AOG ENERGY 2024

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

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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

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]

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

A brief overview of the shipping sector

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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)

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- Ammonia (NH3)
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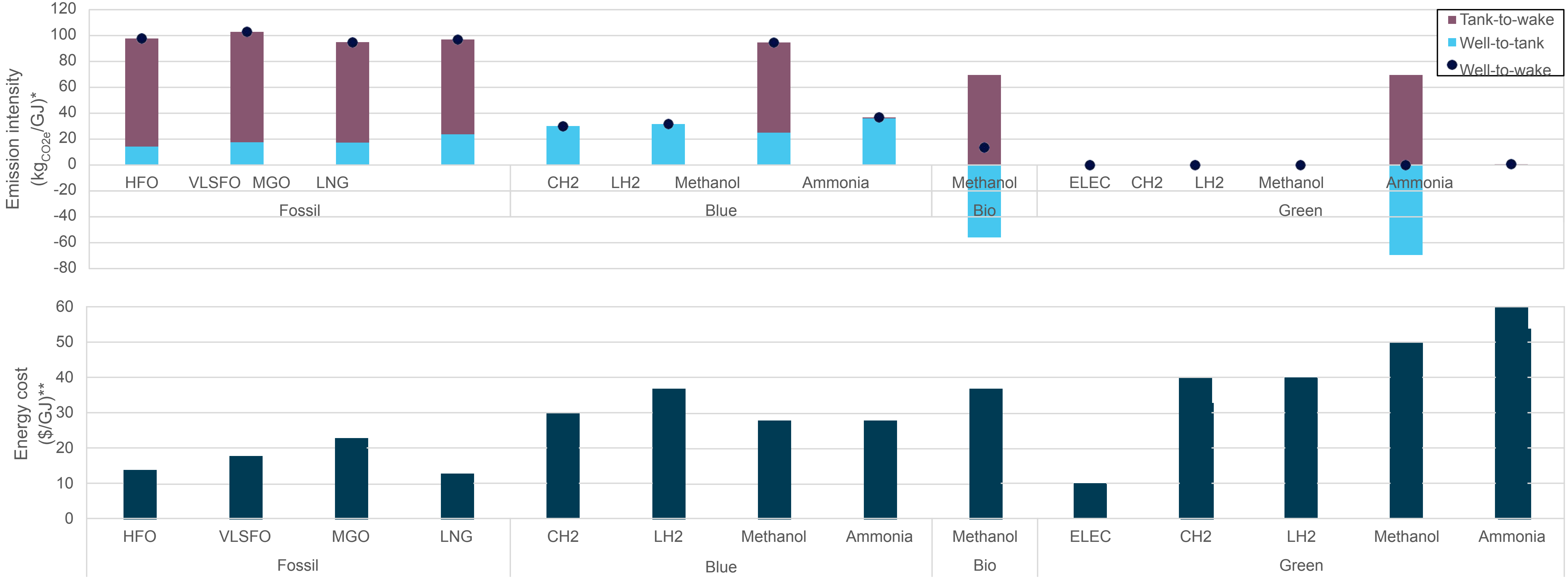
Fuel production pathways considered:

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

Emission intensity and energy cost



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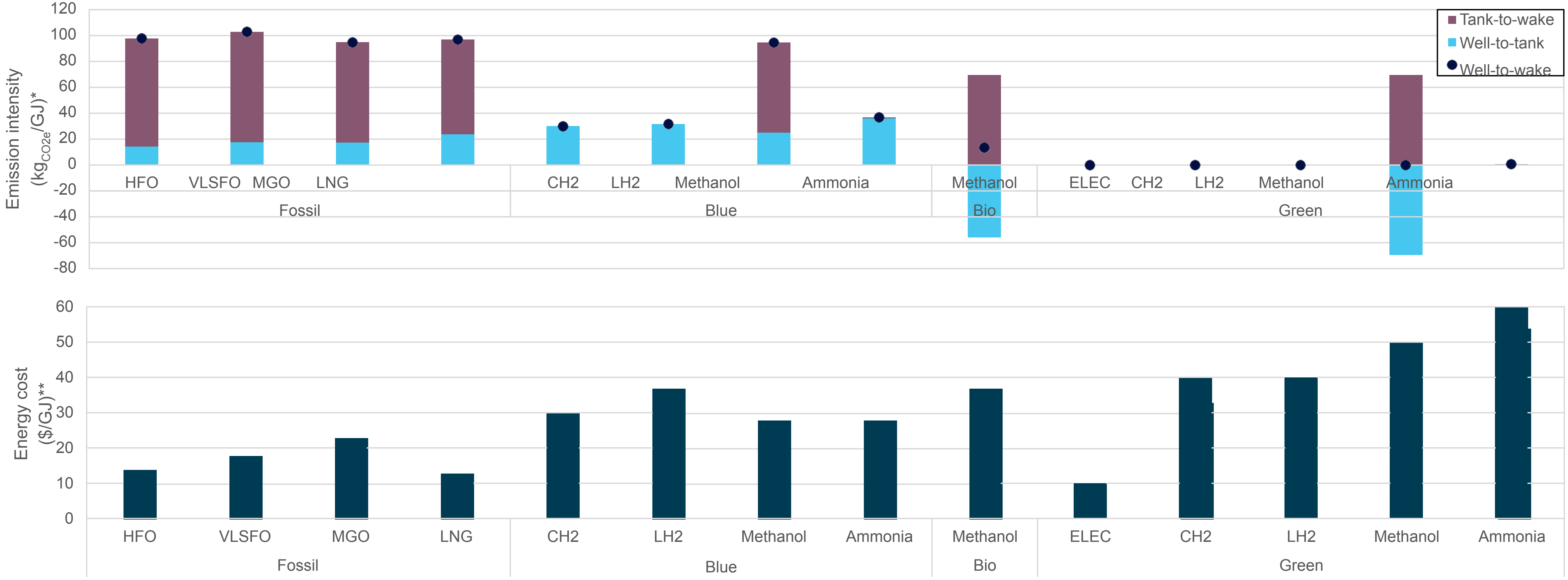
**** The currency used is USD.**

Emission intensity and energy cost

Most to least polluting production pathways: fossil, blue, bio and green.
The reverse is true for the corresponding pathway costs.



