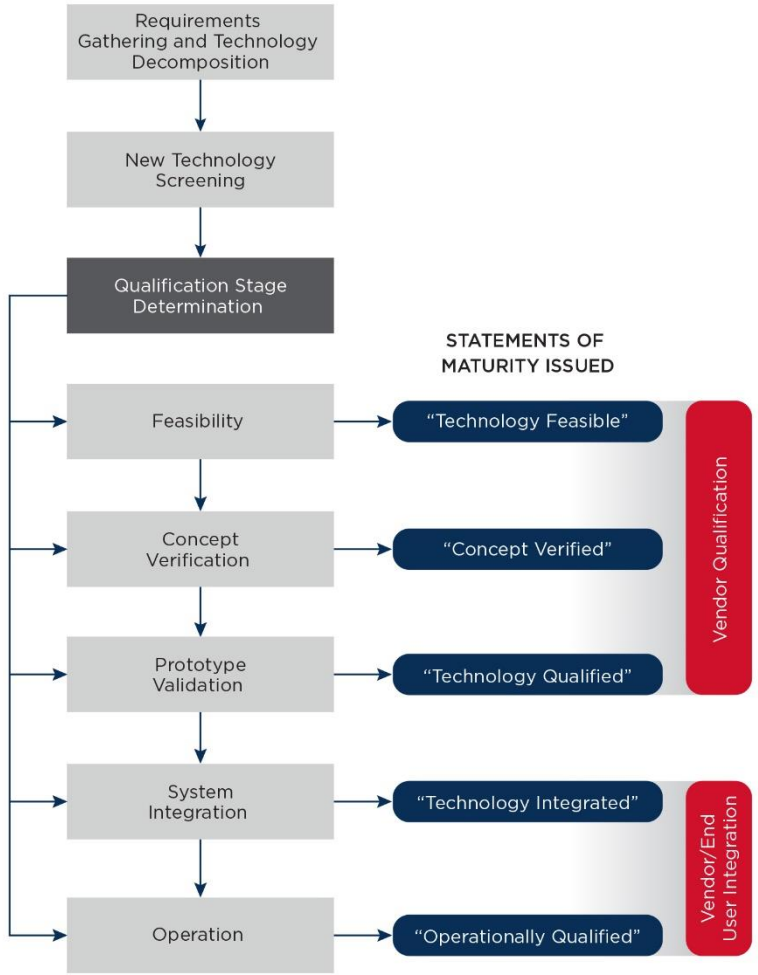
ABS Supporting document:

•ABS Guidance Notes on Review and Approval of Novel Concepts

• ABS Guidance Notes on Qualifying New Technologies

• ABS Guide for Vessels Intended to operate on hydrogen using ICE

• ABS Guide for Carbon Capture



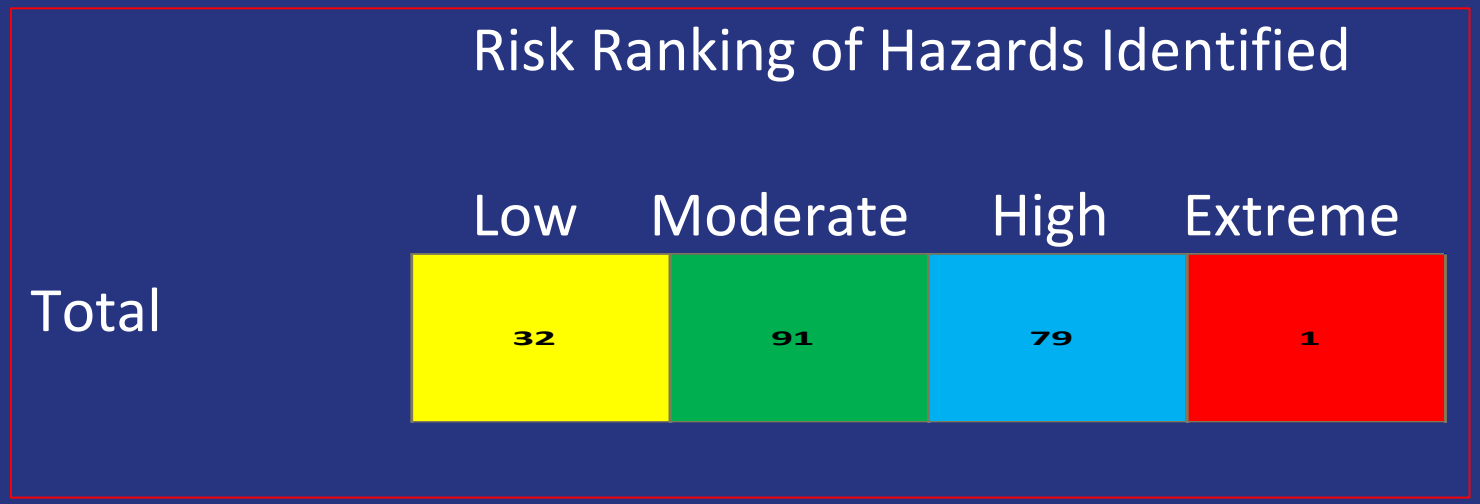
Rotoboost - AIP issued 2022

Safety issues related to the use of Hydrogen:

- Material – susceptibility for H2 embrittlement
- Potential for leak - smallest atom size
- Wide flammability range: 4 - 75%
- Detonation, missile effect
- Gas dispersion, fire and explosion
- Clean burning, no flame visibility
- Stored energy in buffer volume (compressed hydrogen)

Other special safety focus points:

- Pressure relief system in the TDC reactor
- Fire protection
- Dirt in and composition of the NG



All recommendations has been resolved.

Wärtsilä - Hydrogen engine system

Today, no 2-stroke engine manufactures are available with hydrogen engine or a concept for burning hydrogen. But there are long term plans.

Wärtsilä however have development work ongoing.

Engine performance comparison with 15%-vol hydrogen blending into natural gas compared to pure natural gas operation		
	Without combustion tuning	With combustion tuning
NOx	110%	as reference
Max cylinder pressures	20%	10%
Unburnt fuel	-15%	-15%
Combustion duration	-30%	-30%
Engine efficiency	+ 1%-unit	as reference

Conclusion from the blending in test

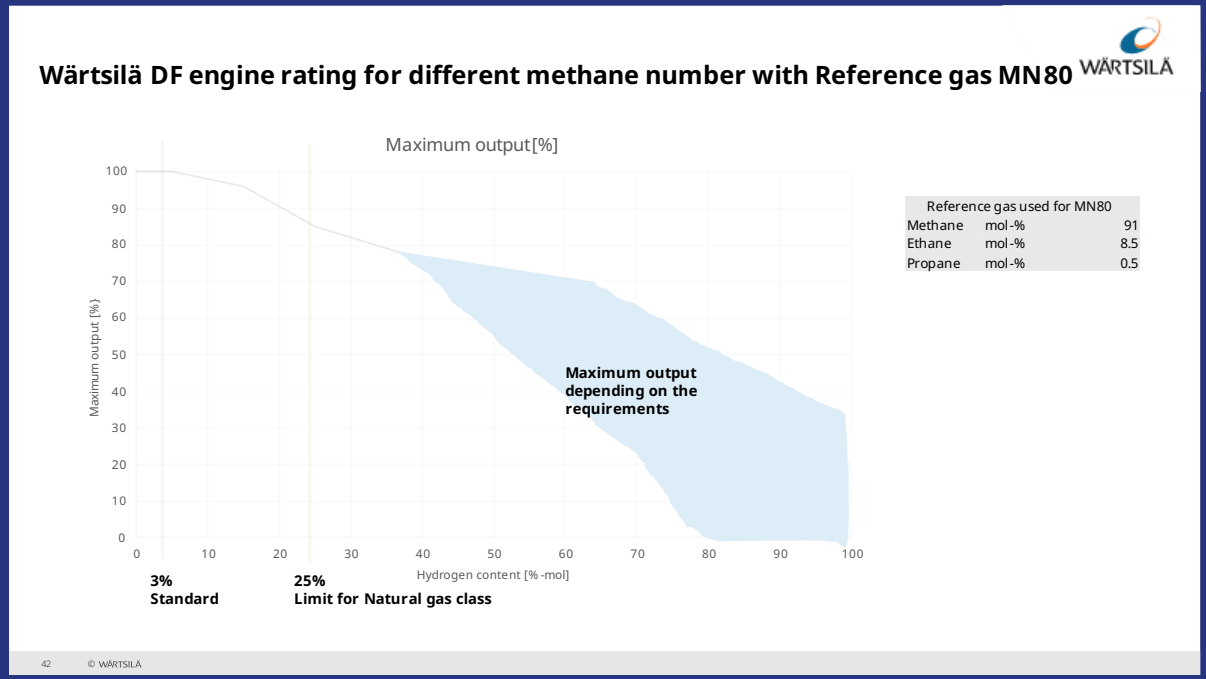
- Blending in hydrogen is improveing the heat release
- Temperature increases so NOx increases also

With a better heat release

- Engine efficiency improves
- Methane slip reduces.

