Fuelling the Future – Hydrogen as an energy carrier

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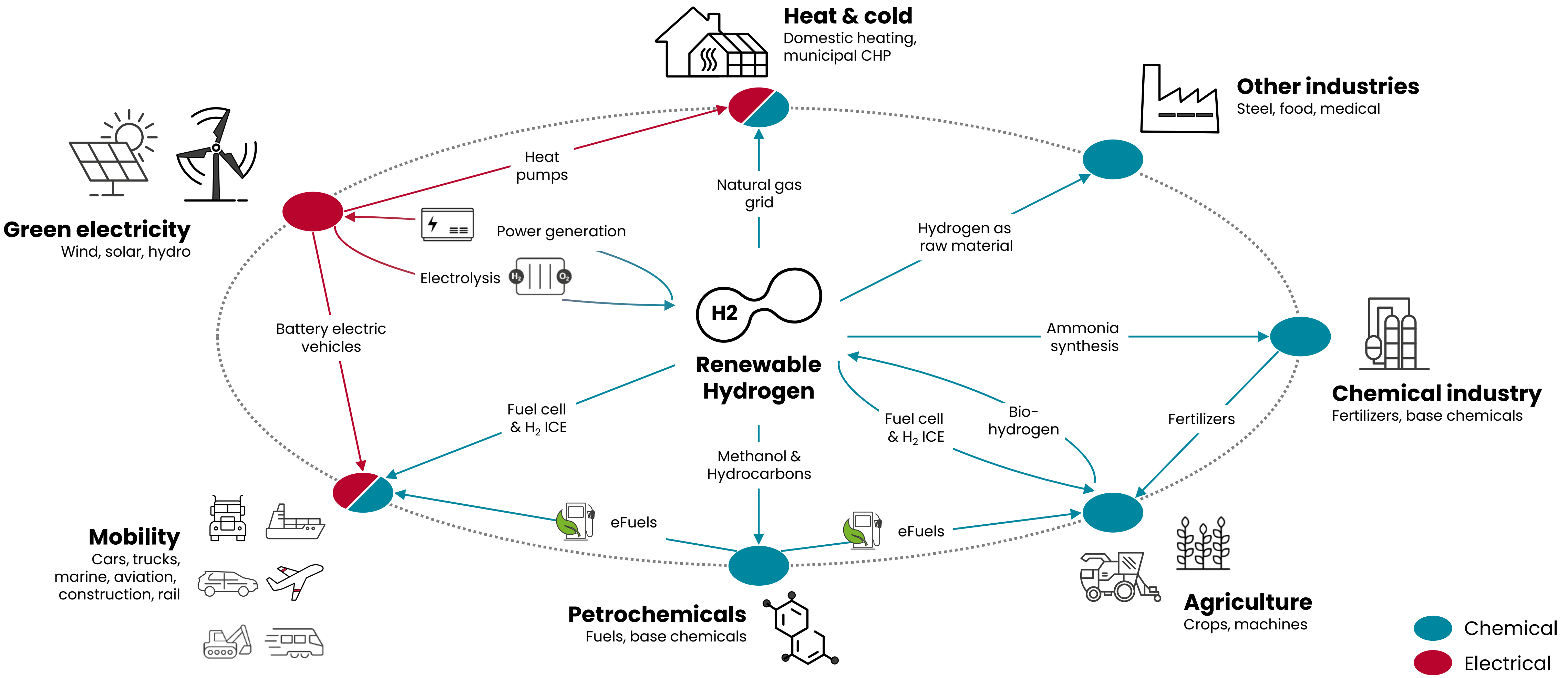
Future Propulsion Conference

Day 1 | Hydrogen Session | Imperial Suite

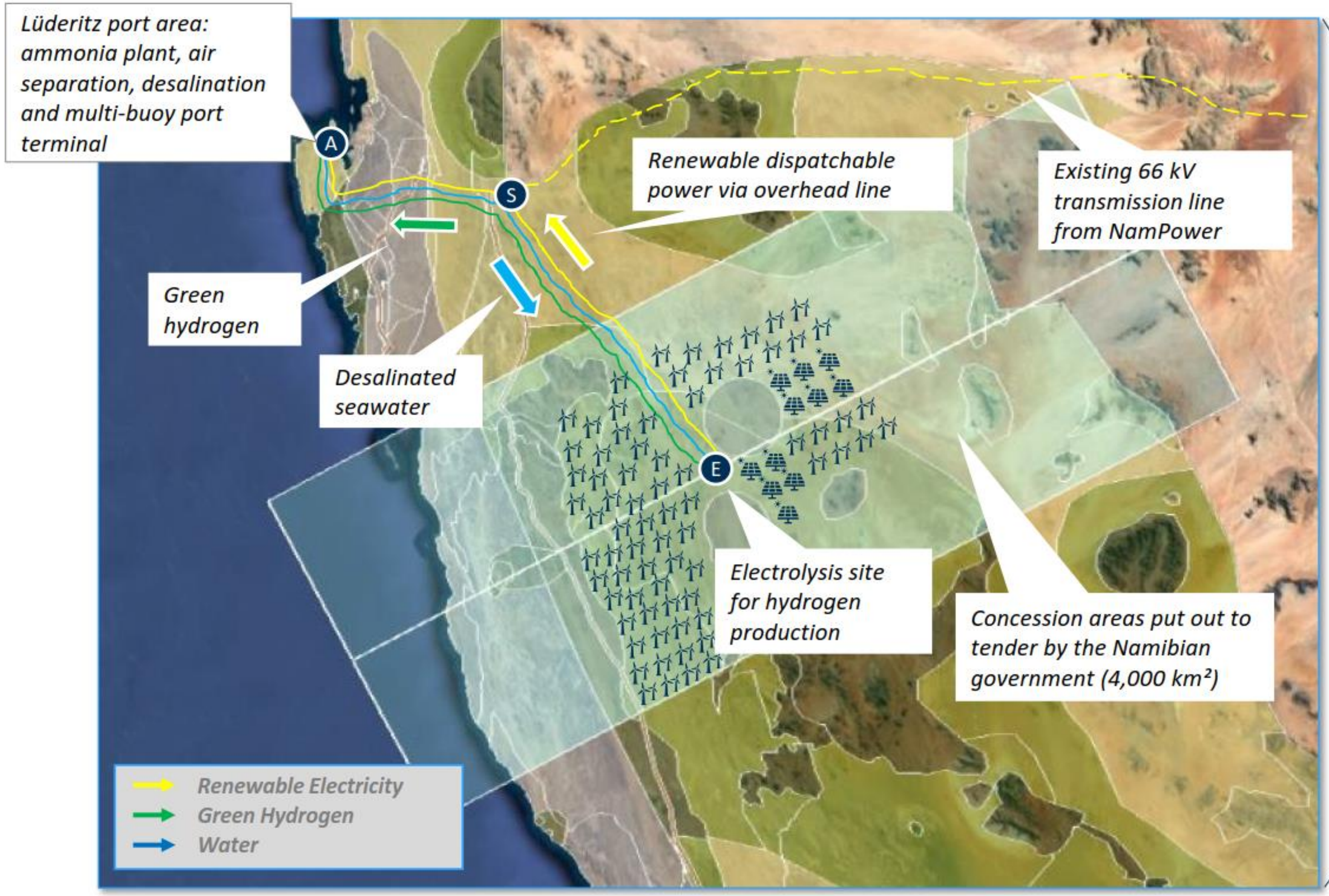
Hydrogen is the integral part of future energy systems, enabling deep decarbonization