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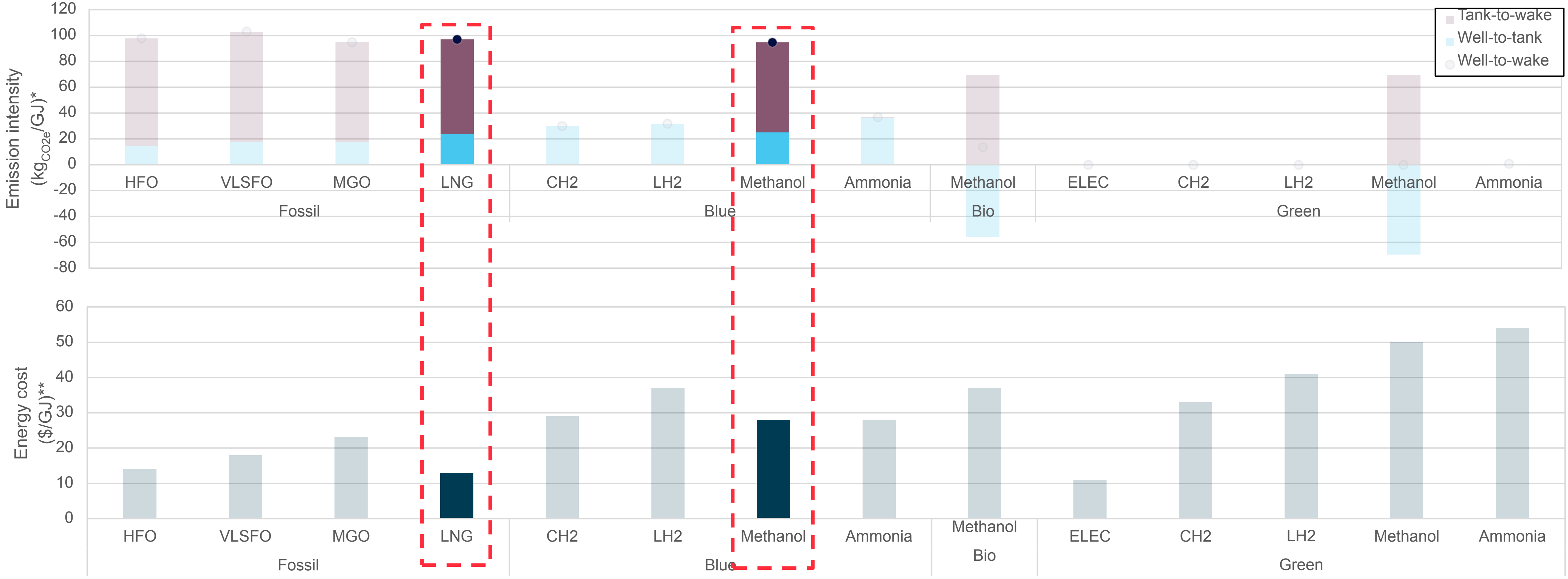
Emission intensity and energy cost

LNG and blue methanol have limited potentials to reduce GHG emissions compared to HFO.
Additionally, blue methanol is priced higher than any of the fuel oils.



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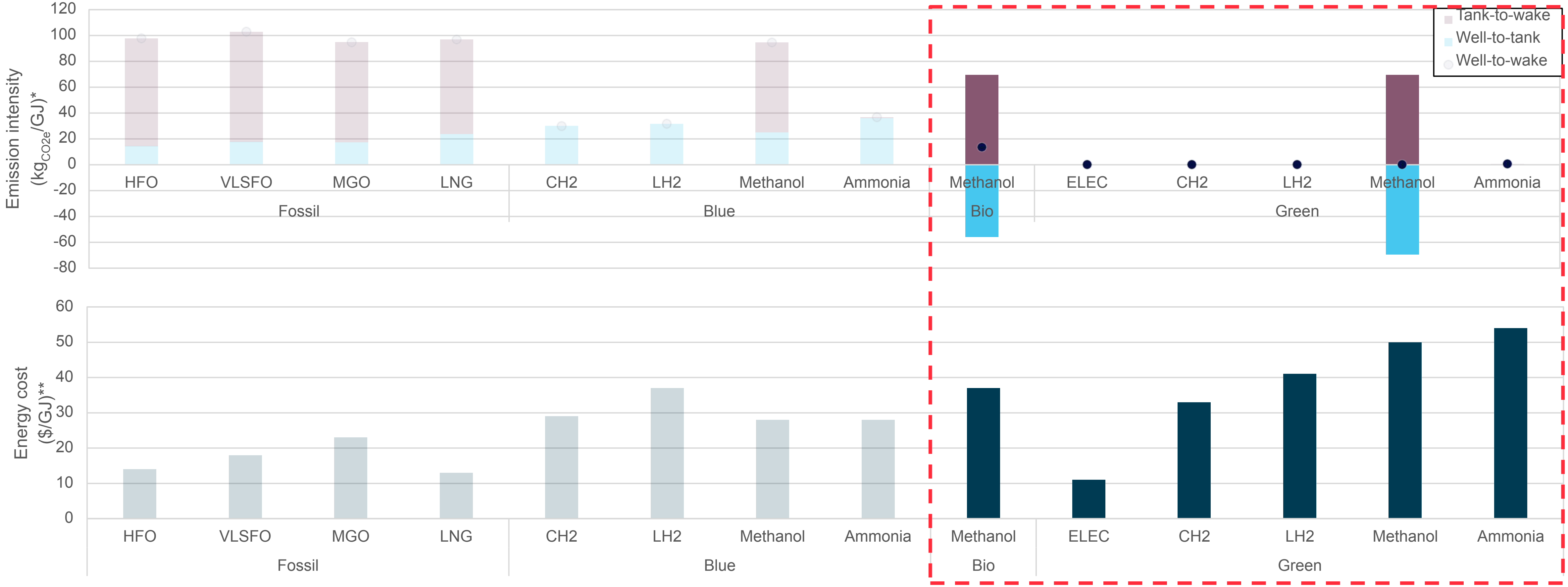
Emission intensity and energy cost

Low and zero GHG emissions options have the potential to achieve 80-100% reduction in GHG emissions compared to HFO.
However, these options are accompanied by a cost increase of up to three times.



