CHALMERS
UNIVERSITY OF TECHNOLOGY

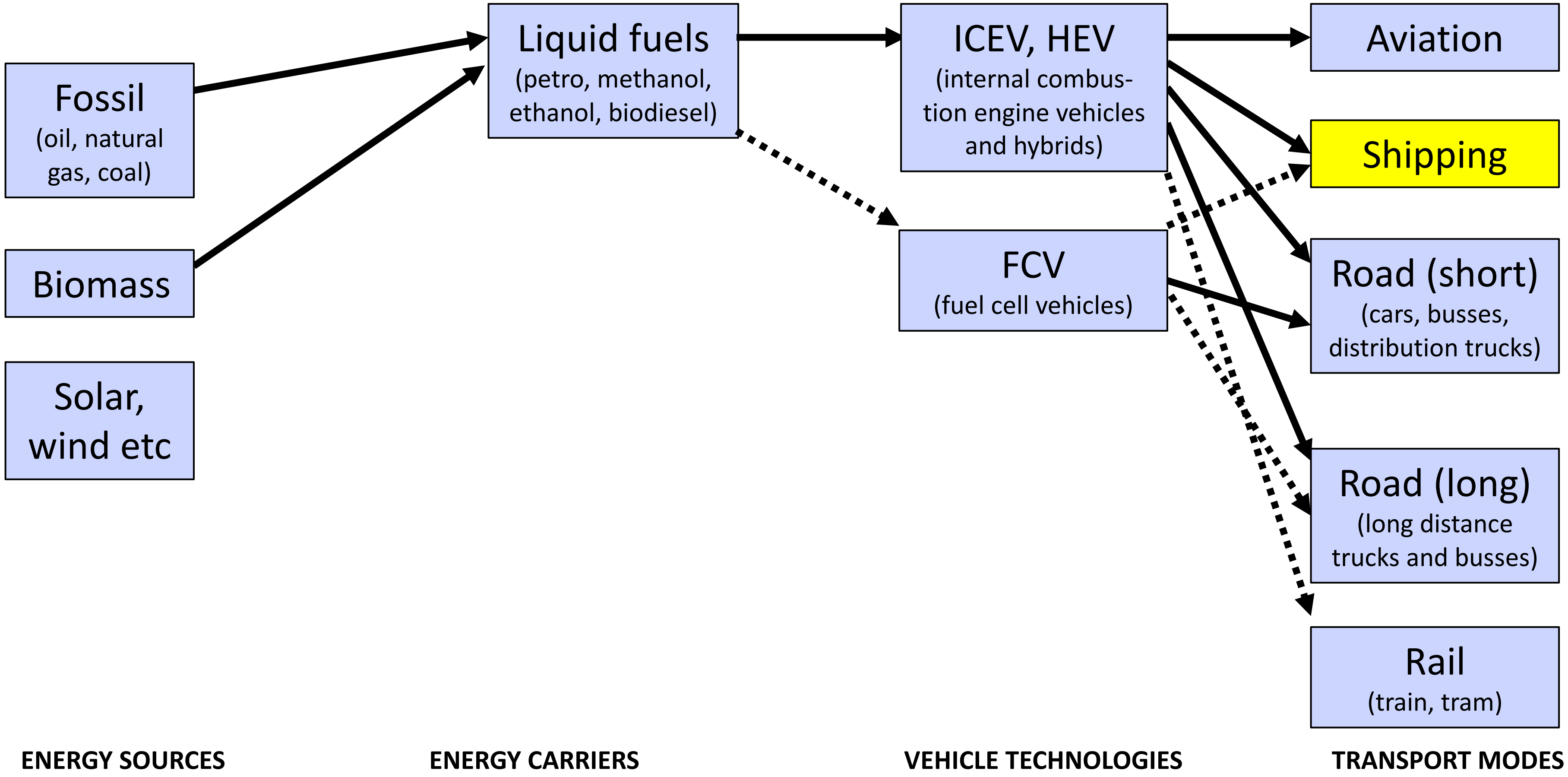
# Shipping projections and demands for low-carbon fuels

ITEM3, Paris, 27 October 2017

**Maria Grahn**

# Different fuels and vehicle technology options are differently well suited for different transport modes

The shipping sector asks for advice



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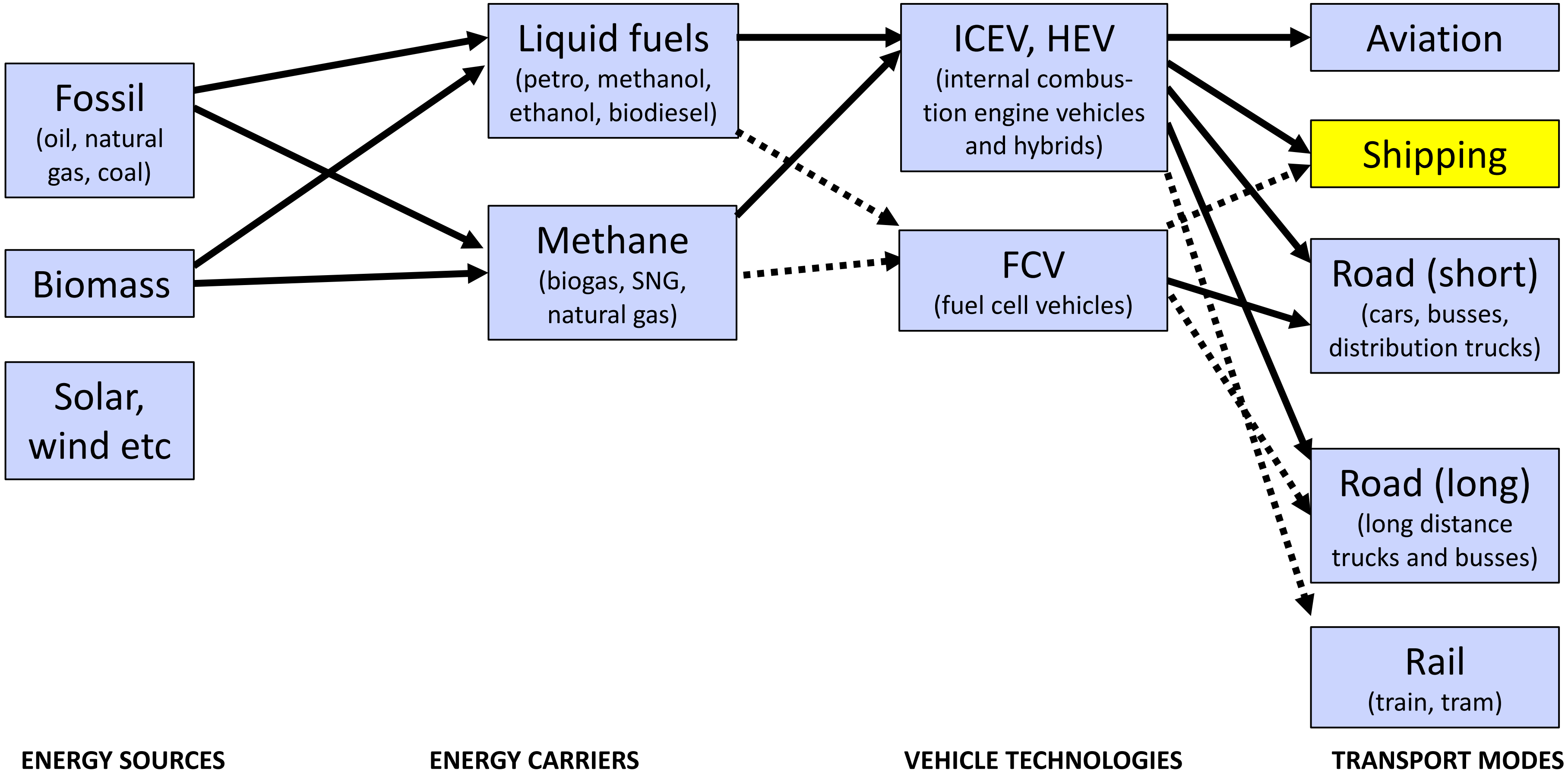

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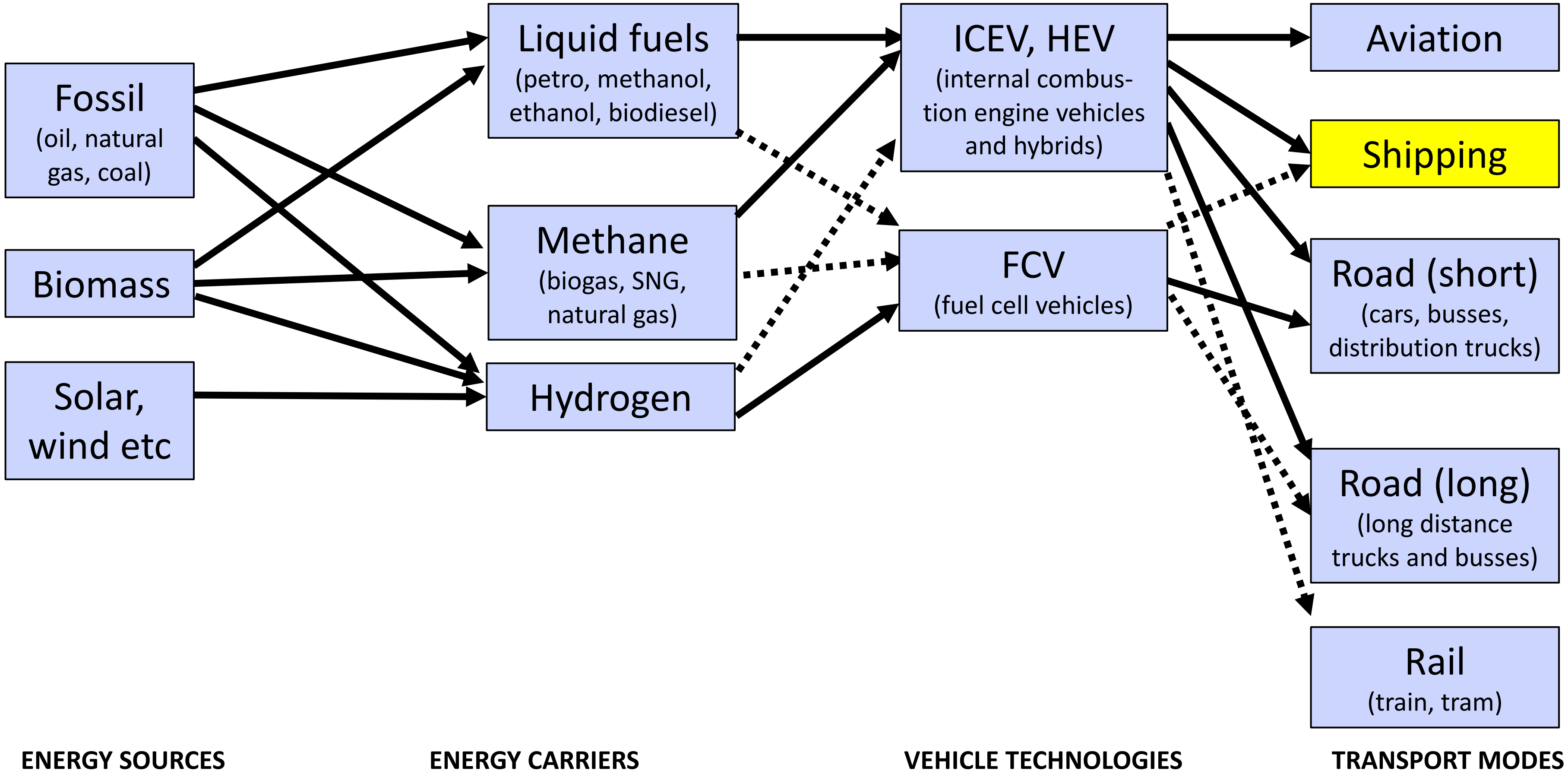