HYDROGEN AS FUTURE ENERGY CARRIER



Source: FEV

Large scale green hydrogen plant project Hyphen in Namibia – using wind and solar power; closely connected to Lüderitz port for shipment



Average wind speed:
> 10 m/s (like offshore)

Solar: 2 600 – 2 800 full-load hours p.a. (only 1 000 in Germany)

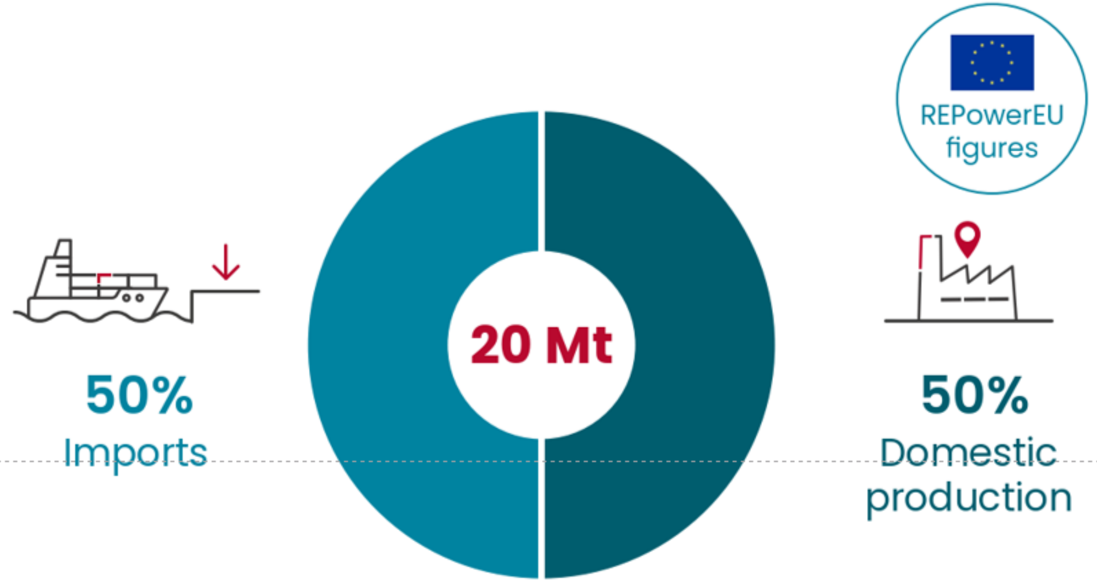
Link to Hyphen video: https://hyphenafrica.com

Source: Enertrag - Zero CO_2 Mobility Conference 2023

With its Hydrogen Strategy and RePowerEU, the EU has committed to ambitious hydrogen infrastructure targets

EU HYDROGEN STRATEGY & REPOWEREU

EU hydrogen supply targets



EU hydrogen corridors (domestic production)

Corridor A:
Nordic & Baltic: 51 TWh

Corridor B:
East Southeast Europe: 84 TWh

Corridor C:
North Africa &
Southern Europe: 70 TWh

Corridor D:
Southwest Europe: 61 TWh

Corridor E:
North Sea: 69 TWh

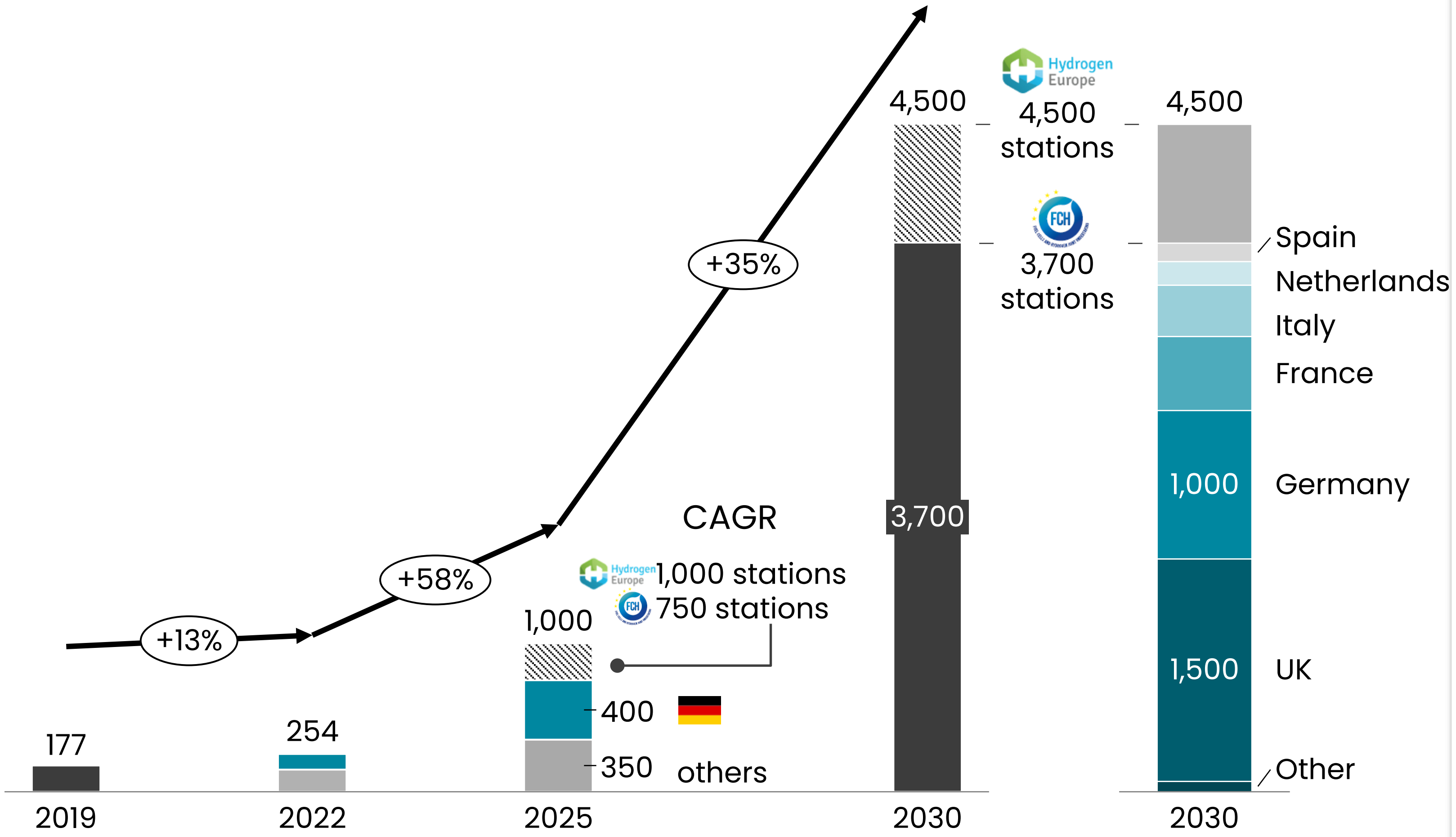
10 million tonnes of **domestic renewable hydrogen** production by **2030**

Source: EU, FEV

Especially Germany and UK pursue a progressive hydrogen infrastructure strategy; FCH and Hydrogen Europe studies predict >3,700 stations for 2030

