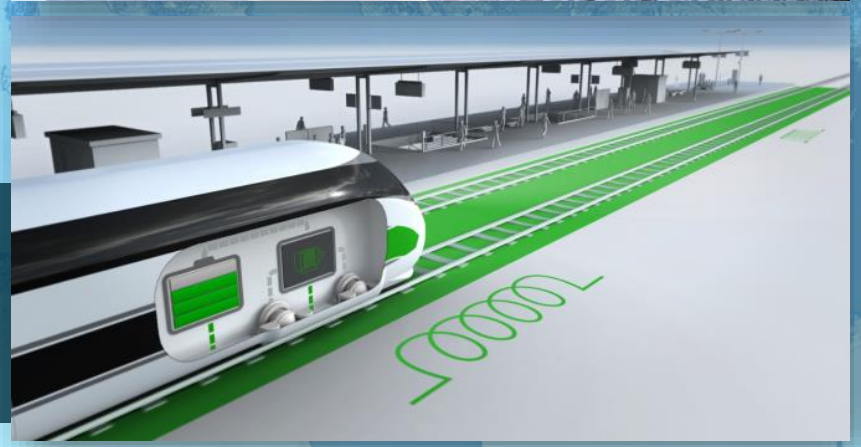
DEVELOPMENT AND DEMONSTRATION OF A BI-MODE FUEL CELL TRAIN



EU Project FCH2RAIL

ERFA H2 Trains, Innsbruck, 25.06.2024

Holger Dittus

FCH2RAIL
Fuel Cell Hybrid PowerPack for Rail Applications

DLR

DLR Hydrogen Research

INSTITUTE:

- Institut für Antriebstechnik
- Institut für CO_2-arme Industrieprozesse
- Institut für Fahrzeugkonzepte
- Institut für Flughafenwesen und Luftverkehr
- Institut für Future Fuels
- Institut für emissionsarme Luftfahrtantriebe
- Institut für Maritime Energiesysteme
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- Institut für Raumfahrtsysteme
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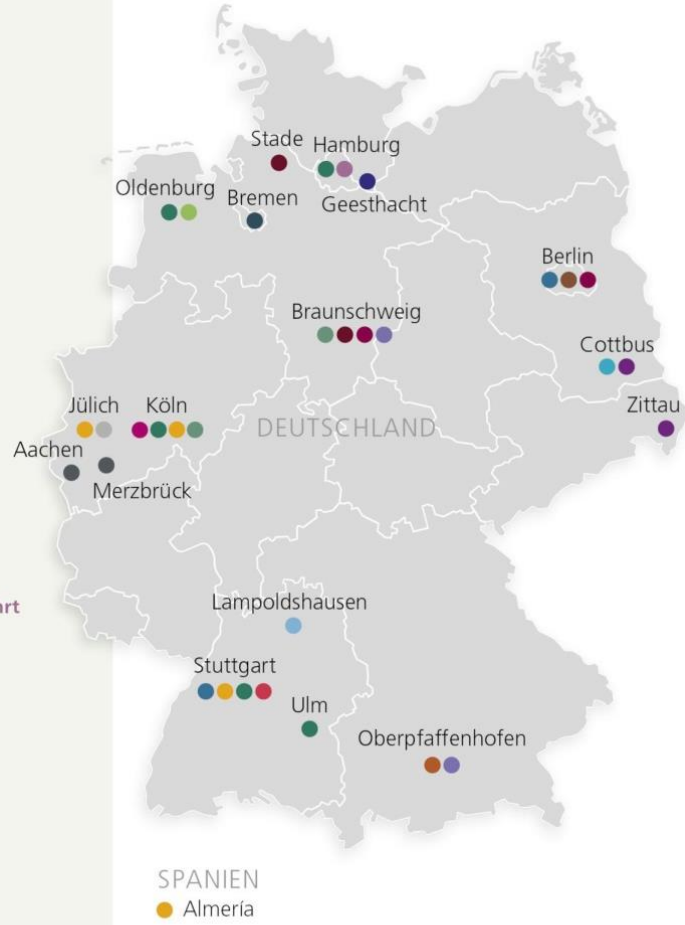
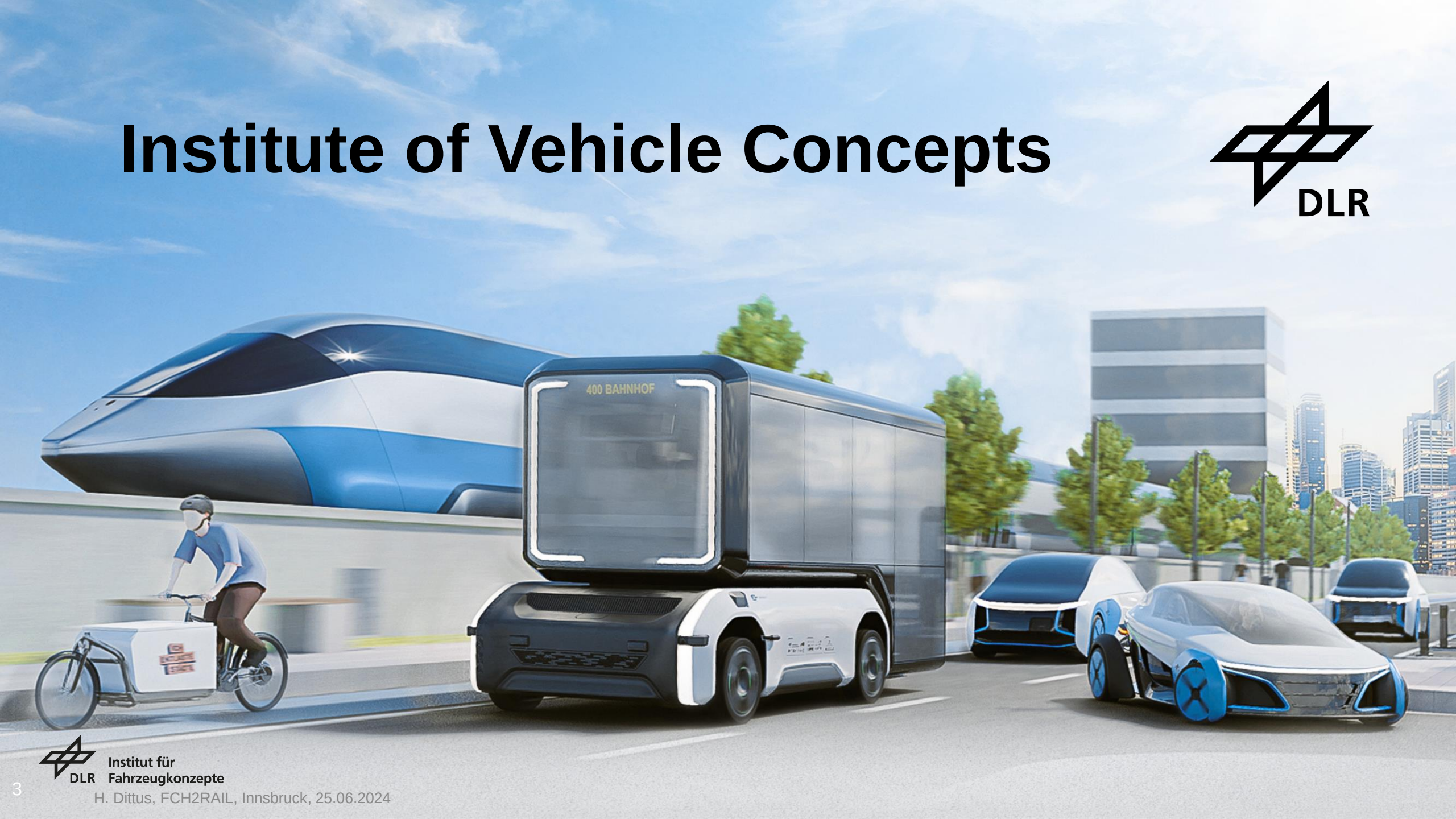
- Institut für Vernetzte Energiesysteme
- Flugexperimente
- Technologien für Kleinflugzeuge
- Zentrum für Leichtbauproduktionstechnologie



