

# Aggregate investment for the decarbonisation of the shipping industry

Raucci Carlo, Bonello Jean Marc, Suarez de la Fuente Santiago, Tristan Smith, Kasper Søgaaard

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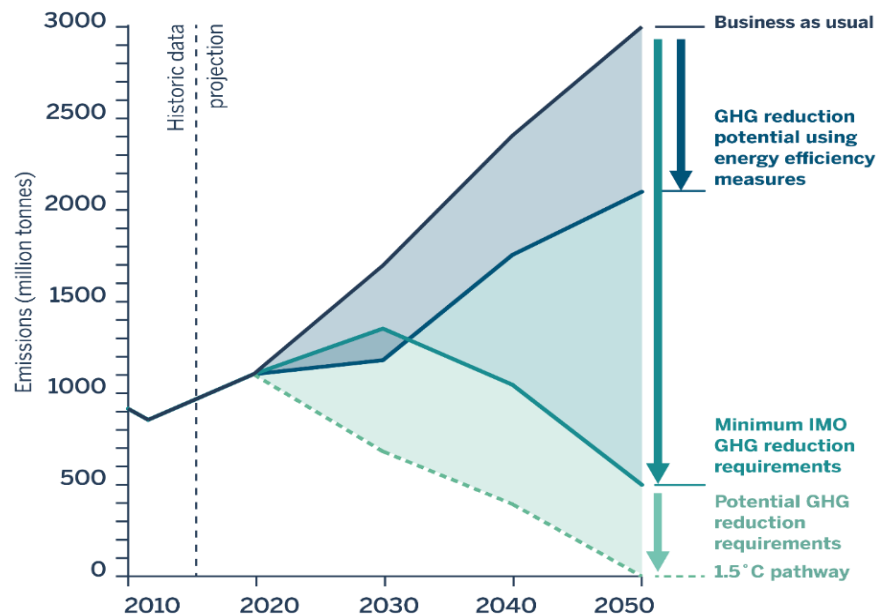


*Maritime consultancy delivering applied solutions for a carbon constrained future*

The International Maritime Organization has committed to reducing greenhouse gas emissions from international shipping by at least 50% by 2050 (2008 baseline)

2050 decarbonization (1.5°C aligned)

Emissions (million tonnes CO<sub>2</sub>)

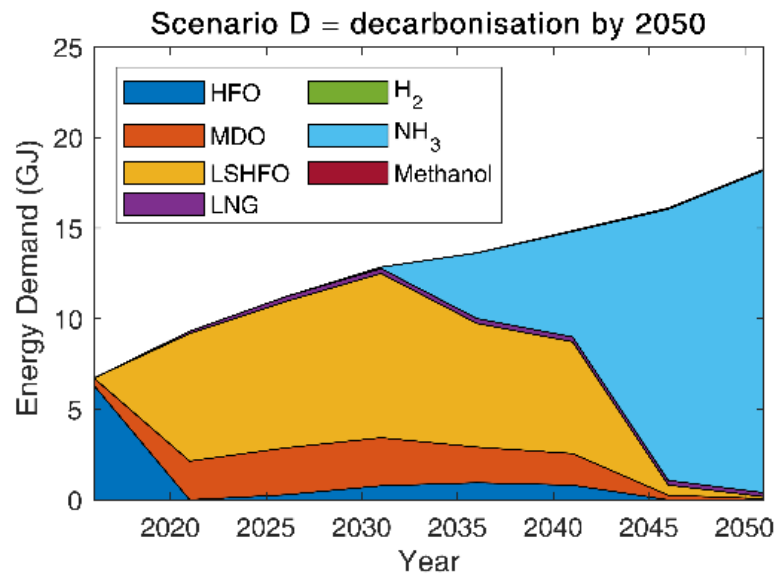


Typical ship operational lifespan 20-30 yrs

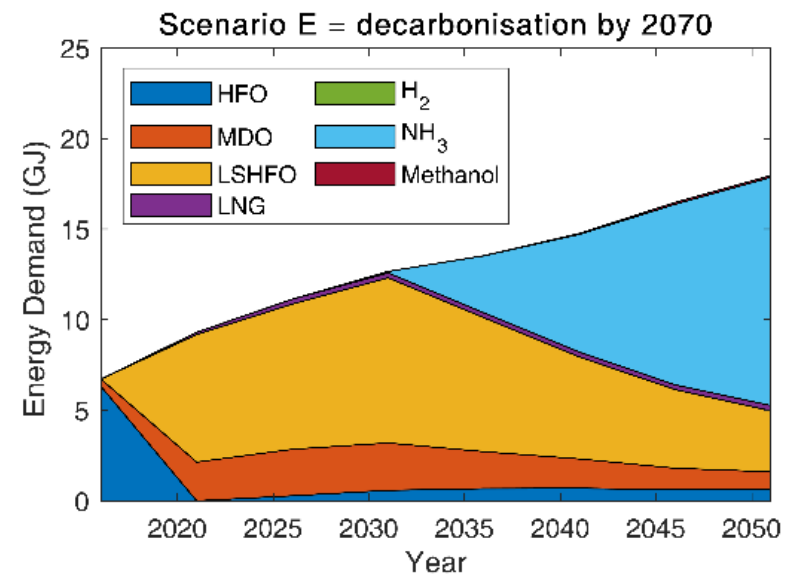
*Efficiency gains alone can't achieve the IMO's GHG reduction targets; a transition to zero-carbon fuels and electricity from renewable energy resources is needed*

Scenario analysis suggests a leading role for ammonia with rapid growth post 2040 and between 75-99% market share by 2050

2050 decarbonization (1.5°C aligned)  
GJ



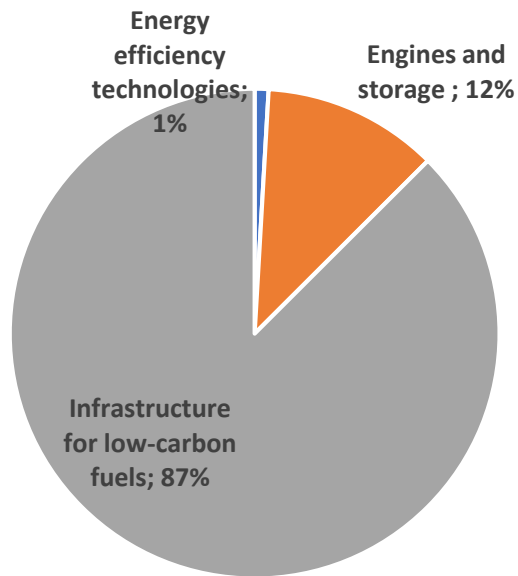
2070 decarbonization (IMO aligned)  
GJ



*The scenarios suggest ammonia is likely to represent the least-cost pathway for international shipping*

