

Solihull, 28 February 2024

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Prepared for



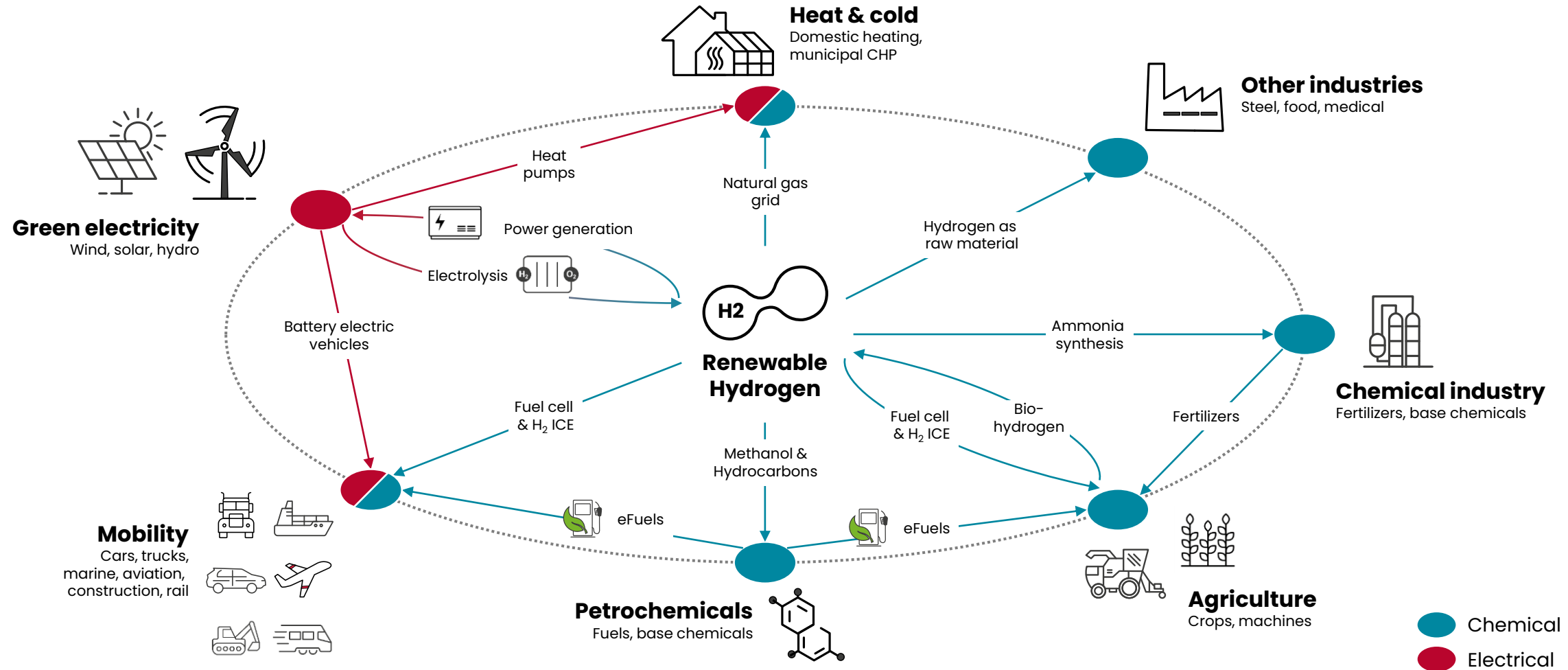
Day 1 | Hydrogen Session | Imperial Suite

The background of the slide is a photograph of a large, white, horizontal hydrogen storage tank with a blue spherical end. The tank is mounted on a concrete base. In the background, there are several wind turbines and solar panels under a clear blue sky. The text 'Fuelling the Future - Hydrogen as an energy carrier' is overlaid on the image in white, bold, sans-serif font, with the first part on a black rectangular background and the second part on a white background.

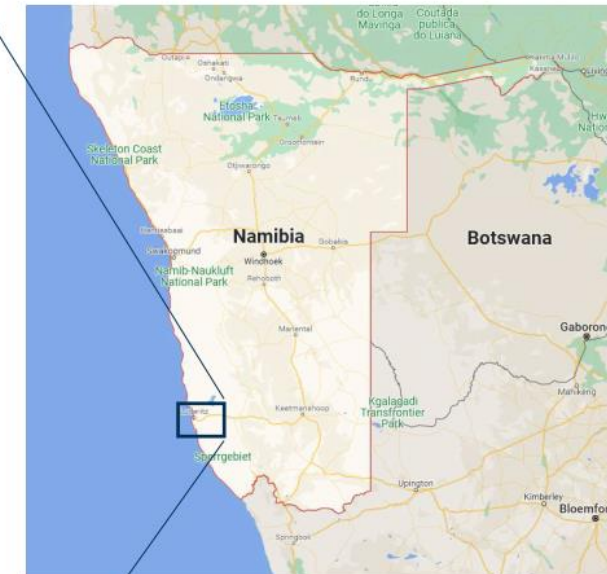
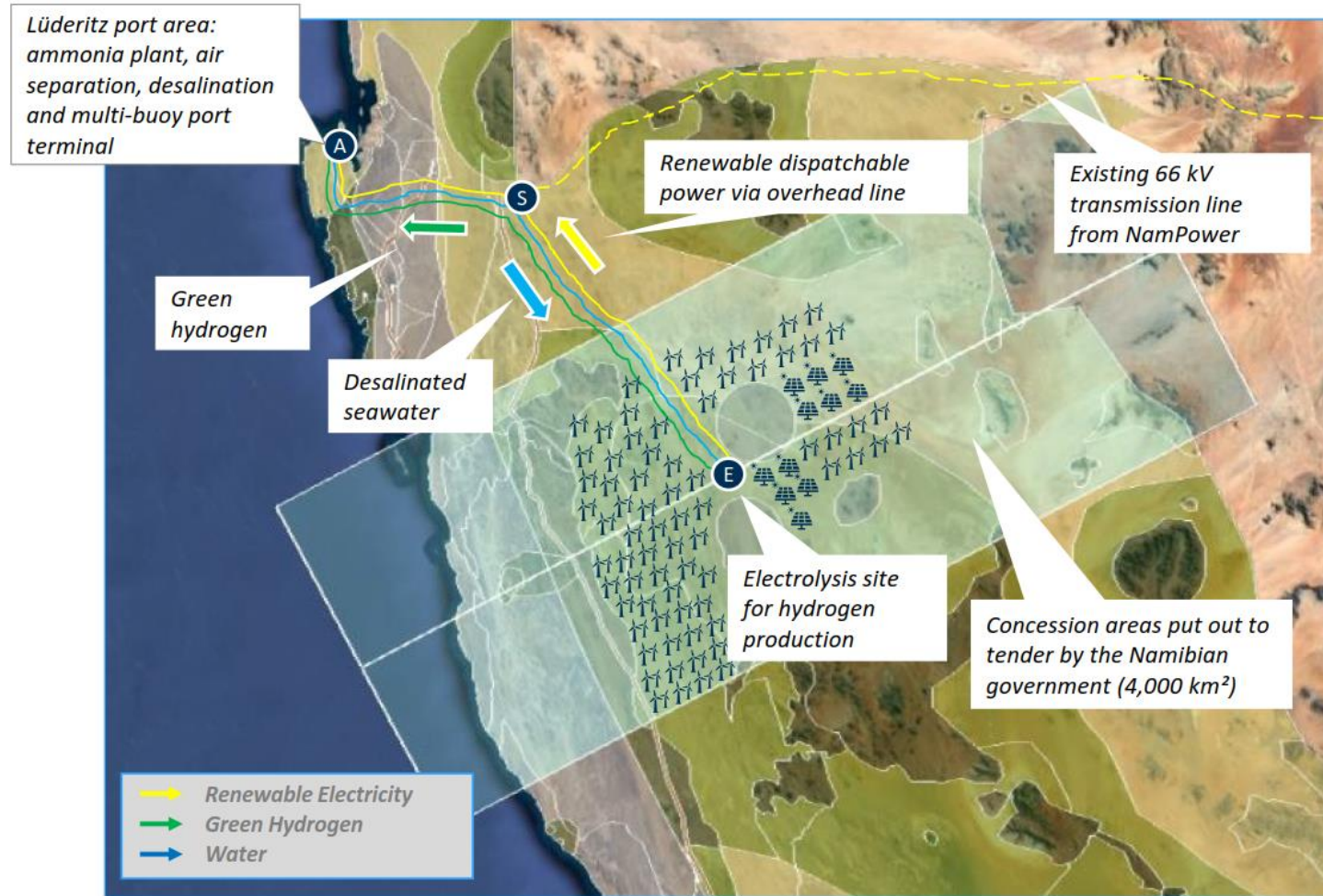
Fuelling the Future – Hydrogen as an energy carrier

