NTNU
Norwegian University of Science and Technology

MOZEES
Mobility Zero Emission Energy Systems

SINTEF

Green hydrogen and synthetic electrofuels for trucking, shipping and aviation

Jonas Martin

IEWT 2023 Vienna, Austria
17/02/23

Agenda

Long-haul:
40 t semi-truck

Short-sea:
740 TEU container feeder

Short/mid-haul:
20 t A320 freighter

1. Oil dependency in heavy transport
2. Fuel options versus load capacity
3. Cost sensitivity of transport modes on fuel substitution
4. Carbon abatement cost as a policy indicator

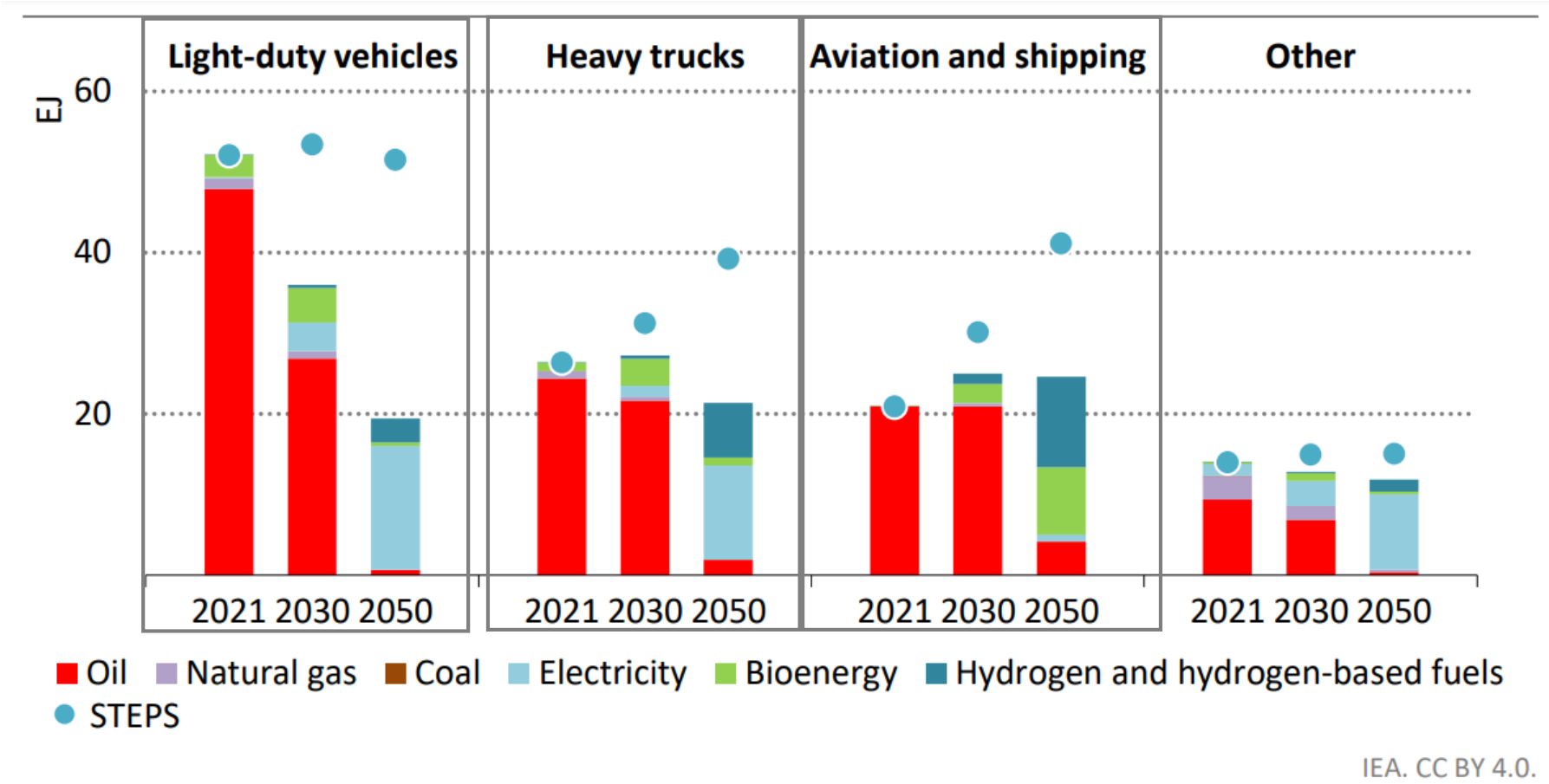
