RAILLIVE!

FCH2RAIL

Fuel Cell Hybrid PowerPack for Rail Applications

FCH2Rail: Demonstration of bi-mode hydrogen trains in Spain and Portugal

Holger Dittus

DLR Deutsches Zentrum für Luft- und Raumfahrt

26/11/2024, Zaragoza

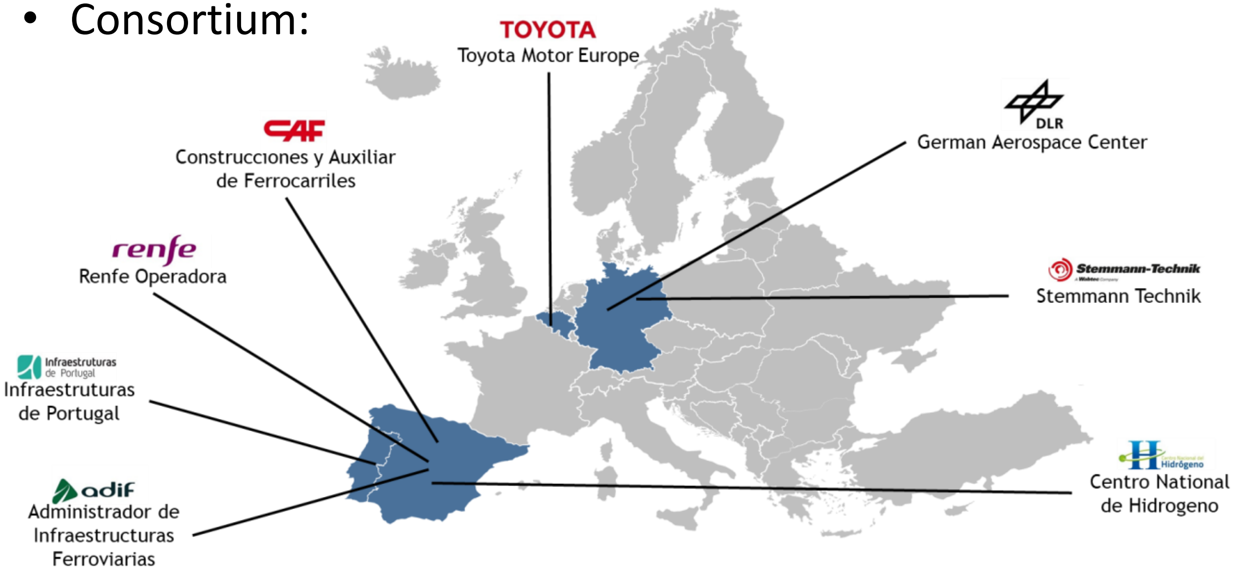
This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 101006633. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation program, Hydrogen Europe and Hydrogen Europe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

Clean Hydrogen Partnership

Co-funded by the European Union

Project Overview

- Project dates: 1 January 2021 - 31 December 2024
- Total budget: 13,4 M€, max. contribution: 10 M€
- Stage of implementation 26.11.2024: 98 %
- Consortium:



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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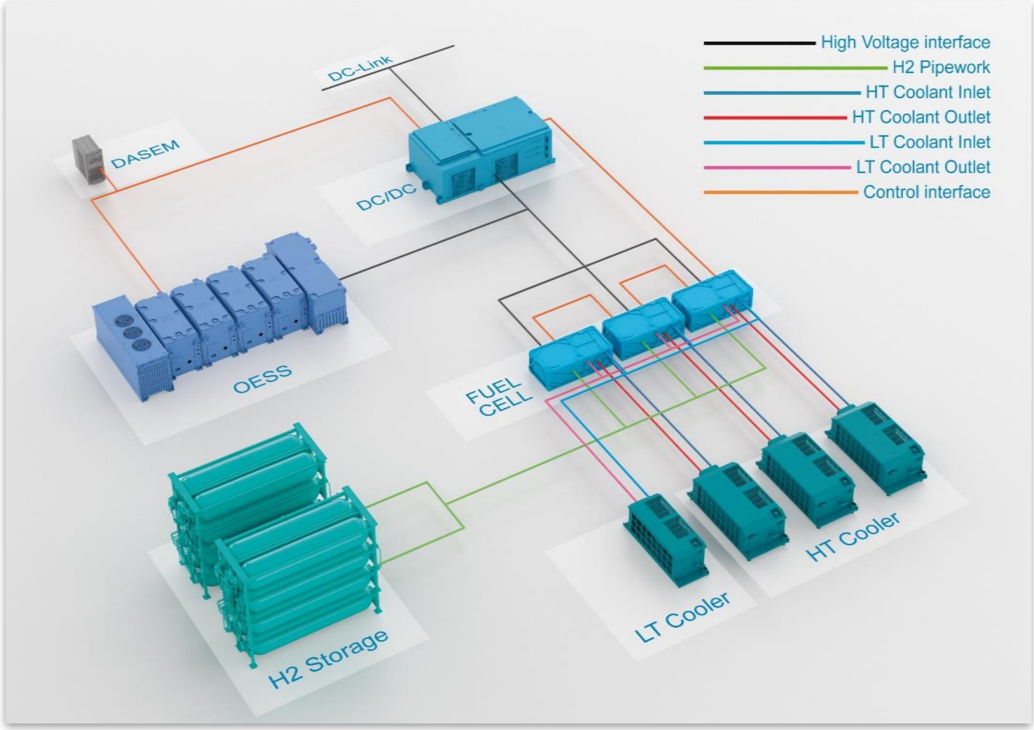
Project Overview