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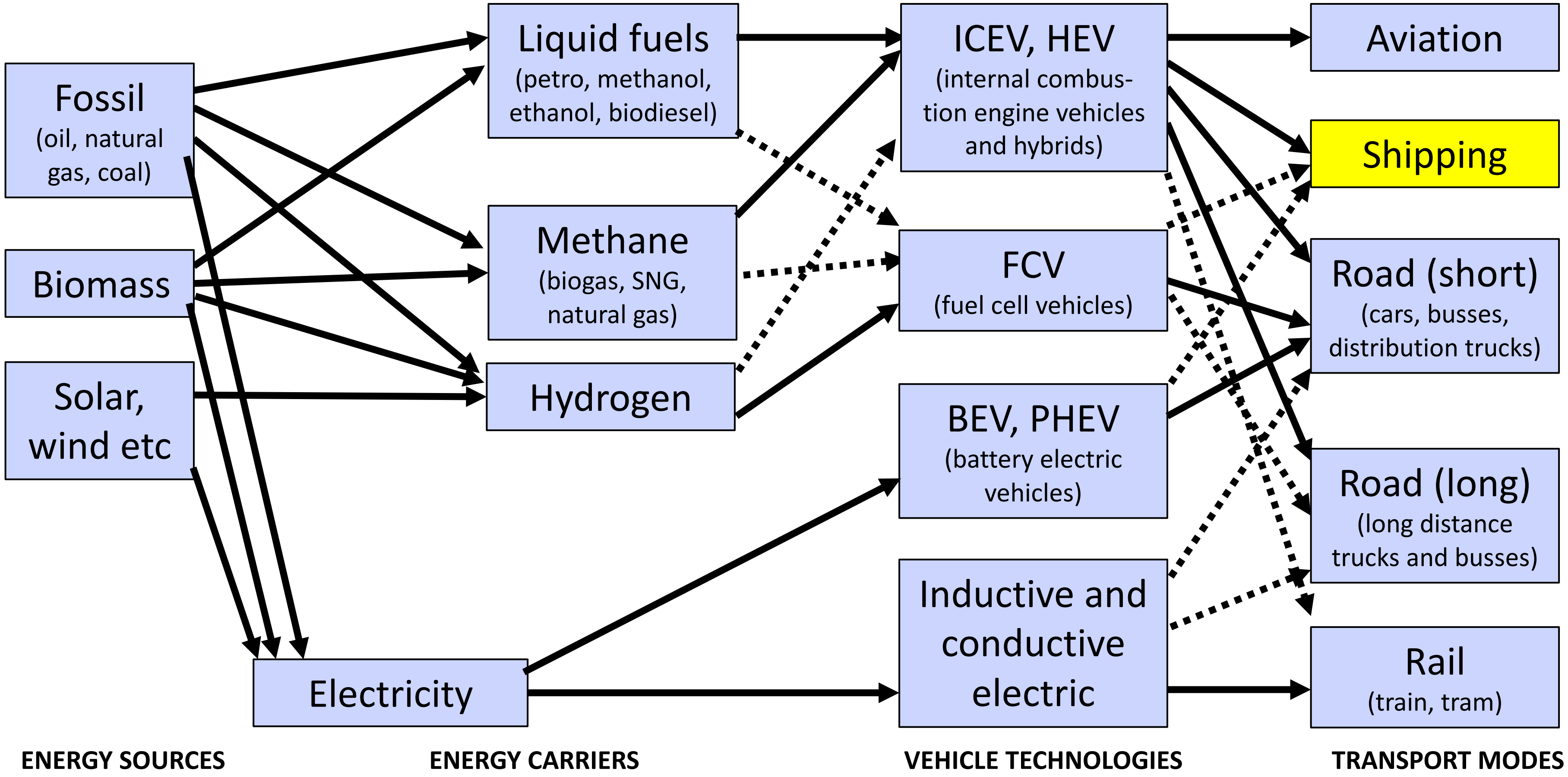

# Different fuels and vehicle technology options are differently well suited for different transport modes

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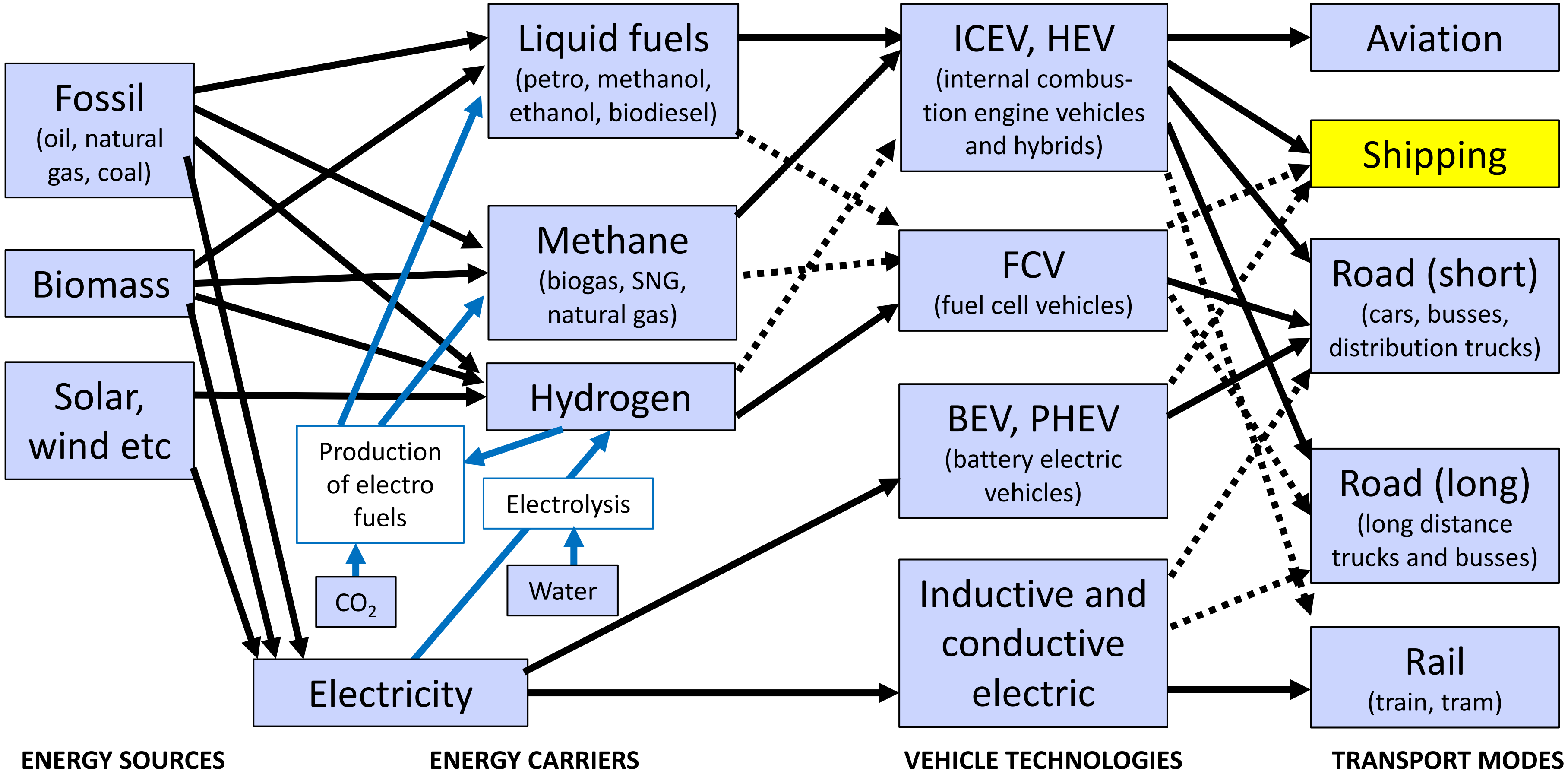
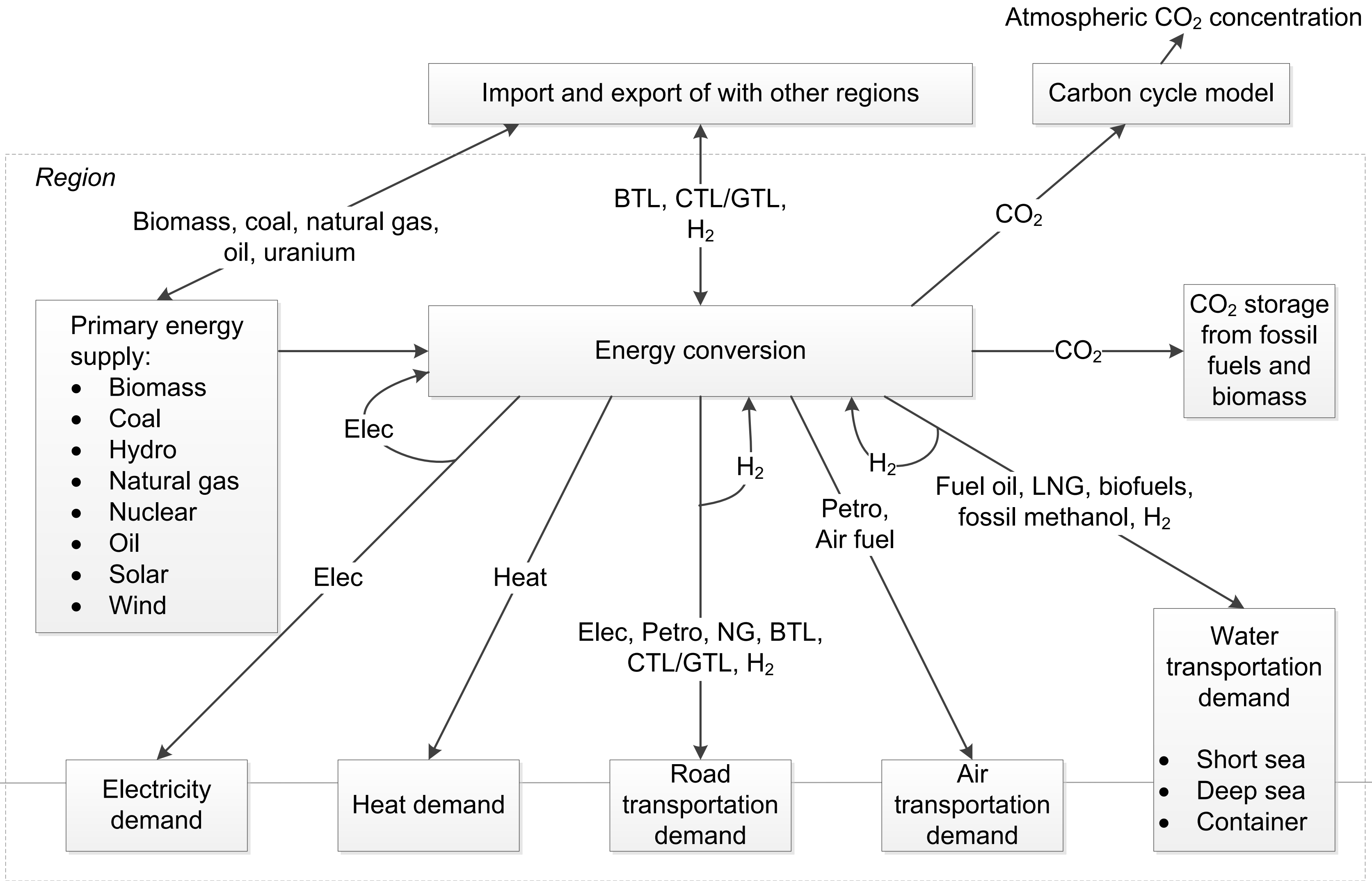


