ROBERT ALLAN
Naval Architects & Marine Engineers

De-carbonization Pathways with Leading Tug Designs

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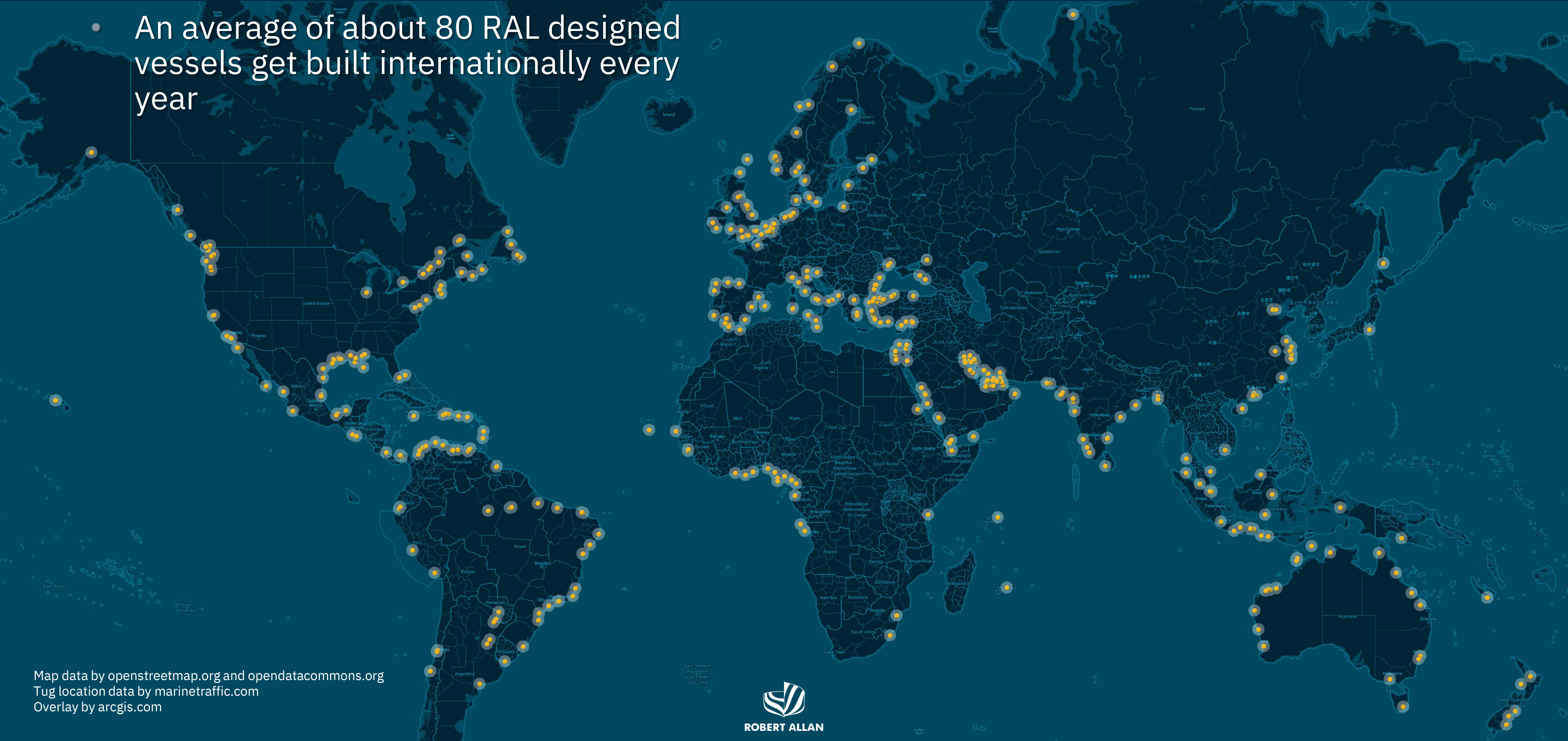
Robert Allan Ltd.

- Founded 1930 in Vancouver; Canada’s oldest consulting naval architectural firm
- Recognized internationally as the leading independent designer of high-performance escort, ship-handling tugs, shallow draft towboats and fireboats
- ~95 employees including ~40 professional engineers

Global Fleet – Latest Thousand Deliveries

- An average of about 80 RAL designed vessels get built internationally every year



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Tug location data by marinetraffic.com
Overlay by arcgis.com