EU HYDROGEN INFRASTRUCTURE

STATUS 2023



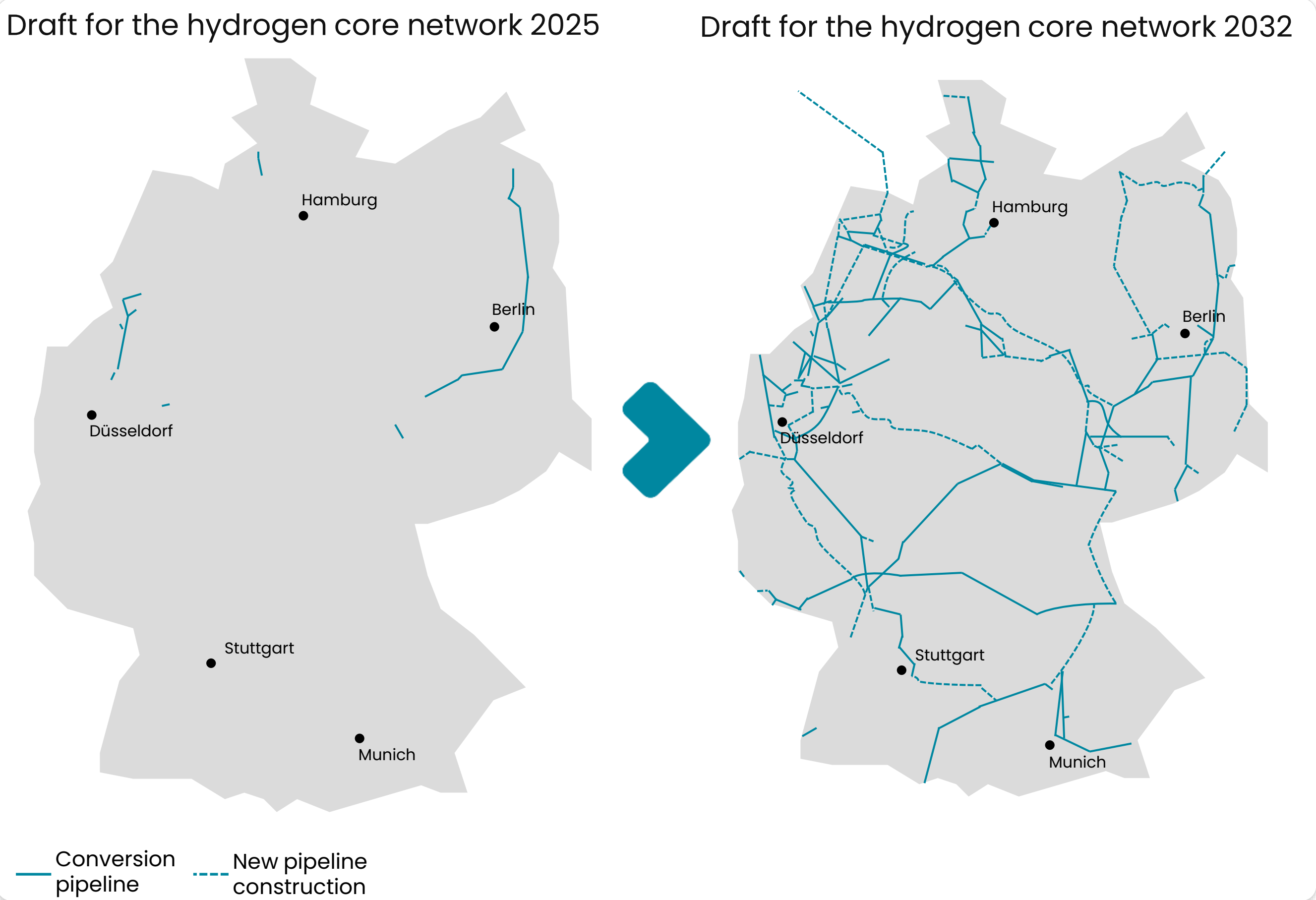
- **Hydrogen refueling infrastructure recently experienced strong growth**
- Already having the largest share of H_2 stations in Europe, Germany intends to reach 400 stations by 2025, investing up to $400 mn
- Especially in **UK & Germany, infrastructure development** is promoted by public-private partnerships
- **FCH developed an H_2 station roadmap** forecasting 750 (2025) / 3700 (2030) hydrogen fuel stations; Hydrogen Europe shows more progressive numbers with 4,500 stations by 2030
- Current H_2 stations are generally suitable for light-duty vehicles but new designs/upgrades are needed to fully support MD & HD vehicle refueling

1) FEV estimation based on numbers of individual countries

Source: H2stations.org, h2-mobile, FCH, Hydrogen Europe, Shell, LBST, TÜV SÜD, Brintbiler; GOV.UK, CertifHY, h2me, theregister, h2moves.eu, MobilityHydrogenFrance, FEV

Starting with the first pipeline conversion in 2025, the hydrogen core network will be progressively built up until 2032 to a length of 9,700 km

PRESENTATION OF THE PLANNED EXPANSION OF THE GERMAN HYDROGEN NETWORK FROM 2025 TO 2030



- The **ramp-up** of the **hydrogen network** is a **crucial** factor in achieving advanced climate goals, given the current geopolitical situation and rapidly rising energy price
- The FNB Gas e.V. submitted a draft for the hydrogen core network expansion to the Federal Network Agency and the Federal Ministry for Economic Affairs and Climate Protection
- **Goal:** Grid operators will be able to commence the construction of hydrogen grids and the conversion of lines starting in 2025
- Key data of the planned hydrogen core network:
  - **Total length** of the optimized core network: **9,700 km**
  - Proportion of **converted natural gas pipelines** in the core network: **about 60%**
  - Investment costs: **€19.8 billion**
  - Feed-in capacity: 100 GW
  - Withdrawal capacity: 87 GW