# What energy carriers will propel ships in future?

# How can we project future demand for seaborne trade?

# Energy system model GET

Linearly programmed energy systems cost-minimizing model. Generates the fuel and technology mix that meets the demand (subject to the constraints) at lowest global energy system cost




Energy demand for the different transport modes are exogenously given

# One way of constructing energy demand scenarios for the shipping sector

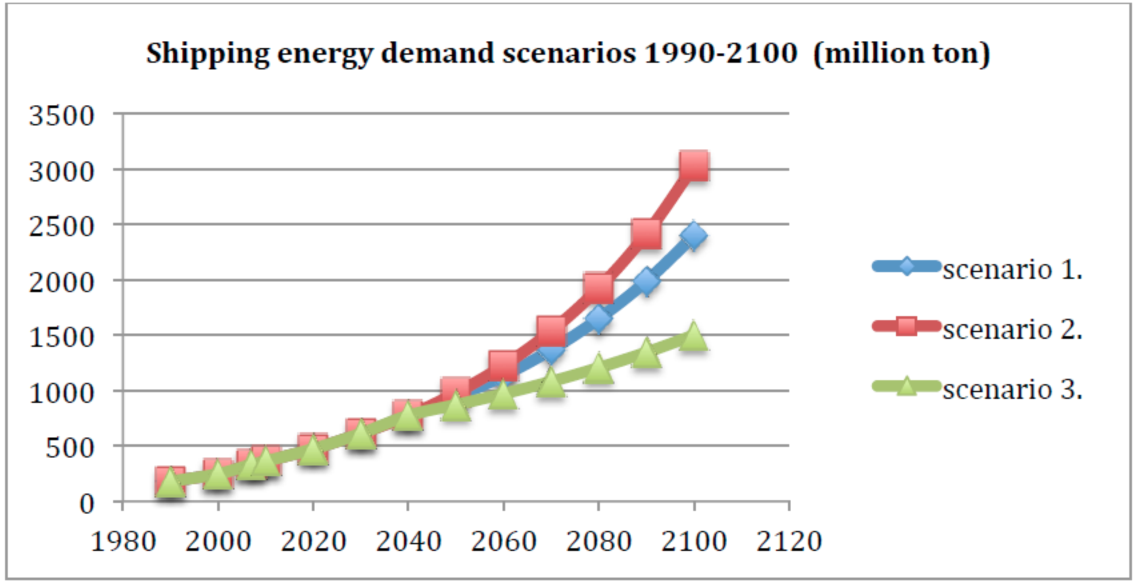
# Scenarios based on historical trends and assumptions for three different scenarios

*Table 2.2. Average historical annual growth of GDP (USD) and world seaborne trade (ton-miles) in percentage per year for different time periods between 1975-2011.*

| Years | Average GDP growth USD/yr | Average shipping growth ton-miles/yr | Annual growth of ton-miles more than GDP |
|---|---|---|---|
| 1975-2011 | 3.1 % | 3.0 % | -0.1 % |
| 1986-2006* | 3.4 % | 4.1 % | 0.7 % |
| 1986-2006** | 3.3 % | 4.1 % | 0.8 % |
| 1986-2011 | 3.4 % | 4.6 % | 1.2 % |
| 1990-2011 | 2.7 % | 3.9 % | 1.2 % |
| 2001-2011 | 2.8 % | 4.0 % | 1.2 % |

**Fearleys, ** UNCTAD*

(Fearleys and UNCTAD, 2011)




Scenario 1: 1.2% growth more than GDP to 2040, then 0.8% to 2100
Scenario 2: 1.2% growth more than GDP to 2100
Scenario 3: 1.2% growth more than GDP to 2040, then same as GDP to 2100

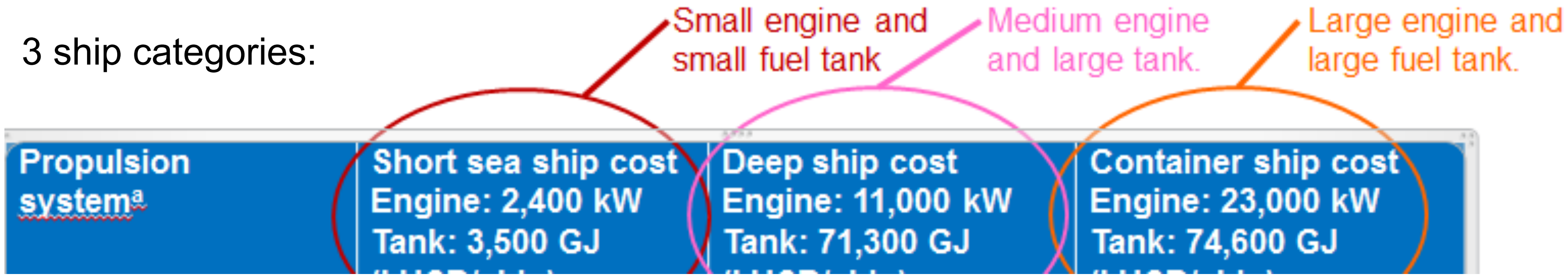
**Ref.** Taljegård M. (2012). "Cost-effective choices of marine fuel under stringent carbon dioxide targets: Results from the Global Energy Transition (GET) model", Master thesis in Environmental science, Gothenburg University, Sweden.

# Demand then constructed for three different ship categories (short sea, deep sea and container ships)

- Three ship categories is a compromise between a detailed and a very rough representation.
- Short sea includes mostly passenger ships, ferries and offshore ships which is smaller ships traveling shorter distances.
- Deep sea ships are larger ships with the capacity for intercontinental trade.
- Container ships are all types of container ships.

Fuel options for the shipping sector
Combustion engines and fuel cells combined with
- oil-based fuels (Petro)
- liquefied natural gas (LNG)
- coal to liquid (CTL)
- biomass to liquid (BTL)
- gas to liquid (GTL)
- hydrogen (H2)
- electrofuels (E-methanol)

3 ship categories:




(Taljegård, 2012)