Institute of Vehicle Concepts

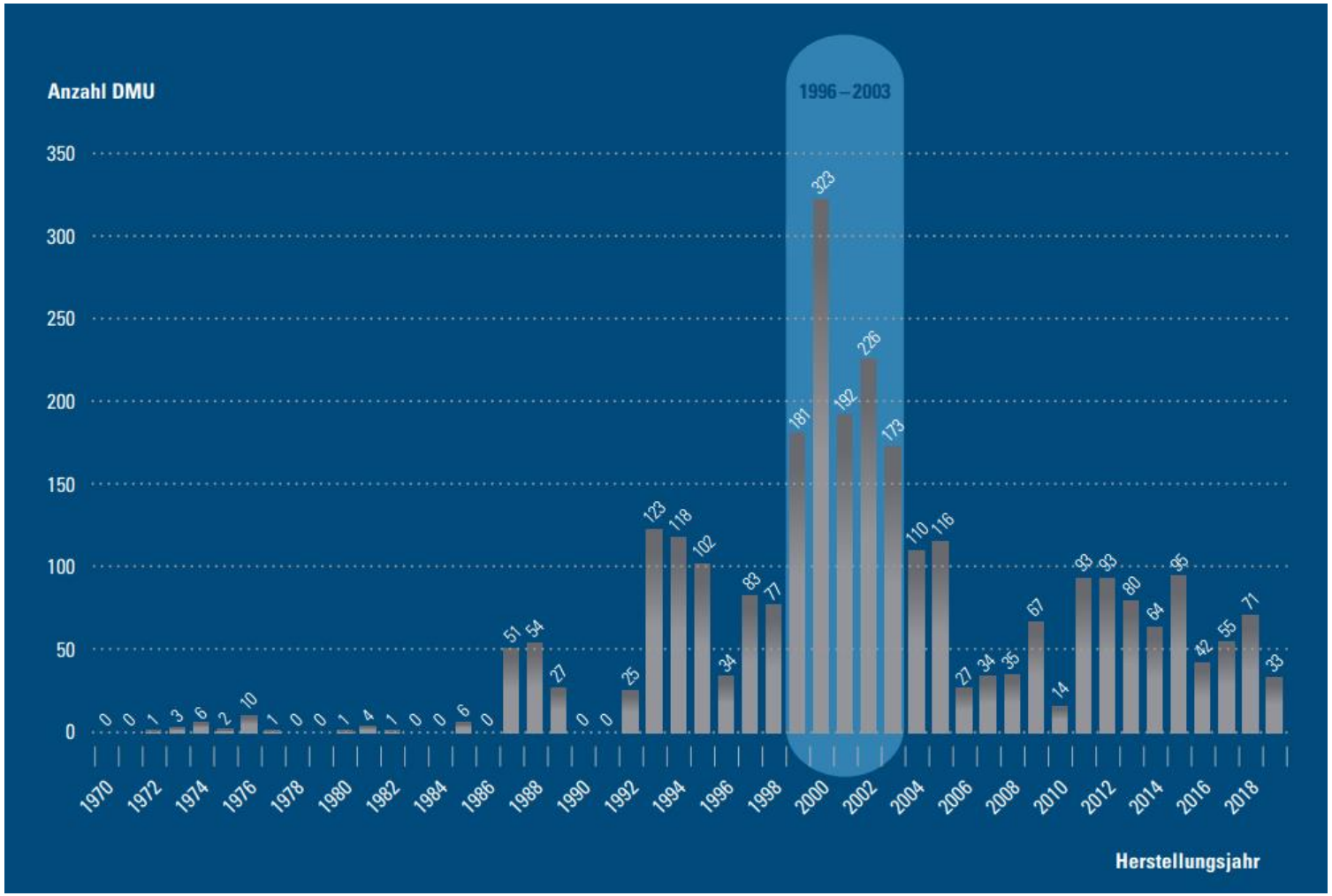


Diesel traction vehicles in regional passenger transport
Almost 2,900 diesel multiple units (DMU) in Germany

Diesel vehicles in regional rail transport

- 2,862 diesel multiple units
- >100 diesel locomotives
- Average age of diesel fleet: 16.5 a
- Registration peak around year 2000

https://www.now-gmbh.de/de/aktuelles/presse/hohes-marktpotenzial-alternativer-antriebe-im-schienenverkehr

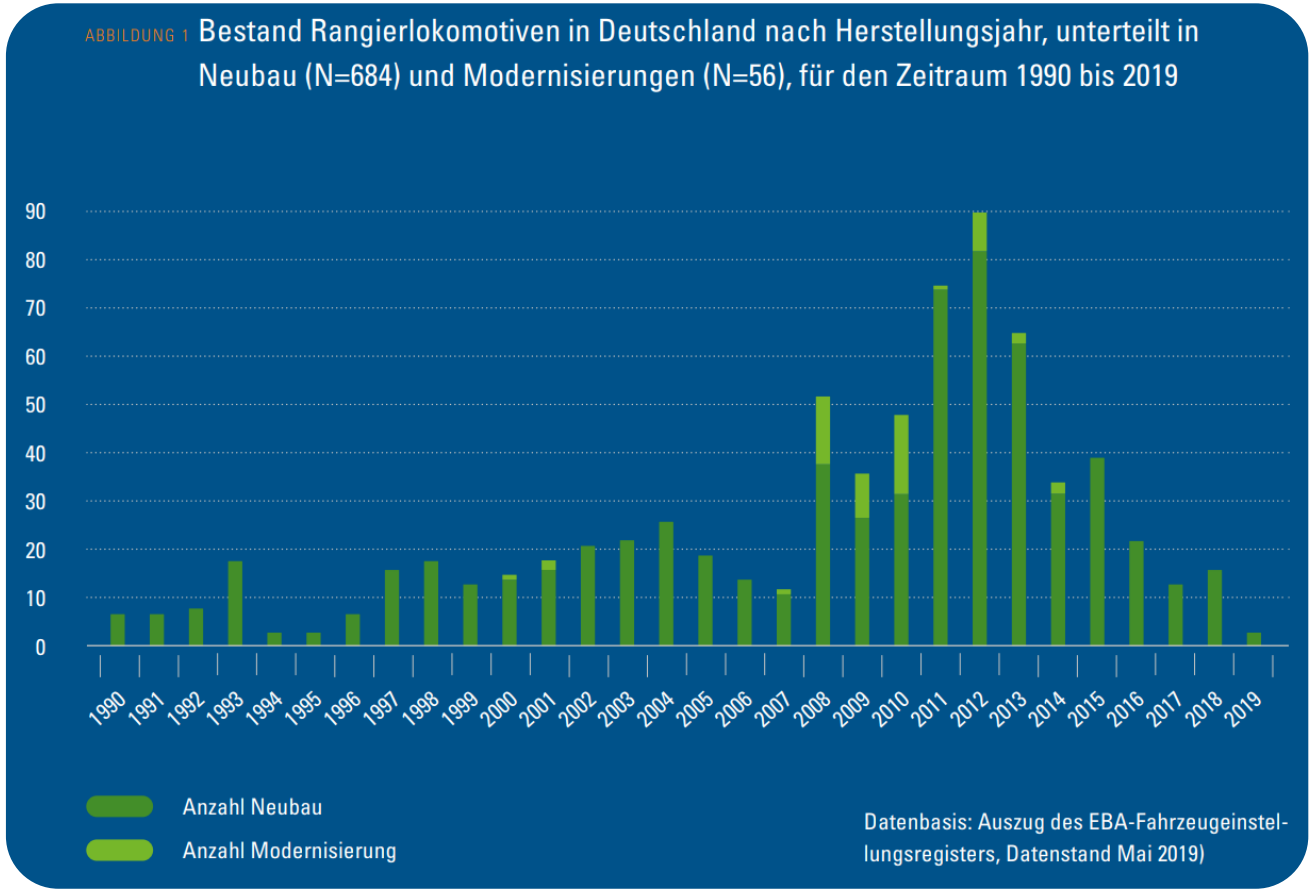


Stand 05/2019

[3)] NVR-Auswertung, Basisdaten: EBA; nur aktive Tz

Diesel shunting locomotives
2800 shunters operated in Germany

Shunter inventory



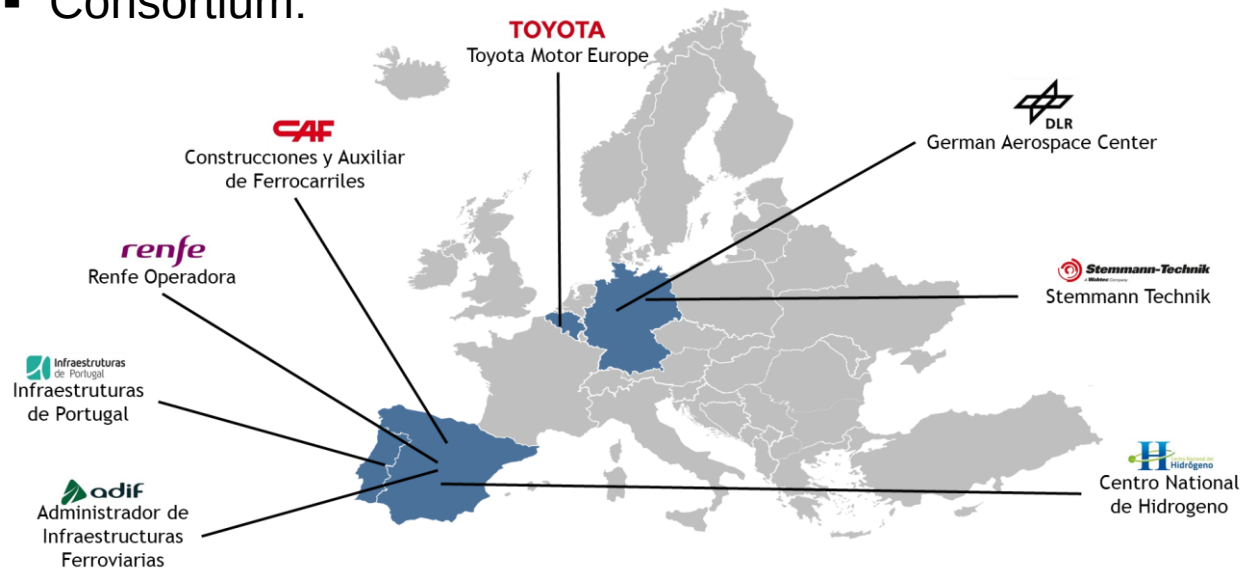
- Currently approx. 2,800 shunting locomotives in Germany
- Mainly diesel locomotives in the fleet
- Frequently hydrodynamic drives
- Average fleet age 42 years

FCH2RAIL
Fuel Cell Hybrid PowerPack for Rail Applications

Project Overview

Clean Hydrogen Partnership
Co-funded by the European Union
DLR

- Project dates: 1 January 2021 - 31 December 2024
- Total budget: 13,4 M€, max. contribution: 10 M€
- Stage of implementation 25.06.2024: 90%
- Consortium:



This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 101006633. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation program, Hydrogen Europe and Hydrogen Europe Research.