# The investment in fuel supply infrastructure represents the major share of decarbonisation investment costs

Aggregate investment costs  
Percentage



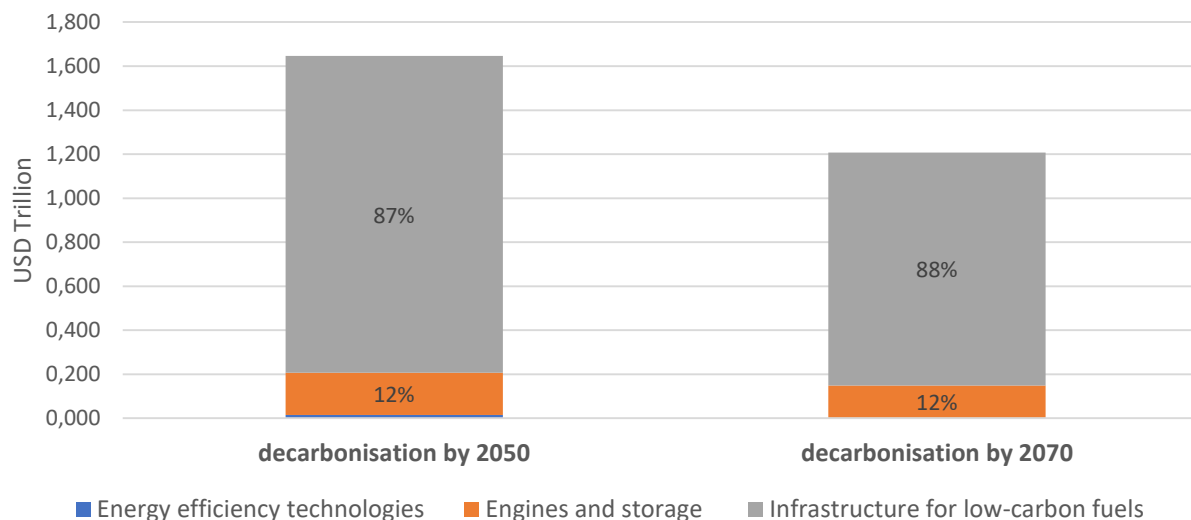
*Although this is associated with an ‘ammonia scenario’, it can be considered close to other decarbonisation pathways using hydrogen and/or methanol. The overall order of magnitude of investment would be similar; hydrogen would need less capex investment for the supply infrastructure, methanol likely a little more. In all pathways a major common element will be major investment either in SMR/CCS, electrolysis or some combination of them both*

Source: UMAS GloTraM (2019)

Note: Sum of the investment costs up to 2050. Decarbonisation by 2050 scenario assuming a mix of NH<sub>3</sub> production methods (SMR+CCS and electrolysis)  
Investment costs up to 2050 capex only

The total cost of decarbonisation up to 2050 is 27% higher in the 2050 decarbonisation scenario compared to a 2070 decarbonisation scenario

Aggregate investment costs by scenario  
USD trillion

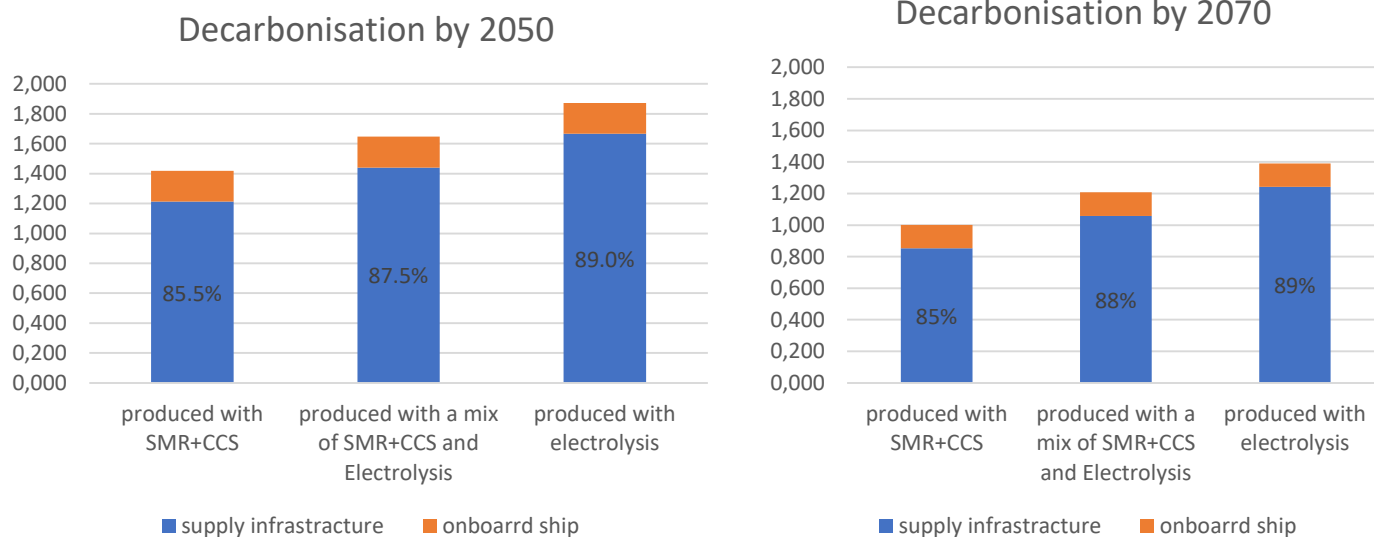


*Total aggregate investment costs for decarbonisation by 2050 equal USD1.65 trillion across the three cost components*

The investment in fuel supply infrastructure represents the major share of the decarbonisation investment costs and is sensitive to the ammonia production pathway

### Aggregate investment by scenario USD trillion

USD trillion



*The estimates includes only capex. The energy prices (electricity and gas prices) need to be taken into account in order to identify the least cost production option*

***Fuel supply infrastructure represents approximately between 85% and 90% of total cost of decarbonisation; cumulative total capital investment by 2050 is estimated to be USD 1 – 1.9 trillion***

Source: UMAS GloTraM (2019)

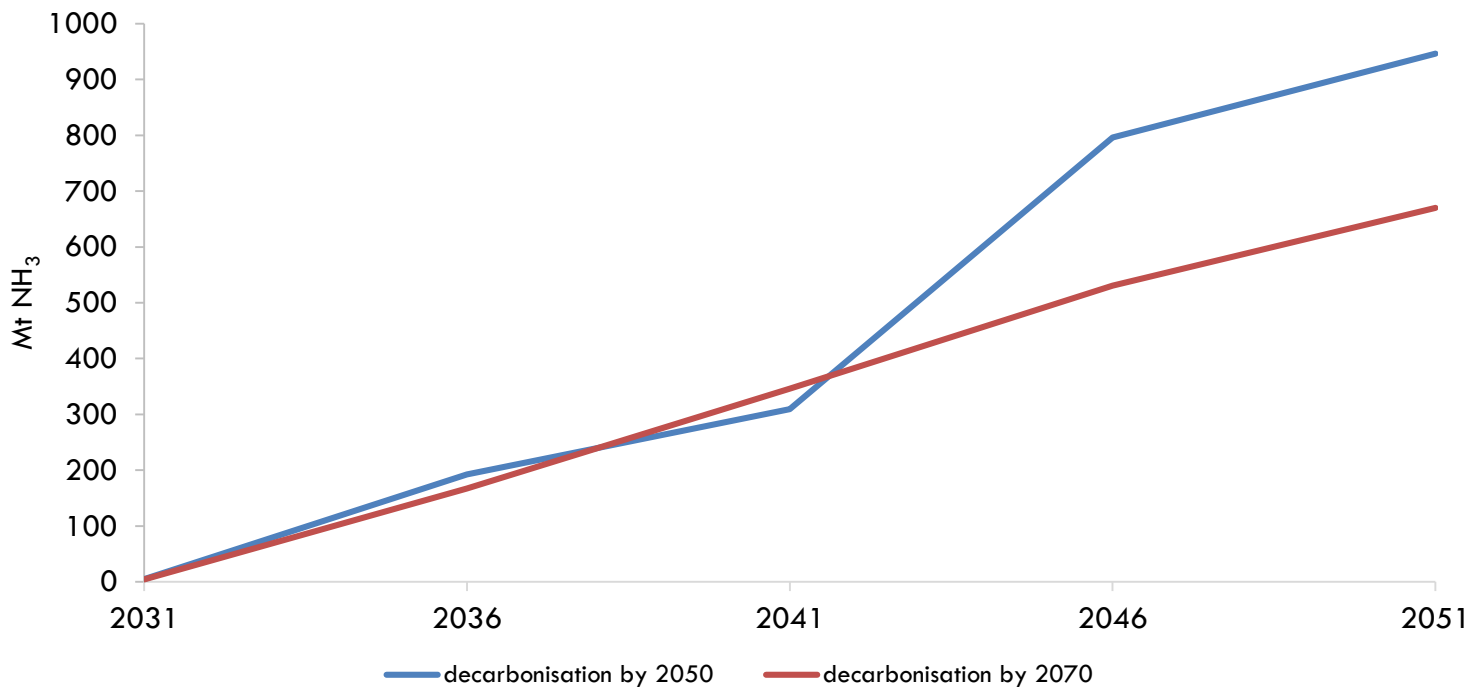
Note: The infrastructure costs exclude the infrastructure for renewable electricity production

