WELCOME
FCH2RAIL Final Event

Zaragoza, 26 November 2024

FCH2RAIL Final Event

Fuel Cell Hybrid PowerPack for Rail Applications

Welcome and Introduction

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.

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FCH2RAIL Final Event

Fuel Cell Hybrid PowerPack for Rail Applications

Holger Dittus

Project Manager,
Project Coordinator FCH2RAIL

DLR Deutsches Zentrum für Luft- und Raumfahrt

Project Background

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Project Background

Jan 14, 2020

Extending the use cases for FC trains through innovative designs and streamlined administrative framework

ID: FCH-01-7-2020

Type of action:

- FCH2-IA Innovation action

Deadline Model : single-stage   Opening: **14 January 2020**   Deadline: **29 April 2020 17:00:00 Brussels time**

Open

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

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Project Consortium

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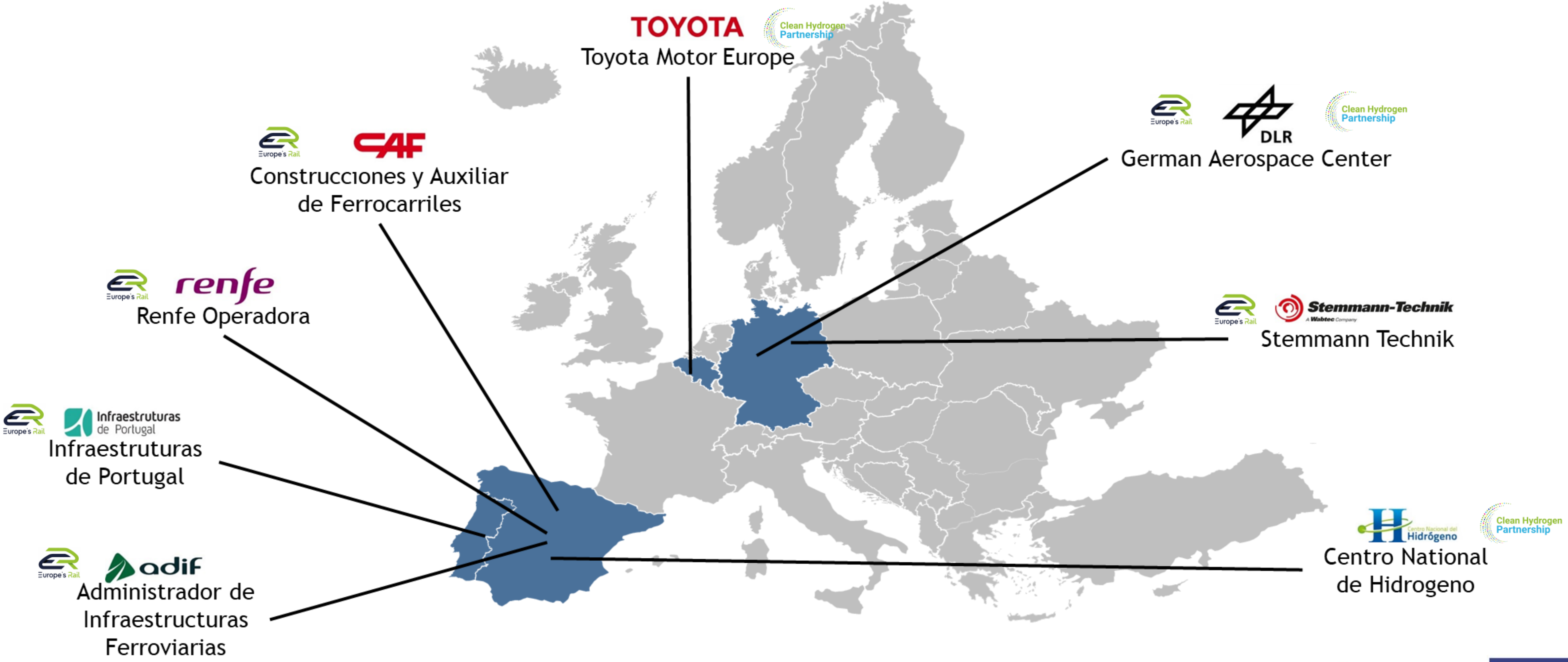

➔ FCH2RAIL consortium well-suited to achieve the given objectives.

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Fuel Cell Hybrid PowerPack for Rail Applications

Eva Terron

Technical Coordinator FCH2RAIL

CAF

Project Technical Background

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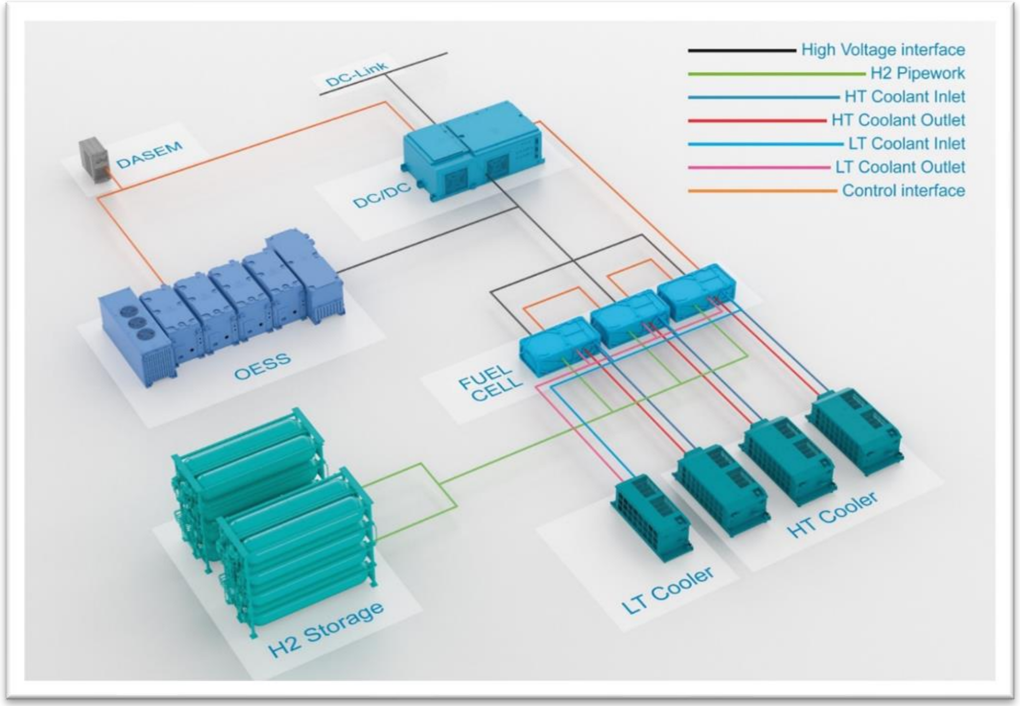
Technical Project Background

- What is an **Fuel Cell Hybrid PowerPack**?
  - Emission-free power generation system,
  - Combines energy provided by Hydrogen Fuel Cells and Batteries
- Why this is **Innovative**?
  - **Bi-mode**
    - Powered by Fuel Cells and Batteries in non electrified infrastructure
    - Powered from Catenay in electrified sections
    - Batteries can be charged from catenary, saving H2 and increasing the autonomy
  - **Modular and Scalable**
    - Suitable for very different power and energy requirements
  - Suitable for new trains but also to **retrofit existing trains**



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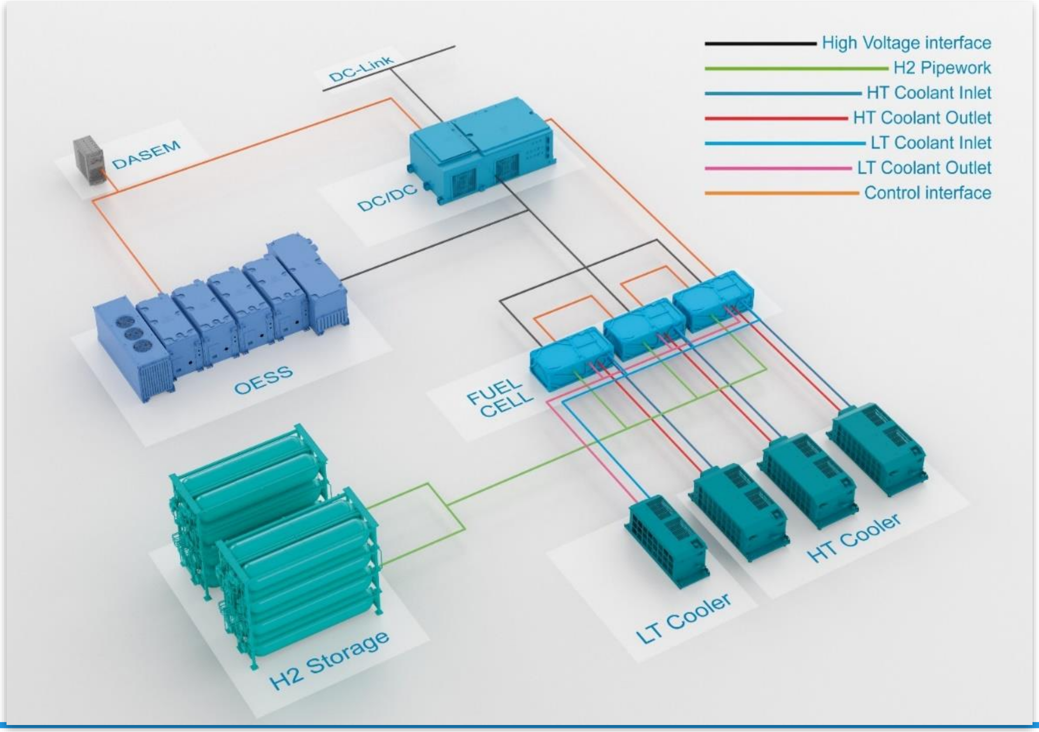
Technical Project Background

- 2 demonstrators have been produced:

Fuel Cell Hybrid PowerPack



Bi-mode train demonstrator

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Technical Project Background

- Authorization of the train demostrator for tests in three Member States of the EU
  - Spain
  - Portugal
  - Germany

- Results and achievements:
  - New technology works well
    - Long demonstration campaign
  - First H2 train in Spain -> commercial service in 6 lines has been demonstrated
  - First H2 train in Portugal -> testing in 1 additional line
  - Testing campaign of the train demonstrator has required refuelling in different locations

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Fuel Cell Hybrid PowerPack for Rail Applications

Abraham Fernández Del Rey

Rolling stock and Innovation Engineer

renfe

Operator's Technical Perspective

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Analysis of Operator Specifics

renfe

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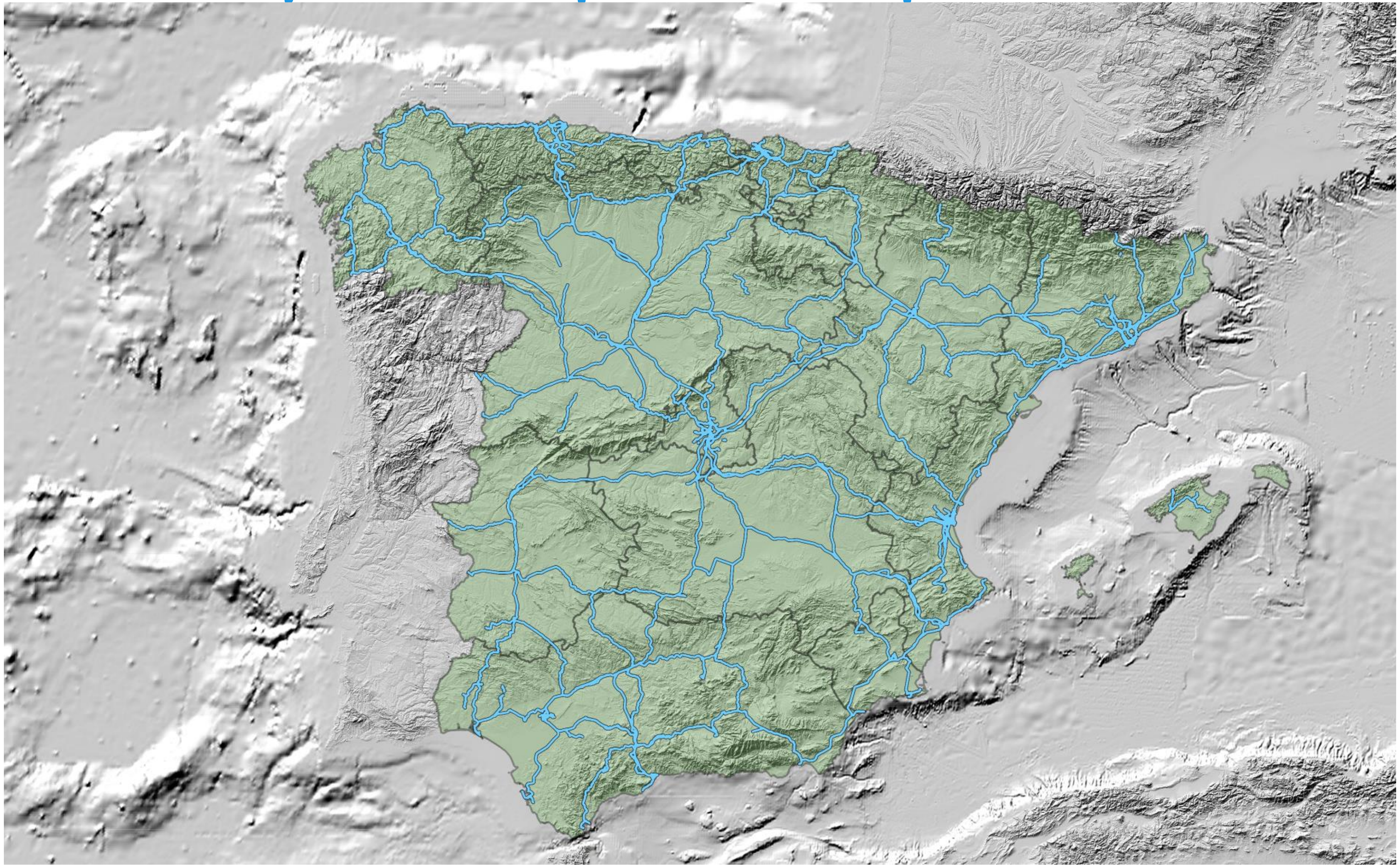

- Technical analysis of currently used vehicles in diesel services:
  - Locomotives+coaches
  - DMUs Metric gauge
  - DMUs Iberian gauge
- Precise understanding of requirements of Spanish services.
- Study of H_2 technology potential application.