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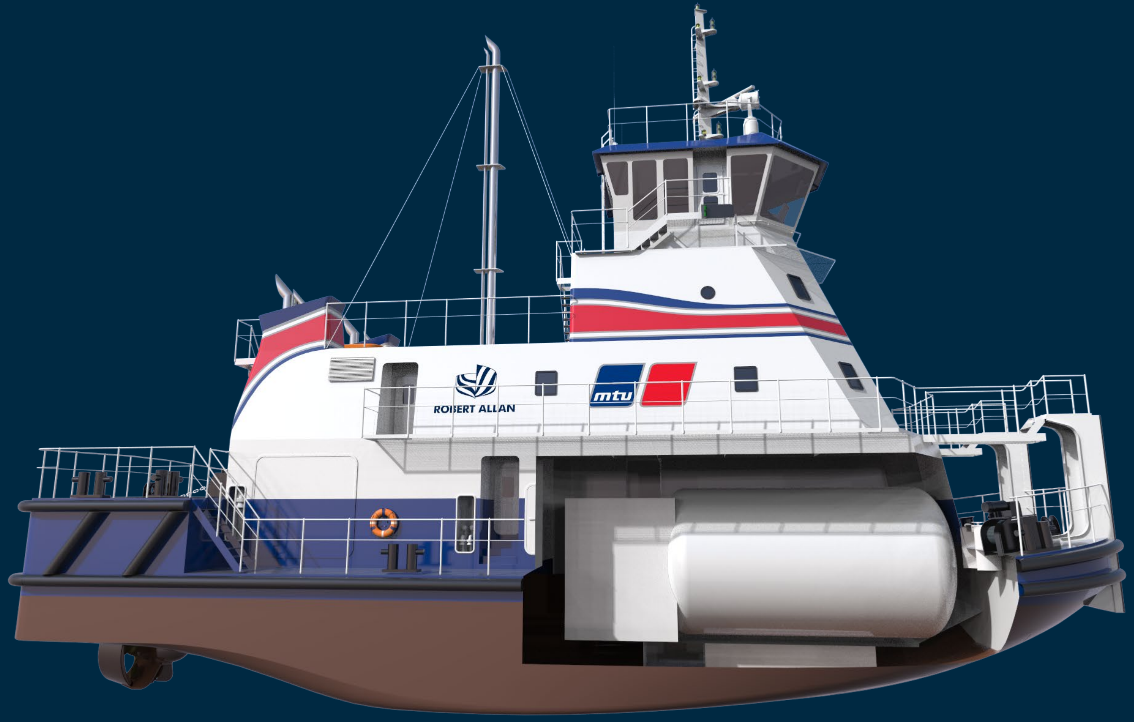
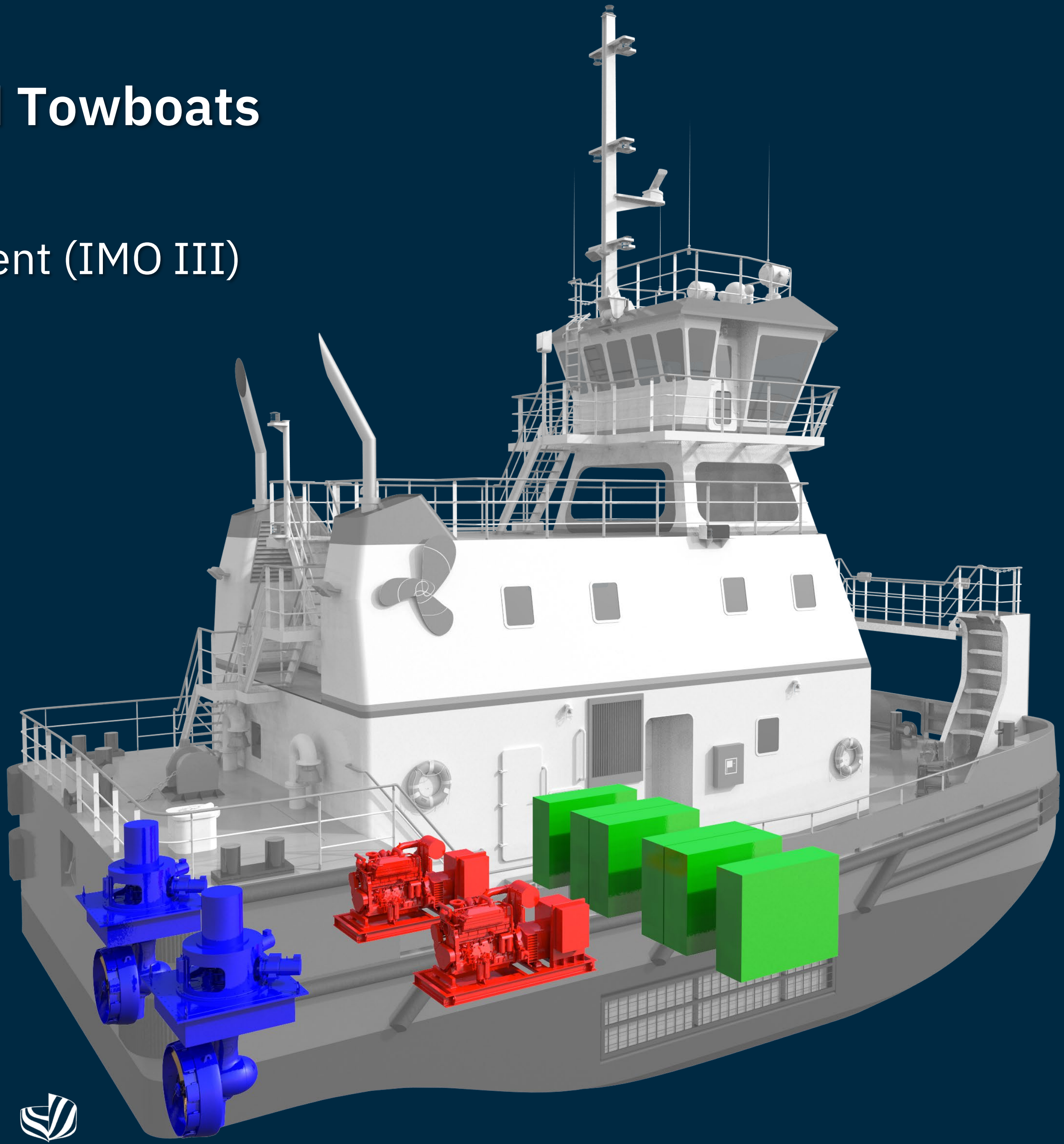
Propulsion Alternatives for Tugs and Towboats

- Diesel Hybrids and Diesel Electric
- Diesel (ULSFO) with exhaust after-treatment (IMO III)
- LNG (dual fuel or pure gas) and CNG
- Hydrogen / Ammonia / Methanol
- Battery Electric





Diesel Hybrids and Diesel Electric

- Limitless flavours
- Just as capable as conventional diesel tugs
- Increased complexity
- Modest CAPEX increase
- Can be *some* OPEX and GHG reductions
  - Diesel electric rarely makes financial sense for tugs or towboats
  - Better case for hybrids with reduced running hours, but fuel savings benefits often overstated
  - Batteries need to utilize shore power to be effective

Diesel + Exhaust Aftertreatment

- IMO III now required in Canada and significantly reduces NOx pollution
- EPA 4 in USA also reduces Particulate Matter pollution
- **Neither reduces Carbon or GHG**

- Moving towards Bio / Renewable Diesel offers limited long term pathway for decarbonization due to limited feed stocks
- May still make sense when supporting infrequent high power operations such as Fi-Fi or salvage