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

HYDROGEN AS FUTURE ENERGY CARRIER



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)**

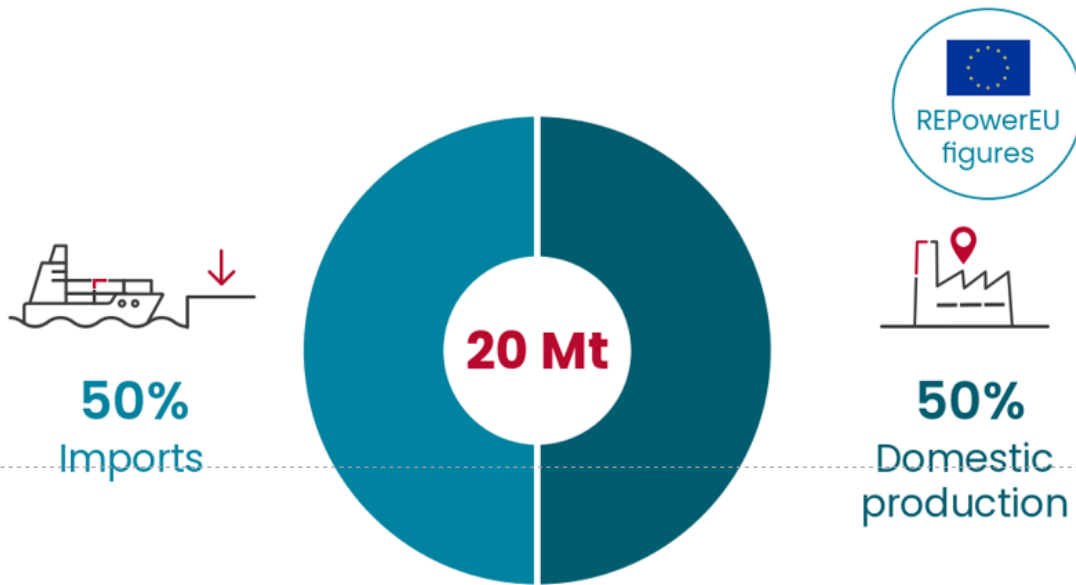
Solar: 2 600 – 2 800 full-load hours p.a. (only 1 000 in Germany)

Link to Hyphen video: <https://hyphenafrika.com>

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

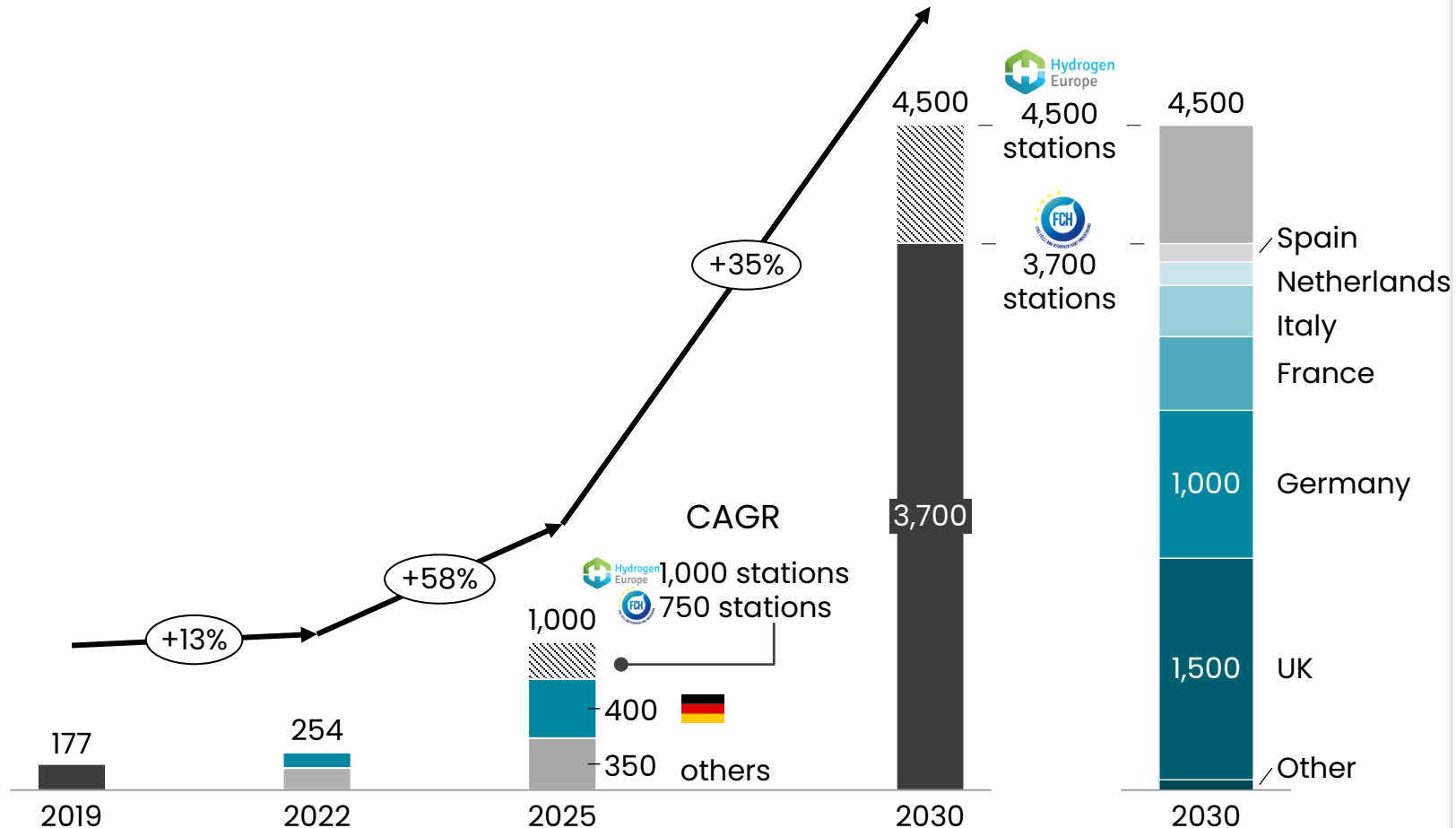
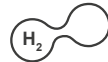
10 million tonnes of domestic renewable hydrogen production by 2030

