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Johnson Matthey
Inspiring science, enhancing life

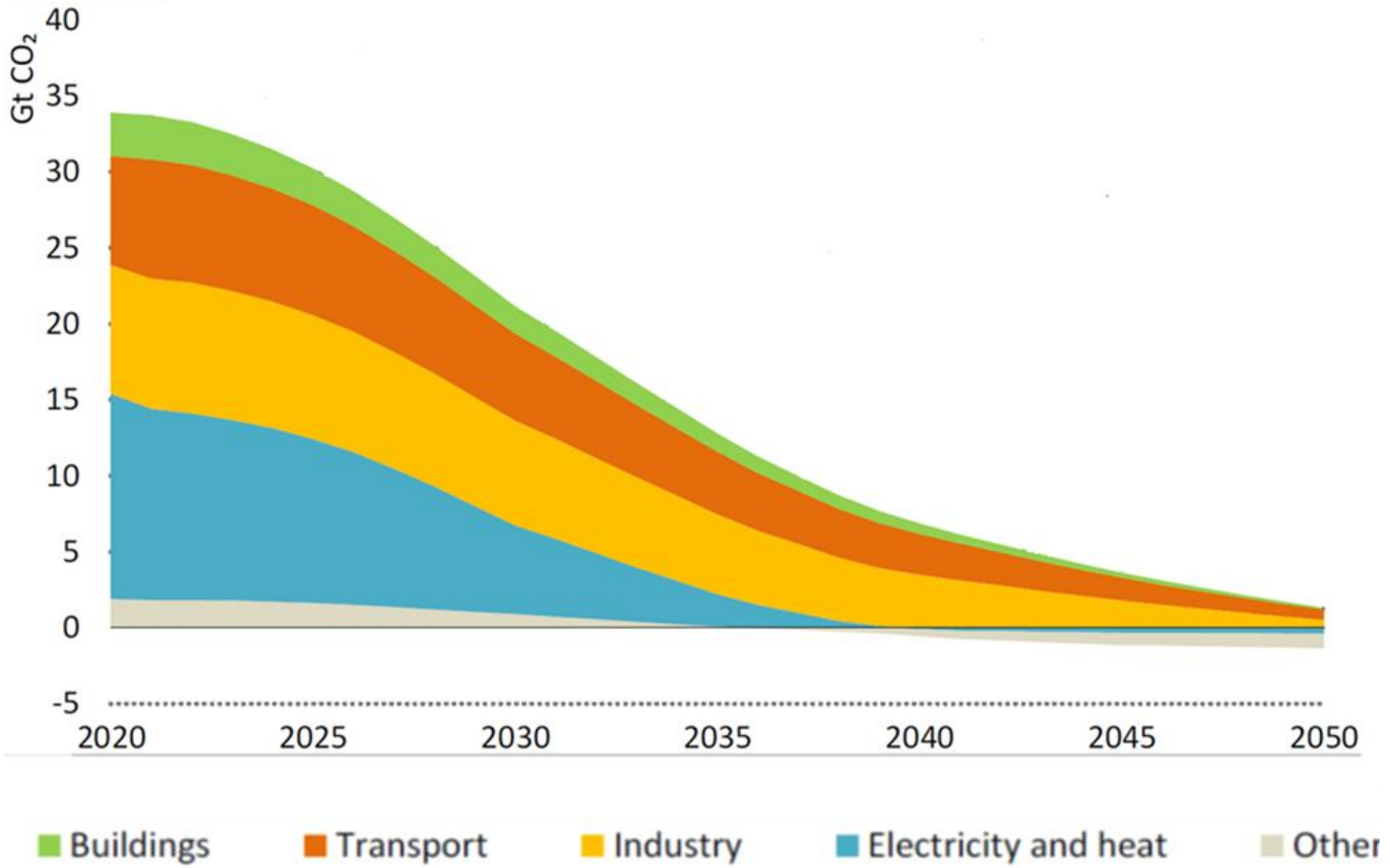
How Rapidly will the Decarbonisation of Mobility occur?

Andy Walker

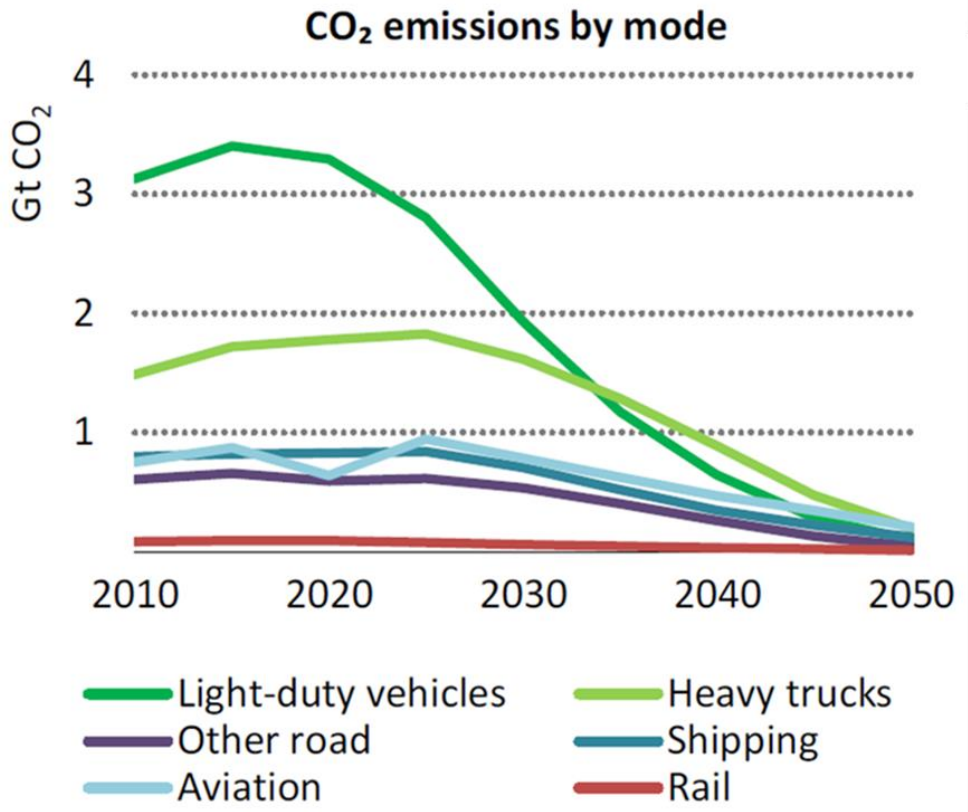
Future Propulsion Conference, March 2022

Global CO_2 emissions by sector and within the transport sector

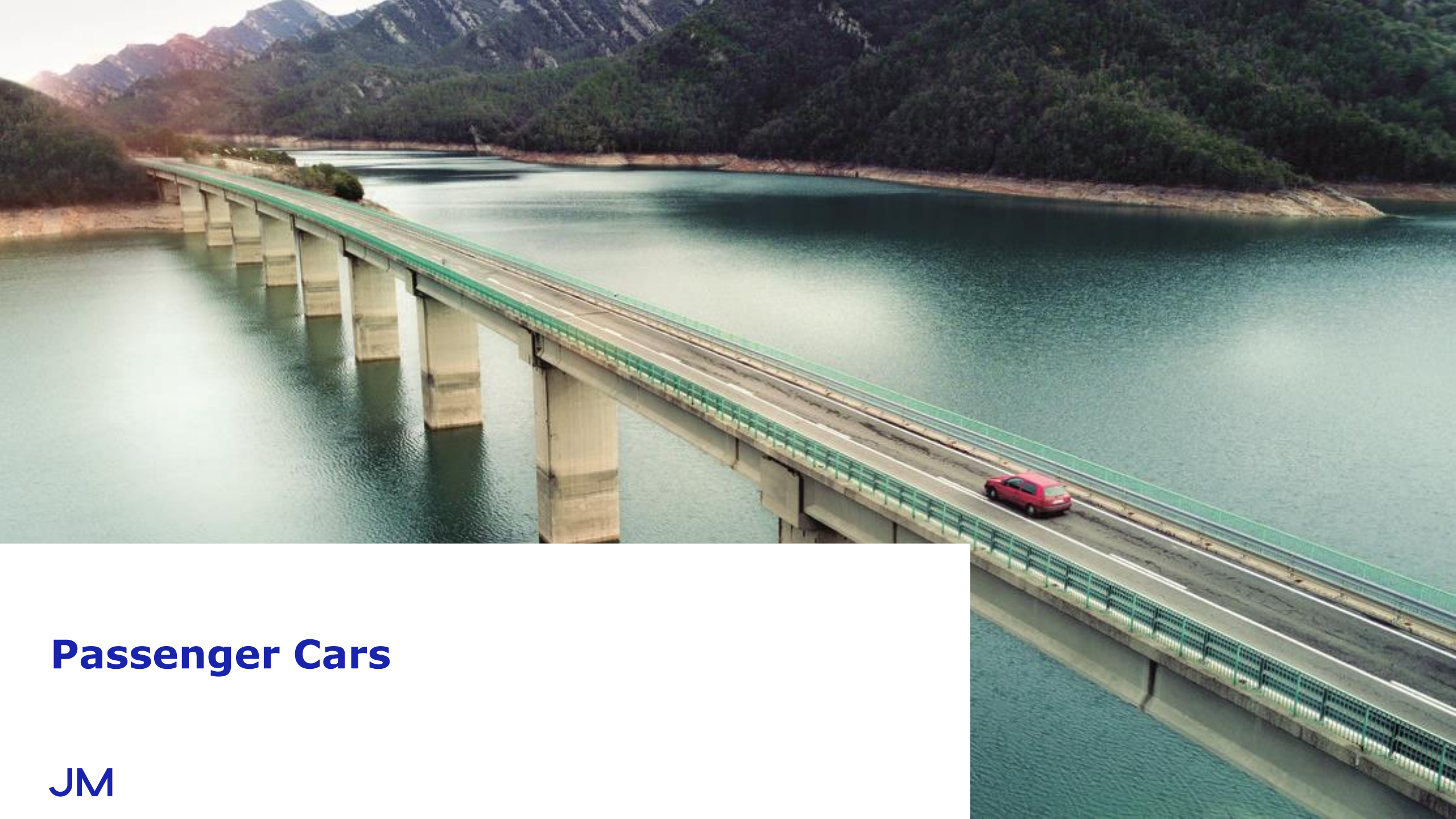
Transport accounts for over 20% of energy-related CO_2 emissions



LDV and HDV are the largest contributors



Source: IEA "Net Zero by 2050: A Roadmap for the Global Energy Sector, May 2021



Passenger Cars

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We use a scenario-based approach to look at key markets and their likely trajectories

Some of the main inputs we use for the automotive market are outlined below

Regulations

Market

Technology

Consumers

Infrastructure

Cost

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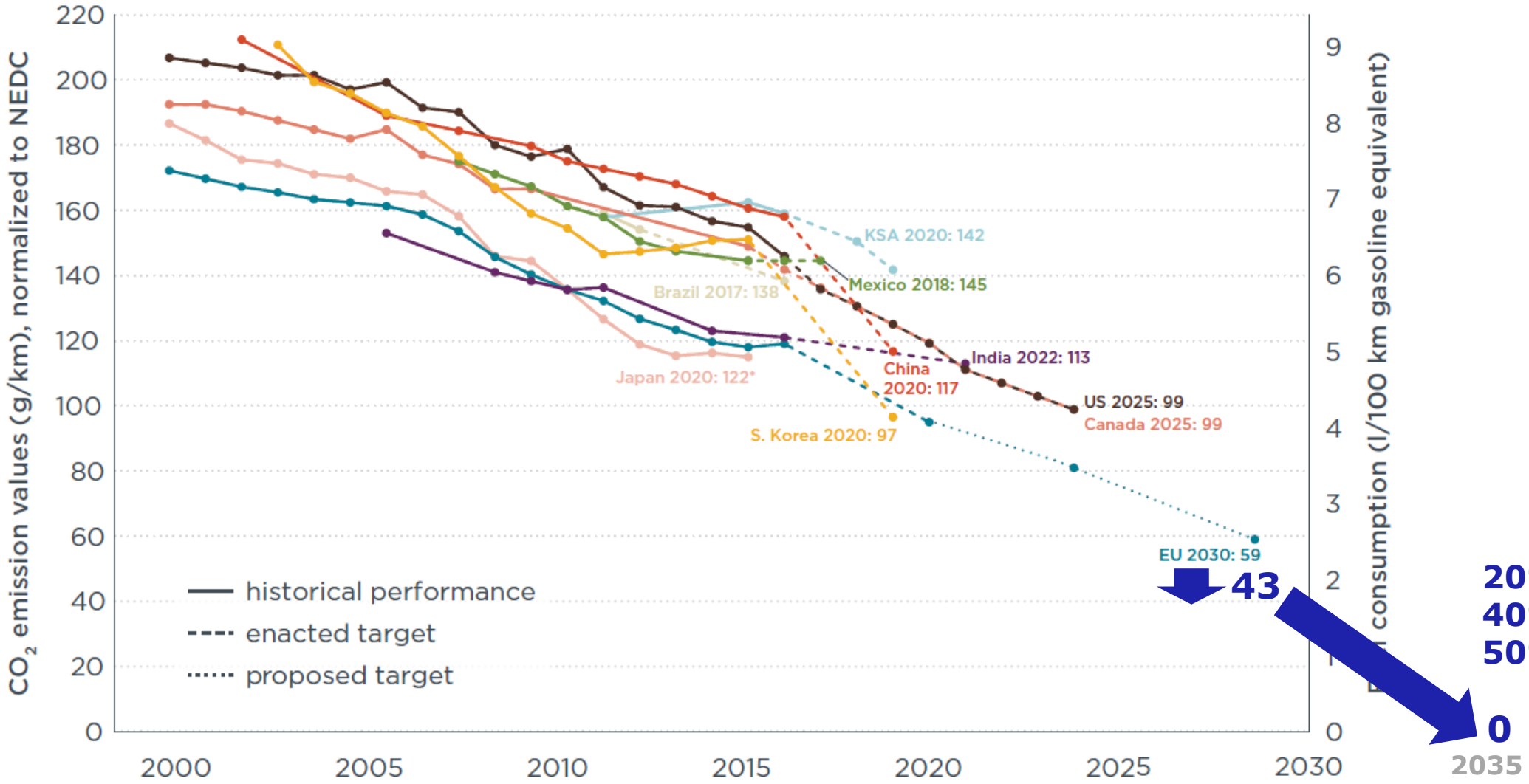
Global car CO_2 legislation – strong downward trajectory will continue