Main Objectives:

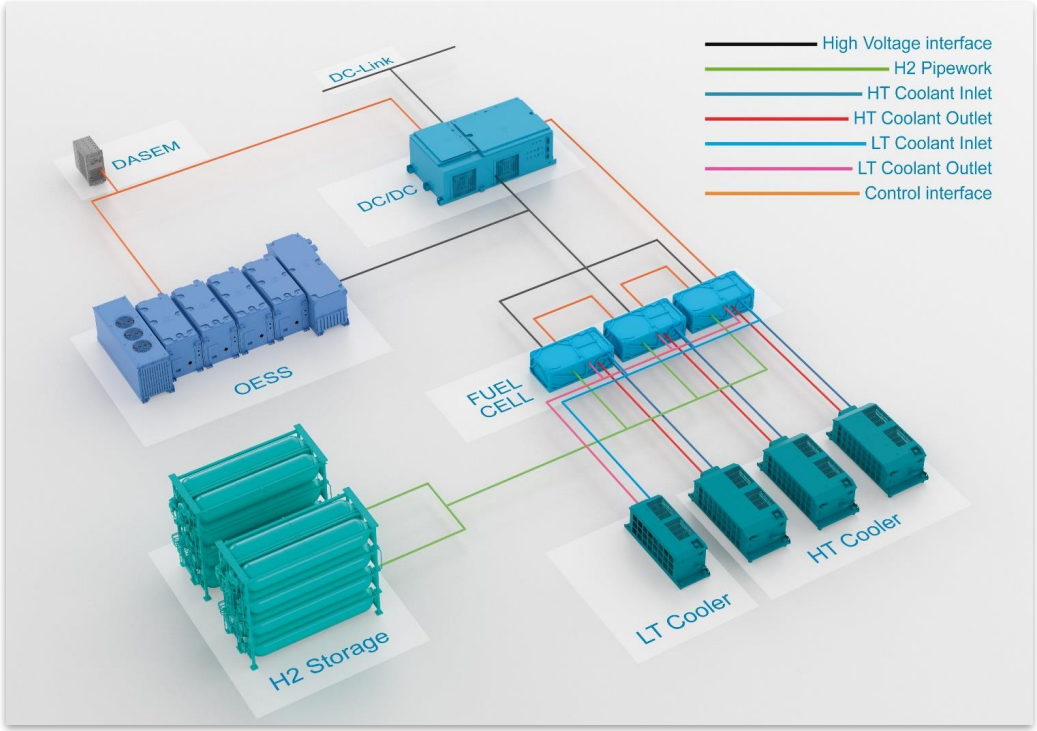
1. Develop, build, test and homologate a multi-purpose Fuel Cell Hybrid PowerPack
2. Demonstrate FCHPP in a Bi-mode Civia multiple unit
3. Propose a normative framework for hydrogen in railway vehicles
4. Demonstrate competitiveness of fuel cell traction against existing diesel solutions
5. Identify and benchmark innovative solutions to improve energy efficiency

Project Overview

Fuel Cell Hybrid PowerPack for Rail Applications

Focus of the project:

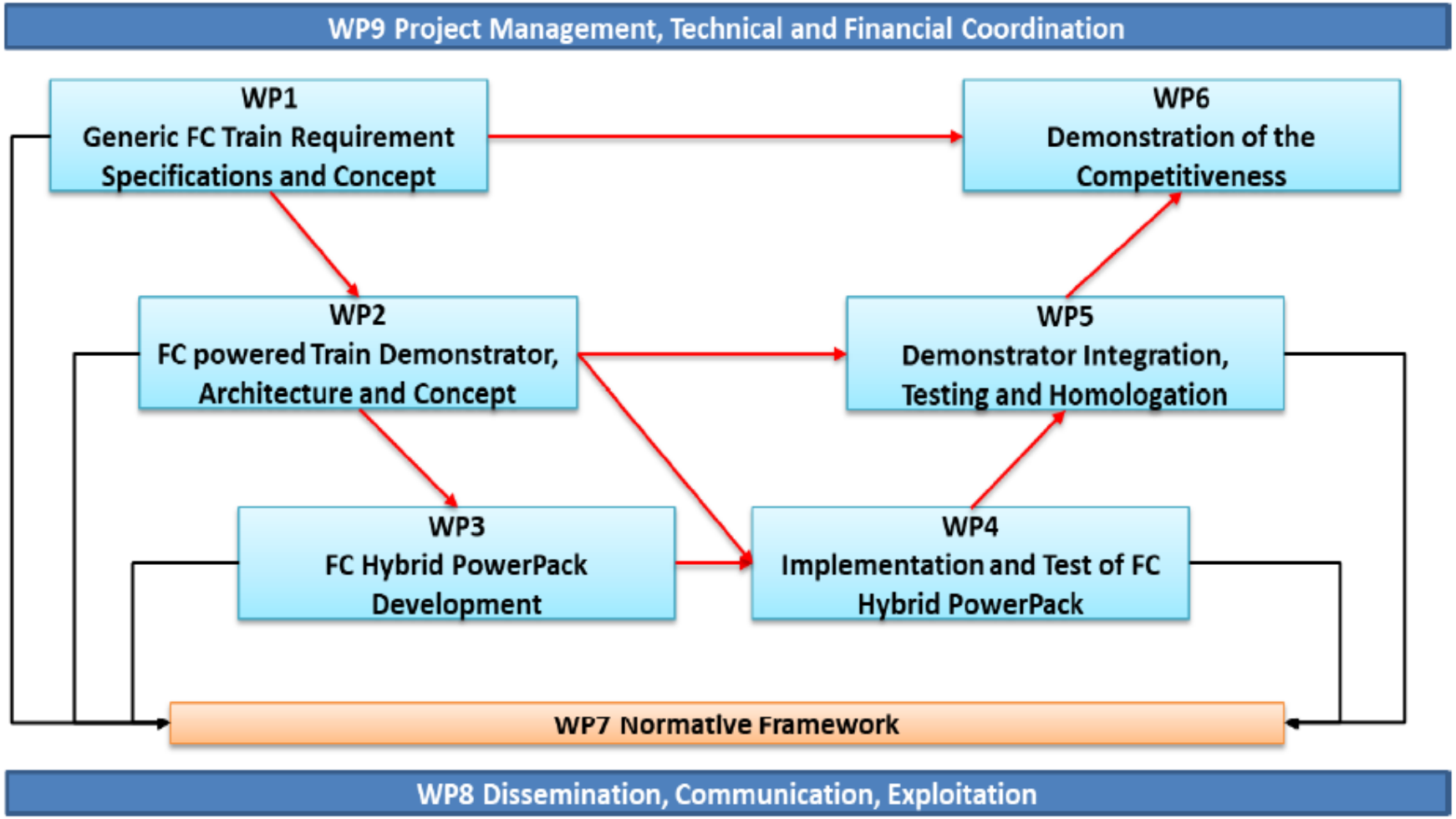
1. Develop, build, test and homologate a multi-purpose **Fuel Cell Hybrid PowerPack**
2. **Demonstrate FCHPP** in a Bi-mode Civia multiple unit



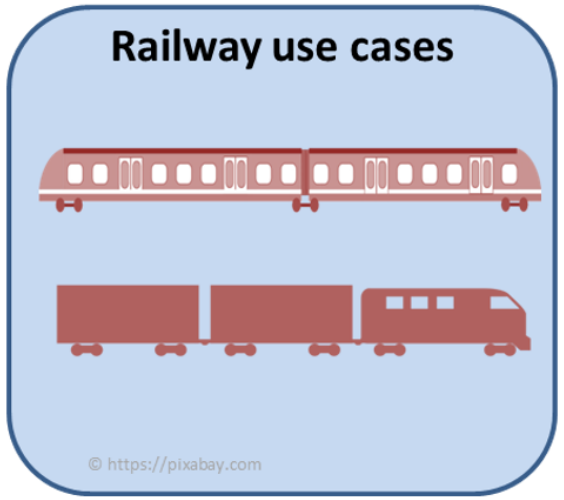
FCH2RAIL
Fuel Cell Hybrid PowerPack for Rail Applications