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LNG & CNG

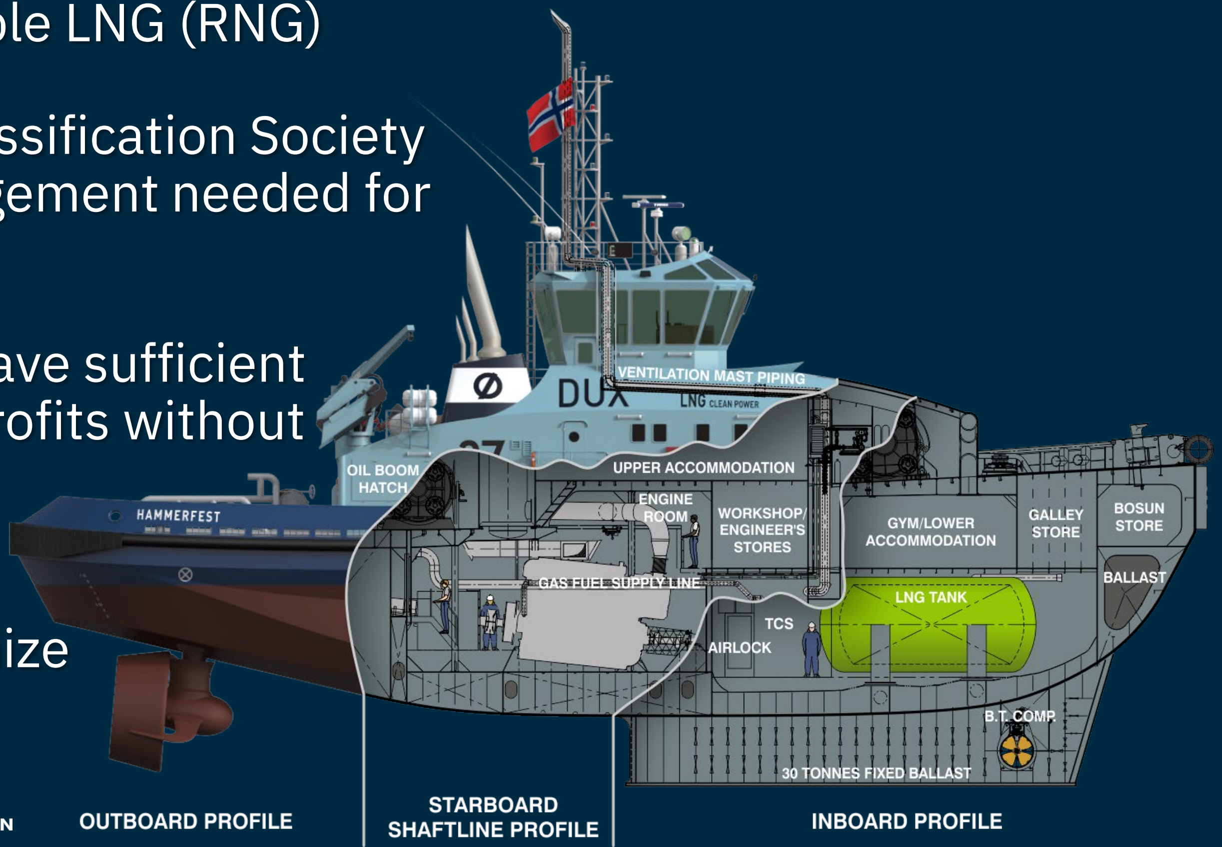
- High CAPEX for LNG. CNG offers limited range/endurance
- Reduced OPEX, but reasonable payback period is only with heavy load profile (ie. Long distance escort tugs)
- Increased complexity vs. diesel
- Reduction in CO_2, but need to control CH_4 emissions (methane slip)
- Range and endurance limitations, bunkering challenges

Experience with LNG Designs & Tugs In-Service

- 5 RAL designed LNG Dual Fuel tugs now in service, 28m (92’) to 40m (131’) in length
- 4 more RAL LNG Dual Fuel tugs currently under construction, 40m and 42m
- Class Approval in Principle (AiP) received for Pure Gas Fleeting Towboat developed with MTU
- Design of LNG Dual Fuel Towboat and Barge to transport bulk LNG completed
- Long term adoption of LNG for tugs is expected to be very limited to unique applications

Lessons from LNG Designs & Tugs In-Service

- Latest gas engines are improving, but still critical to optimize propulsion system to operating role of vessel to achieve true emissions reductions
- Gas Safe machinery approach has been adopted instead of Emergency Shutdown. Expectation is similar strong trend will apply to future fuels as also under IGF Code
- Operators now starting to implement Renewable LNG (RNG)
- As with all future fuels each Flag State and Classification Society approaches slightly differently and early engagement needed for successful projects
- Existing workboats (tugs & towboats) do not have sufficient space, deadweight/trim capacity to enable retrofits without significant reductions in endurance
- New designs must be designed around future fuel system to maximize endurance and minimize large CAPEX increases



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Hydrogen

- **Basis for decarbonized molecule based energy systems**
- **Tank to propeller emissions = only water!**
- Potential for large emissions from upstream production (grey vs. green hydrogen)
- Nontoxic, but very explosive and flammable
- Significant storage issues as Liquid (-253℃) or Compressed (Up to 700 bar)

	MGO	LNG	H_2 (liquid)	Ammonia	Methanol
Density (t/m^3)	0.835	0.428	0.071	0.61	0.792
LHV (GJ/t)	42.7	48.6	120	18.6	19.9
GJ/m^3	35.7	20.8	8.5	11.4	15.8
Volume (m^3/GJ) normalized	1	1.7	4.2	3.1	2.3

- Initial technology demonstrator projects are now reaching market

Hydrogen Production

Grey Hydrogen

- Produced by reforming natural gas
- 96% of worldwide hydrogen production
- Fuel price up to 4 x diesel
- GHG emissions greater than diesel

Green Hydrogen

- Produced by electrolysis
- Fuel price up to 10 x diesel
- Fuel price expected to drop with large scale electrolysis plants; down to 2x diesel
- Zero emissions