For the SMR+CCS option, a cost of approximately 20 USD/ ton CO<sub>2</sub> has been assumed

Annual ammonia demand could increase by 670 to 946 million tonnes and represent a potential 5 USD trillion market up by 2050

### Ammonia market opportunity

Million tonnes ammonia



*Growth in ammonia for shipping could represent +400% capacity increase relative to 2018 global ammonia production capacity*

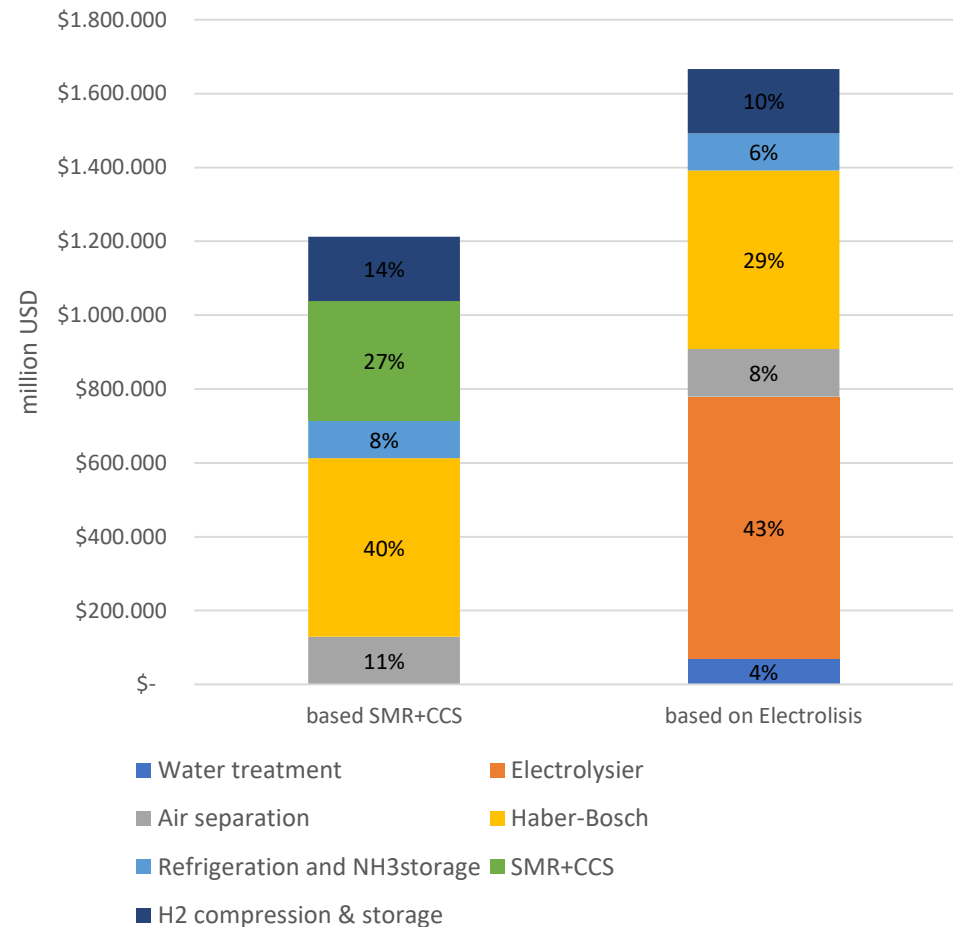
Source: UMAS GloTraM (2019)

Note: assumes NH<sub>3</sub> constant price of USD603/tonne from 2030; reported 2018 global ammonia capacity was 188Mt

## The costs of the zero carbon fuel infrastructure would vary by supply configuration and production pathway

- the capital costs associated with the electrolysis of hydrogen and the Haber Bosh process represent a significant share (~72%) when ammonia is produced from electricity
- Whereas the cost associated with the Haber-Bosch and reforming of hydrogen plant with carbon capture storage process represent a significant share (67%) when ammonia is produced from SMR+CCS

Capital cost breakdown for ammonia infrastructure by production pathway under the decarbonisation by 2050 scenario



Source: UMAS GloTraM (2019)

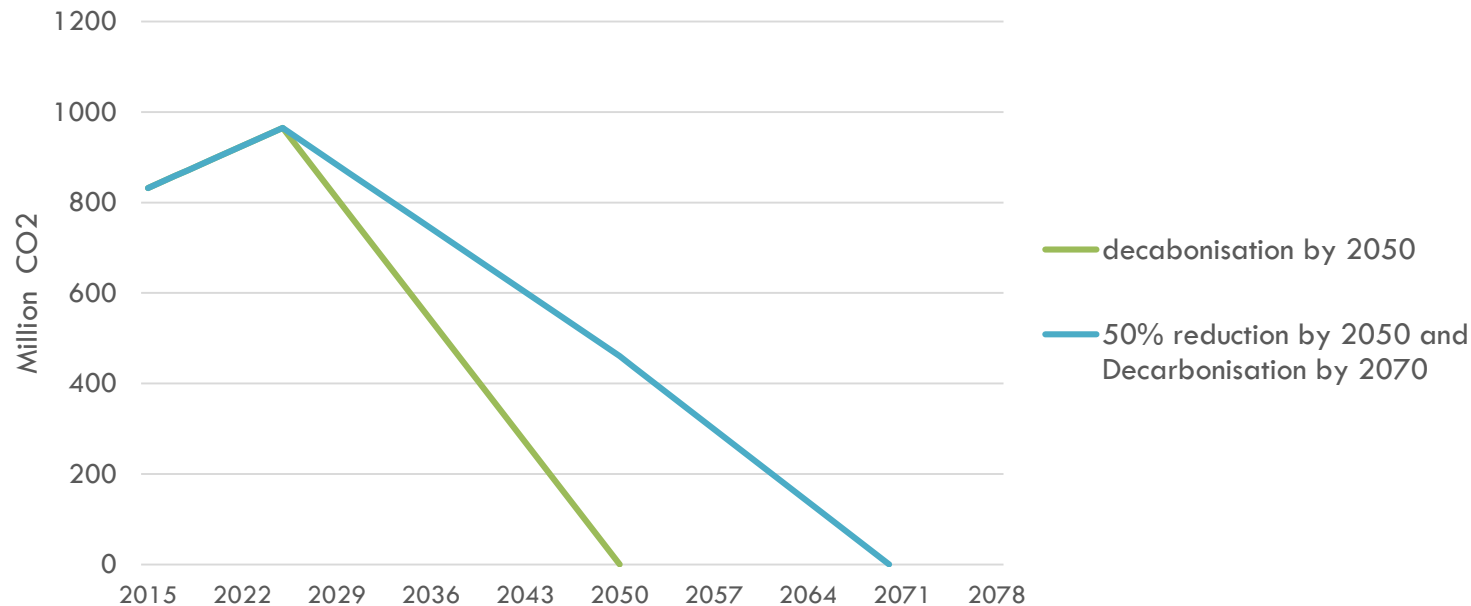


# APPENDIX

# The aim is to assess the investment required under two decarbonisation scenarios

- Two global CO<sub>2</sub> operational emissions target trajectories are identified. One assumes a full decarbonisation by 2050 and another assumes a 50% reduction by 2050 and full decarbonisation by 2070.
- A significant technology change is expected to achieve such target trajectories
- The aim is to assess the aggregate scale of additional investment against a BAU scenario required to achieve those targets.
- The additional investment includes: the ships (engines, storage and energy efficiency technologies) and the low-carbon fuels supply infrastructure