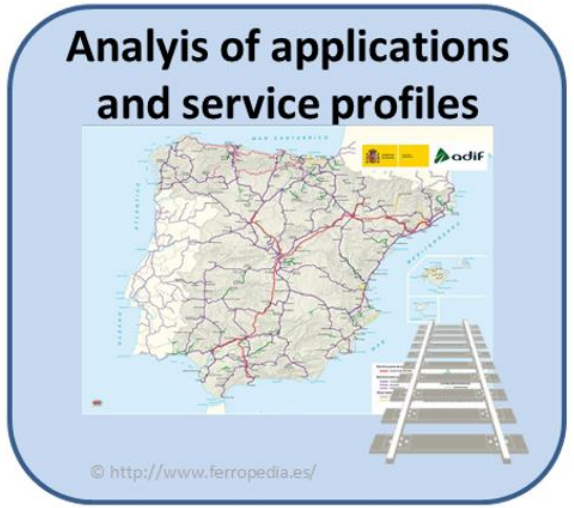
Work Packages

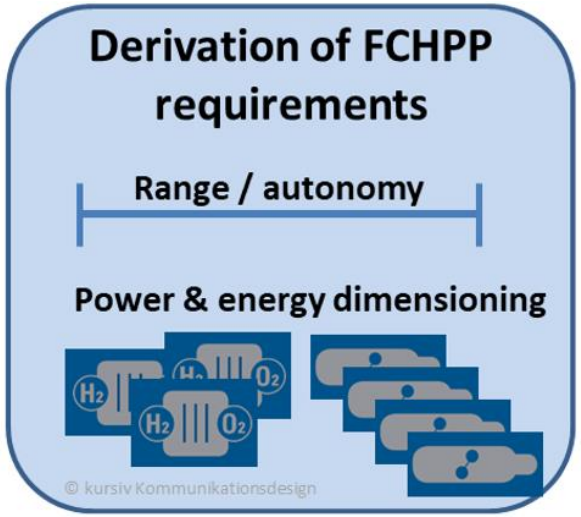
DLR



Developing the Fuel Cell Hybrid PowerPack
Definition of the requirements







Use cases have been analysed in Spain, Portugal, Germany and Slovakia

- DMUs
- Mainline locomotives
- Shunting locomotives

Many services have been analysed

- Spain and Portugal: 10 of 73 services
- Germany: 13 of 1417 services

Very different characteristics:

	min	max
Non electrified section (Km)	80	730
Altitude (m)	20	1000
Av. Distance btw. Stations (Km)	2	25

Global requirements defined:

- Power & energy
- Autonomy or range

Developing the Fuel Cell Hybrid PowerPack
Definition of the requirements: Service Profiles acc. to EN50591

FCH2RAIL
Fuel Cell Hybrid PowerPack for Rail Applications

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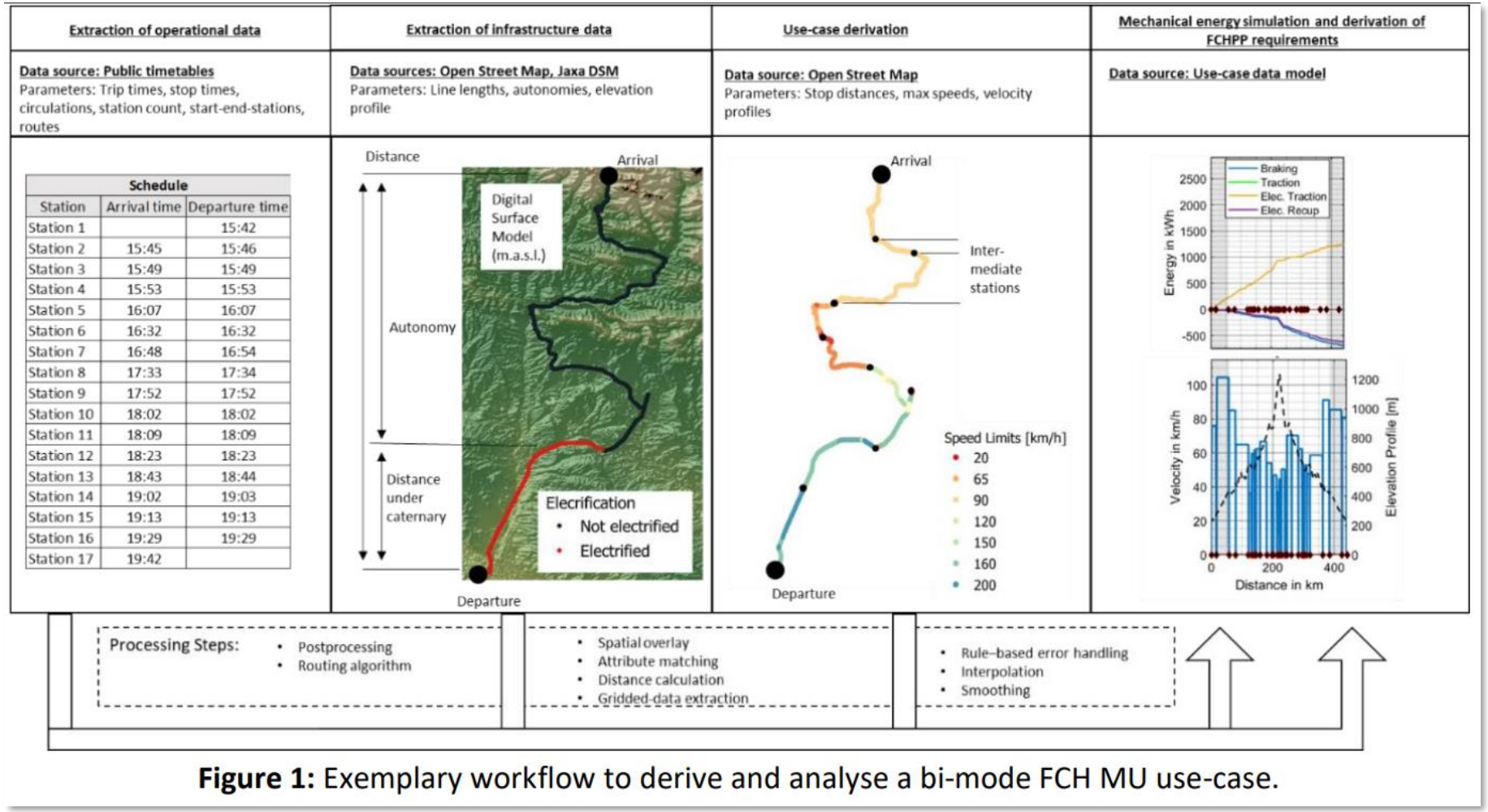


Figure 1: Exemplary workflow to derive and analyse a bi-mode FCH MU use-case.

Herwartz, S. et. al., (2022) Bi-Mode Hydrogen Train Requirements Using Geospatial Line Assessment. WCRR2022

WP1: H2-Refuelling and H2-Storage Concepts

Challenges in Rail Applications:

- Storage concept 35 / 70 MPa or LH2
- Fast train refuelling, mobile / stationary
- Renewable H2 supply and logistics

Work in progress:

- Monitoring train refuelling processes
- Improving refueling times

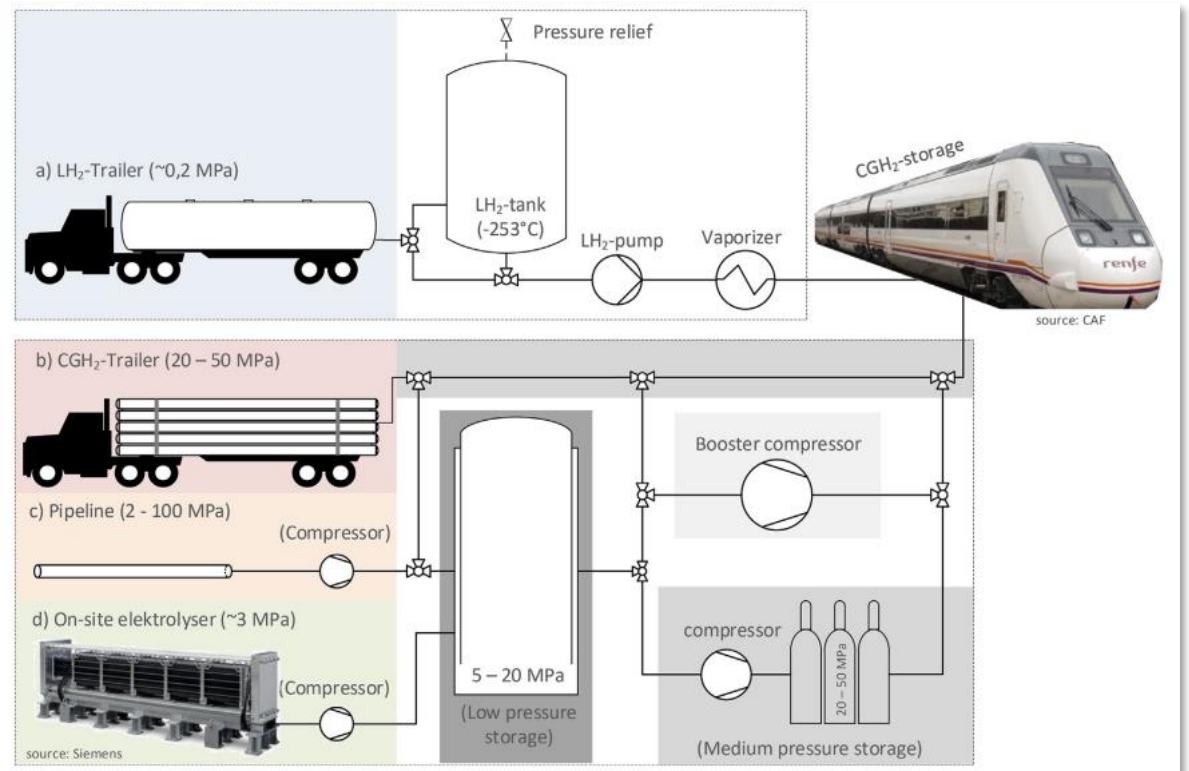
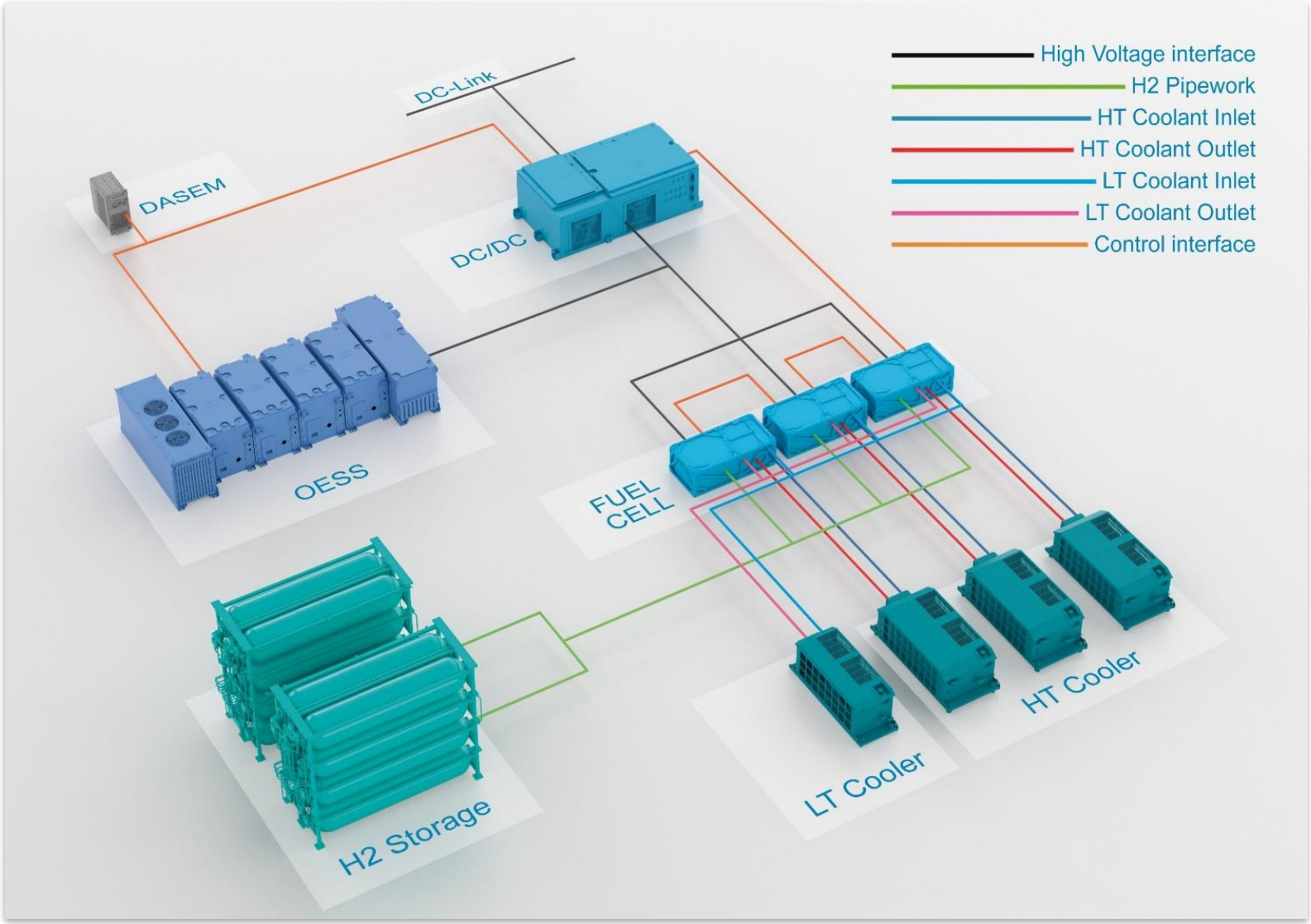


Fig. 7 – Hydrogen refueling concepts for CGH_2 rail vehicle storage: variant a) - d), source own illustration.

Böhm, M. et. Al. (2022) *Review and comparison of worldwide hydrogen activities in the rail sector with special focus on on-board storage and refueling technologies.* International Journal of Hydrogen Energy.

Developing the Fuel Cell Hybrid PowerPack
Definition of the components and architecture



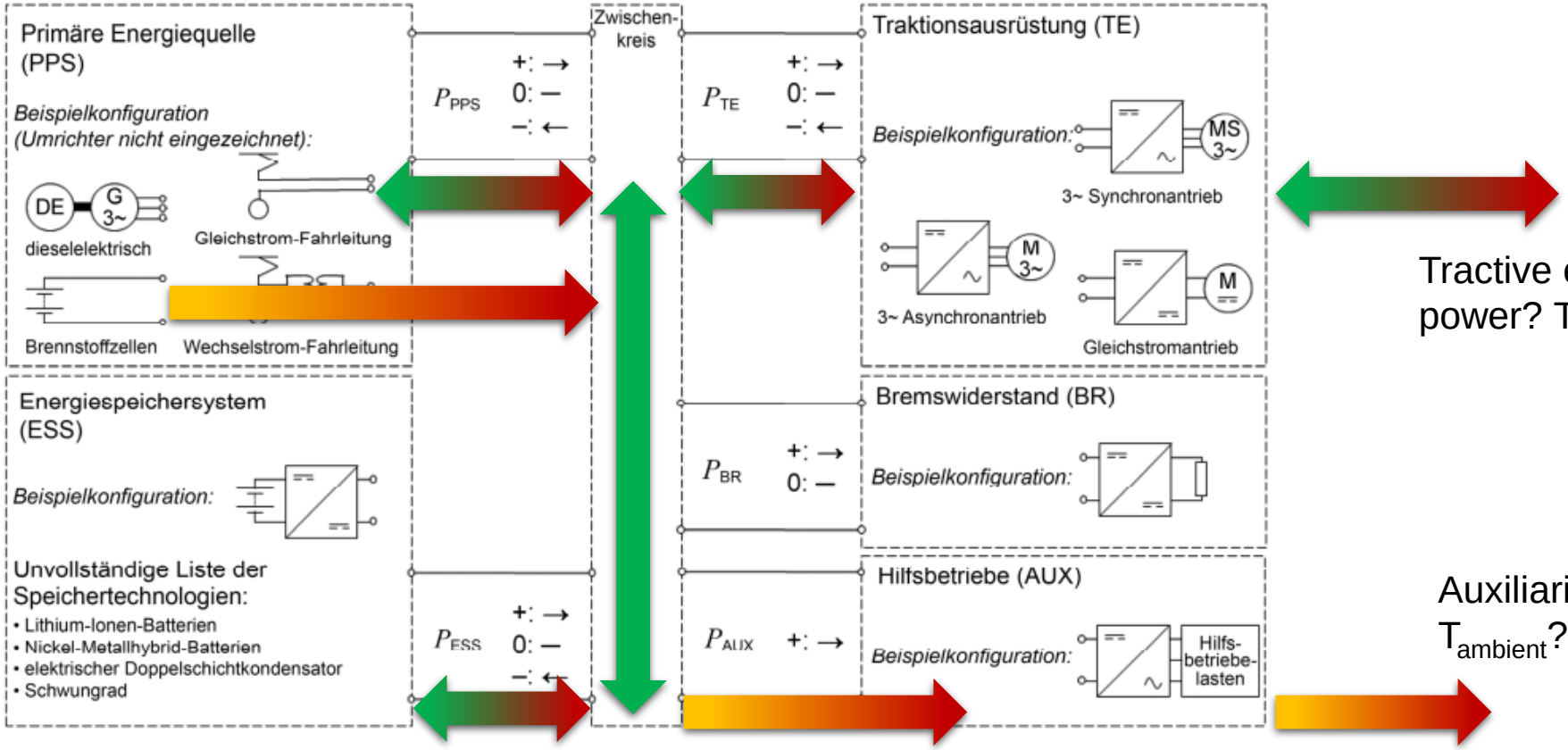
FCHPP Architecture

- Scalable and modular
- Applicable for different rail applications (Multiple Unit, Mainline and Shunting Loco)

Components in FCH2RAIL

- Fuel Cells (TOYOTA)
- Energy storage system OESS (CAF)
- DC/DC converter (CAF)
- Energy management DASEM (CAF)
- Cooling system (Third Party)
- H2 Storage system (Third Party)

Developing the Fuel Cell Hybrid PowerPack
Energy management



Tractive effort? Wheel power? Train speed?

