The Role of Hydrogen-based Technologies in Decarbonising Transport

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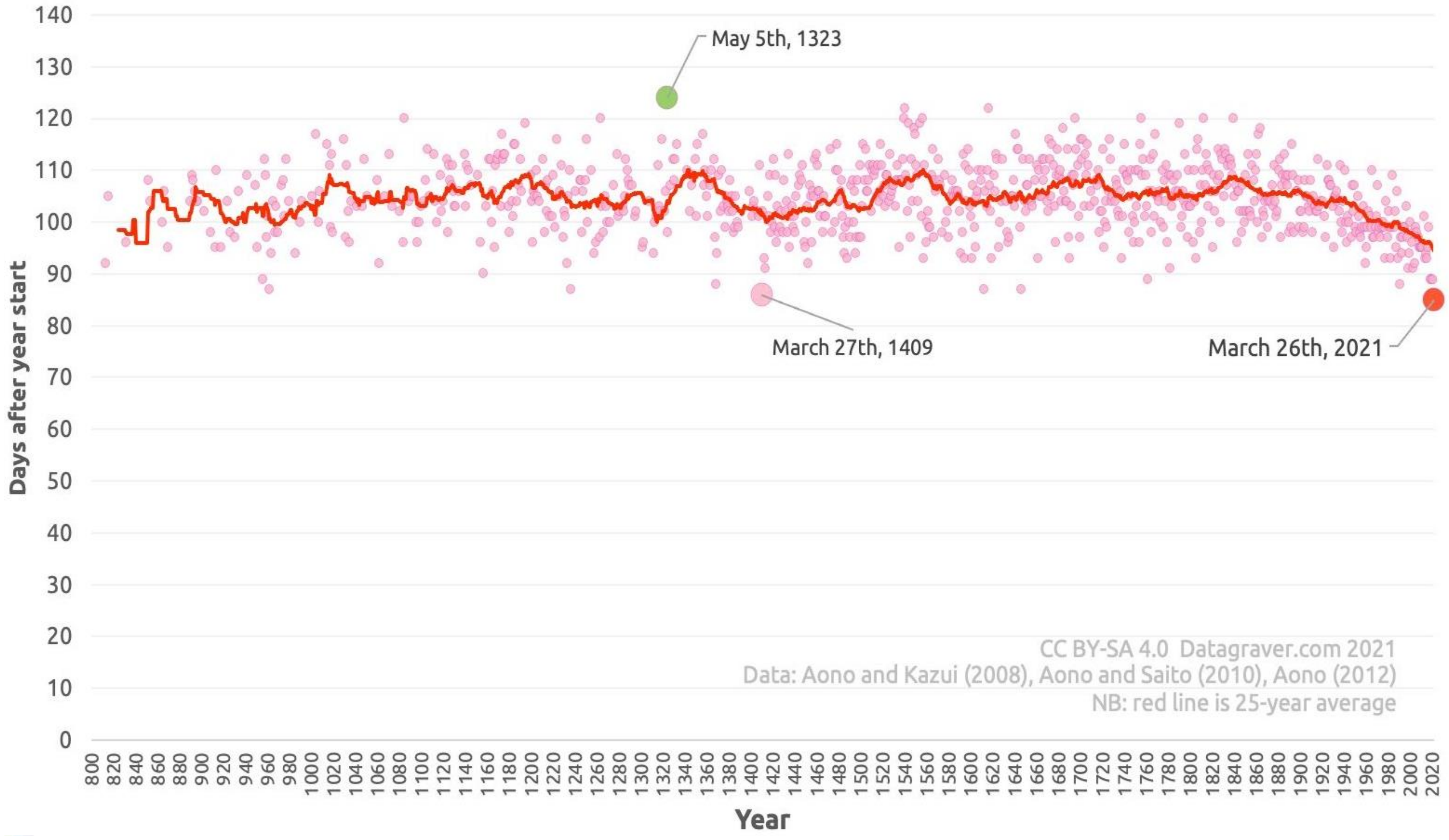
Johnson Matthey

Our climate is changing, driving the need to reduce GHG emissions

Full-flowering cherry blossom day, Kyoto



JM plays widely across the hydrogen economy

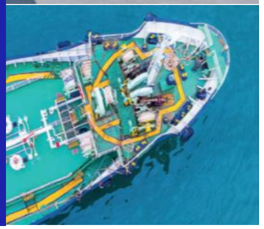
JM technologies enable the production of sustainable fuels for aviation, marine & road transport, the storage & transportation of renewable energy, and fuel cell propulsion systems

Clean hydrogen production technology

- Components for electrolytic (green) hydrogen production
- CCS-enabled (blue) hydrogen technology

Sustainable fuels & chemicals

- **Sustainable aviation fuel**
- Sustainable **methanol and ammonia** to decarbonise shipping
- Sustainable **gasoline and diesel**
- Sustainable **chemicals**



Storing and transporting renewable energy

- Sustainable **methanol and ammonia** to move renewable energy/H_2
- Catalysts to make methanol/ammonia and **release the H_2 when needed**

Fuel cells

- **PEM fuel cells** to power eg
  - Trucks and buses
  - Cars and vans
  - Non road mobile machinery
  - Planes

Passenger Cars

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BEVs will dominate the LDV sector in future, but access to critical raw materials may constrain growth significantly

Lithium supply constraint could reduce EV sales penetration by a third from base case by 2035

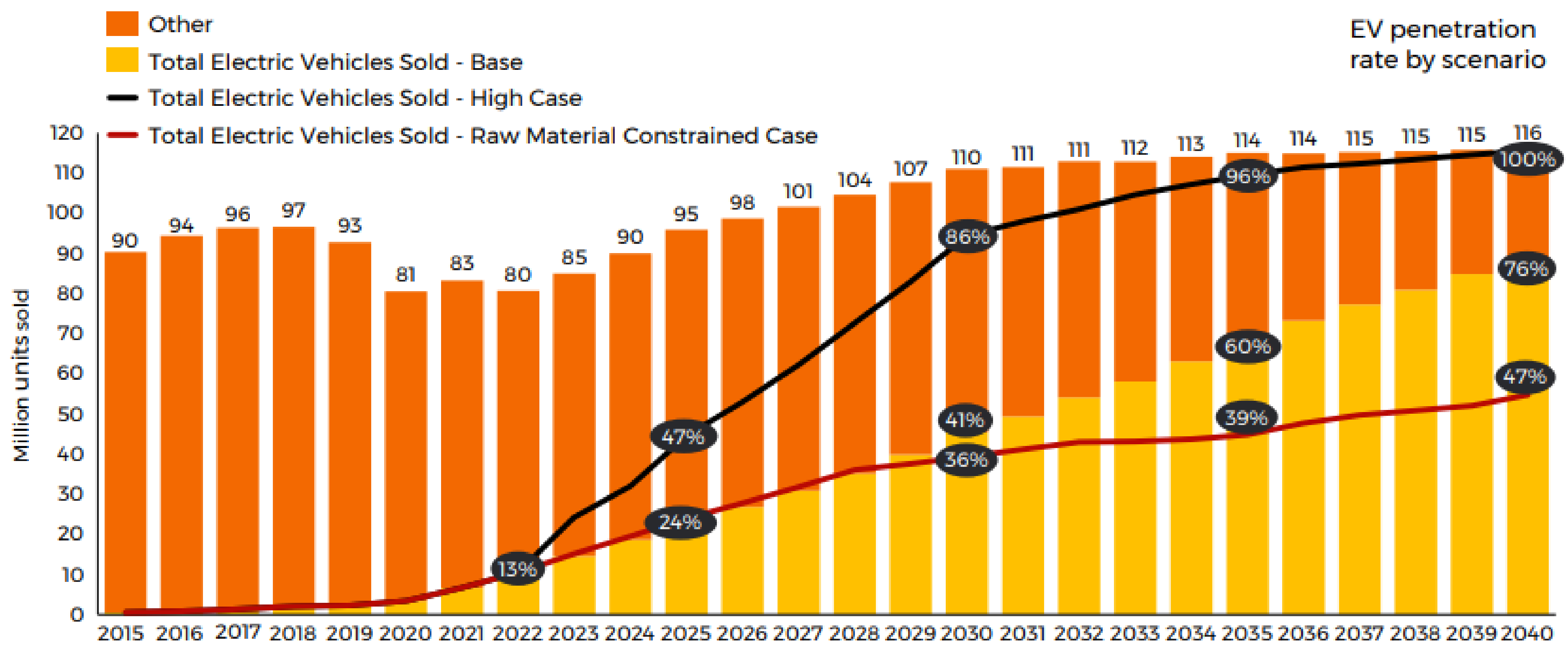
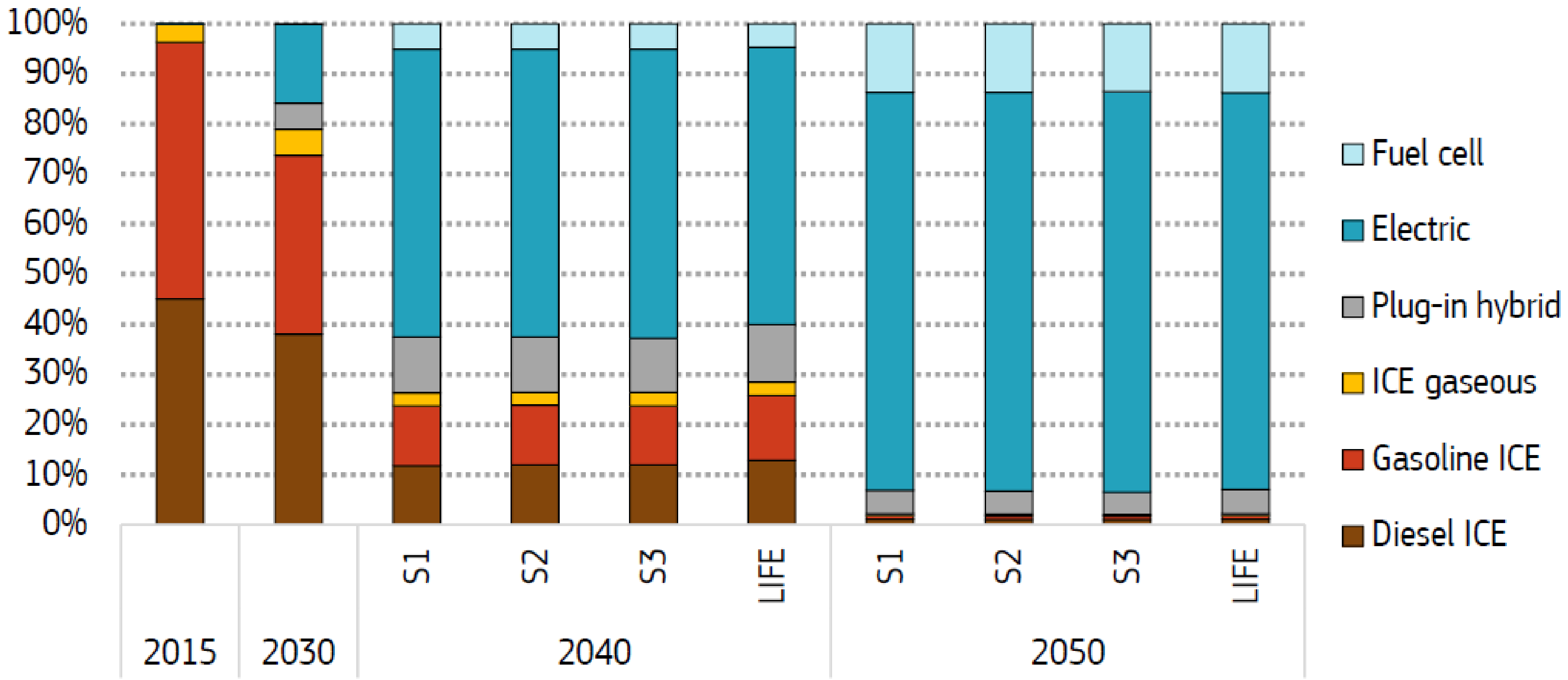