Wärtsilä Specification of the hydrogen engine

- Hydrogen < 3% vol
  - Standard LNG setup without modifications
- Hydrogen 3% vol – 25% vol
  - Engine mechanical setup according to natural gas operation
  - Blending control needed and information about the ratio to be given to the engine control system.
  - Engine automation for combustion control
  - Maximum allowed output according to the methane number derating curve.
- Hydrogen >25% vol
  - Engine setup according to hydrogen operation
  - Blending control needed and information about the ratio to be given to the engine control system.
  - Safety system setup according to hydrogen operation
  - Engine automation for combustion control
  - Maximum allowed output according to the methane number derating curve.



Source: Wärtsilä

Wärtsilä DFDE engine

DFDE engine lay-out

Proposal from Wärtsilä:

2 x 8L46TS DF

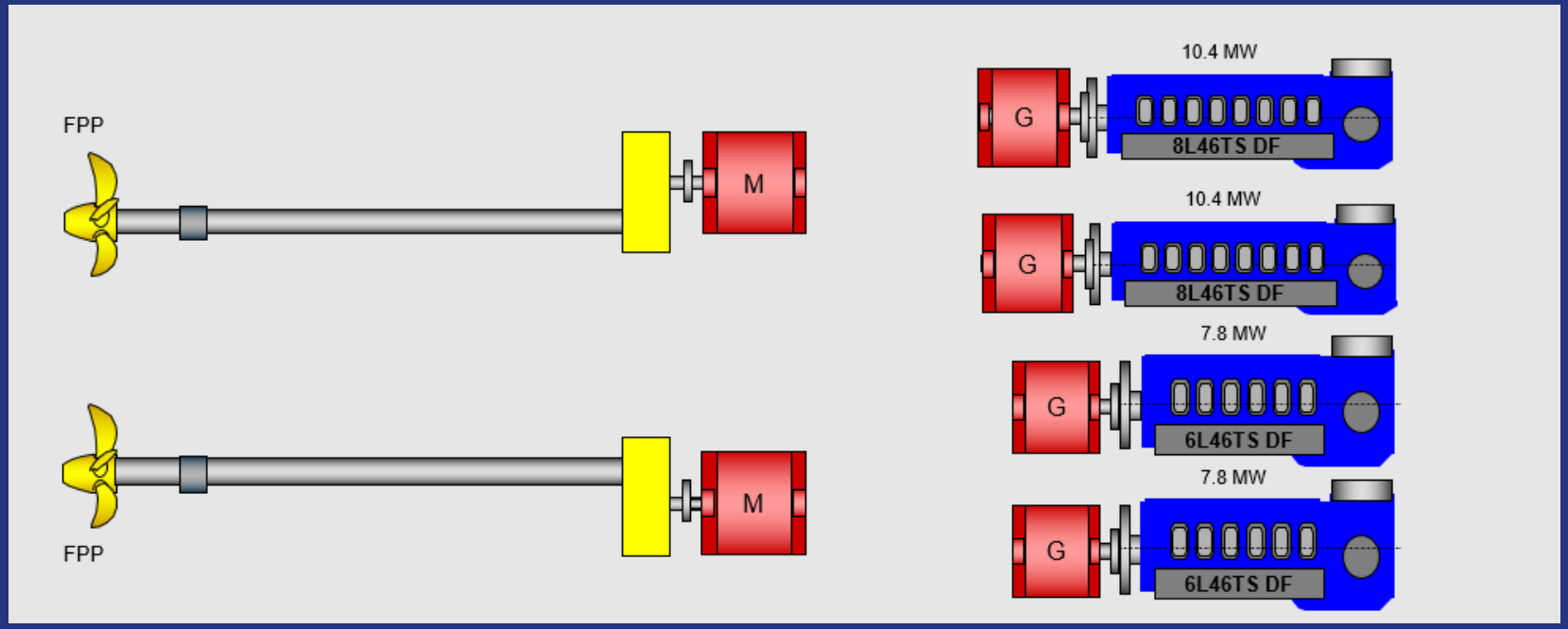
2 x 6L46TS DF

Total installed power:

36.4 MW.

2 x FPP propellers

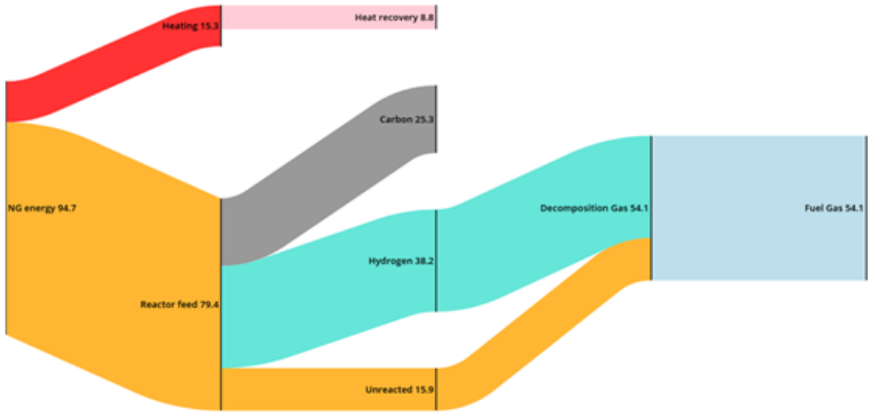
2 x electric motors.



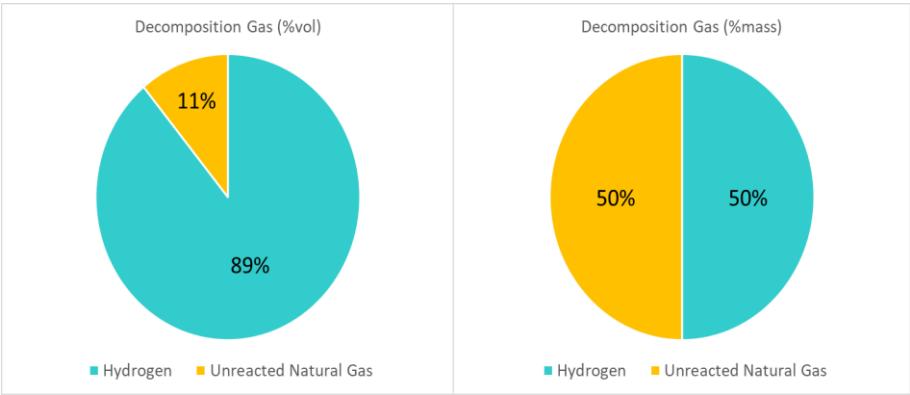
Source: Wärtsilä

Max power output 89/11 mol % blend gives a 45% reduction → **16.4 MW output**

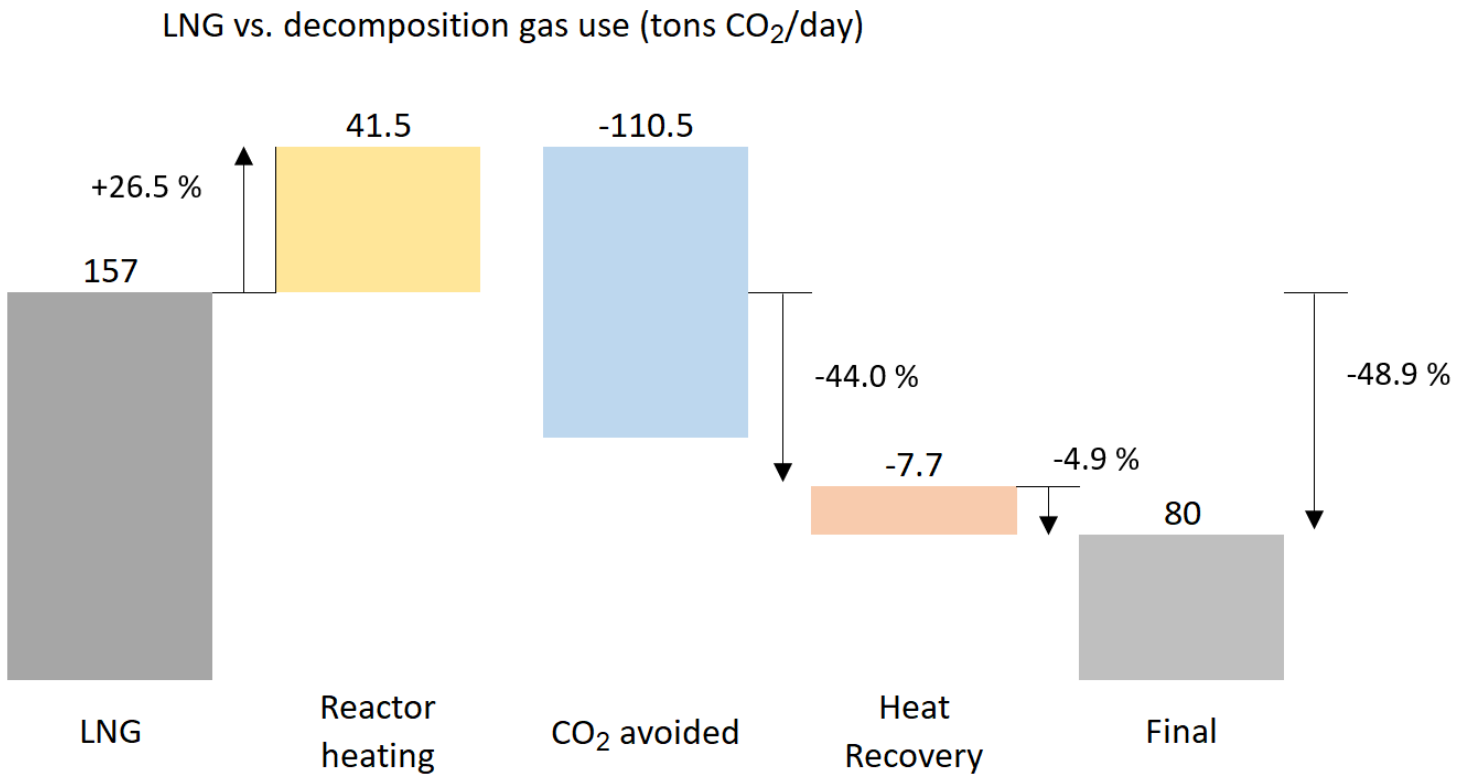
Results:
Carbon capture rate, energy and mass balance