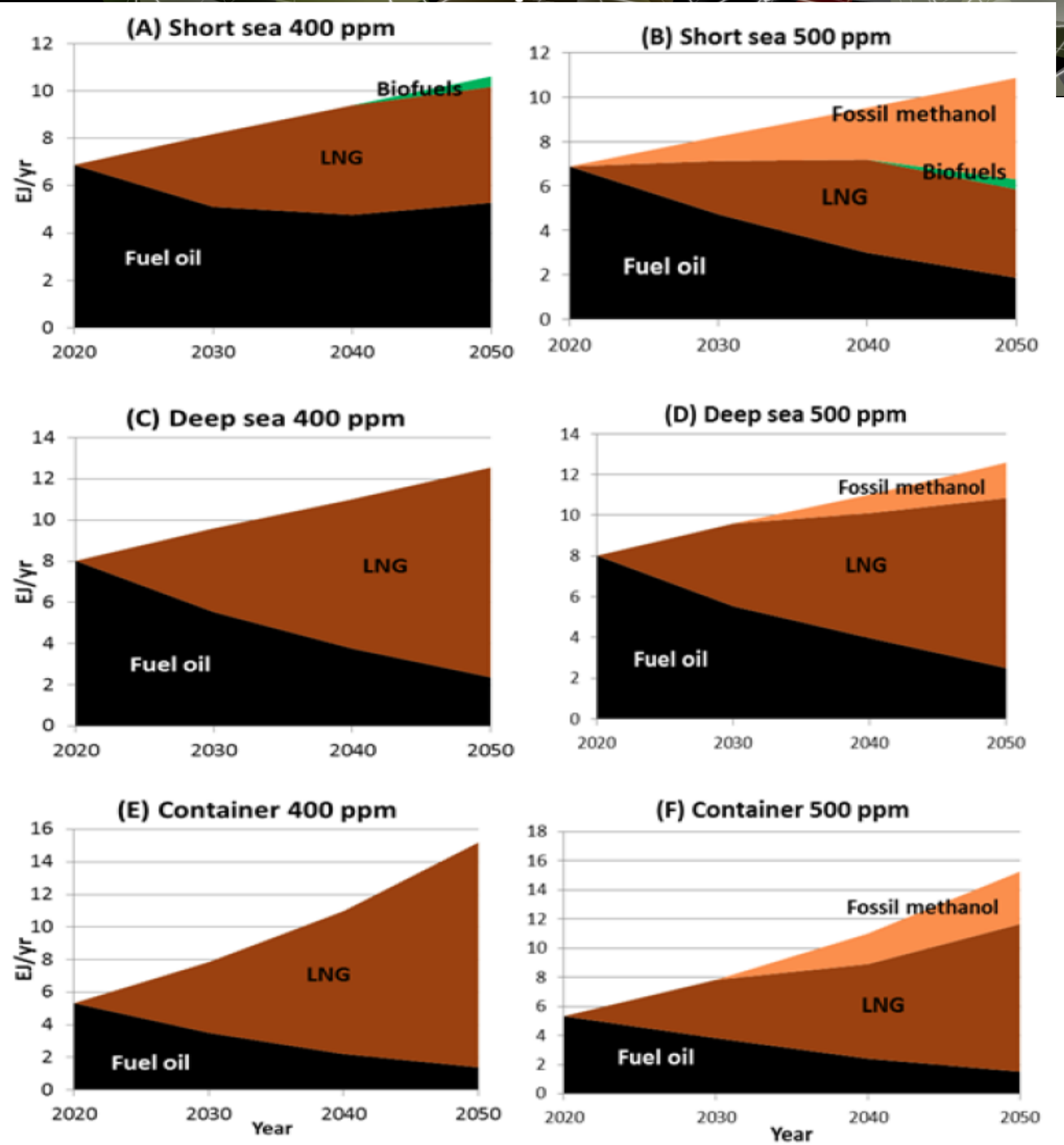
**Ref.** Taljegård M., Brynolf S., Grahn M., Andersson K., Jonsson H. (2014). Cost-Effective Choices of Marine Fuels in a Carbon-Constrained World: Results from a Global Energy Model. Environmental Science and Technology. 48 (21) p. 12986-12993.

# Example of results for the 3 ship categories

Rather similar results for the different categories.

Natural gas-based methanol and LNG rather similar in production cost.

Monte Carlo runs to better understand.

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# Most uncertain parameters are randomly tested

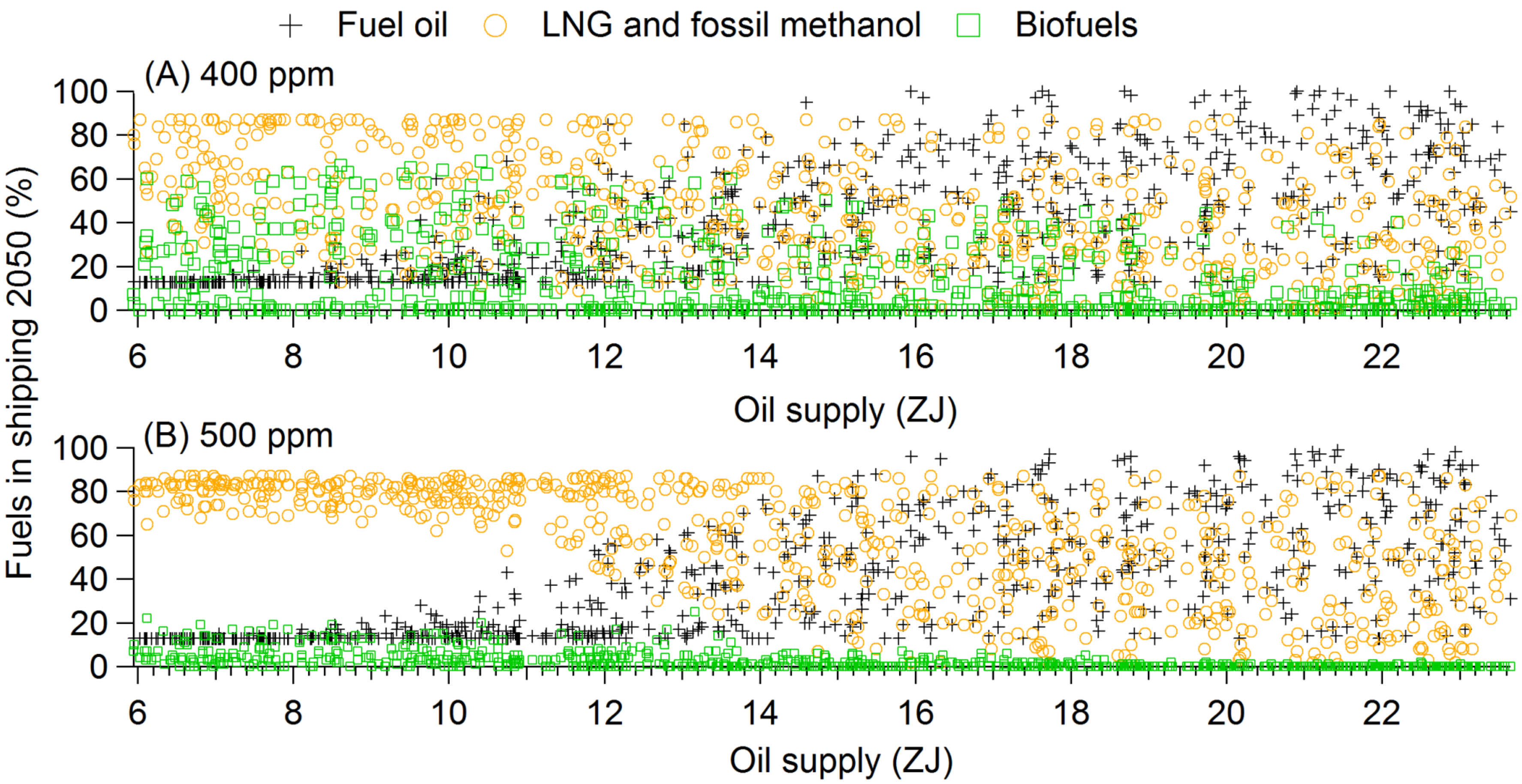
| Parameter | Base case | Minimum | Maximum |
|---|---|---|---|
| Oil resources (EJ) | 12,000 | 6,000 | 24,000 |
| Natural gas resources (EJ) | 11,000 | 5,500 | 22,000 |
| Biomass supply (EJ/yr) | 200 | 100 | 400 |
| LNG tank cost (USD/GJ)[a] | 110 (80) | 110 (80) | 330 (250) |
| Hydrogen tank (USD/GJ)[a, b] | 300 (225) | 220 (160) | 600 (450) |
| Fuel cell cost (USD/kW) | 4000 | 2000 | 6700 |
| LNG infrastructure (USD/kW | 1600 | 1200 | 1600 |
| Fossil methanol infra (USD/kW) | 200 | 100 | 400 |
| Biofuel infrastructure (USD/kW)[c] | 600 | 200 | 600 |
| Methane leakage (wt%) | 2 | 0 | 4 |
| Max share of solid biomass in heat (%) | 75 | 50 | 80 |
| Concentrating solar power (USD/kW) | 4000 | 3500 | 7000 |
| LNG investment cost (USD/kW) | 300 | 150 | 400 |

[a] Numbers are for short sea ships, numbers in parenthesis is for deep sea and container ships.
[b] Will never be lower than the liquefied natural gas tank cost.
[c] Will never be lower than the infrastructure cost for fossil methanol. Acronyms used: liquefied natural gas (LNG).

**Ref.** Taljegård M., Brynolf S., Grahn M., Andersson K., Jonsson H. (2014). Cost-Effective Choices of Marine Fuels in a Carbon-Constrained World: Results from a Global Energy Model. Environmental Science and Technology. 48 (21) p. 12986-12993.

# Sensitivity analysis

**700 Monte Carlo runs assuming that CCS is a large scale technology**

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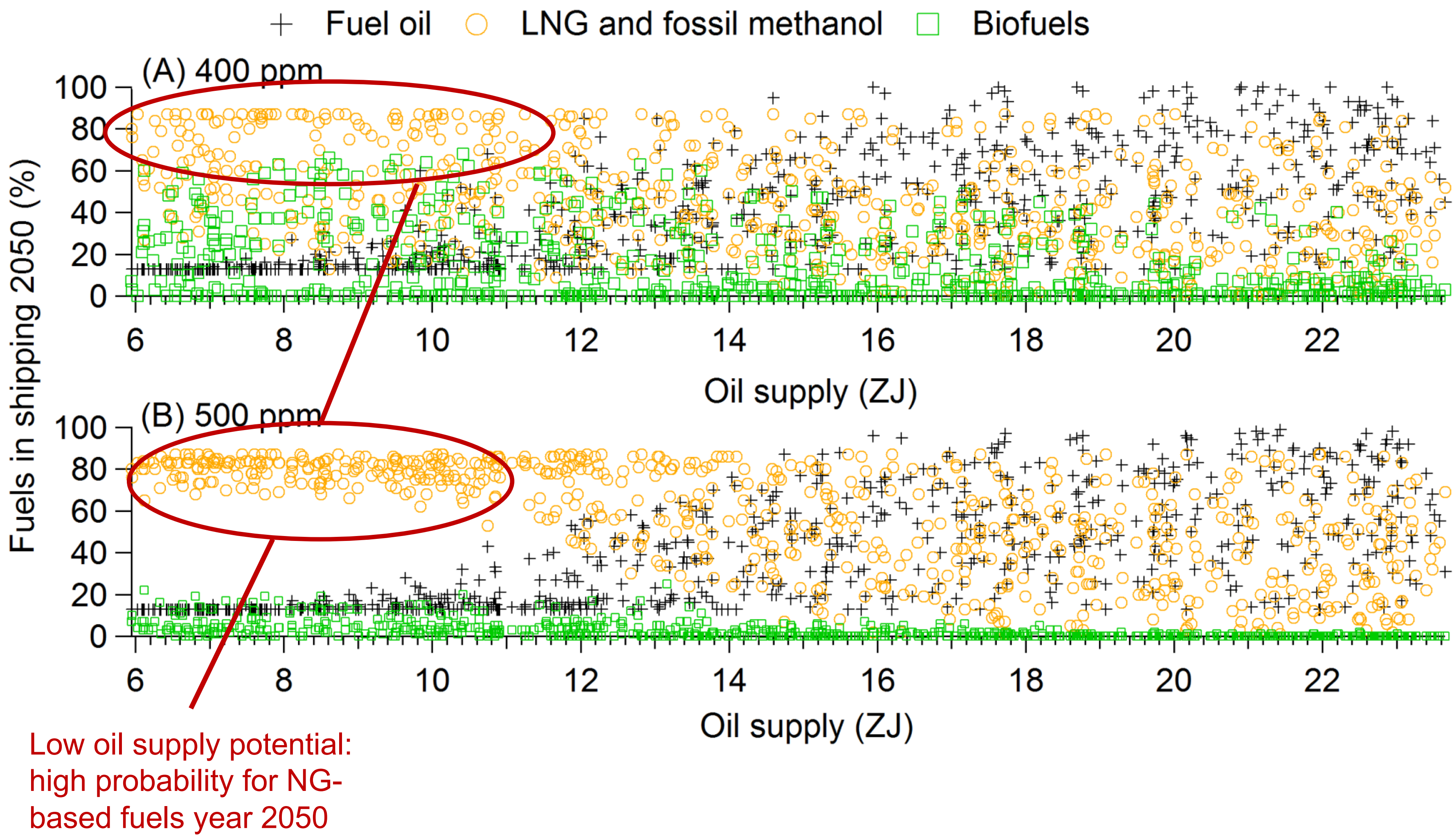