Auxiliaries and HVAC: $T_{ambient}$? $n_{passenger}$?

Challenges in FCHPP development and operation:
1) Design and dimensioning of fuel cell and energy storage systems
2) Optimisation of power requirements and power distribution between fuel cells and energy storage systems

Bildquelle: DIN EN 62864-1 VDE 0115-864-1:2017-05 Bahnanwendungen – Schienenfahrzeuge – Stromversorgung durch Energiespeichersysteme auf Schienenfahrzeugen

Developing the Fuel Cell Hybrid PowerPack
Energy management: Hybridisation Tool

Language	MATLAB
Energy management	Heuristic hysteresis with power tracking
Modelling approach	Functional programming: Reverse component models with power flow and iterative steps for dimensioning
Goal, specific features	• Component dimensioning • Energy consumption calculation

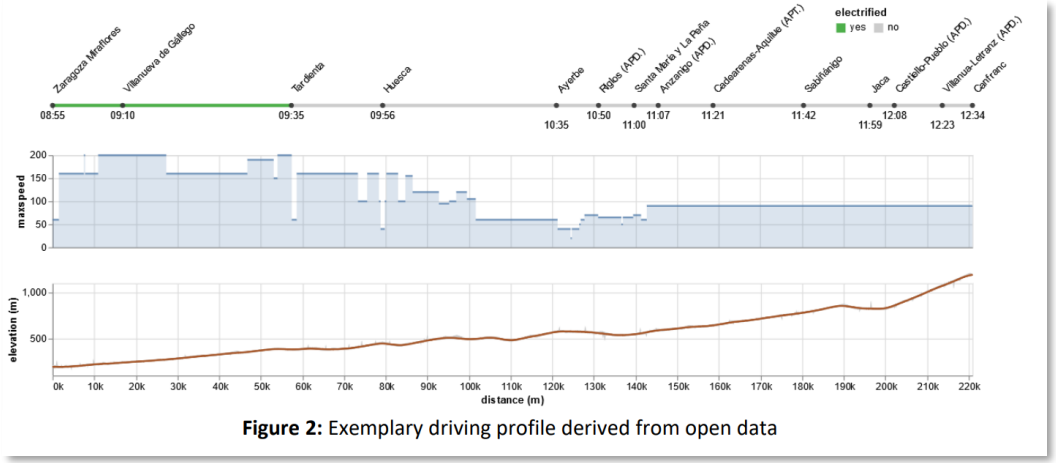
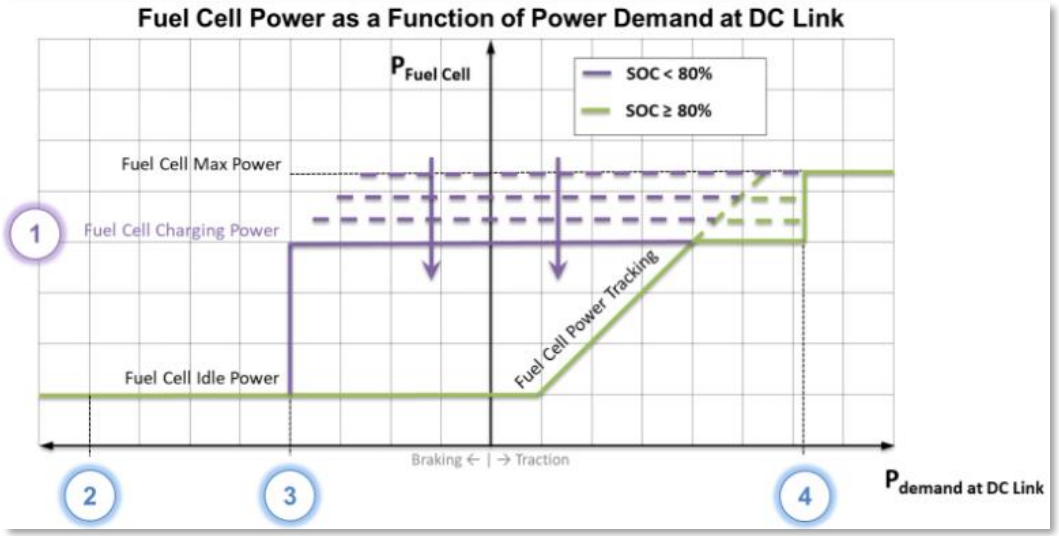


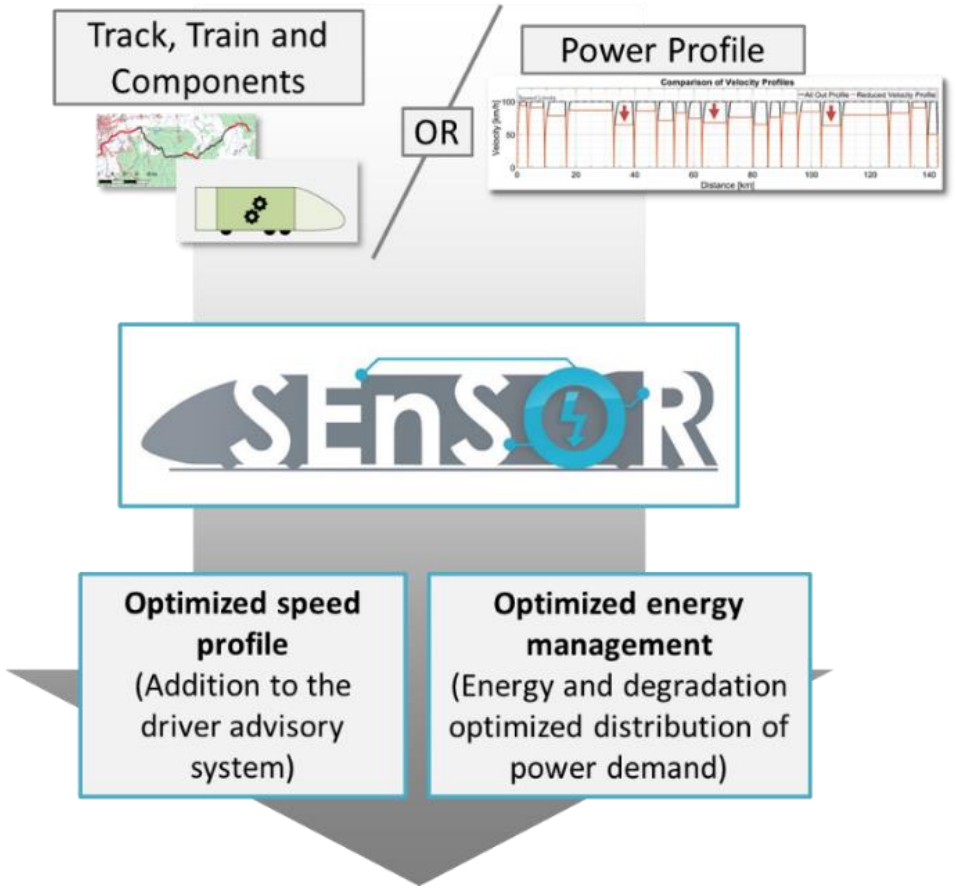
Figure 2: Exemplary driving profile derived from open data



➔ The hybridisation tool supports the FCHPP design and dimensioning

Developing the Fuel Cell Hybrid PowerPack
Smart Energy and Speed Optimizer Rail SEnSOR

Language	MATLAB + IPOPT Toolbox
Energy management	Numerical optimization
Modelling approach	Functional programming: Train in specified environment, including track description, timetable, train and component models.
Goal, specific features	• Optimized energy consumption • Optimized speed profile • Simultaneous optimisation of energy consumption and speed profile

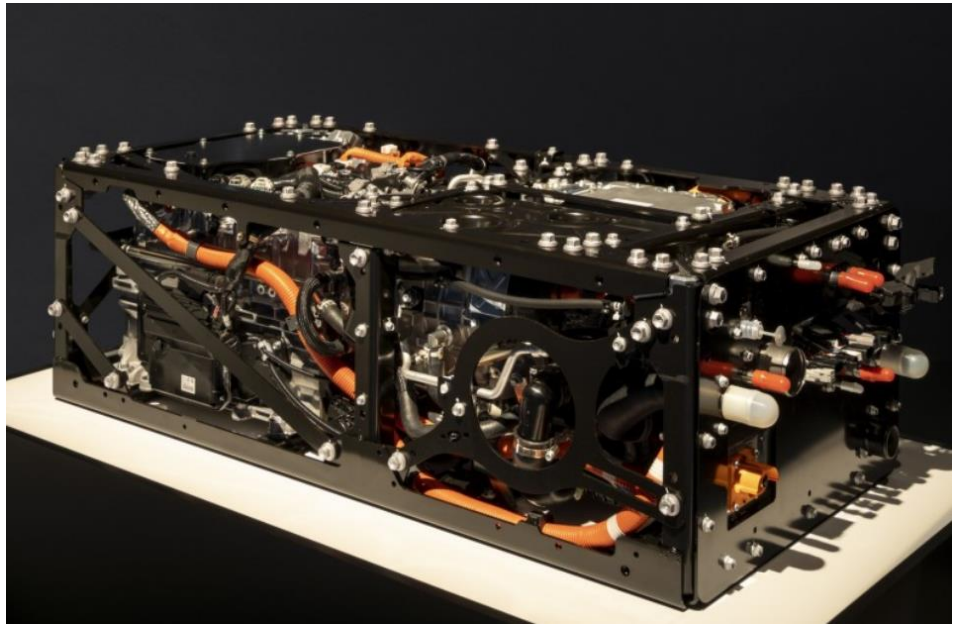


➔ SEnSOR combines the optimisation of the driving profile and power distribution in the FCHPP