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 H₂ 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 H₂ station roadmap** forecasting 750 (2025) / 3700 (2030) hydrogen fuel stations; Hydrogen Europe shows more progressive numbers with 4,500 stations by 2030
- ▶ Current H₂ 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

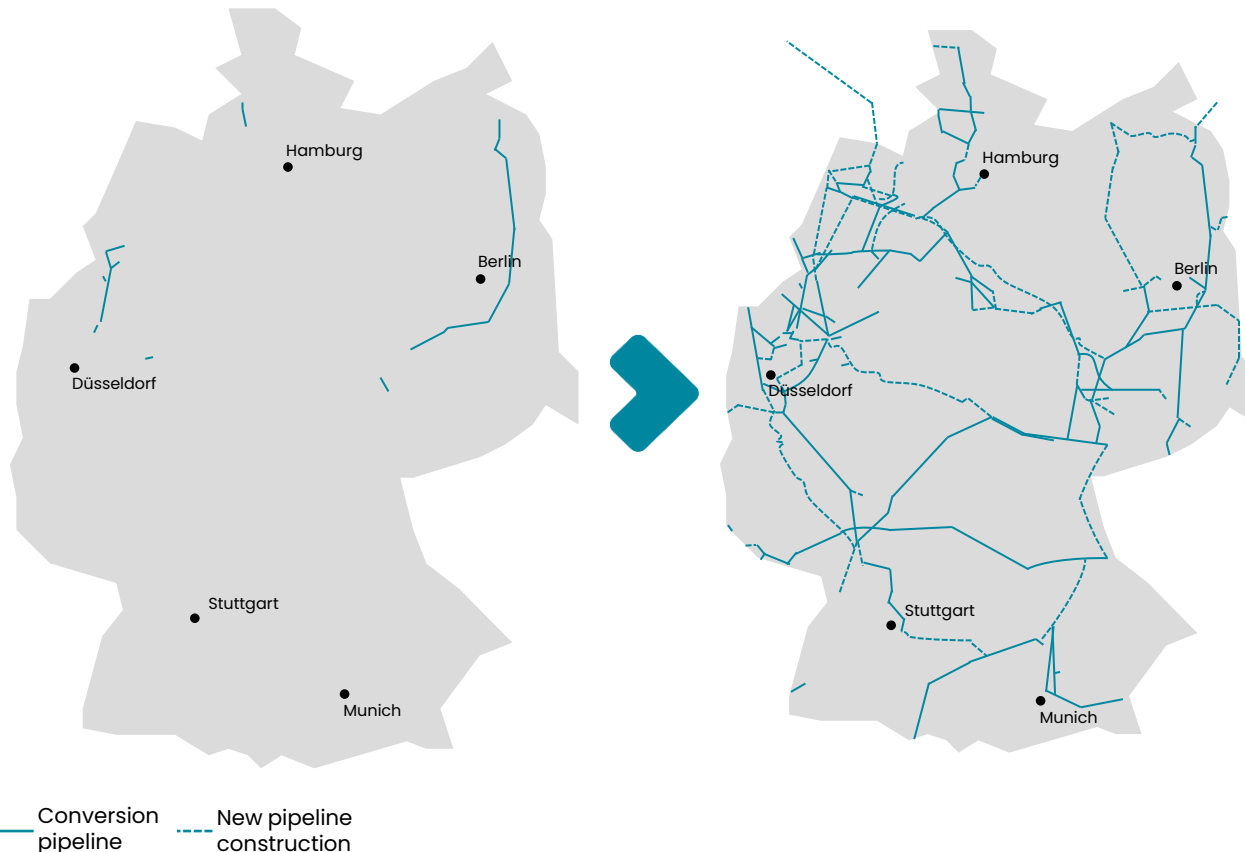
Starting with the first pipeline conversion in 2025, the hydrogen core network will be progressively built up until 2032 to a length of 9,700 km

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



Draft for the hydrogen core network 2025

Draft for the hydrogen core network 2032



- ▶ 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

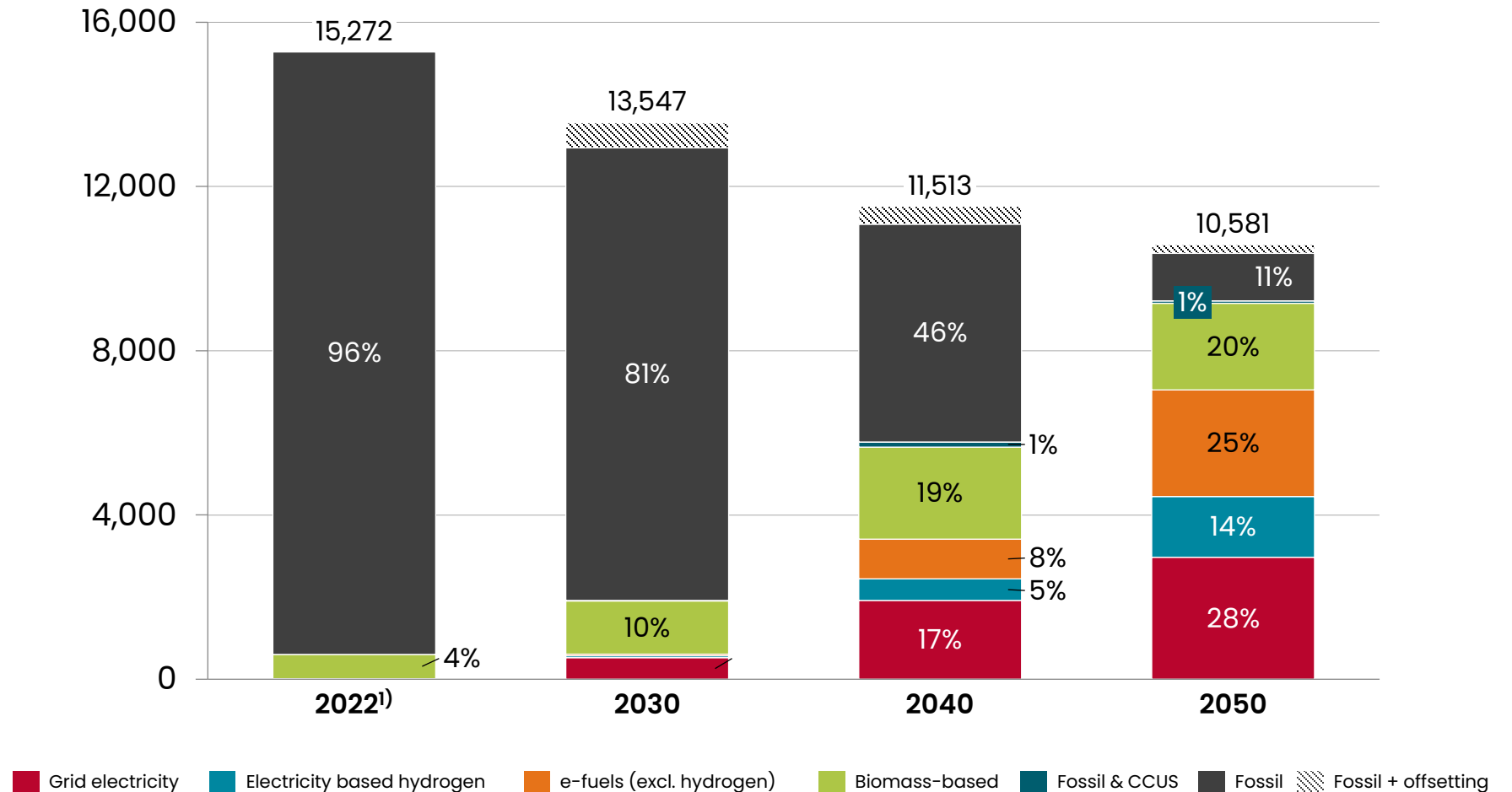
THE ROLE OF HYDROGEN
IN THE TRANSPORT SECTOR