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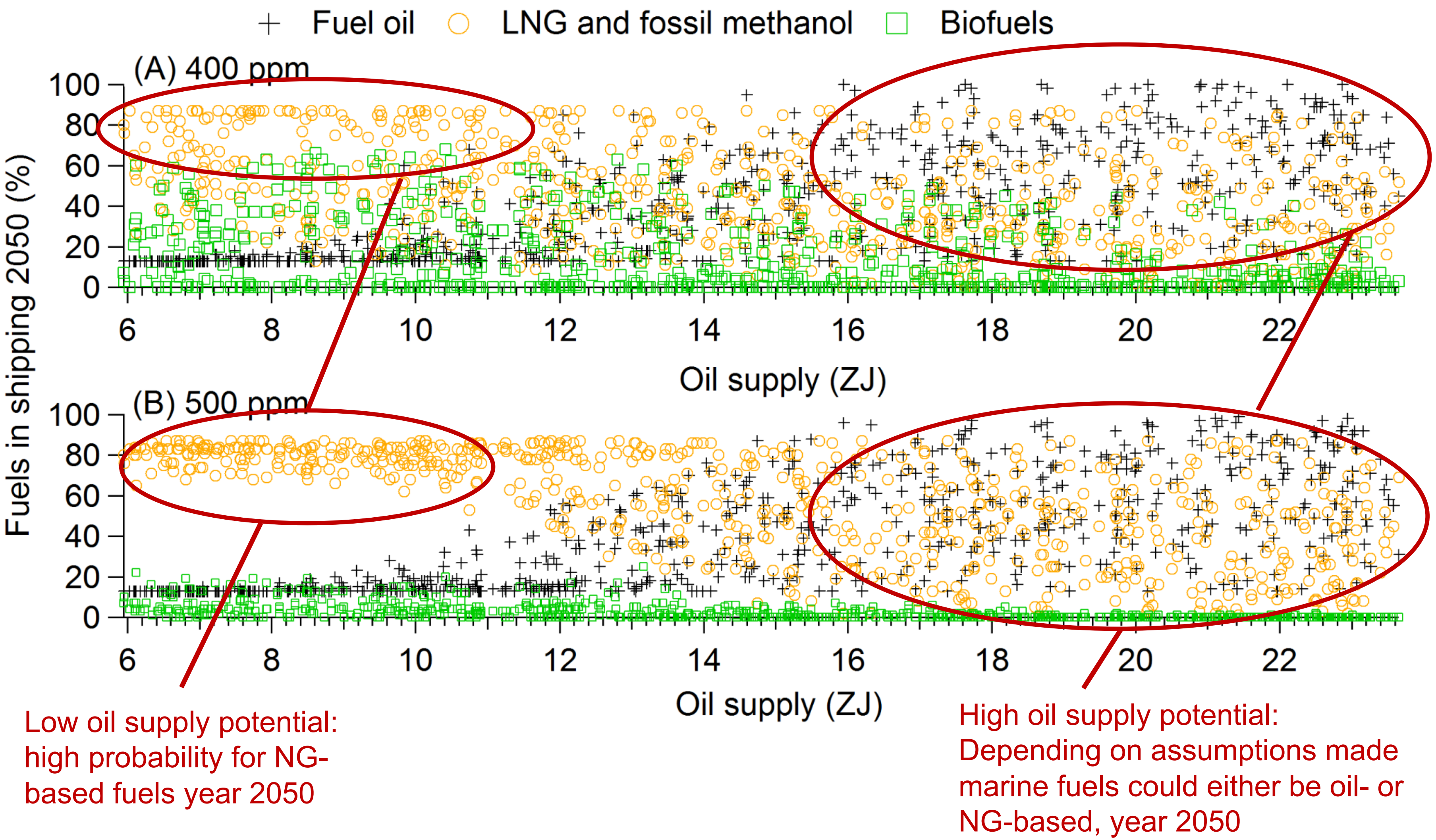


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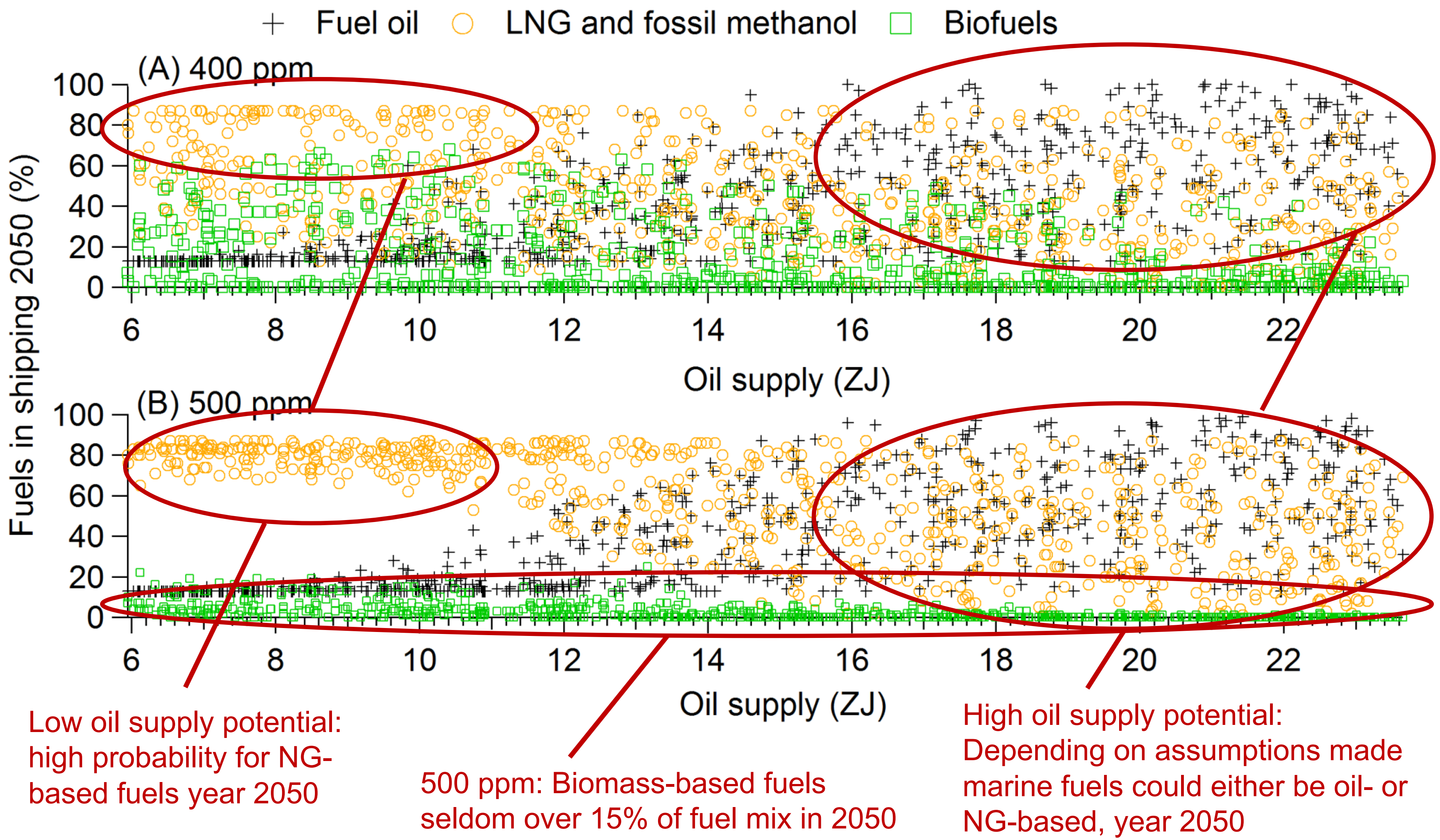