**Global CO<sub>2</sub> operational emissions target trajectories**



# In these scenarios, the evolution of the fleet is based on a profit maximization approach under a constraint on emissions trajectory

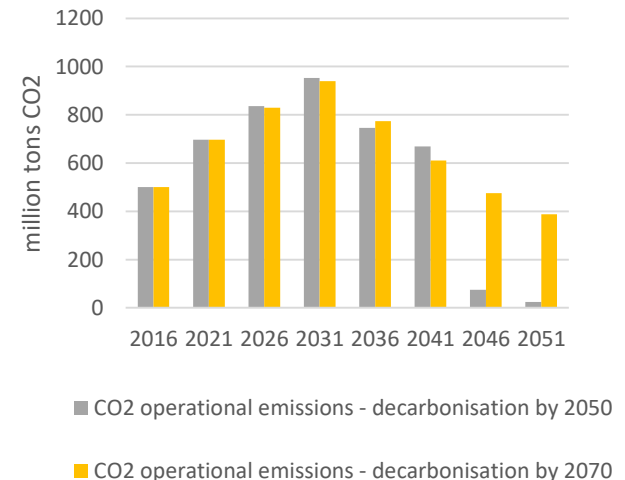
## Profit-maximization approach to assess the future evolution of the shipping fleet

- The UMAS Global Transport Model (GloTraM) was used to simulate the evolution of the fleet. It enables a holistic analysis of the global shipping system, including how shipping activity, costs and emissions might change in response to developments in economic drivers such as fuel prices and to changing environmental regulation.
- The model assumes that individual owners and operators attempt to maximise their profits at every time step, by adjusting their operational behaviour and changing the technological specification of their vessels.
- At each time-step, the existing fleet's technical and operational specification is inspected to see whether any changes are required. Those changes could be driven by regulation (e.g. a new regulation of SO<sub>2</sub> and NO<sub>x</sub> emissions) or by economics (e.g. a higher fuel price incentivising uptake of technology or a change in operating speed). Taking the fleet's existing specification as a baseline, the profitability of a number of modifications (e.g. technology, main machinery, design speed, and fuel choice) applied both individually and in combination is considered, and the combination that returns the greatest profit within the user-specified investment parameters (time horizon for return on investment, interest rate, and representation of any market barriers) is used to define a new specification for the existing fleet for use in the next time-step
- Further, a specification for newbuilds is also generated at each time step. At the baseline year the specification for newbuilds is taken as the average newbuild ship specification in the baseline year. Changes to the technology, main machinery, design speed, and fuel choice of the baseline ship are considered, such that the combination that meets current regulations and generates the highest profits within the constraints of the user-specified investment parameters is selected. The algorithm calculates the operational speed at the year when the newbuild enters the fleet.
- One output of the model is the carbon prices trajectory needed to meet the identified emissions trajectory. It is calculated endogenously by the model in an iterative mode.

Modelling outputs showing the CO<sub>2</sub> operational emissions projections of a subset of the total fleet. The subset covers ~70% of the operational energy demand of the total fleet

The second y axis shows the associated estimated carbon prices needed to achieve such emissions trajectories

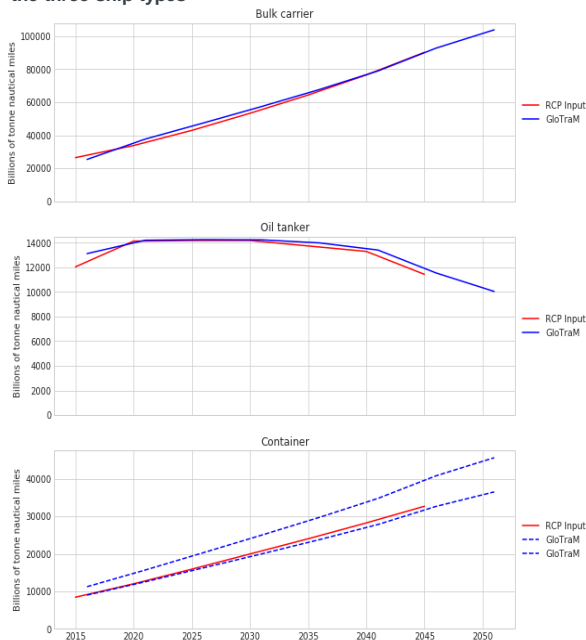
The modelled CO<sub>2</sub> operational emissions projections are in line with the identified target trajectories within +/-10% degree of misalignment.



# The scenarios assume an increase in transport demand resulting in an increasing number of ships over time

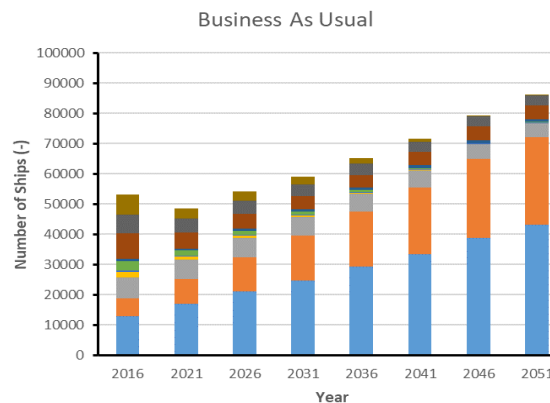
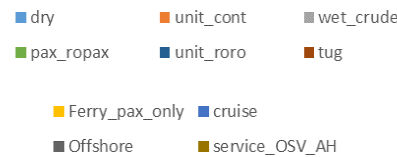
- The global shipping demand scenario that was used in both scenarios is the RCP 2.6 SSP2<sup>(1)</sup>, GloTraM global trade datasets were adjusted to match this. Speed varies slightly between scenarios, but not so much as to materially impact fleet size
- The number of the modelled ships increases over time in all scenarios in a very similar way, reaching almost 90,000 ships in 2050

Comparison of generated global transport work demand within GloTraM against RCP2.6/SSP2 transport demand scenario for the three ship types



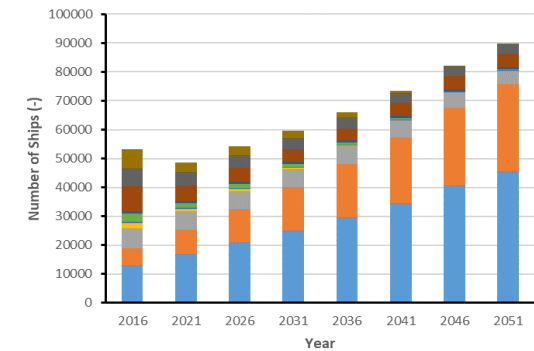
Notes: The blue lines indicate the GloTraM generated values while the red lines indicate the input data values. Note that for container vessels (unit\_cont) there are two blue broken lines: one is based on tonne to TEU ratios of 8 and the other a tonne to TEU ratio of 10.