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Vehicle requirements: from Civia EMU to H2 demonstrator

Original Civia vehicle 463.199

Safety	•Operational SRACS (Safety Related Application Conditions) •Driver Manual and Operational procedures update.
Vehicle technical specifications	•Power and performance •Weight •Autonomy •Limited impact to passenger space available
Operational aspects	•Refuelling •Driving experience •Fleet scalability •Reliability and availability
LCC costs	•Overall vehicle cost •H2 cost •Maintenance •Workshop compatibility

FCH2Rail demonstrator

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Analysis of Operator Specifics

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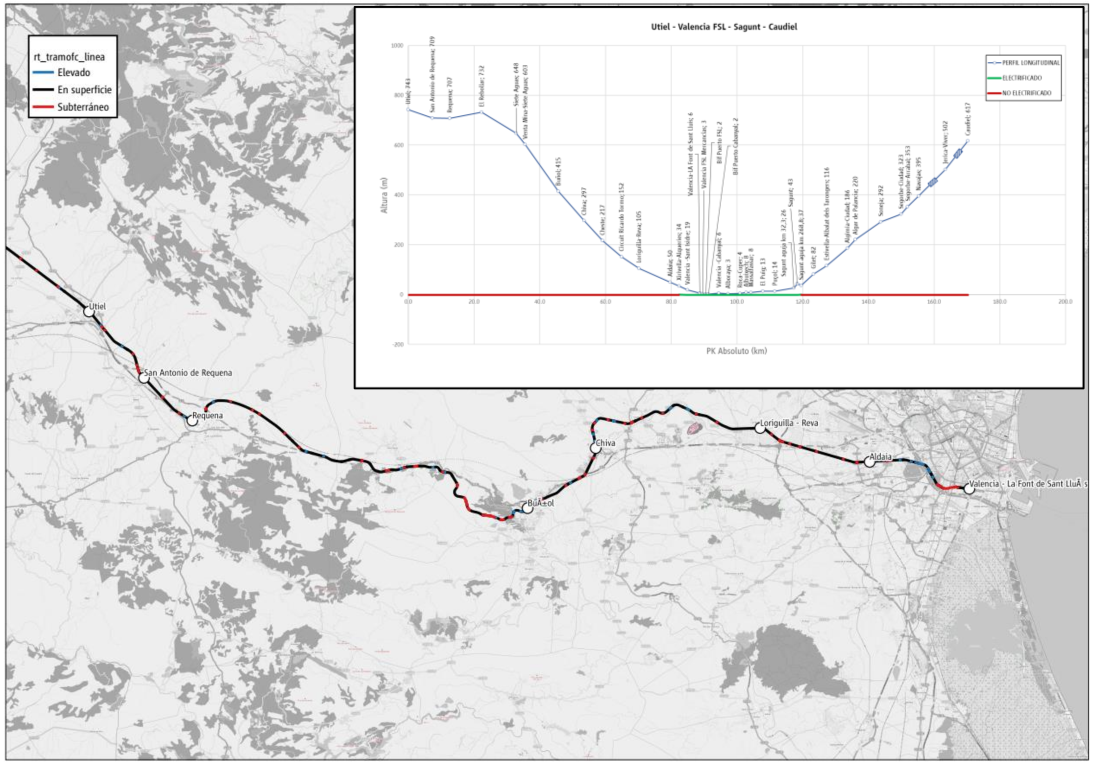

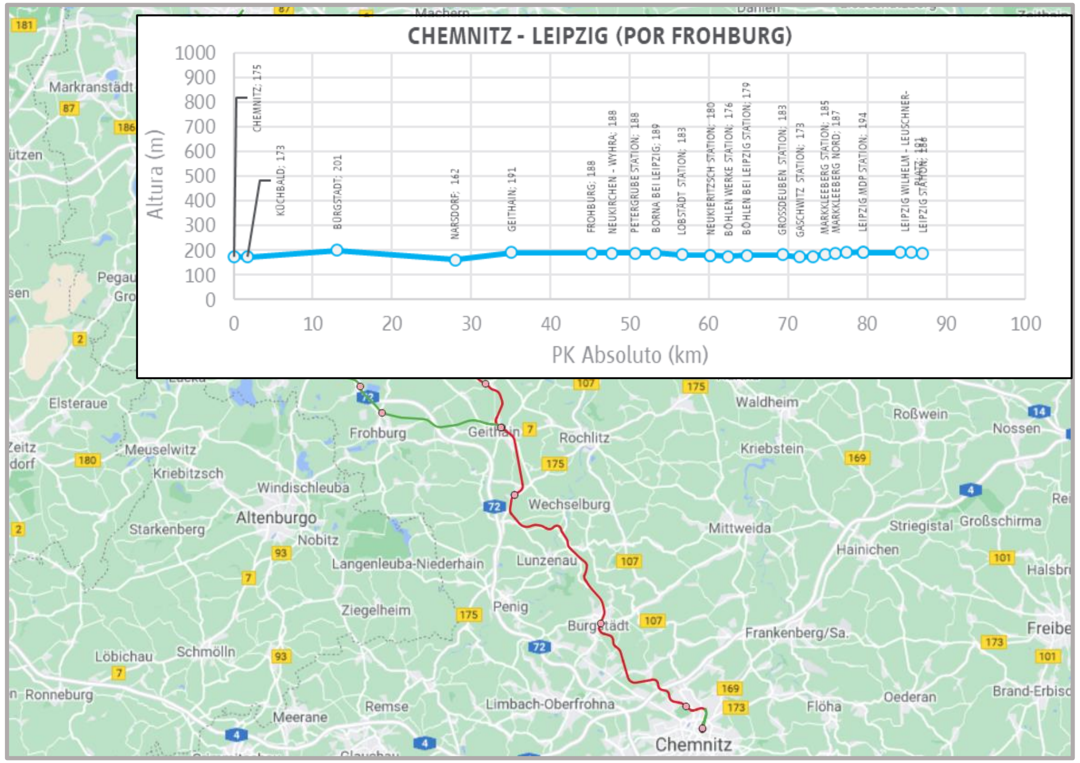

- Yield and discuss data inputs to use in two different simulators (Powerpack and demonstrator dimensioning).
- Results analysis oriented to feasibility in terms of power and energy.

- Other experiences are not extrapolable to Spanish railways:
  - Vehicles designed to operate through the whole network.
  - Orography is esential in vehicle dimensioning.

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Actual use cases and test lines

Source: Oscar López Herrero (Powell 333).

Middle range services		
Line	Rolling stock series	Traffic volume (trains/day)
Granada - Algeciras	S598	2
Huelva - Jabugo	S598	2
Sevilla - Almería	S599	2
Sevilla - Málaga	S598	4
Sevilla - Málaga	S599	
Salamanca - Madrid	S599	12
Salamanca - Valladolid - Palencia	S594	5
Valladolid - Palencia - León	S594	6
Valladolid - Puebla Sanabria	S594	2
Murcia - Cartagena	S599	10
Teruel - Zaragoza	S594	7
Valencia - Alicante - Murcia - Cartagena	S599	4
Valencia - Teruel - Zaragoza	S599	5
Valencia - Xativa - Alcoi	S592	8
Zaragoza - Canfranc	S596	4
Zaragoza - Canfranc	S599	
Madrid - Puertollano - Badajoz	S599	8
Madrid - Soria	S598	5
Madrid - Soria	S599	
Madrid - Talavera	S599	11
A Coruña - Ferrol	S594	6
A Coruña - Lugo - Monforte	S594	4
A Coruña - Vigo	S599	29
Santiago - Carballiño - Ourense	S594	3
Vigo - Ourense - Ponferrada	S594	4
Madrid - Siguenza	S599	9
Vigo - Oporto	S592	-

(*) Spanish network is in constant evolution. Hence, some of the lines have evolved to electrified services.

Agreed by all partners:

Middle range test services	
Line	Rolling stock series
Teruel - Zaragoza	S594
Valencia - Teruel - Zaragoza	S599
Zaragoza - Canfranc	S596
Zaragoza - Canfranc	S599
Madrid - Soria	S598
Madrid - Soria	S599
Madrid – Talavera (*)	S599
A Coruña - Ferrol	S594
A Coruña - Lugo - Monforte	S594
A Coruña - Vigo	S599
Santiago - Carballiño - Ourense	S594
Vigo - Ourense - Ponferrada	S594
Vigo - Oporto	S592

(*) Extended to Madrid - Cáceres

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Conclusions

Vehicle Related		Refuelling		Other Operational Factors	
Indicator	Status 2024	Indicator	Status 2024	Indicator	Status 2024
Vehicle requisites: Performance	Satisfactory	H2 cost	Further research needed	Fleet scalability	Further research needed
Vehicle requisites: Power at wheel	Satisfactory	H2 supply chain	sufficient for demonstration		
Vehicle requisites: Autonomy	Satisfactory	H2 Refuelling	Further research needed	Safety / Security	sufficient for demonstration
		Homologation			
Driver's experience	Satisfactory	Indicator	Status 2024		
Hybridization behavior	Satisfactory	Standardization Homologation	Further research needed	Maintenance	sufficient for demonstration

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Fuel Cell Hybrid PowerPack for Rail Applications

Inés Vadillo Cortázar

Head of R&D Sustainability Projects

adif

Authorization experience in hydrogen test train in Adif

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Adif Authorization process

Climbing our mountain:

- Spain: complex orography
- Several tunnels
- Ramps up to **30 ‰**

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Adif experience

Hydrogen tests in Spain

1) Tardienta – Canfranc_June 2023

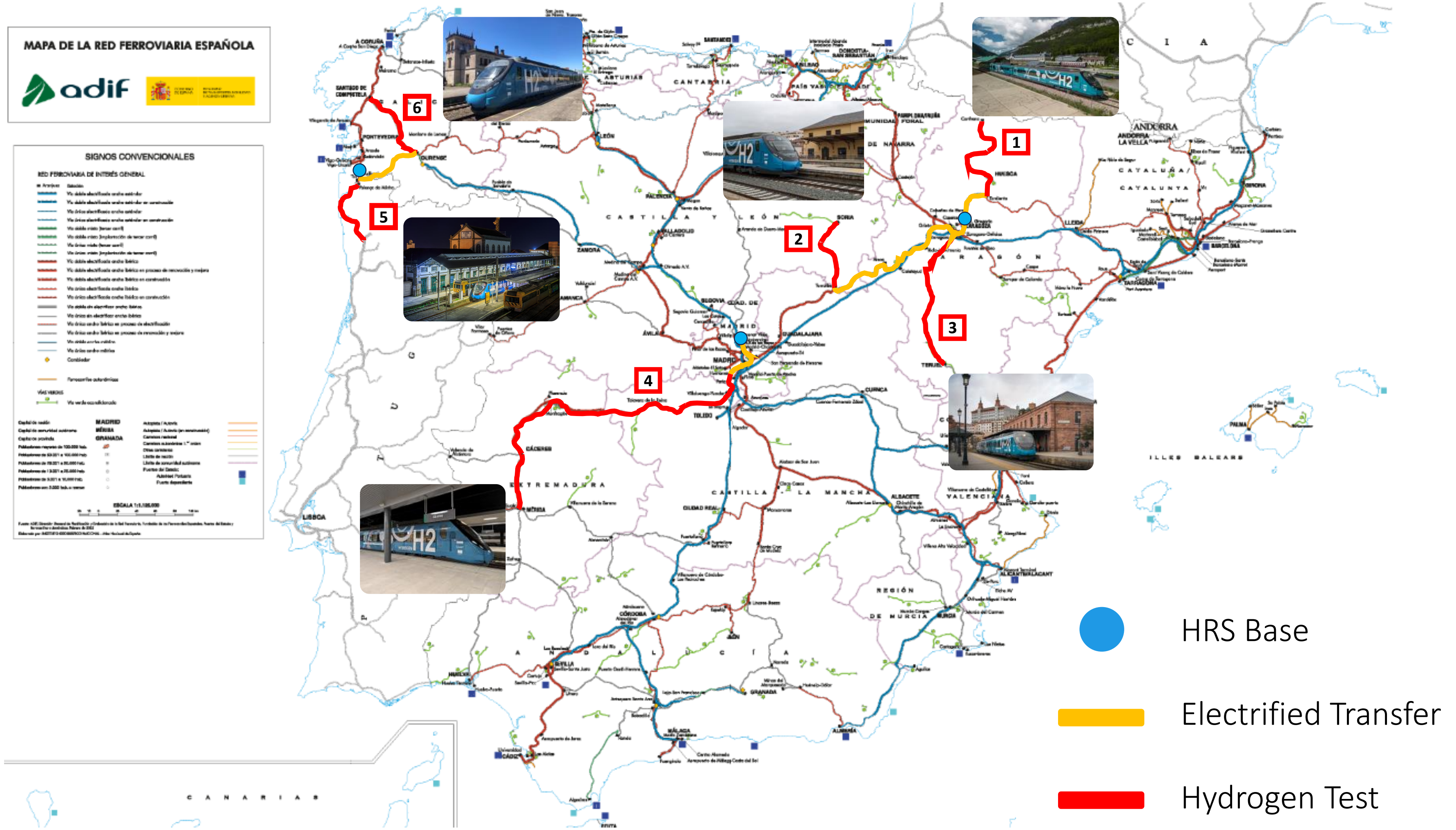
2) Torralba – Soria_November. 2023

3) Zaragoza – Teruel_Dec/Jan 2023

4) Madrid – Mérida_March 2024

5) Tui – Nune (Portugal)_April 2024

6) Ourense – Santiago de Compostela April 2024



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Emergency management

- Protective measures and emergency protocol.
- **Contingency plan** with operator.
- Risk control and emergency **response measures**.
- Management Risks in stops, parking
- Evacuation in emergency cases.
- **Tunnel Emergency** Plan.
- Communication protocols revision.
- **Training**


adif

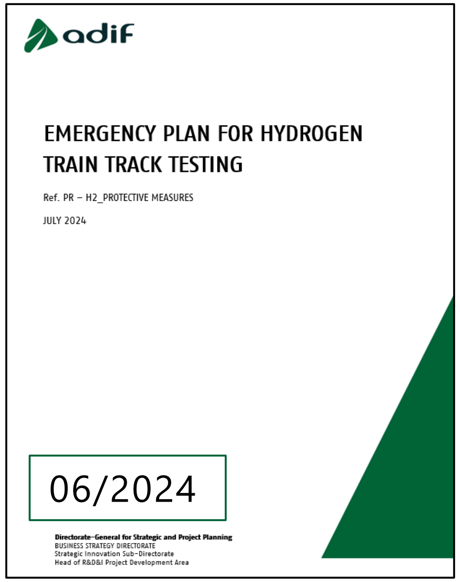
COORDINATION PROTOCOL FOR PROTECTIVE MEASURES AND TESTING EMERGENCIES ON FCH2RAIL TRAIN TRACKS