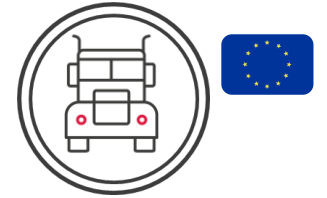
>50 % of the energy demand in 2050 will still be provided by liquid hydrocarbons

Final energy carrier demand in transport sector (PJ)

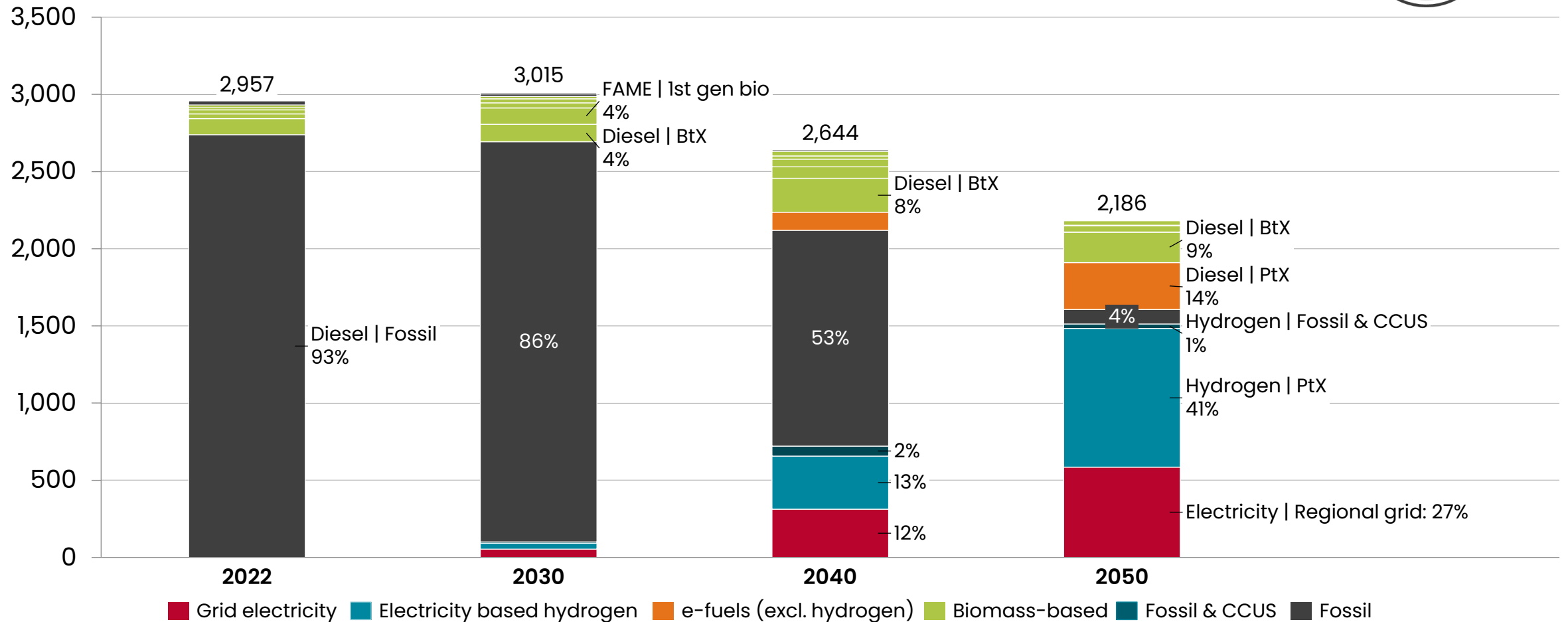


By 2050, green hydrogen will be the most important final energy carrier for commercial vehicles in the EU