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



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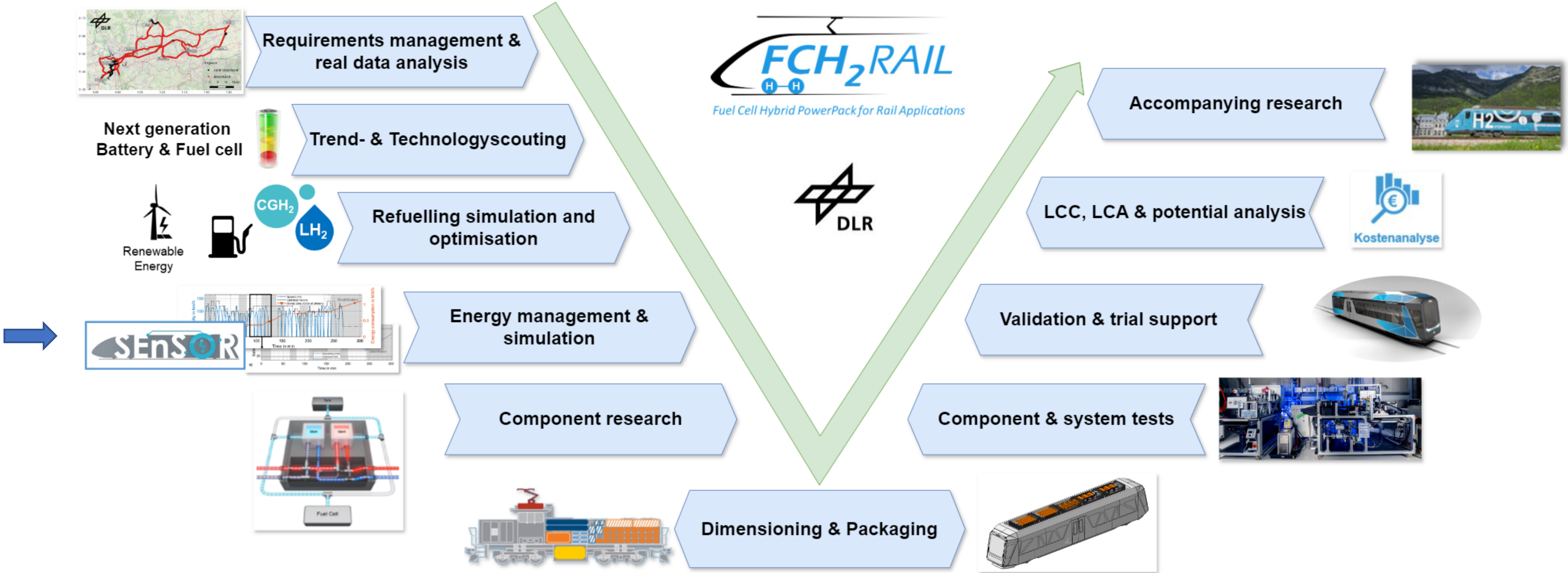
DLR Research in FCH_2Rail

Research and expertise in the field of alternative drives in rail vehicles



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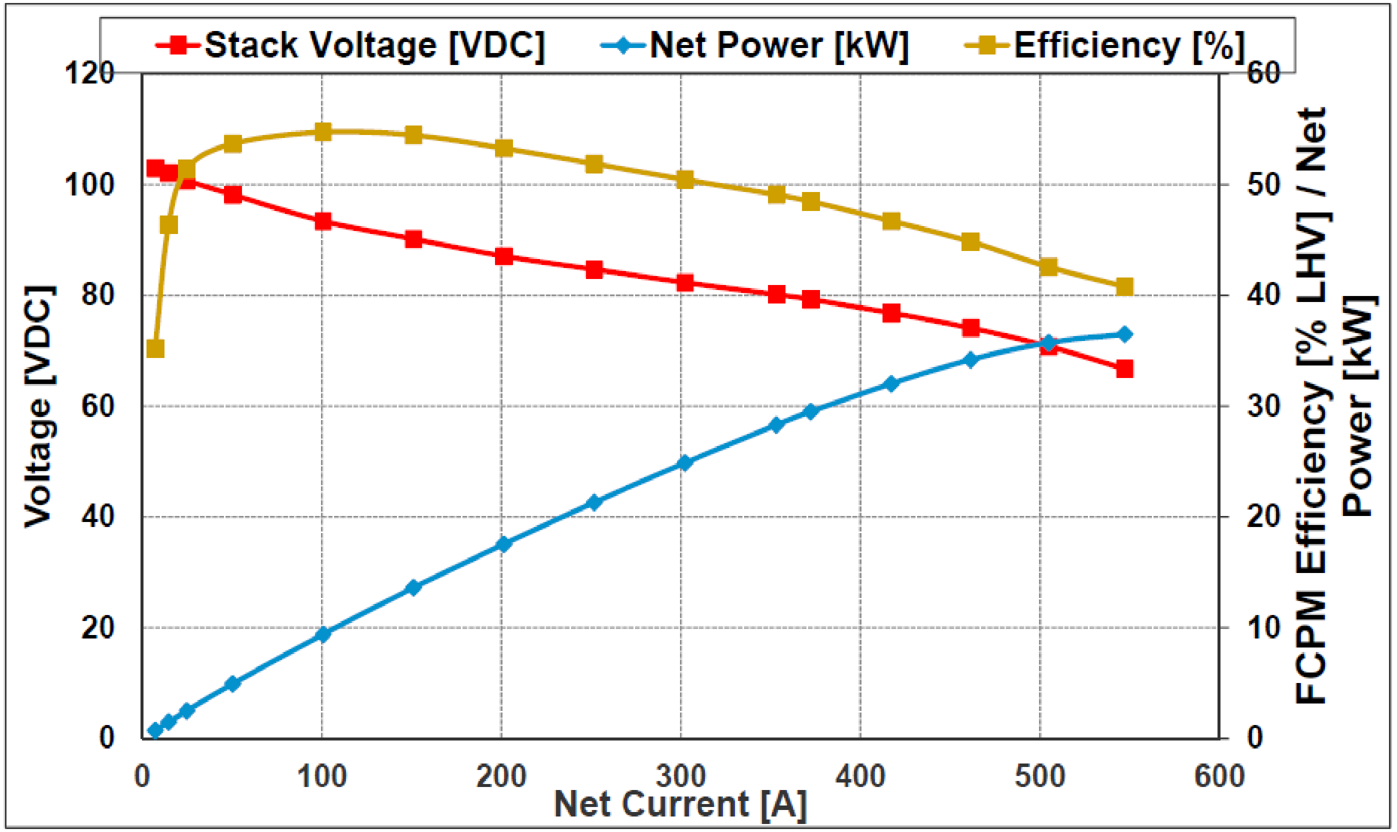
Developing the Fuel Cell Hybrid PowerPack
Fuel cell characteristics and operating behaviour

Fuel cell systems...