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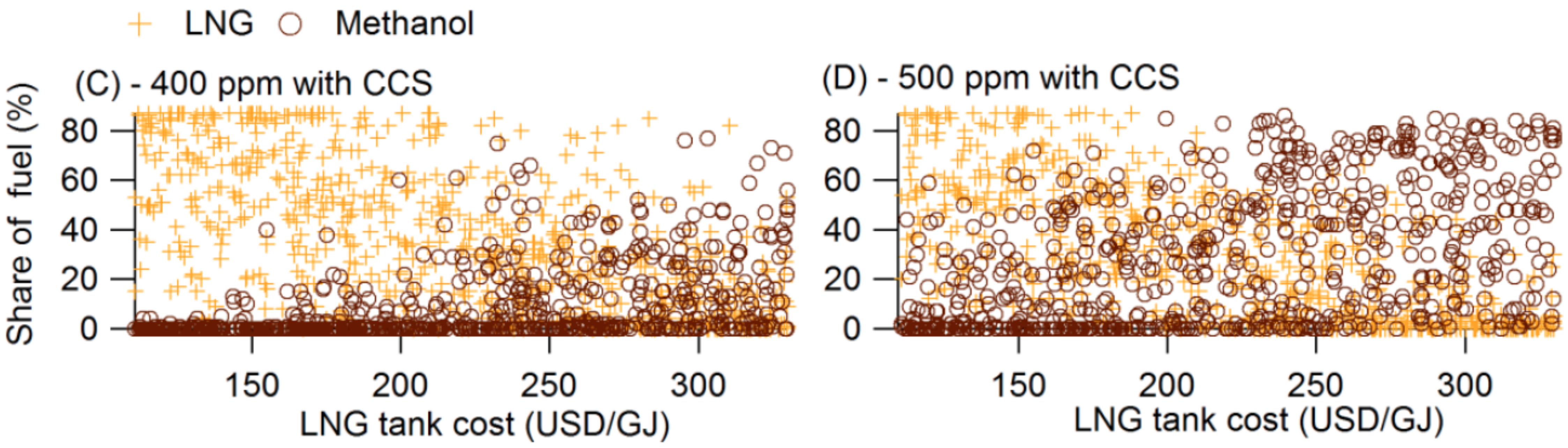
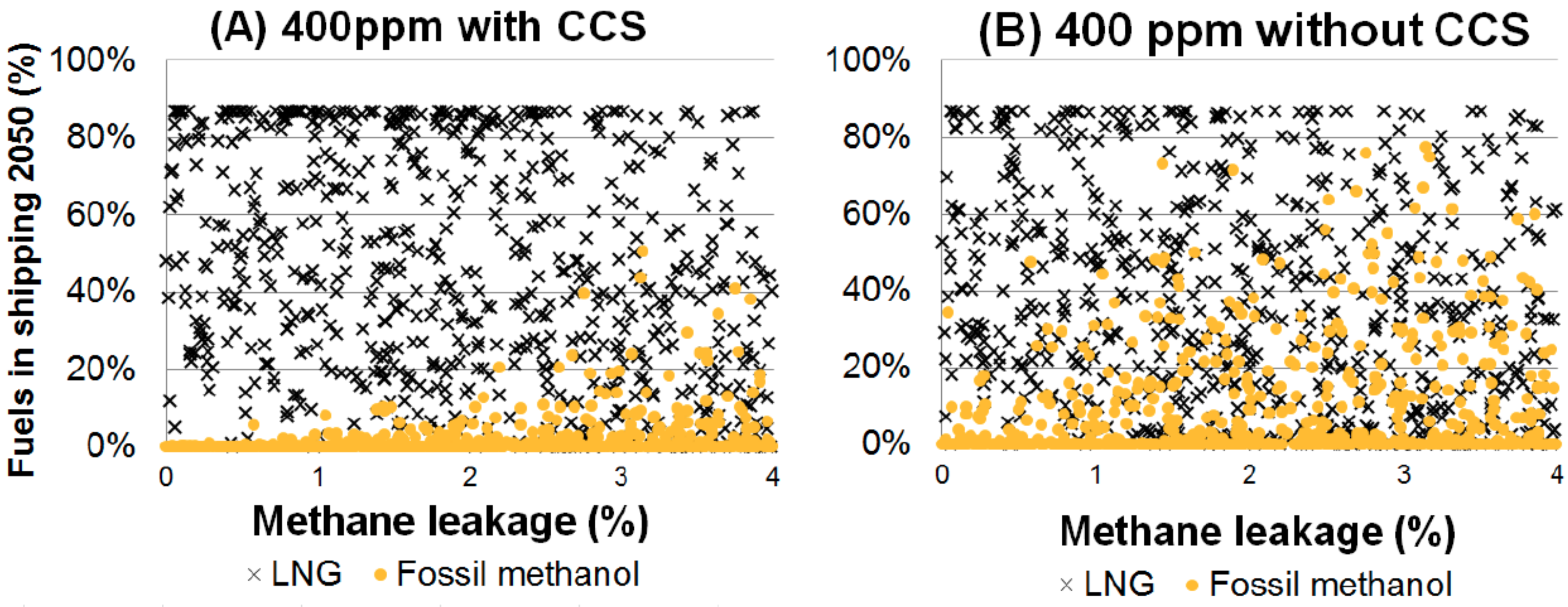
# More examples of results from the Monte Carlo runs



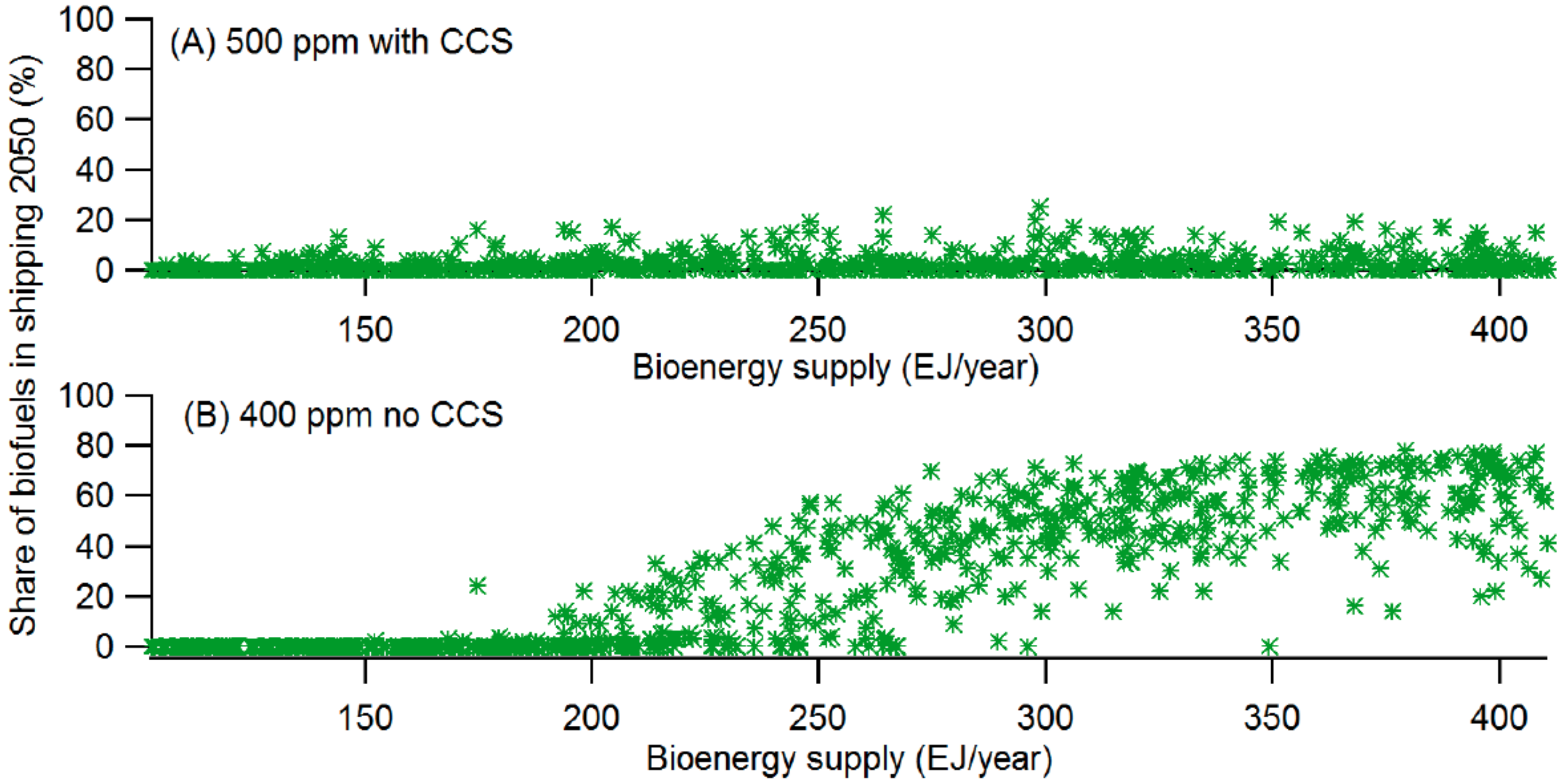

Results from a Monte Carlo analysis with 700 runs. The share of liquefied natural gas (LNG) and natural gas-based methanol in the shipping sector in 2050, meeting a CO2 concentration of (A) 400 ppm and (B) 500 ppm, assuming that carbon capture and storage (CCS) will be a large-scale technology option, plotted against the LNG tank cost.

**Ref.** Taljegård M., Brynolf S., Grahn M., Andersson K., Jonsson H. (2014). Cost-Effective Choices of Marine Fuels in a Carbon-Constrained World: Results from a Global Energy Model. Environmental Science and Technology. 48 (21) p. 12986-12993.




Share of the LNG and fossil methanol for shipping in 2050 in the Monte Carlo analysis for 700 runs with a CO2 concentration of 400 ppm (A) with CCS and (B) without CCS plotted against the methane slip from the LNG engine.

**Ref.** Taljegård M., Brynolf S., Grahn M., Andersson K., Jonsson H. (2014). Cost-Effective Choices of Marine Fuels in a Carbon-Constrained World: Results from a Global Energy Model. Environmental Science and Technology. 48 (21) p. 12986-12993.