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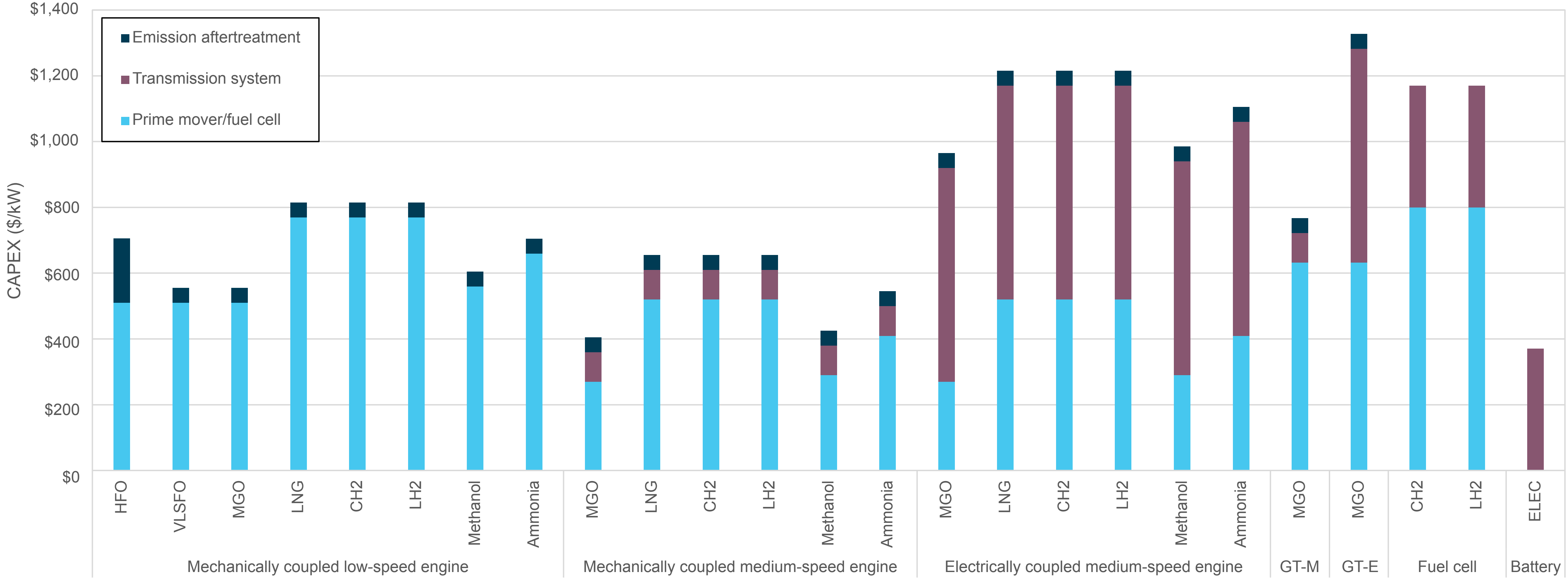
Conventional and alternative propulsion systems

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

Alternative

Capital cost



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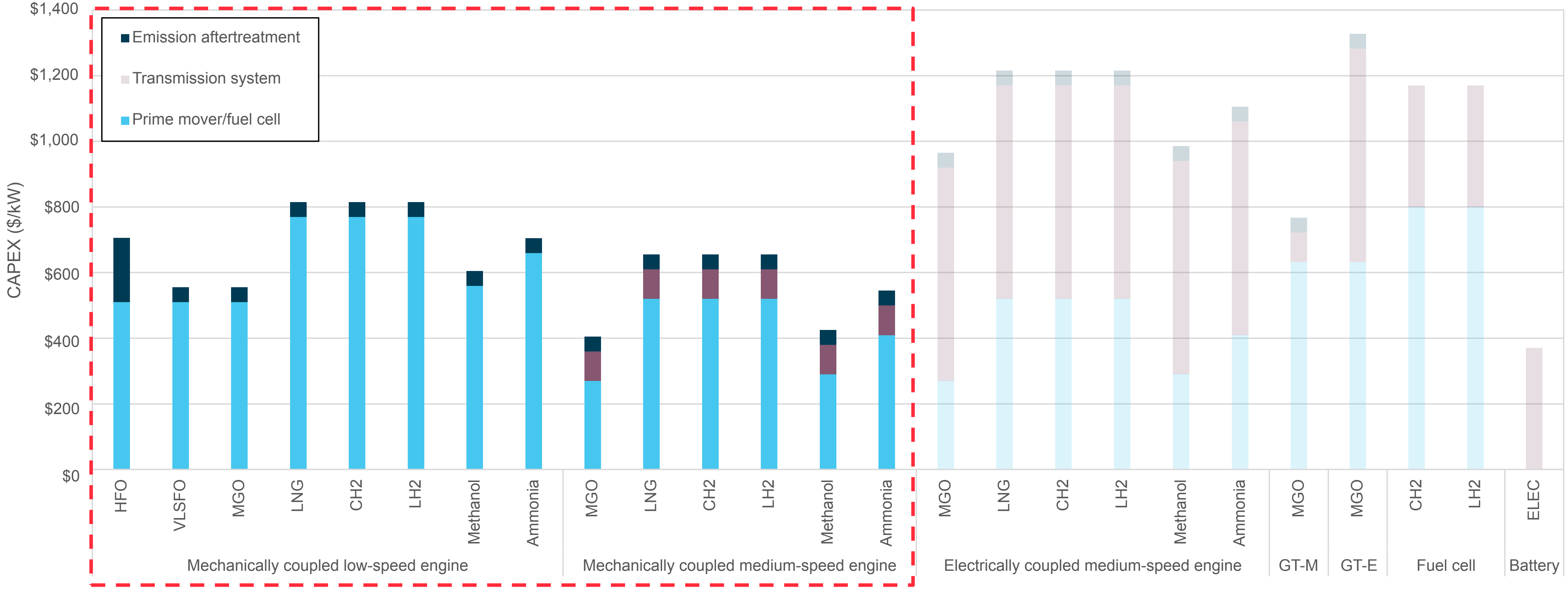
[1]Korberg, A. D. et. al. (2021), [2]Aurecon. (2022), [3]Kanchiralla, F. M. et. al. (2022), [4]Trivyza, N. L. et. al. (2022)

Capital cost

Medium-speed engines appear to require the lowest level of capital expenditure, followed by low-speed engines.