Ref. PR – FCH2RAIL_PROTECTIVE MEASURES

MAY 2023

05/2023

Directorate–General for Strategic and Project Planning
BUSINESS STRATEGY DIRECTORATE
Strategic Innovation Sub–Directorate
Head of R&D&I Project Development Area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EMERGENCY PLAN FOR HYDROGEN TRAIN TRACK TESTING

Ref. PR – H2_PROTECTIVE MEASURES

JULY 2024

06/2024

Directorate–General for Strategic and Project Planning
BUSINESS STRATEGY DIRECTORATE
Strategic Innovation Sub–Directorate
Head of R&D&I Project Development Area

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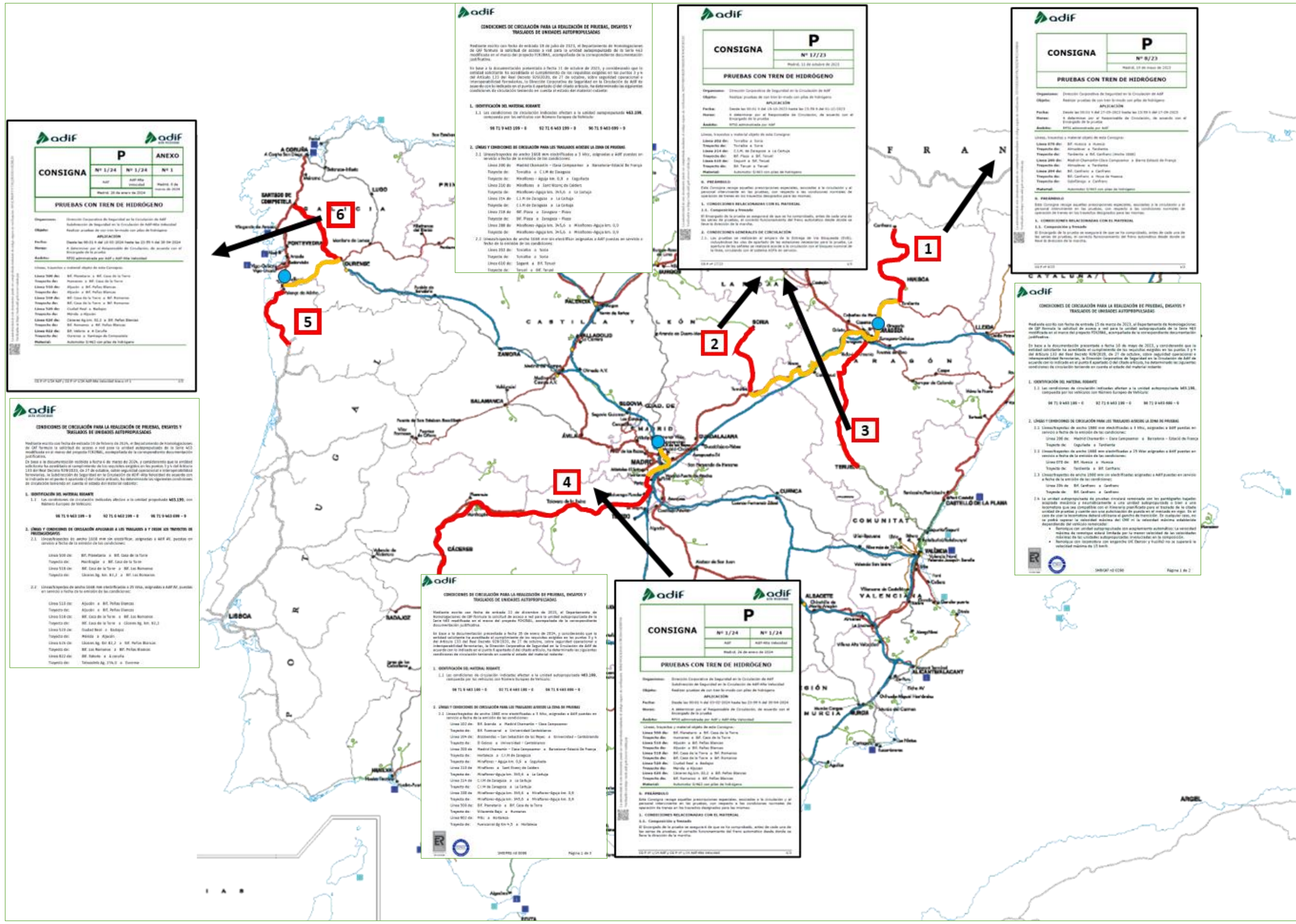
Authorizations= Consignas

- Object: Conduct **bi-mode** train tests with **hydrogen fuel cell.**
- Delivery of Specific Blocked Rules.
- Scope **RFGI** by Adif.
- Same **speed as** the original train.
- 2 drivers + test driver

+ Safety Operational Rules

-> 4 Authorizations + 4 SOR



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Lessons learned

- **January 2021**

➢ It is quite "impossible" to run a H_2 train in RFGI.

➢ There are no protocols for emergencies in case of an H_2 train.

➢ H_2 train, HRS, and other equipment need to be adapted to safety rail regulations (RD 402).

➢ A 10.000km test in 10 different lines is not possible due to the daily operation, maintenance, renovation, and electrification works.

- **November 2024**

✓ It is possible to authorize and test an H_2 train in Spain.

✓ 1st Authorization gets just about 3 moths after presented to Adif´s corporative safety department in 2023.

✓ A new **emergency document** was issued to ensure emergencies and tunnels.

✓ **10.000 km test** in H_2 during 10 months without any incidents.

✓ TRL 7 Train Authorization fullfilt.

✓ Decarbonization is possible.

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Conclusions

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Francisco Ganhão

Innovation Project Manager

Infraestruturas de Portugal

Train Demo in Portugal

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Tests in Portugal

Infraestruturas de Portugal

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- Only one line – Minho line
- The Civia train is not operated / homologated in Portugal
  - Need Civia train drivers for Portugal
  - Speed limitations due the track possession conditions
- Previous knowledge of the tests in Spain

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Summary & Outlook

Summary

- Authorization process (for TRL7 tests) completed in due time
- Tests done with no incidents
- Coordination between IP, Portuguese regulator (IMT) and safety authorities
- Tests done with the full possession of the line
  => done by night, reduce period for tests
- First H2 train demonstrator with TRL7 authorisation in Portugal!

Outlook

➔ For commercial services more tests and more complex validation process needed

➔ No experience with HRS systems in Portuguese network

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Fuel Cell Hybrid PowerPack for Rail Applications

Sergio Gascon

Technical Project Manager FCH2RAIL

CAF

Train Manufacturer perspective

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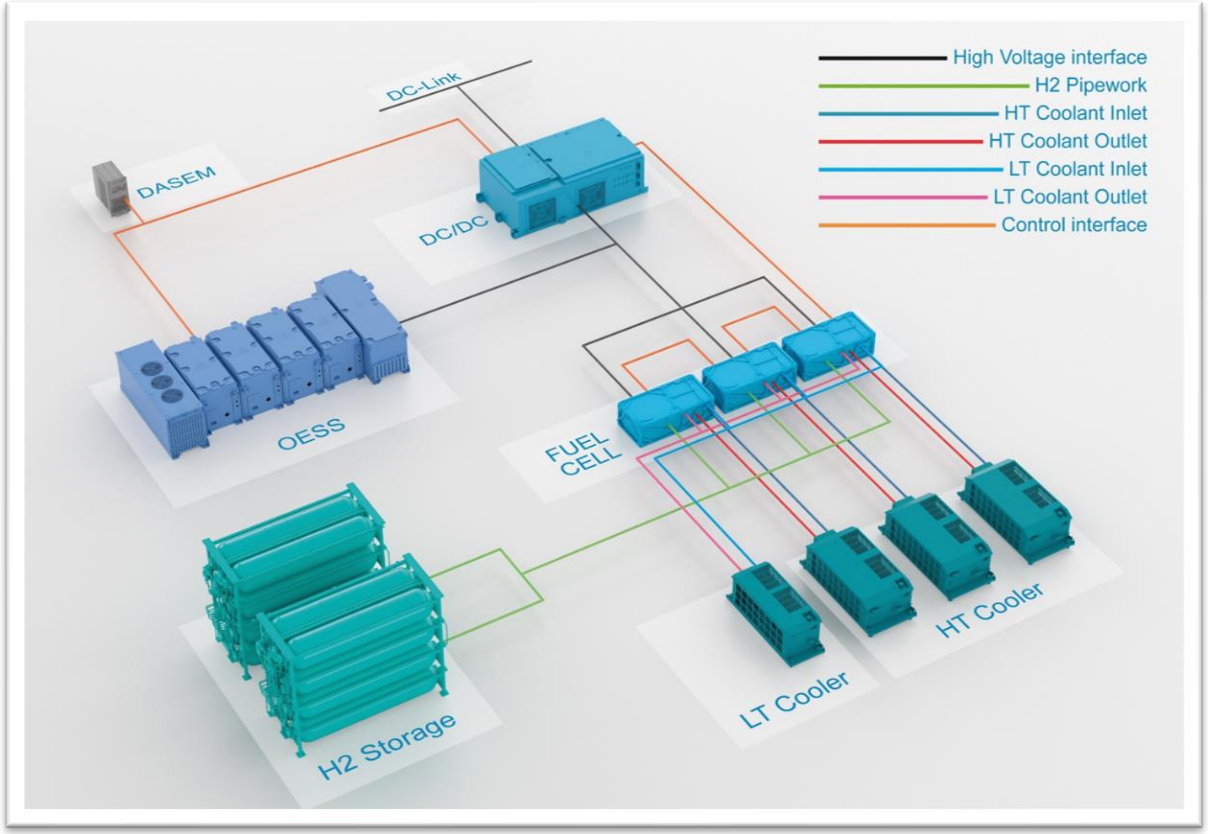
DEVELOPMENT OF THE FCH POWERPACK

Fuel Cell Hybrid PowerPack Components:

- **Fuel Cells** Modules - TOYOTA
- **OESS** (Battery) – CAF
- **HV DC/DC Converter** – CAF
- **DASEM** – CAF
- **H2 Storage** modules – CAF/ext. Supplier
- **FC Colling System** (HT+LT) – CAF/ext. Supplier



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INTEGRATION OF THE FCHPP COMPONENTS INTO THE TRAIN DEMONSTRATOR

- An existing CIVIA 3-car **EMU** has been **transformed into a Bi-mode Fuel Cell Hybrid Multiple Unit**
- **Two FCH Powerpacks** has been integrated into the CIVIA original traction and control architecture
- **Safety analysis** was carried out to consider all hazards and mitigation measures to be implemented
- The **transformation** of the train **to be reversible**, to roll back the train to its original state and return back to commercial servie

Train transformation

https://youtu.be/bFBR6nhyEVI

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VALIDATION OF THE TRAIN DEMONSTRATOR

November 2021
Testing of each FCH Power Pack component (OESS)

December 2021
Testing of FCH PowerPack integration in a simulator bench (CAF HIL)

March-July 2022
Testing 1 FCHPP in stationary in test bench at CNH2 facilities

May-June 2022
TRAIN WITH 1 FCHPP
Stationary testing at CAF Zaragoza factory

July-Sept. 2022
TRAIN WITH 1 FCHPP
Dynamic testing in San Gregorio closed line

February 2023
TRAIN WITH 2 FCHPPS
Dynamic testing in San Gregorio closed line

https://youtu.be/s4JfnDbrLW8

May 2023
Dynamic testing in Spanish National NetworK (Zaragoza-Canfranc line)

October 2023
Authorization for TLR7 Spanish National Network by ADIF

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SERVICE EXPERIENCE DEMOSTRATION

November 2023
Madrid-Soria

December 2023
Zaragoza-Teruel

February 2024
Madrid-Talavera

March 2024
Madrid-Merida

Autonomy of 804 km in H2 mode

Authorization for TLR7 Portuguese National Network by IP

April 2024
Portugal
Valença-Nine line

April 2024
Ourense-Santiago Compostela

Service experience in 6 additional routes in the Spanish and Portuguese National Network from November 2023 to April 2024 proving the performance and reliability of the vehicle

37 days of dynamic testing, covering more than 16,000 km, **10,000 km** of which have been **in hydrogen mode,** and **2,200 kg of H2 consumed**

Train Service Experience

https://youtu.be/fFuYwuVSyII

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OUTCOMES

Project objectives achieved:

- Develop, build, test and homologate a multi-purpose Fuel Cell Hybrid PowerPack ✔
- Demonstrate the FCHPP in a Bi-mode H2 multiple unit ✔

Additional achievements:

- The battery modules developed by CAF and applied in the demonstrator train has reached the maturity level necessary for its use in commercial service.
- Capability to simulate (model validation) the Fuel Cell Hybrid PowerPack in any operating condition, and implementing the advanced hybridization strategy into the DASEM system to optimize performance and consumption.
- New and valuable partners of the H2 market have been developed during the project

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CONCLUSIONS

AVAILABLE NOW	OUTLOOK

AVAILABLE NOW

Technological maturity: Hydrogen technology applied to railways is technically viable and ready to develop railway vehicles with promising performance and reliability.

Operational suitability: High-range of service autonomy of a bi-mode H2 train.

OUTLOOK

H2 supply chain: The supply chain of green H2 is not yet sufficiently mature. The logistics of the H2 is complex and the cost is high.

Commercial Hydrogen Refuelling Solutions suitable to refuel train fleet are still scarce in the market. High capacity H2 fast refueling not solved, a research topic for next years.

Regulatory framework: The current railway approval process does not cover the hydrogen railway vehicles, what makes the approval process uncertain, costly, and time-consuming.