FINAL ENERGY CARRIER DEMAND – COMMERCIAL ON-ROAD VEHICLES



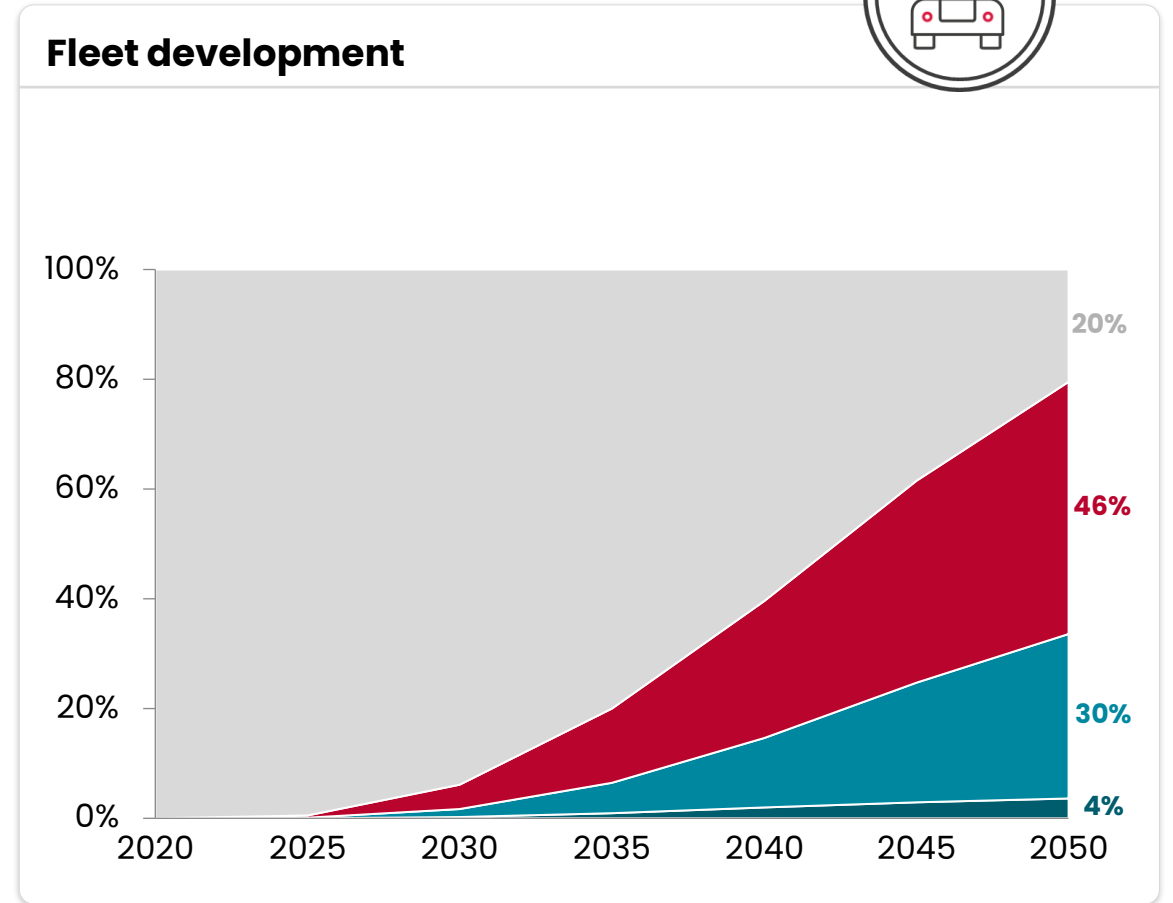
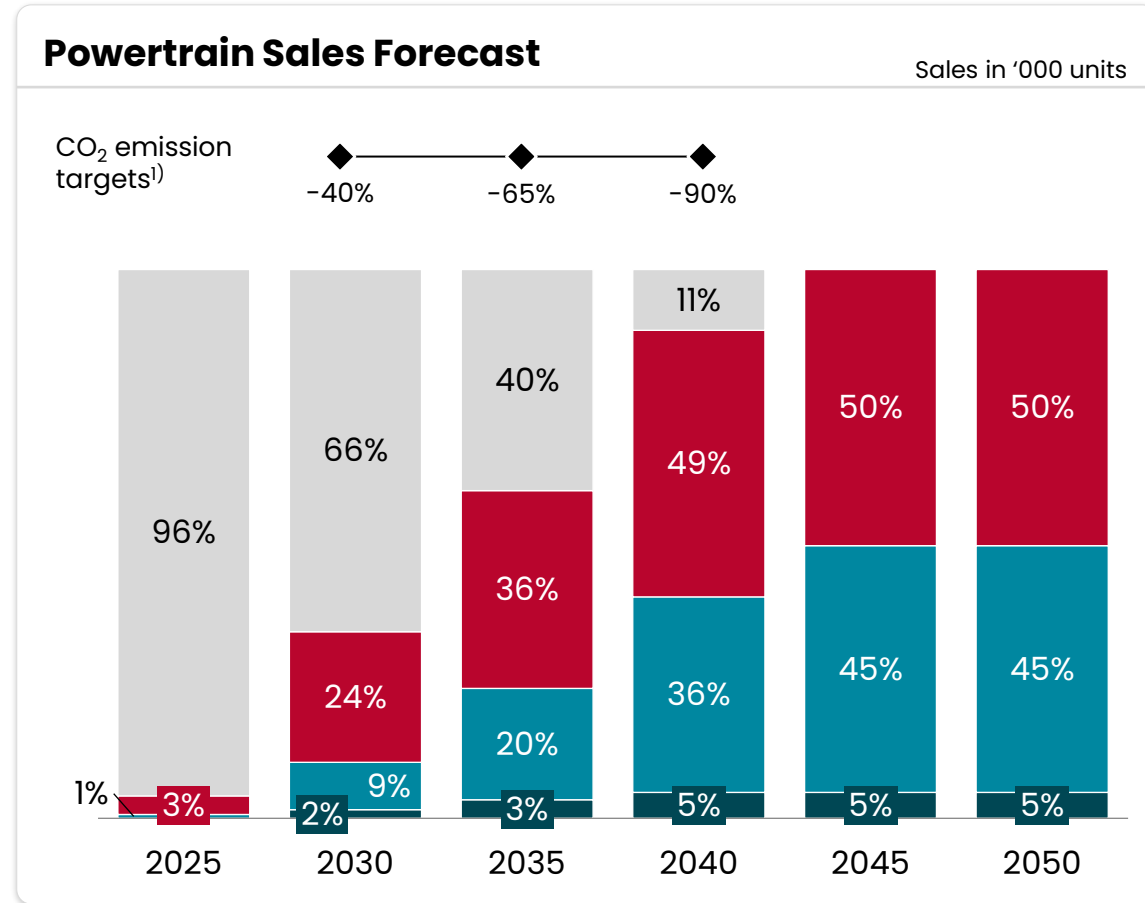
Final energy carrier demand in commercial vehicles (PJ)