- ...are energy converters (H2 → electrical)
- ...cannot store energy
- ...should not be operated at low load
- ...has its maximum efficiency in the lower and medium partial load range
- ... typically degrade through...
  - ...frequent on / off switching
  - ...operation in unfavorable load ranges
  - ...frequent load jumps, dynamic operation



Current, voltage and power characteristics of the Hydrogenics HD30 fuel cell[1].

→ FC is always used in combination with battery as a hybrid

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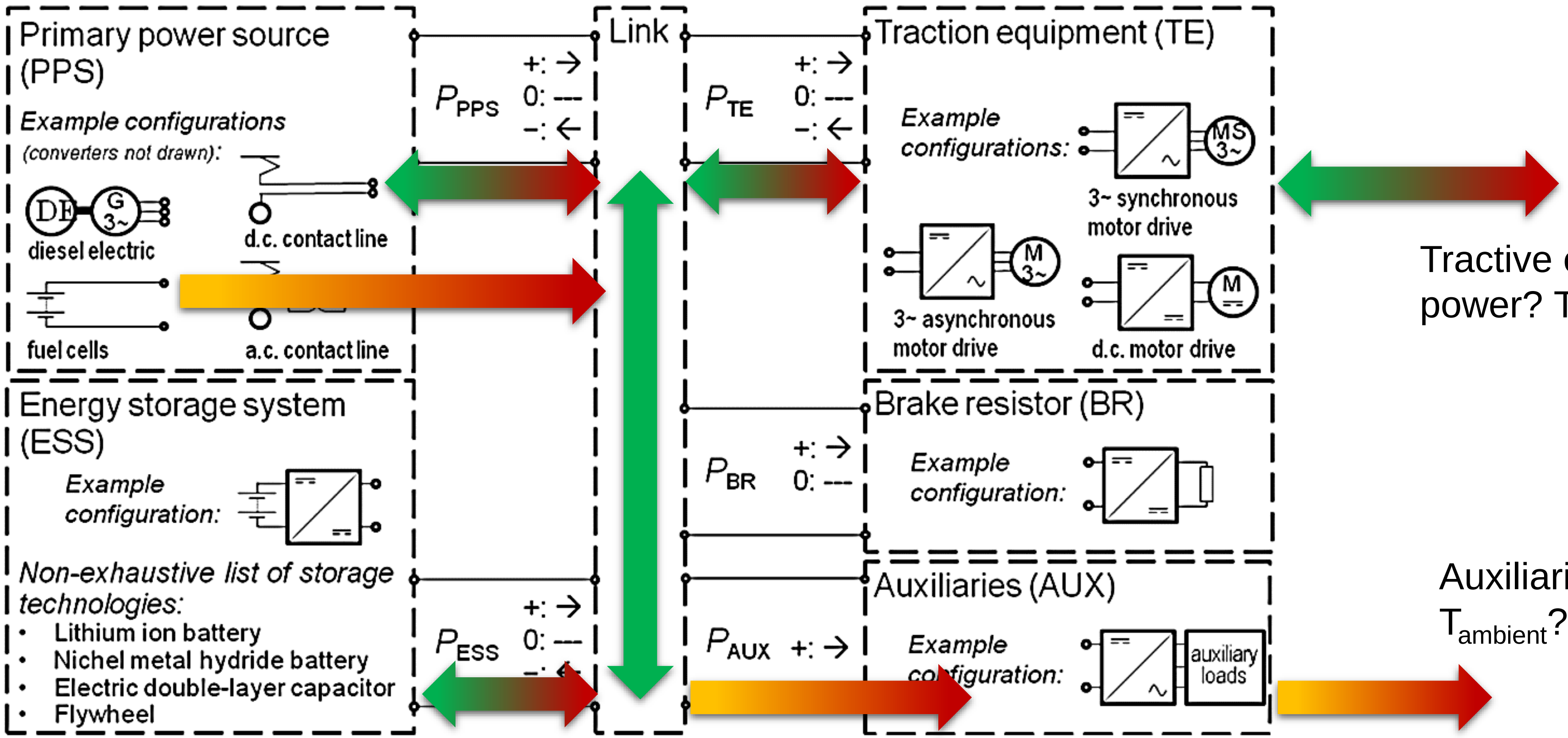
[1] Kammerer,M.: **“HyPM™ Fuel Cell Power Modules & Systems“**. In: International Hydrail Conference, 2014.

Energy management



Tractive effort? Wheel power? Train speed?

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

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

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

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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