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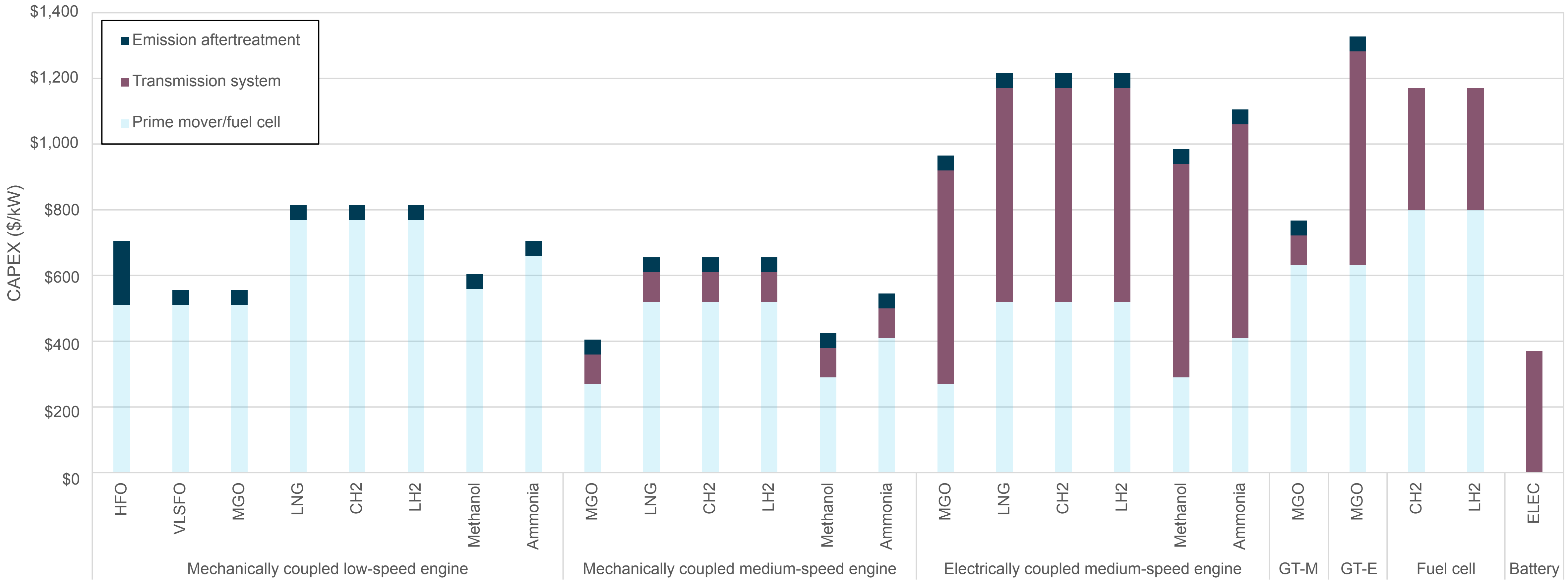
Capital cost

Transmission and emission aftertreatment systems contribute significantly to the overall CAPEX.



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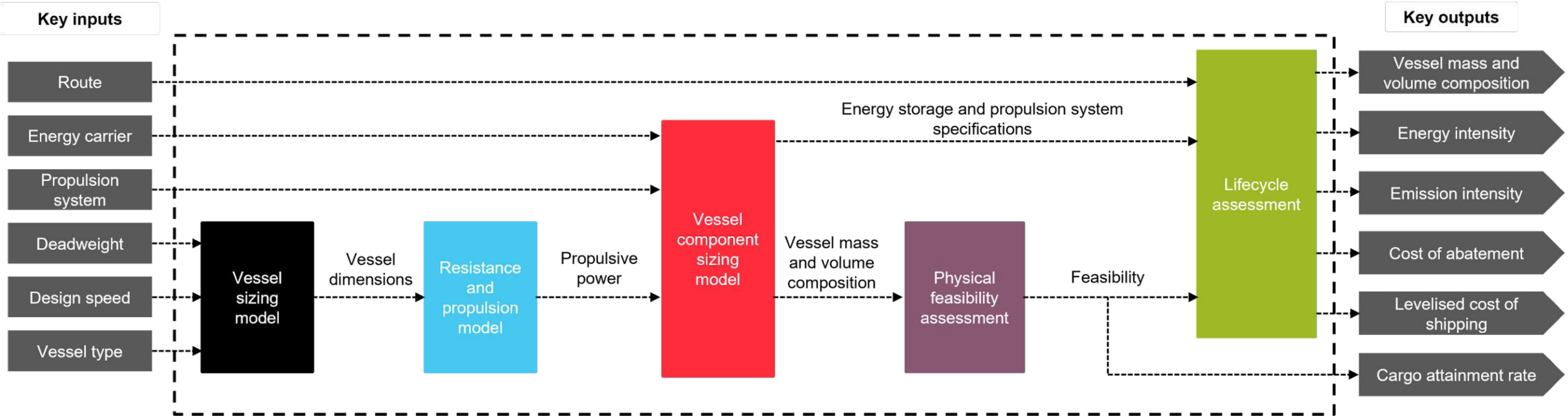
Modelling of shipping performance



Key inputs

- Route
- Energy carrier
- Propulsion system
- Deadweight
- Design speed
- Vessel type