40-50% ZEV by 2030

100% ZEV by 2035

China SAE
20% NEV by 2025
40% NEV by 2030
50% NEV by 2035

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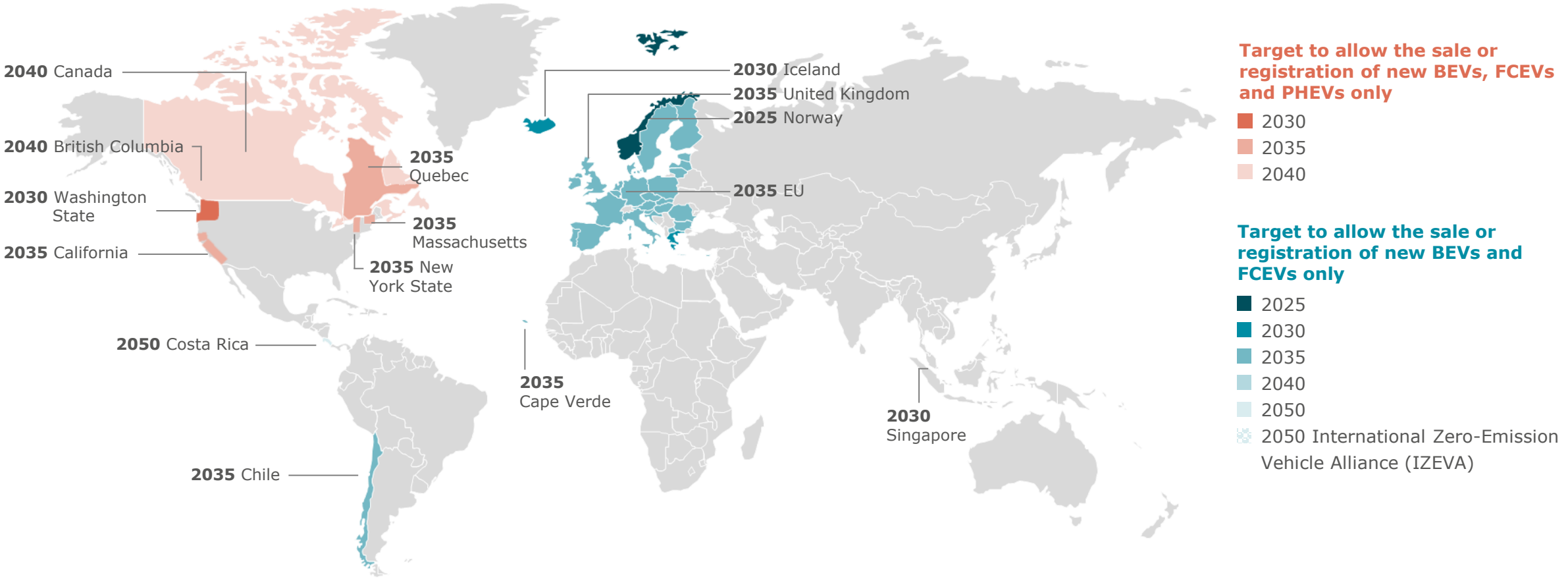
Source: ICCT "CO_2 emission standards for passenger cars and light-commercial vehicles in the EU", January 2019

Countries/States with proposed phase-out dates for new ICE car sales

Governments with official targets to 100% phase out sales or regulations of new internal combustion engine cars by a certain date



Announced phase-out dates cover around 25% of global ICE sales

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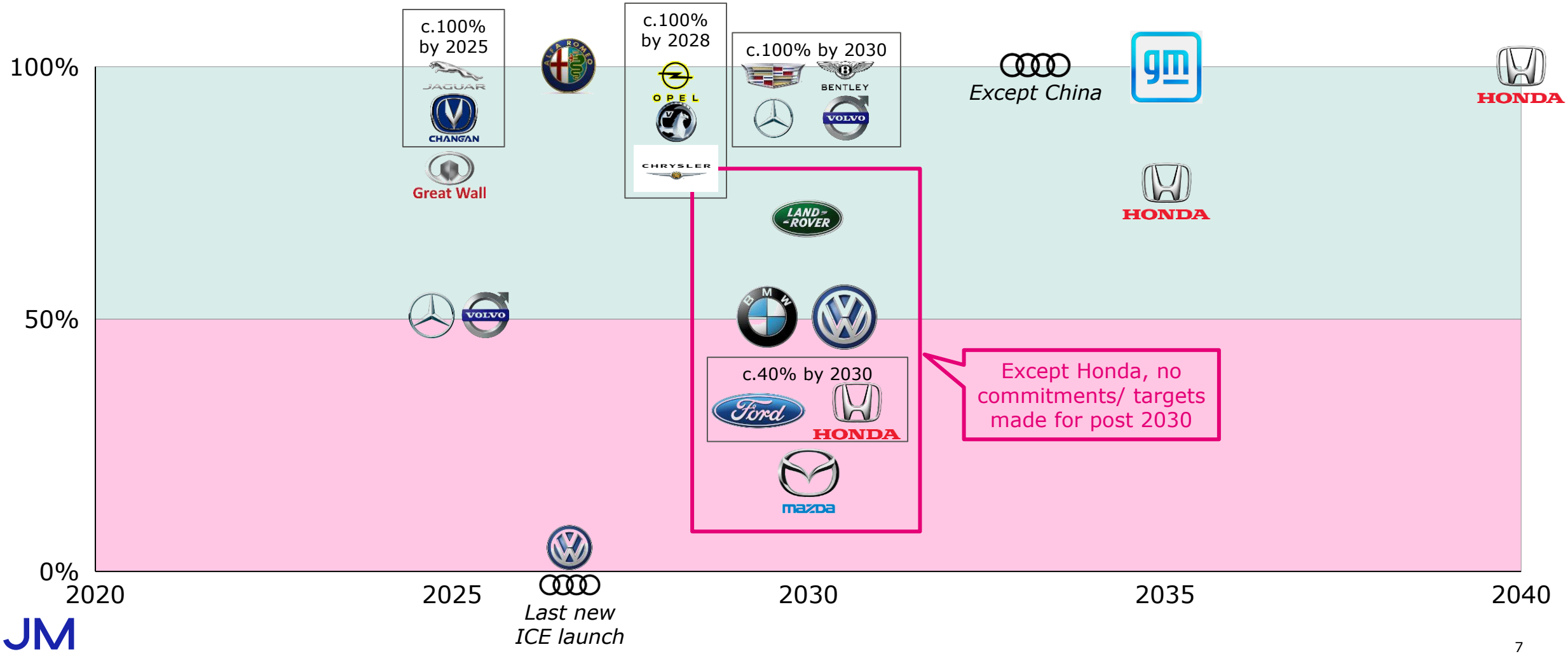
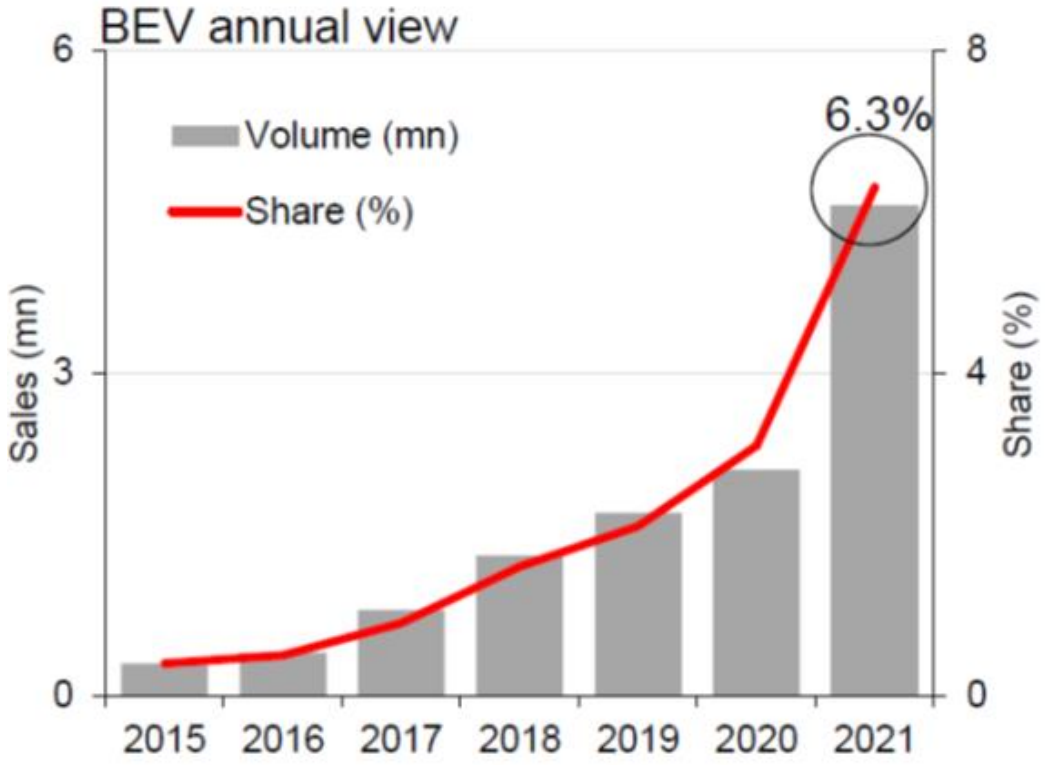
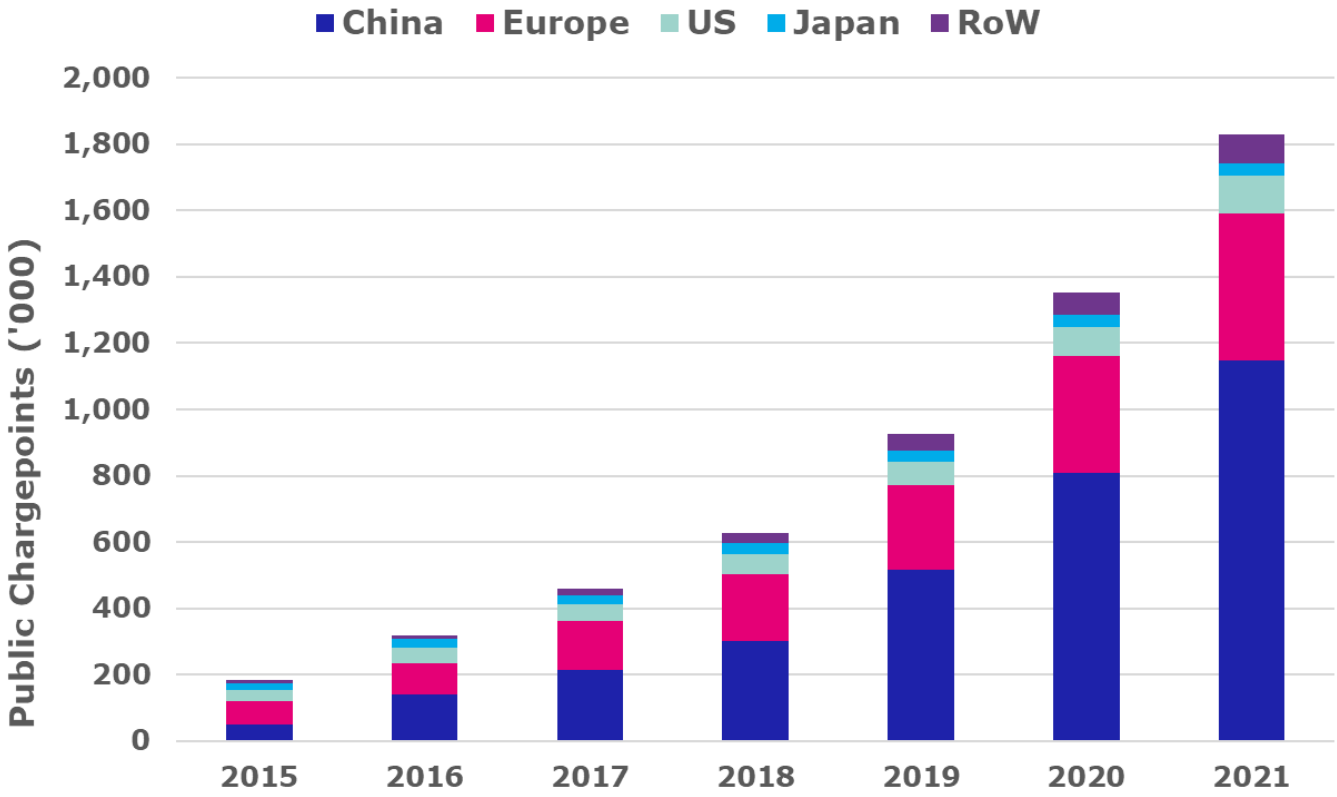
…and numerous OEMs are announcing targets for the ZEV share of their planned LDV sales