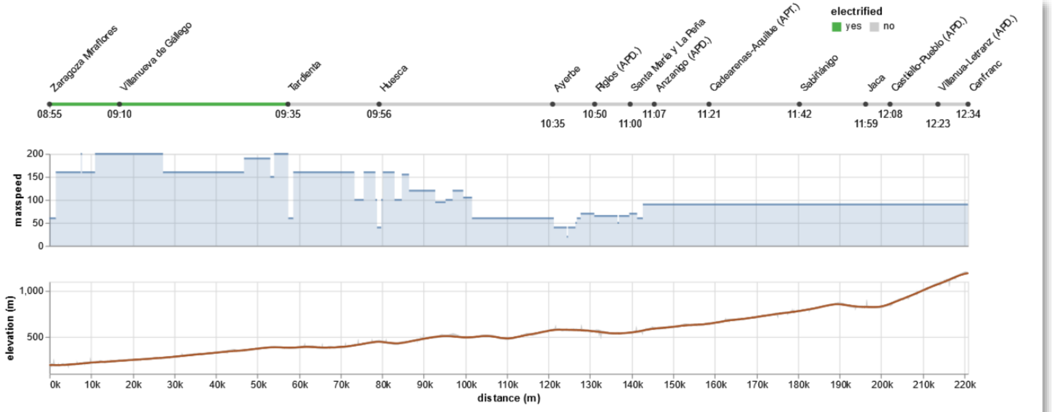
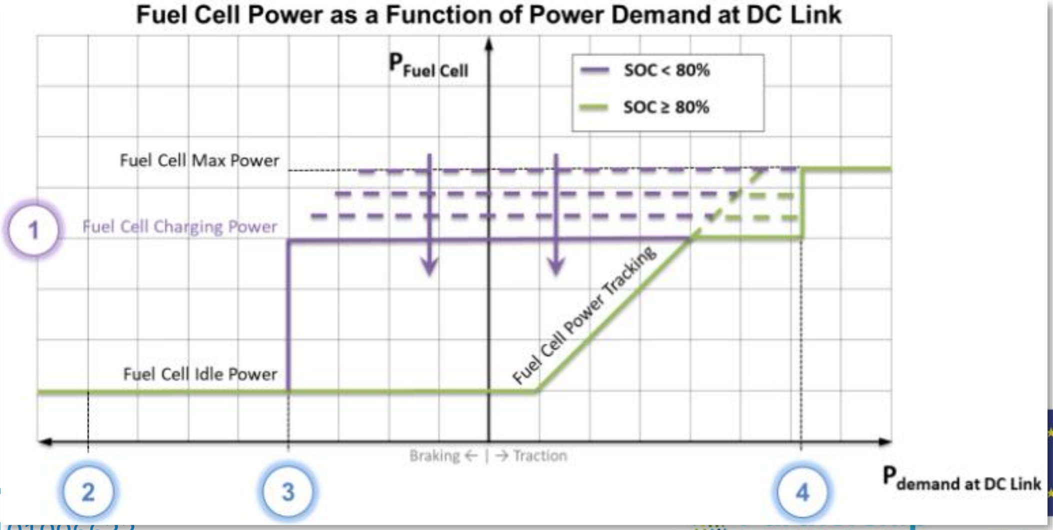


Figure 2: Exemplary driving profile derived from open data



➔ The hybridisation tool supports the FCHPP design and dimensioning

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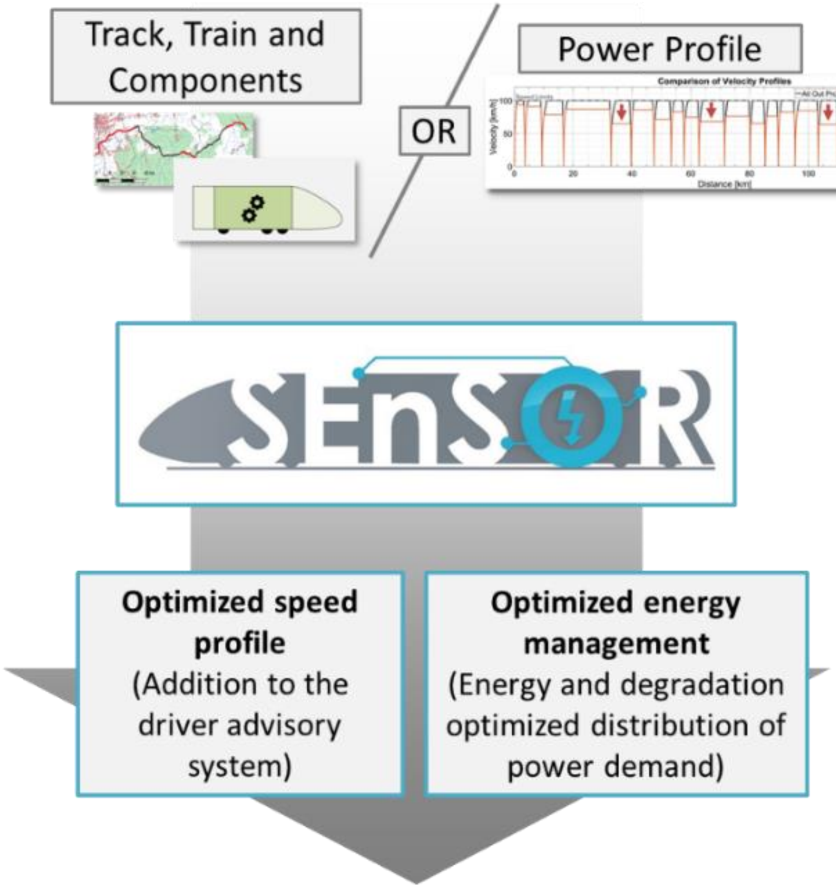
Developing the Fuel Cell Hybrid PowerPack