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



COMMERCIAL ON-ROAD VEHICLES – ACCELERATED TRANSFORMATION SCENARIO

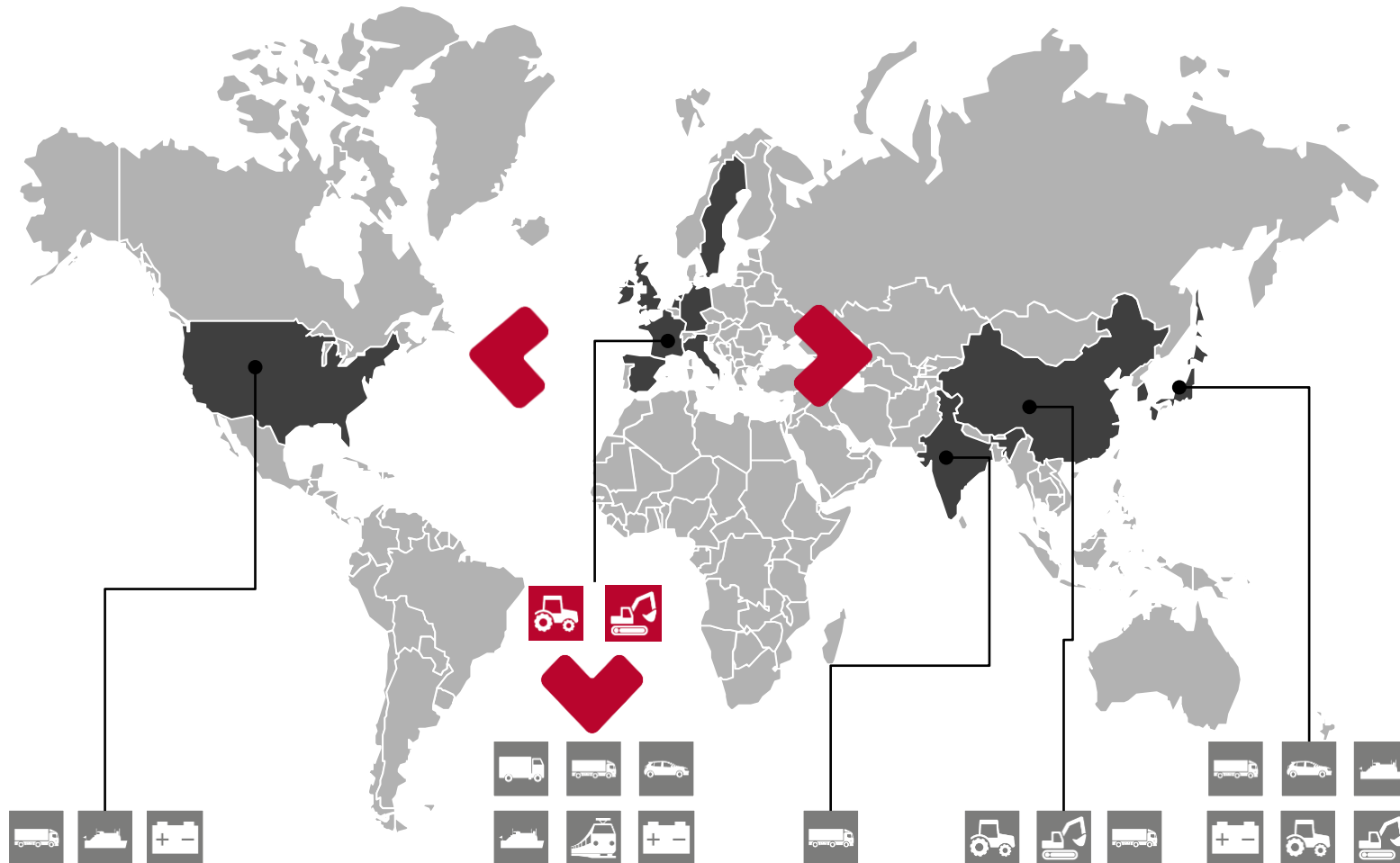


ICE & hybrids Battery Electric Fuel Cell H₂-ICE

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

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

H₂-ICE – REGULATORY CONSIDERATION AS ZEV

EU 	UK 	US 	CN 	
<p>3 types of ZEVs:</p> <ol style="list-style-type: none"> No combustion engine Combustion engine with less than 3-5 g/tkm¹⁾ or 5-1 g/pkm¹⁾ emissions from fuel according to Vecto simulation <ul style="list-style-type: none"> Fulfilled by pure H₂-ICE Combustion engine with less than 1 g/kWh tailpipe emissions according to EU 595/2009 <ul style="list-style-type: none"> Revised UN R49 (underlying test methodology) defines pure H₂-ICE as 0g/tkm 	<ul style="list-style-type: none"> UK does not (yet) plan to recognize H₂-ICE as ZEV as regulation excludes vehicles that emit any CO₂ or “harmful pollutants” Permission for H₂-ICE may occur due to industry interest and expected developments in EU 	<ul style="list-style-type: none"> Federal: <ul style="list-style-type: none"> As of now not considered as ZEV New EPA proposal for CO₂ emissions defines H₂-ICE as ZEV and considers it to be relevant for heavy-duty applications ACT states: <ul style="list-style-type: none"> As of now H₂-ICE not considered as ZEV by CARB Recently, discussions started to account H₂-ICEs as ZEVs 	<ul style="list-style-type: none"> Currently, H₂-ICE is not recognized as NEV in China Calculation of CO₂ emissions using life cycle assessment (LCA) calculation is currently under discussion (would benefit H₂-ICE) Draft LCA calculation already released for passenger cars Introduction of LCA calculation for commercial vehicles is possible 	
<div style="background-color: #00838f; color: white; padding: 10px; text-align: center; font-weight: bold;"> H₂-ICE = ZEV? </div>	<div style="display: flex; align-items: center; justify-content: center;">  <p>New EU emission regulation expected to define H₂-ICE as ZEV</p> </div>	<div style="display: flex; align-items: center; justify-content: center;">  <p>Not defined as ZEV yet – future alignment with EU regulation possible</p> </div>	<div style="display: flex; align-items: center; justify-content: center;">  <p>EPA GHG emission proposal (04/2023)</p> </div> <div style="display: flex; align-items: center; justify-content: center; margin-top: 10px;">  <p>CARB is actively discussing H₂-ICE</p> </div>	<div style="display: flex; align-items: center; justify-content: center;">  <p>Currently not defined as ZEV but possible introduction of LCA emission calculation would benefit H₂-ICE</p> </div>

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




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



Sustainable energy solutions

- ▶ H₂ electrolysis & infrastructure
- ▶ Energy storage
- ▶ Power2X & Bio2X
- ▶ Sustainability

FEV
energy



Hydrogen ICE and fuel cell development

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

FEV
propulsion



Technical and strategic consulting

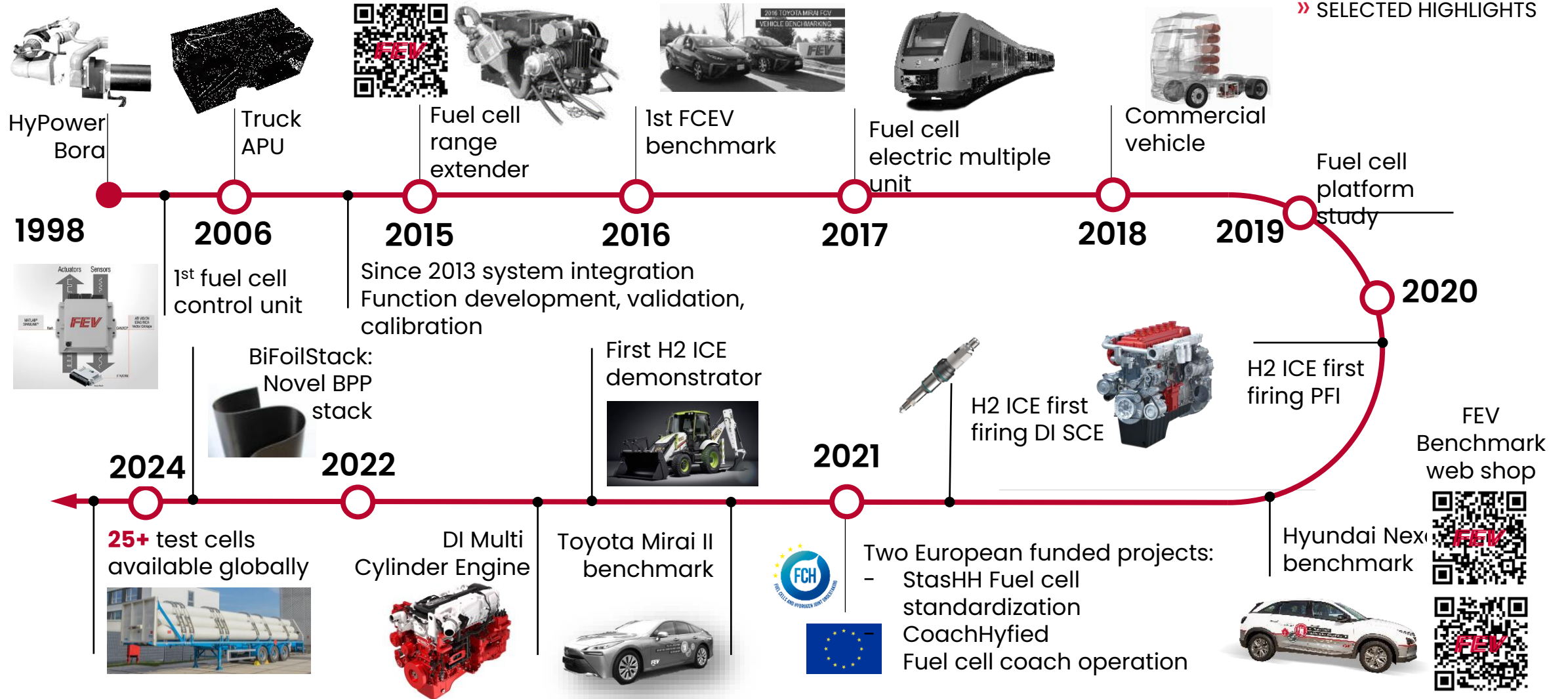
- ▶ Market analyses
- ▶ Feasibility studies
- ▶ Cost assessment
- ▶ Benchmarking