Global LDV electrification (ZEV) share, % of sales/OEM



2021 was a banner year for BEV sales, and public charging infrastructure deployment continues to increase





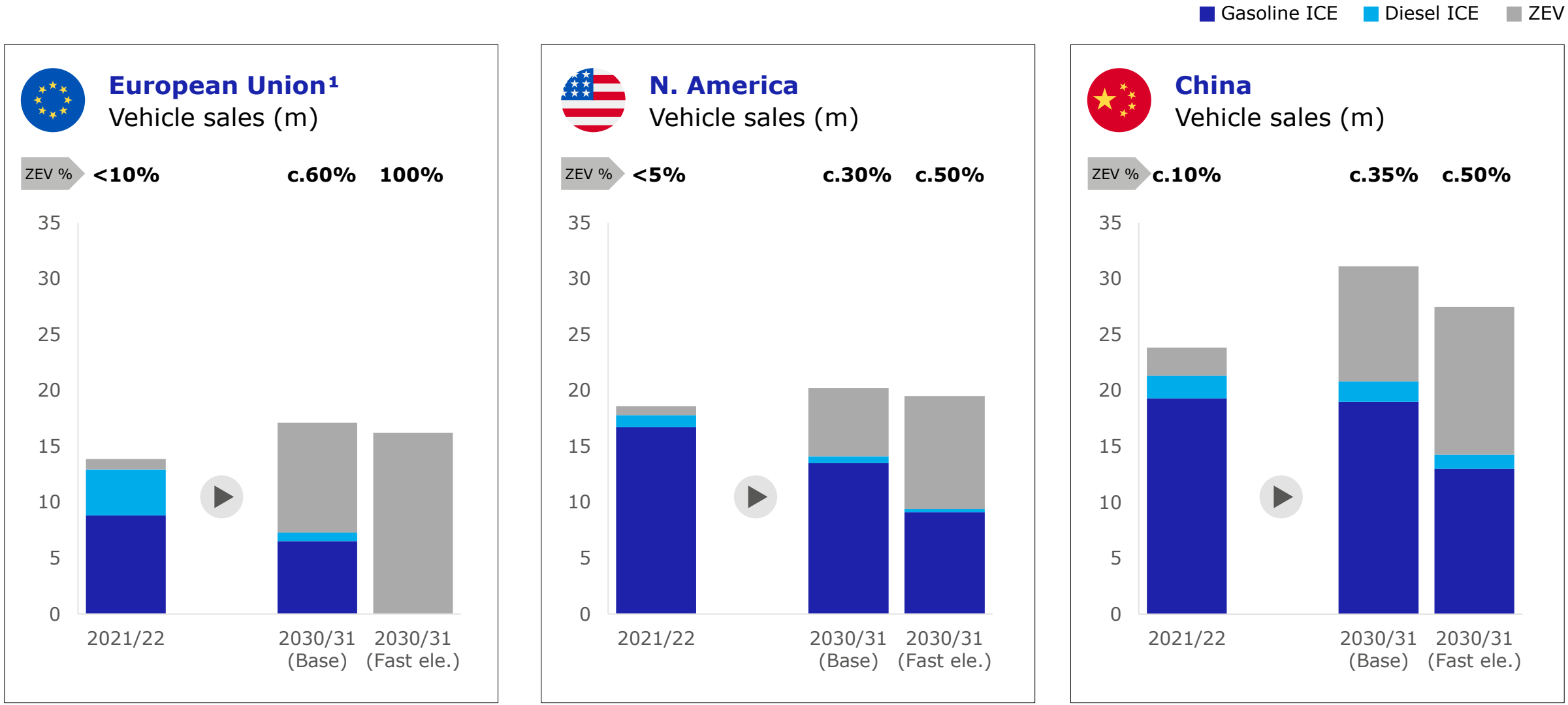
JM Source: LMC; BNEF

Main JM scenarios for the evolution of the LDV market to 2030

	Metric	Pragmatic Evolution (Base case)	Rapid Transition (Faster electrification)
01	Global LD vehicle production in 2030/31 (million vehicles)[1]	c.100m	c.90m
02	EU7 legislation[2]	2026	2027
03	% global LD BEV penetration in 2030/31[1]	c.30%	c.50%
04	Share of Europe LD ICE that is diesel in 2030/31[1]	c.10%	-

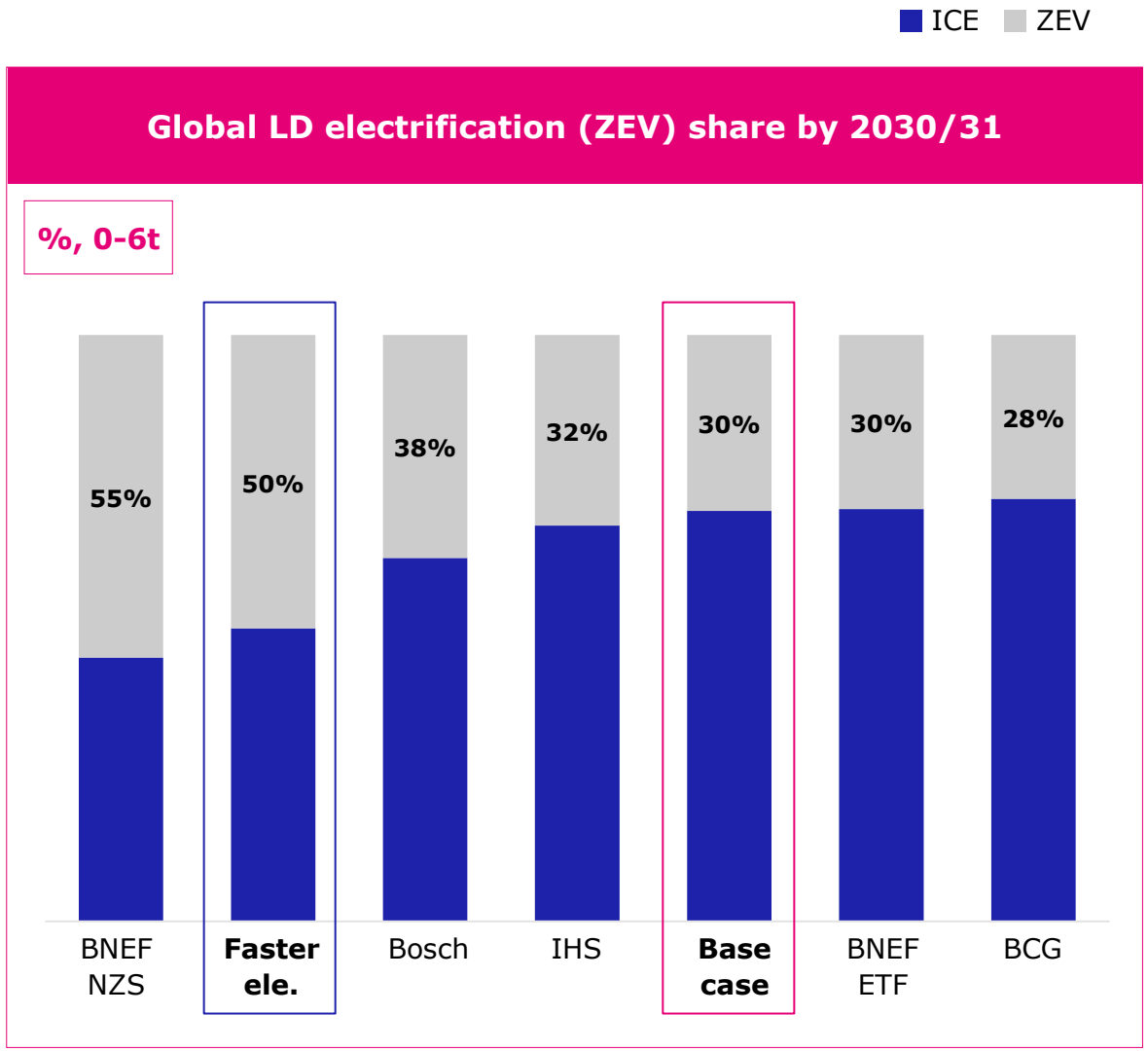
Note: LD – light duty, BEV – battery electric vehicle, ICE – internal combustion engine.
1. JM and IHS estimates. Production of 0-6 tonnes vehicles globally in 2030/31.
2. Expected implementation date for EU7 emissions legislation – 31st December 2026 (base case) and 31st December 2027 (faster electrification case).

LDV (0-6T): shift to BEV will be fastest in Europe by 2030



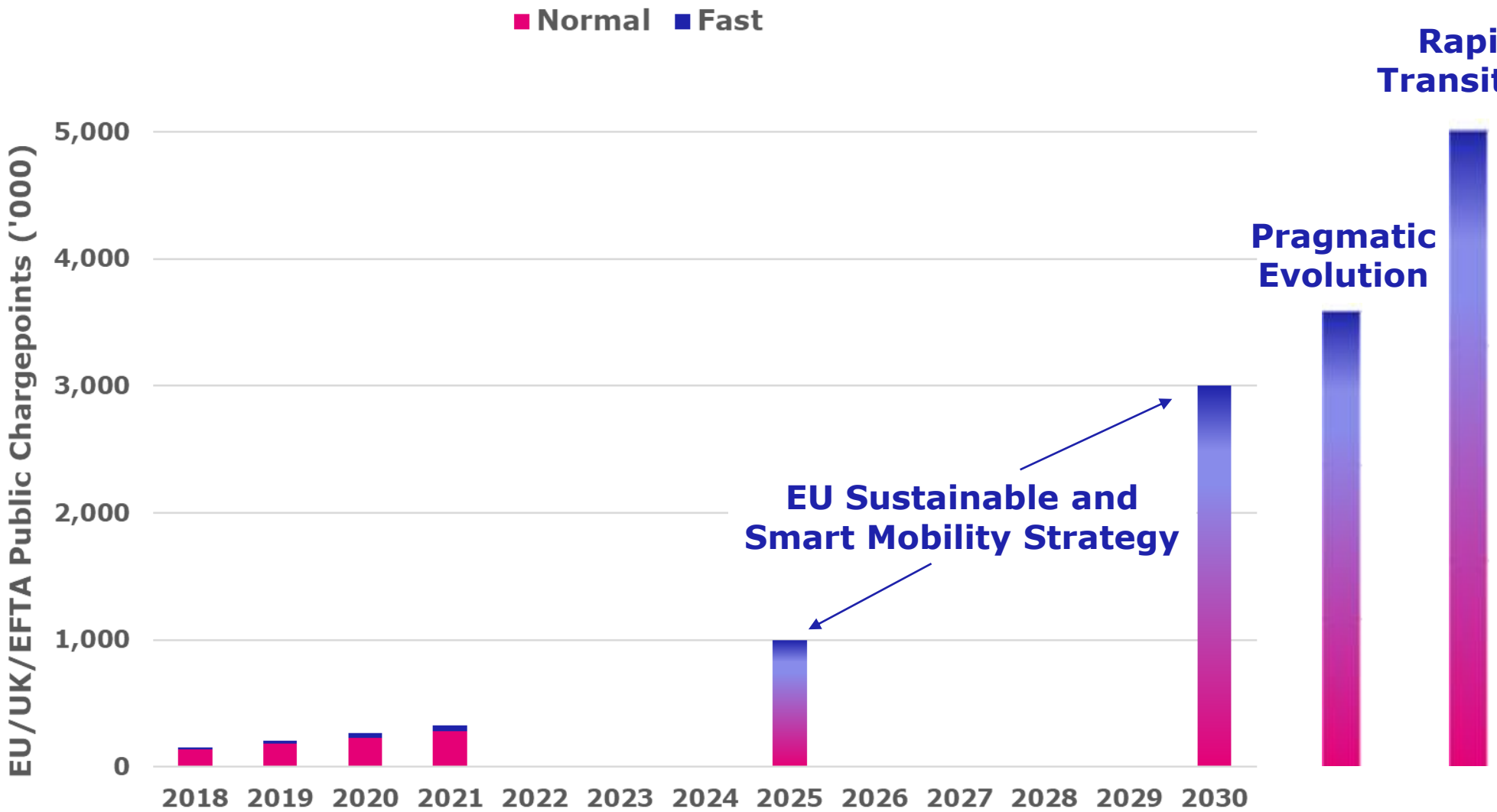
Source: JM estimates based on external IHS estimates.
Note: ICE includes ICE hybrid. ICE – internal combustion engine, ZEV – zero emission vehicle.
1. Includes EU, UK, Norway, Switzerland and the Balkans.