Chart source: Benchmark Minerals, Q1 2023. Auto sales forecast source Rho Motion Q1 2023

European Commission see a small but very significant role for FCEVs in the car market

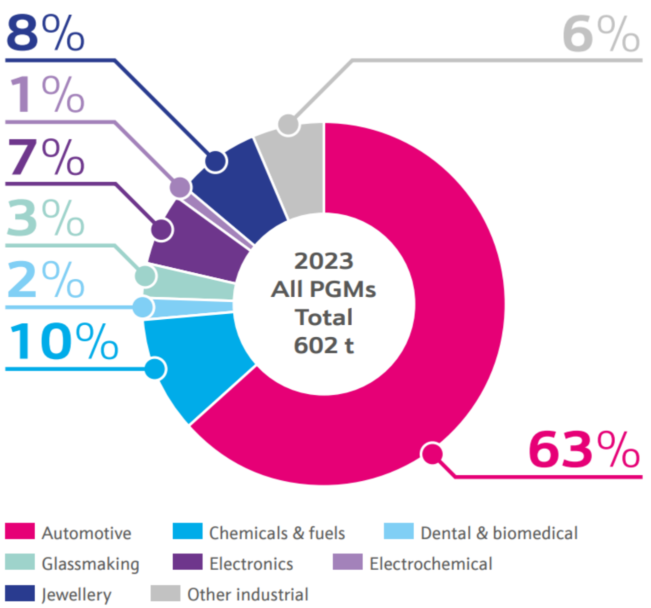
Figure 67: Distribution of the EU passenger car stock per type of drivetrain

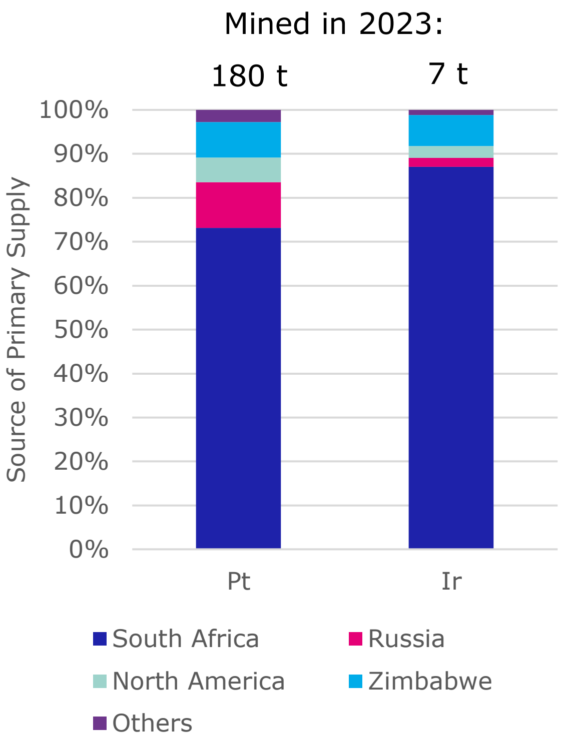


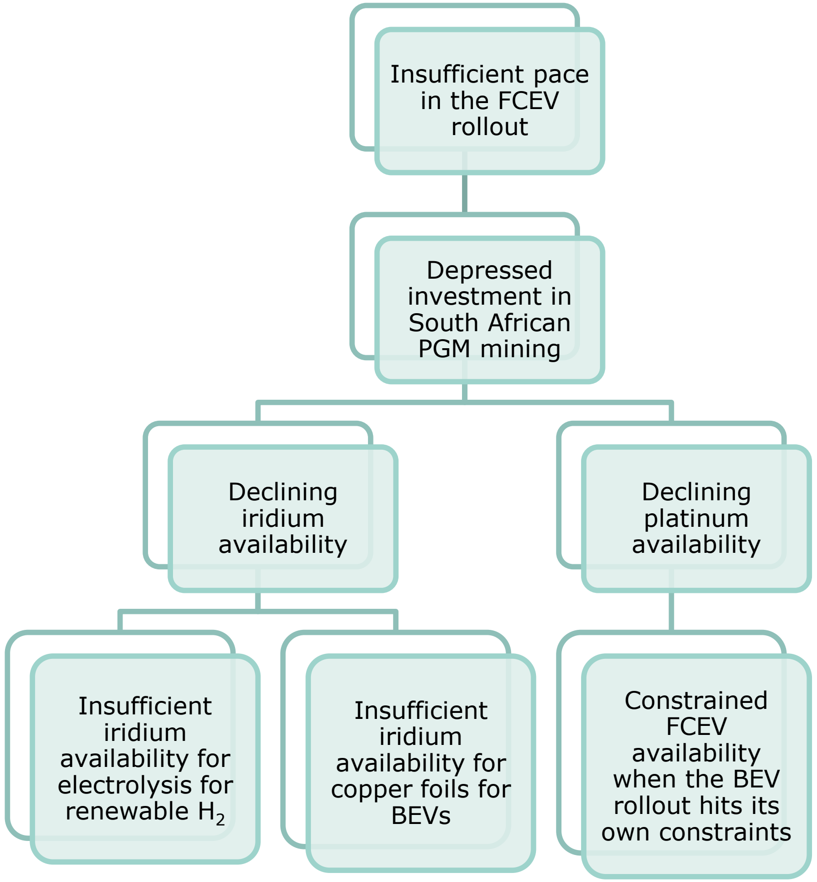
Source: European Commission, “Securing our future Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society”, Feb 2024

The crucial link between iridium and platinum in the energy transition

Net demand for all five PGMs by application







The largest market for PGMs today is catalytic converters for ICE vehicles, which use platinum, palladium, and rhodium. The future decline in this market is already being priced into these PGMs. We need to see FCEVs coming in as a replacement market to support continued investment in PGM supply and recycling

The vast majority of iridium is obtained as a minor by-product of South African PGM mining, and platinum is the primary product of that mining, while its co-products palladium and rhodium have supported mining profitability over the last decade. Iridium only occurs in trace quantities in the ore and will never be mined in its own right