Oil dependency in heavy transport

| Trucking

| Shipping

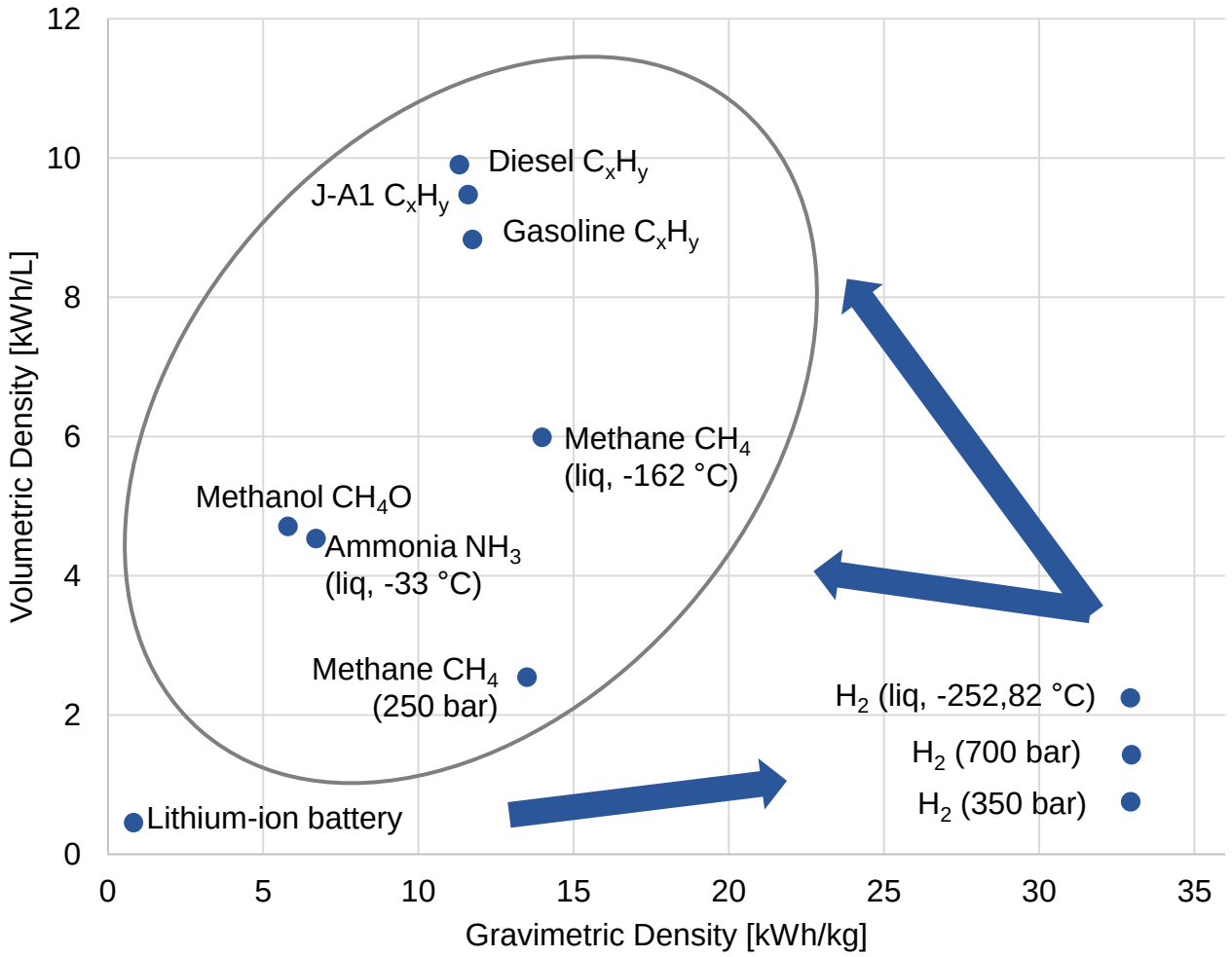
| Aviation

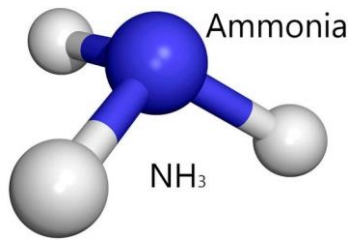
Oil dependency in heavy transport

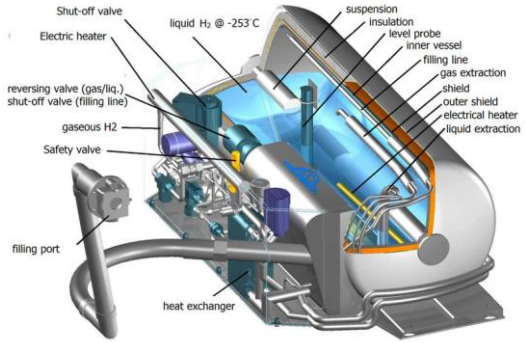


Source: World Energy Outlook 2022

Energy density - a challenge in transport







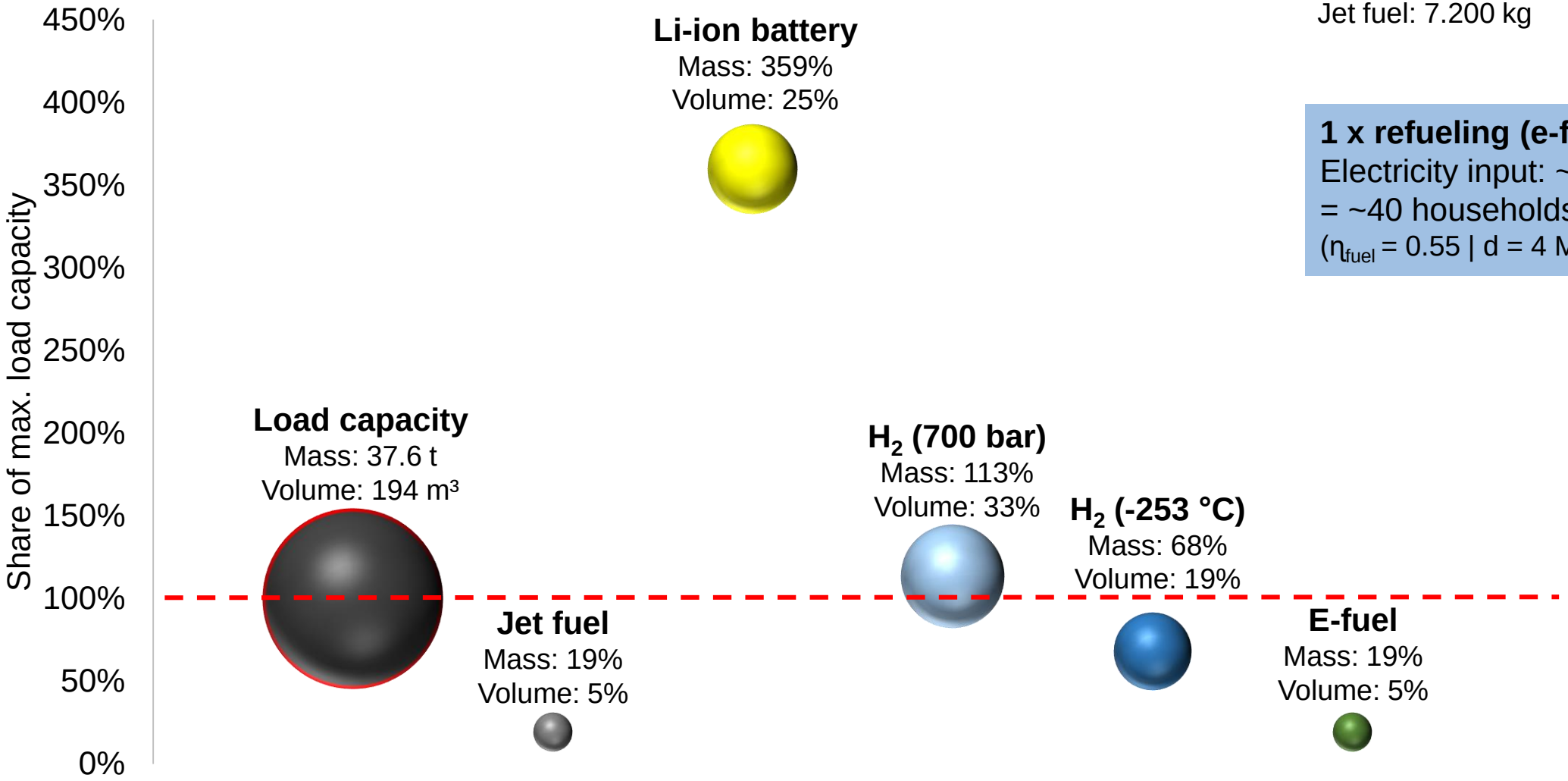
Source: Data based on the US Department of Energy
https://www.researchgate.net/publication/347521265_Energy_Transition_in_Aviation_The_Role_of_Cryogenic_Fuels
https://global.toyota/en/newsroom/corporate/22647198.html