Our scenarios are well placed within the range of market scenarios



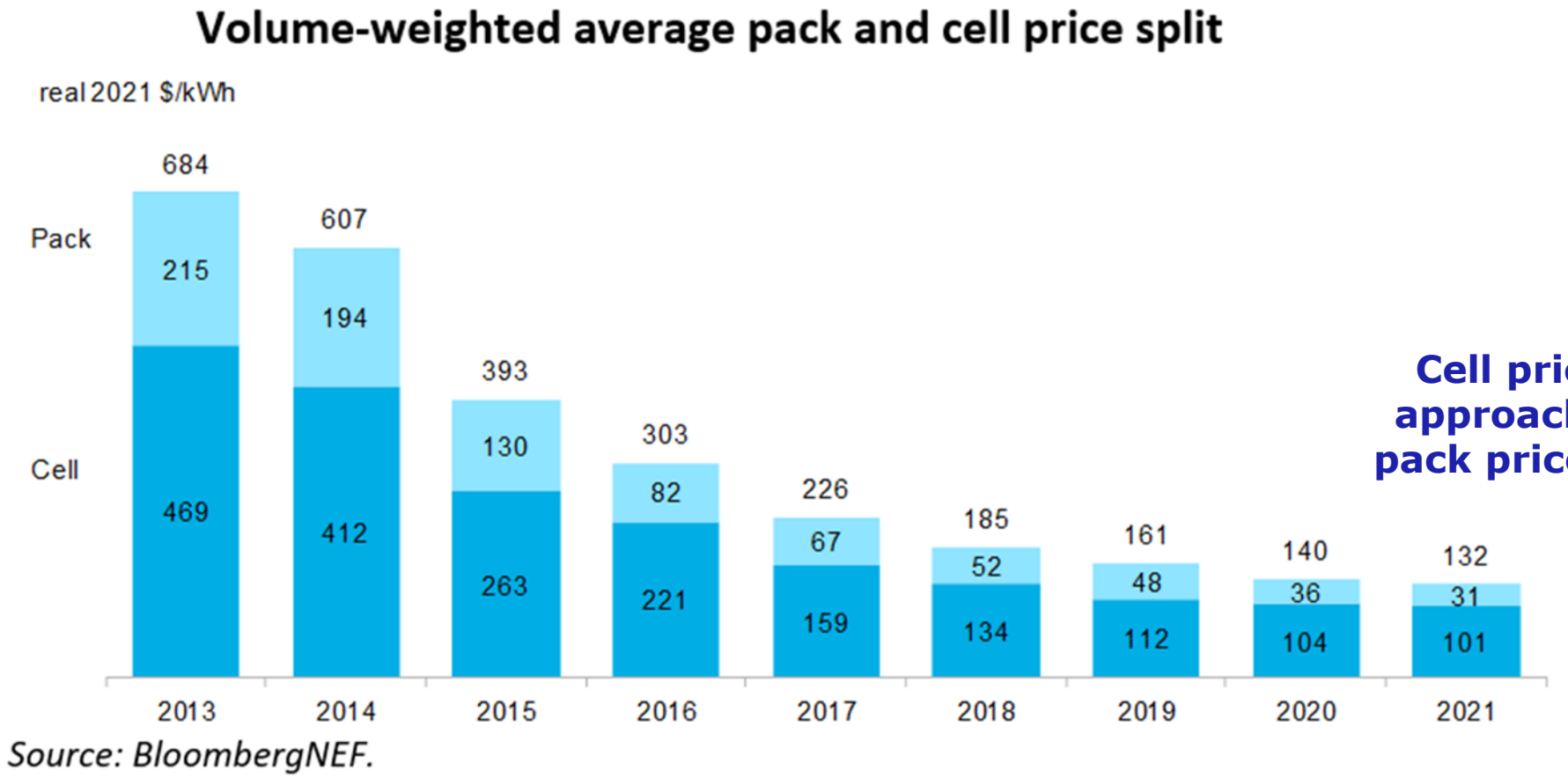
Note: ICE – internal combustion engine, ZEV – zero emission vehicle.
Source: external data sources (various). Note: calendar year 2030 approximated for 2030/31.

Headwinds facing the Rapid Transition scenario: Infrastructure



Headwinds facing the Rapid Transition scenario: Raw Materials

Battery cell and pack price reductions are slowing/reversing



Cell prices in Q4 2021 were approaching $110/kWh, with pack prices starting to increase

Increasing concern about raw material availability is driving price increases and battery chemistry changes – increasing LDV demand likely to exacerbate this; CV BEV uptake would add further pressure

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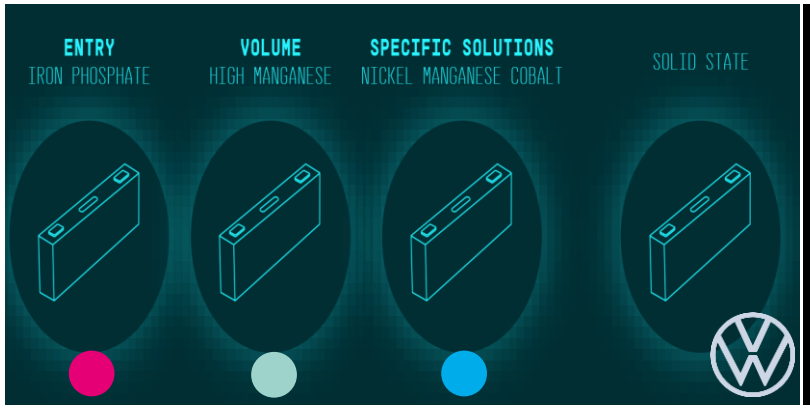
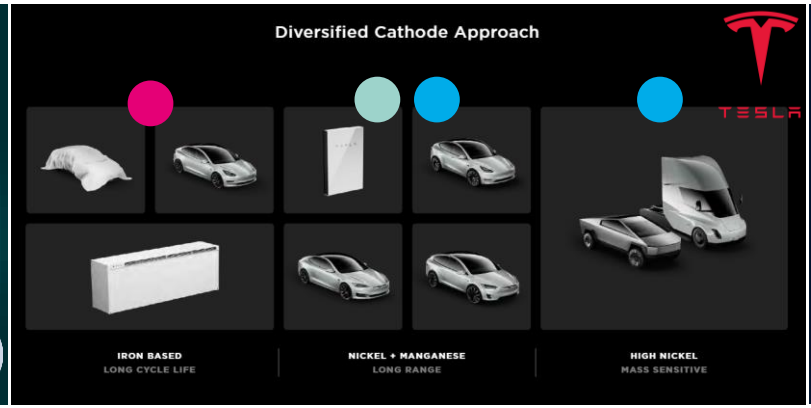
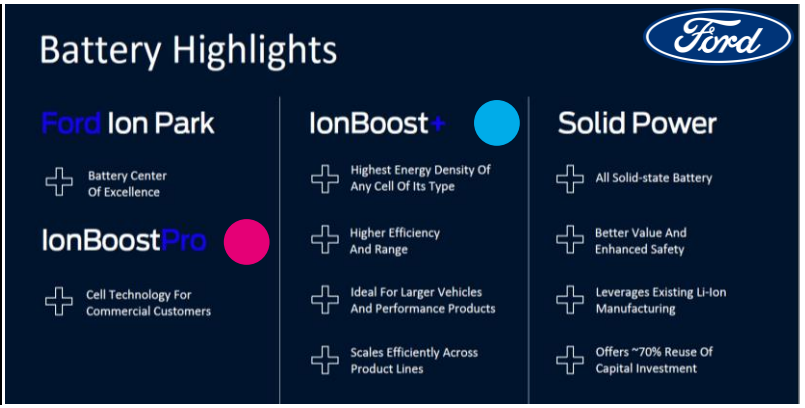
Source: BNEF

Major OEMs have outlined plans to diversify their cathode chemistry portfolios for a variety of use-cases







- Although OEMs like **VW**, **Mercedes** and **Tesla** have revealed plans to utilise LFP for entry passenger vehicles, we are yet to see such vehicles outside of China
- **Ford** recently indicated that LFP would only be used for commercial vehicle applications

LFP

High manganese

High nickel

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Source: Company reports

Trucks and Buses

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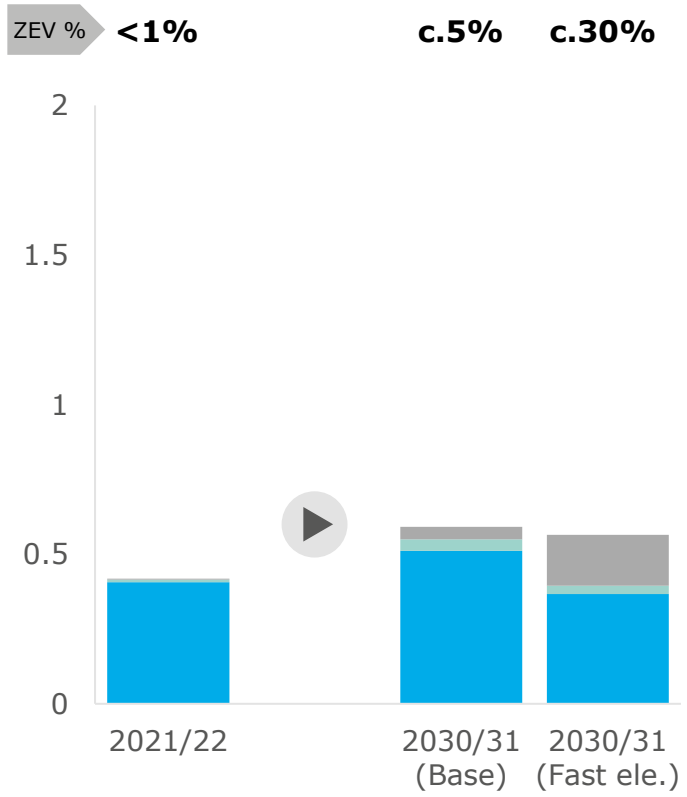
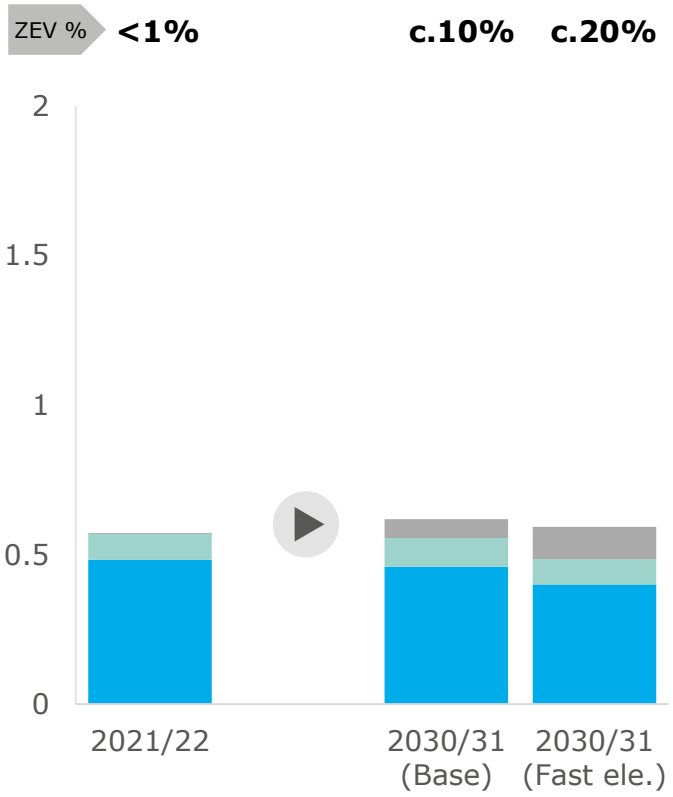
Heavy Duty (6T+): electrification constrained by infrastructure build and availability of ZEV models