FEV
CONSULTING

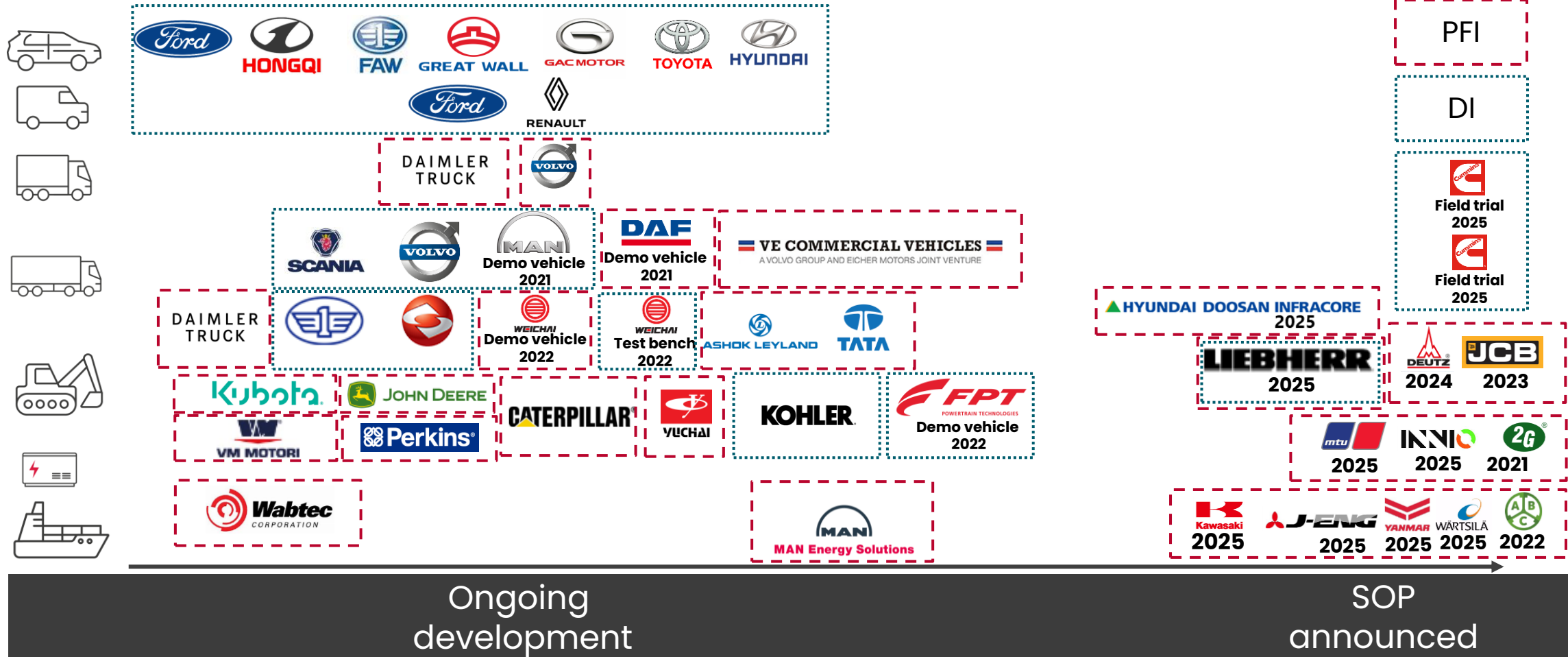
25 years of experience in hydrogen powertrain development



» SELECTED HIGHLIGHTS



Publicly announced interest and investment in H₂-Engine development is now growing strongly amongst on-and off-highway industry players



Examples of successful cooperation with our customers



Reference project FEV propulsion Courtesy of JCB Ltd.



Hydrogen combustion engine Demonstrator integration

- Hydrogen ice integration**
- 4.8 l engine, 71 kW

FEV deliverables

- Concept development
- Engine commissioning and testing
- Development of control software
- Commissioning support



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Reference project FEV propulsion Courtesy of Cummins Inc.



DI ENGINE DEVELOPMENT

Hydrogen combustion DI engine development

- Conversion of a Cummins MD engine to H₂ DI demonstrator

FEV involvement

- Concept definition and design
- Thermodynamic simulation
- Manufacturing and procurement of new/modified components for H₂ DI
- Engine commissioning, first firing and thermodynamic investigations on a test bench



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Reference project FEV propulsion Courtesy of IVECO Group



Fuel cell demonstrator light commercial vehicle

FEV is development partner for the complete electrification of IVECO's LCV segment. Based on an early-stage battery electric vehicle of this development, FEV supported the design, build-up and commissioning of the fuel-cell demonstrator.

Highlights

- Mechanical, electrical and thermal integration of Hyundai fuel cell system and hydrogen tanks
- Gateway development and implementation FEV energy manager for fuel cell powertrains

FEV involvement

- LV & HV system specification (FC, tanks, PDU, ...)
- Geometrical integration into existing donor vehicle
- Electrical, hydrogen and functional safety concept
- Controls adaptation through RCP (mats)
- Vehicle assembly and commissioning



Picture source: Iveco Group, Hyundai Motor Corporation, FEV © by FEV - all rights reserved. Confidential - no passing on to third parties 188

Reference project FEV propulsion DAKAR RACE! Fuel Cell for Battery Electric Vehicles (2021)



FEV & GCK to develop fuel cell rally car

Highlights

- Development of complete fuel cell system 200kW**
- Design
 - Development
 - Testing
 - Integration

Fuel cell in specific environment

- Dust
- Race constraints
- Shocks
- Environmental conditions



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Reference project FEV propulsion Courtesy of Plastic Omnium New Energies



150 kW Fuel cell development

Background

Plastic Omnium New Energies is designing innovative Hydrogen solutions for zero-emission electric mobility. This is why PO New Energies is developing an advanced fuel cell system dedicated to heavy-duty vehicles, combining innovative fuel cell components and optimized manufacturing process.

