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A Technical, Economic and Environmental Assessment of Clean Marine Fuel Options for Australia

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Mr. Nguyen Cao, Dr. Denis Andrianov and Prof. Michael Brear

Outline

1. A brief overview of the shipping sector
2. Conventional and alternative energy carriers
3. Conventional and alternative propulsion systems
4. Modelling of shipping performance
5. Case study: Australia-China Iron Ore Corridor
6. Conclusions
7. Project Deliverables

A brief overview of the shipping sector

International

Trade volume = 12 billion tonnes p.a.[1]

Growth = 2.1% p.a.[1]

CO_2 emissions = 706 million tonnes p.a. (~2% of global energy related CO_2 emissions)[1]

Australia

Trade volume = 1.7 billion tonnes p.a. (99% of Australia trade volume)[2,3]

Growth = 1.4% p.a.[2]

Value = $600 billion (85% of Australia trade value)[2,4]

CO2 emissions = 2 million tonnes p.a.[5]

– Estimated from miniscule bunker fuel sales

[1] UNCTAD. (2023), [2] BITRE. (2023), [3] Shipping Australia. (2020), [4] ABS. (2023), [5] DCCEEW. (2023)

Conventional and alternative fuels

Conventional fuels considered:

- Heavy fuel oil (HFO)
- Very low sulphur fuel oil (VLSFO)
- Marine gas oil (MGO)

Alternative fuels considered:

- Liquefied natural gas (LNG)
- Compressed hydrogen (CH2)
- Liquefied hydrogen (LH2)
- Ammonia (NH3)
- Methanol (CH3OH)

Fuel production pathways considered:

- Fossil (F)
- Blue (BL)
- Bio (BIO)
- Green (E)

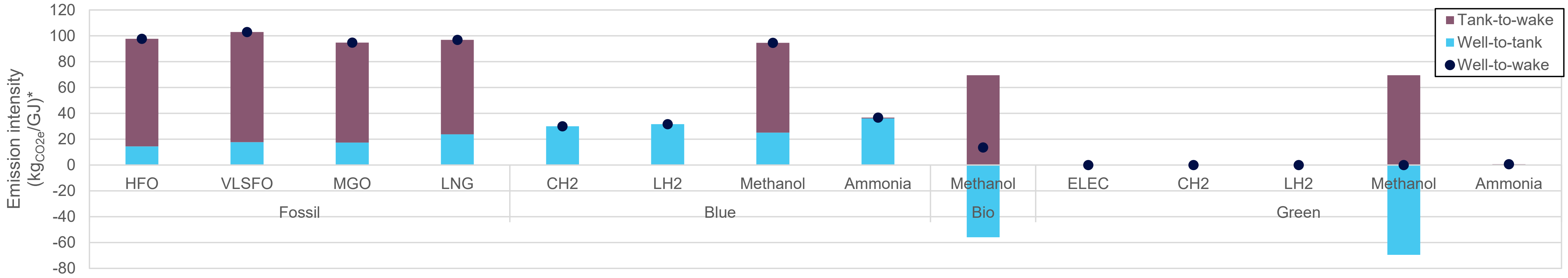
Emission intensity and energy cost

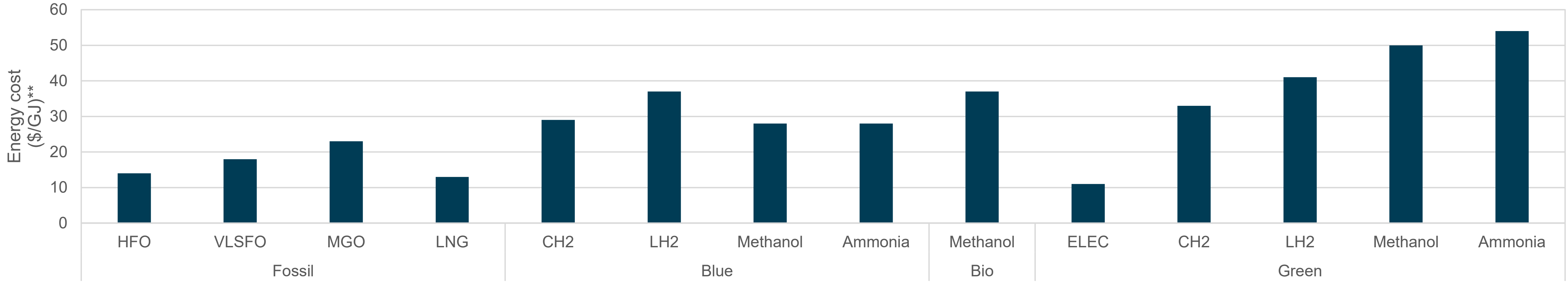
Many groups have costs and emissions data. The pathways are complex, uncertain and a large topic on its own.