Inadequate support for FCEVs and the slow pace of the rollout today will hamper the energy transition tomorrow

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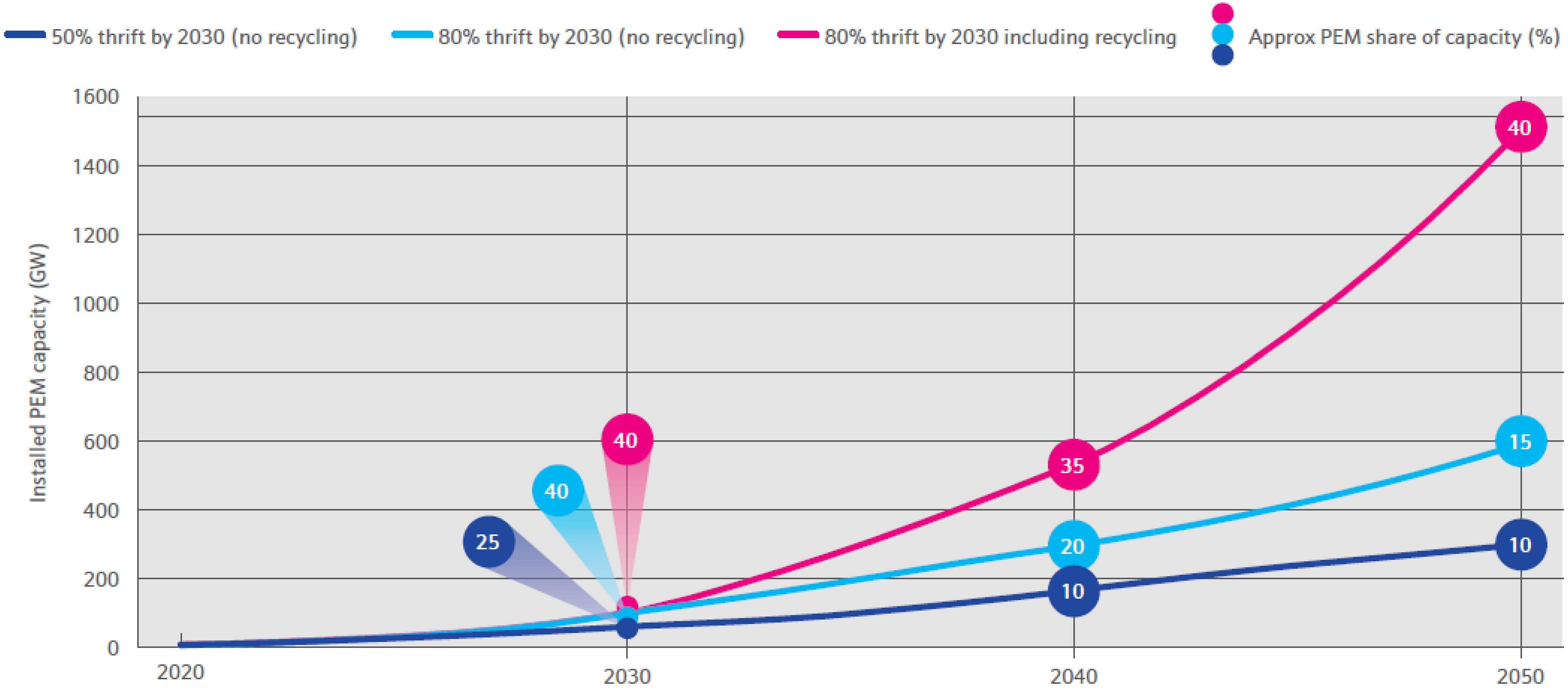
Will there be enough Iridium to meet potential PEM electrolyser demand?

Impact of thrifting and recycling on PEM capacity, based on 1.5 tonnes pa iridium supply



Analysis indicates that even in an aggressive net zero (1.5°C) scenario, there will be enough iridium for PEM electrolysers to take a 40% share, using reasonable recycling and thrifting assumptions

Source: Hydrogen Council, JM analysis

Trucks and Buses

There is no silver bullet to decarbonise commercial vehicles

LCV
Buses/coaches
MDV
Some HDV

Battery Electric
- Very efficient use of renewable energy (RE)
- Zero emission at tailpipe
- BEVs being introduced
- TCO competitive with diesel for some MDVs
- Limited range and slowest refuelling
- Heavy batteries may limit payload
- Resource competition from LDV
- Critical raw material concerns (Li, Cu etc)
- Lack of charging infrastructure

LCV
Buses/coaches
Long haul HDV

H_2 Fuel Cell
- Efficient/very efficient use of RE
- Zero emission at tailpipe
- FCEVs being introduced
- Relatively long range and rapid refuelling
- Some components currently expensive
- Packaging H_2 on vehicle
- Requires very high purity hydrogen
- Lack of refuelling infrastructure

Some HDV
(eg India)
NRMM

H_2 ICE
- Builds on existing ICE supply chains
- Can use less pure H_2 than FCEV
- Intermediate range and rapid refuelling
- Packaging H_2 on vehicle
- Less efficient use of RE
- Not zero emission at tailpipe
- Lack of refuelling infrastructure

??All??
NRMM?

E-fuel ICE
- Uses existing ICE supply chains
- Uses current refuelling infrastructure
- Long range and rapid refuelling
- Least efficient use of RE
- Relies on DAC CO_2 as feedstock
- Not zero emission at tailpipe
- High cost of fuel/high TCO
- Fuel competition from other sectors (eg SAF)

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Range of options, so technology neutral regulations should be adopted

Alternative Fuel Infrastructure Regulation: HRS implications

	HRS in Urban nodes TEN-T	HRS on TEN-T Core Network every 200km	Total	Number of petrol stations
Austria	9	5	14	2,733
Belgium	11	4	15	3,085
Bulgaria	7	8	15	4,600
Croatia	5	6	11	N/A
Cyprus	3	1	4	315
Czechia	7	5	12	4,008
Denmark	6	4	10	2,051
Estonia	2	2	4	495
Finland	7	5	12	1,869
France	42	26	68	11,160
Germany	77	32	109	14,459
Greece	17	9	26	6,100
Hungary	9	5	14	2,014
Ireland	3	2	5	1,850
Italy	49	21	70	21,750
Latvia	1	4	5	612
Lithuania	5	3	8	718
Luxembourg	1	1	2	238
Malta	1	1	2	69
Netherlands	24	3	27	4,142
Poland	30	19	49	7,739
Portugal	13	5	18	3,418
Romania	22	12	34	1,615
Slovakia	4	4	8	973
Slovenia	2	2	4	N/A
Spain	49	29	78	11,650
Sweden	18	15	33	2,701
TOTAL	**424**	**233**	**657**	**110 364**

Mandates one gaseous hydrogen refuelling station (HRS) every 200 km on TEN-T core network by end of 2030, as well as one HRS in every urban node (TEN-T core covers 88% of EU long-haul freight activity)

Stations will have a daily supply capacity of at least one ton of hydrogen for all modes of road transport

Member States must prepare an HRS deployment plan by 2027 that will satisfy the needs of hydrogen powered road mobility

Around 660 Hydrogen Refuelling Stations expected across the EU by the end of 2030

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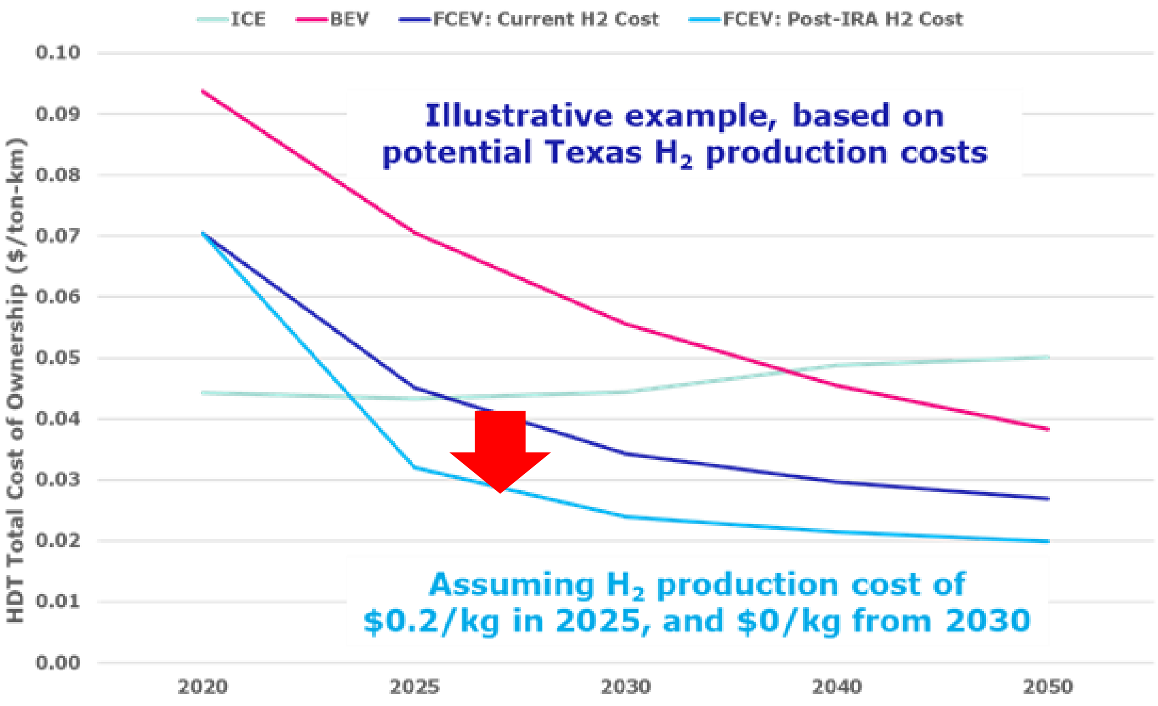
TCO analyses are fraught with difficulty until industries and technologies are operating at scale, and can be strongly impacted by policy and subsidy decisions