Smart Energy and Speed Optimizer Rail SEnSOR

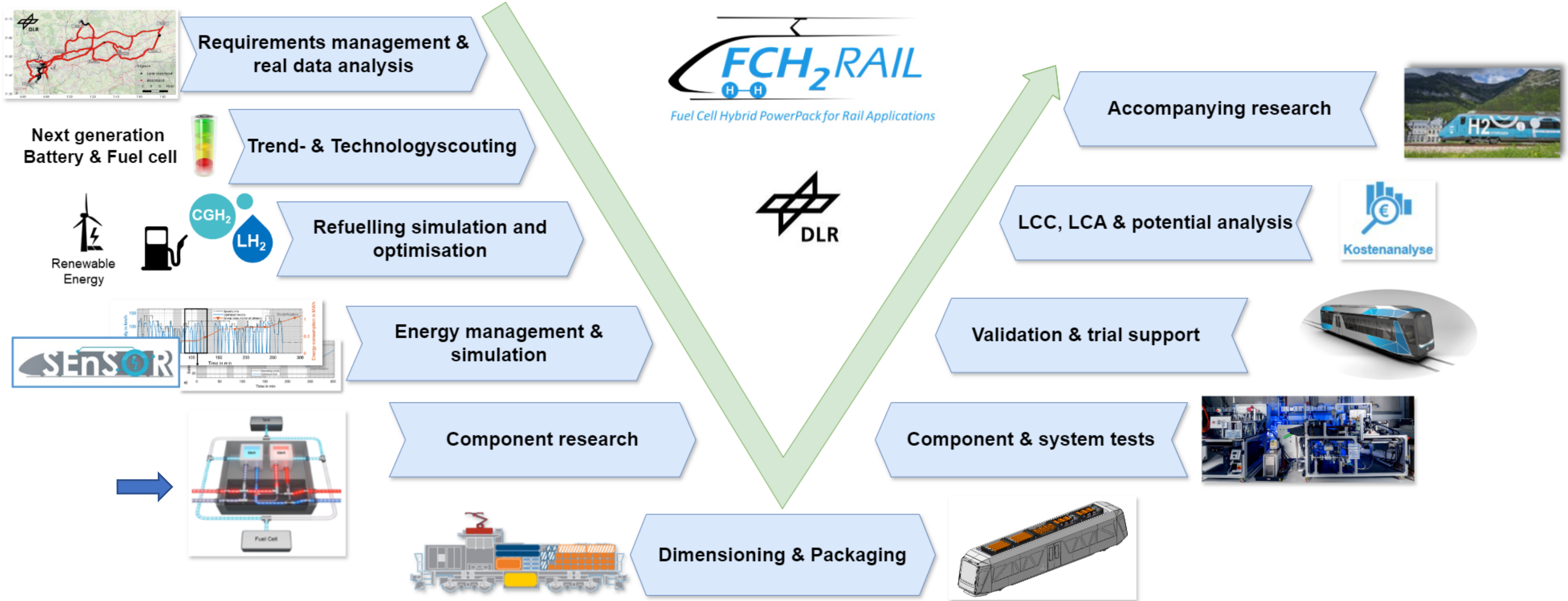
Language	MATLAB + IPOPT Toolbox
Energy management	Numerical optimization
Modelling approach	Functional programming: Train in specified environment, including track description, timetable, train and component models.
Goal, specific features	• Optimized energy consumption • Optimized speed profile • Simultaneous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



➔ SEnSOR combines optimisation of driving profile <u>and</u> power distribution in the FCHPP

DLR Research in FCH_2Rail

Research and expertise in the field of alternative drives in rail vehicles



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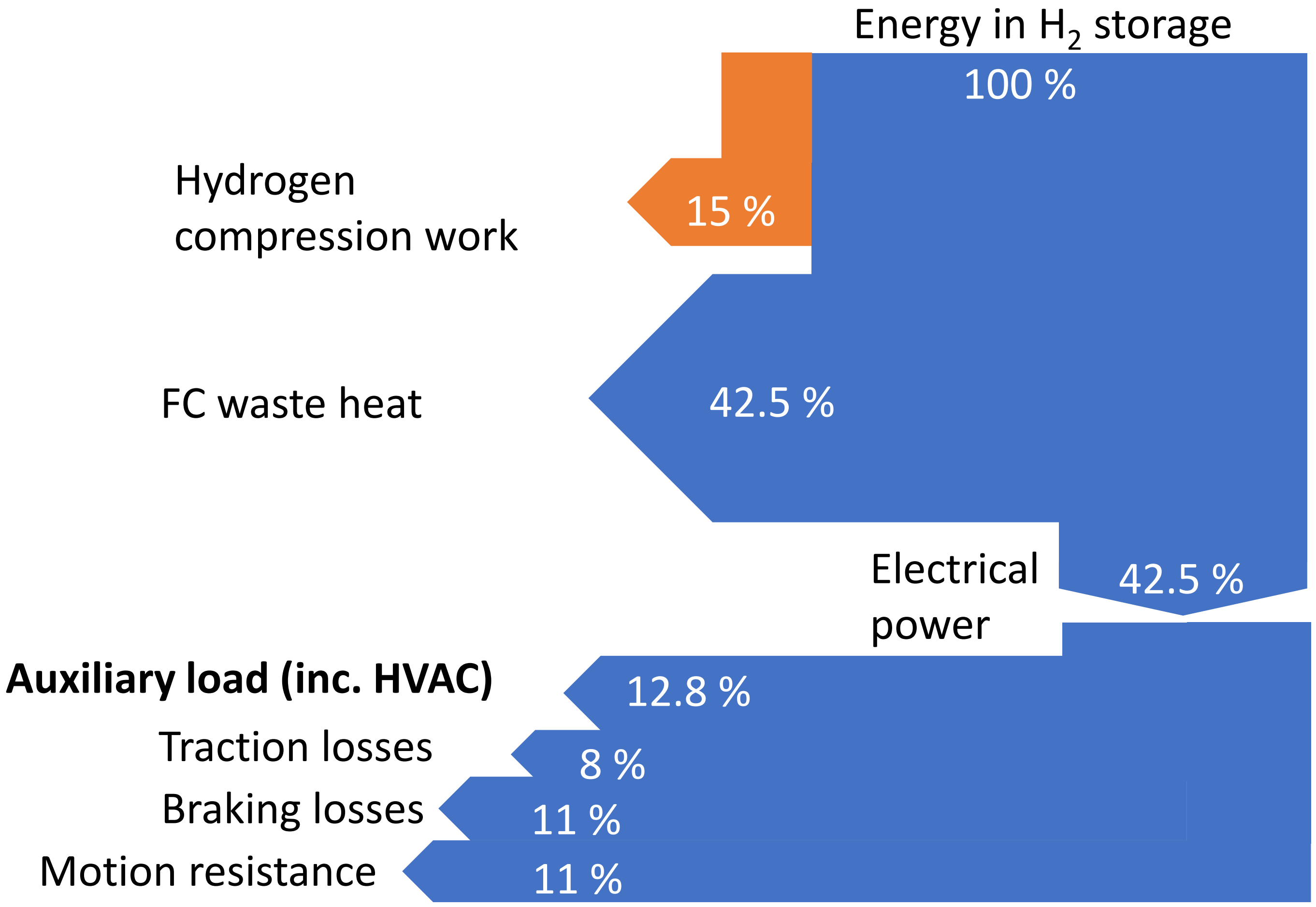
HyPAC:
Hydrogen Powered Air Conditioning