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Fuel Cell Hybrid PowerPack for Rail Applications

Thomas Landtmeters

Senior Project Manager

TOYOTA

Fuel cell modules in rail application

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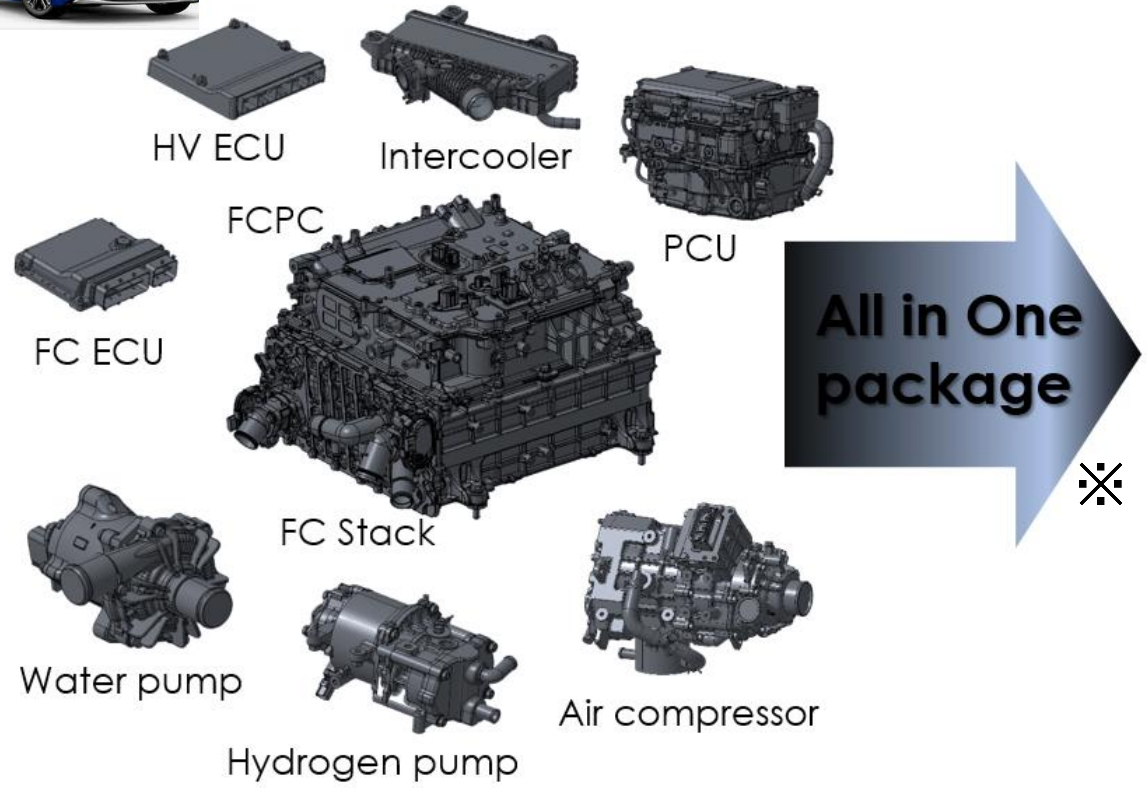
TOYOTA FUEL CELL MODULE



PCU: Power Control Unit; FCPC: FC Power Control Unit

※ Adaptations made to some components to match application requirements

GEN2 Module

- 80kW net power out
- Easy integration and installation
- Integrated DC/DC converter
- As single unit or combined

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ASSEMBLY OF MODULE IN TME BRUSSELS

TOYOTA

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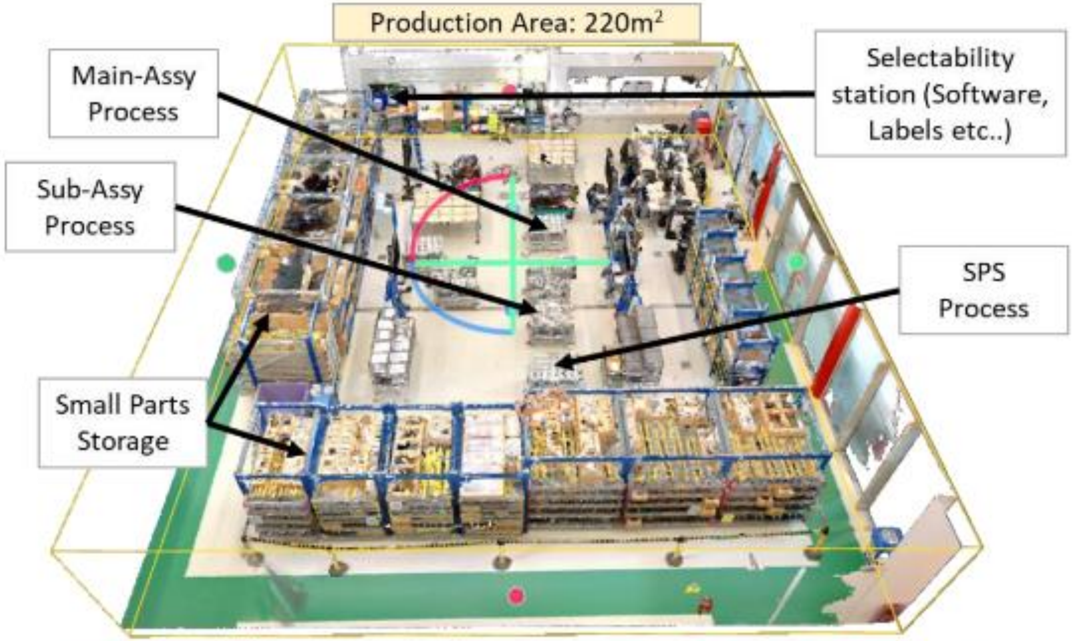
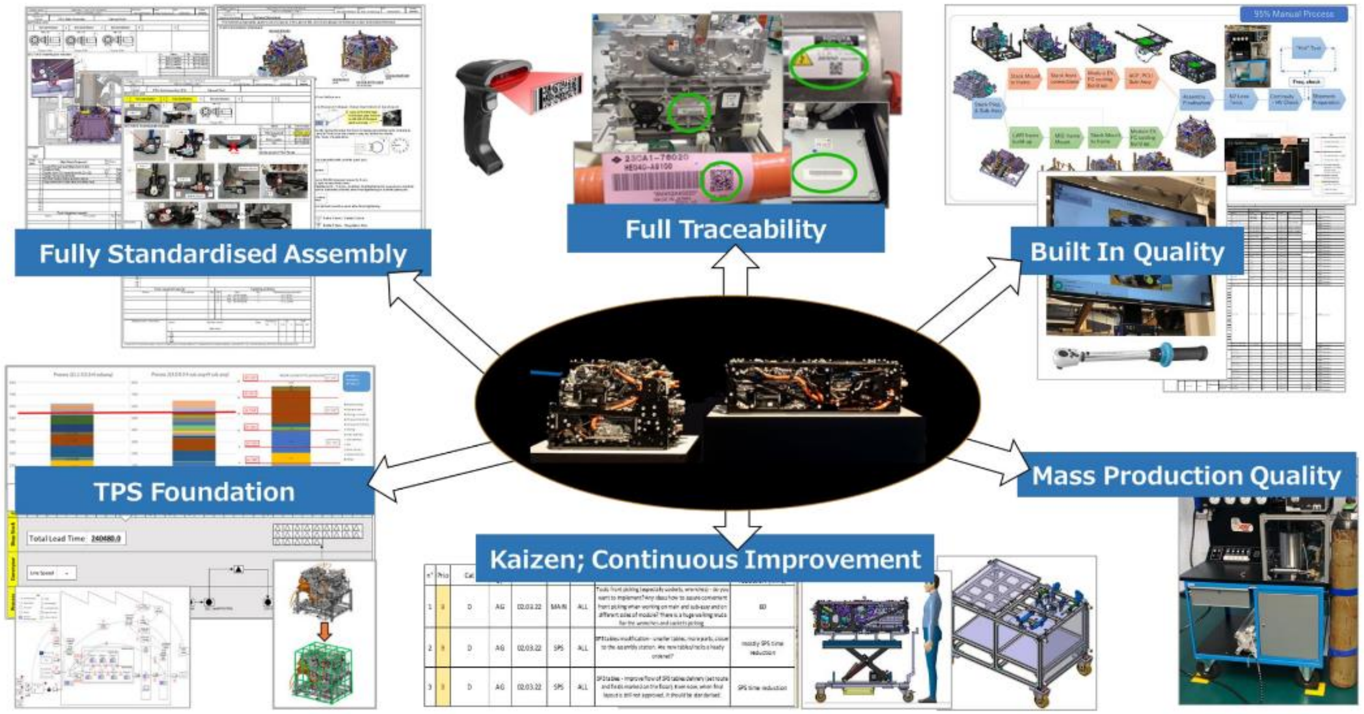
Assembly area



Assembly principles



- First modules assembled in TME
- All TPS principles in place

TPS: Toyota Production System

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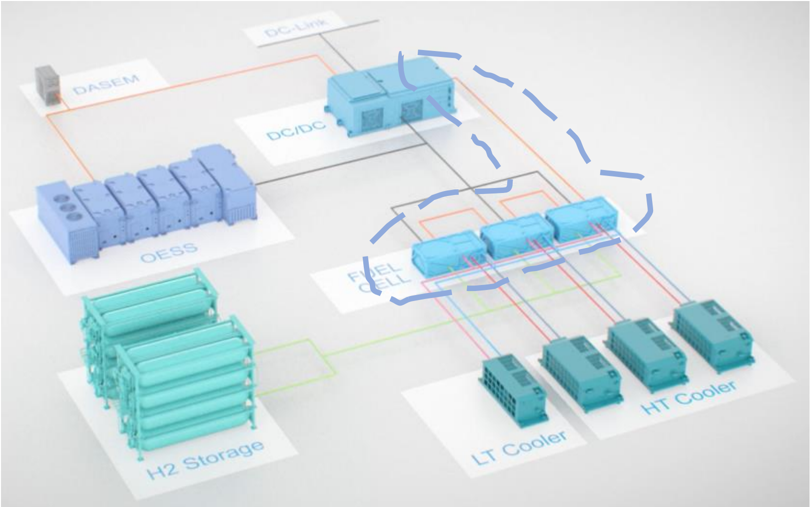
BENCH TESTING

Quality Check

- 1 Fuel Cell Module
- TOYOTA control system
- Functional Check
- Performance Confirmation

CAF FCHPP Control check



- 3 Fuel Cell Module in parallel
- CAF control system
- Functional Check

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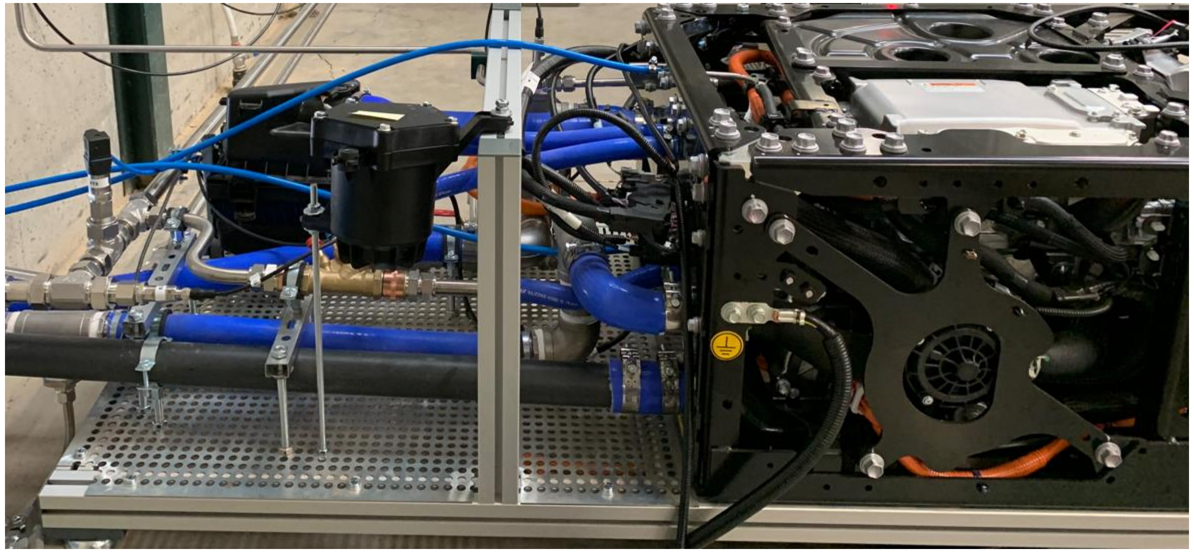
FCM IN OPERATION

CNH2 TEST BENCH



- Safety response confirmed
- Tekstbook behaviour

FCH2RAIL DEMO TRAIN

- No concerns encountered
- No unexpected stops
- FCM always deliver requested power

LEARNING POINTS

- Need more power
- Space is precious

} Power density must go up

- Regulation & Certification → Need standard for FCM*

*IEC will publish dedicated FC standard for railway by Jan’25 (IEC 63341-1)

>> For this demonstration project: TOYOTA GEN2 FCM OK

>> For future train: Improvements can be expected on next generation Fuel Cell Modules.