(1) [http://www.iiasa.ac.at/web/home/about/events/8.dettef.ssp2\\_2.pdf](http://www.iiasa.ac.at/web/home/about/events/8.dettef.ssp2_2.pdf)

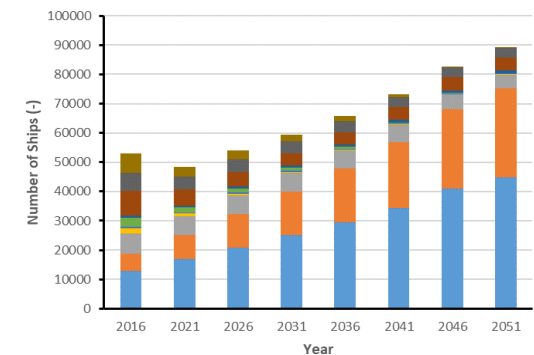


Notes: The first time-step 2016 to 2021 there is a decreasing number of ships because the model estimates the number of ships that would be active over the number of total ships available at base year. So, if demand is insufficient some ships are laid-up.

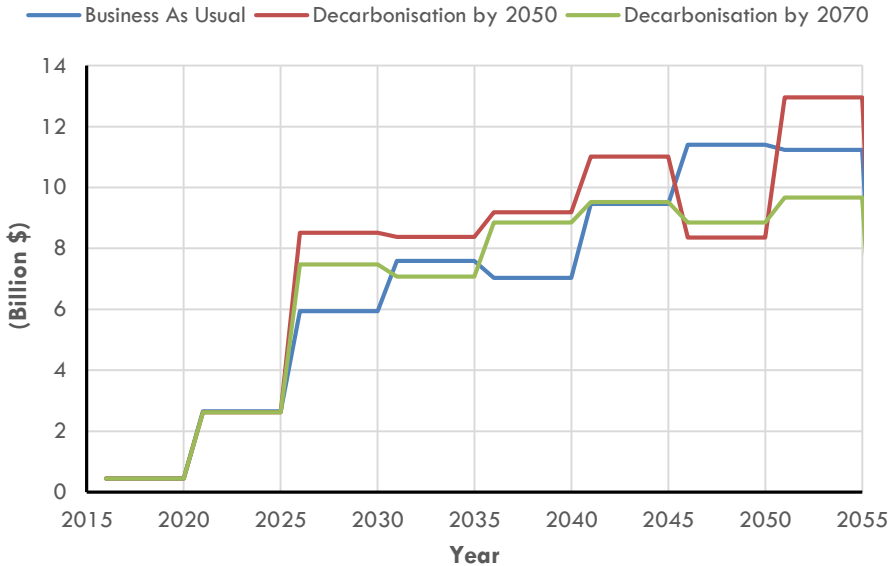
Decarbonisation by 2070



Decarbonisation by 2050

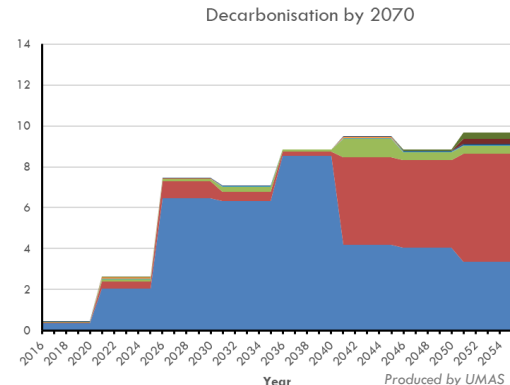
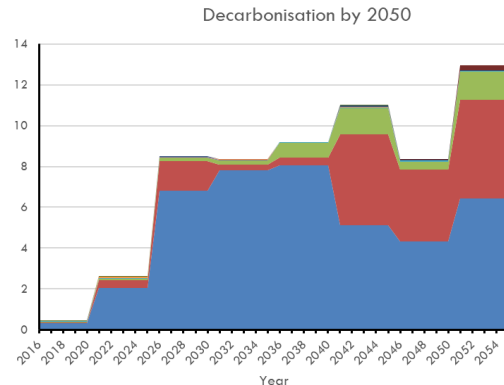
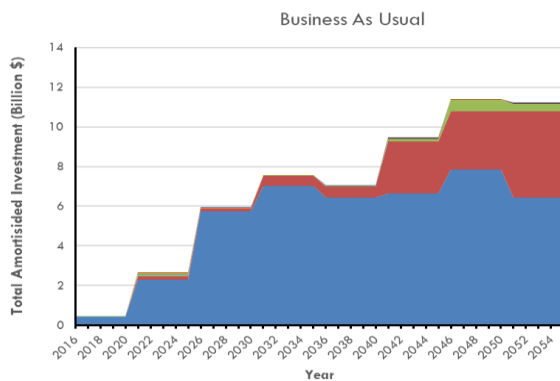


# The capital cost associated with the changes in energy efficiency technologies are comparable with the BAU scenario



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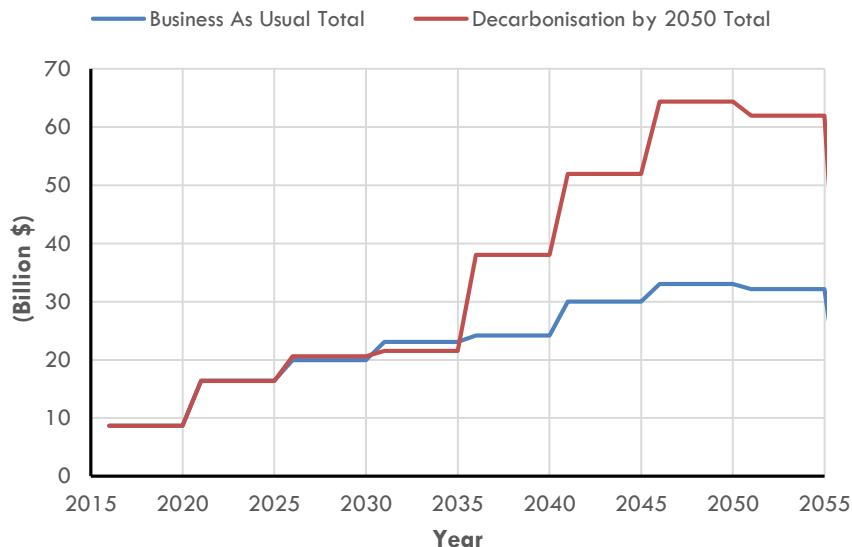
- The additional investment cost relative to the BAU scenario is driven by market forces, overall this is comparable with the decarbonisation scenarios because the latter uses a large amount of low-carbon fuel to decarbonise.
- The scenario with decarbonisation by 2050 has a higher investment in EEF technologies relative to the other scenarios (~ 11%) which reflects the stringent emissions targets.
- The dry cargo fleet is the segment that invest the most, although, in the decarbonisation by 2070 scenario, the container segment also takes a significant share.
- As an illustrative example, the figures shows the trend over time of annual amortized investment costs using an interest rate of 10%



- service\_OSV\_AH
- Offshore
- tug
- unit\_roro
- pax\_ropax
- cruise
- Ferry\_pax\_only
- wet\_crude
- unit\_cont
- dry

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# The switch to other fuel/engine is the main driver of decarbonisation.