Vessel sizing model

Vessel dimensions

Resistance and propulsion model

Propulsive power

Vessel component sizing model

Energy storage and propulsion system specifications

Vessel mass and volume composition

Physical feasibility assessment

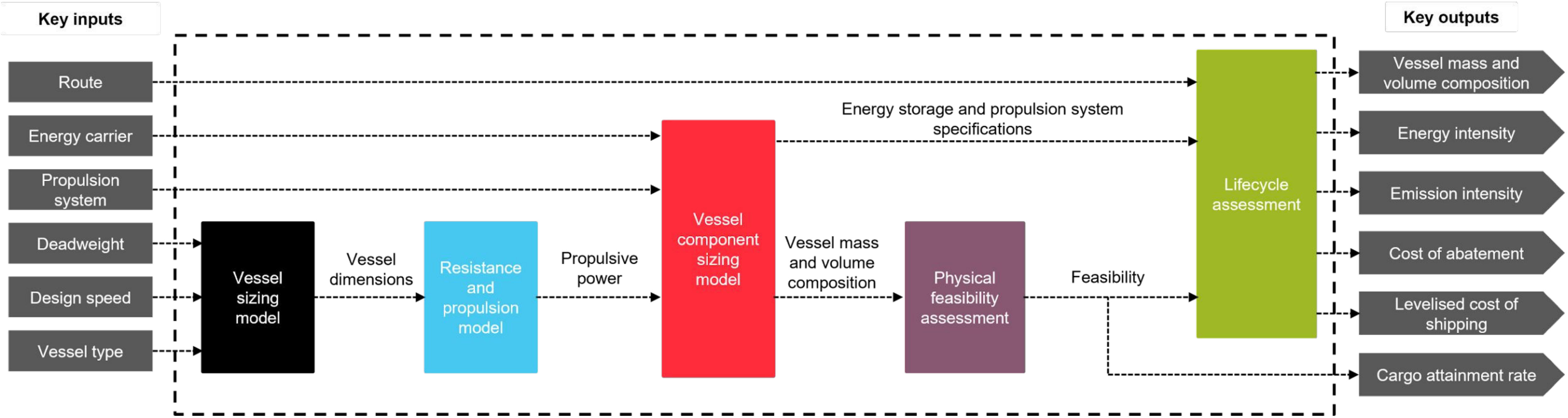
Feasibility

Lifecycle assessment

Key outputs

- Vessel mass and volume composition
- Energy intensity
- Emission intensity
- Cost of abatement
- Levelised cost of shipping
- Cargo attainment rate

Modelling of shipping performance



The model accounts for **route** and **ship specifications** to determine **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

- The levelised cost of shipping (LCOS):

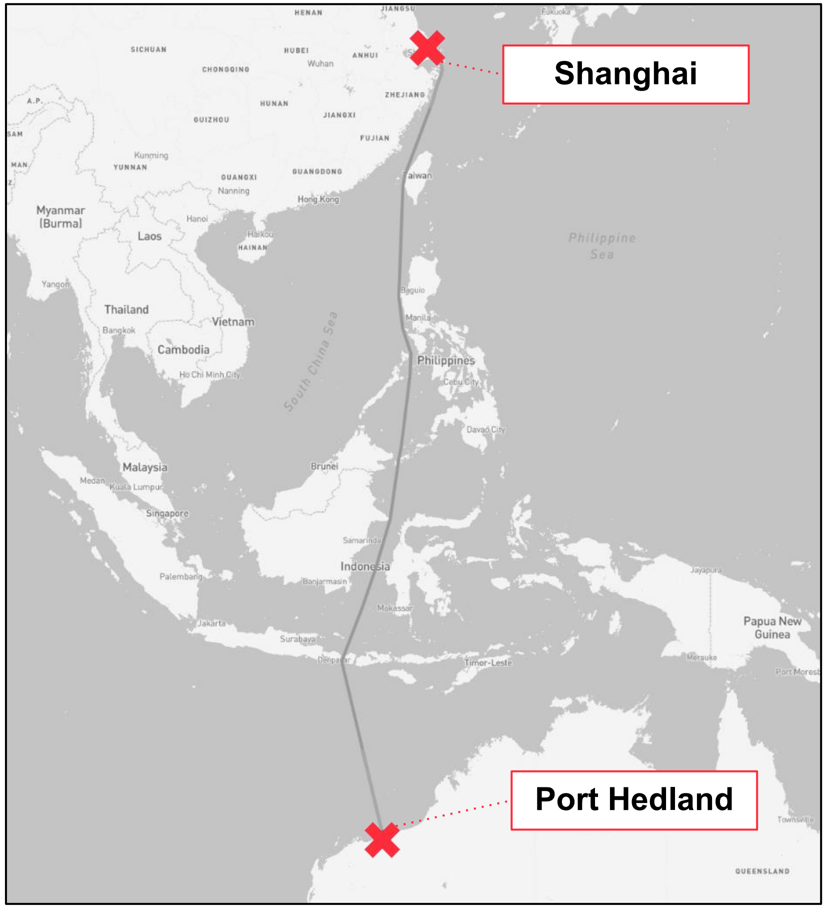
$$LCOS\left(\frac{\$}{tonne \cdot km}\right) = \frac{(capital\ costs) + (fuel\ costs) + (other\ operating\ costs)}{\underbrace{(mass\ of\ goods\ carried) \cdot (distance\ travelled)}_{\text{Transport work}}}$$

- 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 tonnes bulk carrier
- Total annual energy consumption = 213 PJ p.a.*
- Total annual GHG emissions = 21 million tonnes$_{CO2e}$ p.a.*