Fuel options versus load capacity

| Battery
| Hydrogen
| E-fuels
| Ammonia

Fuel systems in the Airbus A320

Type: Airbus A320
Jet fuel: 7.200 kg



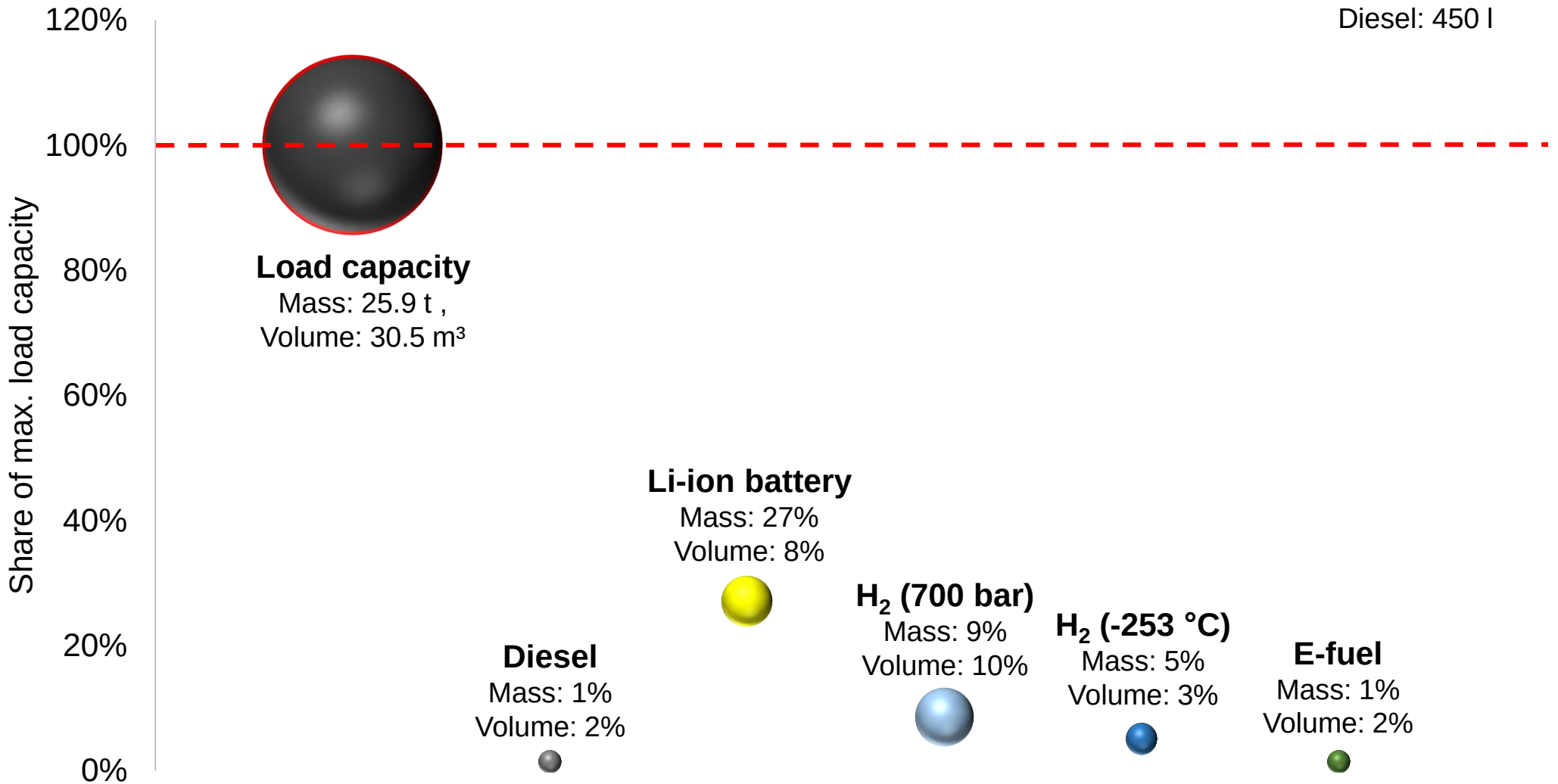
1 x refueling (e-fuel):
Electricity input: ~156 MWh
= ~40 households per year
(η_{fuel} = 0.55 | d = 4 MWh/a)

*Equal range to fossil-based transport

Source: Gray et al. 2021: Decarbonising ships, planes and trucks; and own calculations

Fuel systems in the 40 t semi-truck

Type: 40 t long-haul
Diesel: 450 l



*Equal range to fossil-based transport

Source: Gray et al. 2021: Decarbonising ships, planes and trucks; and own calculations