Waste Energy Analysis

- Hydrogen compression work and FC waste heat is currently unused in rolling stock
- HVAC consumption is significant



Energy flow in urban FC rail systems (modified [1, 2])

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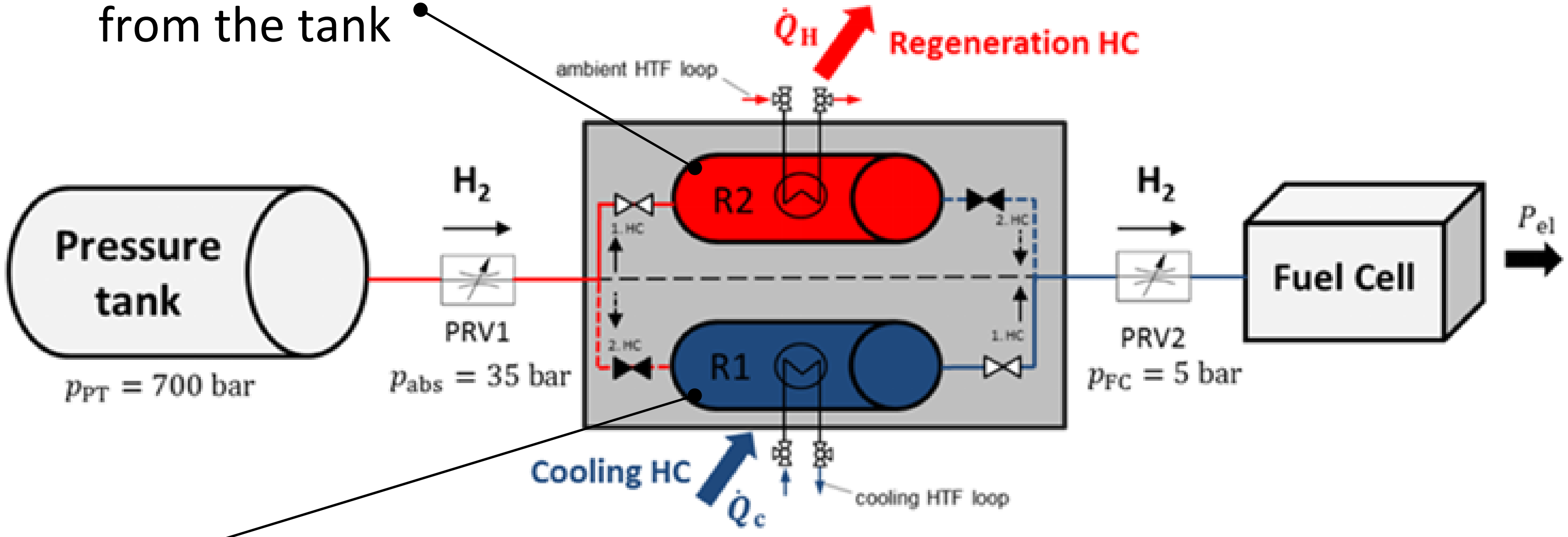
H2 Compression work utilization: Hydrogen Powered Air-Conditioning HyPAC

Reaktor R2 absorbs H2 from the tank



Reaktor R1 desorbs H2 towards the fuel cell (FC).

- Temperature level is pressure dependent
- Cooling power is hydrogen mass flow dependent

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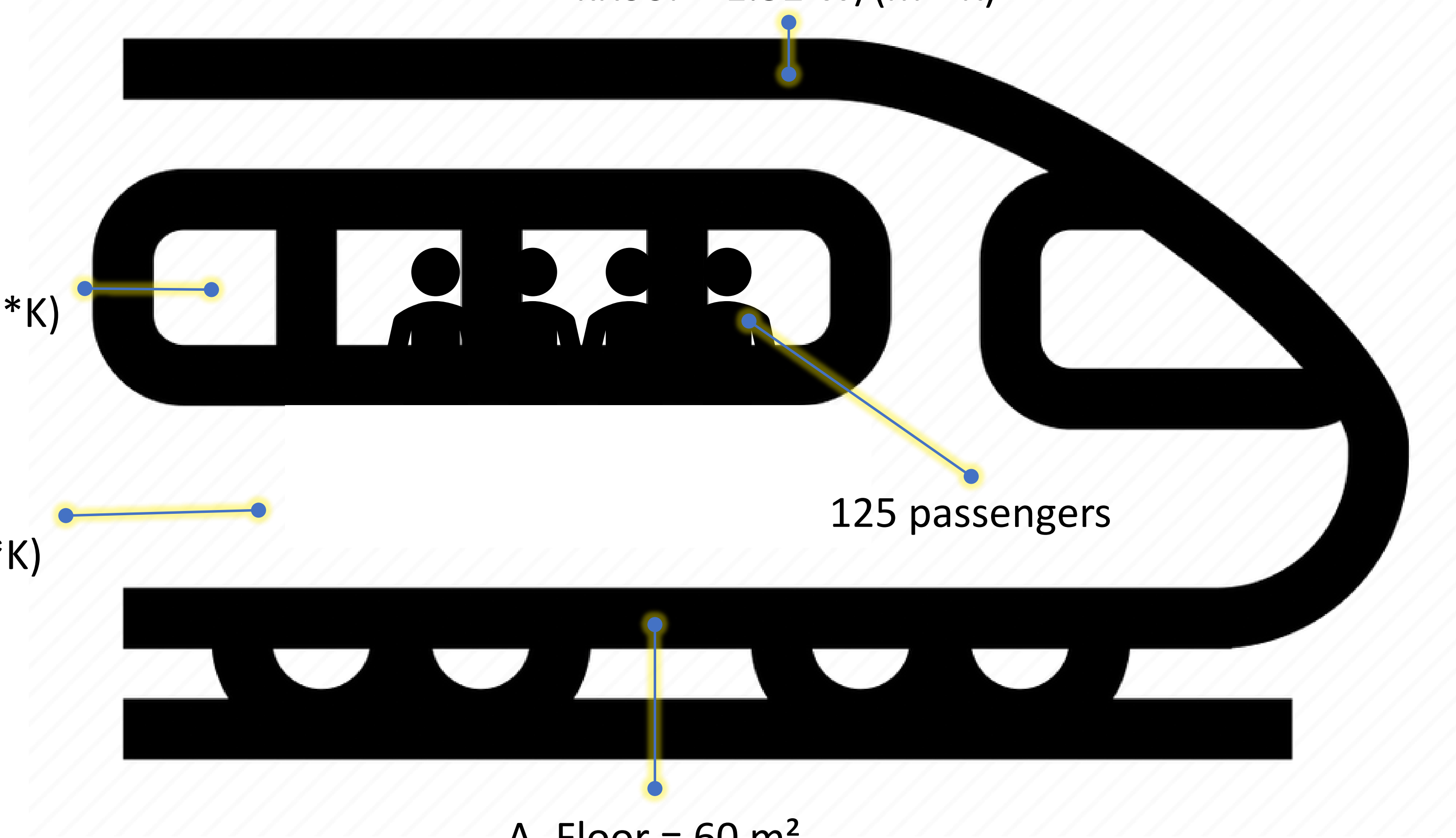
Car Body Model