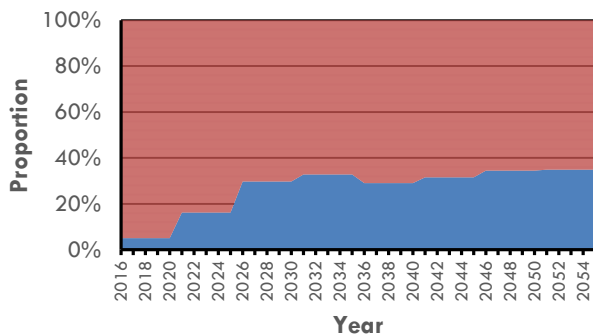


- The capital cost for the machinery includes the cost of the engines and of the fuel storage system
- The machinery cumulative investment represents 72% of the total investment costs for shipping (machinery plus EEF technologies costs) for the BAU scenario, 79% for the decarbonisation by 2050 scenario and 80% for decarbonisation by 2070 scenario.
- In both decarbonisation scenarios, there is a significant switch to ammonia used in an internal combustion engine; this reflects the higher investment costs in these scenarios.
- The machinery for ammonia vessels is estimated to cost approximately twice as much as the conventional 2-stroke engine with HFO tank.
- As an illustrative example, the figures show the trend over time of annual amortized investment costs using an interest rate of 10%

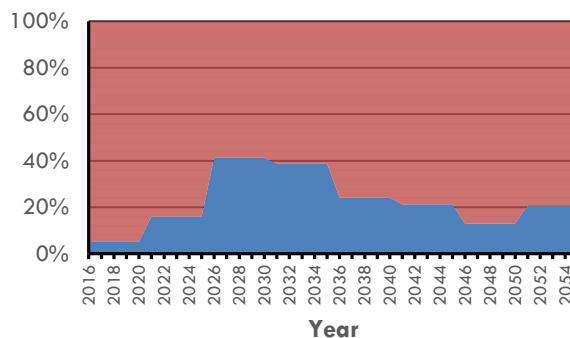
Notes: This plot quantifies the investment cost of new machinery – either a new ship build or change of machinery in the ship life – and EEF technologies. BAU scenario investment progressively increases due to the insertion of new vessels and the EEF take-up, no retrofitted machinery is seen in this scenario.

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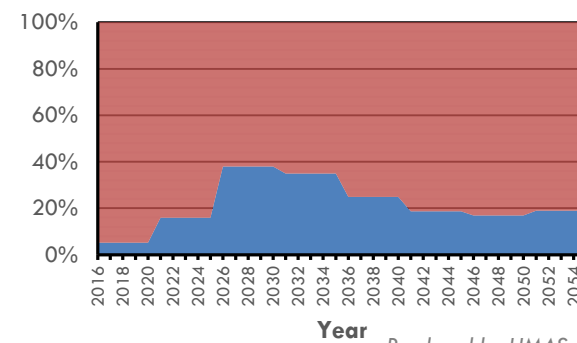
Business As Usual



Decarbonisation by 2050



Decarbonisation by 2070

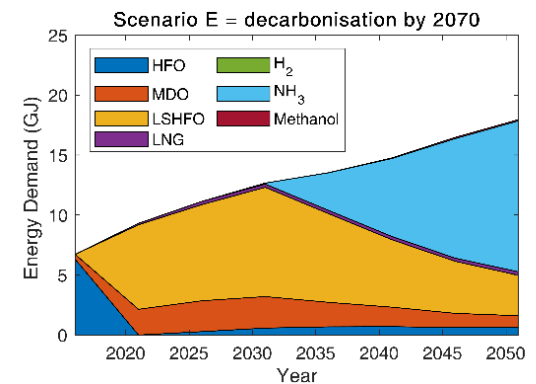
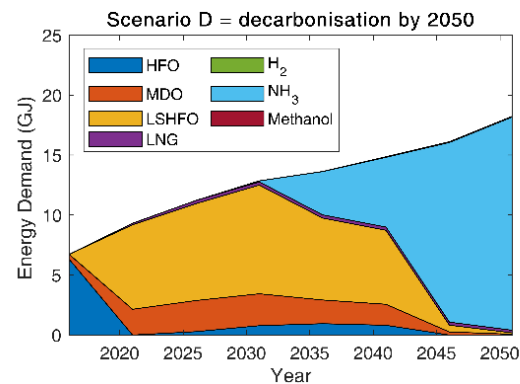
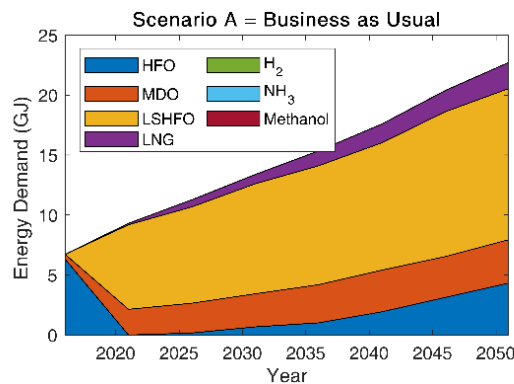


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# The fuel mix is dominated by ammonia

- The fuel selection is a key element as it influences the investment costs of the main machinery (engines/fuel storage) as well as the investment cost of the supply infrastructure
- The decarbonisation scenarios are characterised by a large take up of ammonia, reaching 99% of the total energy demand in 2050 in the decarbonisation by 2050 scenario, and 84% in the decarbonisation by 2070 scenario
- The decarbonisation by 2050 scenario shows a drastic switch to ammonia from 2040 onwards, with almost 100% of the fleet using ammonia by 2050.
- In the competition amongst low carbon fuels, ammonia results a most viable due to the competitive relative price and lower capex for fuel storage onboard.
- Electric ships represents a very small share of the international fleet, therefore, the electricity demand in the fuel mix is negligible



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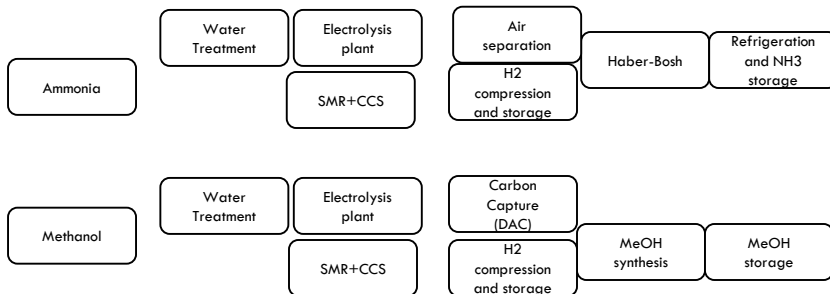
# The investment cost of the supply infrastructure for the low-carbon fuels (ammonia and methanol) depends on the production methods

The investment cost of the supply infrastructure is given for three potential configurations:

1. The production of the fuels is based entirely on electrolysis process from 2030 onwards
2. The production of the fuels is based entirely on the SMR+CCS process from 2030 onwards
3. The production of the fuels is based entirely on the SMR+CCS process in 2030 and gradually shift on electrolysis process over time until be entirely based on electrolysis in 2050

The estimates of the investment required of the three potential configurations would provide the scale of aggregate investment needed under each decarbonisation scenario

## The supply infrastructure investigated in this study



*The production of ammonia and synthetic methanol needs hydrogen as input source.*

*This study assumes that hydrogen can be produced with the electrolysis or through the reforming of natural gas and carbon capture technology (SMR+CCS)*

## Approach

The fuel mix from the decarbonisation scenarios is used as fuels demand to estimate the additional investment cost for the supply infrastructure

Ammonia e methanol are the two zero carbon fuels that are taking up in the decarbonisation scenarios with ammonia being the dominant fuel, therefore, the supply infrastructure cost estimates are mainly representative of the ammonia supply infrastructure