Inflation Reduction Act

$13bn for Clean H_2 Production Tax Credits

Production technology	Estimated H_2 cost 2025 ($/kg)	Estimated H_2 cost 2030 ($/kg)
Renewable electrolytic	0.2	-0.17
CCS-enabled	1.12	1.23
Conventional	0.96	1.11

Renewable electrolytic (green) H_2 will have VERY LOW production cost

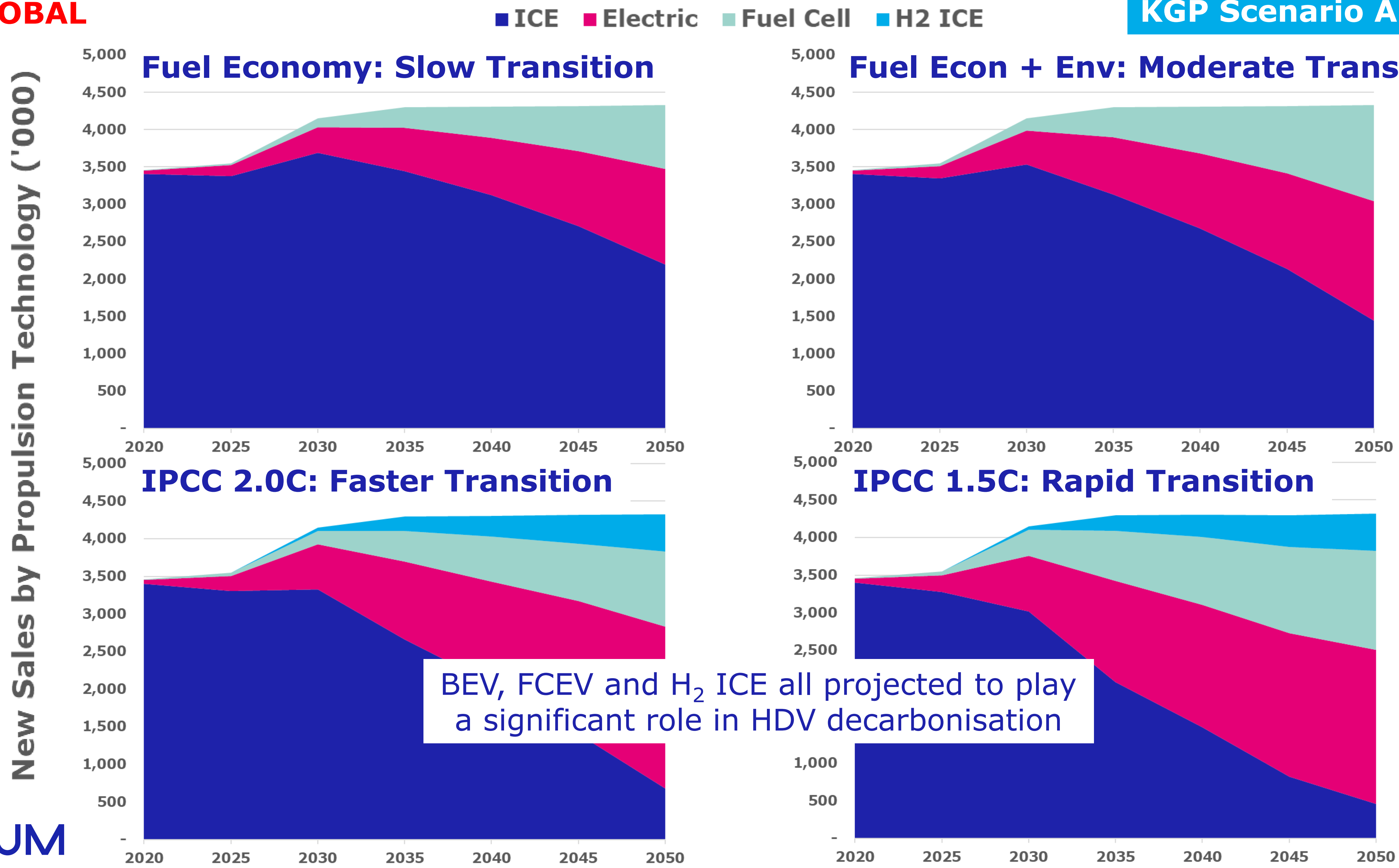


VERY favourable TCO of US FC Heavy Duty Trucks

JM Source: JM analysis

GLOBAL

KGP Scenario Analysis



BEV, FCEV and H_2 ICE all projected to play a significant role in HDV decarbonisation

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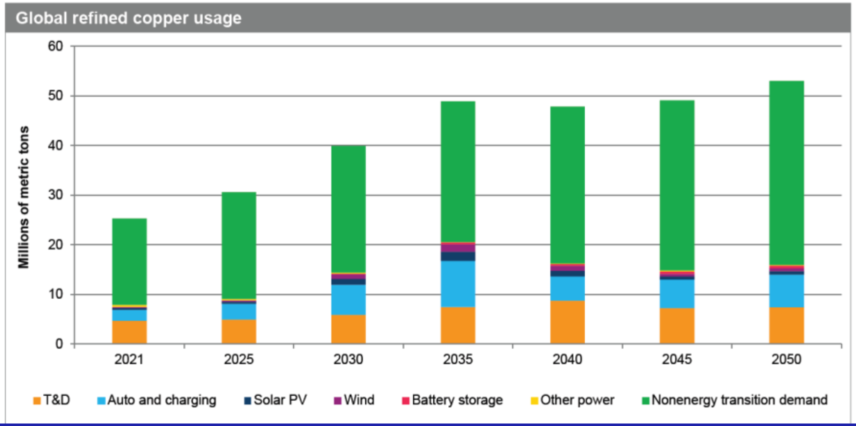
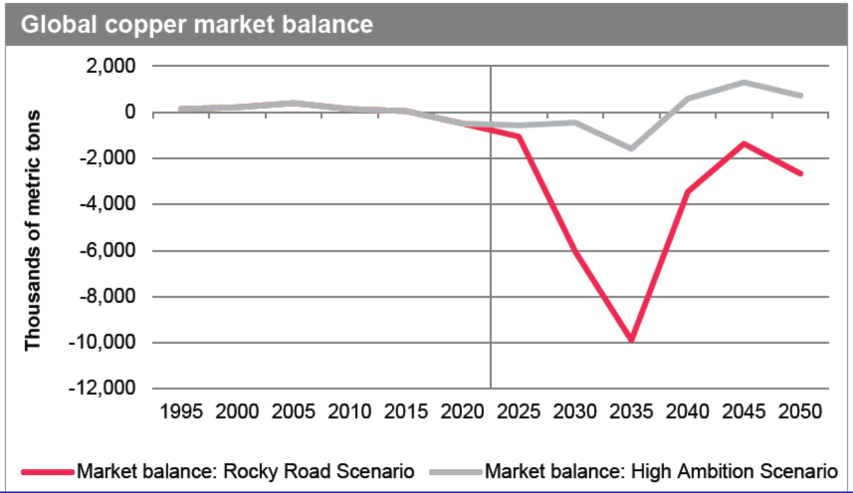
Critical material considerations will increase significantly going forward

Let's look at copper supply/demand….