The below is the most authoritative and current independent data we could find, other than our own!

Most to least polluting production pathways: fossil, blue, bio and green – plausible.

The reverse is true for the corresponding pathway costs – plausible.





*** Emission intensity data from: [1]Comer and Osipova (2021), [2]IEA. (2019), [3]IRENA & Methanol Institute. (2021), [4]European Union. (2018), [5]IEA. (2023), [6]Zaimes, G. G. (2021).**
**** Cost data from: [2]IEA. (2019), [3]IRENA & Methanol Institute. (2021), [5]IEA. (2023), [7]Ship & Bunker. (2023).**
**** The currency used is USD.**

Conventional and alternative propulsion systems

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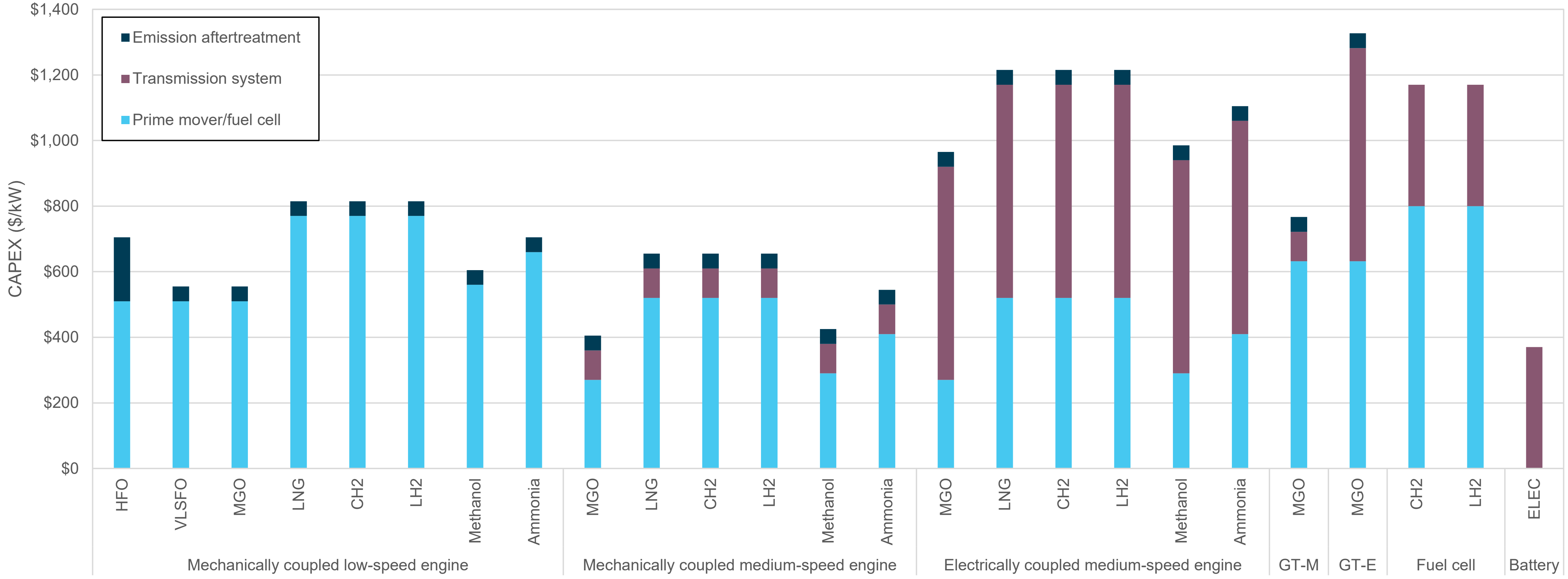
Low-speed engine	Medium-speed engine	Gas turbine	Fuel cell	Battery
• Mechanically coupled (LSE-M)	• Mechanically coupled (MSE-M) • Electrically coupled (MSE-E)	• Mechanically coupled (GT-M) • Electrically coupled (GT-E)	• Electrically coupled (FC-E)	• Electrically coupled (B-E)

Conventional (Low-speed engine, Medium-speed engine, Gas turbine)

Alternative (Fuel cell, Battery)