Decomposer energy balance diagram



Decomposition gas composition



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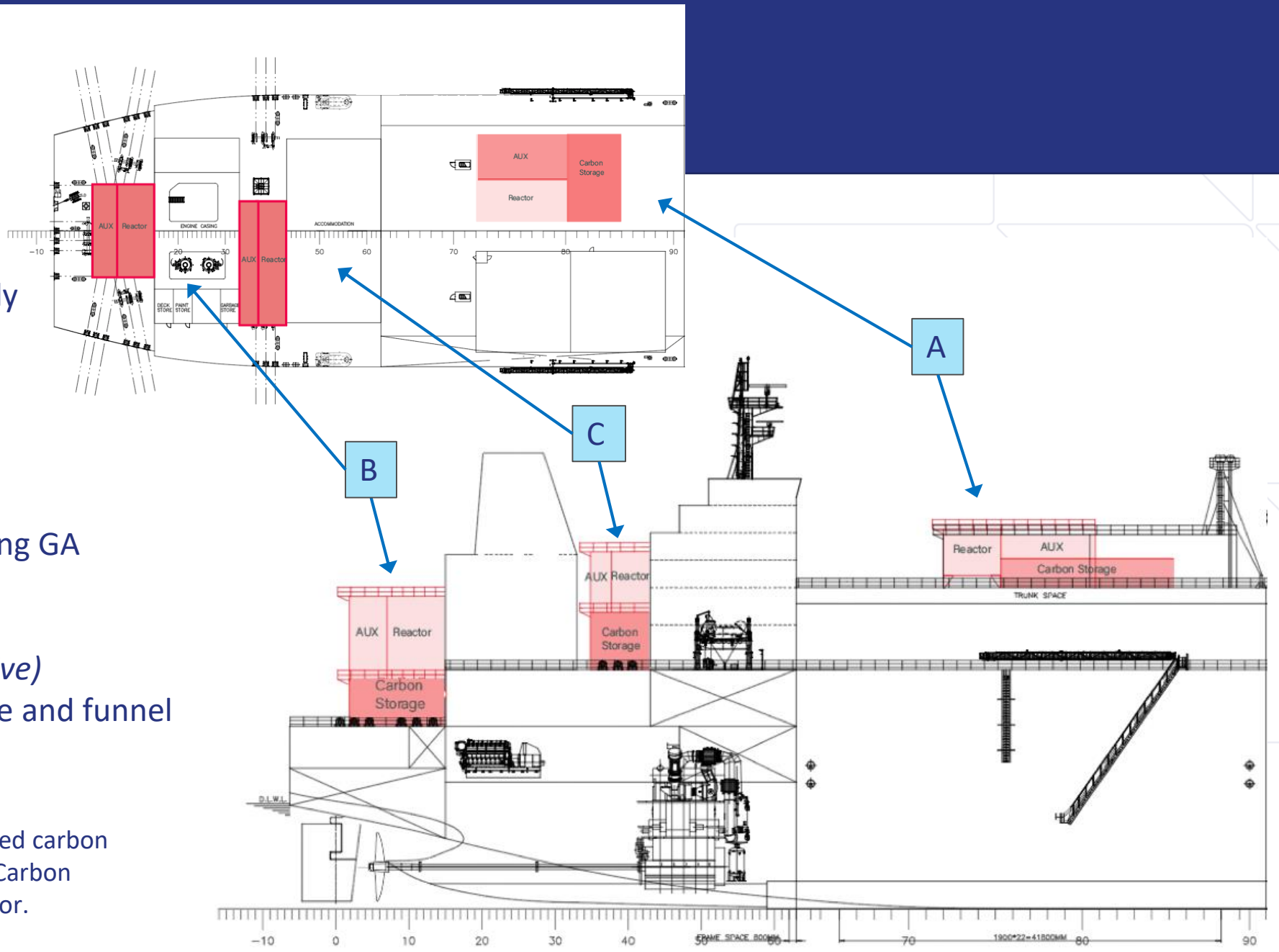
TDC & carbon storage equipment locations onboard LNG Carrier
(3 alternatives)