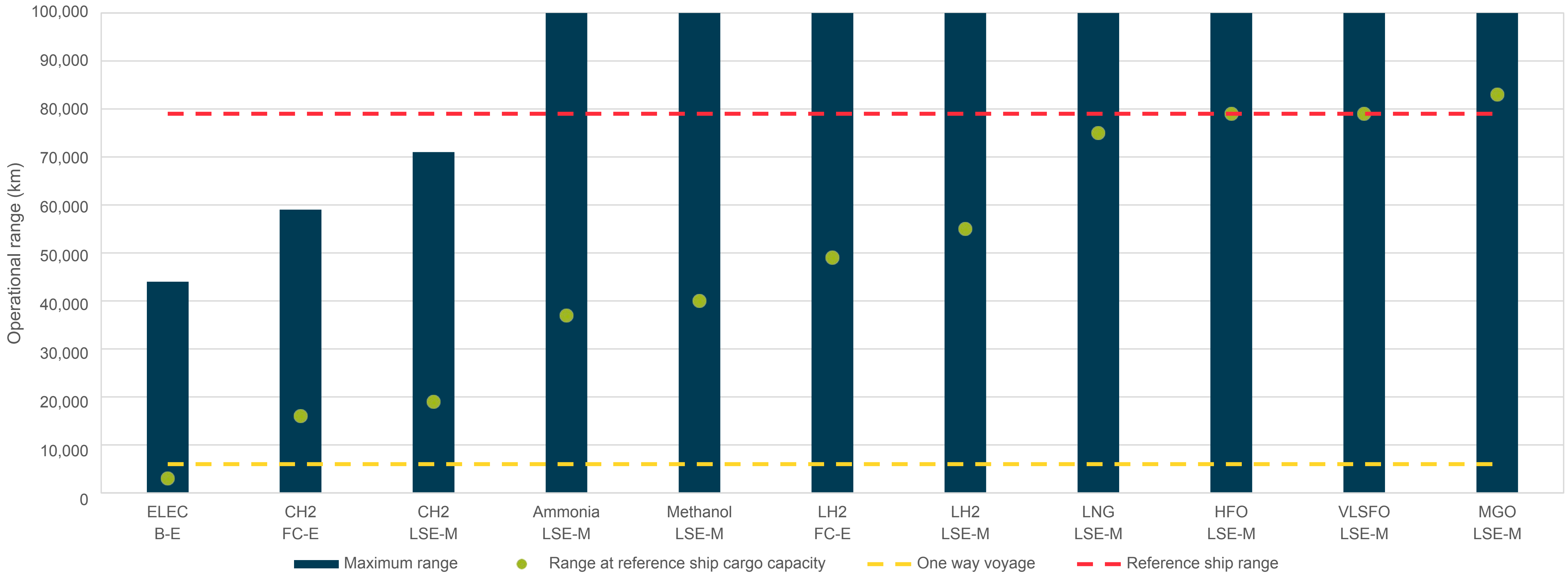


*Modelled results using methodology described. All iron ore exported to China is assumed to follow the illustrated route, transported by 250,000 tonne deadweight bulk carriers at 14 knots, powered by HFO-fueled LSE-M.

[1 BITRE. (2023), [2] DCCEEW. (2022), [3] DCCEEW. (2023)

Maximum operational range

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

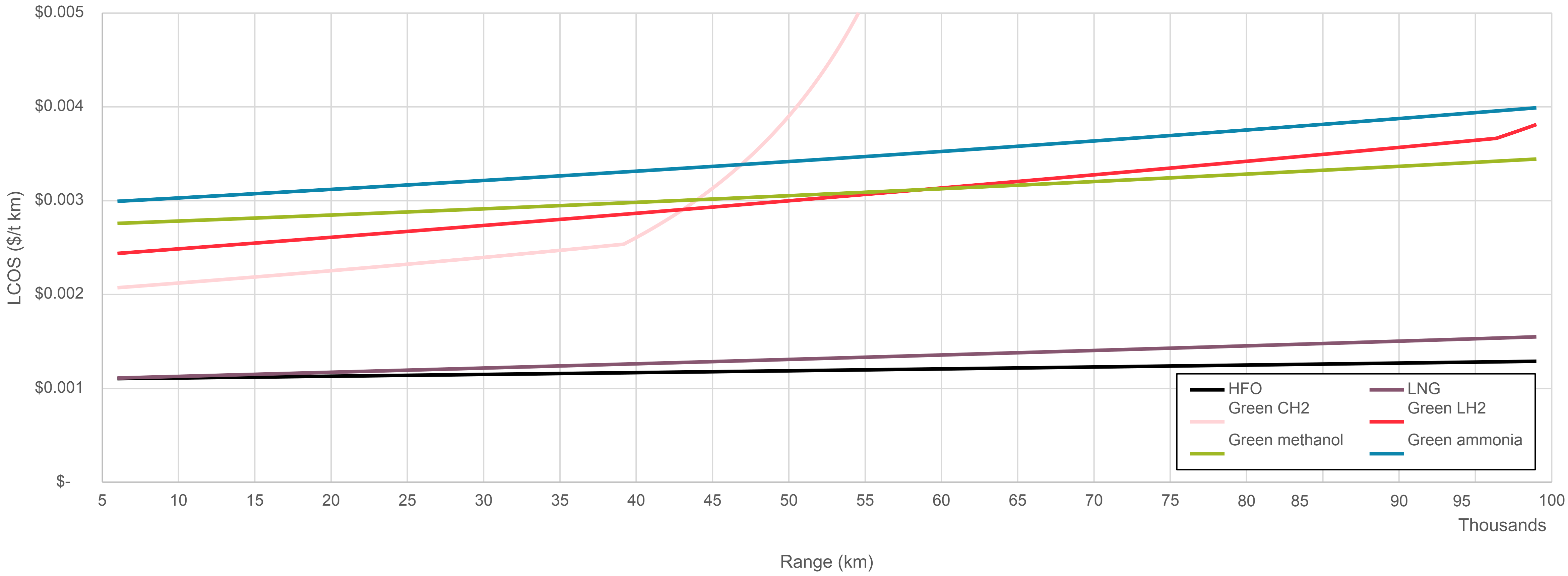


***Modelled results using the methodology described.**
****Operational ranges exceeding 100,000 km were omitted as they are less relevant and increasingly compromise cargo capacity.**

LCOS as a function of range

Results shown are for options employing low-speed engines.