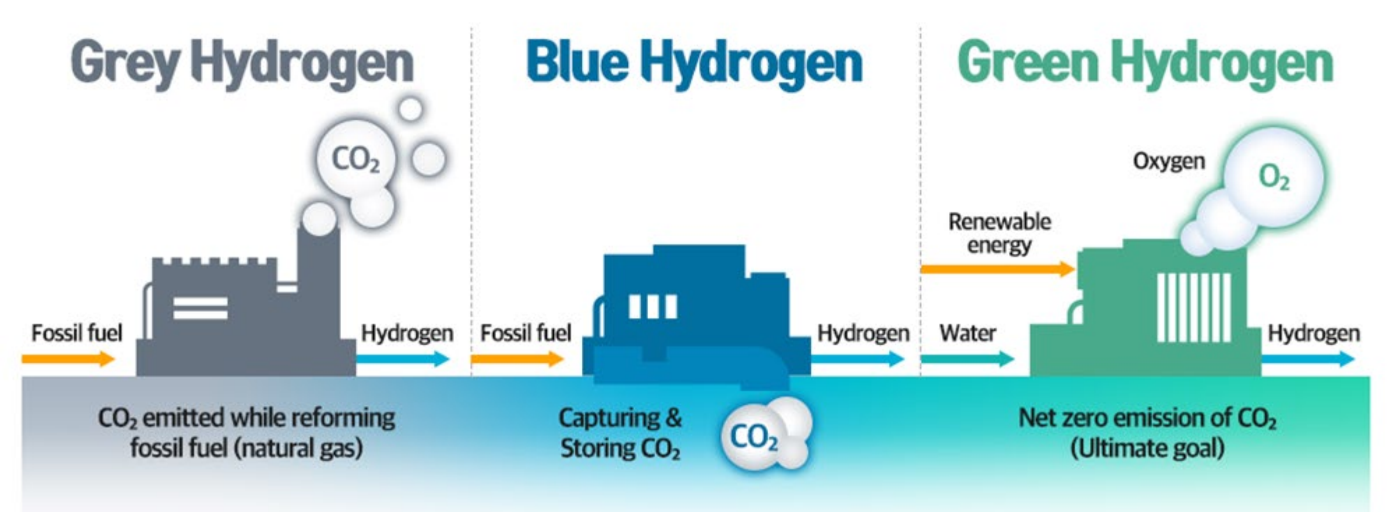


Image: POSCO

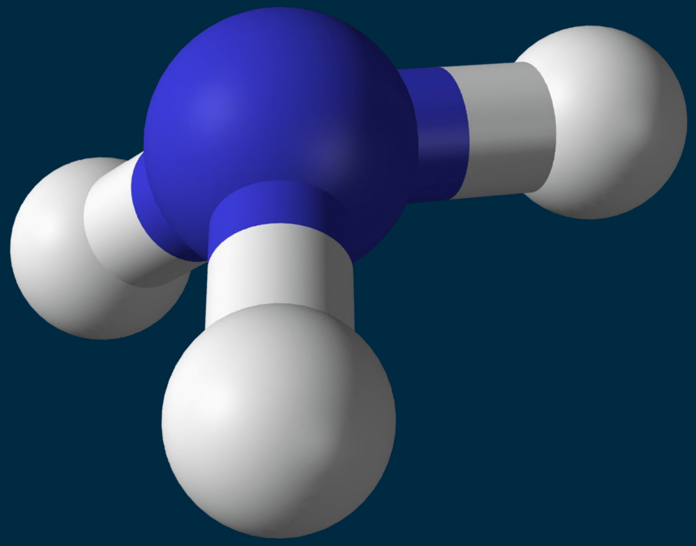
Hydrogen – Combustion and Fuel Cells

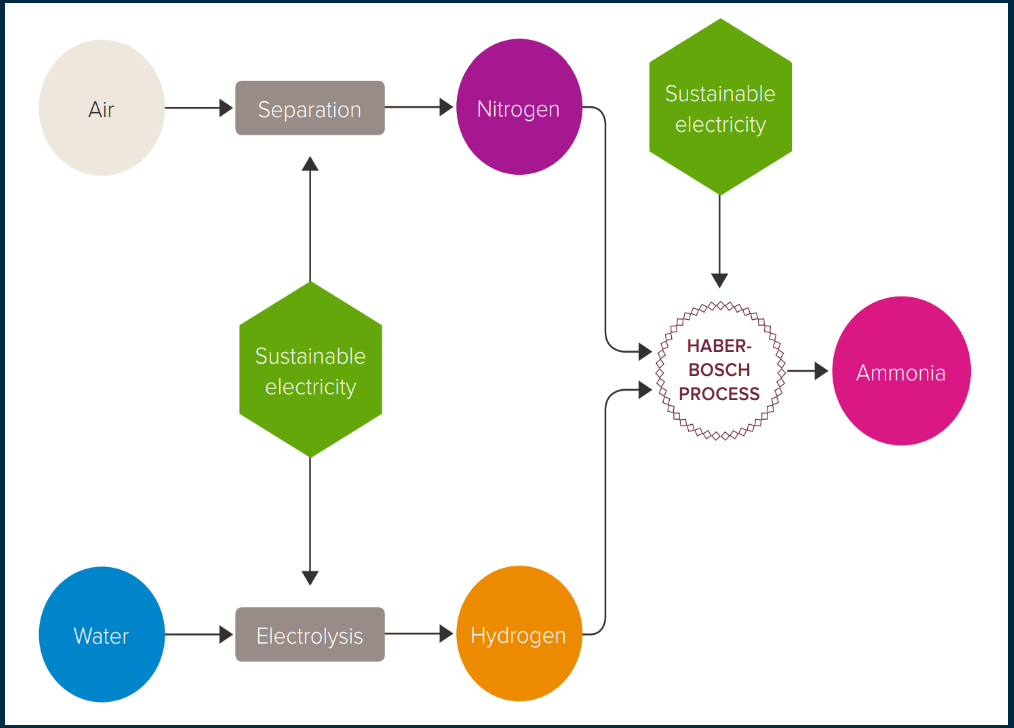
- Hydrogen combustion – **still expensive and unproven**
  - Cryogenic storage required for long endurance
  - Difficult hazardous zone considerations
  - Pricing and availability of green vs. grey hydrogen
  - Limited engine options slowly coming to market

- Fuel cells – Decent range and endurance **but very high CAPEX**
  - Still need batteries or additional power sources to handle propulsion load response, larger vessel to accommodate all equipment
  - Compressed hydrogen possible for short range/endurance operations
  - Cryogenic storage required for long endurance
  - Potential reforming options from Ammonia and Hydrogen Storage
  - Prices need to come down to be economically viable for workboats