A. On deck *(ideal for newbuild)*
- ❑ More space available typically
- ❑ Closer to BOG systems

B. Aft of vessel *(ideal for retrofit)*
- ❑ Easier retrofit installation
- ❑ Minimal influence into existing GA

C. Front of/next to funnel *(alternative)*
- ❑ Short distance to both engine and funnel

30 day round-trip allow only single centralized carbon unloading location at gas loading terminal. Carbon storage tank can be placed below TDC reactor.



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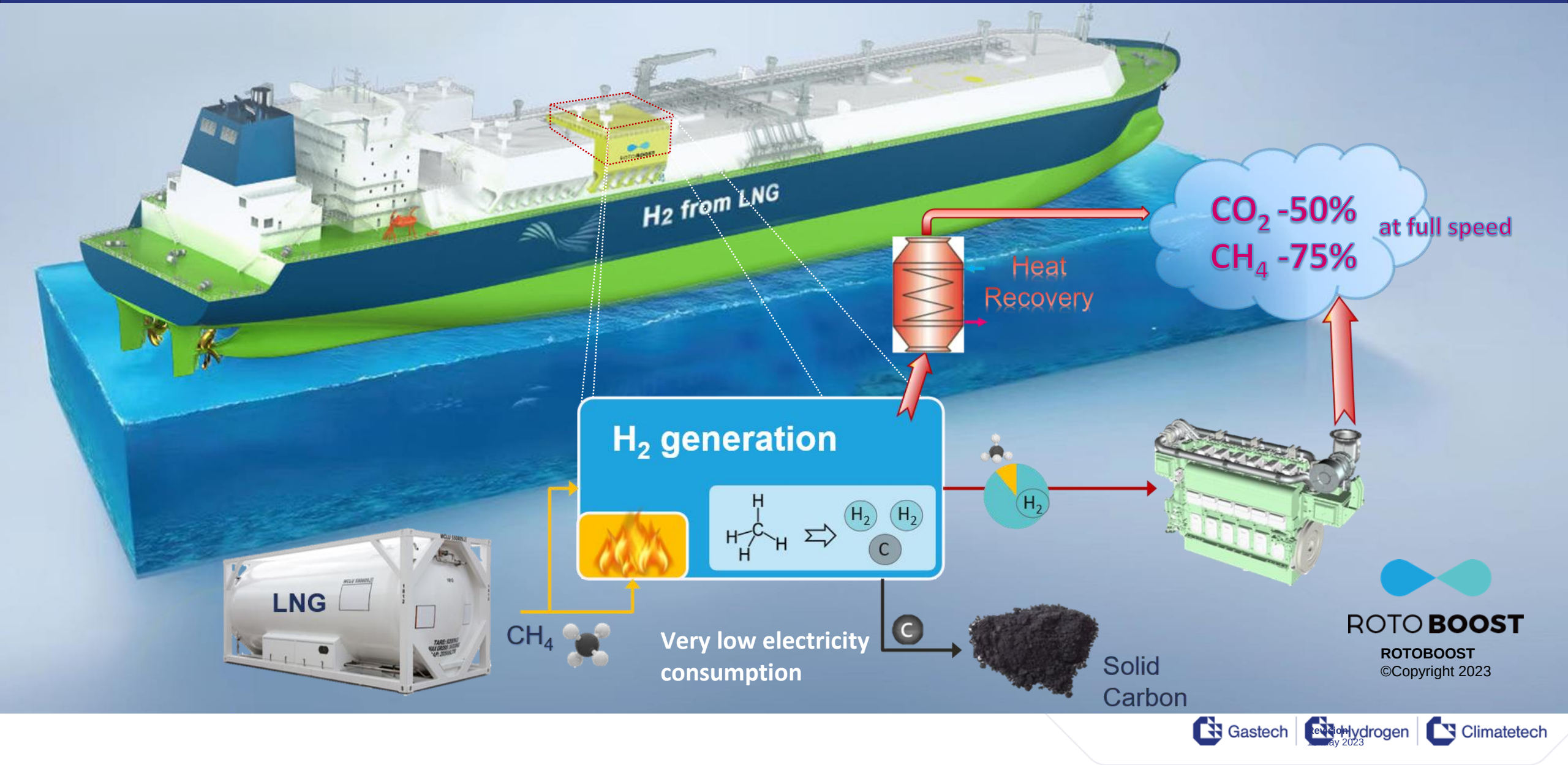