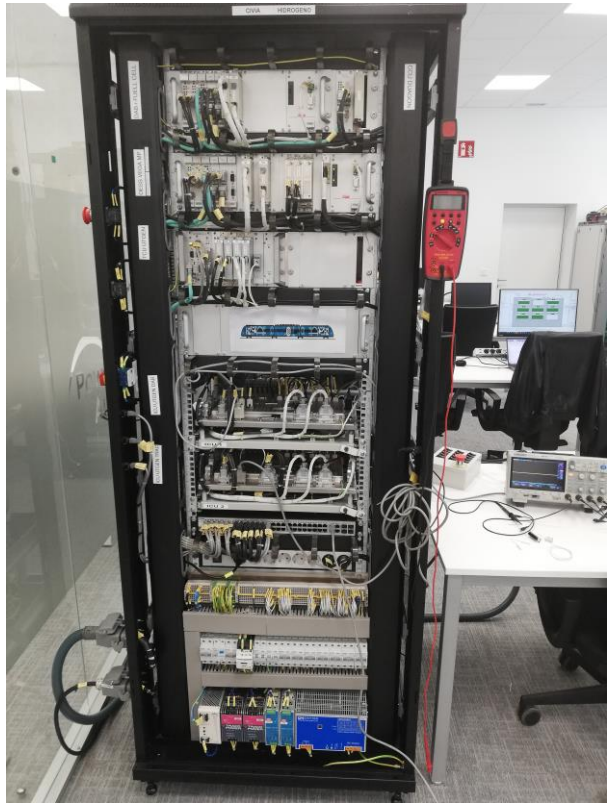
Kühlkamp, F. et. Al. (2022) *Applicability and development of a direct method algorithm for simultaneous optimization of trajectories and energy minimizing control for hybrid fuel cell railway vehicles.* Journal of Rail and Rapid Transit JRRT

Developing the Fuel Cell Hybrid PowerPack
Detailed design, manufacturing and testing the subsystems

- Components tested at origin and ready for installation



Developing the Fuel Cell Hybrid PowerPack
Development of Hardware in the Loop (HIL)



- HIL test bench developed in CAF
- HIL includes:
  - Electronic controllers of the subsystems of the Fuel Cell Hybrid PowerPack
  - New Train Control and Monitoring System (TCMS)
  - Traction control unit of the existing traction equipment in the CIVIA train
  - TCMS of the CIVIA train

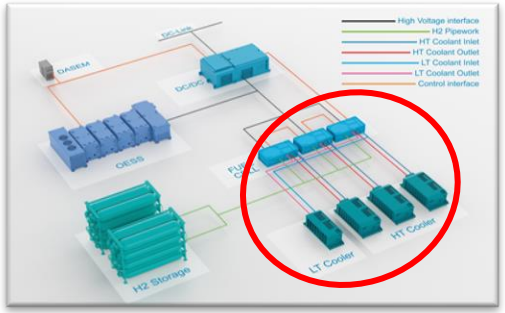
- Functionality of the new FCHPP and interaction with existing train control and traction equipment is extensively tested

Testing the FCHPP – Start in February ´22

Facilities at CNH2 (prototypes area):

- Clean and clear
- Nothing implemented

Testing the FCHPP
Fuel cells and H2 supply



FCH2RAIL
Fuel Cell Hybrid PowerPack for Rail Applications

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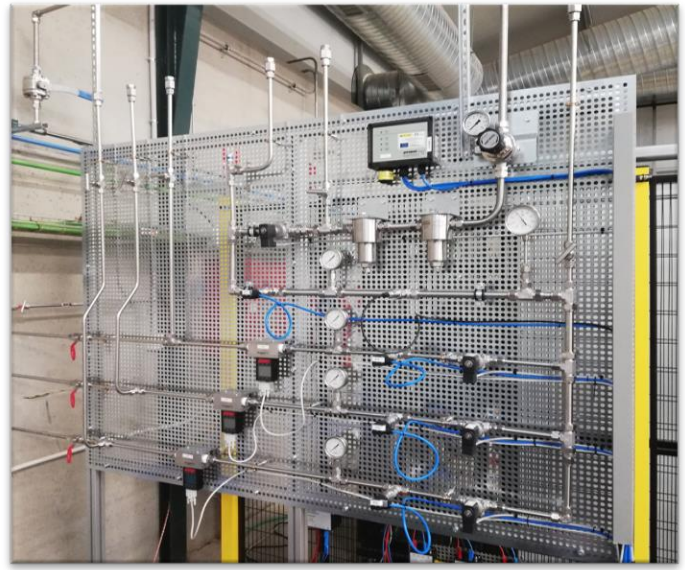
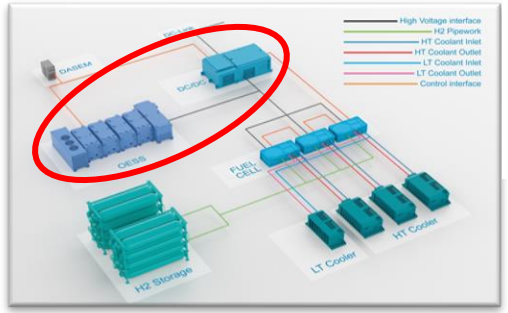


Fuel cells, cooling systems and hydrogen supply and monitoring panel

Testing the FCHPP
Energy Storage and DC/DC



FCH2RAIL
Fuel Cell Hybrid PowerPack for Rail Applications

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Energy storage with BTMS and DC/DC placing, mechanical and electrical installation

Testing the FCHPP: Summary

Test program:

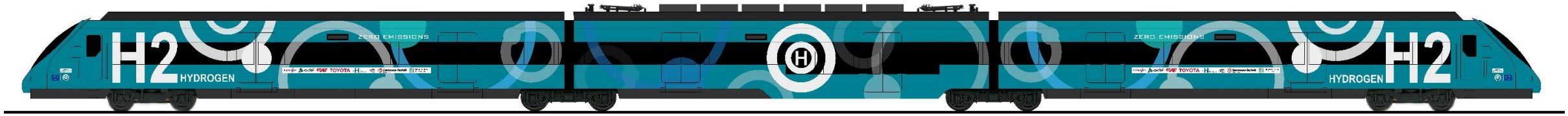
- Standard polarization curves for fuel cells, etc.
- H2 consumption tests, driving cycle test, ramp-up test, etc.
- Tests related especially to the specific use cases / service profiles / railway profiles, etc.

Results:

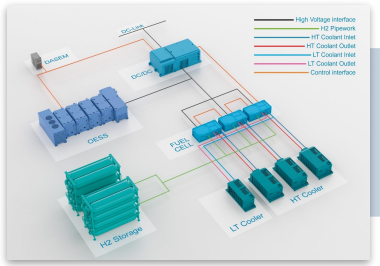
- More than 220 kg of green H2 consumed during the tests.
- Detailed knowledge of the systems and subsystems performance was obtained.
- Control and energy management system was optimized.

➔ Full functionality and requested performance of the FCHPP is achieved.