Industrial Developments

GenH2 by Daimler Trucks

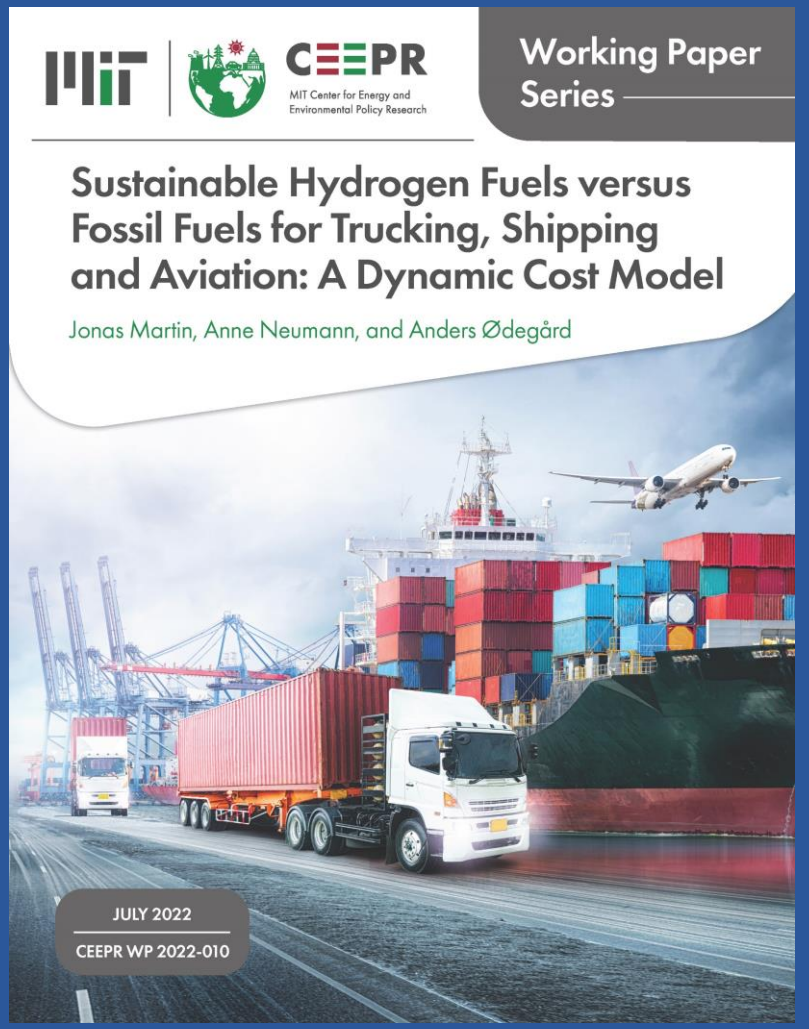
Viking Energy by Equinor

ZEROe by Airbus

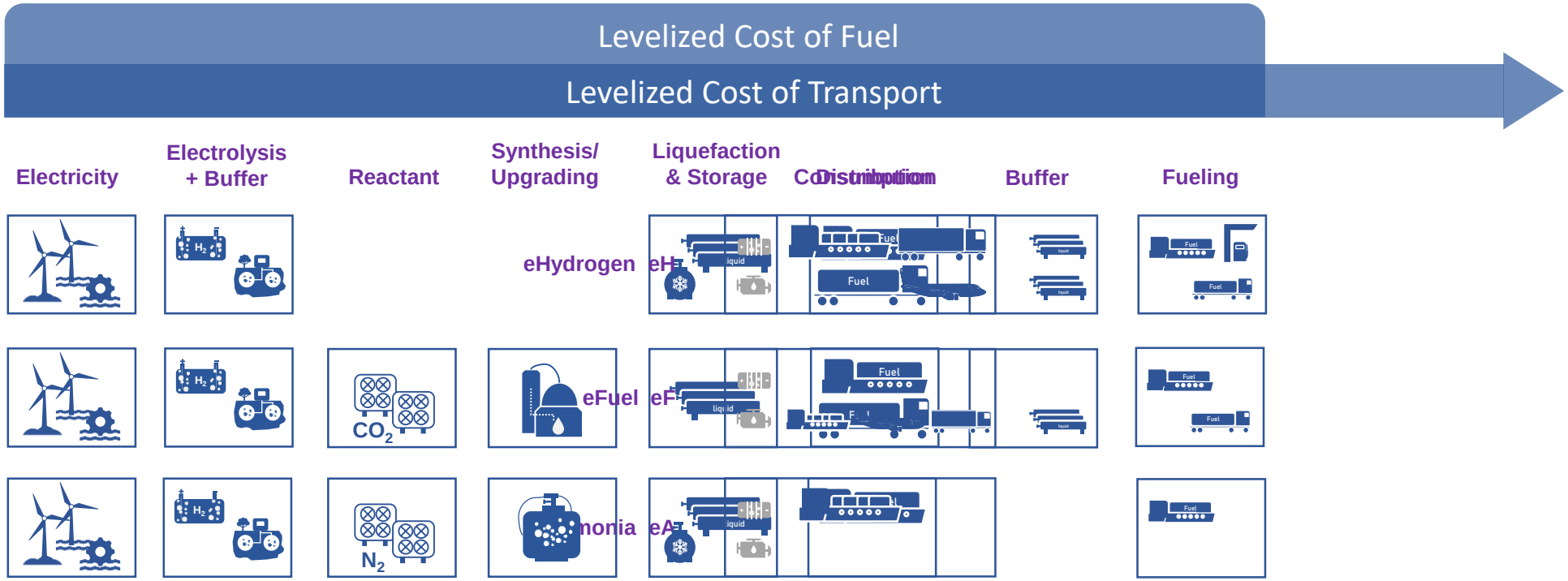
Sources:
https://www.electrive.net/2022/06/27/daimler-truck-testet-bz-lkw-mit-fluessigwasserstoff/
https://vpoglobal.com/2020/12/23/ammonia-fuel-cells-for-deep-sea-shipping/
https://www.airbus.com/en/innovation/zero-emission/hydrogen/zeroe

Economics of clean trucking, shipping and aviation

| Long-haul trucking
| Short-sea shipping
| Short-haul aviation
| 2020-2050



A holistic cost model covering the whole value chain



- ~ 140 techno-economic parameters along the value chains
- Excluding any governmental intervention by taxes or subsidies

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J. Martin, A. Neumann, A. Ødegård, 2022

Transport cost sensitivity

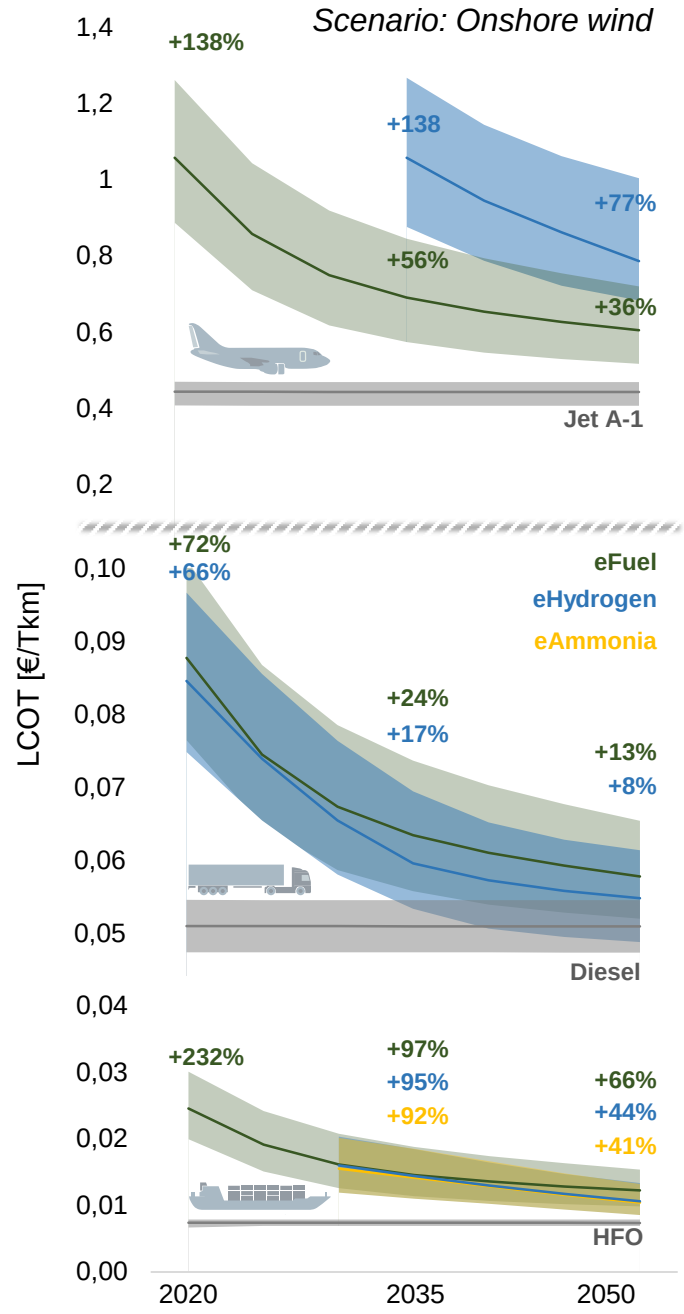
1) Cost-optimal fuel choices are eH for trucking, eA and eH for shipping, eF for aviation

2) Shipping costs are most sensitive if it comes to renewable fuels (risk of modal shift)

3) Among the transport modes, alternative fuels do not change the overall cost ranking

4) Electricity cost has a significant impact on early transport decarbonization

5) Decarbonization pathways are out of reach without the use of economic instruments by 2050