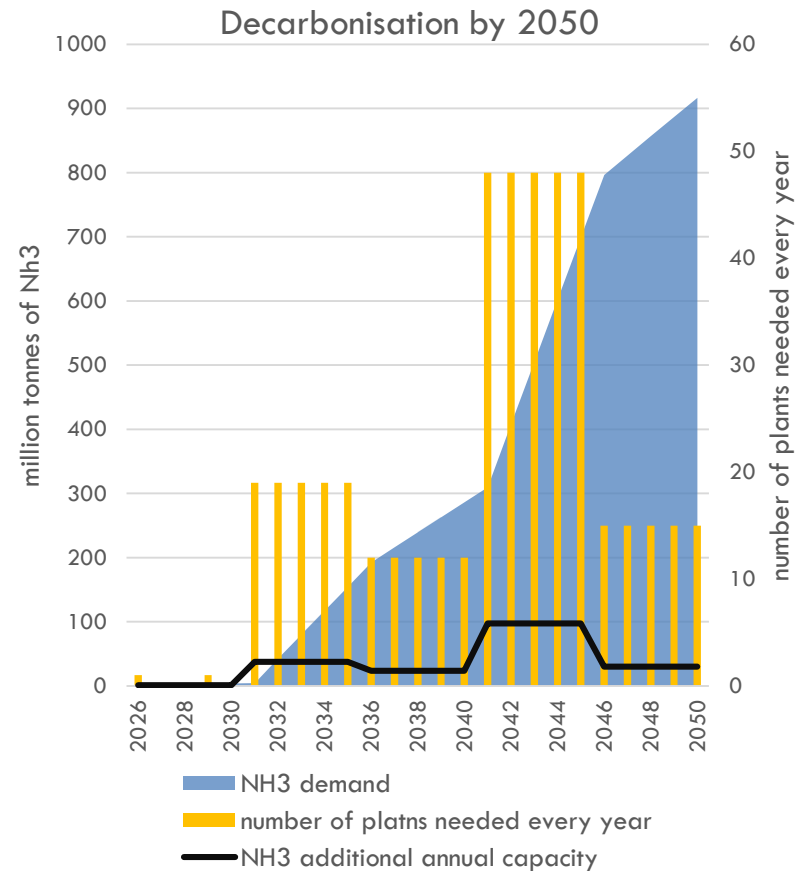
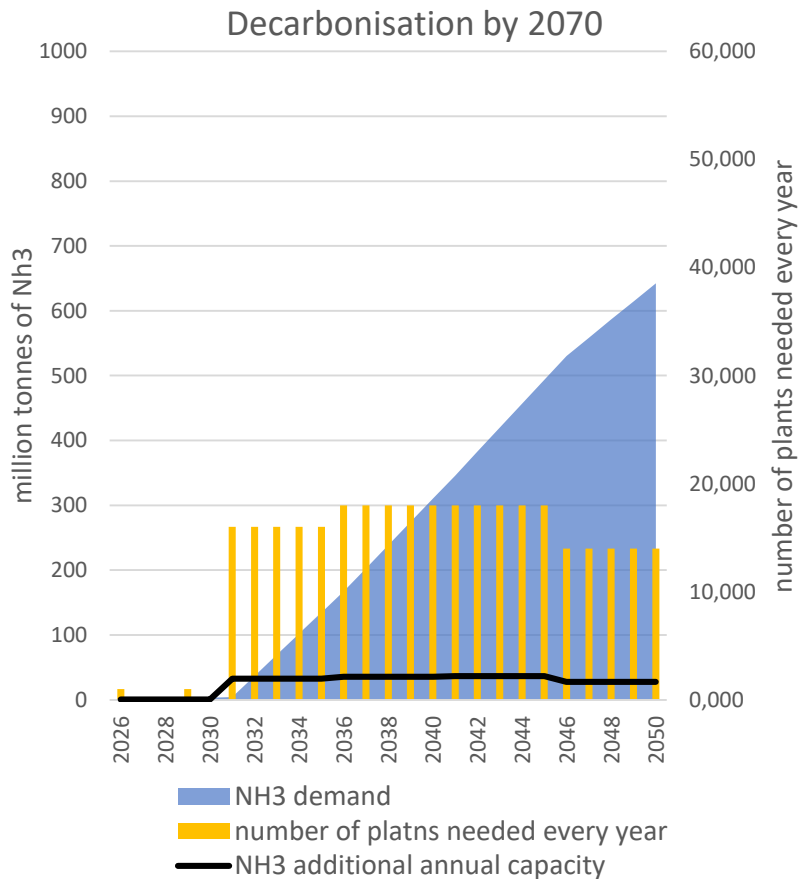
The BAU scenario does not have any uptake of zero carbon fuels, therefore, we use the investment cost of the supply of zero carbon fuels as proxy of the additional investment required relative to the BAU scenario. This calculation overestimates the additional investment for the supply infrastructure because we are not discounting for the cost needed to expand the conventional oil-based infrastructure in the BAU scenario

The capital costs of each component of the supply infrastructure are obtained from available literature (see details in slide 22). The unit costs are kept constant over time. Rather than assuming technological improvements and efficiencies of scale over time, when appropriated middle values indicating a long-term future cost was used as indicated in the literature. For example for the electrolyser a constant value of 472 USD/KW has been assumed.

The fuels demand in conjunction with the capital costs of the components are used to compute the annualised investment costs



# A rapid increase of NH3 shipping demand will require additional annual production capacity and several NH3 production plants going online every year up to 2050



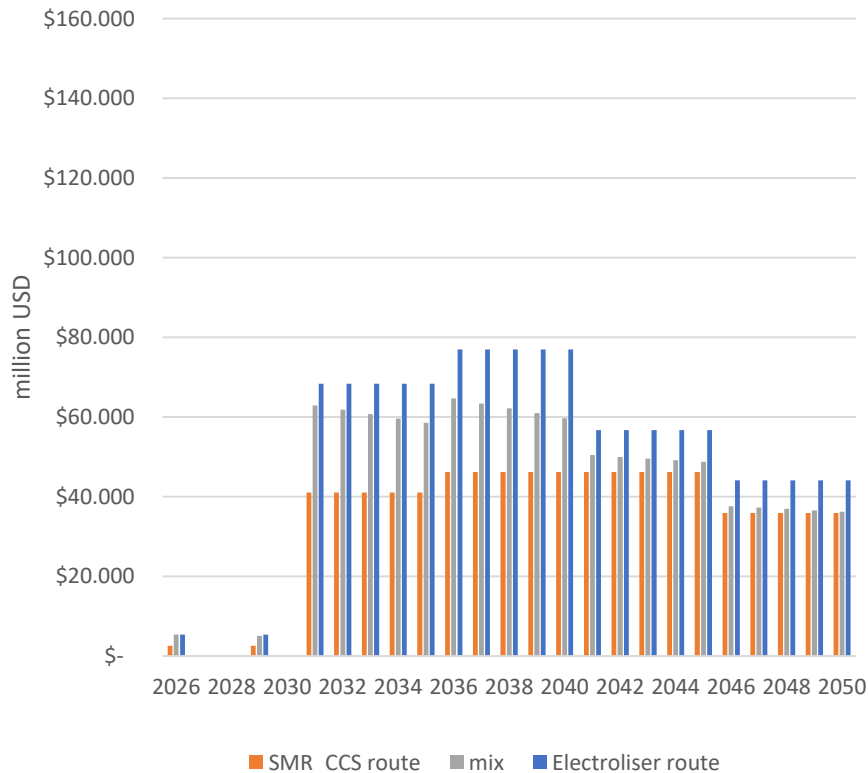
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Note: Assuming capacity plant of 7000tonnes of ammonia per day