FEV involvement

- System layout
- Mechanical design
- Simulation (thermal, structural and electrical)
- I/E development
- Functional safety
- SW development (in workshop with customer)
- Assembly of first prototype fuel cells
- Calibration
- Validation



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Reference project FEV propulsion Courtesy of Husqvarna Construction



NRMM: CONCRETE PLACEMENT EQUIPMENT FUEL CELL

NRMM: concrete placement equipment fuel cell

- **Powertrain/propulsion concept**
 - Continuous and peak power demand according to use case
 - Hybridization concept for entire electric propulsion system
 - Hydrogen storage requirements
- **Package feasibility concept**
 - **Supplier suggestions**
 - FCS and radiator
 - Tank system
 - Battery and electric motor

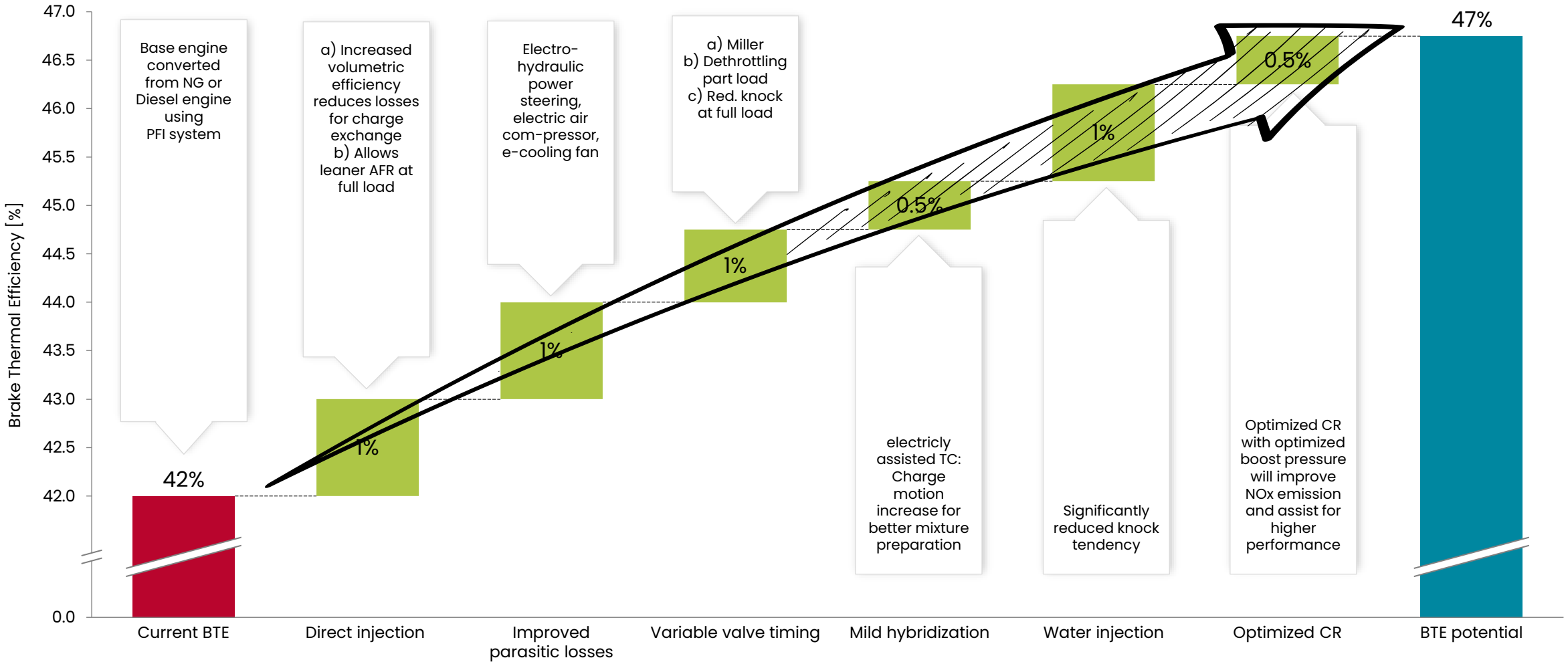


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Thermal efficiency of ~47% for future high technology package DI engine is foreseen for hydrogen internal combustion engines



HYDROGEN COMBUSTION ENGINE – OUTLOOK

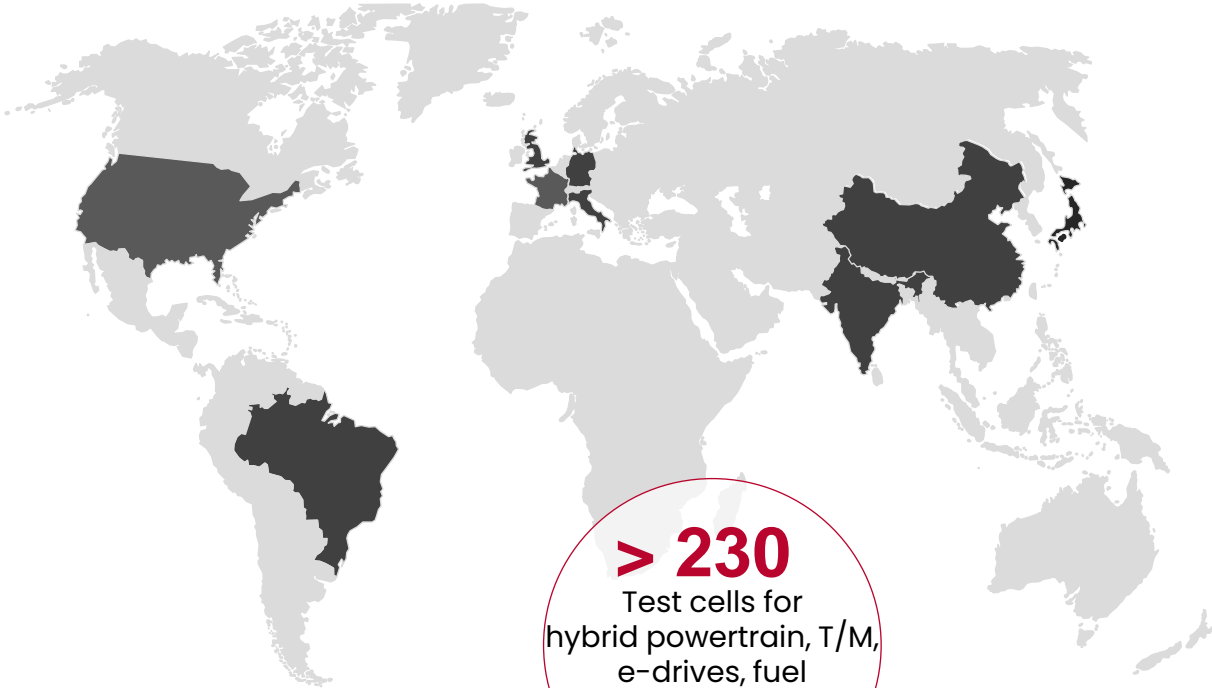


Source: FEV

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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