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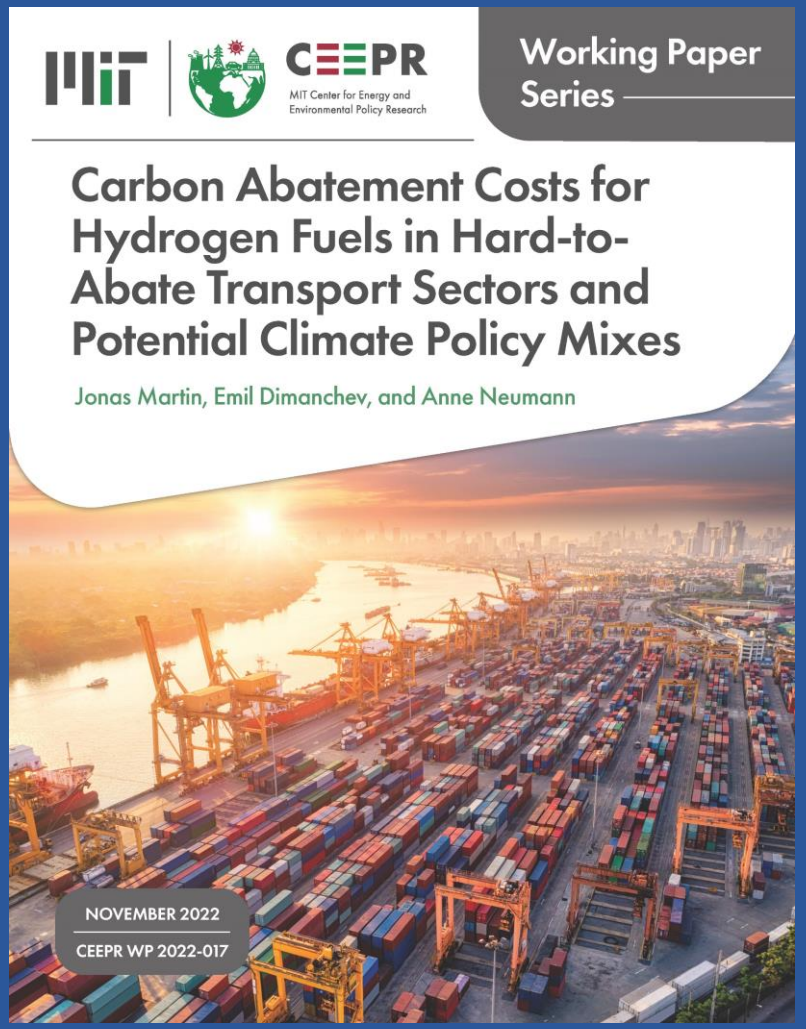
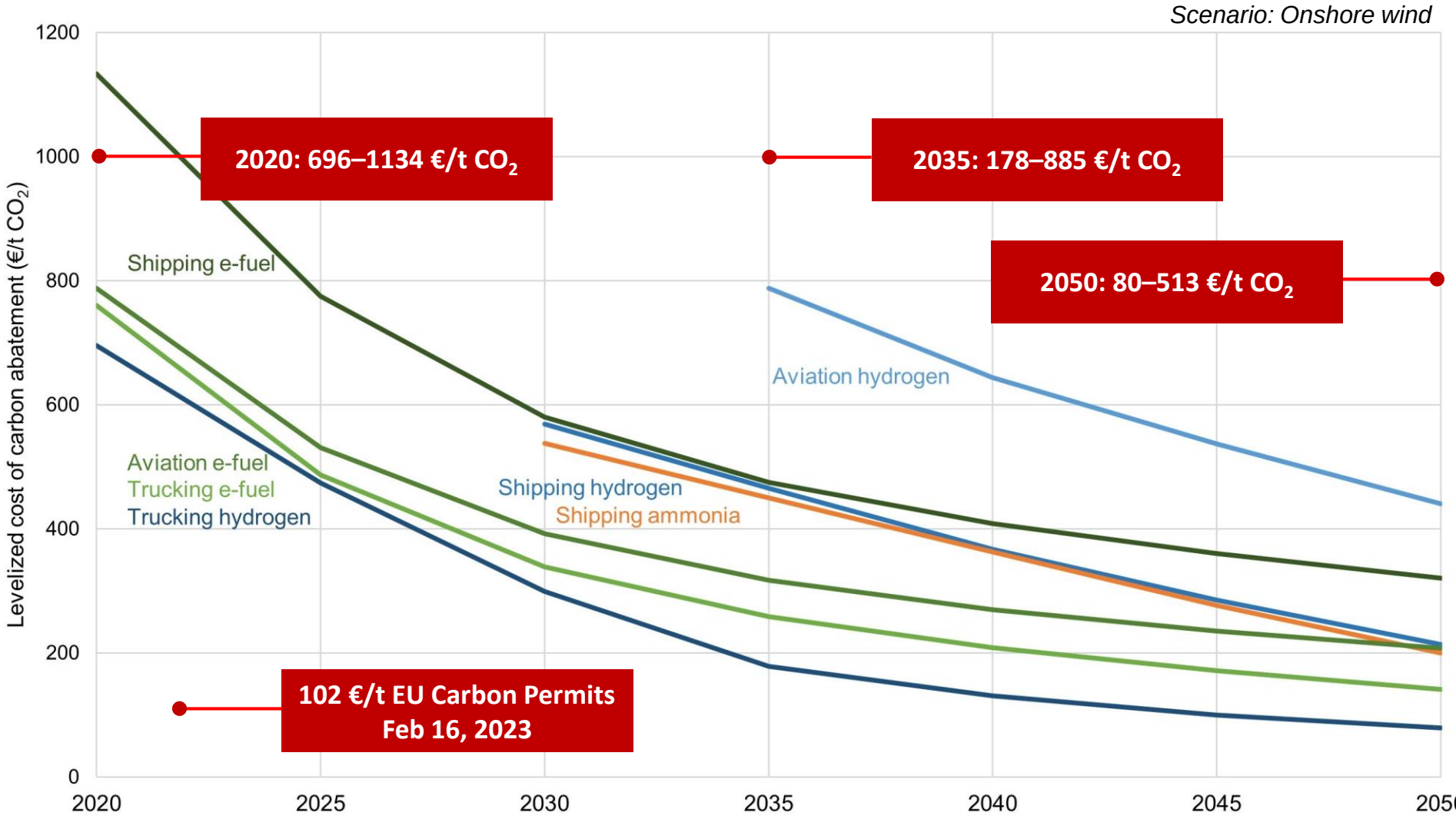
Carbon abatement costs

| For hydrogen fuels in hard-to-abate transport sectors



CO_2 abatement cost as an indicator



MIT CEEPR Working paper: *„Carbon abatement costs for hydrogen fuels in hard-to-abate transport sectors and potential climate policy mixes"*
J. Martin, E. Dimanchev, A. Neumann, 2022

Conclusion

1) Heavy transport is one of the „hard-to-abate“ sectors

2) Vehicle manufacture and operation depend on high-energy fuels

3) Vehicle load capacities significantly limit the fuel options

4) Economics of trucking, shipping, and aviation are affected by fuel substitution to varying degrees

5) Policy measures across value chains are necessary to incentivize adoption

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Thank you.