Diesel ICE | Other ICE | ZEV

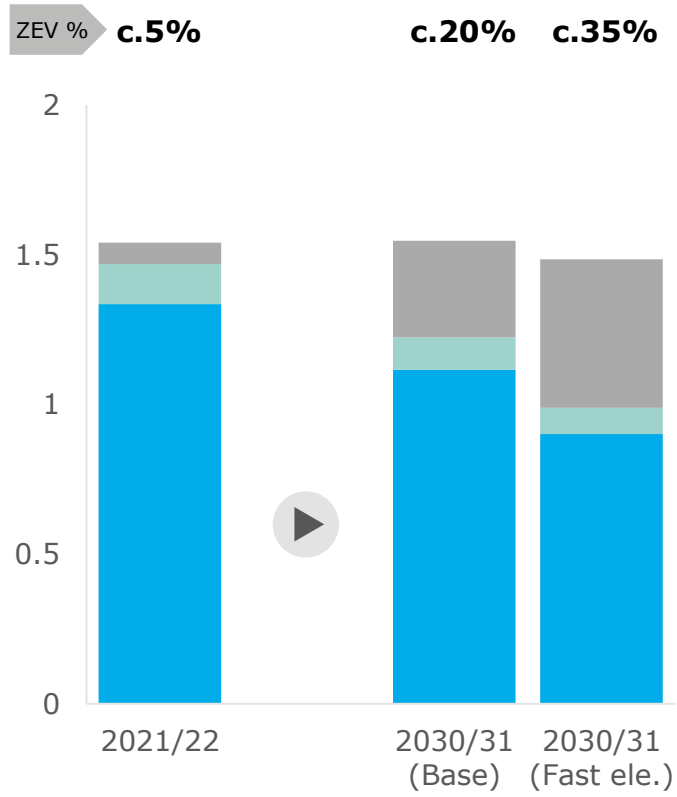
European Union[1]
Vehicle sales (m)



N. America
Vehicle sales (m)



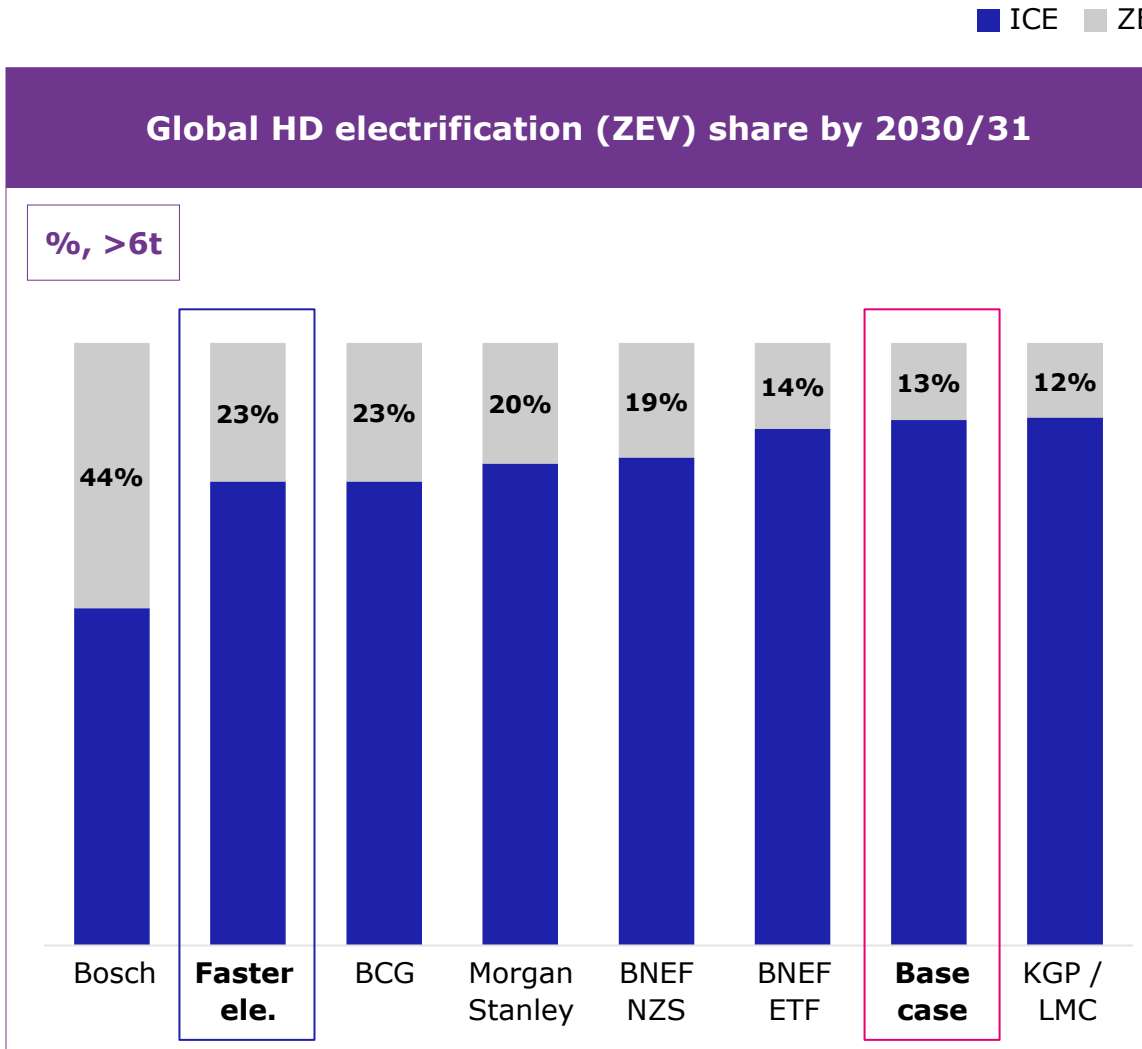
China
Vehicle sales (m)



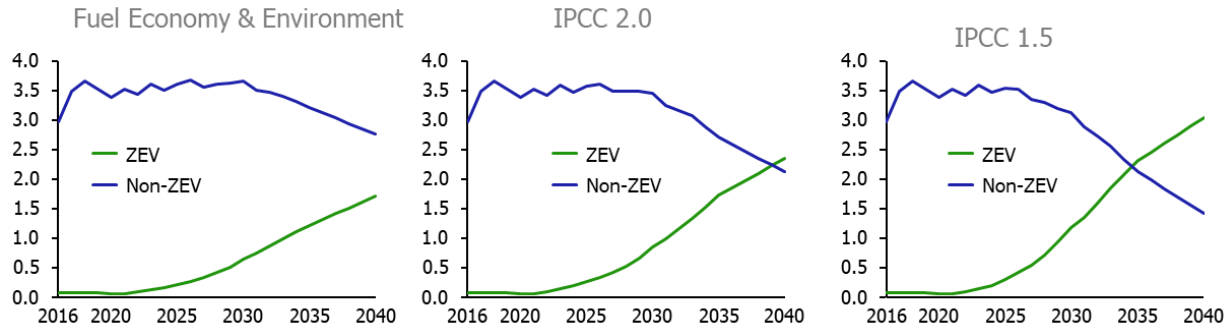
Source: JM estimates based on external IHS estimates.
Note: ICE includes ICE hybrid. ICE – internal combustion engine, ZEV – zero emission vehicle.
1. Includes EU, UK, Norway, Switzerland and the Balkans.

Our scenarios are well placed within the range of market scenarios

Global HD electrification (ZEV) share by 2030/31

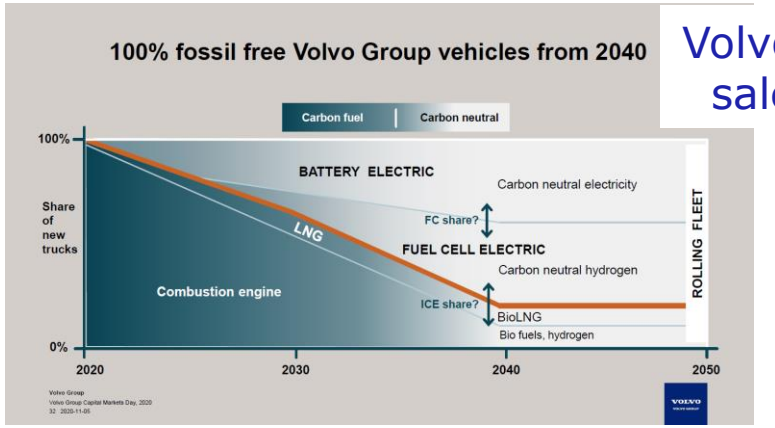


KGP Global ZEV Scenarios



2030: 15% ZEV **19% ZEV** **26% ZEV**

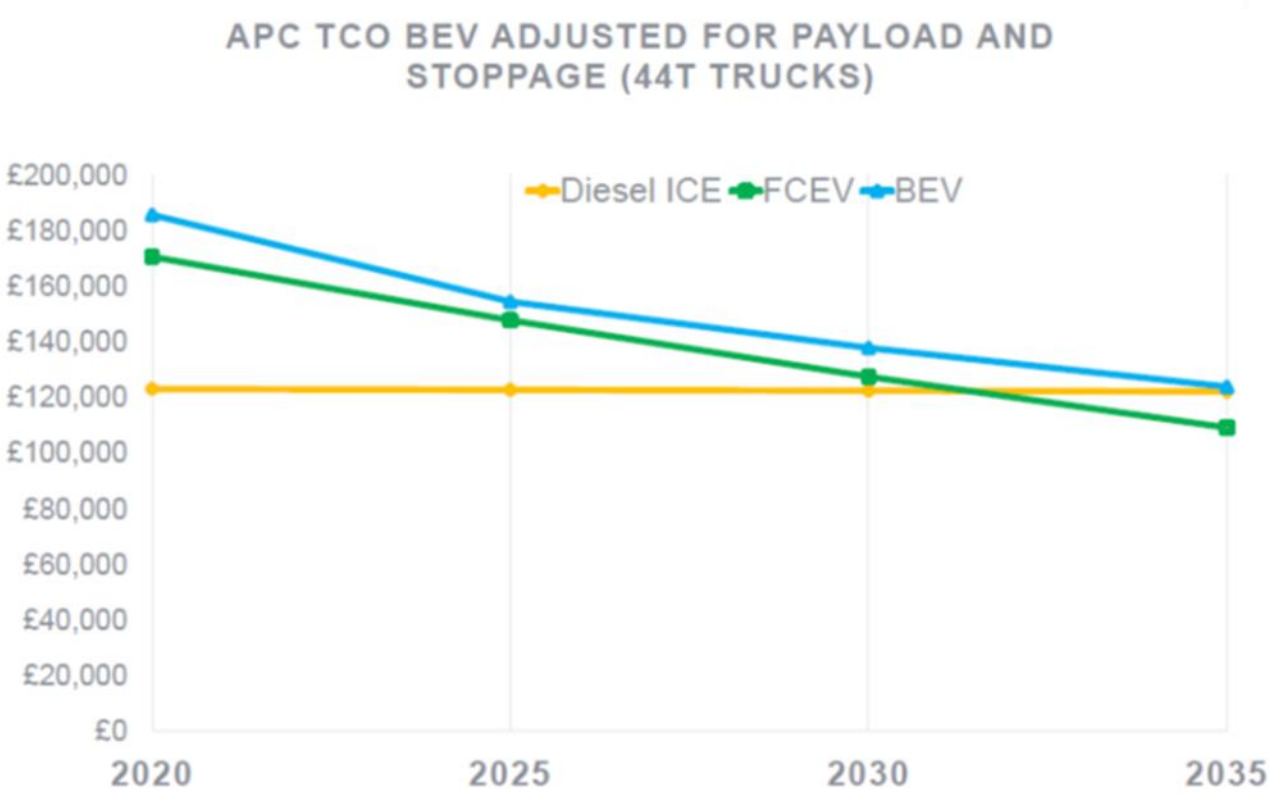
But things might move faster!



Volvo sees up to 35% of its sales being ZEV by 2030

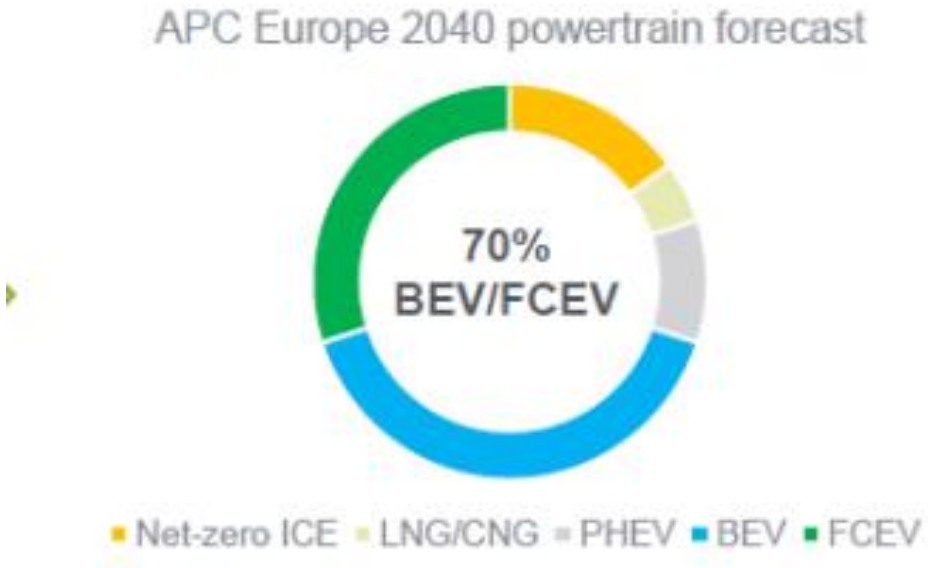
Note: ICE – internal combustion engine, ZEV – zero emission vehicle.
Source: external data sources (various). Note: calendar year 2030 approximated for 2030/31.