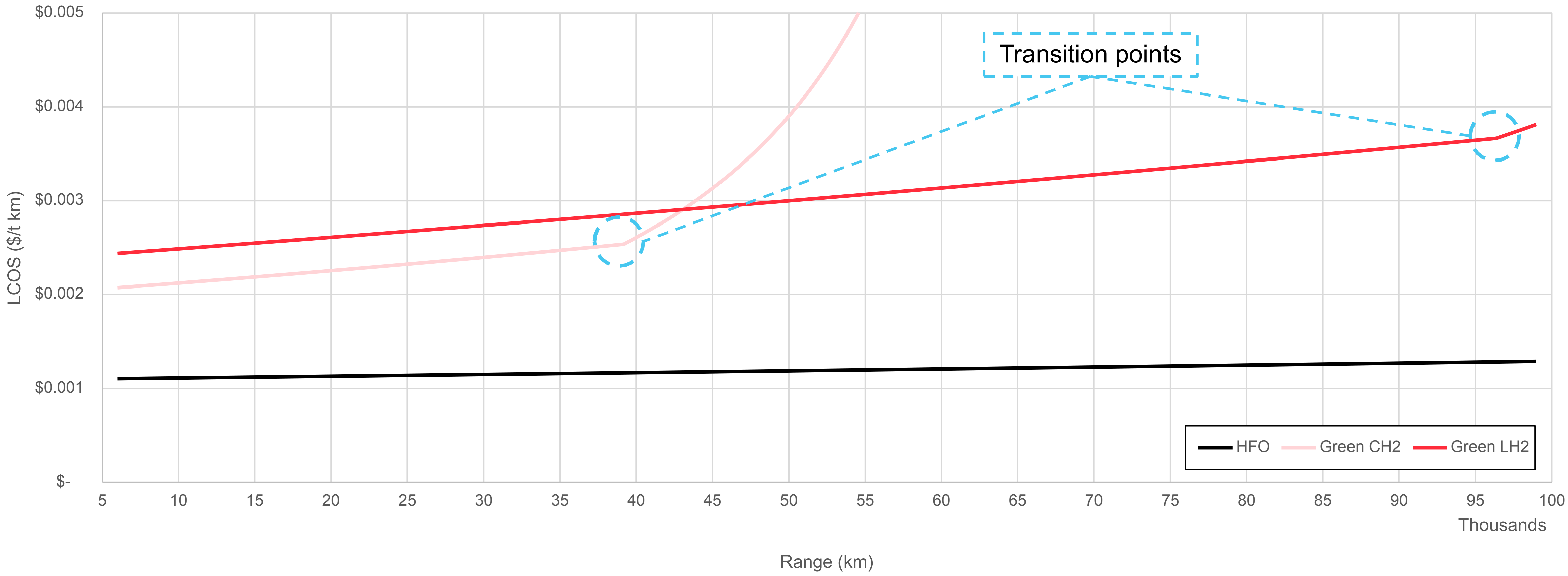
Other propulsion systems demonstrate similar trends but higher LCOS relative to the low-speed engine cases due to their lower efficiencies. The battery-powered option is at least 1 order of magnitude more expensive than the HFO-fuelled options.



***Modelled results using the methodology described.**

LCOS as a function of range

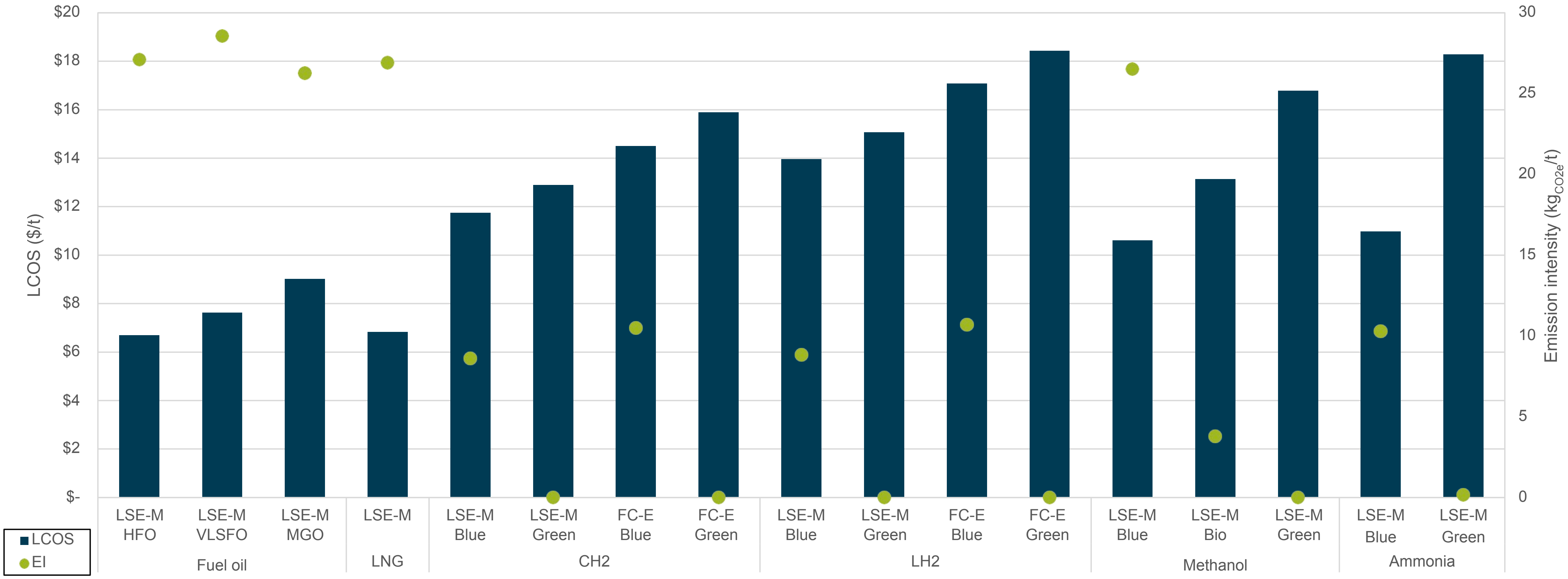
Beyond a certain range, the use of compressed and liquefied hydrogen rapidly becomes uneconomic as the vessel transitions from being weight-limited to volume-limited.