2020

FCH2RAIL Project start

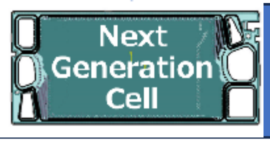
80kW

Increase cell active area

TODAY

85kW

+ better lifetime



Increase number of cells

FUTURE

Higher power, longer lifetime, better efficiency, lower cost…

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Fuel Cell Hybrid PowerPack for Rail Applications

Carlos de la Cruz Rodríguez

Head of Simulation, Control and End-Use Unit

Centro Nacional del Hidrógeno

FCHPP testing and HRS development

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FCHPP Testbench

Objectives

- To **test a complete Fuel Cell Hybrid PowerPack.**
- To **demonstrate operation and performance** of the Fuel Cell Hybrid PowerPack.
- To **know how** the individual equipment performs **before the integration** into the train.
- To **optimize** the **controls and energy** management **system.**

Challenges

- How to **test** a H2 train propulsion system **without a train**
- Where to find **large facilities** to accommodate huge and heavy equipment
- How to provide **high flow and total amount of green H2** and load dissipation required
- How to do it in a complete **safety** manner

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FCHPP Testbench

https://youtu.be/mC7EGb9VA7w

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Modular H_2 Refuelling Station

Objectives

- Provide hydrogen for the demonstration train at different locations → Portable design
- Do it with tight budget and time frame and in a safe way
- Manage administrative procedures in different regions

Challenges

- Different technical and administrative requirements for different locations
- Lack of normative framework → Protocols and refuelling curves development
- Low availability of components

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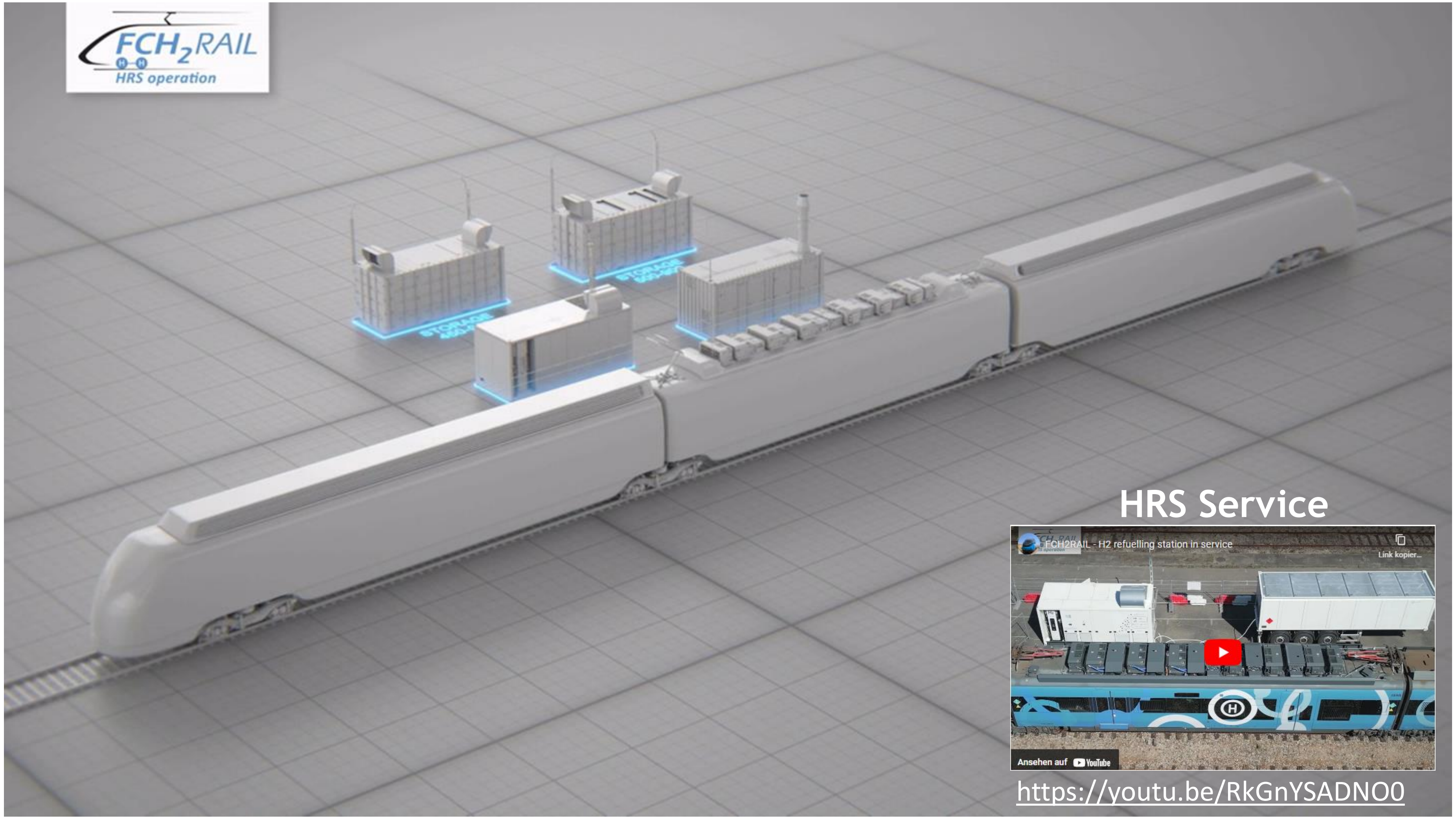
Modular H_2 Refuelling Station



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CONCLUSIONS

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Conclusions Refuelling station

- Refuelling station development was initially underestimated.
- We finally developed solutions under challenging conditions in terms of budget and time to carry out the demonstration.

Conclusions FCHPP Testbench

- Collaboration of all partners involved was key to success, specially CAF P&A
- We validated and optimized the FCHPP systems early before they have been used in the demonstrator train

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FCHPP test bench

“Best Innovation Award” by Clean H2 Partnership

The test bench developed by CAF and CNH2 to test and optimize a full-scale FCHPP “in the lab” received the Best Innovation Award from the Clean Hydrogen Partnership during the EU Hydrogen Week 2024.

Grant Agreement Number: 101006633

Clean Hydrogen Partnership
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FCH_2RAIL

Final Event

Fuel Cell Hybrid PowerPack for Rail Applications

Lutz Boeck

Head of Center of Competence HVAC

Wabtec CORPORATION

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.

Clean Hydrogen Partnership

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Investigation of alternative cooling/heating technologies

Background

- Heating/Ventilation/Air Conditioning (HVAC) is second largest electrical consumer in regional trains
- Significant influence on H2 vehicle range

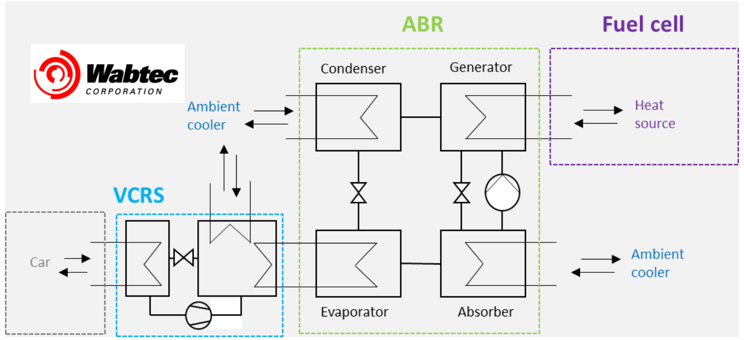
Technologies

- HyPAC: Hydrogen Powered Air Conditioning (TRL 5)
- ABR: Absorption Refrigeration System (TRL 3)
- Heating by direct usage of FC waste heat (TRL 7)

Hydrogen Powered Air Conditioning HyPAC

→ Uses pressure difference between H2 storage and fuel cells
→ Provides cooling power

Absorption Refrigeration System ABR



→ Uses FC waste heat and converts to cooling power

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Investigation of alternative cooling/heating technologies

Project results and conclusion:

- ✓ Identified saving potential for **HVAC yearly energy** consumption **10..15%** (6000 – 8000 kWh/year)
- ✓ **HyPAC ready for demonstration** on train; further investigation on weight, dimensions and costs are needed
- ✓ **ABR needs higher waste heat temperatures**, results become **relevant in HT-FC applications**
- ✓ **Heating by direct usage** of waste heat from fuel cell system should be applied

➔ Saving potential for HVAC in hydrogen trains is relevant and further development and optimization is needed

Project objective achieved:

- Identify and benchmark innovative solutions to improve energy efficiency ✓

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FCH2RAIL Final Event

Fuel Cell Hybrid PowerPack for Rail Applications

Markus Kordel

Research Associate

DLR Deutsches Zentrum für Luft- und Raumfahrt

Methods and tools for hybrid trains

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.

Clean Hydrogen Partnership

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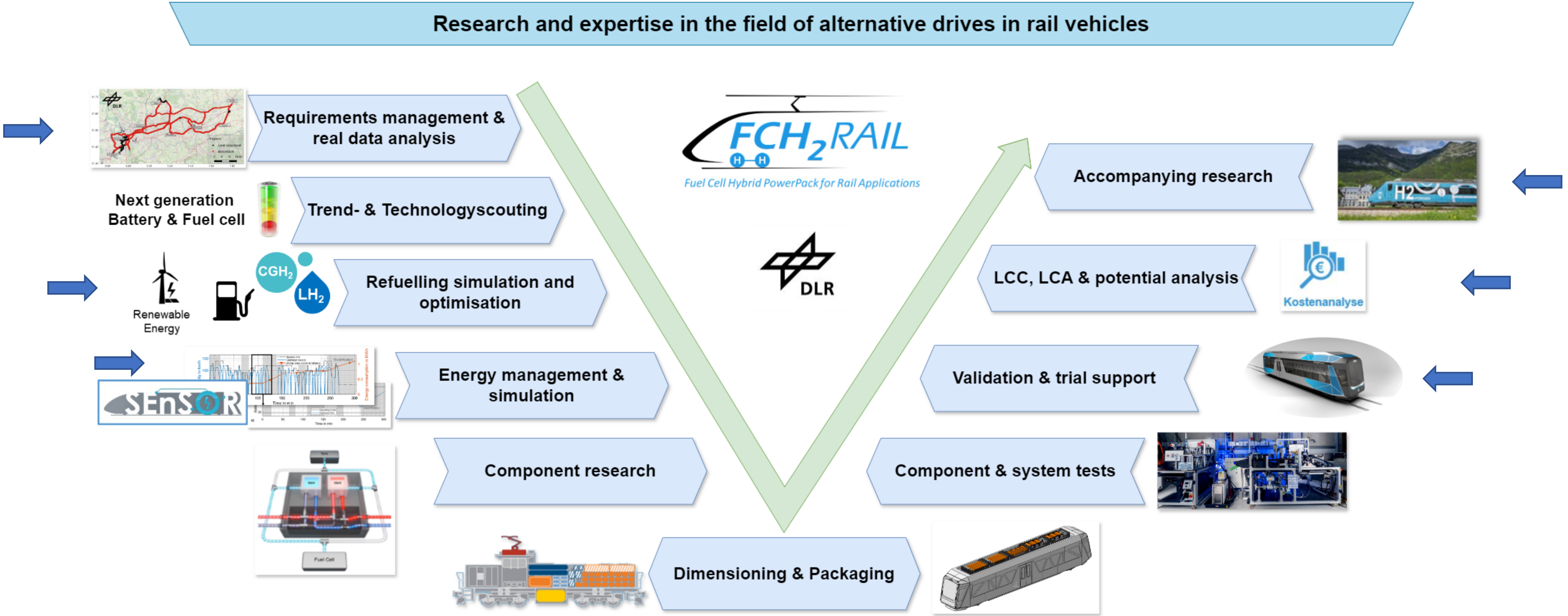
DLR Research in FCH_2Rail



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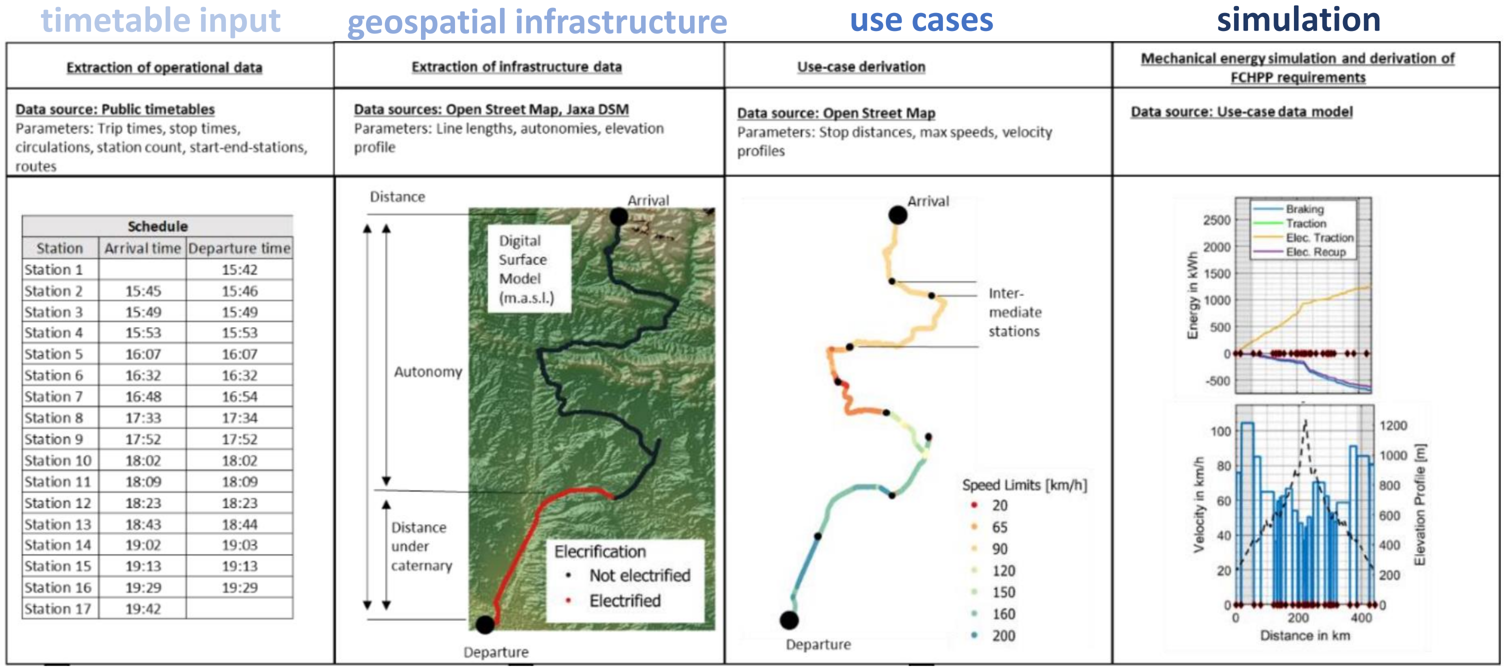
FCHPP requirements toolchain
Geospatial assessment and simulation

- DLR developed a data-driven **toolchain** to derive **requirements** on **FCHPP component dimensioning**
- **It includes:**
  - a timetable input module
  - a geospatial infrastructure module (routing and elevation profile production)
  - a use case module
  - a **longitudinal dynamic simulation module** to determine traction power at wheel



Schedule		
Station	Arrival time	Departure time
Station 1		15:42
Station 2	15:45	15:46
Station 3	15:49	15:49
Station 4	15:53	15:53
Station 5	16:07	16:07
Station 6	16:32	16:32
Station 7	16:48	16:54
Station 8	17:33	17:34
Station 9	17:52	17:52
Station 10	18:02	18:02
Station 11	18:09	18:09
Station 12	18:23	18:23
Station 13	18:43	18:44
Station 14	19:02	19:03
Station 15	19:13	19:13
Station 16	19:29	19:29
Station 17	19:42	