Generic Thermal Car Body



Schindler (2020), Fine 2: D4.1, State-of-the-art of HVAC Technologies
Donner et al. (2021), Validation of a BEMU Thermal Car Body Model for the Shift2Rail Project FINE-2
EN 14750-2:20006 Apendix A Max Speed

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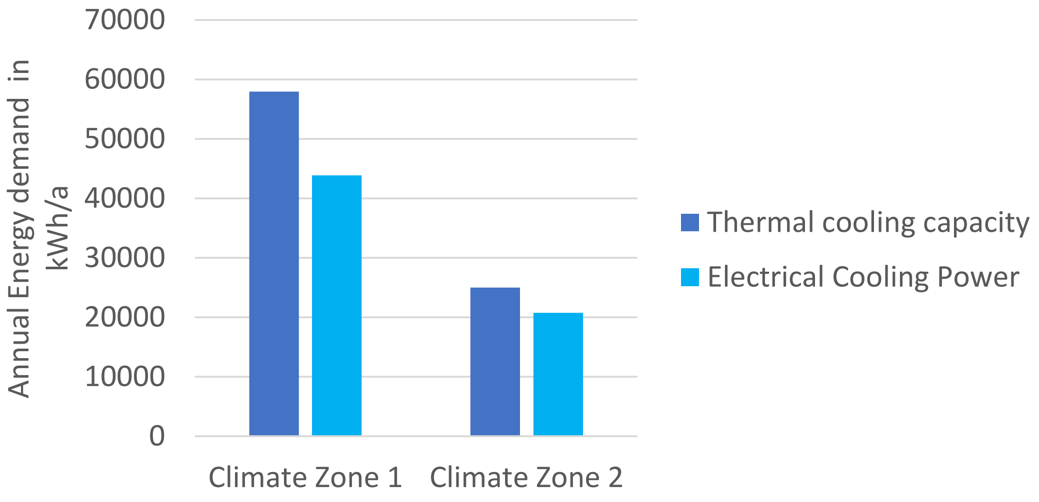
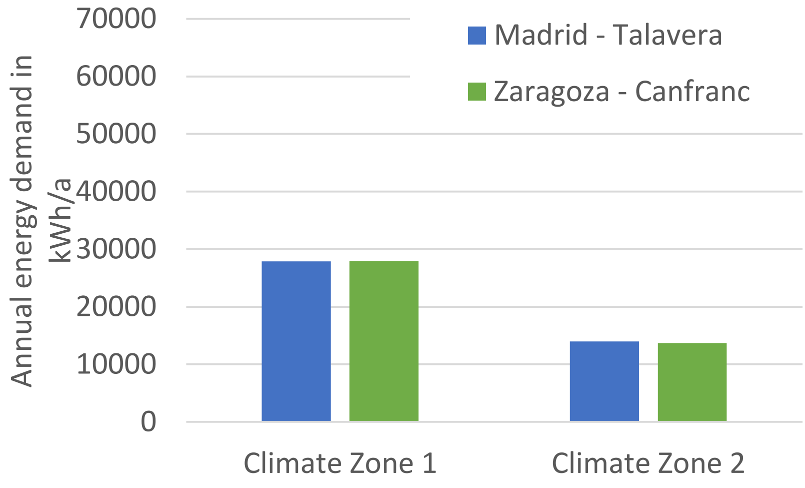
Results

Summary



1-car energy demand Conventional HVAC



HyPAC 1 car electrical energy demand

- HyPAC can reduce the HVAC energy demand significantly → more autonomy!
- Current TRL5, further work to increase TRL is required:
  - Design, weight, costs, validation with a prototype

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Publications

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

What are we dealing with here?

Functional comparison.

An optimized dimensioning of propulsion components for vehicles.

From tool description to design.

Proceedings of the 4th International Railway Symposium Aachen 2023

Session 14
Marcel Scharmach, Moritz Schenker, Holger Dittus

Comparison of simulative methods for dimensioning of fuel cell-battery hybrid powertrains in FCH2Rail and Virtual-FCS

Scharmach, Marcel[1], Schenker, Moritz[1] und Dittus, Holger[1]

[1]German Aerospace Center (DLR) - Institute of Vehicle Concepts, Pfaffenwaldring 38-40, Stuttgart 70569, Germany

Summary

The dimensioning process of fuel cell and batteries in hybrid railway applications is one of the biggest challenges in this kind of powertrain. In this paper, methods for modelling and designing fuel cell hybrid power trains are investigated and functionally compared. Subsequently, an exemplary dimensioning is carried out on the basis of a specific scenario. The tools in focus are, on the one hand, the Hybridization Tool and SEnSOR, both developed by the German Aerospace Center and used in the European project FCH2Rail and, on the other hand, the open source model developed by the European project Virtual-FCS. The approach and target of the tools is fundamentally different. Their features are compared in order to understand which impact different models can have on the design and evaluation process of fuel cell hybrid powertrains.