Classification and application of carbon products

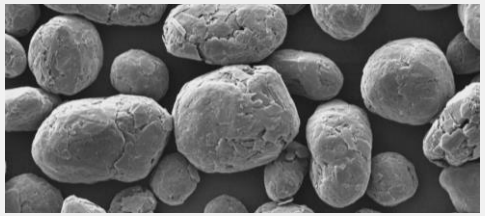
1 Carbon Black

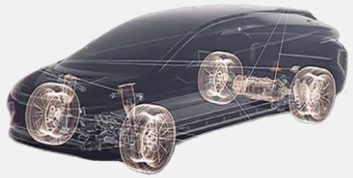
— Enhances the wear resistance

— Increase the tensile strength

— Improve the aging resistance

2 Pyrolytic Graphite





— Tap Density：≥ 1.05（g/cm³）

— Specific surface area:≤1.8（m²/g）

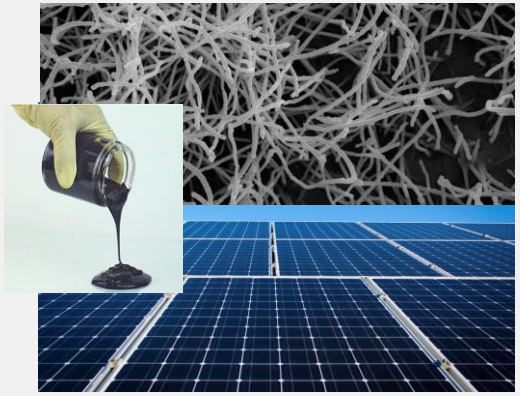
— Capacity：≥425（mAh/g）

— Density:1.75-1.8 （g/cm³）

— Charging Cycle：≥ 10000

Each TESLA Model 3 use：≥ 85 (kg）

3 Carbon Nanotube



— Tensile strength of 50-200 GPa equivalent to 100 times that of steel, but with a weight of only 1/6 of steel

— Axial thermal conductivity of 2000-3000W/mK, about 10 times that of copper and 3 times that of diamond.

— Advanced Lightweight Composites for Aerospace Automotive and Satellites

— Transparent Conductive Films

— Nanoelectronics and Semiconductor Devices

4 Graphene

— Concrete and steel additives boosting x100 higher strength

— Graphene has a thermal conductivity of up to 5300 W/(m.K), 13 times that of copper