Ammonia

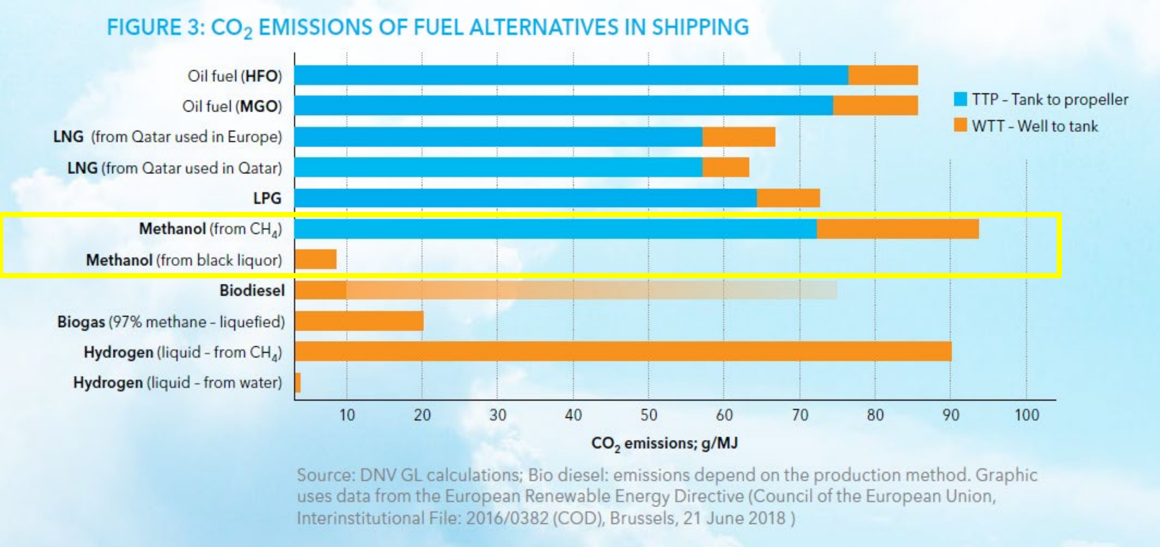
- No Carbon!
- Flammable Gas, Very Toxic, Highly Corrosive
- Very toxic to marine life
- Boiling Point -33.4°C, can be stored as a liquid at room temperature at 8.6 bar
- Some lessons from LNG can be applied, but considerable challenges remain:
  - Regulations and Risk Assessments need to be developed by Class to suit smaller vessels
  - Engine development would be needed for engines to fit within tugs. High speed engines unlikely in near future
  - Potential Nitrous Oxide concerns similar to Methanol Slip
  - Requirements as written make compliance on <40m tugs near impossible. Detailed risk assessments would need to be performed in order to proceed.

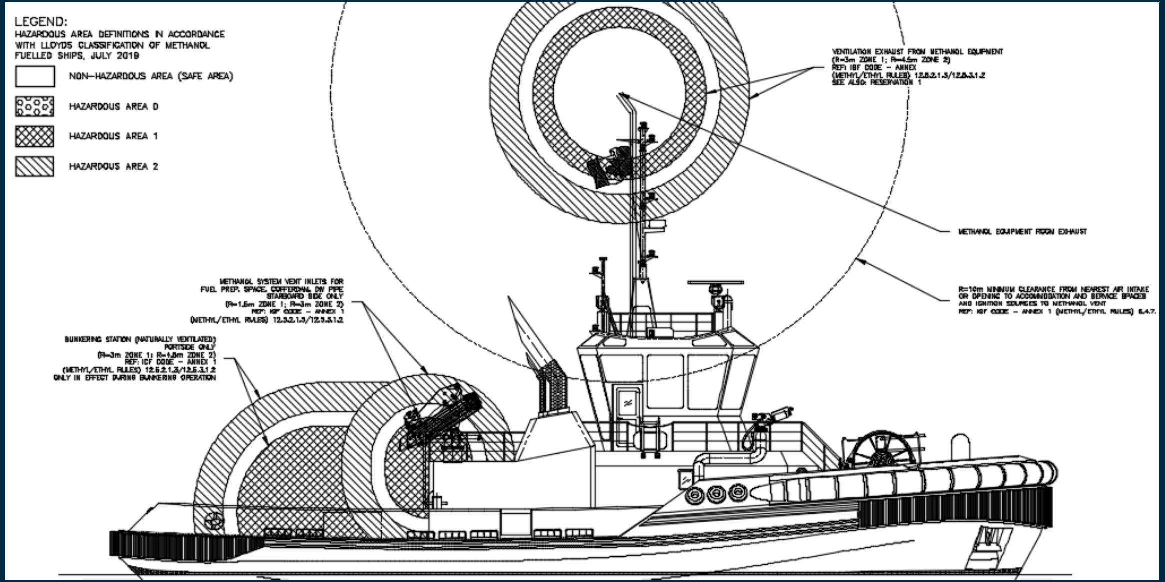




Methanol

- Not cryogenic, not toxic like Ammonia, but still low-flash under IGF Code so requires segregation from machinery spaces and sources of ignition
- Lower CAPEX hit to vessel once engines developed
- Not many engine options yet, but additional options coming to market
- Burning of methanol can be carbon-neutral,
  but must consider upstream production
- **Strong potential for future fuel for tugs**