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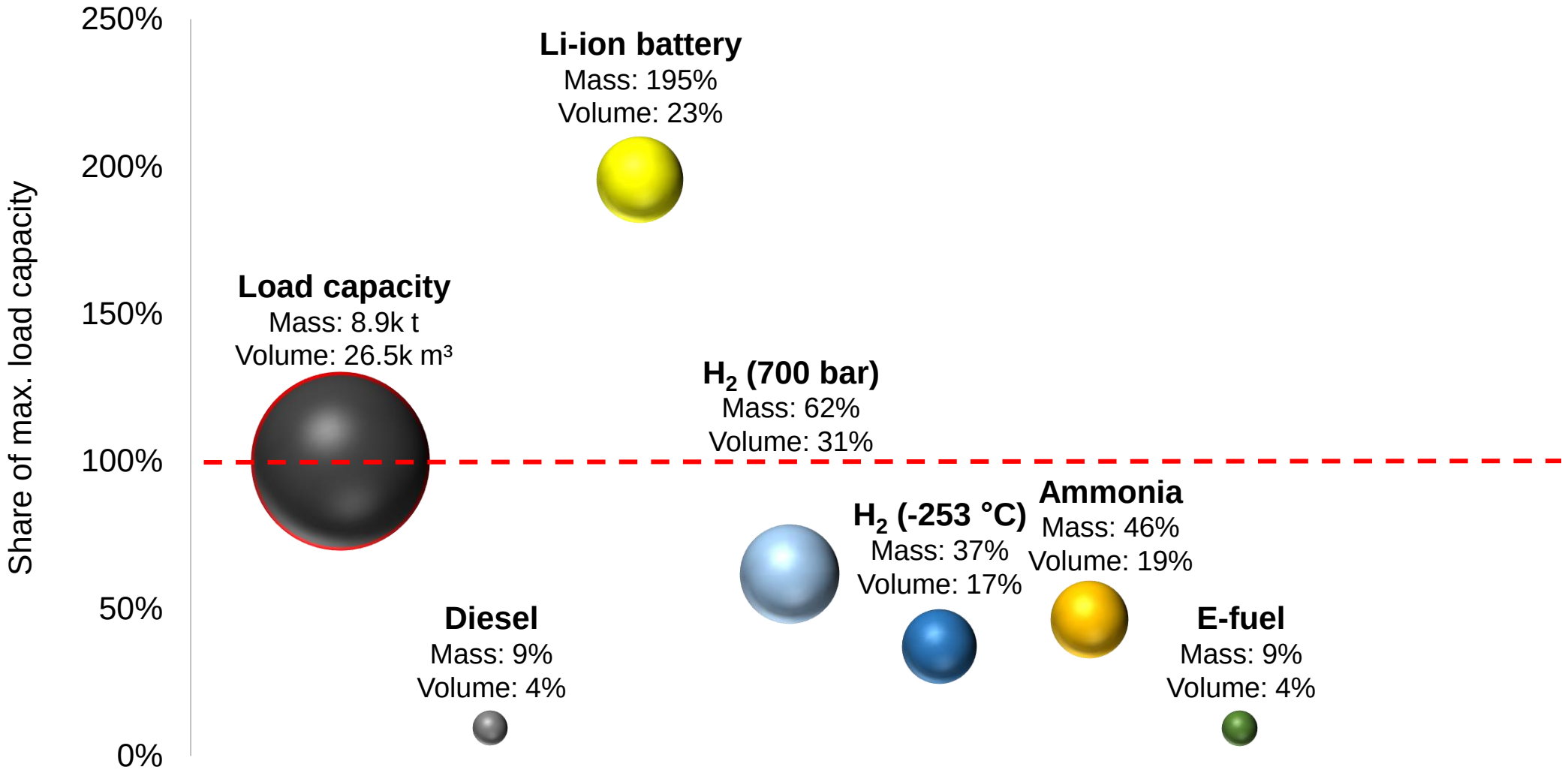
Fuel for a short-sea container feeder



Source: Gray et al. 2021: Decarbonising ships, planes and trucks, and own calculations

Energy efficiency

| Battery

| Hydrogen

| E-fuels

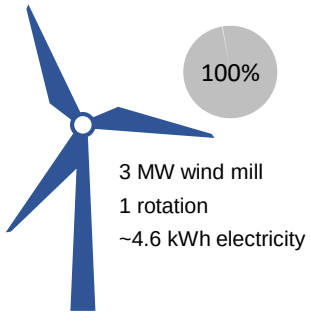
Sources:
https://www.zeit.de/zustimmung?url=https%3A%2F%2Fwww.zeit.de%2Fmobilitaet%2F2016-04%2Fmodel-3-tesla-vorbestellungen-elektroauto

Sources:
https://motor.at/news/hyundai-nexo-so-faehrt-sich-das-brennstoffzellen-auto/400068242

Sources:
https://www.auto-motor-und-sport.de/fahrbericht/vw-passat-20-tdi-4motion-erste-fahrt-mit-dem-240-ps-diesel/

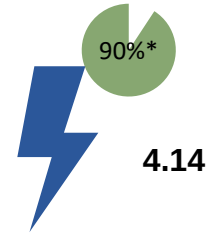
Direct electrification - most efficient by far

Power...

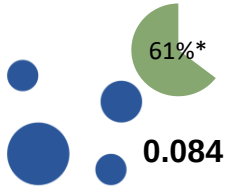


3 MW wind mill
1 rotation
~4.6 kWh electricity

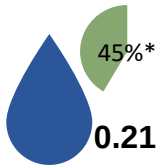
...to tank...



4.14 kWh



0.084 kg



0.21 l

...to wheel

4.14 kWh → 20.7 km
Tesla Model 3 Long Range[2]
~20 kWh/100 km
(Lithium-Ionen: 200 Wh/kg, 400 Wh/l[1])

0.084 kg → 7.0 km
Hyndai Nexo[3]
~1.2 kg/100km
(H_2 350 bar: 24 kg/m³, 33.33 kWh/kg)

0.21 l → 3.6 km
VW Passat TDI[4]
~5.8 l/100km
(Diesel: 11.8 kWh/kg, 9.8 kWh/l)

Energy efficiency in total

"Hydrogen [and synthetic electrofuels are] is not the future fossil oil, but the champagne of all energy carriers."