— Energy Storage-Supercapacitors and Batteries

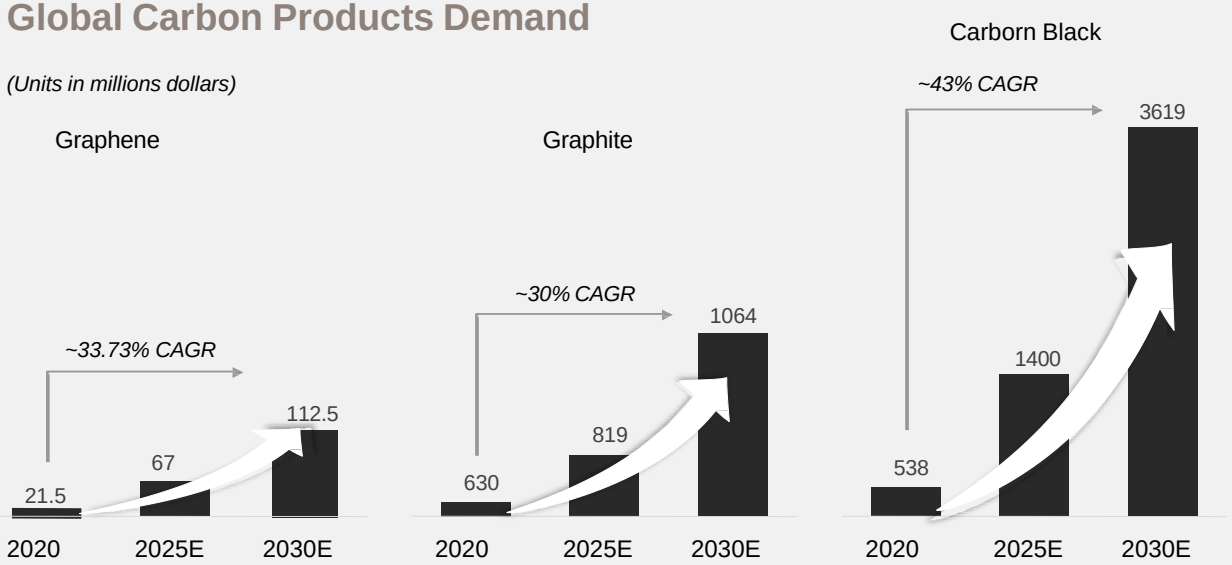
— Nano-Electronics- Transistors, Flexible Displays and Integrated Circuits

— Coatings - Ultra-High Barrier against corrosion, abrasion and UV rays

ROTO BOOST

The market for solid carbon

Global Carbon Products Demand



Carbon Products Market Drivers

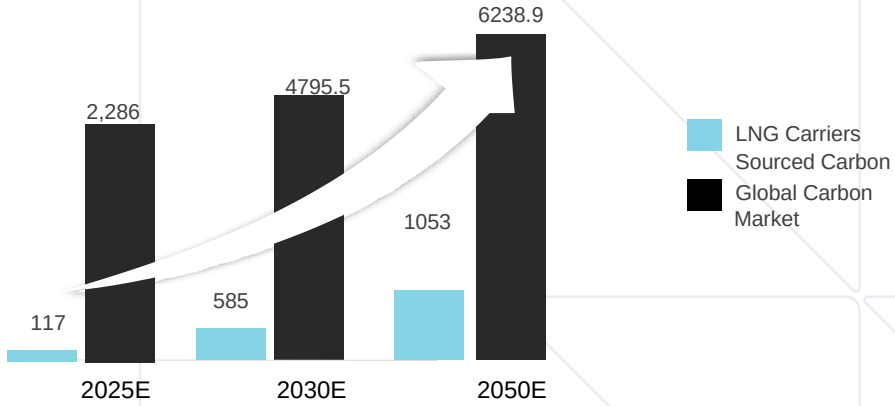
Global CO_2 emission legislation continues to tighten

Carbon downstream applications include automotive, chemical and semiconductor industries increasing rapidly every year

Carbon materials are the back-bone of almost all decarbonzation efforts, such as batteries,fuel cell, solar panels,high performance steel, speciality paint, etc

LNG Carriers Contribution to Global Carbon Supply

(Units in millons dollars)



New Global Carbon Materials Supply Chain

—a typical LNG carrier generates over 60 tons carbon materials daily.

—Traditional LNG export countries have potential to become the new global carbon material hubs

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Conclusion

TDC & DFDE using a hydrogen/NG fuel blend applied in LNG carrier

- **Blending in hydrogen improves the heat release and engine efficiency improves.**
- **Methane slip reduces**
- **Combustion temperature increases so NOx increases also, needs to be considered in the DFDE layout.**
- **In this study the 89/11 mol % blend was used in the L46TS, however the engine needs to be upgraded. No such plans are readily available, the market entry will be dependent on market request.**
- **DFDE system with an initial output of 36.4 MW seems possible in FO mode, even though output it reduced to 45% in fuel blend mode.**
- **DFDE in LNG carrier is proven technology.**
- **Capture – rate of 49% can be achieved with an 89/11 %mol blend.**
- **3 potential locations for the TDC and carbon storage tank are identified.**
- **Shipyard and owners need to be involved to finalize system integration.**
- **Solid carbon - goes into a circular economy.**

Thank you

Questions?