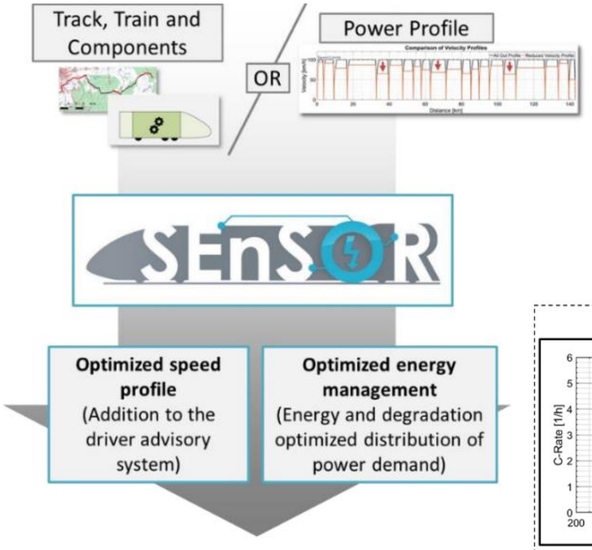
- Kühlkamp, Florian und Schenker, Moritz und Pagenkopf, Johannes und Dittus, Holger und Herwartz, Sebastian und Fernández Del Rey, Abraham und Varela, Maider (2022) *The FCH2RAIL Project: A Demonstration of a Modular Fuel Cell Hybrid Power Pack.* In: 2022 Conference Proceedings Transport Research Arena, TRA Lisbon 2022. TRA - Transport Research Arena, 2022-11-14 - 2022-11-17, Lissabon. doi: 10.1016/j.trpro.2023.11.615. ISSN 2352-1457.
- Herwartz, Sebastian und Kühlkamp, Florian und Pagenkopf, Johannes und Fernandez del Rey, Abraham und Valera, Maider und Martin-Carillo, Antonio und Ganhao, Francisco (2022) *Bi-Mode Hydrogen Train Requirements Using Geospatial Line Assessment.* World Congress on Railway Research 2022, 2022-06-06 - 2022-06-10, Birmingham, UK.

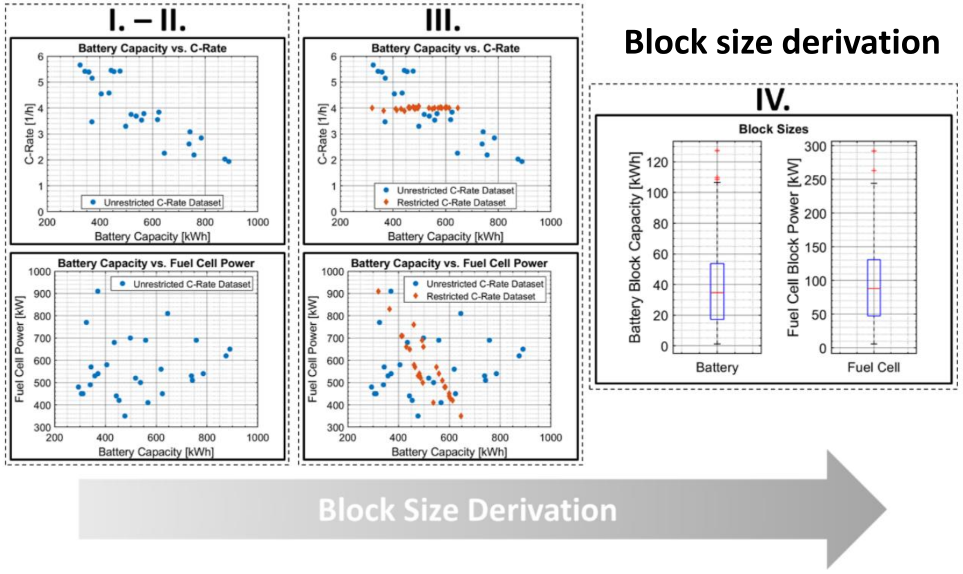
Grant Agreement Number: 101006633
Deutsches Zentrum für Luft- und Raumfahrt DLR
FCH2RAIL Final Event – Fuel Cell Hybrid PowerPack for Rail Applications
Clean Hydrogen Partnership
Co-funded by the European Union

FCHPP requirements toolchain
Energy management + block sizes

- DLR developed a data-driven **toolchain to derive requirements** on **FCHPP component dimensioning**
- **It includes:**
  - a **timetable input module**
  - a **geospatial infrastructure module** (routing a
    elevation profile production)
  - a **use case module**
  - a **longitudinal dynamic simulation module** to determine traction power at wheel
  - an **energy minimizing control strategy (SEnSOR)**
  - a **hybridization** framework to derive meaningful **FC** and **BAT block sizes**

→ the **DLR toolchain** enables a rapid investigation of single lines and entire networks





- Kühlkamp, Florian und Schenker, Moritz und Pagenkopf, Johannes und Dittus, Holger und Herwartz, Sebastian und Fernández Del Rey, Abraham und Varela, Maider (2022) *The FCH2RAIL Project: A Demonstration of a Modular Fuel Cell Hybrid Power Pack.* In: 2022 Conference Proceedings Transport Research Arena, TRA Lisbon 2022. TRA - Transport Research Arena, 2022-11-14 - 2022-11-17, Lissabon. doi: 10.1016/j.trpro.2023.11.615. ISSN 2352-1457.
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FCH2RAIL Final Event
Fuel Cell Hybrid PowerPack for Rail Applications
Clean Hydrogen Partnership
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Publications

Deutsches Zentrum für Luft- und Raumfahrt DLR

FCH2RAIL Final Event — Fuel Cell Hybrid PowerPack for Rail Applications

Review and comparison of worldwide hydrogen activities in the rail sector with special focus on on-board storage and refueling technologies
Mathias Böhm, Abraham Fernández Del Rey, Johannes Pagenkopf, Maider Varela, Sebastian Herwartz-Polster, Beatriz Nieto Calderón
International Journal of Hydrogen Energy 47 (2022) 38003–38017 — Review Article

FCH2RAIL insights — Demonstration of the Fuel Cell Hybrid PowerPack
Join us at InnoTrans 2022, Hall 7.2 A
22 September from 13.30 - 14.30
videostream via https://plus.innotrans.de/

Optimization algorithm for minimizing railway energy consumption in hybrid powertrain architectures: A direct method approach using a novel two-dimensional efficiency map approximation
Rahul Radhakrishnan and Moritz Schenker
Proc IMechE Part F: J Rail and Rapid Transit 2024

Waste Energy AC Technologies in H2-Multiple Units
Kordel, Markus, Heeland, Matthew Maikel, Knetsch, Kevin
Proceedings of the 4th International Railway Symposium Aachen 2023, Session 14

Bi-Mode Hydrogen Train Requirements Using Geospatial Line Assessment
Sebastian HERWARTZ, Florian KÜHLKAMP, Johannes PAGENKOPF, Abraham FERNANDEZ DEL REY, Maider VARELA, Antonio Martin CARRILLO DOMINGUEZ, Francisco Manuel ROMA GANHÃO
WCRR Birmingham UK 2022

FCH2RAIL: Comparison of simulative methods and fuel cell-battery hybrid powertrains

Comparison of simulative methods for dimensioning of fuel cell-battery hybrid powertrains in FCH2Rail and Virtual-FCS
Scharmach, Marcel, Schenker, Moritz und Dittus, Holger
Proceedings of the 4th International Railway Symposium Aachen 2023, Session 14

Using Absorption Refrigerator and Metal Hydrides in Hydrogen Fuel Cell Trains: Draft Design Process and Feasibility
M. Kordel, K. Knetsch, F. Heckert and L. Boeck
European Hydrogen Energy Conference 18-20 May, 2022. Madrid, Spain

The FCH2RAIL Project: A Demonstration of a Modular Fuel Cell Hybrid Power Pack
Florian Kühlkamp, Moritz Schenker, Johannes Pagenkopf, Holger Dittus, Sebastian Herwartz-Polster, Abraham Fernández Del Rey, Maider Varela
Transport Research Arena (TRA) Conference — Transportation Research Procedia

Limitations in the Hydrogen Refueling Process of Railway Vehicles
S. Wieser, L. Brünner, M. Böhm, F. Heckert, S. Rubio and M. Soto
Proceedings of the Sixth International Conference on Railway Technology: Research, Development and Maintenance, Civil-Comp Press, 2024

Hydrogen on-board storage options for rail vehicles
M. Boehm
European Hydrogen Energy Conference 18-20 May, 2022. Madrid, Spain

FCH2RAIL insights — Demonstration of the Fuel Cell Hybrid PowerPack
f-cell 2022 | Session Trains, Ships, Airplanes | 04.10.2022 | Stuttgart
Holger Dittus | German Aerospace Center (DLR)

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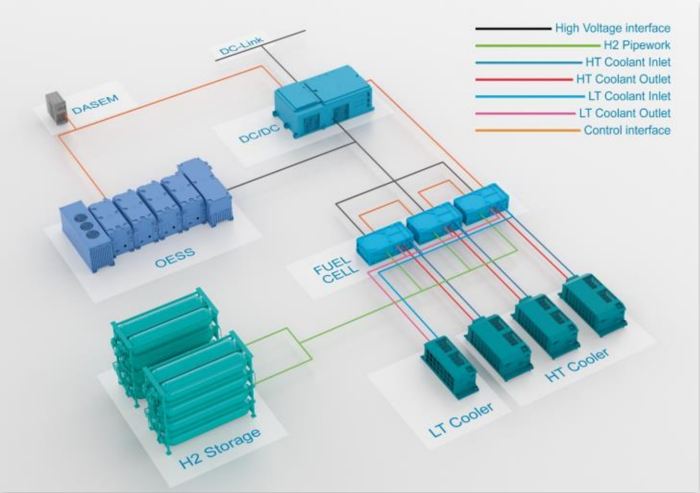
Summary & Outlook

Summary

- Research tool-chain was set up:
  - requirement analysis → FCHPP layout → energy management / hybridization → KPI/LCC
- Project data and measurements were used for tool validation



Outlook

→ high capacity H2 fast refuelling: not solved, a research topic for next years

→ FCHPP concept: further development for other rail applications, i.e. high power / high energy, locomotives

→ HVAC solutions (HyPAC): to be intensified

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Q&A

FCH2RAIL Final Event

Fuel Cell Hybrid PowerPack for Rail Applications

Beatriz Nieto Calderón

Head of Engineering Unit

Centro Nacional del Hidrógeno

Normative Framework & Networking

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.

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OBJECTIVES

Propose a normative framework for hydrogen in railway vehicles

Development of the fundamental basis of a normative framework for the use of hydrogen technology in different railway applications across Europe.

→ Identification of the **existing regulatory gaps** for application of hydrogen in the railway sector.

→ **Propose actions** to solve these gaps and facilitate the introduction of hydrogen technology in the railway sector.

→ **Networking activities**

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LEGISLATIVE GAP ANALYSIS

TRAIN

- Numerous regulatory gaps have been found
  - Specific regulations for railway systems
  - From other industries

INFRAESTRUCTURE

- After train experience regulatory gaps that were not currently taken into consideration was identified.
  - Authorisation procedures
  - Technical issues

PANTOGRAPH

- No new gaps found

HYDROGEN REFUELLING

- Certain lack in addressing technical specifications.
- Difficulties with standards regarding hydrogen refuelling protocols for high capacity heavy-duty vehicle.

TSI

- Interoperability requiring some type of modification
  - Environmental protection
  - Fire safety on tunnels
  - ...

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RESULTS

FCH2RAIL deliverable D7.1 - Gaps in regulatory framework

+

FCH2RAIL Deliverable D7.4 - Complementary Gaps in regulatory Framework

FCH2RAIL deliverable D7.2 – Proposal of modifications of normative framework

Dissemination, communication and Networking Activities

Stakeholders engagement

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STAKEHOLDERS

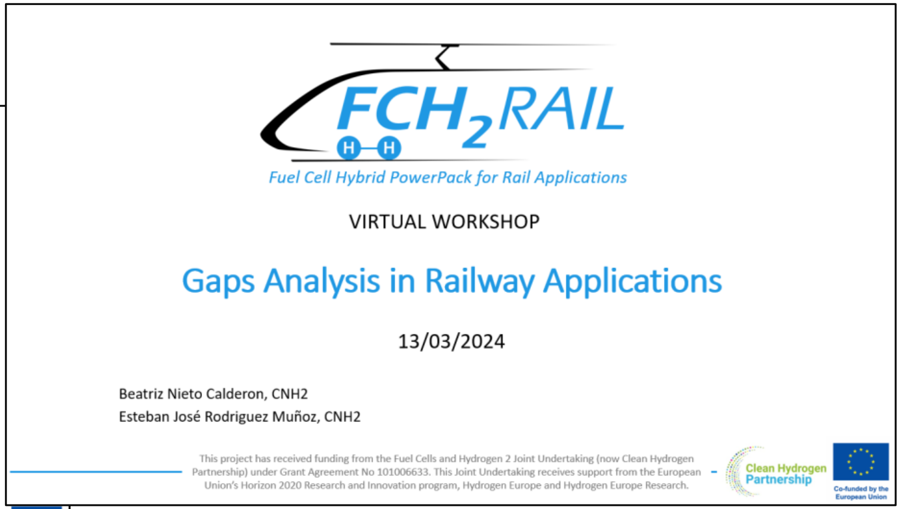
Industry, administration

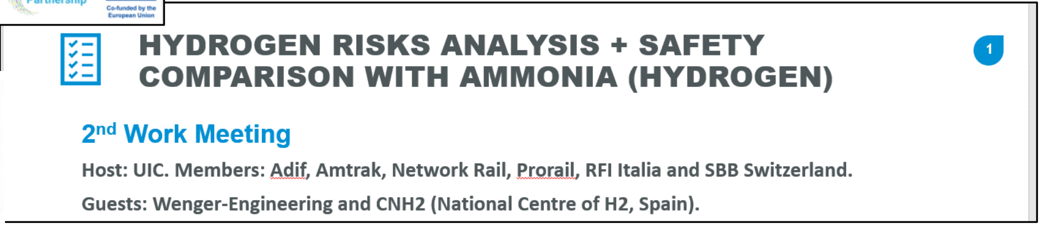
Research Projects

Project Advisory Board (AB)

NETWORKING ACTIVITIES

Fuel Cell Hybrid PowerPack for Rail Applications





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CONCLUSIONS

- FCH2RAIL has taken very **important steps** that would allow the **implementation of the hydrogen technology in the railway sector**.
- One of the **challenges** of the project has been the **lack of regulations** to follow operational or administrative procedures.
- The **stakeholders engagement** could be **achieved** even in a difficult boundary conditions.
- Important **partners from H2 and railway sector** could be activated to engage in the normative and standardisation topics. The interest has been quite high. Both sectors **are actively and openly discussing the H2 related issues.**
- Together with the contributions it was **possible** to create the results and **to align** on further **future activities**:
  - UIC accepted results as input
  - German H2 standardization committee integrated results from the project
  - Spanish AESF used the FCH2Rail results and considers them.
  - …..