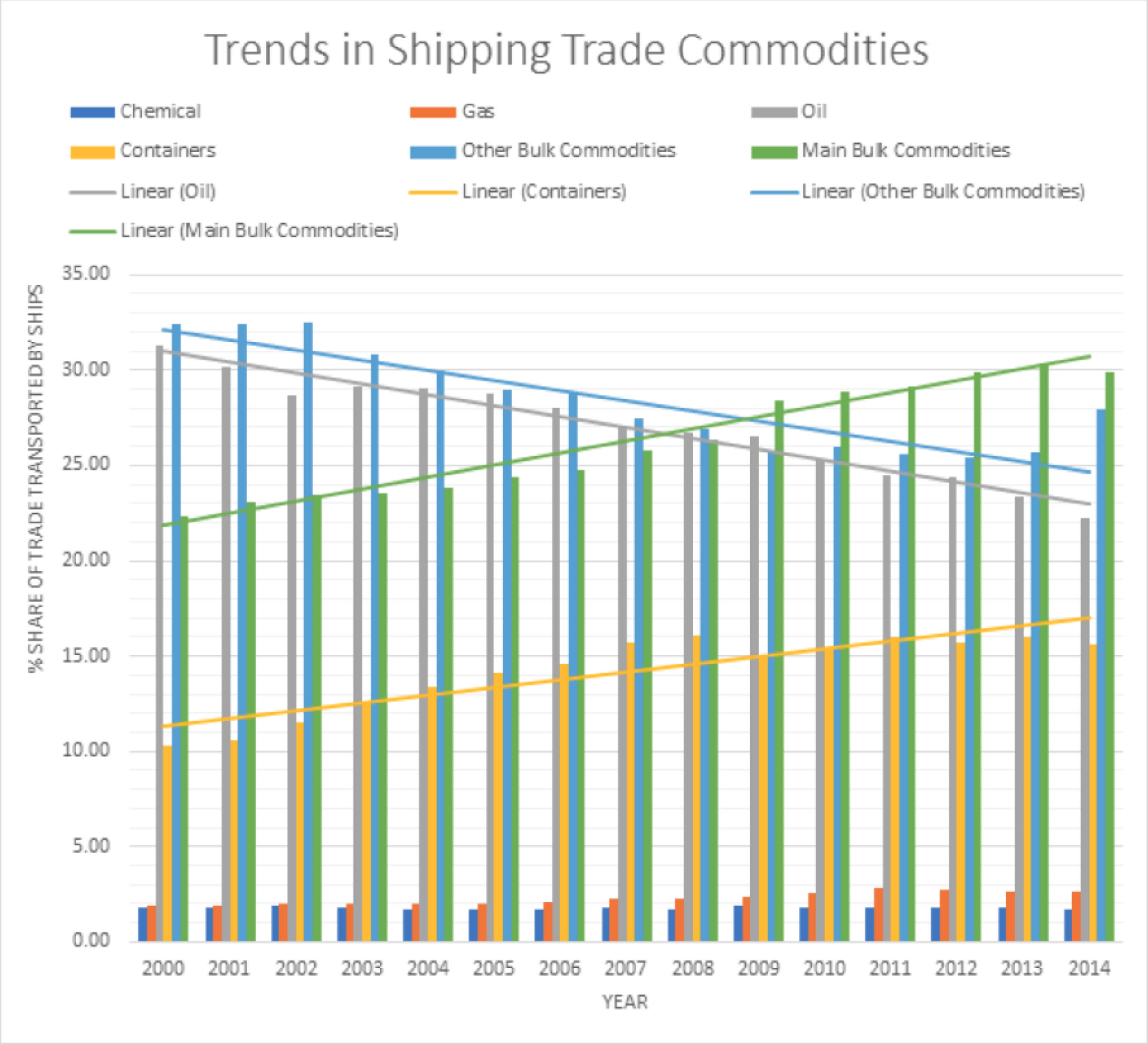



Share of biofuels for shipping in 2050 in a Monte Carlo analysis of 700 runs with a CO2 concentration of (A) 500 ppm with CCS and (B) 400 ppm without CCS plotted against the bioenergy supply.

**Ref.** Taljegård M., Brynolf S., Grahn M., Andersson K., Jonsson H. (2014). Cost-Effective Choices of Marine Fuels in a Carbon-Constrained World: Results from a Global Energy Model. Environmental Science and Technology. 48 (21) p. 12986-12993.

# Another way of constructing energy demand scenarios for the shipping sector

# Historical trends, regression analysis, to project future scenarios for five different commodities




Regression coefficient for the relation between economic growth, population and shipping demand for different ship categories

| Sector | $\beta_1$ | $\beta_2$ | $\beta_0$ | R-Squared |
|---|---|---|---|---|
| **Chemical** | 1.94E-12 | 2.88E-07 | -1330 | 99.84 |
| **Gas** | 2.02E-11 | 1.69E-07 | -1490 | 98.58 |
| **Containers** | 8.9E-11 | 1.85E-06 | -12400 | 98 |
| **Main bulk** | 6.87E-11 | 6.05E-06 | -34100 | 98.75 |
| **Oil** | 2.69E-11 | 1.44E-06 | -670 | 84.67 |
| **Total** | 3.99E-10 | 7.41E-06 | -35300 | 99.12 |

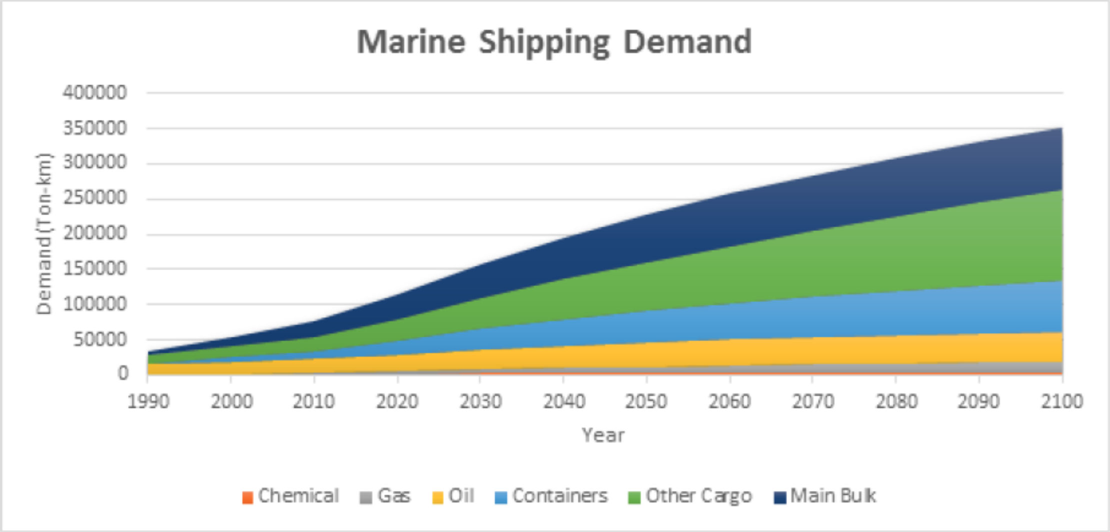
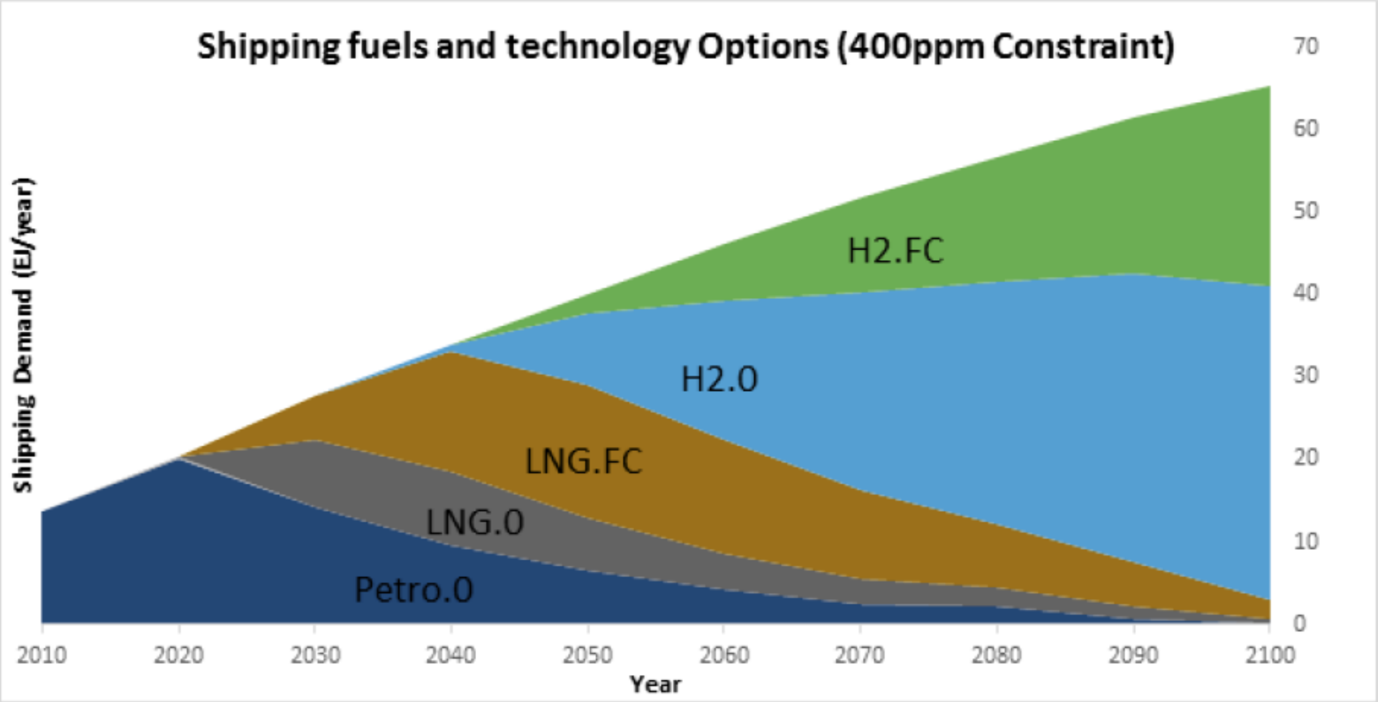



**Figure 4.3:** Estimated future shipping demand expressed in ton-km for each category of commodity

# Example of results on cost-effective fuel choices when results from the five different ship categories are added together