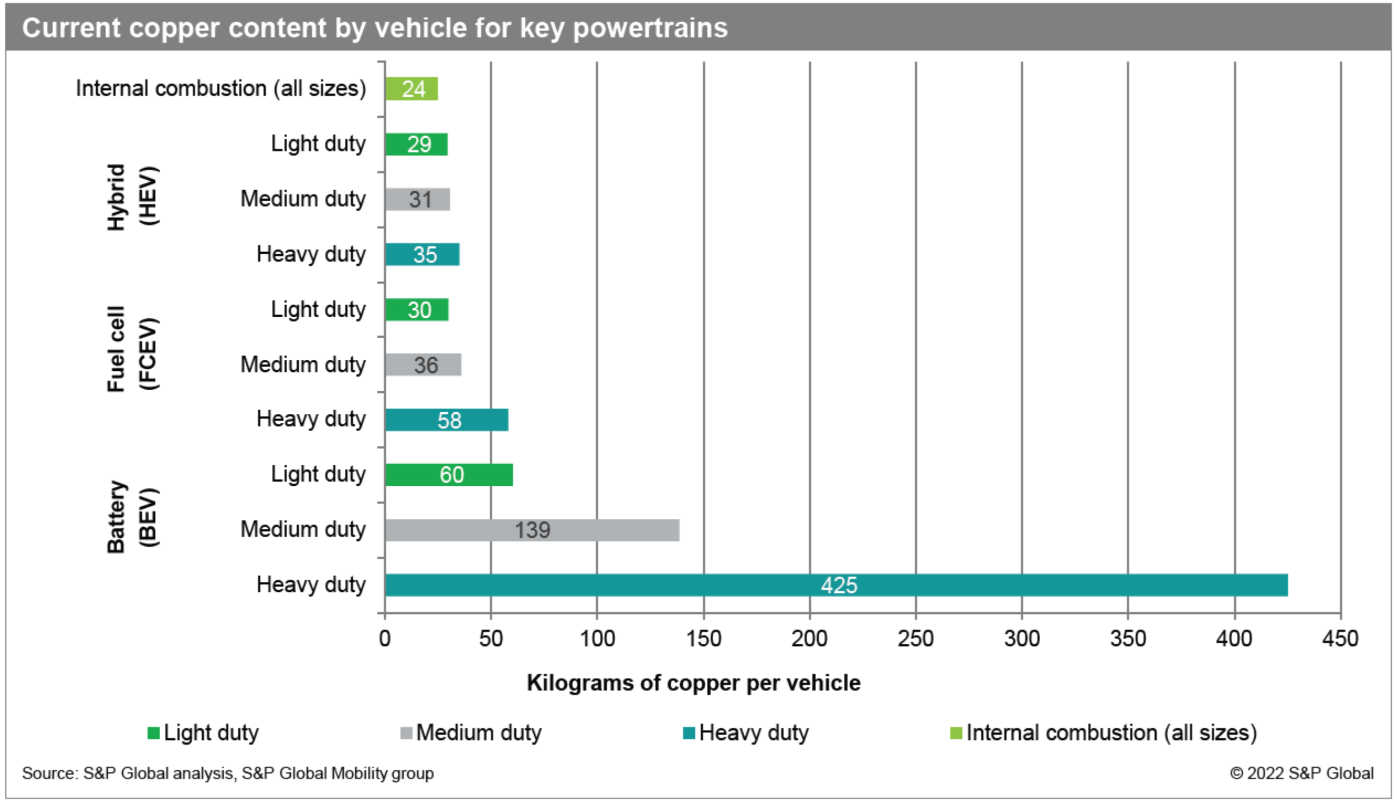


Cu demand doubles between today and 2035



Leading to potential major supply shortfalls

Cu use in HDVs: BEV >> FCEV > HEV >ICE



Strategic/critical materials availability may influence aspects of the clean energy transition, and of decarbonisation choices in HDVs

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Source: S&P Global, "The Future of Copper: Will the looming supply gap short-circuit the energy transition?", July 2022

Marine

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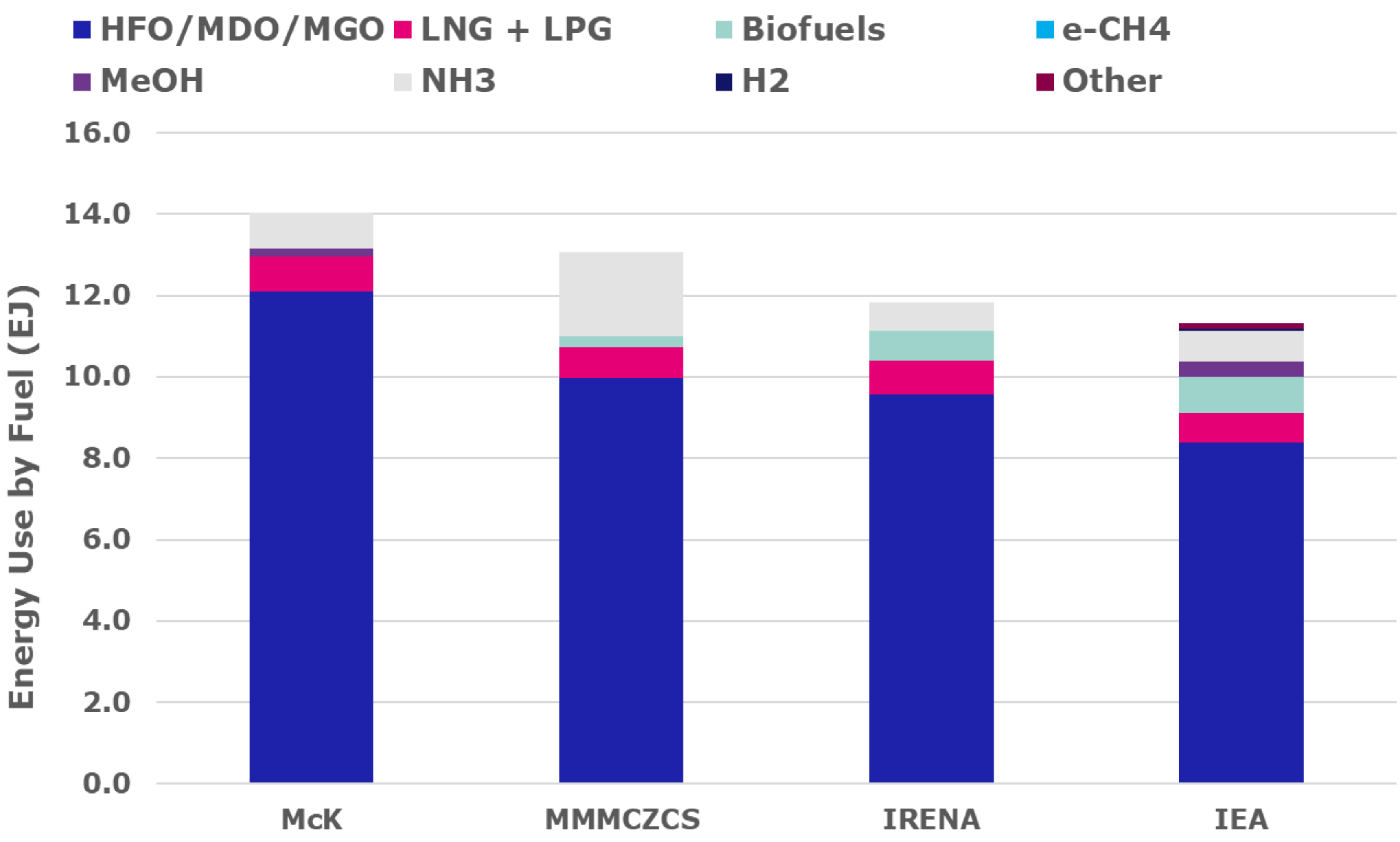
Overview of Net Zero Marine scenarios: 2030