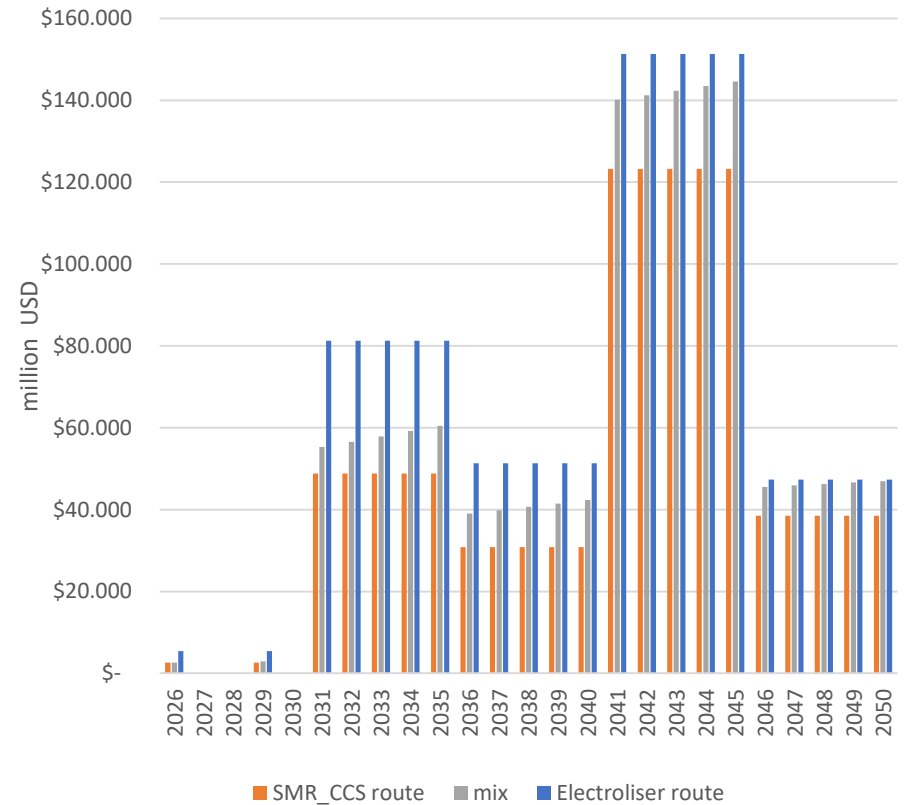
# The capital investment needed for the supply infrastructure of ammonia depends on the production methods and the specific fuel production pathways.

The capital needed for SMR+CCS route appears lower than the one needed for the electrolyser route. Note that operational costs are not included in this figure.

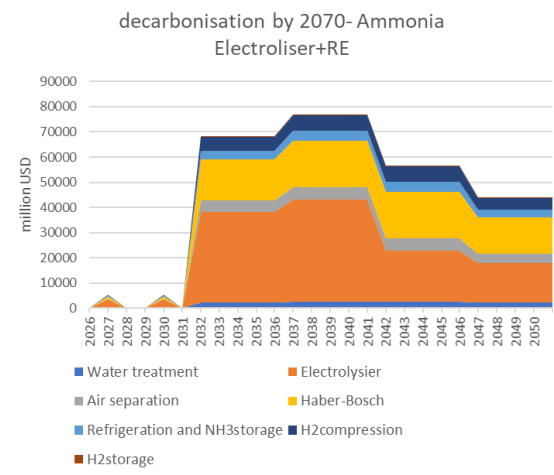
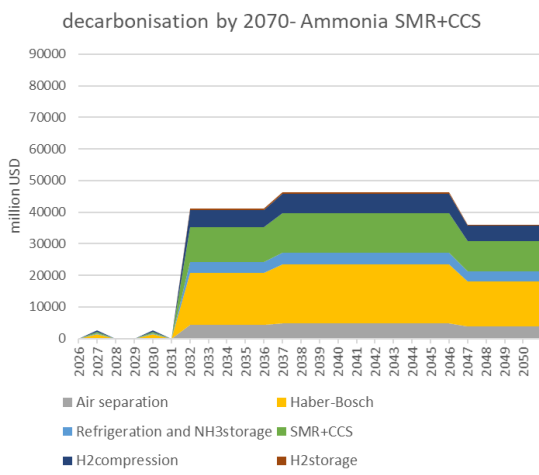
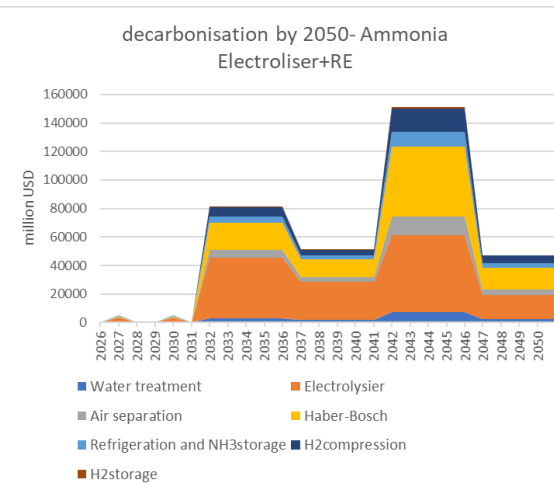
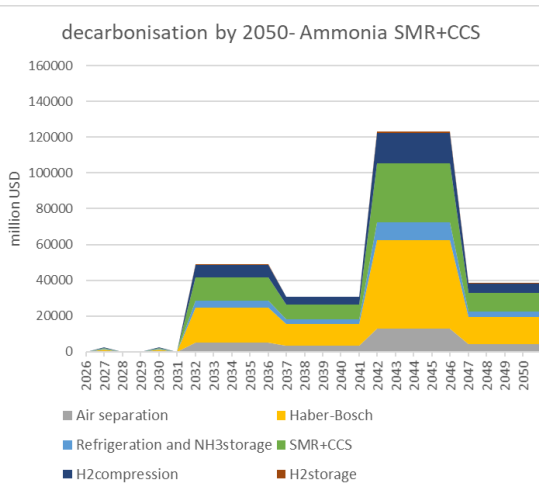
Decarbonisation by 2070



Decarbonisation by 2050



# Electrolysis and the Haber-Bosch process are the largest contributors to fuel supply capital cost



- Focusing on the production of ammonia, the capital costs associated with the electrolysis of hydrogen and the Haber Bosh process represent a significant share when ammonia is produced from electricity
- Whereas the cost associated with the Haber-Bosch process represents a significant share when ammonia is produced from SMR+CCS, followed by the reforming of hydrogen plant with carbon capture storage

## Supply infrastructure assumptions

Description	Values	Note	Key input assumptions
Ammonia plant production	6943 tpd		
Methanol plant production	6164 tpd		
Operational hours	7000 hr/year		
Ammonia plant investment cost (Electrolysis)	~3.1 billion USD	Water Treatment 4%, Electrolysis 43%, Haber-Bosch 29%, H2 compression and storage 11%, Air separation 8%, Refrigeration and NH3storage 6%	472 USD/KW Electrolyser 14.5 \$2010/GJ/yr SMR+CCS 3540 USD/kg/NH3 h Haber-Bosch Replacement costs for the electrolyser are also considered and added to the capital cost, so that:
Ammonia plant investment cost (SMR+CCS)	~4.1 billion USD	SMR+CCS 27%, H2 compression and storage 15%, Air separation 11%, Refrigeration and NH3storage 8%, Haber-Bosch 40%,	- for the plants built from 2026 to 2030, the electrolyser stack needs to be replaced three times up to 2050, - for the plant built from 2031 to 2040, the electrolyser needs to be replaced two times up to 2050
Operational period	30 years		

For more information contact:

[carlo.raucci@u-mas.co.uk](mailto:carlo.raucci@u-mas.co.uk)

[tristan.smith@ucl.ac.uk](mailto:tristan.smith@ucl.ac.uk)

[www.u-mas.co.uk](http://www.u-mas.co.uk)

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