***Modelled results using the methodology described.**

LCOS and emission intensity for 12,000 km range

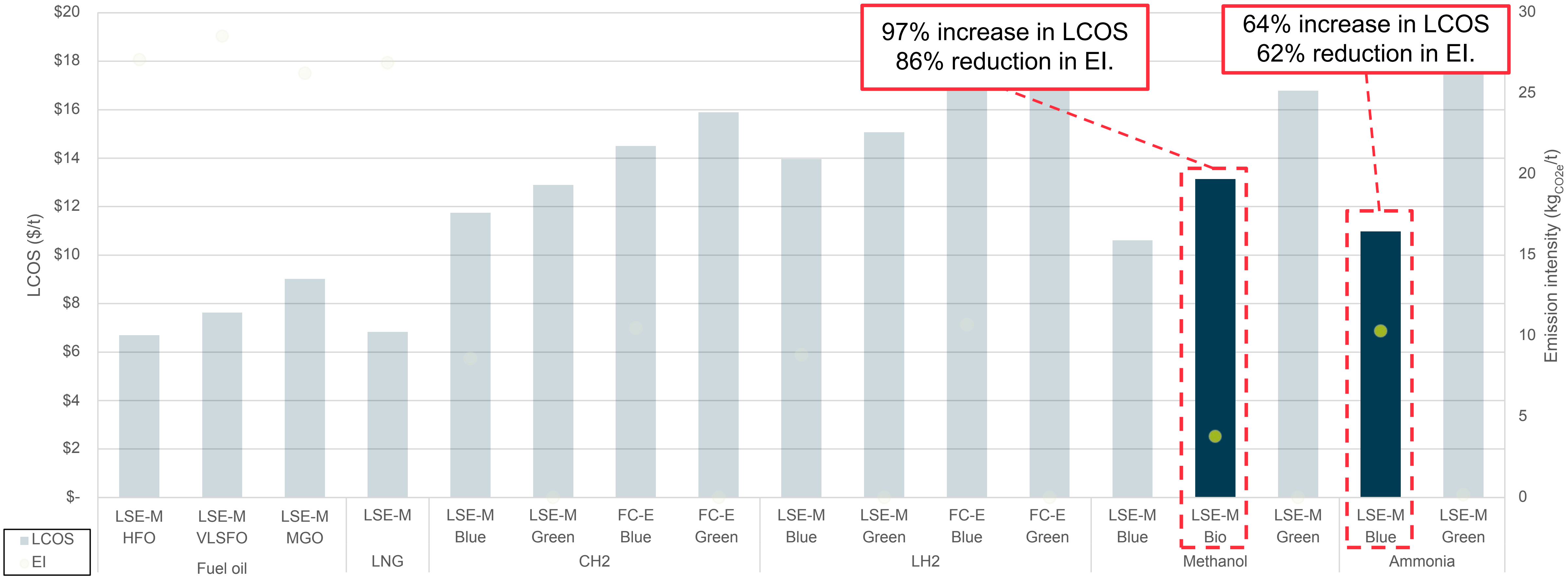
Low and zero emissions options may increase the delivered costs of Australian iron ore to China by $5-12/tonne, or 10-20% of the iron price of $100/tonne.



***Modelled results using the methodology described.**

LCOS and emission intensity for 12,000 km range

Bio methanol or blue ammonia fuelled low-speed engines are the most cost-effective low GHG emissions options.



97% increase in LCOS
86% reduction in EI.

64% increase in LCOS
62% reduction in EI.

***Modelled results using the methodology described.**

LCOS and emission intensity for 12,000 km range

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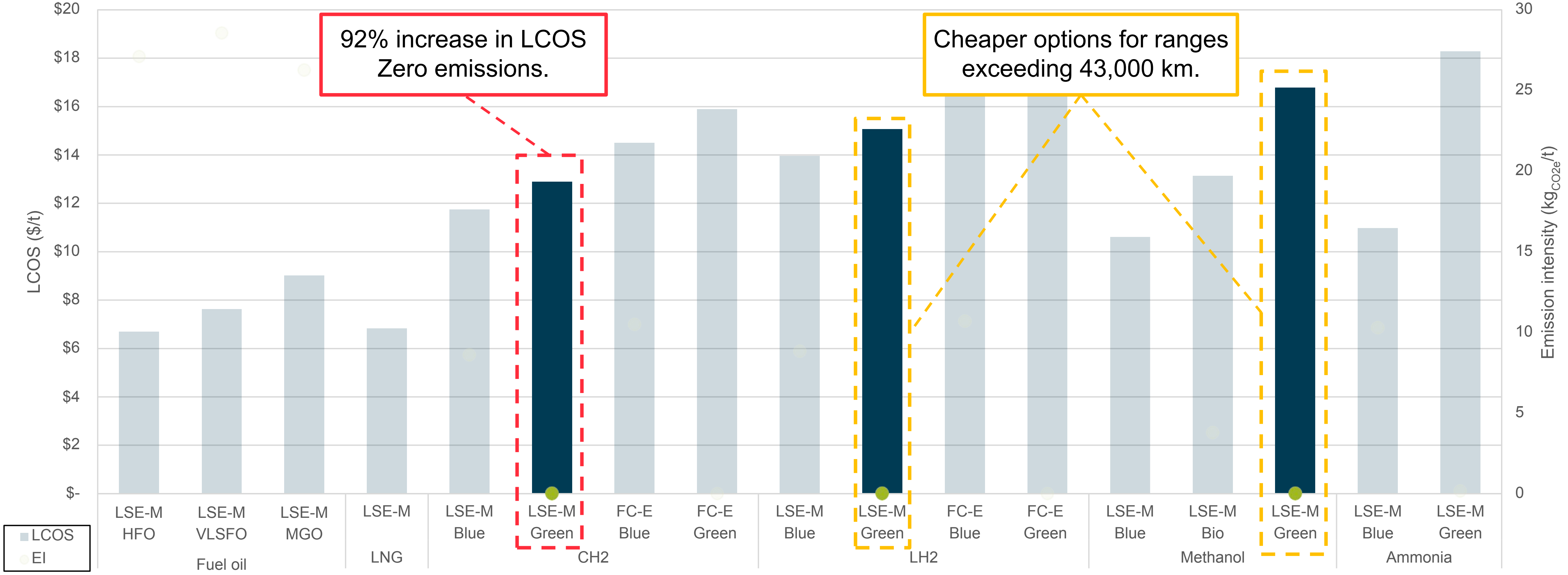
Green compressed hydrogen fuelled low-speed engine is the cheapest zero emission option.

However, for operational ranges exceeding 43,000 km the green liquefied hydrogen or methanol fuelled low-speed engine options are expected to have better economic performance.



92% increase in LCOS
Zero emissions.

Cheaper options for ranges
exceeding 43,000 km.

***Modelled results using the methodology described.**

Conclusions

- 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 10-20% 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 bio methanol 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.

Acknowledgement

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Q&A

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