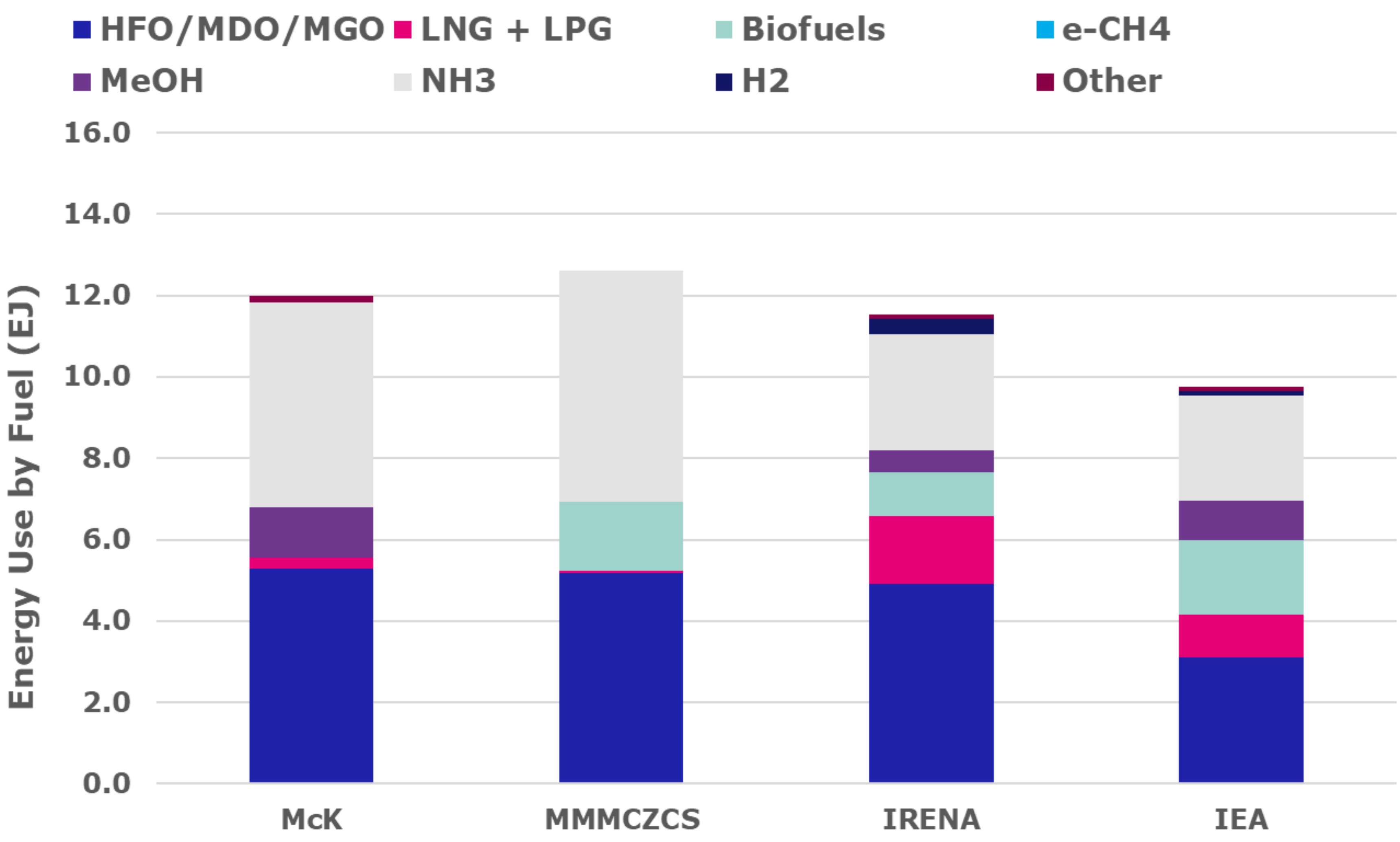


Comments

- IEA lowest overall energy requirement
- LNG increases its role as a transitional fuel, with lower carbon intensity than HFO
- Ammonia, biofuels and clean methanol start to appear in the scenarios
- MMMCZCS ammonia amount would require around 20mtpa hydrogen

Note that IRENA's HFO/LNG ratio used for IEA

Overview of Net Zero Marine scenarios: 2040

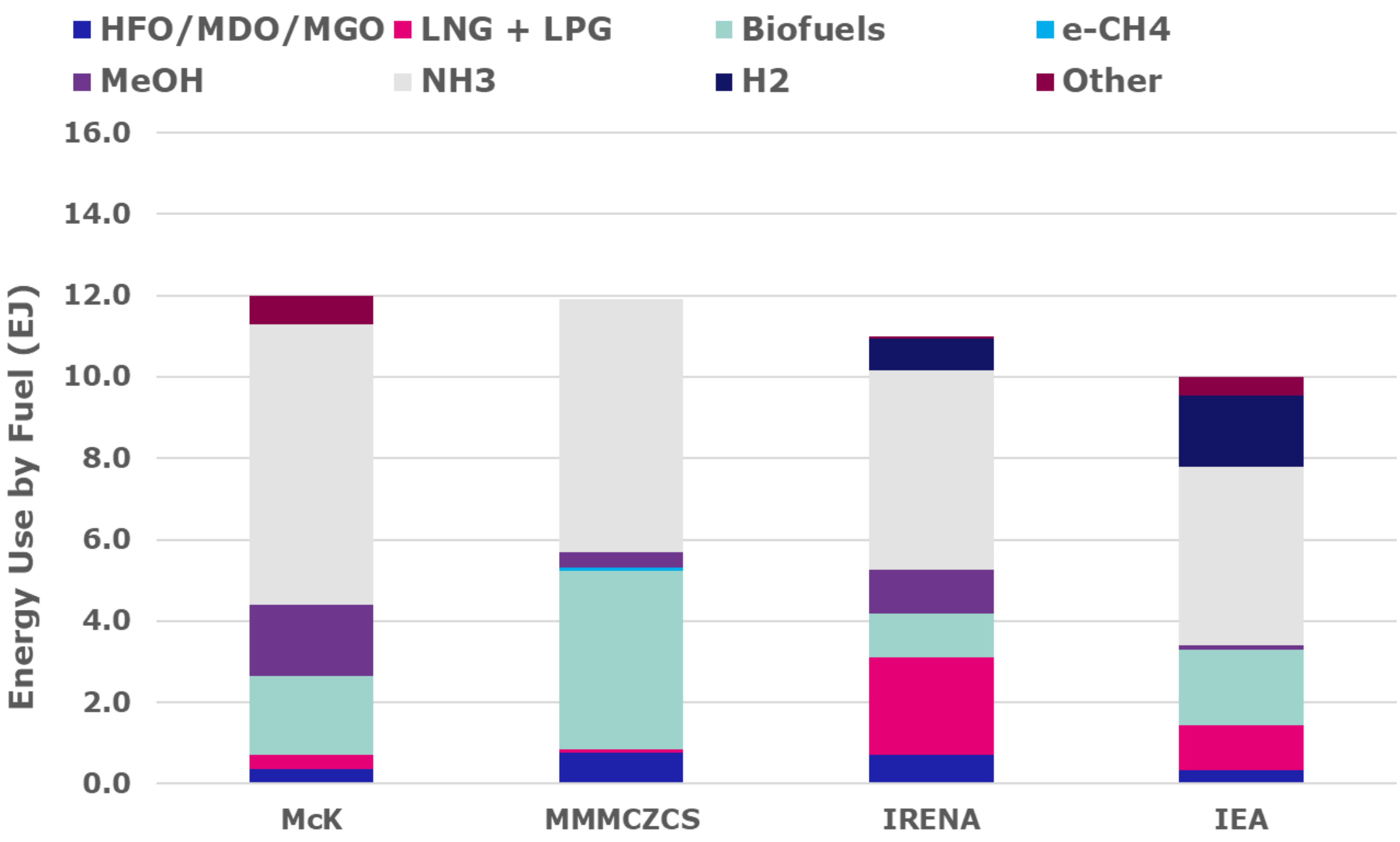


Comments

- Efficiency improvements lead to lower marine energy use
- Big reduction in use of HFO/MDO/MGO between 2030 and 2040
- Ammonia, methanol, biofuels and LNG/LPG, lead the decarbonisation drive
- Up to 55 mtpa clean hydrogen required to make clean ammonia