C. Kemfert, 2020

[1] Springerprofessional, 2021
[2] ADAC, 2021
[3] ADAC, 2019
[4] ADAC, 2020
*Reaming engery after conversion; Heinemann., 2019

Renewable fuel production

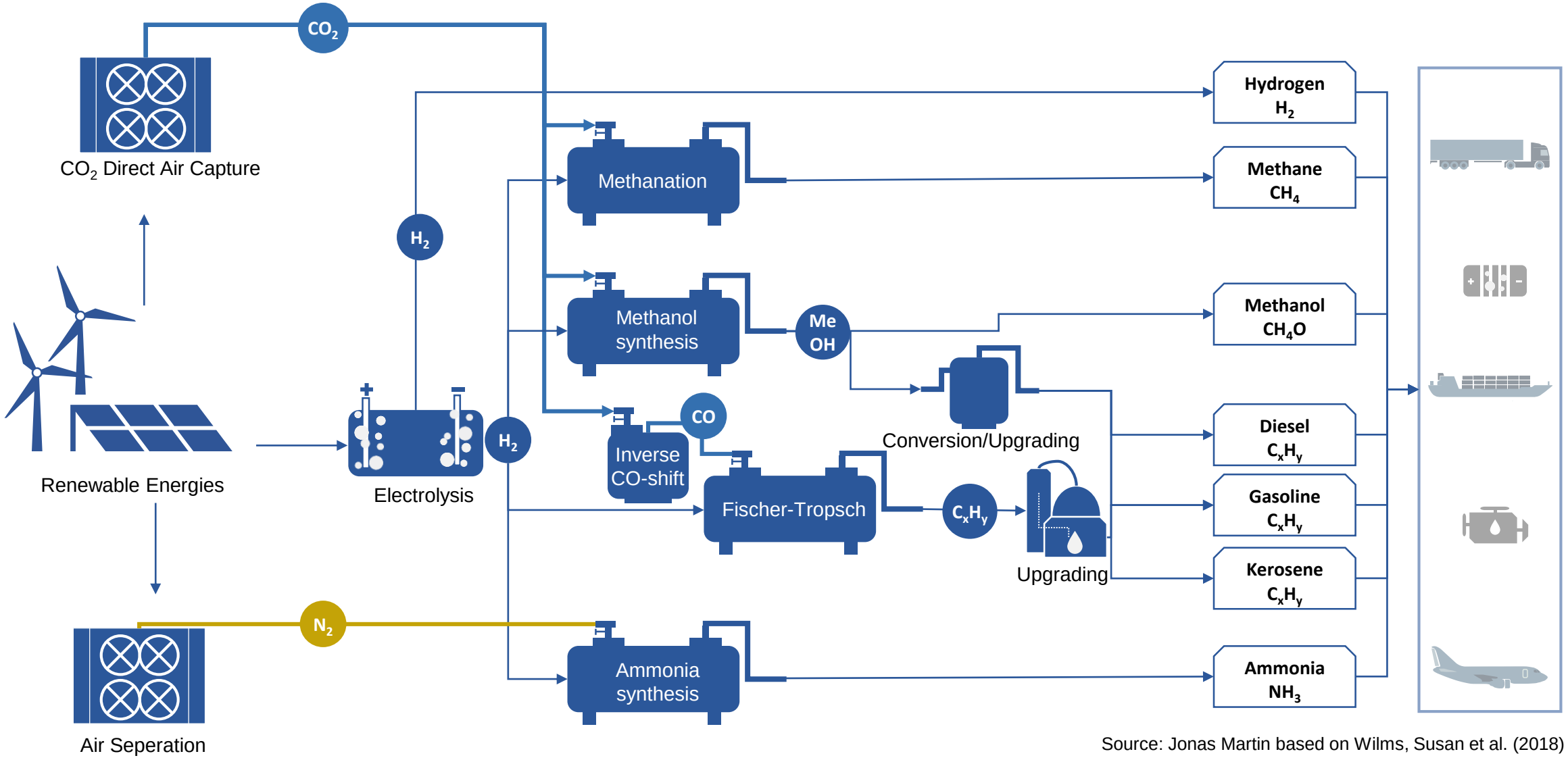
| Hydrogen

| E-fuels

| Ammonia

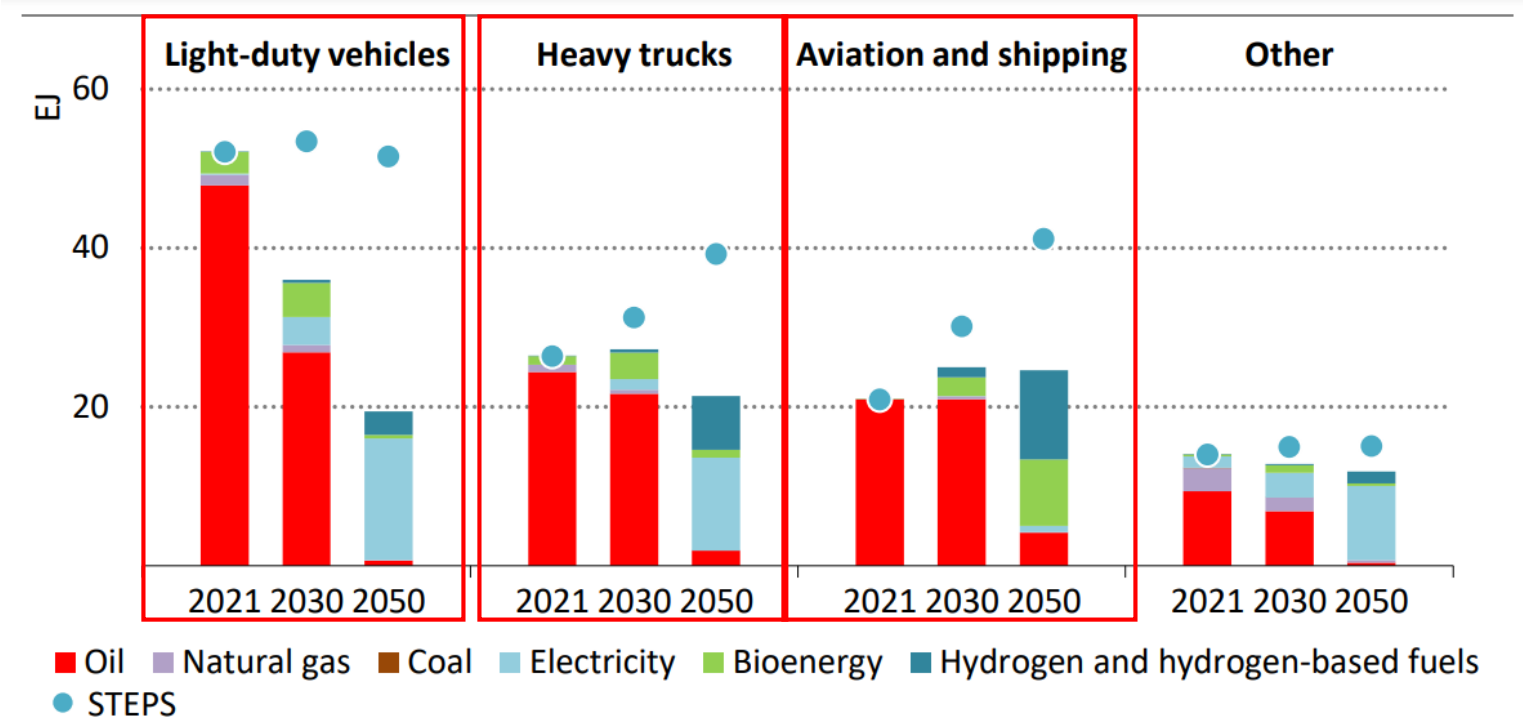
Sources:
https://thema.no/nyheter/forsterker-hydrogenportefolje-med-to-nye-initiativer/