APC see lowest HGV TCO for Fuel Cells, and see BEV/FCEV having 70% of the European MD/HD market by 2040



> 7.5 t in Europe

2040



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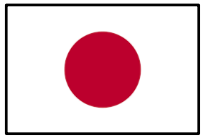
Fuel cell electric vehicle and hydrogen infrastructure development

- >1m FCEVs in 2030
- >1,000 hydrogen refuelling stations (HRS) by 2030

- >1.8m FCEVs in 2030
- >500 HRS in 2030
- $2.2bn investment by 2022

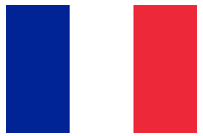


- Strong drive towards hydrogen economy
- 800k FCEVs by 2030
- 900 HRS by 2030

- Zero emission vehicle mandate
- 50k FCEVs by 2025
- 200 HRS by 2025

EU Sustainable and Smart Mobility Strategy calls for 500 HRS across EU by 2025, and 1,000 by 2030

FCEV/HRS deployment by 2030 from EU Member States National Hydrogen Strategies

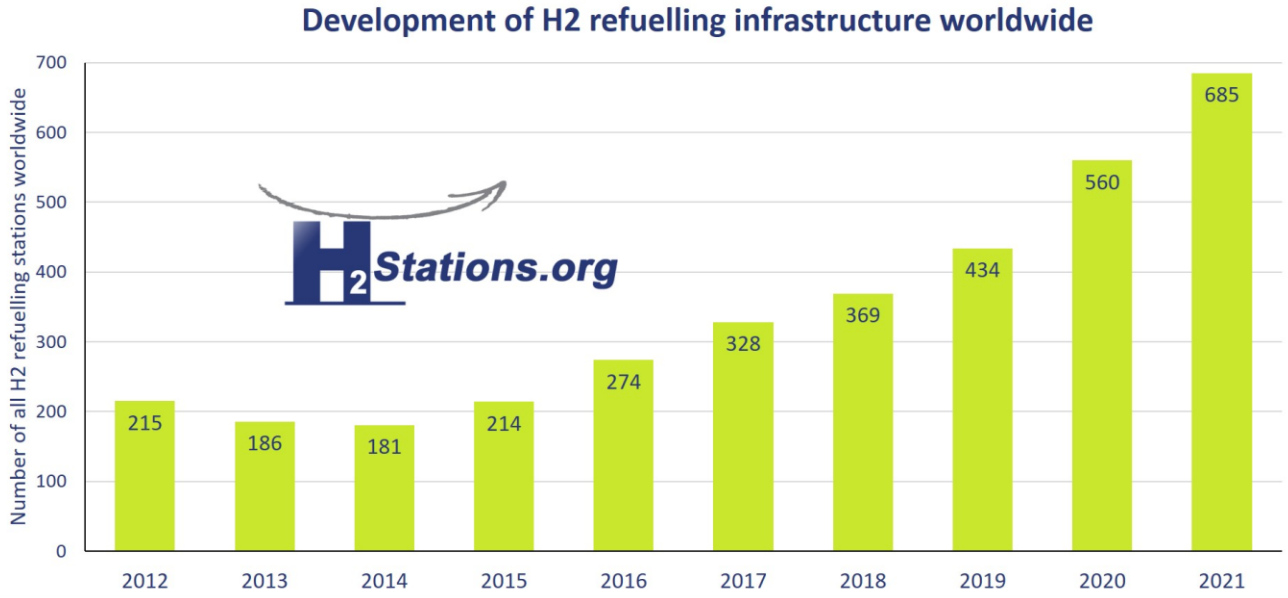


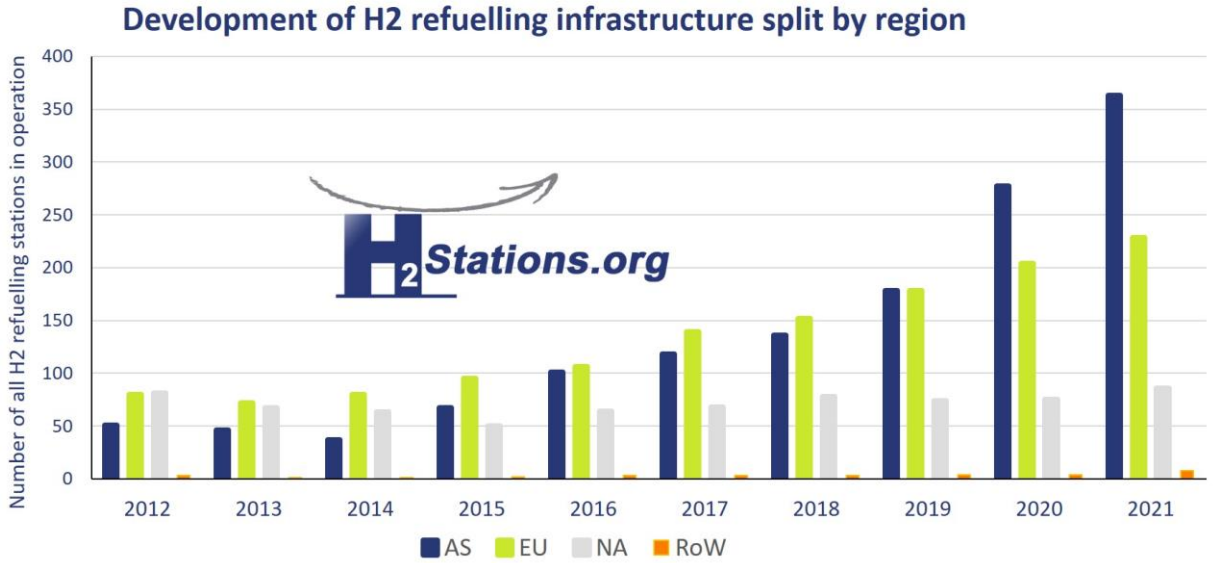



		Bavaria	North-Rhine Westphalia				
LDV	20-50k (2028)	80k	6k	15k (2025) 300k (2030)		5% of road transport powered by H_2	5-7.5k
HCV	0.8-2k (2028)	3k	15k	3k (2025)	2k		
HRS	400-1,000 (2028)	400	200	50 (2025)	150	50-100	100-150

Note: FCEV – fuel cell electric vehicle; HRS – hydrogen refuelling station

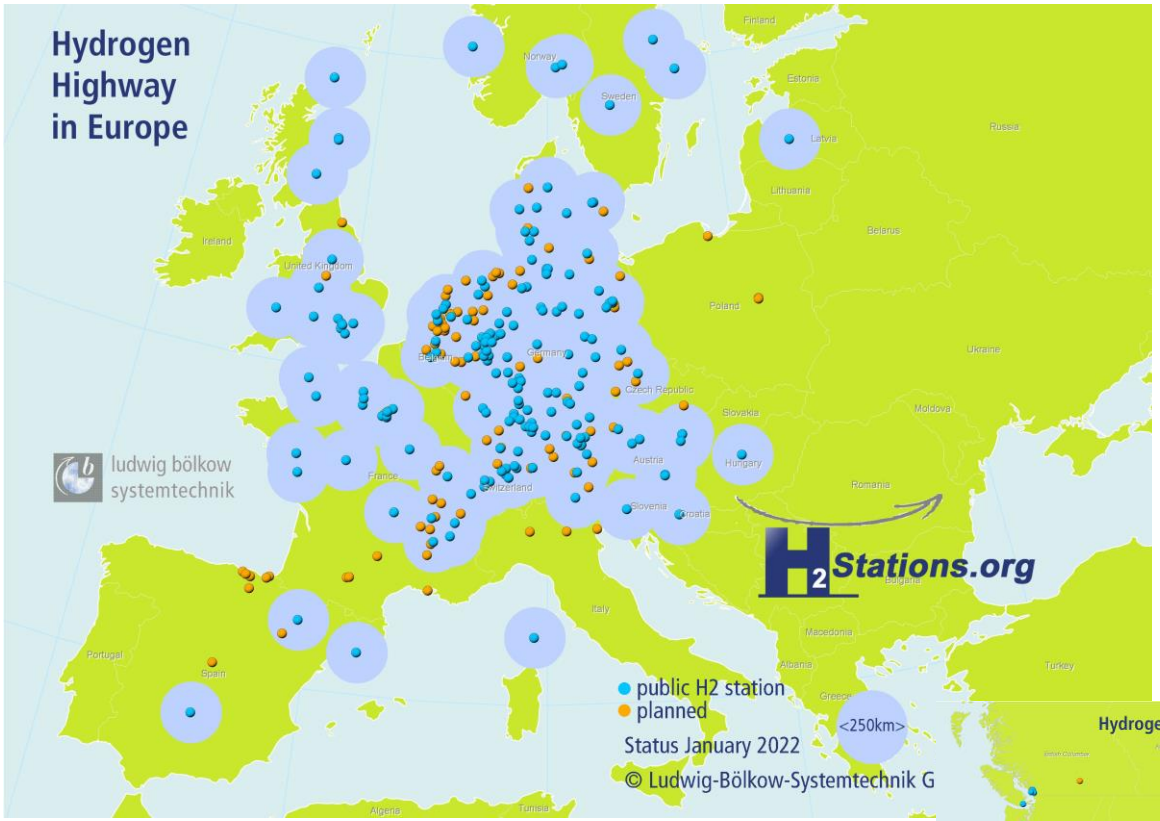
Hydrogen Refuelling Station (HRS) infrastructure development





Source: H2stations.org by LBST

Hydrogen Refuelling Station (HRS) infrastructure development



Rapporteur proposing HRS to be deployed every 100km along the EU TEN-T network by end of 2027

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Source: H2stations.org by LBST

Recent Examples of Fuel Cell Electric Vehicles on China's Roads

Heavy-Duty FCEVs

- According to the IEA more than 90% of the world's commercial FCEVs are on China's roads
- 170 heavy-duty FCEVs hit China's roads during Q2/Q3 '21 powered by JM and REFIRE technology

Beijing Winter Games

- >1000 FCEVs were deployed during the Beijing Winter Games, including ~500 buses
- Demonstrates China's leading role in building the industrial value chain for FCEVs
- JM components are powering over 1,300 FCEVs in China including some of these vehicles in Beijing

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A sign of things to come?