Note that IRENA's HFO/LNG ratio used for IEA

Overview of Net Zero Marine scenarios: 2050

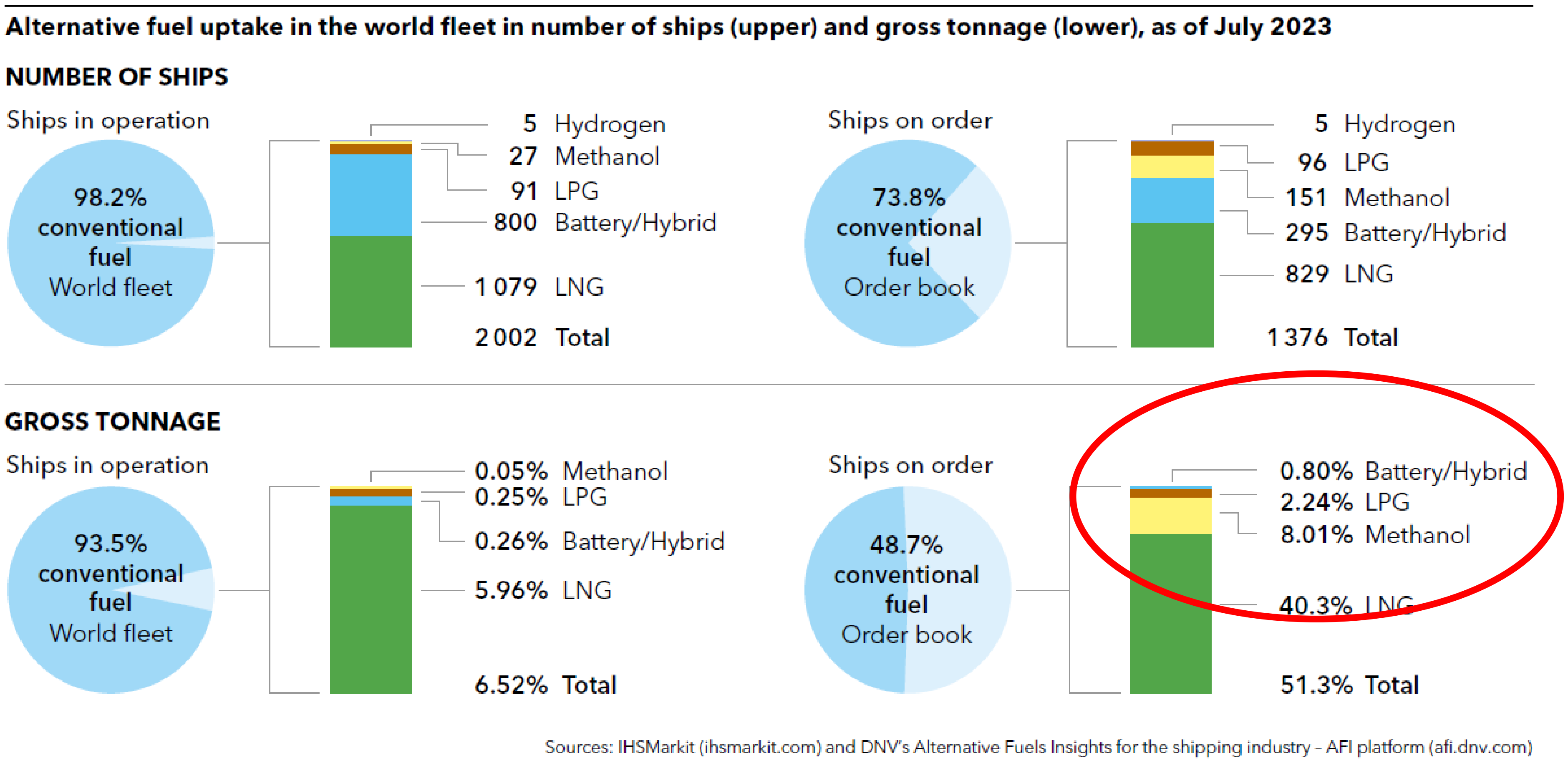


Comments

- Total energy use is broadly similar to 2040
- Clean ammonia is projected to become the main fuel in all scenarios
- Clean methanol and biofuels also play a significant role
- IEA and IRENA both see significant clean hydrogen use
- Up to 65 mtpa clean hydrogen needed to make clean ammonia

JM Note that IRENA's HFO/LNG ratio used for IEA

Alternative fuel uptake in the world fleet: Methanol ahead of Ammonia today



Methanol is developing first mover advantage, and ammonia has to deal with toxicity and potentially N_2O emission challenges, so the winner is not clear today….and methanol also contains hydrogen!

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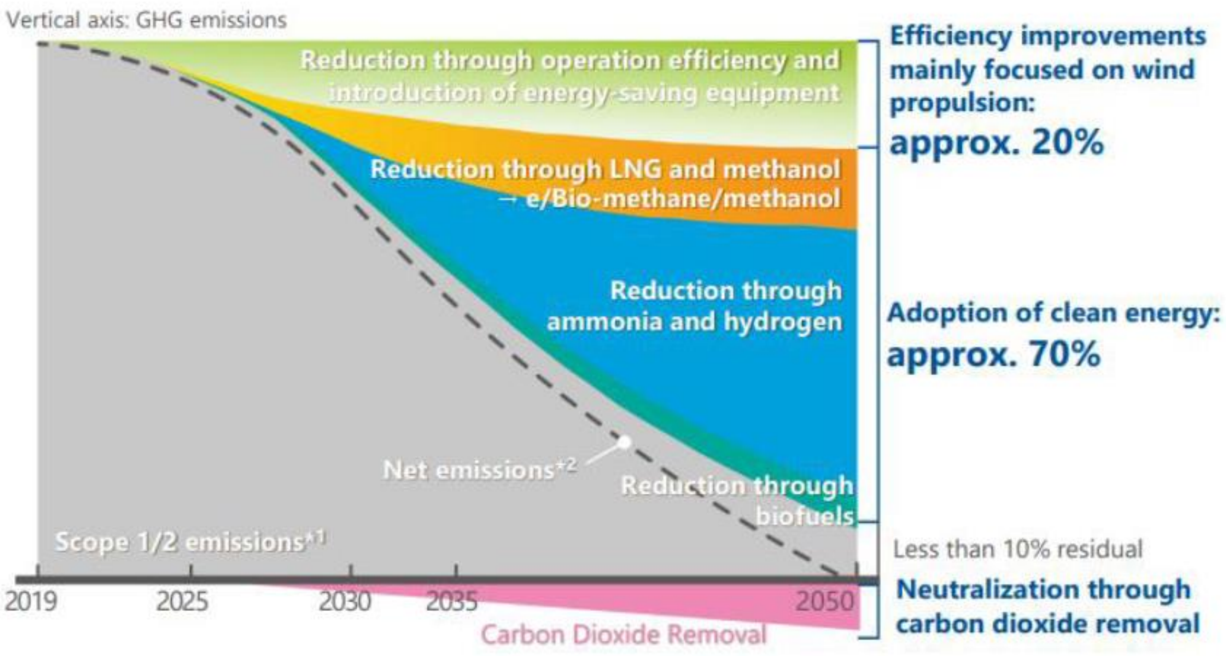
Source: DNV Energy Transition Outlook 2023; Maritime Forecast to 2050

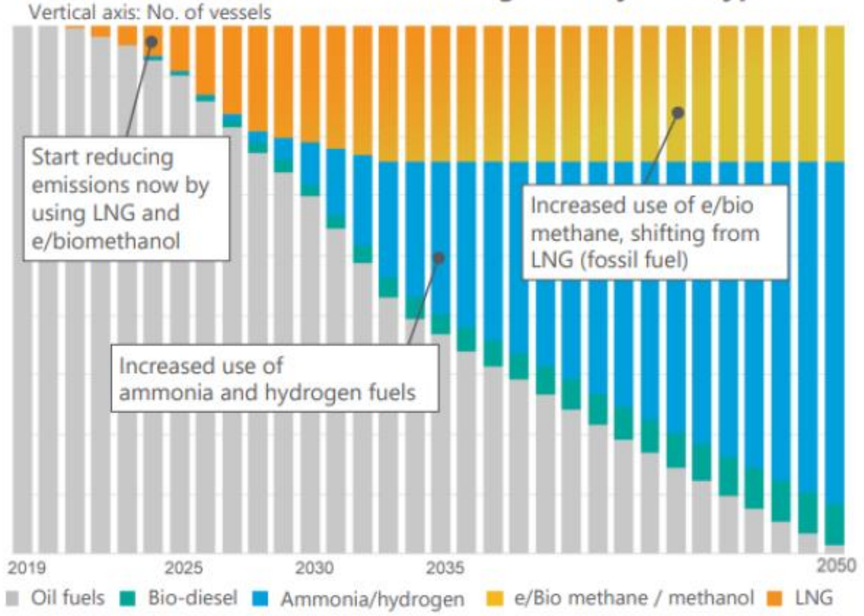
Mitsui have a nuanced view, with ammonia the main fuel but with e/bio methane/methanol making a significant contribution

4 MOL Group Pathway to Net Zero

- Proactive Industry leader in actively decarbonizing group operations with a clear pathway to net zero emissions.
- Quantative KPIs in relation to alternative fuel-powered vessels: 2030 LNG/Methanol fueled vessels = 90, 2035 Net Zero Vessels = 130.
- Phasing out of heavy oil a shifting to alternative marine fuels including Ammonia, Hydrogen and battery through development at present day.



Composition of MOL's Ocean-Going Fleet by Fuel Type



Source: https://www.mol-service.com/en/clean_energy

Aviation

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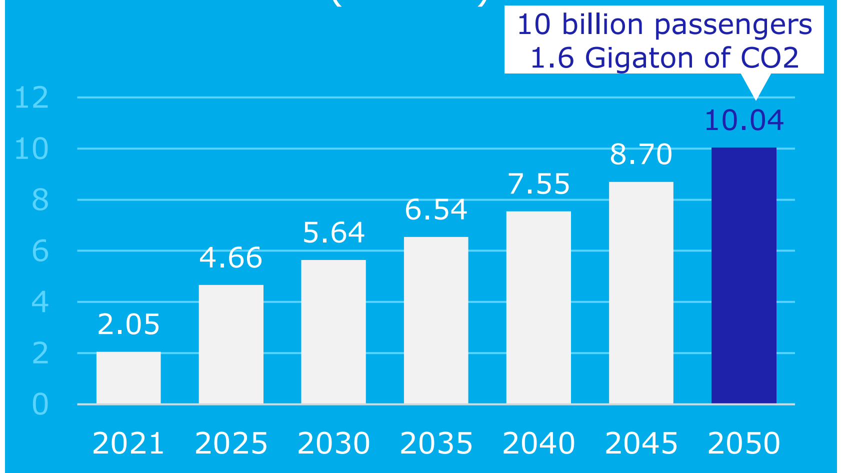
IATA member airlines have pledged net zero by 2050

Sustainable Aviation Fuel (SAF) seen as the major enabler of this target, with some direct hydrogen use in gas turbines and fuel cells