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NEXT STEPS

- To **continue developing standardization and normalization protocols** that have been partly initiated.
- To **continue working on the different committees** for the development of standardization and regulation.
  - IEC TC9 Electrical equipment and systems for railways
    - IEC 63341-1, IEC 63341-2, IEC 63341-3
  - TIR SAE 2601-5
  - …
- To continue the **collaboration with stakeholders and European Projects**.
  - Rail4Earth
  - ERA
  - AESF
  - ……

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Fuel Cell Hybrid PowerPack for Rail Applications

Holger Dittus

Project Manager,
Project Coordinator FCH2RAIL

DLR Deutsches Zentrum für Luft- und Raumfahrt

Project Summary

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Summary?

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

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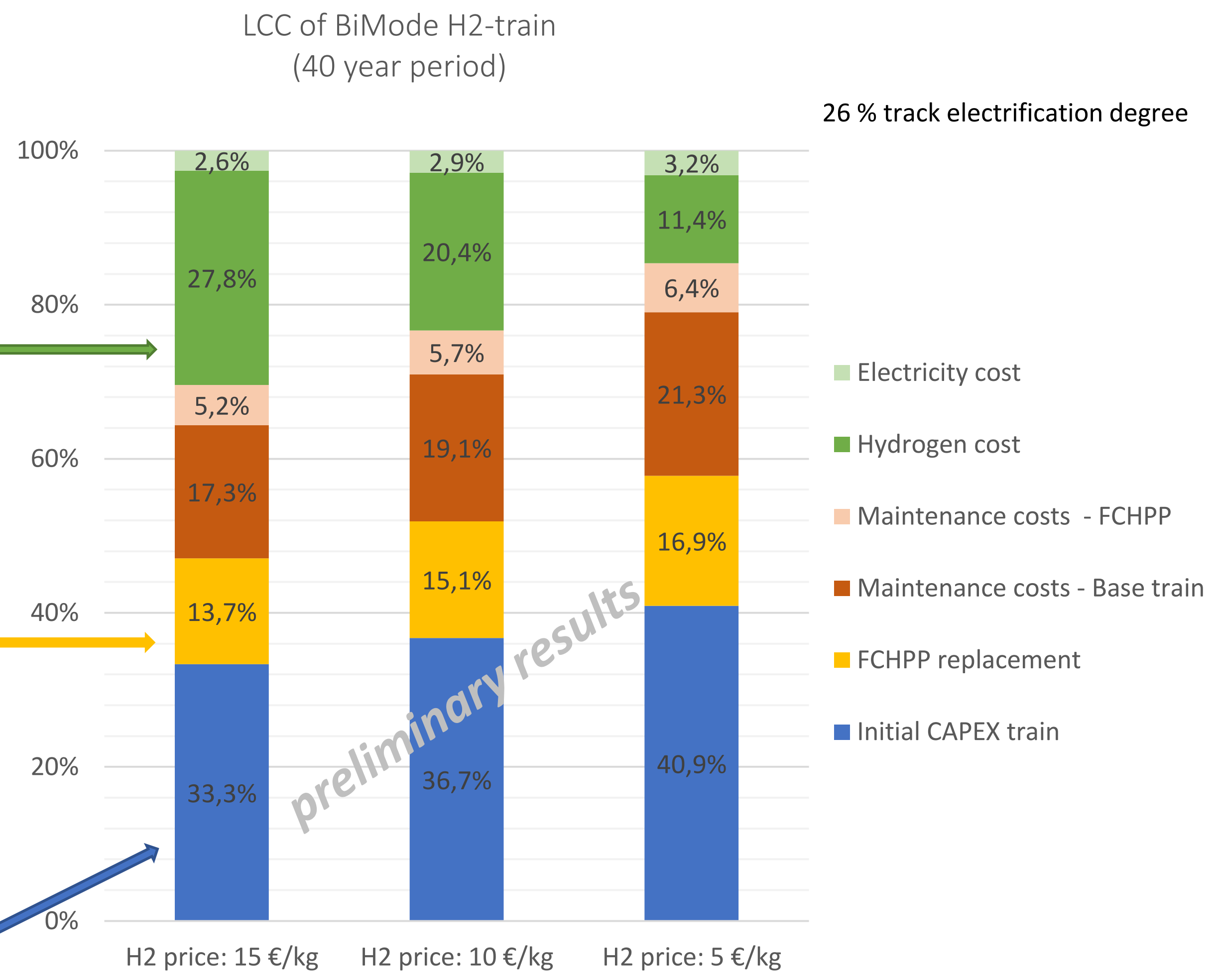
4. Demonstration of competitiveness: LCC

- Bi-mode H2 train benefits
  - → reduced energy costs
  - → less wear and tear of FC and batteries
  - → lower OPEX on partly-electrified routes

- H2 cost share is manageable at low H2 prices (5…10 €/kg)

Main cost drivers	Areas for cost reduction
H2 costs	- Purpose-fit H2 supply concept - Reduction of H2 consumption
FCHPP component costs	Improve lifetime of FC modules, batteries and H2 storages
Train CAPEX	Exploit economies of scale of FCHPP components



Preliminary scenario results, LCC calculations still in progress

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4. Demonstration of competitiveness

Fuel Cell Hybrid PowerPack for Rail Applications

Bi-mode H2 Demonstrator Train:

✓ **Autonomy** – 800km achieved

✓ **H2 consumption**: between 0.14 – 0.25 kg/100 ton-km (pure H2 feed, real profile, gradients, incl. HVAC)

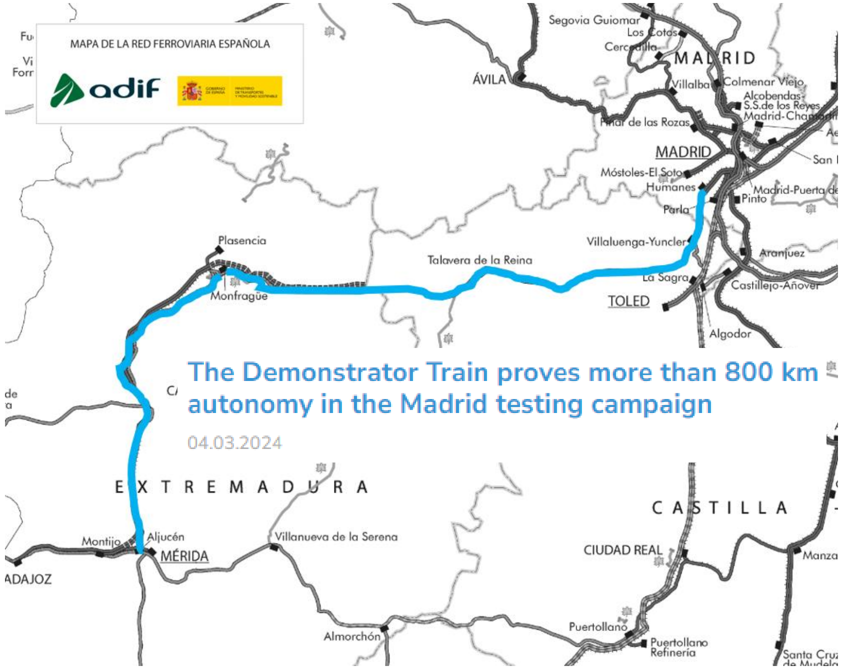
✓ **Traction performance** equal to or better than DMU performance

✓ FCHPP **availability** during demonstration phase: 100%

✓ Requirements of current DMU **commercial service** on demonstration lines were **successfully fulfilled**

Theoretical analysis:

✓ **Refueling time** can be competitive with DMU



Refueling competitiveness (theoretical analysis):
Use Case according to SAE J2601-2 (heavy duty H2 refueling)

- 2 x 80 kg storage modules on train
- 4 kg H2/min on average
- parallel refueling

→ Approx. 20 minutes for full refueling (similar to DMU)

➔ Demonstrate competitiveness of fuel cell traction against existing diesel solutions ✓

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1. Develop, build, test and homologate a multi-purpose FCHPP

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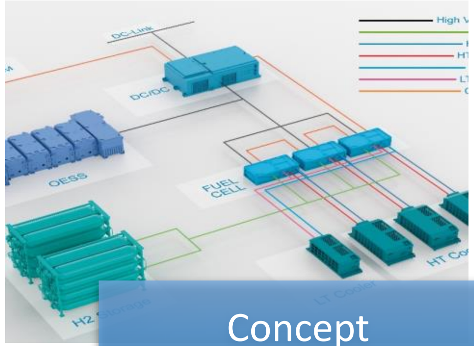
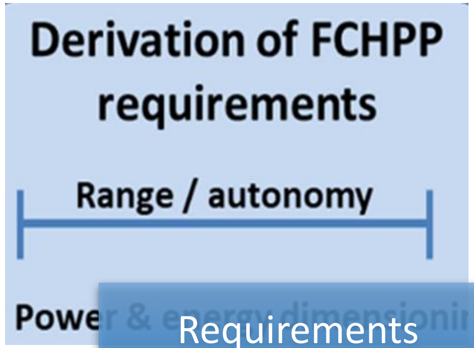
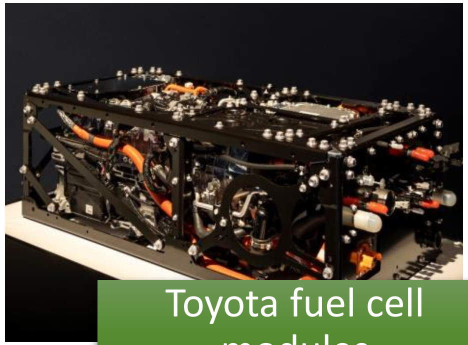
Fuel Cell Hybrid PowerPack for Rail Applications



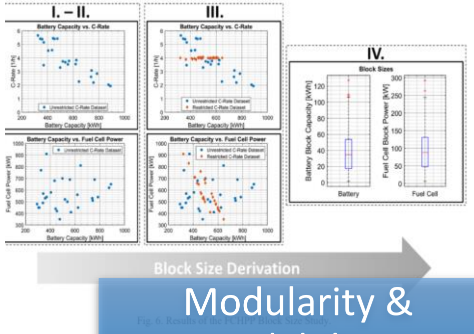
Concept



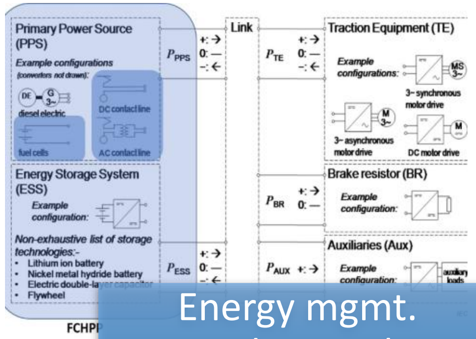
Requirements


Toyota fuel cell modules


CAF battery storage



Modularity & scalability



Energy mgmt. and controls


CAF power electronics


H2 supply at CNH2

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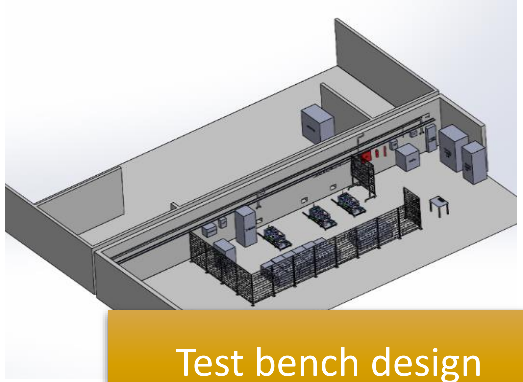
1. Develop, build, test and homologate a multi-purpose FCHPP



Test bench design

Assembly and commissioning

Control center

Test crew

Best Innovation Award 2024

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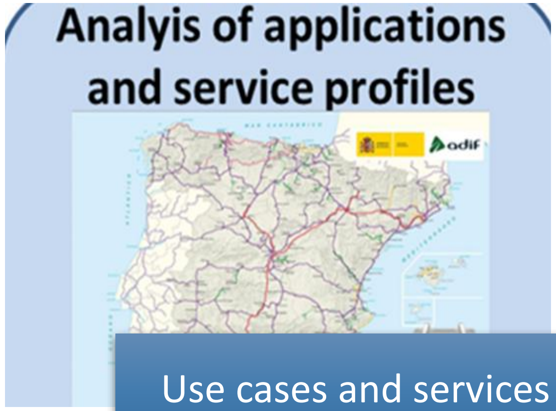
2. Demonstrate FCHPP in a Bi-mode Civia multiple unit

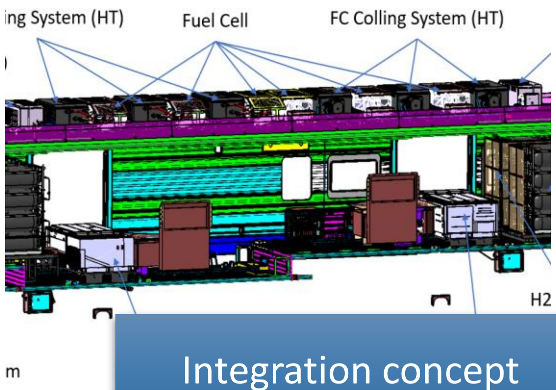
Starting point: Civia EMU



Use cases and services

	series
Teruel - Zaragoza	S594
Valencia - Teruel - Zaragoza	S599
Zaragoza - Canfranc	S596
Zaragoza - Canfranc	S599
Madrid - Soria	S598
Madrid - Soria	S599
Madrid – Talavera (*)	S599
A Coruña - Ferrol	S594
A Coruña - Lugo - Monforte	S594
A Coruña ...	
Santiago ...	
Vigo – Ou...	