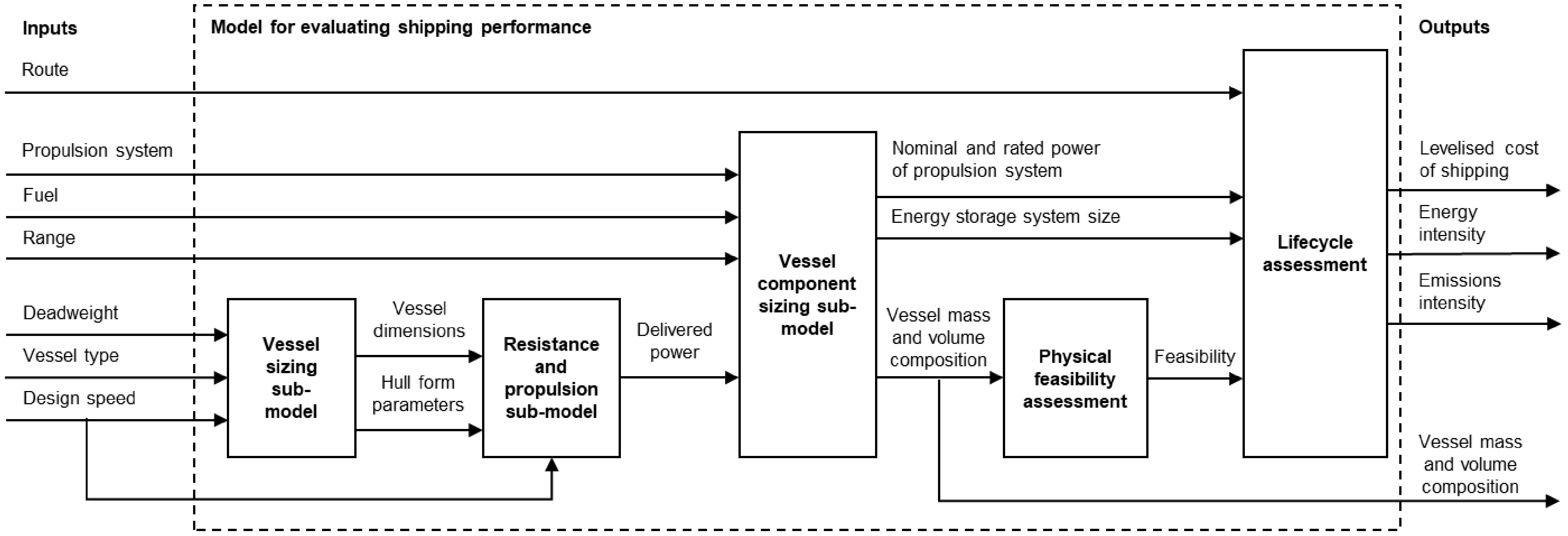
Capital cost

Again, many groups have propulsion system cost data. These are uncertain and a large topic on its own.
But, capital cost of propulsion systems matters **far less** to the ship's overall economics than their efficiency and fuel costs.



*** The capital costs presented above exclude the energy storage components.**
**** The currency used is USD.**
[1]Korberg, A. D. et. al. (2021), [2]Aurecon. (2022), [3]Kanchiralla, F. M. et. al. (2022), [4]Trivyza, N. L. et. al. (2022)

Modelling of shipping performance



The model accounts for **route, range** and **ship specifications** to determine **vessel sizes** and **propulsive power** and subsequently **feasibility** as well as **energy**, **emission** and **cost** factors for each **fuel** and **propulsion system** option.

Shipping performance metric

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- The levelised cost of shipping (LCOS):