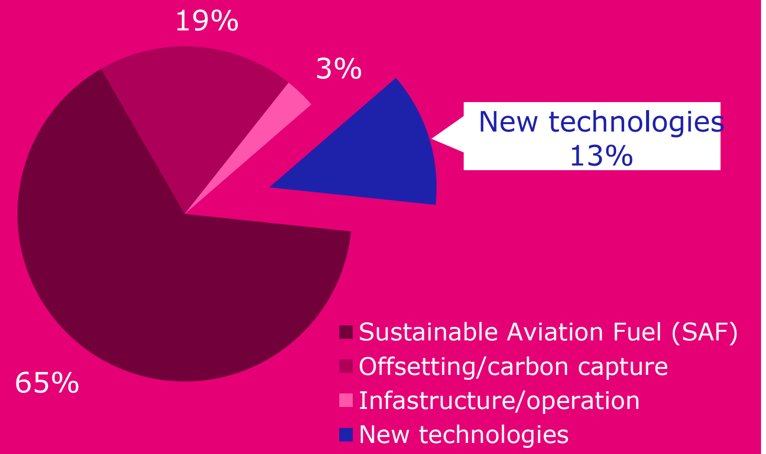
The Challenge: Forecasted increase of air transport passenger traffic

Passengers
(billions)



The plan: Contribution to achieving Net Zero Carbon in 2050

Scenario contribution to net zero



13% contribution from **new aircraft technology**

New aircraft technology

	By 2025	By 2030	By 2035
Engine	Electric	Electric or Hydrogen	Hydrogen
Seats	9 to 19	50 to 100	100 to 150
Flight time	< 60′	Up to 90′	Up to 120′

Regional and short-haul services in 2030s and 2040s

Source: IATA

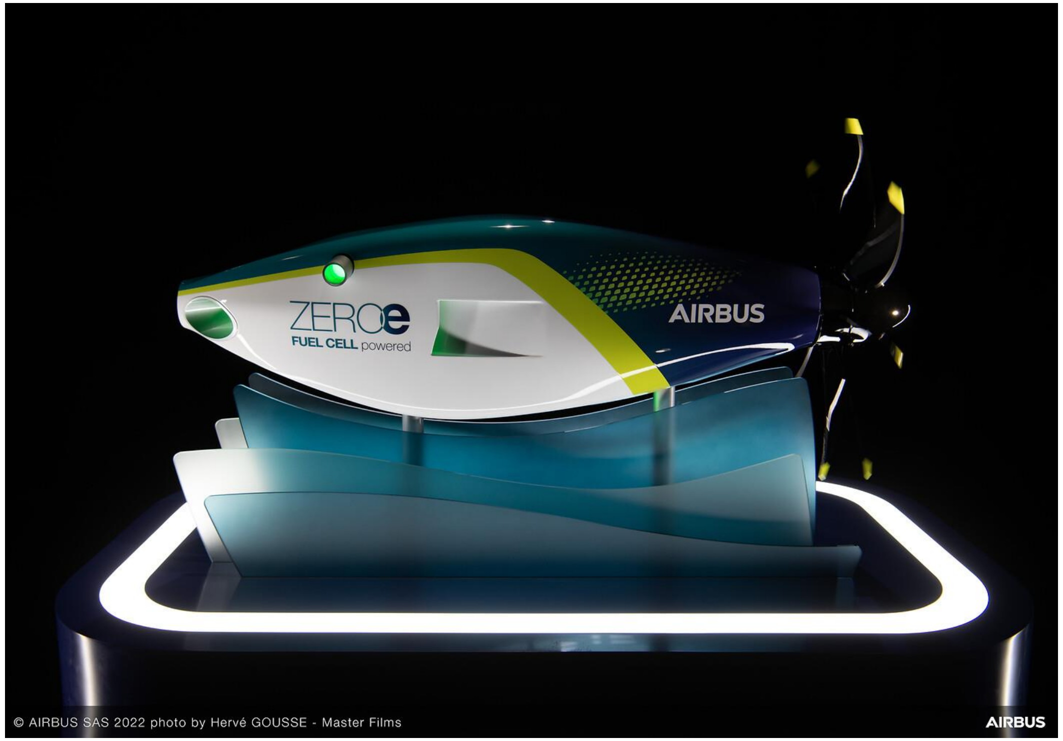
Fuel Cells and H_2 for aviation

UK's ATI (Aerospace Technology Institute) sees a large role for hydrogen in decarbonising aviation – both with fuel cells and gas turbines

Airbus (and others) working on fuel cells for eg regional flights

FC being considered as one of the potential solutions to equip its zero-emission aircraft that will enter service by 2035

Commuter and regional aircraft make up 17% of the global aviation fleet



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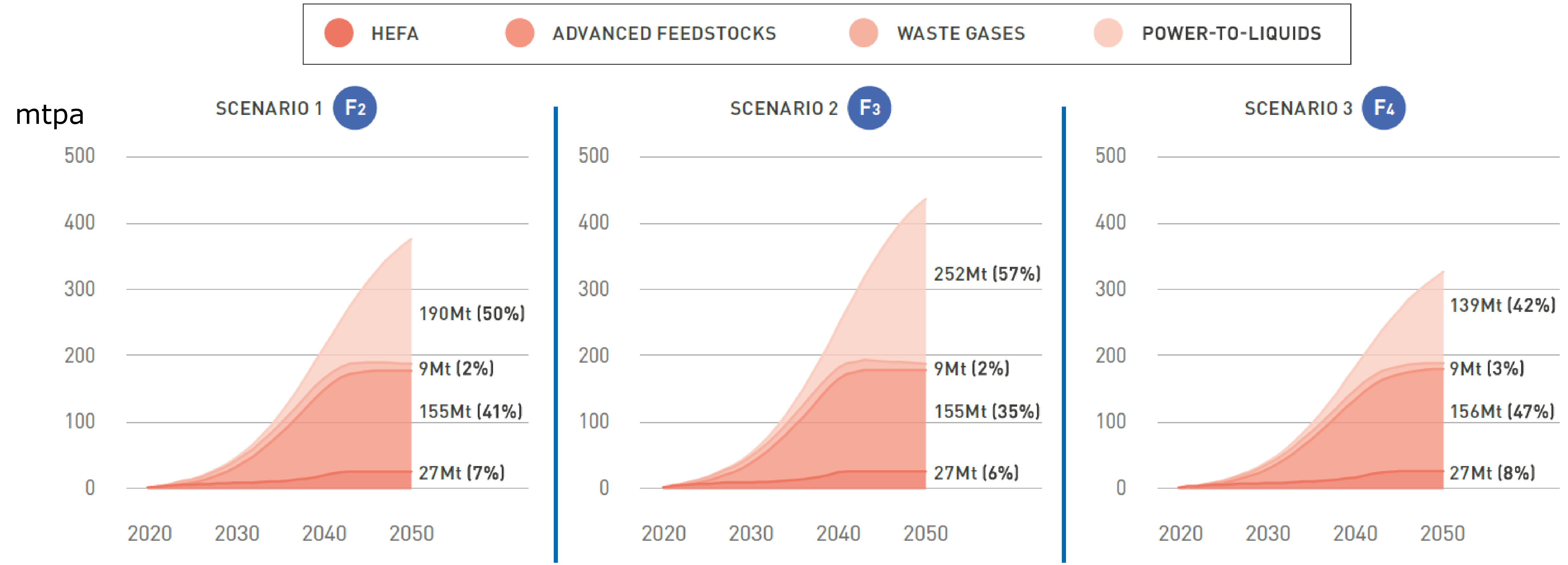
Scenarios for the likely evolution of SAF sources through to 2050
HEFA and Advanced Bio-Feedstocks become capacity constrained, so PtL essential



Source: https://aviationbenefits.org/media/167417/w2050_v2021_27sept_full.pdf

PtL SAF can be a significant demand driver for clean H_2

Assessment of potential clean hydrogen demand for PtL SAF

Using projected 2030 total aviation fuel demand (1.2x 2019 level)

Region	Projected 2030 AF use (kb/d)	2030 PtL SAF target (%)	2030 Clean H_2 use in PtL SAF (mtpa)	Region 2030 Clean H_2 target (mtpa)	Aviation %age of 2030 Clean H_2 demand
UK	320.7	1%*	0.113	1	**11.3%**
EU	1,227.5	1.2%	0.518	20	**2.6%**

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* Assuming UK opts for the most ambitious PtL level from recent consultation, other potential levels are: 0.05%, 0.1% and 0.2% - the latter level would lead to a similar aviation %age of 2030 clean H_2 demand as in the EU

Reflections and Conclusions

Hydrogen will play a critical role in the decarbonisation of the transport sector

Directly: in cars, buses and trucks, and some regional rail, short distance marine and regional aviation (fuel cell) and longer distance (H_2 gas turbines) applications

Indirectly: in marine (likely as ammonia and methanol) and aviation (SAF), and some auto applications (e-fuel)

Carbon intensity is important when considering future decarbonisation approaches, and so, increasingly, is critical mineral intensity

- Access to lithium, nickel and copper could all present significant challenges
- Iridium is critical to both battery technology and PEM electrolysers, and requires continued investment in mining of Platinum Group Metals to ensure availability

There is no single silver bullet for the decarbonisation of several transport sectors, so we will need to scale and deploy several options to identify the best choice(s) – but we need to get on with it!

JM


"This needs Cathedral Thinking.
We can build the foundations without knowing exactly how we will complete the roof"
Greta Thunberg