Demo line selection



Integration concept

Fuel Cell Hybrid PowerPack for Rail Applications

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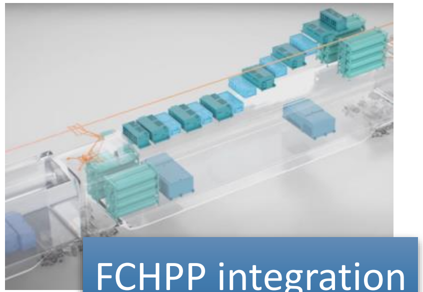
2. Demonstrate FCHPP in a Bi-mode Civia multiple unit

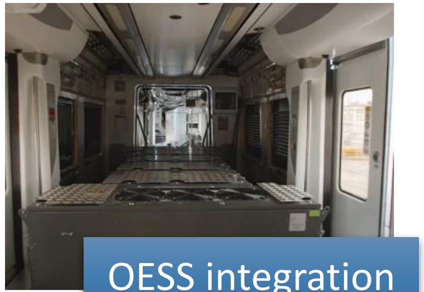


FCHPP integration

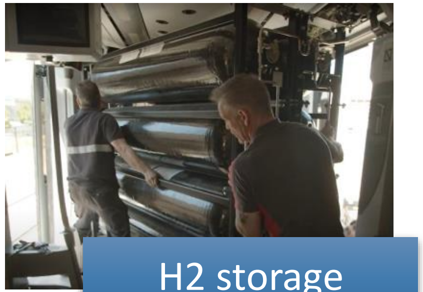
Fuel cell modules

FC & cooling systems

OESS integration



OESS integration



H2 storage

Train controls and monitoring

TCN & Driver desk integration

Static tests – catenary mode

Static tests – H2 hybrid mode

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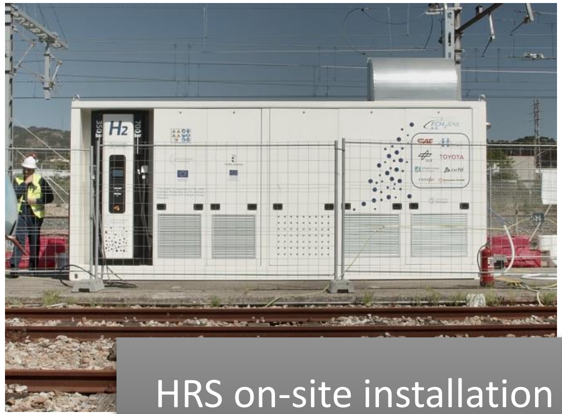
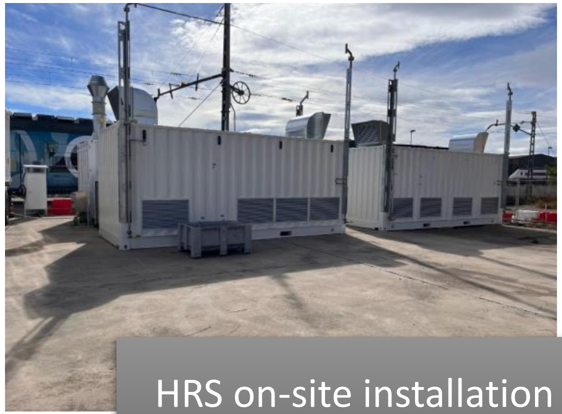
2. Demonstrate FCHPP in a Bi-mode Civia multiple unit

Transportable HRS concept

Setting up the HRS



HRS on-site installation


HRS on-site installation


Train refueling

Train refueling

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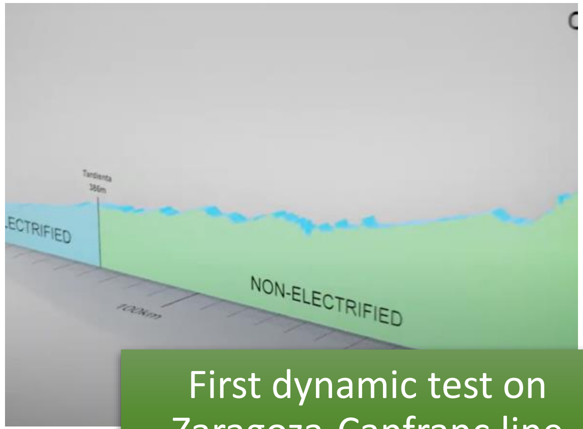
2. Demonstrate FCHPP in a Bi-mode Civia multiple unit



First dynamic test on Zaragoza-Canfranc line

The journey begins!

In the Spanish Pyrennees

Arrival in Canfranc 2023

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2. Demonstrate FCHPP in a Bi-mode Civia multiple unit

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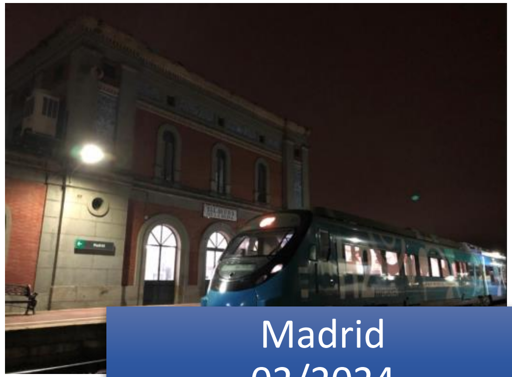
Fuel Cell Hybrid PowerPack for Rail Applications

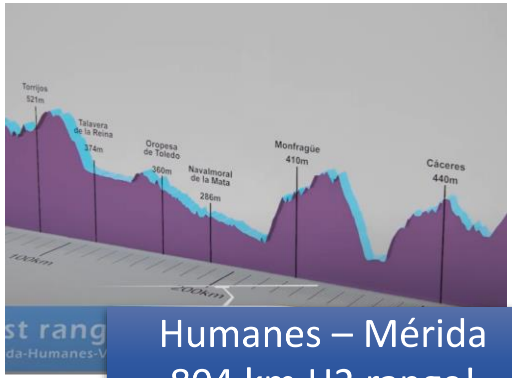
TRL7 demo in Spain

Soria
2023

Teruel
2023



Madrid
02/2024



Humanes – Mérida
804 km H2 range!

Extremadura
02/2024

Galicia
04/2024

Santiago de Compostela
04/2024

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2. Demonstrate FCHPP in a Bi-mode Civia multiple unit

Portugal TRL7 demo

Portugal 04/2024

Portugal 04/2024

Portugal 04/2024

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3. Propose a normative framework for hydrogen in railway vehicles

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Fuel Cell Hybrid PowerPack for Rail Applications

FCH2RAIL
Fuel Cell Hybrid PowerPack for Rail Applications
VIRTUAL WORKSHOP
Legislative Gaps Analysis in Railway Applications
21/07/2022
Beatriz Nieto Calderon, CNH2

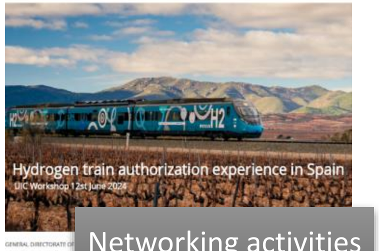
Gap analysis #1

FCH2RAIL
Fuel Cell Hybrid PowerPack for Rail Applications
VIRTUAL WORKSHOP
Gaps Analysis in Railway Applications
13/03/2024
Beatriz Nieto Calderon, CNH2

Gap analysis #2

D7.2–Proposal of modifications of normative framework
WP 7 – Normative Framework

Proposal for modifications



Networking activities

adif
COORDINATION PROTOCOL FOR PROTECTIVE MEASURES AND TESTING EMERGENCIES ON FCH2RAIL TRAIN TRACKS
MAY 2023

Train authorisation process

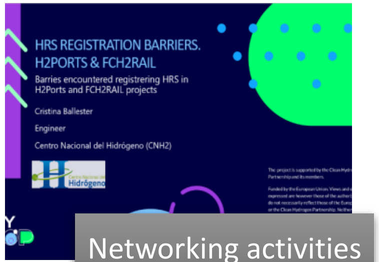
adif
EMERGENCY PLAN FOR HYDROGEN TRAIN TRACK TESTING
Ref. PR – H2_PROTECTIVE MEASURES
JULY 2024

Emergency plan

Install the prototype
Final work certificate
Inspection by a

HRS authorisation process

Networking activities



Networking activities

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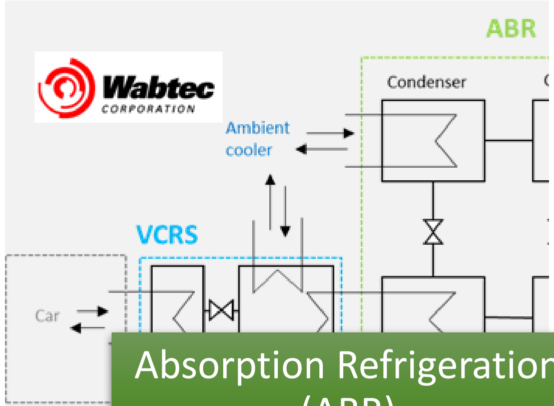
5. Identify and benchmark innovative solutions to improve energy efficiency



Absorption Refrigeration (ABR)

Hydrogen powered AC (HyPAC)

European Hydrogen Energy Conference 18-20 May, 2022. Madrid, Spain

Using Absorption Refrigerator and Metal Hydrides in Hydrogen Fuel Cell Trains: Draft Design Process and Feasibility

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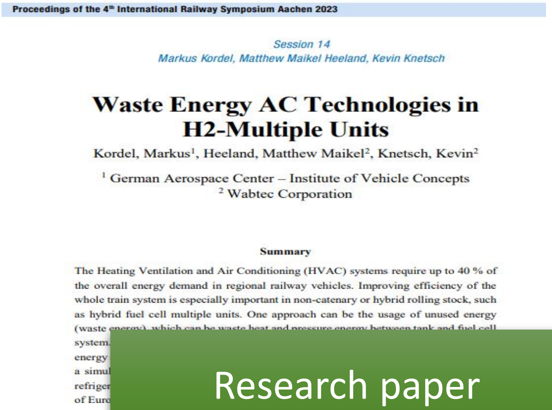
HVAC installations on trains are the 2nd largest consumer of energy after traction. For long-distance trains this can be 15% to 20% and for regional vehicles up to 40% of the total energy requirement [1, 2]. An annual energy demand for heating, ventilation and air conditioning (HVAC) of 54.7 MWh in a local tram train was described for a specific project [3]. For fuel cell trains with an efficiency of appr. 50 %, this number would lead to an additional hydrogen consumption of 3.2 t H_2 per year, if HVAC is performed with electrical power only. To reduce this energy demand, we investigate the feasibility and benefits of Hydrogen Powered Air Conditioning (HyPAC) and absorption AC in a simulation study. Both technologies use the energy which is already on board. The HyPAC exploits the pressure difference between hydrogen tank, while the absorption AC relies on waste heat from the fuel cell system.

Introduction

Within the project FCH2Rail, a hydrogen fuel cell regional train will be demonstrated and to outline future efficiency improvements, the feasibility of two heating, ventilation and Air-Conditioning (HVAC) systems (example in Figure 1) will be investigated in a simulation study. The energy consump... impose a higher power... For overhead line ind... battery electric and hyd... therefore be reduced...

Research paper



Proceedings of the 4th International Railway Symposium Aachen 2023

Session 14
Markus Kordel, Matthew Maikel Heeland, Kevin Knetsch

Waste Energy AC Technologies in H2-Multiple Units

Kordel, Markus[1], Heeland, Matthew Maikel[2], Knetsch, Kevin[2]

[1] German Aerospace Center – Institute of Vehicle Concepts
[2] Wabtec Corporation

Summary

The Heating Ventilation and Air Conditioning (HVAC) systems require up to 40 % of the overall energy demand in regional railway vehicles. Improving efficiency of the whole train system is especially important in non-catenary or hybrid rolling stock, such as hybrid fuel cell multiple units. One approach can be the usage of unused energy (waste energy) which can be waste heat and pressure energy between tank and fuel cell system. ... energy ... a simul... refriger... of Euro...

Research paper

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Summary

Main Objectives:

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

More info on www.fch2rail.eu

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

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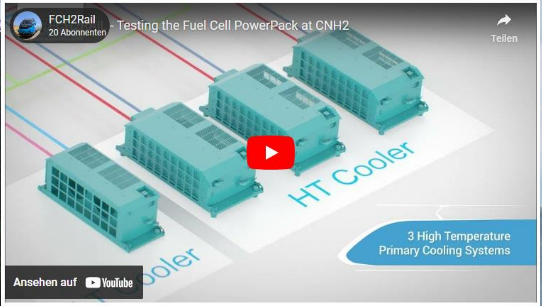
Testing the FCHPP



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

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Centro Nacional del Hidrógeno

TOYOTA

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Project Advisory Board

- European Union Agency for Railways
- UIC
- DB
- Deutsches Zentrum für Schienenverkehrsforschung beim Eisenbahn-Bundesamt
- AP2H2 Associação Portuguesa para a Promoção do Hidrogénio
- ÖBB
- CER
- European Commission
- Železničná spoločnosť Slovensko Národný dopravca
- Bundesverband SchienenNahverkehr – Wir gestalten Mobilität.

Industry, administration

- Iberdrola
- TÜV SÜD
- IEC International Electrotechnical Commission
- AESF Agencia Estatal de Seguridad Ferroviaria
- Hiperbaric 25 Years – High Pressure Technologies
- Medway Transporte & Logística
- Ercros
- Calvera Hydrogen
- Stellantis
- SCI Control & Inspección
- ARPA
- Vanguardland 10 Years
- Gobierno de España – Ministerio de Industria, Comercio y Turismo
- Gobierno de España – Ministerio de Transportes y Movilidad Sostenible

Research Projects

- Europe's Rail
- Rail4EARTH / FP4
- H2goesRail
- HSbooster.eu – Horizon Standardisation Booster
- HYLAND – Wasserstoffregionen in Deutschland
- VIRTUAL-FCS
- Hy Responder
- tunnel HP
- STASHH – Towards a standardised fuel cell module
- HyPOP

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Thank YOU for your attention!

FCH2RAIL Final Event
Fuel Cell Hybrid PowerPack for Rail Applications

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