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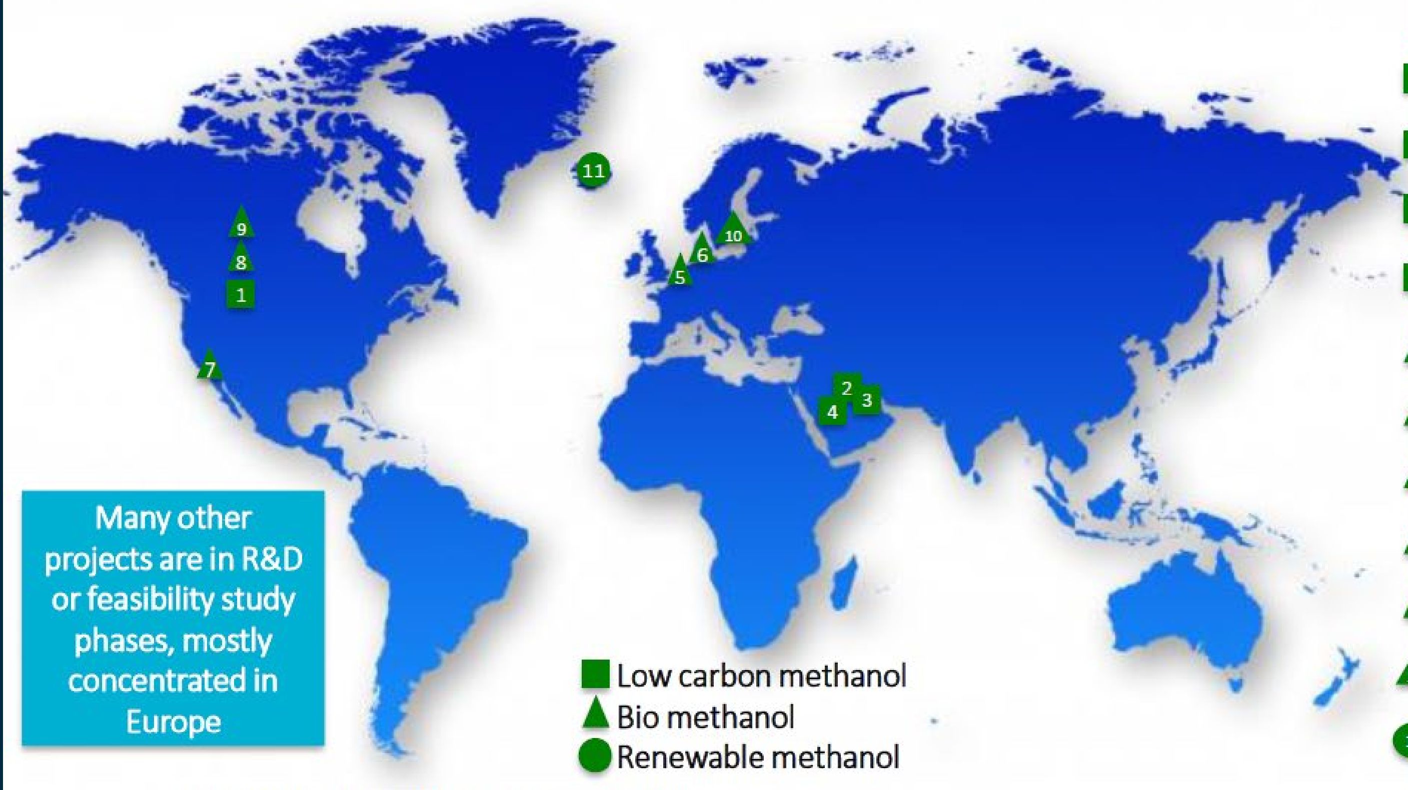
Green Methanol Production

Production facilities for Green Methanol

Many manufacturing operations exists, proving the technological feasibility



Company	Country	Feedstock
1 Methanex	Canada*	CO_2
2 GPIC	Bahrain	CO_2
3 QAFAC	Qatar	CO_2
4 Sabic	Saudi Arabia	CO_2
5 BioMCN	Netherlands	Bio-methane
6 New Fuel	Denmark	Biogas
7 Oberon	USA	Biogas
8 Enerkem	Canada	MSW
9 Al-Pac	Canada	Forest Biomass
10 Sodra	Sweden	Forest Biomass
11 CRI	Iceland	Renewable power

* Only 80kta out of a total 670kta production
Source: Methanol Institute

(Image Source: Methanex)

Methanol Designs

- Agreement with Uzmar in Turkey for four Methanol fuelled tug designs
- First based on proven **RAstar 3200-W** design with ~120m³ of Methanol capacity expected based on current regulations (Current design ~200m³ of diesel)
- New fully customized designs also underway to maximize endurance

- Methanol fuelled tug design being developed for Svitzer

- Jointly working with Class to update current Methanol guidance to reflect tug configurations and lessons learned from LNG tugs, to increase flexibility and endurance

- Methanol fuelled Crew Transfer Vessel has been developed for wind farm market

- ***With supply of low carbon Methanol from Alberta production facility BC has potential decarbonization pathway for applications where batteries not possible***

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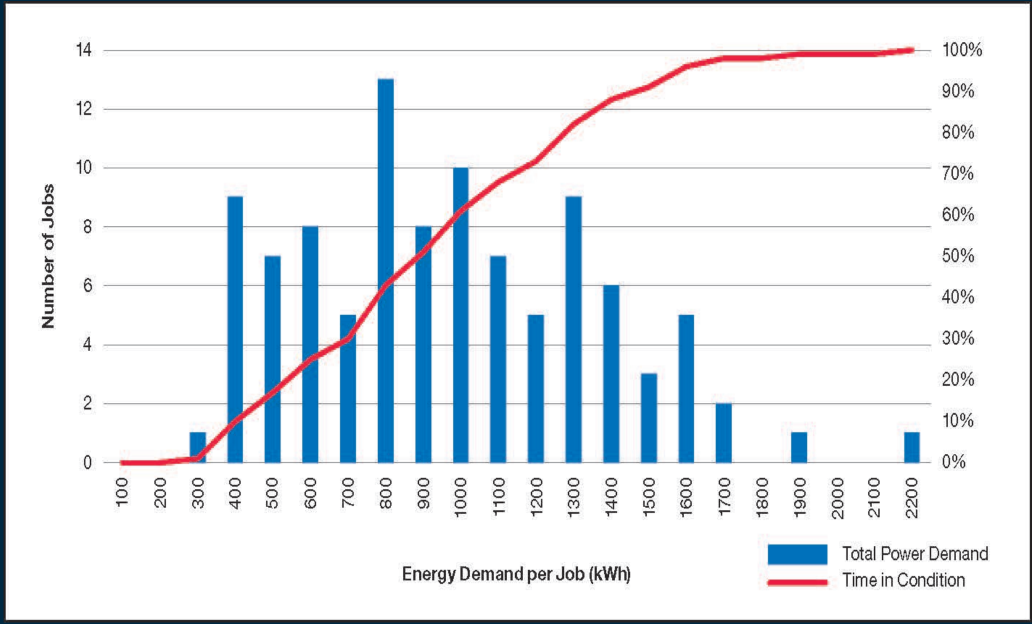
Battery Electric

- **Removes inefficiencies of creating green hydrogen/ ammonia/methanol by utilizing electricity directly**
- **Zero emission** operation *when charged from <u>clean shore power</u>*
- Early adoption in other regions will receive benefits of greening power grid
- CAPEX increase highly dependent on installed batteries capacity
- Reduced OPEX; payback period dependent on differential between prices of diesel and electricity
- Range and endurance limitations, but can be acceptable in harbour/fleeting operations
- Strongest cases for adoption where applied in fleets with large number of short duration jobs
- Integration with shore power infrastructure key for successful project
- ***First adoptions already a reality and BC leading this path to decarbonization***