Producing hydrogen and synthetic electrofuels



Source: Jonas Martin based on Wilms, Susan et al. (2018)

Oil dependency in heavy transport



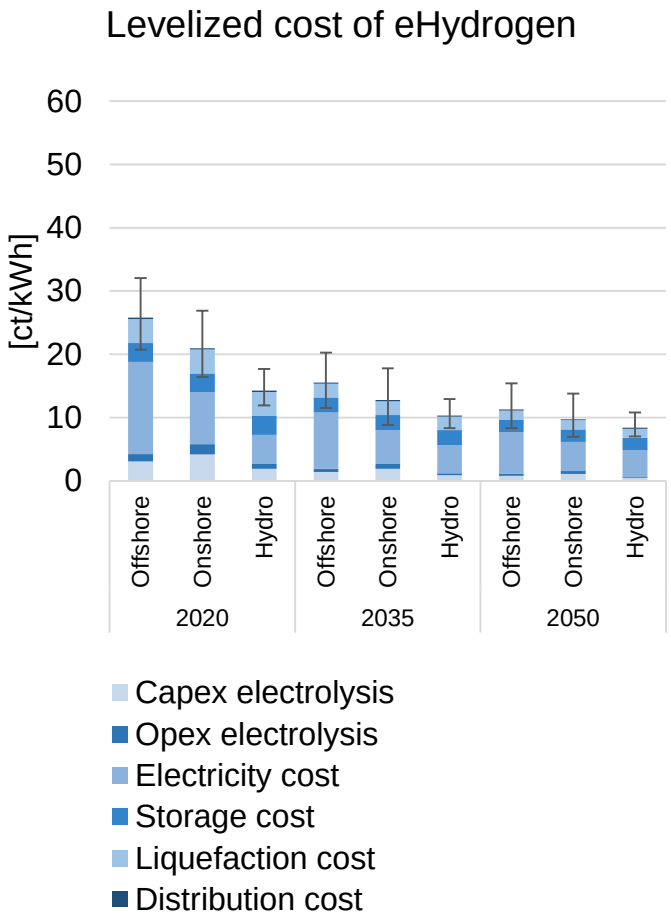
Direct electricity use is key to decarbonising road transport and rail; hydrogen and hydrogen-based fuels play a major role in aviation and shipping

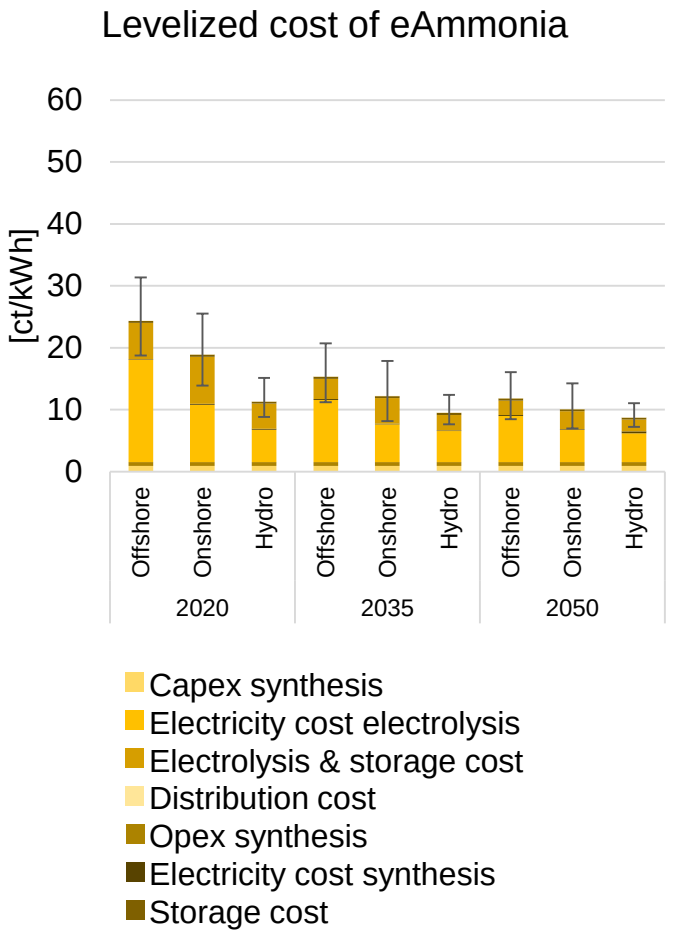
Transport companies:

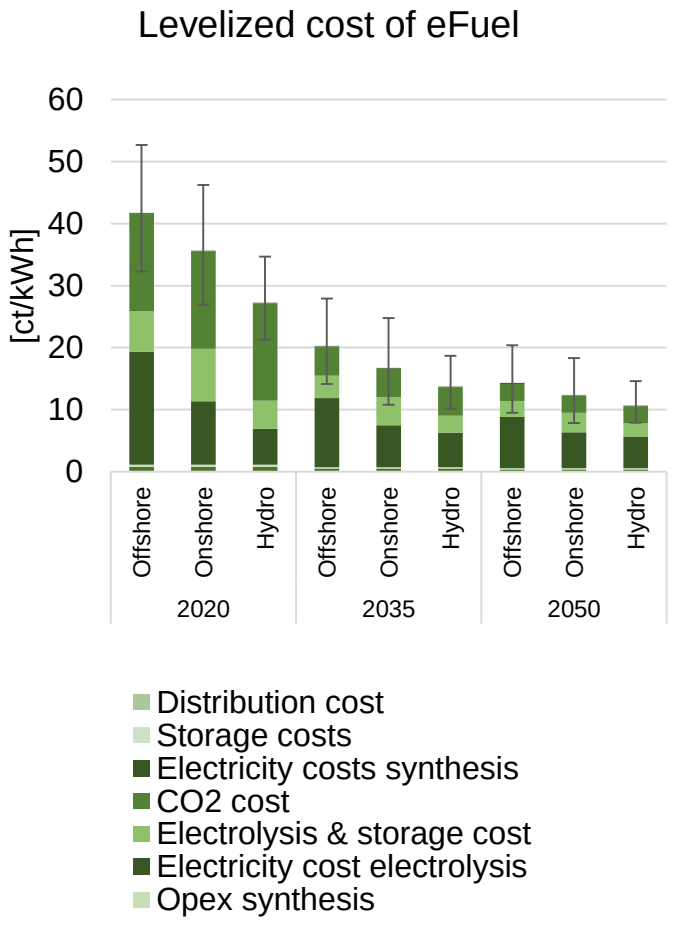
- High-cost pressure
- International competition
- Infrastructure dependencies
- Large and long-term investments
- Operating patterns optimized for energy-dense fuels

Source: World Energy Outlook 2022

Levelized cost of fuels







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