Beijing Summer Games 2008

BEV fleet for the Summer Games

Beijing Winter Games 2022

FCEV fleet for the Winter Games

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Rail

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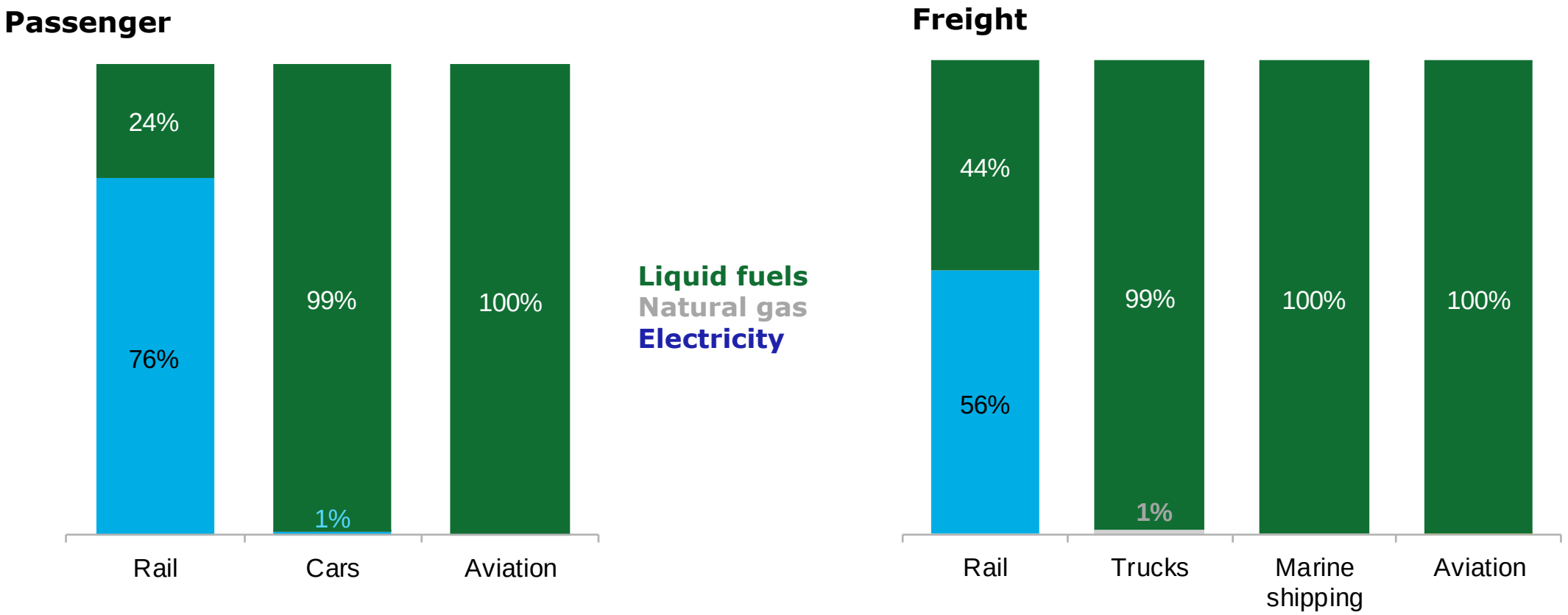
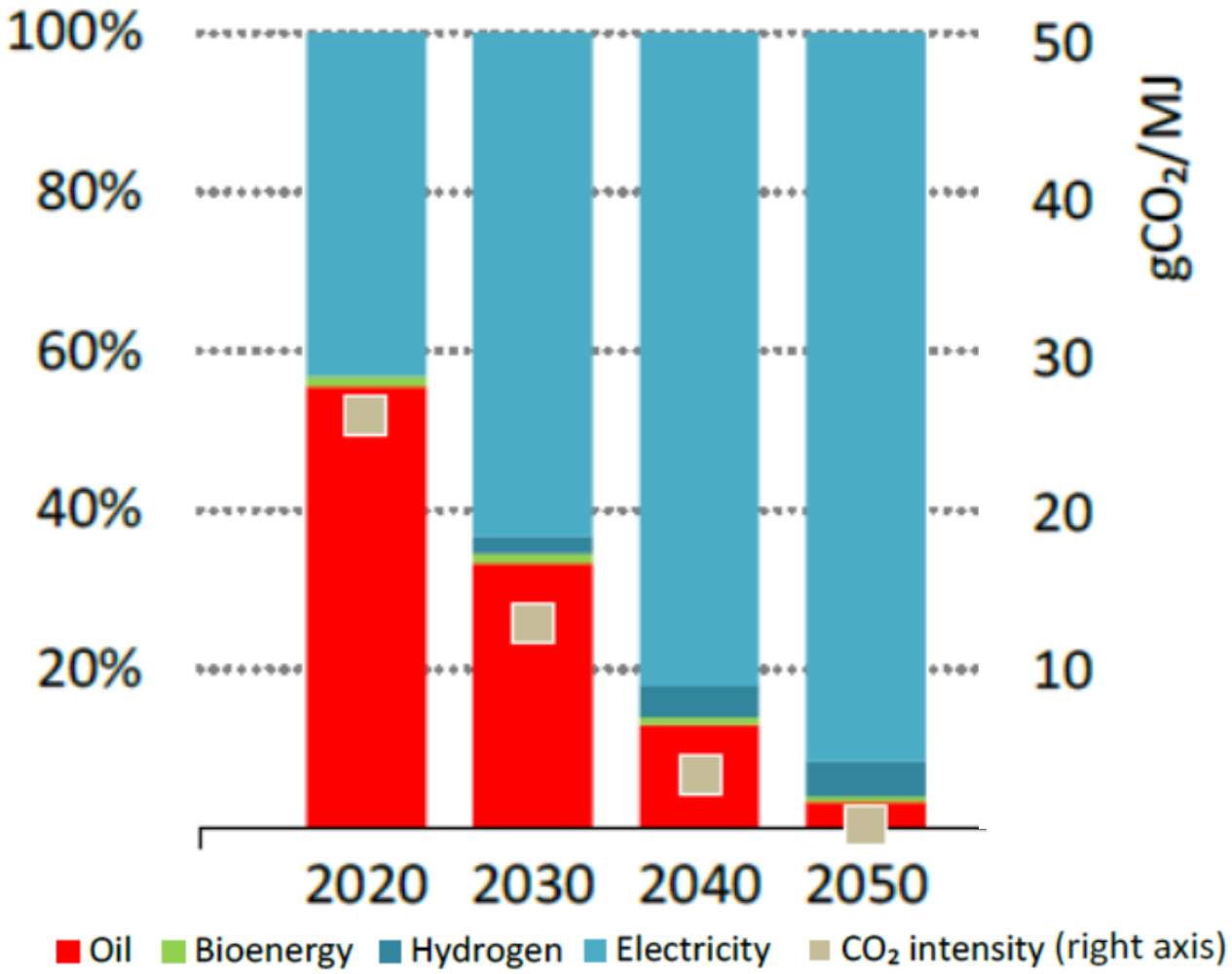
Rail is the transport sector most on the way to electrification today

Global transport activity by fuel, 2019



Source: BNEF. Note: Automotive segments reflect vehicle-km. Other passenger (freight) segments show passenger-km (ton-km). For road transport, liquid fuels include oil products and biofuels.

Further electrification with some clean H_2 gets rail to very low CO_2 by 2050



Catenary electrification economics don't work well for regional lines, where both battery electric and fuel cell electric trains (eg Alstom Coradia i-Lint FC train (above)) will play significant roles

Source: IEA "Net Zero by 2050: A Roadmap for the Global Energy Sector, May 2021; https://www.alstom.com

Marine

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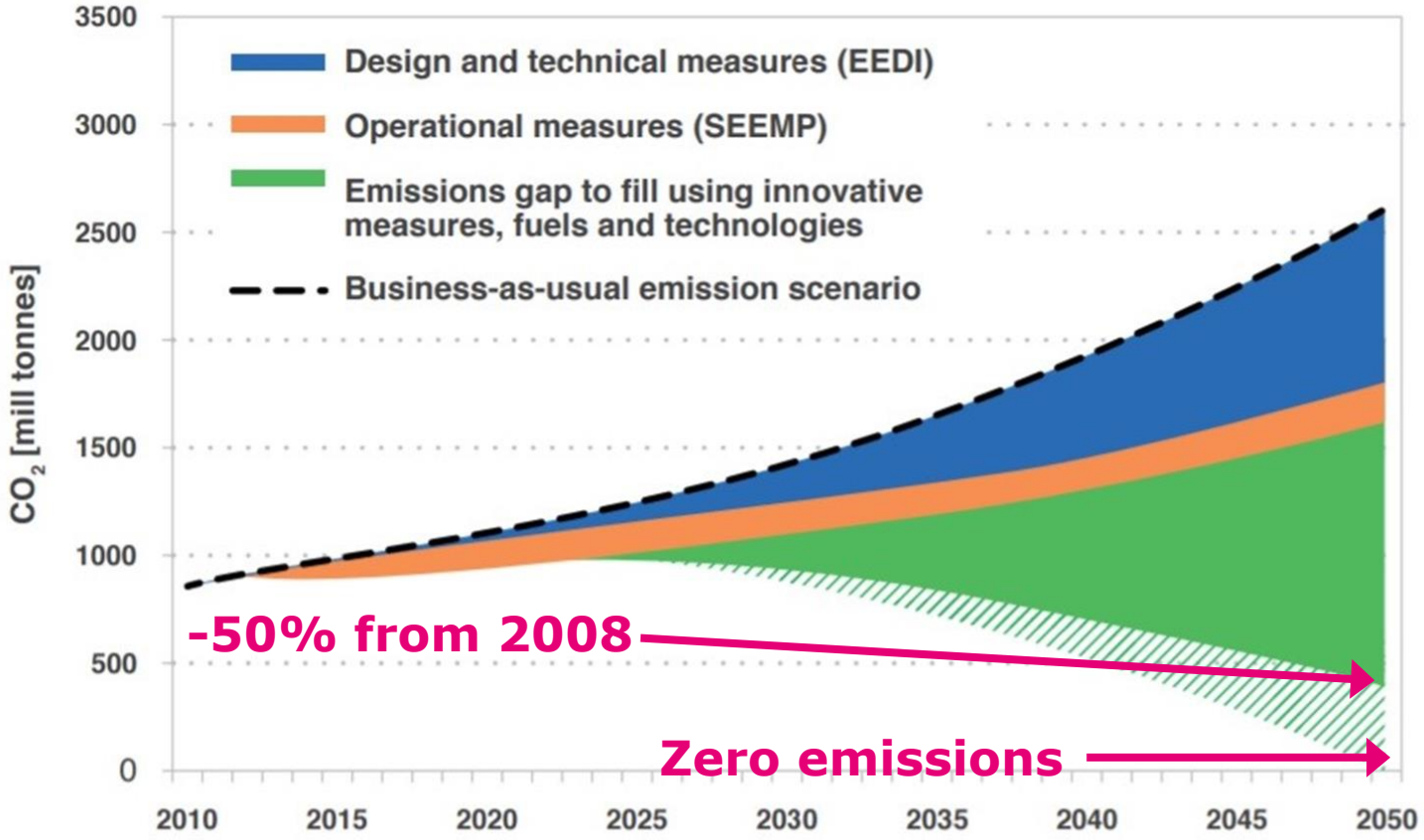
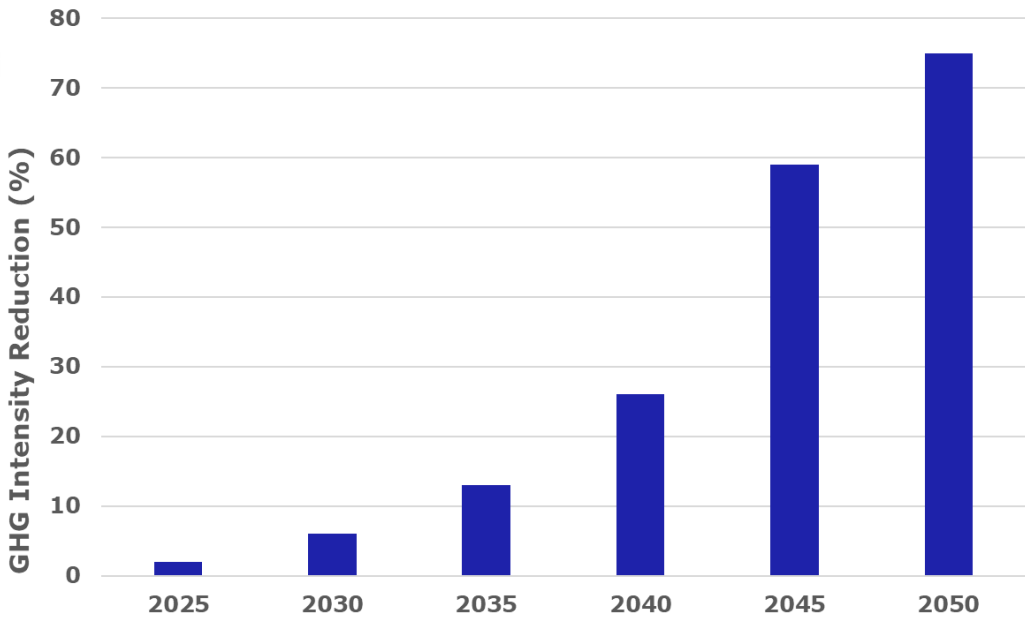
Current IMO and EU Policy Framework

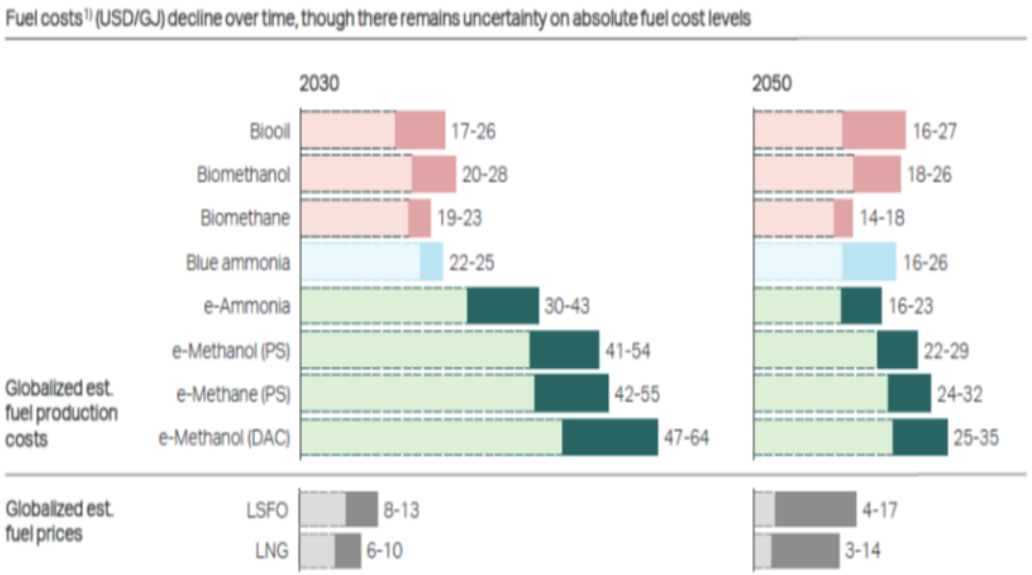
IMO intends to reduce the total annual GHG emissions (CO_2, CH_4, N_2O, water vapour, fluorinated gases) from international shipping by **at least 50% by 2050** vs 2008