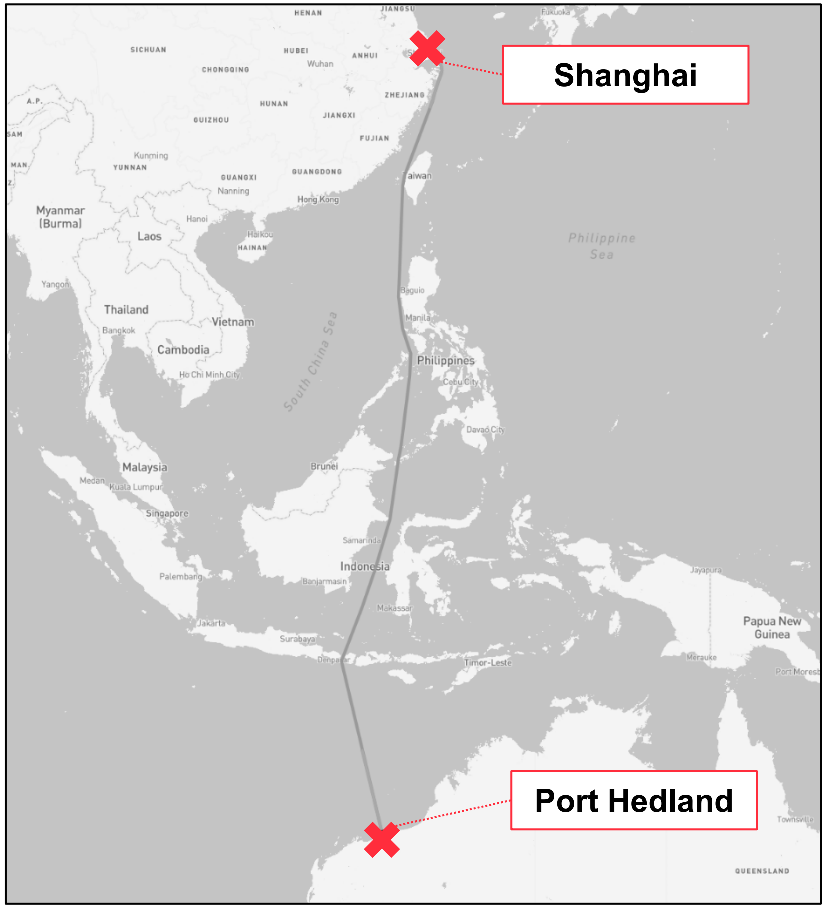
$$LCOS\left(\frac{\$}{tonne \cdot km}\right) = \frac{(capital\ costs) + (fuel\ costs) + (other\ operating\ costs)}{\underbrace{(mass\ of\ goods\ carried) \cdot (distance\ travelled)}_{\text{Transport work}}}$$

- Emission intensity (EI):

$$EI\left(\frac{kg_{CO2e}}{tonne \cdot km}\right) = \frac{total\ mass\ of\ GHG\ emissions}{\underbrace{(mass\ of\ goods\ carried) \cdot (distance\ travelled)}_{\text{Transport work}}}$$

Case study: Australia – China iron ore corridor

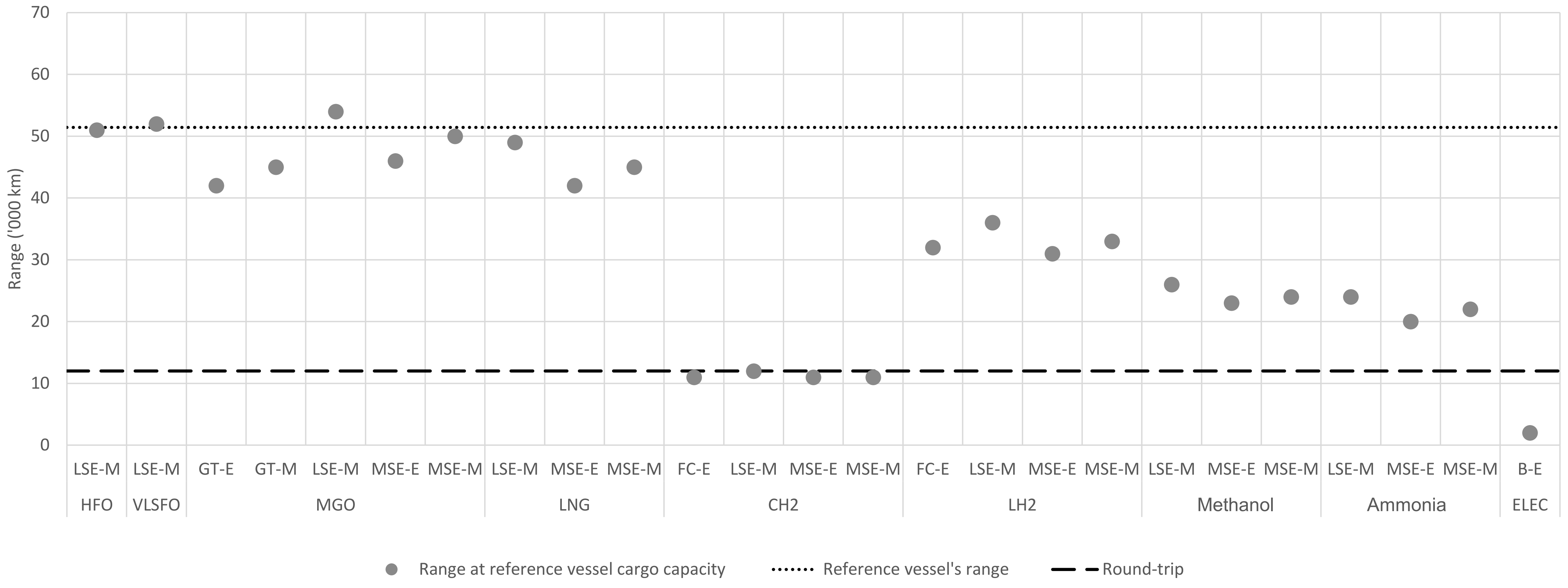
- Mass of iron ore traded = 722 million tonnes p.a.[1]
- Route distance = 6,000 km
- Vessel = 250,000 tonne bulk carrier
- Total annual energy consumption = 213 PJ p.a.*
- Total annual GHG emissions = 21 million tonnes_{CO2e} p.a.*