Train Demonstrator Development

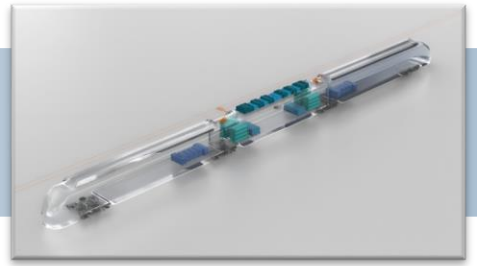


A1/A2 A3 A1/A2



2021
FCHPP development

2022
FCHPP testing



2022
FCHPP integration

2022/2023
Train tests and homologation

May 2023
1st Authorization

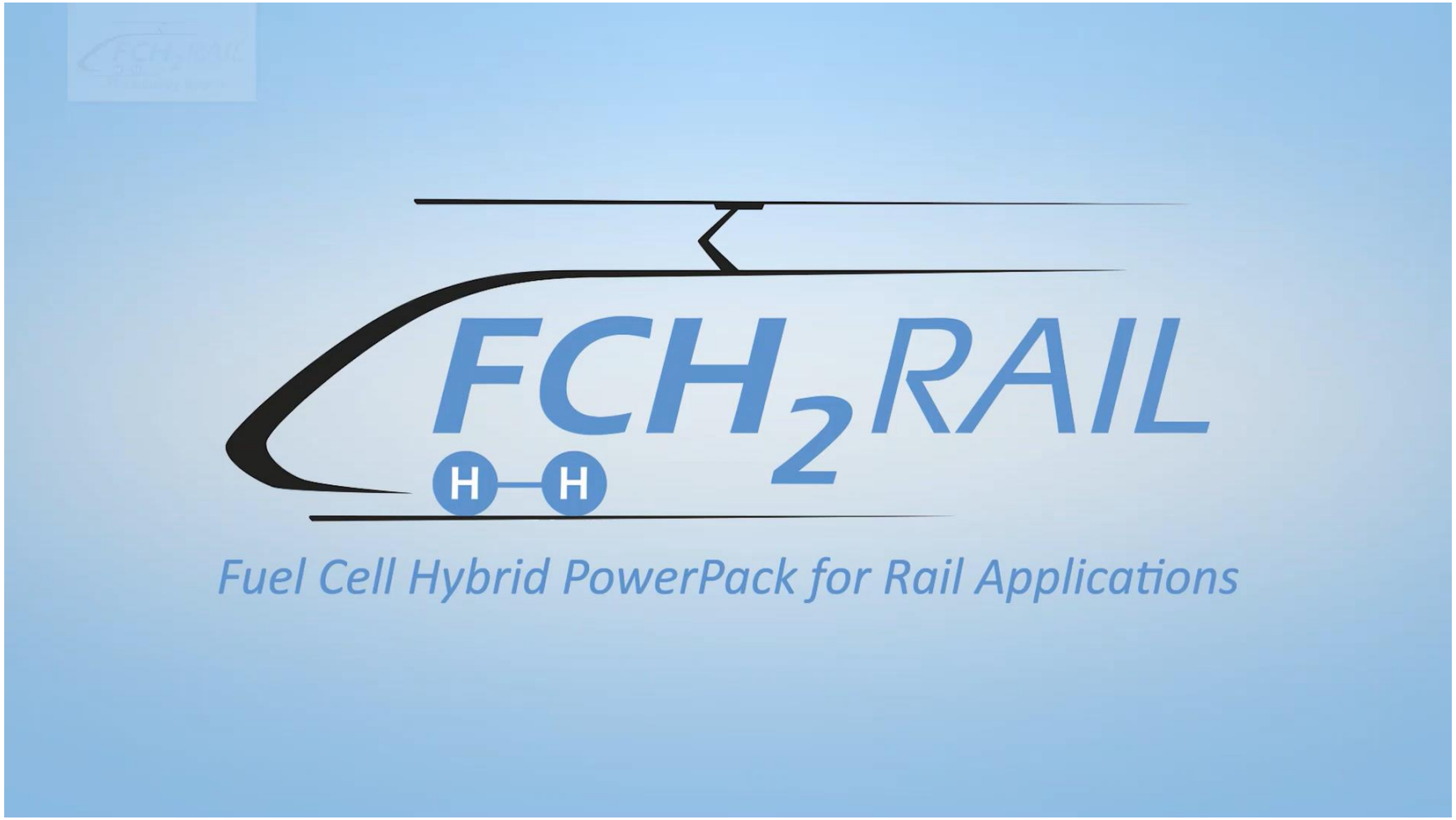
H2 supply and refuelling
Portable H2 refuelling station in the FCH2RAIL project

Fill up once a day - what does it take?

1x compressor container,
2x high pressure storage containers

Container with dispenser, pressure control and control system for the HRS

Clean Hydrogen Partnership
Co-funded by the European Union


FCH2RAIL
Fuel Cell Hybrid PowerPack for Rail Applications

Project Highlights

FCH2RAIL project: First hydrogen train on the Spanish railway network

The testing phase in the Spanish tracks has started with the first test run on the Zaragoza-Canfranc line, in the Aragonese Pyrenees and it will continue on lines in Madrid and Galicia.

Project News

Video: First hydrogen train on Spanish and Portuguese lines
12.06.2024
READ MORE »

Video: Hydrogen refuelling station in service
05.06.2024
READ MORE »

The hydrogen train finalises tests in Galicia
23.04.2024
READ MORE »

The first Hydrogen train carried out tests on the Portuguese railway network
16.04.2024
READ MORE »

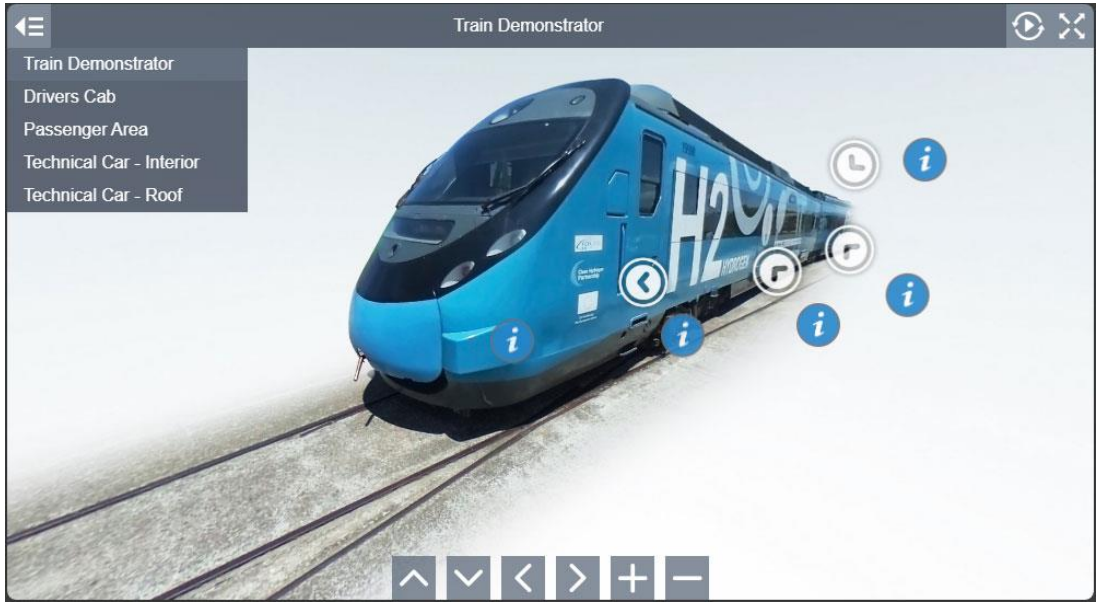
The Demonstrator Train proves more than 800 km autonomy in the Madrid testing campaign
04.03.2024
READ MORE »

https://fch2rail.eu/

Data of Demo-Train and Demonstration campaign
Visit the Train – FCH2RAIL

Train Demonstrator:

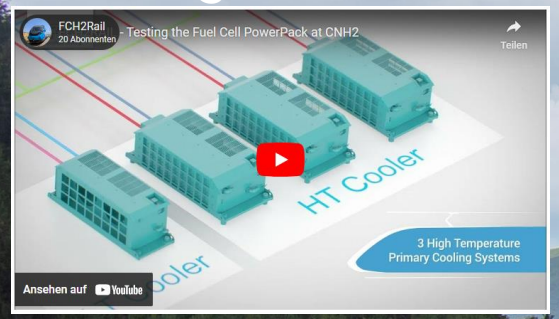
- 3 car Civia Unit with 2 FCHPP
- Pantograph for 3kV DC catenary
- ESS:
  - Max Power: 1044 kW
  - Capacity: 238 kWh
- Fuel Cells:
  - Six Toyota 2nd generation Fuel Cell Modules
  - 80 kW each, 480 kW in total
- H2 Storage:
  - 160 kg @350 bar in total, type III
  - 4 racks, 8 vessels/rack, 5 kg/vessel



Demonstration campaign:

- Several lines in Spain and Portugal
- 10,000 km in H2 mode
- 6,000 km in electric mode
- >2,000 kg H2 consumed
- >800 km autonomy

Testing the FCHPP



https://youtu.be/mC7EGb9VA7w

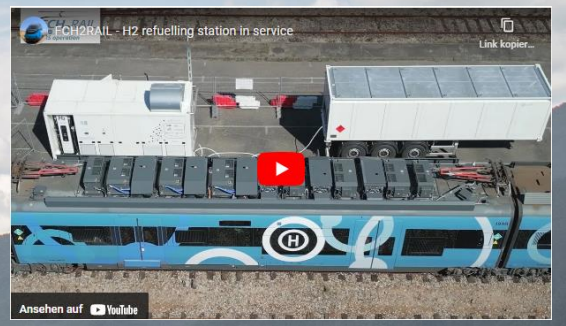
Train transformation

https://youtu.be/bFBR6nhyEVI

The Journey Begins!

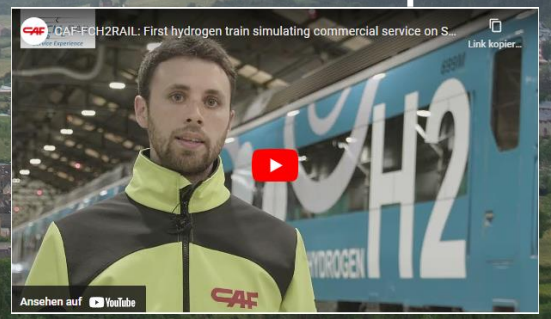
https://youtu.be/s4JfnDbrLW8

HRS Service



https://youtu.be/RkGnYSADNO0

H2 Train Service Experience



https://youtu.be/fFuYwuVSyII