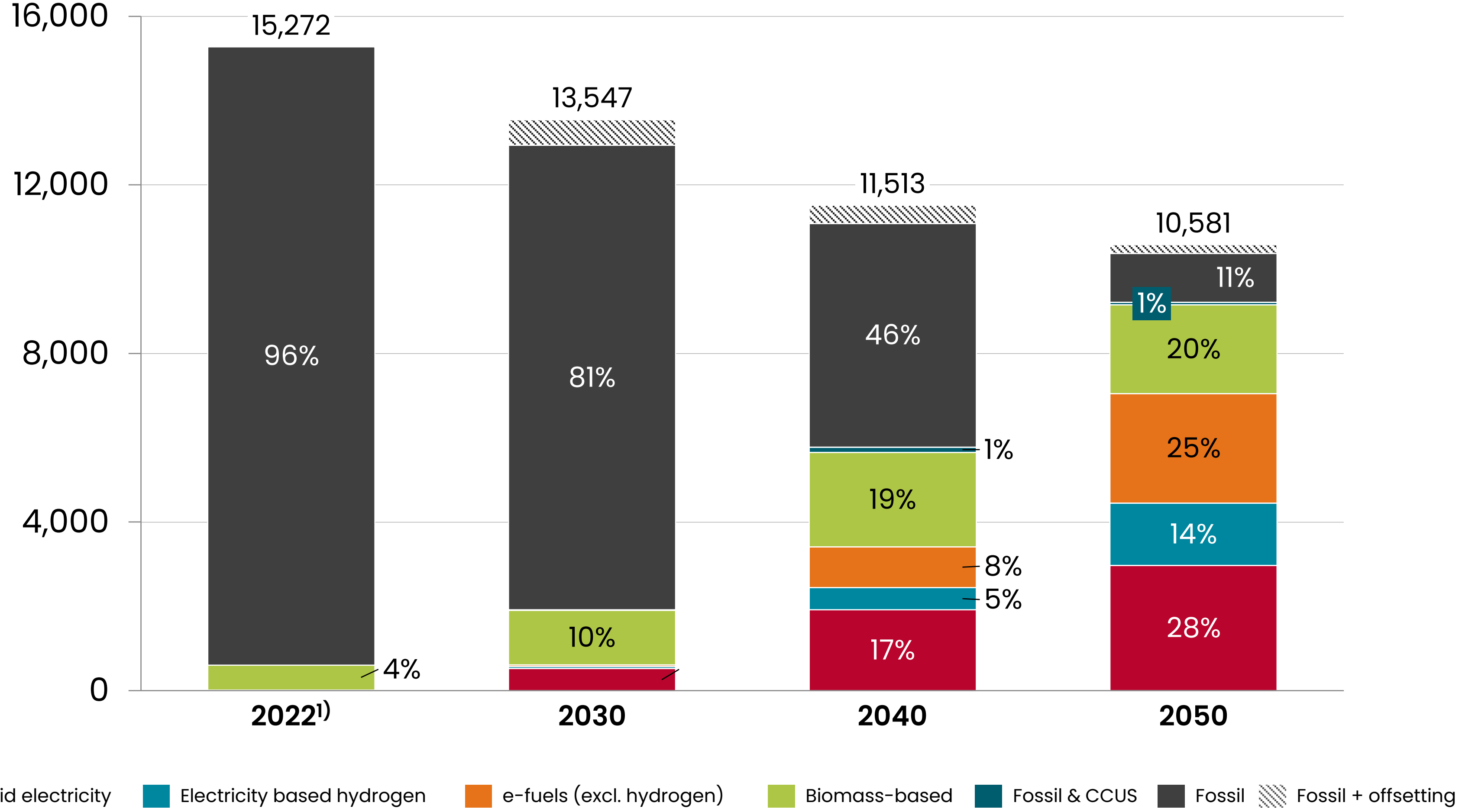
Source: FNB Gas e.V.

THE ROLE OF HYDROGEN IN THE TRANSPORT SECTOR

›50 % of the energy demand in 2050 will still be provided by liquid hydrocarbons

FEV CONSULTING

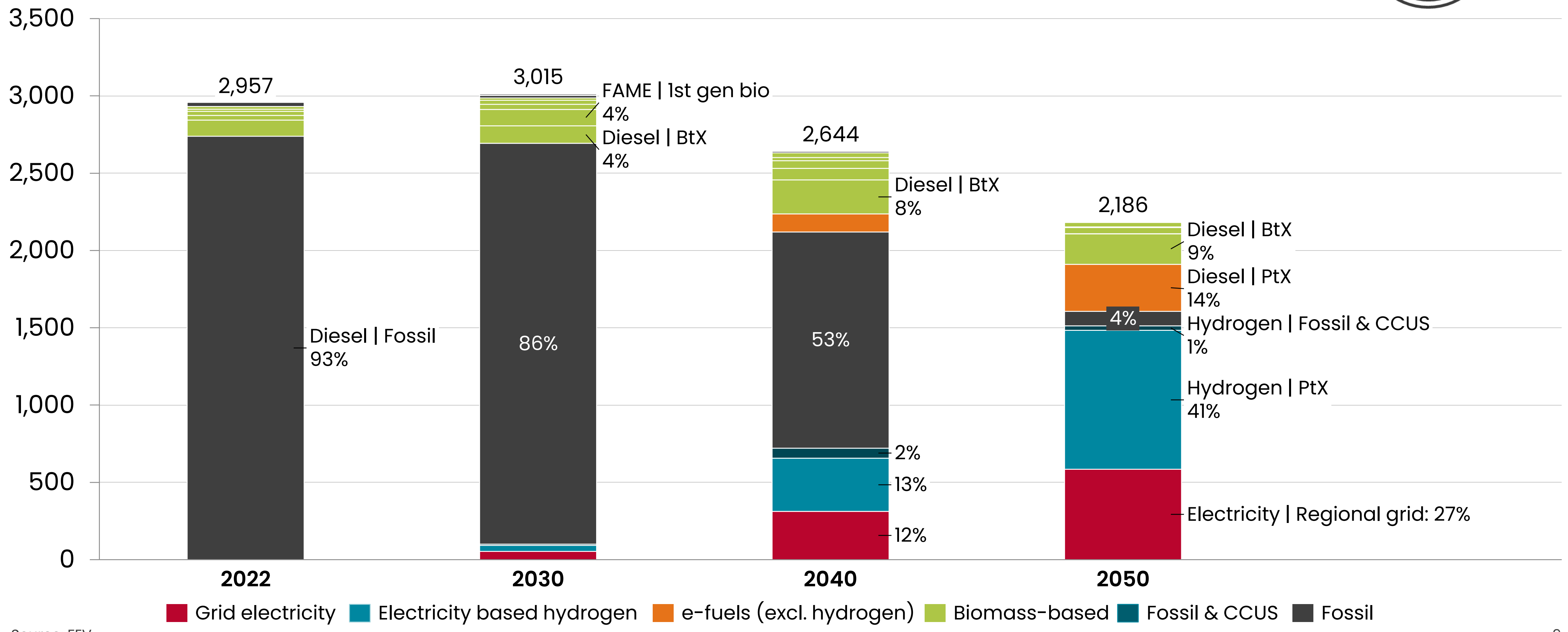
Final energy carrier demand in transport sector (PJ)



By 2050, green hydrogen will be the most important final energy carrier for commercial vehicles in the EU

FINAL ENERGY CARRIER DEMAND – COMMERCIAL ON-ROAD VEHICLES

Final energy carrier demand in commercial vehicles (PJ)