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ElectRA Series

- Utilize proven, high performance hullforms with stylishly designed low-profile superstructures for working under high-flare ships
- Industry-leading battery capacity in compact vessel dimensions, best-in-class range and endurance
- Battery capacity and backup generator power customizable to operator specific requirements
- Multi-layered battery safety systems
- Optimized for industry leading Corvus Orca batteries but customizable for alternative suppliers
- Optional Fi-Fi and escort notations on most designs
- Flexible to wide range of bollard pulls

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ElectRA Series

- +10 Battery Electric Tugs under construction or design for Sanmar in Turkey that will be delivered in 2023 & 2024. Market is driving rapid adoption of this decarbonization pathway

ElectRA 1900 & 2300
Flush deck, day boat configurations
2.0 to 3.6 MWh battery capacity
1 or 2 Gensets, Limited or Full Fi-Fi Capability
40t to 70t BP

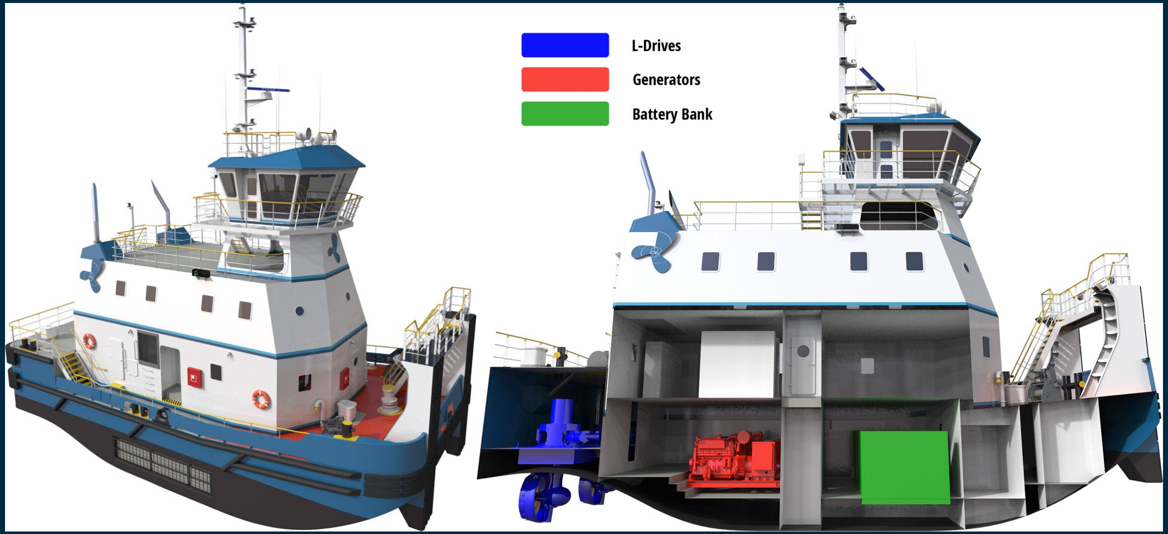
ElectRA 2500 & 2800
Stepped deck, full accommodations
3.4 to 6.1 MWh battery capacity
2 x Large Gensets, Full Fi-Fi 1 Capability
+70t BP, 40t BP Continuous