*Modelled results using methodology described. All iron ore exported to China is assumed to follow the illustrated route, transported by 250,000 tonne deadweight bulk carriers at 14 knots, powered by HFO-fueled LSE-M.
[1BITRE. (2023), [2]DCCEEW. (2022), [3]DCCEEW. (2023)

Maximum operational range

Every ship, except those powered by battery and compressed hydrogen, can make 1 return trip without comprising the cargo capacity!

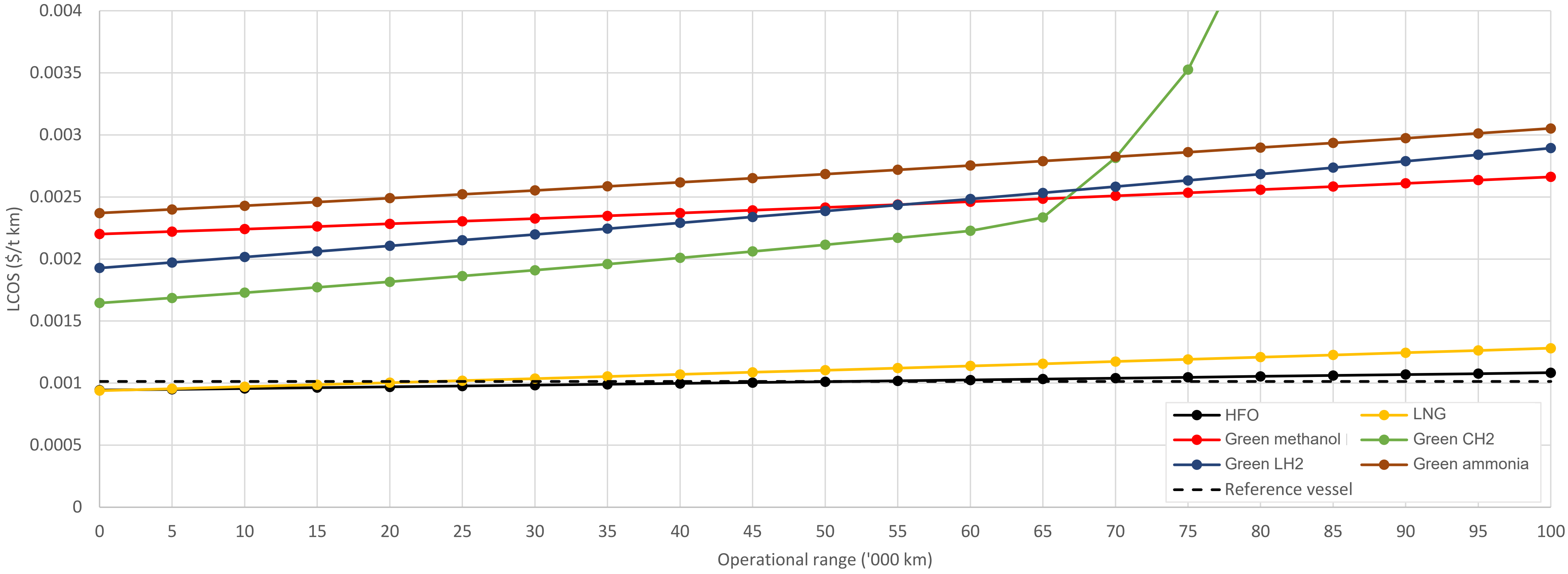


***Modelled results using the methodology described.**
****Operational ranges exceeding 100,000 km were omitted as they are less relevant and increasingly compromise cargo capacity.**