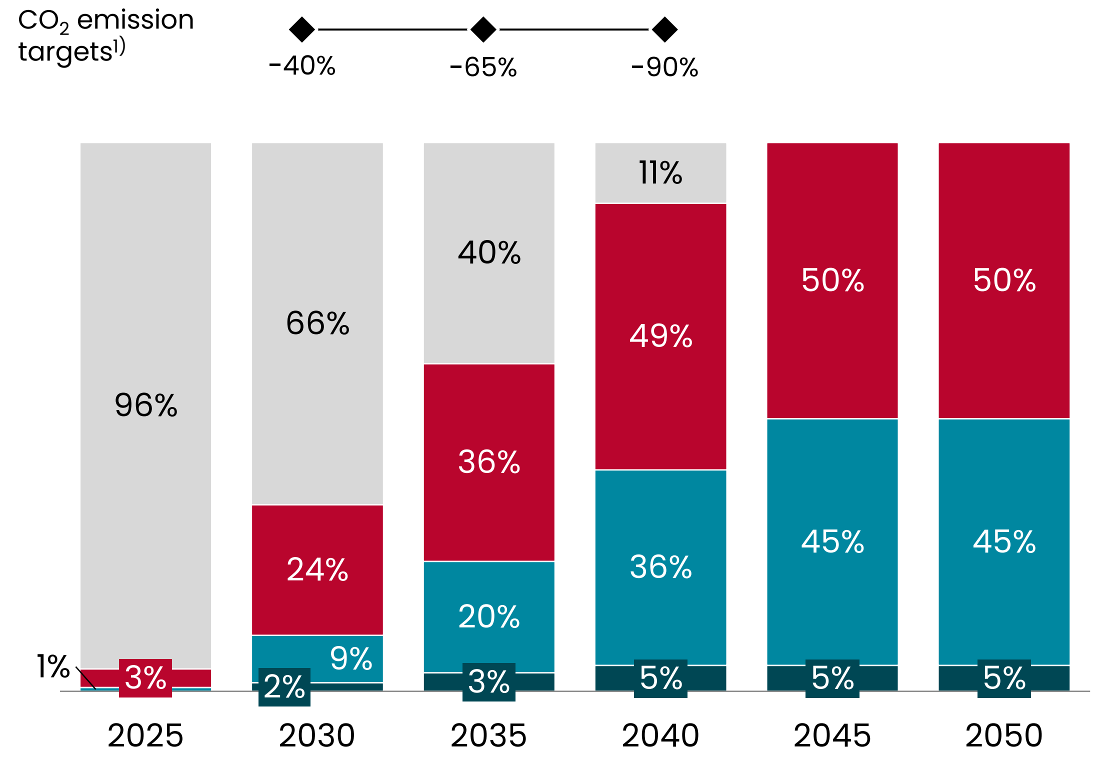
Source: FEV

Strong transformation of commercial vehicle fleet expected, with battery-electric powertrains dominating

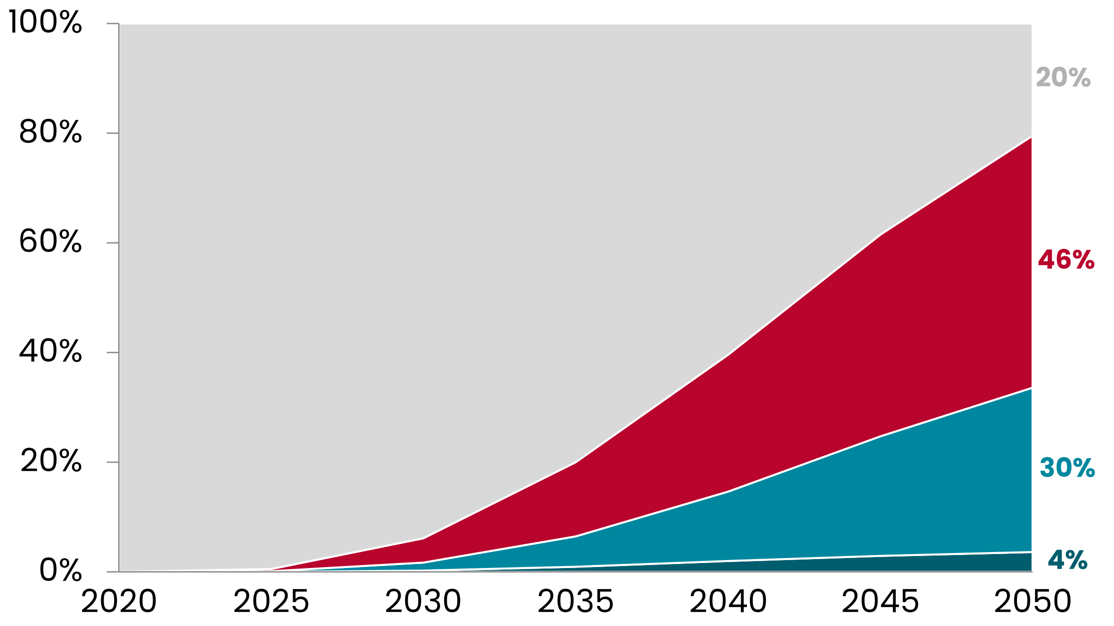
COMMERCIAL ON-ROAD VEHICLES – ACCELERATED TRANSFORMATION SCENARIO

Powertrain Sales Forecast

Sales in '000 units



Fleet development

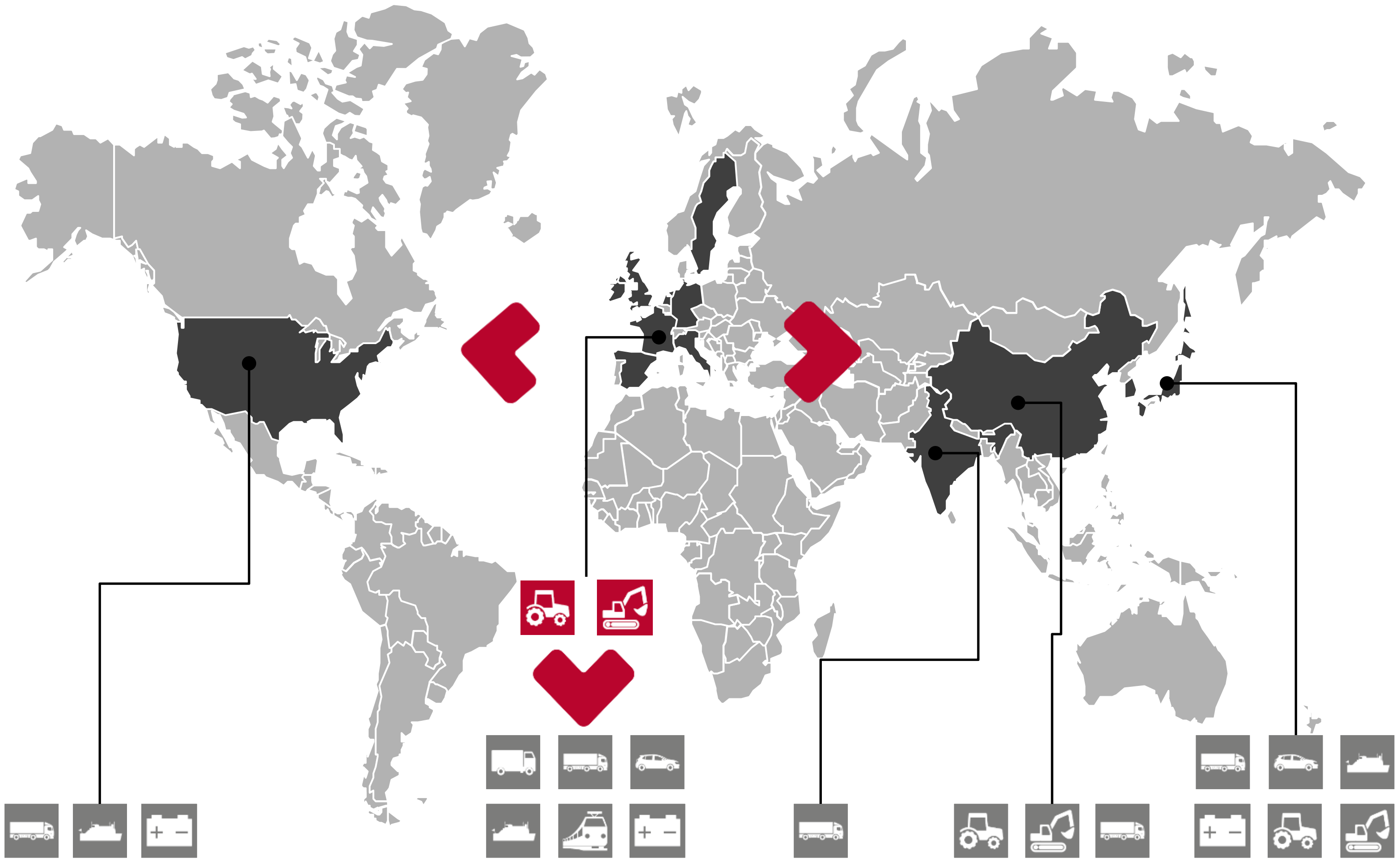


ICE & hybrids | Battery Electric | Fuel Cell | H_2-ICE

1) CO2 targets (tailpipe emissions values with 2019 as reference) based on regulation in force as of 03/2023, 2025 targets expected for HD vehicles only, 2030+ targets for MD & HD vehicles
Source: FEV