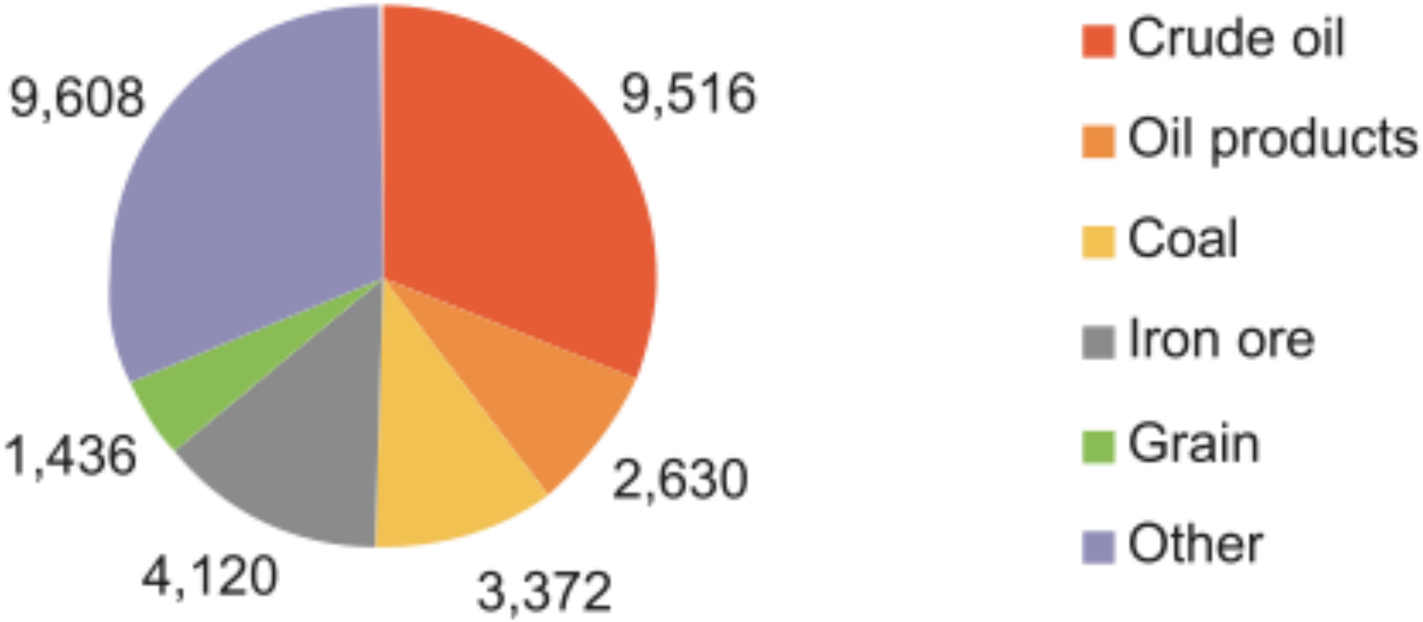



Cost-effective choice of shipping fuels and its corresponding propulsion technology options under 400ppm constraint and SSP2 scenario. Results from the 5 ship categories are added together to one global figure.

# Other aspects currently not fully understood

50% of all seaborne trade is fossil fuels
Will these ships be phased out when meeting stringent CO2 reduction targets?
Will there be new type of commodities traded? Biofuels? Hydrogen? Water? Food?

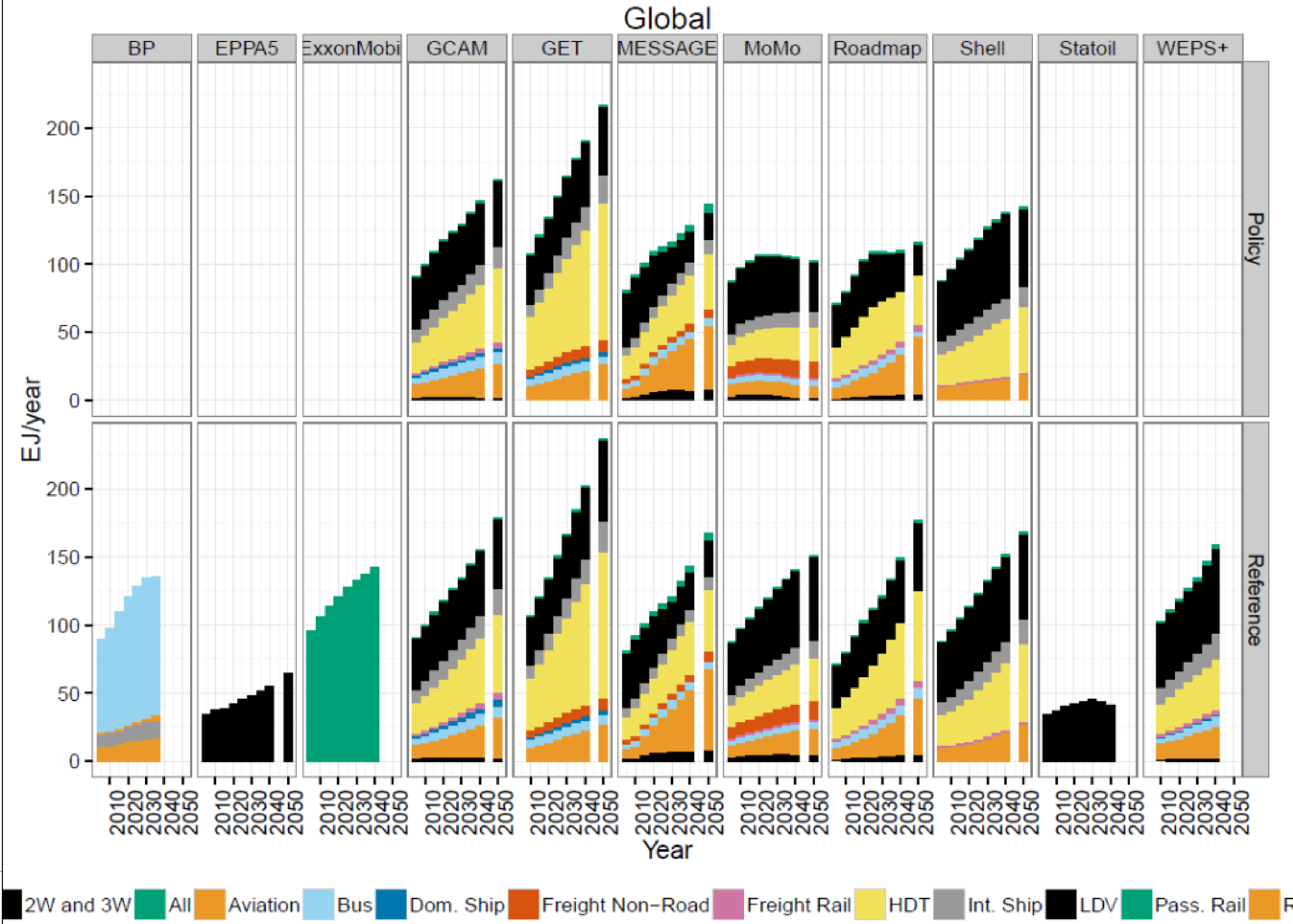
**World seaborne trade 2006 (billion ton-miles)**




**Ref.** IMO and Fearnleys, 2011

# I am curios…

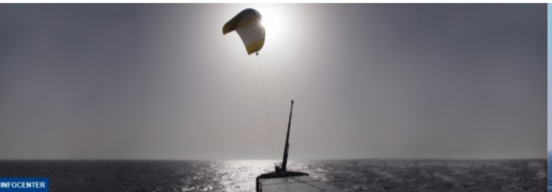
- From the ITEM2 results, I can see that at least GCAM, Message, Momo, Shell and WESP+ have included shipping in your models.
- How have you constructing your energy demand scenarios for the shipping sector?
- Which fuel options do you allow for the shipping sector?
- What are your results (or input data) on shipping demand and fuel choices?
- Would you like to carry out a model comparison study focussing on shipping?



# Extra

# Results

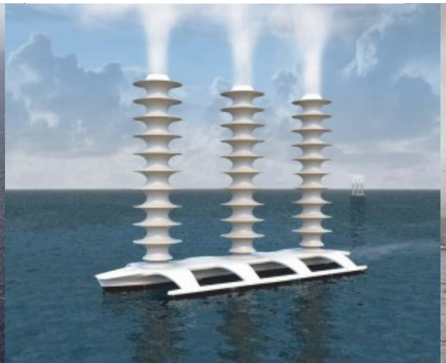
- The use of **fuel oil** (HFO/MGO)
  - Depends on NG price, methane leakage, NG resources, and annual bioenergy supply.
- Almost all runs show NG-based fuels (**LNG or methanol**) in 2030-2050.
  - Depends mainly on oil resources, LNG-tank cost, and to some extent on bioenergy supply and NG resources.
- LNG or natural gas based methanol?
  - The fuel cost dominates the life cycle cost of a ship. LNG and NG-based methanol are similar.
  - Methanol is more affected, than LNG, by increasing NG-price and cost for emitting CO2.
  - Methanol is generally shown in scenarios when assuming **methane leakages over 2%** or LNG tank cost over 250 USD/GJ.
- The limited amount of **Bioenergy** can reduce $CO_2$ at a lower cost if substituting fossil fuels in the stationary energy sector
  - When high biomass supply potential, hard CO2 reduction scenario, low NG and oil resources, the share of biofuels in the shipping sector may reach 40% of the shipping fuel demand (otherwise 3-28%).




# Insights

- The study can not point out one fuel winner, but learn how different assumptions affect cost-competitiveness between the fuel options.
- Need for immediate action
  - Ship's long lifetime, implies that when a fuel is shown to be cost-effective in a scenario it must have been considered by the market long before (it can take decades, to develop, test and implement).
- Implications for policy makers
  - The model results indicate that the shipping sector would have lower emission reduction requirements, compared to other energy sectors, if it were included in a global emissions reduction scheme.
  - In order to reduce the emissions in the shipping sector more than shown in these scenarios, a higher cost for $CO_2$-emissions would be needed in the shipping sector than in other sectors.






# Available fuel and shipping propulsion technologies in the model

Small engine and small fuel tank

Medium engine and large tank.

Large engine and large fuel tank.

| Propulsion system[a] | Short sea ship cost Engine: 2,400 kW Tank: 3,500 GJ (kUSD/ship) | Deep ship cost Engine: 11,000 kW Tank: 71,300 GJ (kUSD/ship) | Container ship cost Engine: 23,000 kW Tank: 74,600 GJ (kUSD/ship) |
|---|---|---|---|
| Fuel oil (HFO/MGO) ICE | 17,500 | 77, 400 | 127,100 |
| Methanol ICE | 17,600 | 78,900 | 128,800 |
| LNG ICE | 18,600 | 84,800 | 136,800 |
| $H_2$ ICE | 19,400 | 98,200 | 150,800 |
| Fuel oil FC | 25,400 | 114,700 | 207,400 |
| Methanol FC | 25,500 | 115,900 | 208,700 |
| LNG FC | 25,700 | 118,800 | 211,700 |
| $H_2$ FC | 26,600 | 132,400 | 226,000 |

[a]Fuel oil ICE, Methanol ICE, LNG ICE, $H_2$ ICE are internal combustion engines powered by fuel oil, methanol produced from natural gas, coal or biofuels liquefied natural gas and liquefied hydrogen. Fuel oil FC, Methanol FC, LNG FC, $H_2$ FC are ships with fuel cells powered by fuel oil, methanol produced from natural gas, coal or biofuels, liquefied natural gas and liquefied hydrogen.