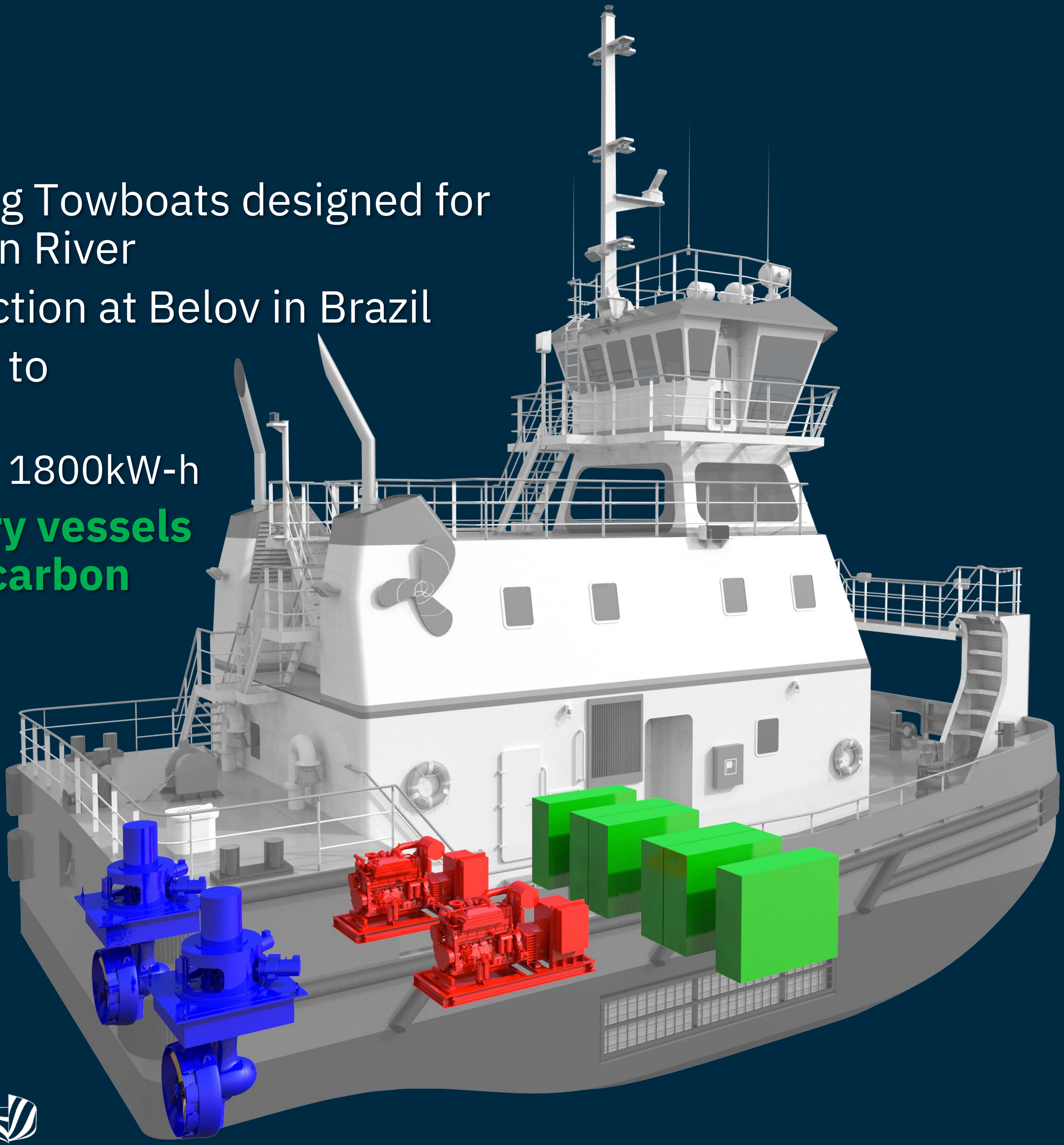
Battery Electric Harbour Tug Examples

- 28m ***ElectRA 2800*** Battery Electric Harbour Tug designed for HaiSea Marine (JV of Haisla First Nation and Seaspan) for operations in Kitimat, BC to serve LNG Canada export terminal
- 3 ***ElectRA 2800***s currently under construction at Sanmar in Turkey
- 5,300kW-h initial battery capacity with potential expansion to 6,100kW-h
- Initial capacity allows for all regular port assistance of gas carriers purely on battery power
- Clean hydro power allows maximum potential carbon reduction
  - Approx. 2,000 tonnes carbon saved per year, per tug
- ***ElectRA 2800***s paired with ***RAstar 4000-DF*** Dual Fuel Escort Tugs to handle 160nm high speed escort of gas carriers. Important example of selecting technology for each role.

Battery Electric Fleeting Towboat

- 20m ***RApide 2000-E*** Battery Electric Fleeting Towboats designed for Hidrovias do Brasil for operations on Amazon River
- 2 x ***RApide 2000-E*** towboats under construction at Belov in Brazil
- Being built with expandible battery capacity to increase range and endurance in future
  - 600kW-h initially with potential expansion to 1800kW-h
- **As the power grid becomes greener battery vessels directly gain the benefits of that reduced carbon**





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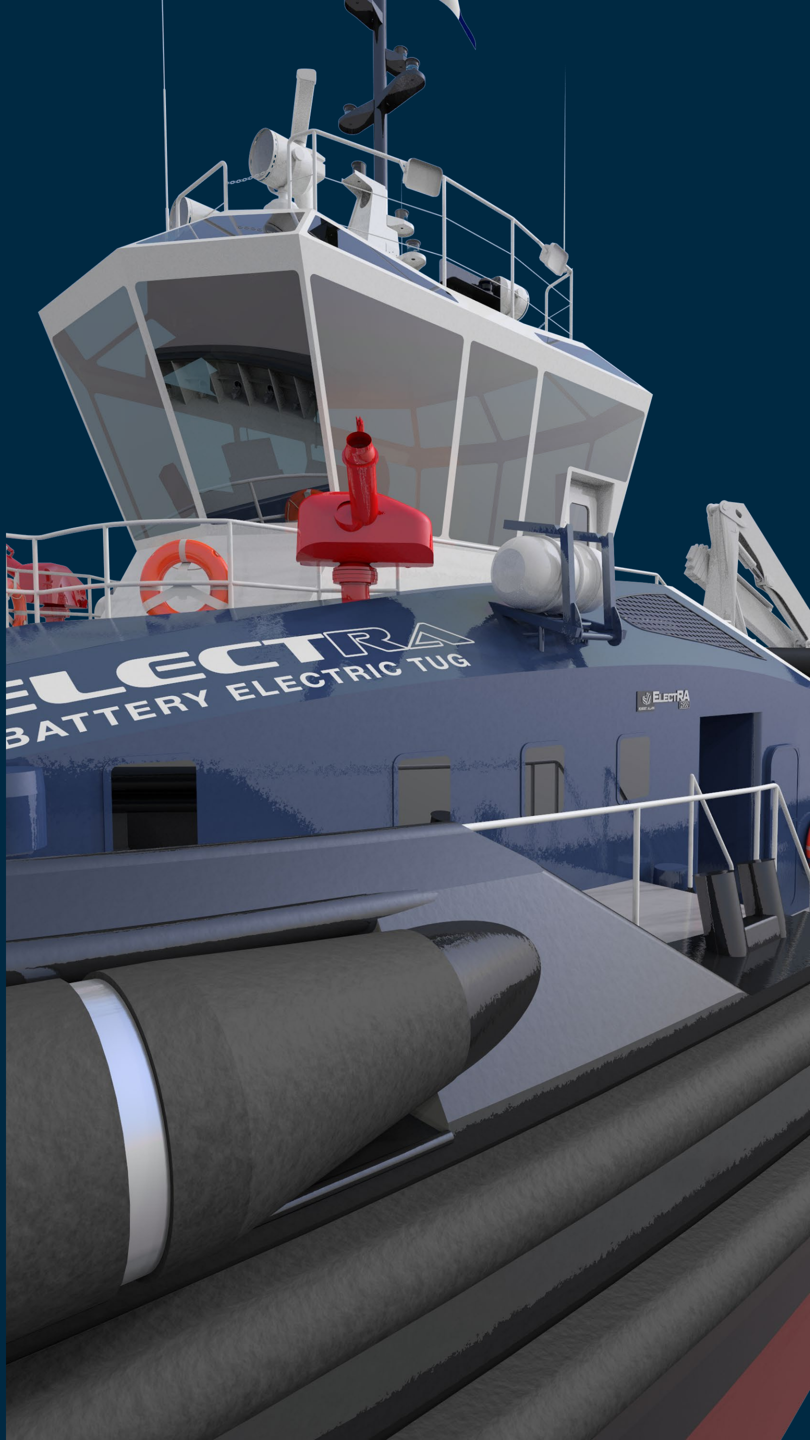
In Summary

- Selection of energy technology will be dependent on unique requirements of each project
- Conventional diesel with after-treatment (EPA 4 / IMO III) will have a place for years to come with some hybrids justified however is not a direct path to decarbonization
- Fuel cells are potential long term zero emissions option
- Availability of green methanol, ammonia, hydrogen combustion could present financially attractive low-emission opportunities
- Adoption of battery electric workboats is rapidly accelerating
  - A good fit when clean shore power exists or grid will green over time to enable operations with zero emissions
  - Wide range of ***ElectRA*** series tugs are now available and is continually being expanded
  - Shore infrastructure to support battery electric tugs important consideration



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Thank you for your time