The interest in H2-ICE originated from off-road segment in Europe has spread out to various applications and regions around the world

WORLD INTEREST OVERVIEW



Main Drivers

- MD/HD market in Europe is pushing the development of hardware, esp. direct Injection system
- Hardware can be used in other classes as well and makes business case attractive
- Certain applications see major drawbacks for fuel cell
  - OFFROAD
  - AGRICULTURE
- For larger bore size dedicated injectors might be developed at a later timing but PFI solutions available soon

H_2-ICEs are increasingly considered as ZEVs by overarching regulations; some markets still do not include H2-ICEs but might adapt in future

FEV

H2-ICE – REGULATORY CONSIDERATION AS ZEV

	EU	UK	US	CN
	3 types of ZEVs: 1. No combustion engine 2. Combustion engine with less than 3-5 g/tkm[1] or 5-1 g/pkm[1] emissions from fuel according to Vecto simulation – Fulfilled by pure H_2-ICE 3. Combustion engine with less than 1 g/kWh tailpipe emissions according to EU 595/2009 – Revised UN R49 (underlying test methodology) defines pure H2-ICE as 0g/tkm	• UK does not (yet) plan to recognize H_2-ICE as ZEV as regulation excludes vehicles that emit any CO_2 or "harmful pollutants" • Permission for H_2-ICE may occur due to industry interest and expected developments in EU	• Federal: – As of now not considered as ZEV – New EPA proposal for CO_2 emissions defines H_2-ICE as ZEV and considers it to be relevant for heavy-duty applications • ACT states: – As of now H2-ICE not considered as ZEV by CARB – Recently, discussions started to account H_2-ICEs as ZEVs	• Currently, H_2-ICE is not recognized as NEV in China • Calculation of CO_2 emissions using life cycle assessment (LCA) calculation is currently under discussion (would benefit H_2-ICE) • Draft LCA calculation already released for passenger cars • Introduction of LCA calculation for commercial vehicles is possible
H_2-ICE = ZEV?	✓ New EU emission regulation expected to define H_2-ICE as ZEV	? Not defined as ZEV yet – future alignment with EU regulation possible	✓ EPA GHG emission proposal (04/2023) ? CARB is actively discussing H_2-ICE	? Currently not defined as ZEV but possible introduction of LCA emission calculation would benefit H_2-ICE

1) Final value still under discussion
2) ACEA /DG CLIMA: Based on calculated zero emissions from fuel consumption (ignoring carbon in lubricant oil & SCR)

FEV SERVICES

EXPERIENCE . PROJECTS . OUTLOOK

feel evolution

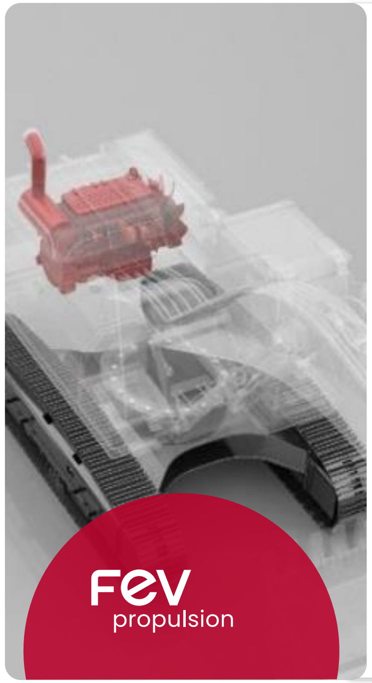
FEV offers the full range along the hydrogen value chain from production support through to application development

FEV

We are the innovation powerhouse for mobility, energy and software that fosters sustainability and a greater quality of life for all

Sustainable energy solutions

- H_2 electrolysis & infrastructure
- Energy storage
- Power2X & Bio2X
- Sustainability



Hydrogen ICE and fuel cell development

- Concept development
- Series development
- After-treatment
- Calibration

Technical and strategic consulting

- Market analyses
- Feasibility studies
- Cost assessment
- Benchmarking

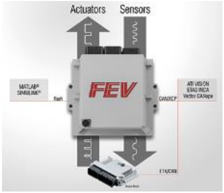
25 years of experience in hydrogen powertrain development

FEV

» SELECTED HIGHLIGHTS

HyPower Bora

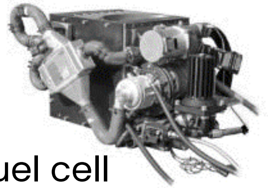
1998



Truck APU

2006

1st fuel cell control unit



Fuel cell range extender

2015

Since 2013 system integration
Function development, validation, calibration

1st FCEV benchmark

2016

Fuel cell electric multiple unit

2017

Commercial vehicle

2018

Fuel cell platform study

2019

2020

H2 ICE first firing PFI

H2 ICE first firing DI SCE

FEV Benchmark web shop

Hyundai Nexo benchmark

2021

Two European funded projects:

- StasHH Fuel cell standardization
- CoachHyfied Fuel cell coach operation

First H2 ICE demonstrator

Toyota Mirai II benchmark

DI Multi Cylinder Engine

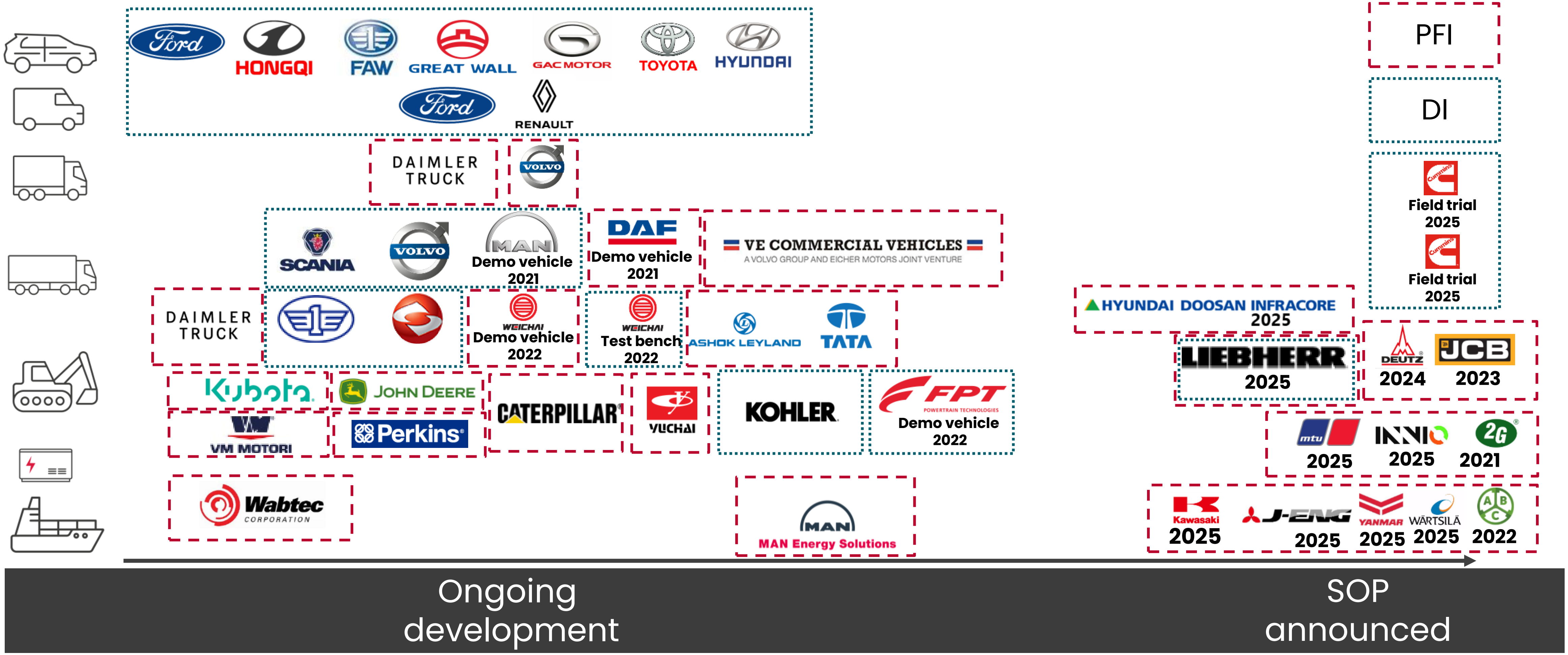
2022

BiFoilStack: Novel BPP stack

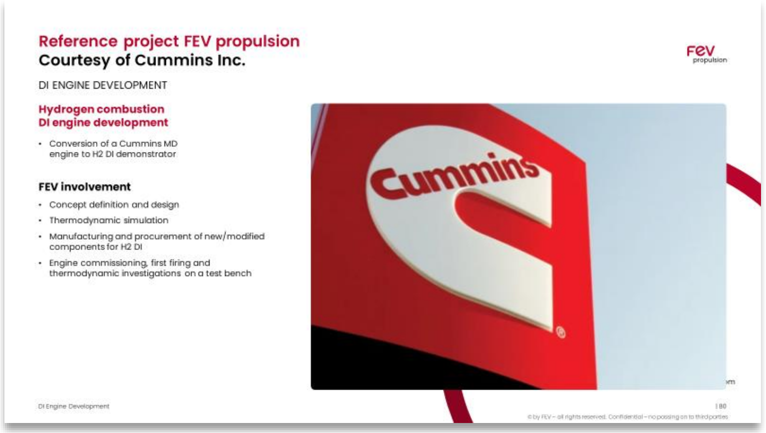
2024

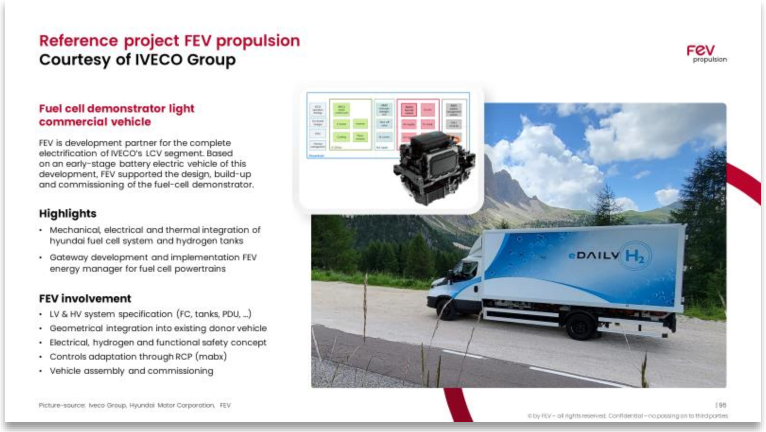
25+ test cells available globally

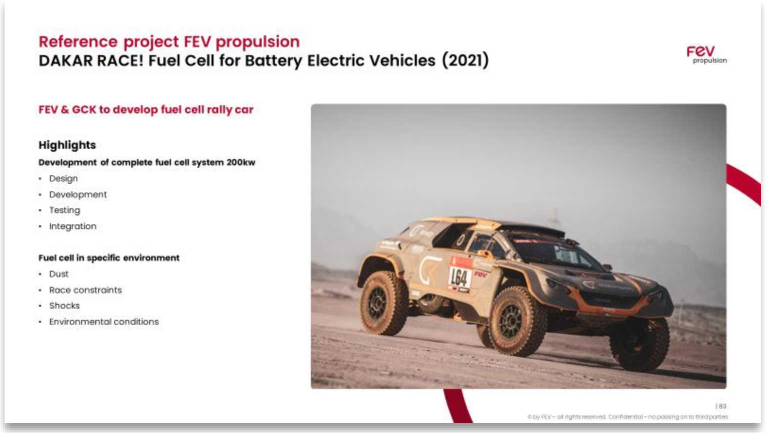
Publicly announced interest and investment in H_2-Engine development is now growing strongly amongst on-and off-highway industry players

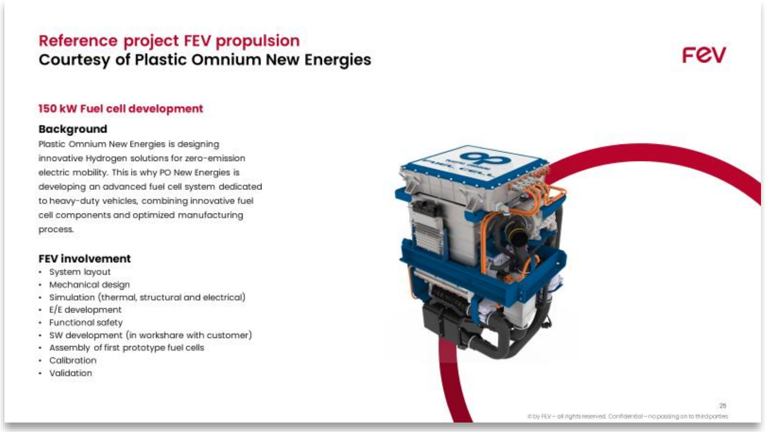


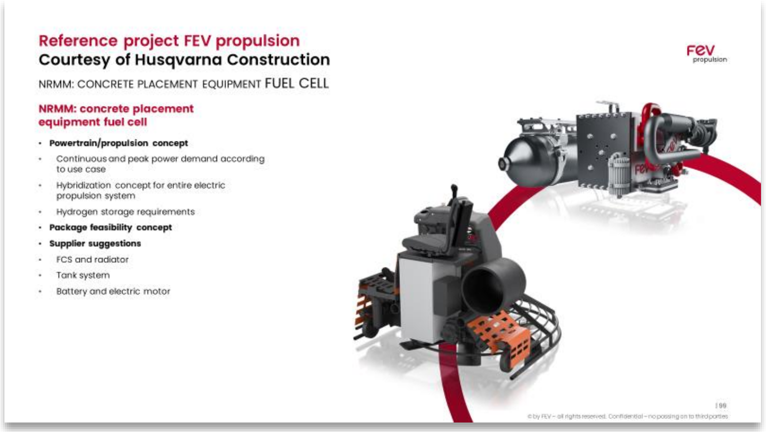
Examples of successful cooperation with our customers