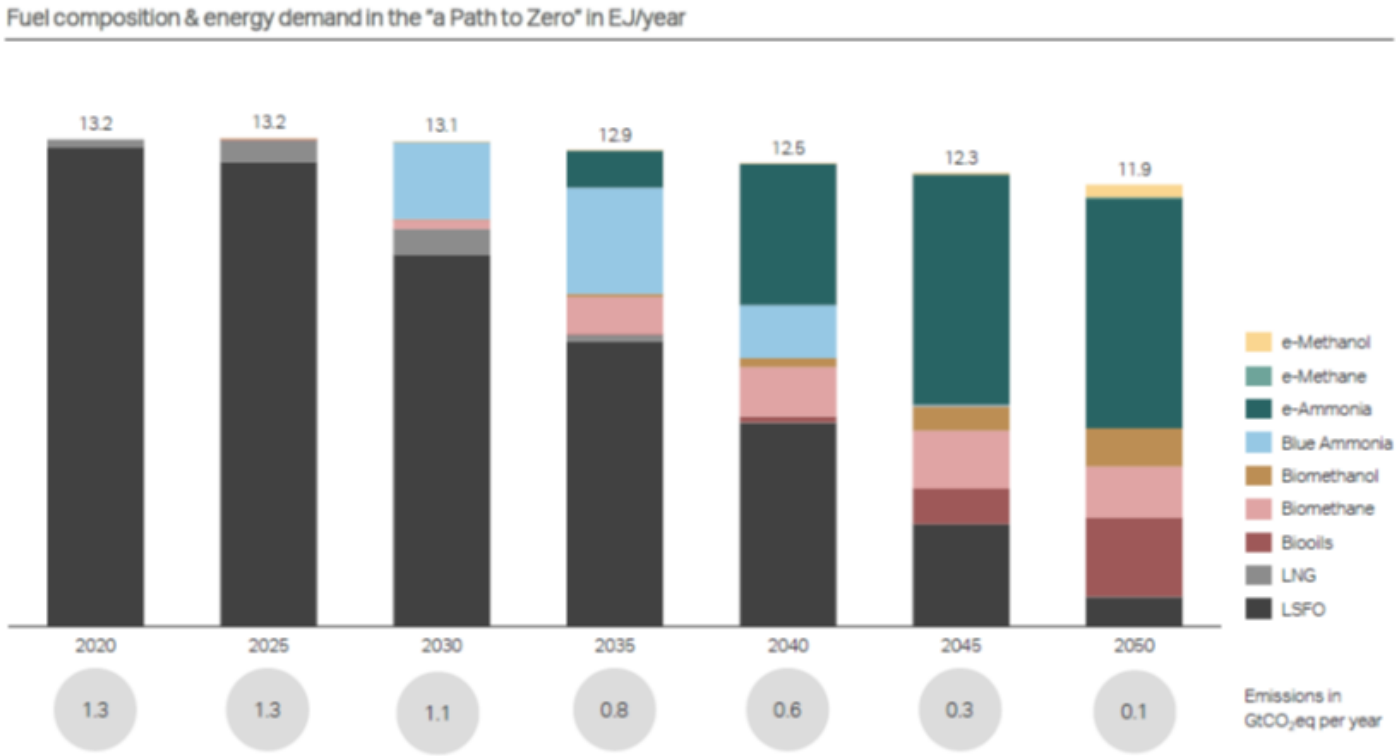


EC FuelEU Maritime: Proposed reduction in GHG intensity of the energy used on-board by a ship



MMMCZCS view on zero shipping path if ammonia enabled as a fuel





e-NH_3 $16-23/GJ by 2050

e-MeOH $22-29/GJ by 2050

Around 52% e-NH_3 by 2050

IRENA 1.5°C pathway has 43% e-NH_3

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Source: MMMCZCS, Position Paper, Fuel Option Scenarios, October 2021

Aviation

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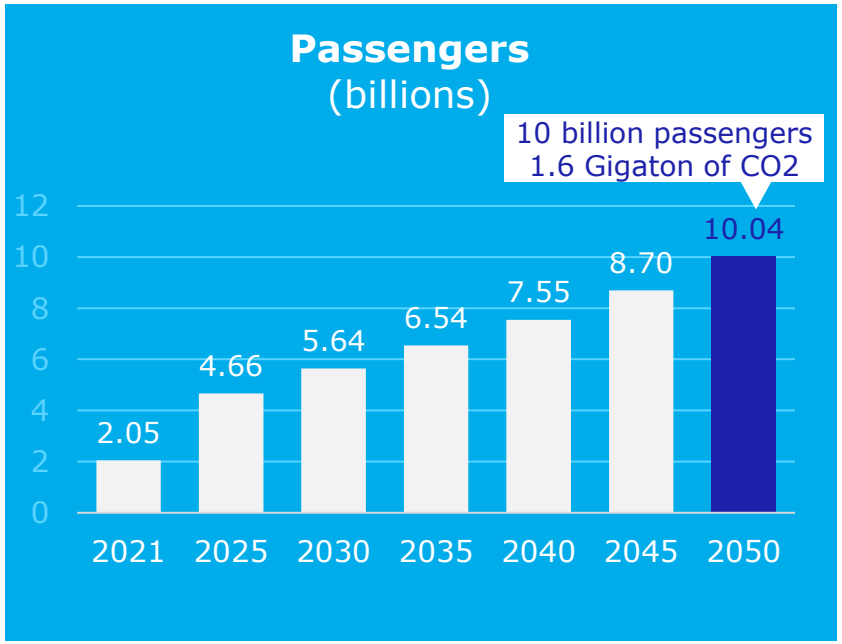
IATA member airlines recently pledged net zero by 2050

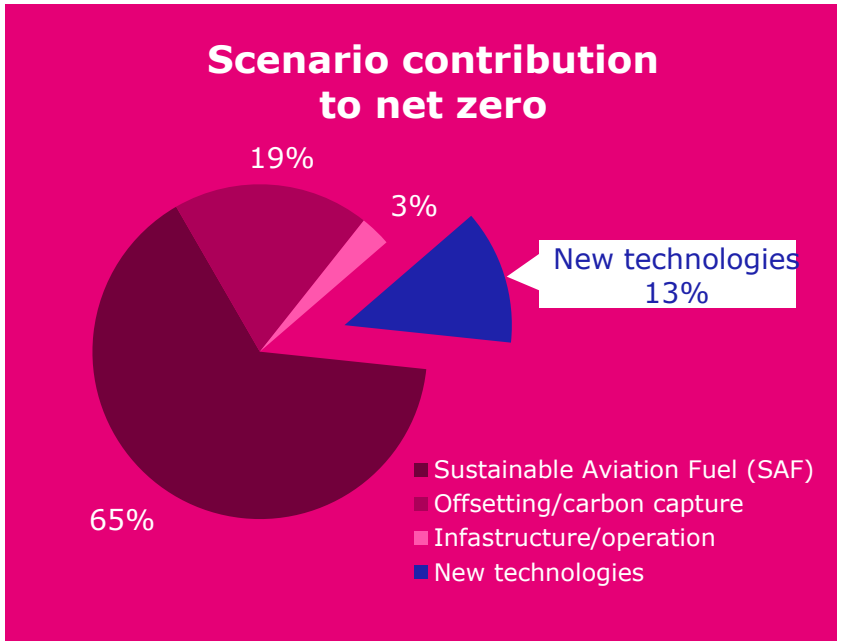
Sustainable Aviation Fuel (SAF) seen as a major enabler of this target

IATA estimates SAF use needs to increase 4,500x from today (~ 0.0017 mb/d, to 7.8 mb/d)

The Challenge: Forecasted increase of air transport passenger traffic



The plan: Contribution to achieving Net Zero Carbon in 2050



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

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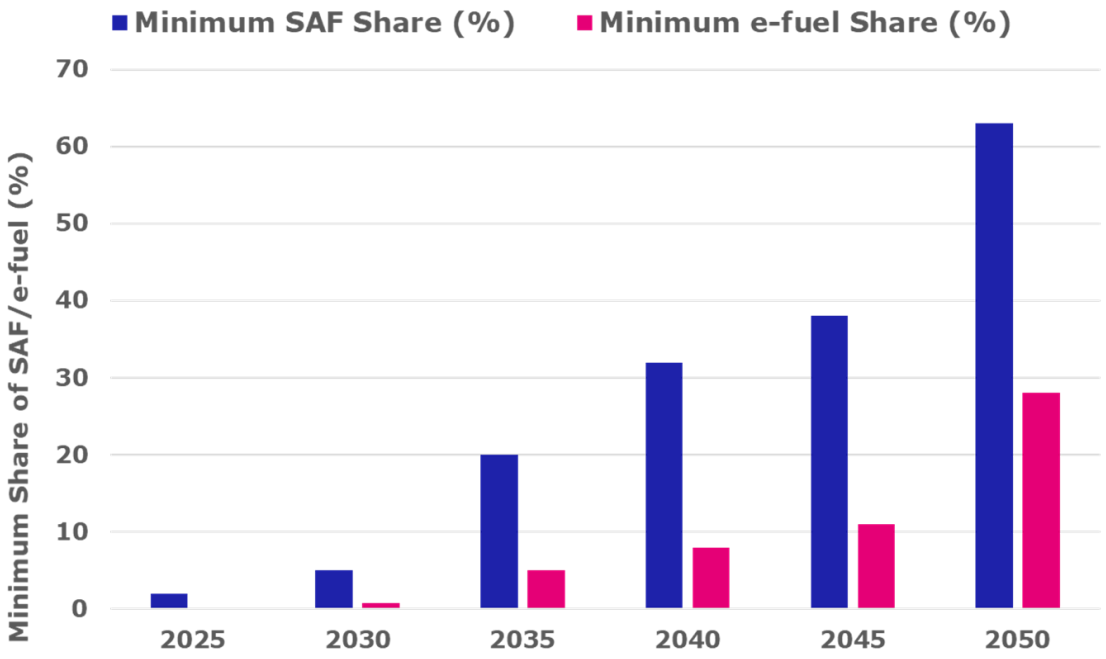
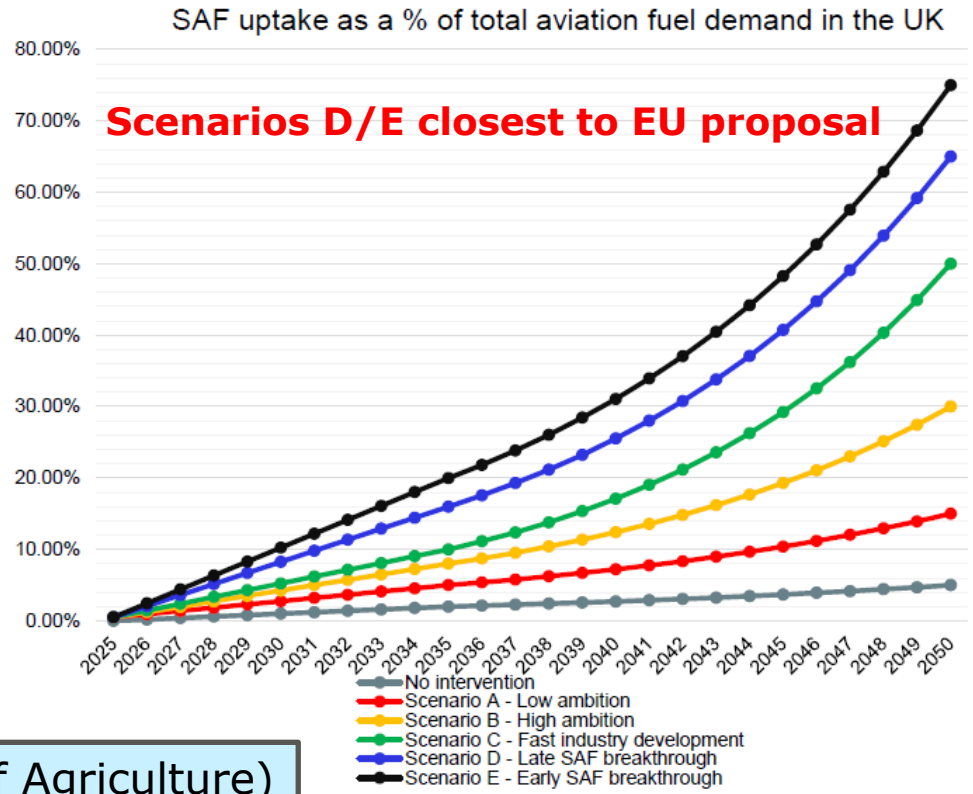
Source: IATA

SAF mandates are being proposed to accelerate its uptake

European Commission "Fit for 55": Proposed SAF Mandate for planes fuelling at EU airports



UK Govt scenarios for incoming UK SAF mandate – currently under consultation



US SAF Grand Challenge (led by DoE, DoT, Dept of Agriculture) aims to reduce the cost, enhance the sustainability, and expand the production and use of SAF while:

- Reducing LCA GHG emissions by at least 50%
- Enabling 100% SAF use across entire US fuel demand by 2050 (130bn L pa), with an interim 2030 SAF target of 11bn L pa

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SAF will play a key role, but what about H_2?

1st passenger carrying flight with 100% SAF on Dec 1st 2021

Chicago to Washington DC

Enabled by JM technology

Increasing focus on the potential of H_2 to decarbonise aviation

Combustion for long haul
Maybe FC for regional

Airbus targeting 2035 for commercial H_2 combustion application, with trials scheduled for middle of this decade

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Conclusions

LDV well on the way with BEV uptake

HDV focus on BEV and FCEV, with H_2 ICE investigations underway

Rail already largely electrified

Ammonia and methanol-based routes for marine

SAF and H_2 for aviation

There are routes to decarbonise all sectors of the transport network by or shortly after 2050

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Q&A

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