LCOS as a function of range

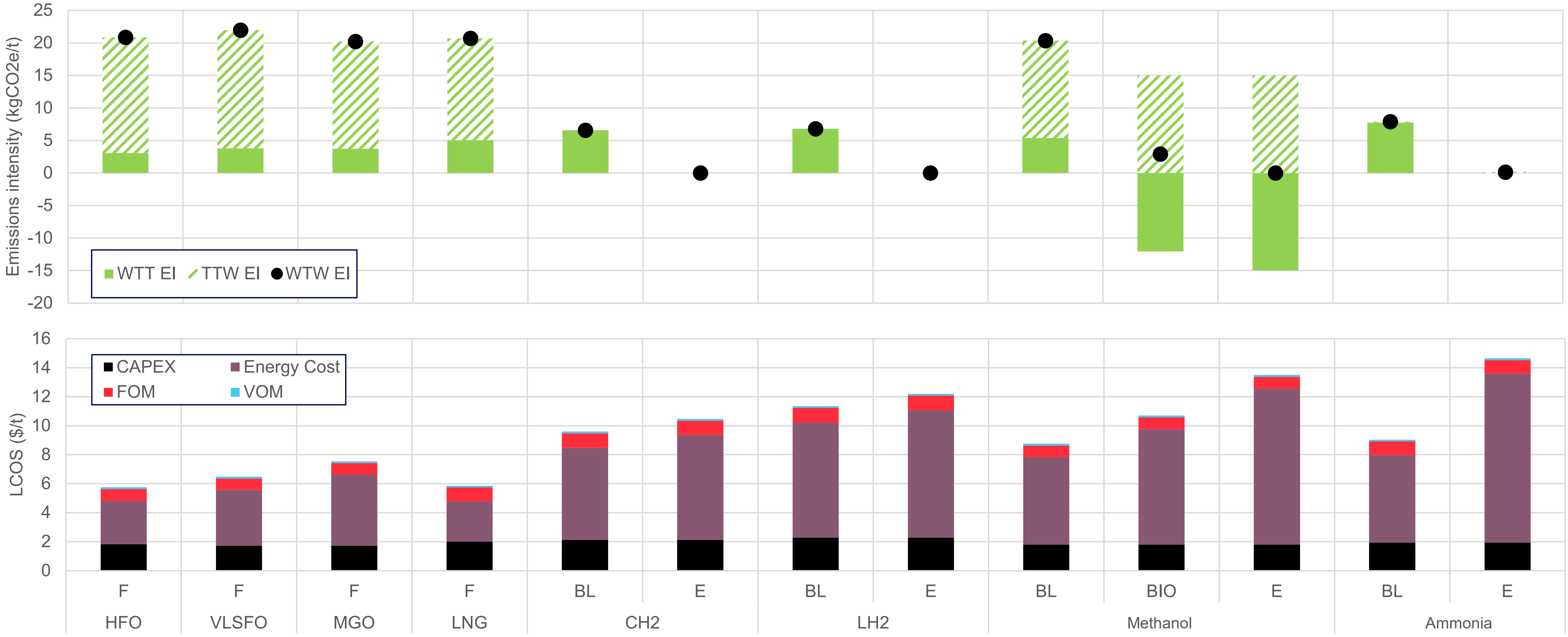
Results shown are for options employing low-speed engines.

Other propulsion systems demonstrate similar trends but higher LCOS relative to the low-speed engine cases due to their lower efficiencies. The battery-powered option is at least 1 order of magnitude more expensive than the reference vessel.



*Modelled results using the methodology described.

LCOS and emission intensity for 12,000 km range



***Modelled results using the methodology described.**
**** Results shown here is for the fuels used with the LSE-M option only.**

Conclusions

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- Except for the battery option, all combinations of fuel and propulsion system considered appear to be plausible for shipping Australian iron ore to China on bulk carriers with representative deadweight. This even includes a single, return trip fuelled with gaseous hydrogen.
- Whilst low-emission fuels may at least double shipping costs, this is anticipated to increase the delivered costs of Australian iron ore to Asian trading partners by about 10-15% if the fuel tank is sized for 1 return trip. This is potentially a justifiable “green premium”, and there may be options to reduce these costs.
- Noting the many uncertainties in this work, blue ammonia and blue compressed hydrogen appear to be the lowest cost low-emission shipping options, whilst green compressed or liquefied hydrogen and green methanol appear to be the lowest cost zero-emission shipping options.
- Ongoing work is examining how to reduce the LCOS further for different clean shipping types.

Acknowledgements

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