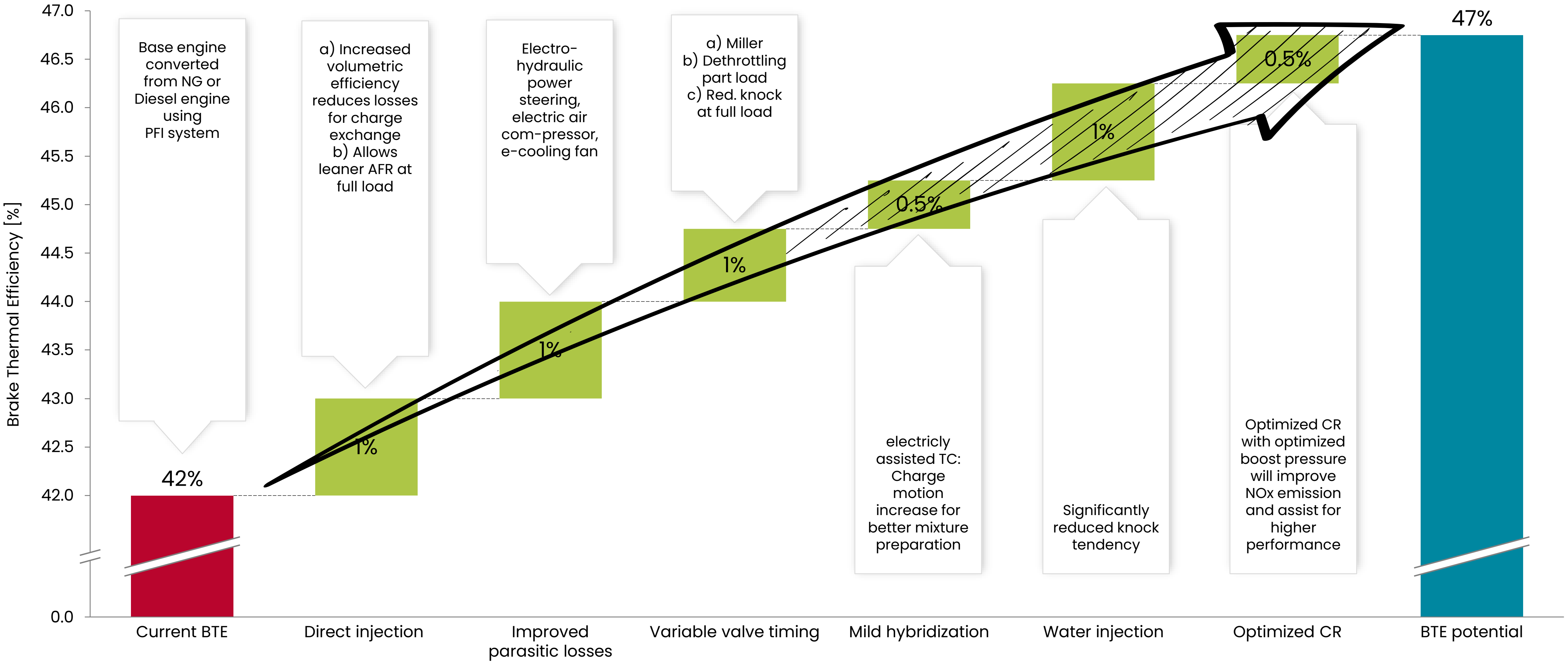






Thermal efficiency of ~47% for future high technology package DI engine is foreseen for hydrogen internal combustion engines

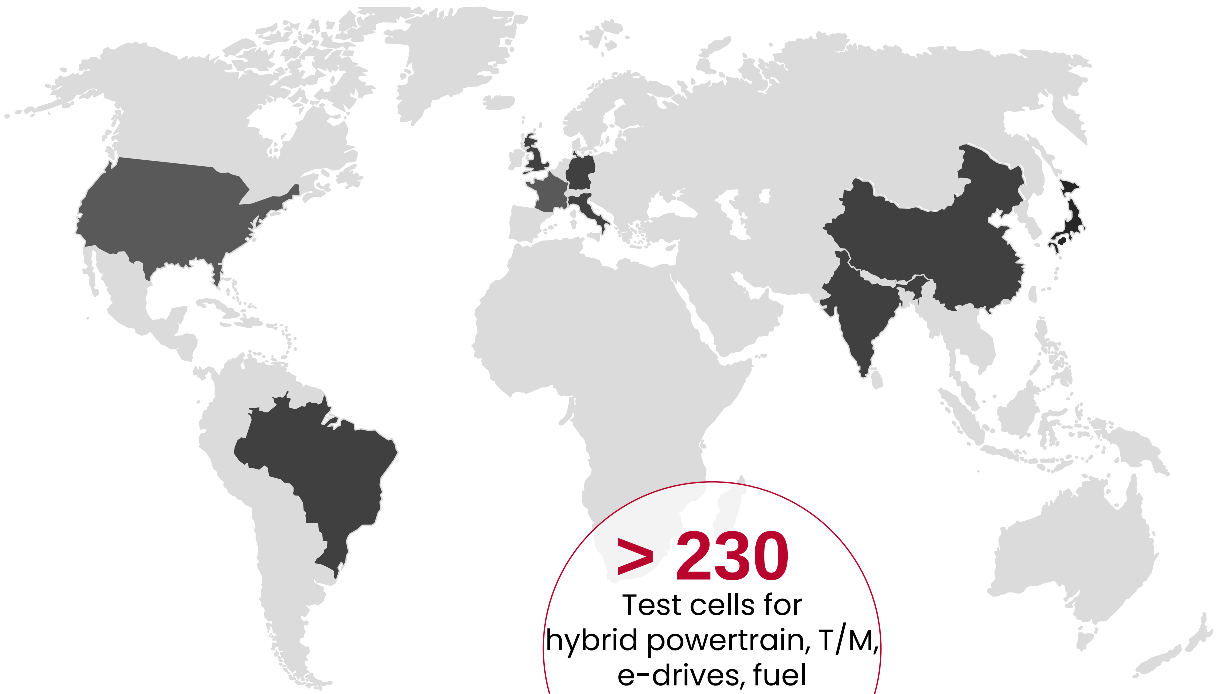
HYDROGEN COMBUSTION ENGINE – OUTLOOK



Source: FEV

Rapidly growing hydrogen propulsion system testing facilities at almost every FEV testing center with outlook for growth by > 70 % until 2024

OVERVIEW OF KEY FEV HYDROGEN TEST CENTERS



> 230
Test cells for hybrid powertrain, T/M, e-drives, fuel cells & battery packs

1	HQ Aachen, GER		14 H_2 test cells
2	Coventry, UK		5 H_2 test cells
3	Trappes/Rouen, FRA		3 H_2 test cells
4	Pune, IN		2 H_2 test cells
5	Auburn Hills, USA		2 H_2 test cells
6	Beijing, CN		1 H_2 test cell

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