Keywords: Fuel cell hybrid power pack; FCH2Rail; Virtual-FCS; alternative powertrain dimensioning; railway; powertrain; series hybrid

Article

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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

Abstract

SEnSOR (Smart Energy Speed Optimizer Rail) is a direct method based optimization algorithm developed at DLR for determining minimum energy speed trajectories for railway vehicles. This paper aims to reduce model error and improve this algorithm for any alternative powertrain architecture. Model simplifications such as projecting the efficiency maps of different train components onto one-dimensional space can lead to inaccuracies and non-optimalities in reality. In this work, 2D section-wise Chua functional representation was used to capture the complete behavior of efficiency maps and discuss its benefits. For this purpose, a new smoothing method was developed. It was observed that there is an average of 6% error in the energy calculation when both, 1D and 2D, models are compared against each other. Previously, solving for different powertrain architectures was time consuming with the requirement of manual modifications to the optimization problem. With a modular approach, the algorithm was modified to flexibly adapt the problem formulation to automatically take into account any changes in powertrain architectures with minimum user input. The benefit is demonstrated by performing optimization on a bi-mode train with three different power sources as developed within the EU-project FCH2RAIL. The advanced algorithm is now capable to adapt to such complex architectures and provide feasible optimization results within a reasonable time.

Keywords

Railway optimization, direct method, optimal control, smoothing, canonical piecewise-linear model, bi-mode powertrain, energy management

Date received: 31 July 2023; accepted: 11 January 2024

Introduction

Compared to diesel engines, electric motors are more efficient, require less maintenance and allow for more environmental-friendly operation of railway. Thus, diesel-powered trains which previously covered non-electrified railway sections are more and more replaced by electric solutions. If overhead line electrification is not an option due to economic or technical constraints, train architectures with onboard energy storage are being developed, for example consisting of batteries, fuel cells, capacitors and sometimes additional overhead line power supply.[1]

Even with electrified operation, there is still a need to reduce energy demand and corresponding costs, as the transformation to sustainable power supply requires heavily increased amounts of renewable electricity and green hydrogen in all sectors.[2] Thus, to reduce energy demand in railway transport, Scheepmaker et al.[3] highlight four main approaches: minimum energy train control, energy-efficient timetabling, efficient components and demand analysis.

Focusing on optimal control, they found Pontryagin's Maximum Principle (PMP) to be intensively applied to determine energy-efficient train operation regimes. The optimal switching points between these regimes and hence the optimal trajectory are then usually obtained by other numerical algorithms such as Gradient Search, Dynamic Programming (DP) or Genetic Algorithms. The application of Direct Methods (DM) to such problems is still rare in the literature.

Macian et al.[4] found that using DM for combined energy management and trajectory optimization on a diesel-electric train yields similar results in comparison to that obtained by DP and PMP, while requiring heavily reduced computational time and memory. This motivated the development of

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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 consumption through state-of-the-art HVAC systems impose a higher power demand on the drivetrain of railway applications. For overhead line independent technologies such as diesel powered, battery electric and hydrogen-based drivetrains, the coverable range will therefore be reduced, if HVAC systems are used. To provide a comfortable riding experience, air conditioning (e.g. cabin cooling or heating) is indispensable. Thus, it is necessary to investigate in more efficient concepts to fulfill the need of air conditioning in order to reduce the train's overall energy consumption [4]. Therefore, novel HVAC concepts will be investigated to reduce energy consumption while still meeting the required passenger comfort. The study will be focused on two technologies for hydrogen trains.

Figure 1. Rooftop Air-Conditioning System for Train applications

Metal Hydride Refrigerator

The HyPAC utilizes the pressure energy between pressure tank and fuel cell to generate a heating and cooling effect with exothermic absorbing and endothermic desorbing hydrogen in metal hydrides. Weckerle already demonstrated that metal hydrides filled in two plate reactors can provide a quasi-continuous cooling and heating flow with using suitable hydrogen and heat transfer (HTF) valves in a valve switching process [5].

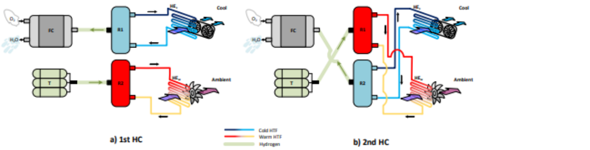

Figure 2. Metal Hydride Two Reactor Concept with half cycle 1 a) and half cycle 2 b) [6].

Figure 2 shows a schematic of these two reactors, which are connected to the fuel cell (FC) and hydrogen tank (T) as well as to a cooling loop and an ambient loop. In the first half cycle (a), reactor 1 desorbs hydrogen and directs it towards the fuel cell and the cold heat transfer fluid will be directed to a heat exchanger that cools down the supply air for the train's saloon. Meanwhile rector 1 absorbs the hydrogen from the hydrogen tanks, the aforementioned exothermic reaction than heats up the HTF. If equilibrium state is nearly reached, the HyPAC controller switches from first half cycle

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Session 14
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Waste Energy AC Technologies in H2-Multiple Units

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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. Currently no market ready systems for rolling stock exist to utilize this waste energy and the potential of novel systems is not investigated sufficiently. Here we show a simulative investigation of a metal hydride refrigeration system and an absorption refrigeration system in a generic thermal car body. The results are evaluated on the basis of European standards (e.g. EN 50591) and two realistic tracks in Spain. The potential annual energy savings are highly climate zone dependent and vary between 795 kWh/a and 6106 kWh/a for the absorption refrigeration system and between 1547 kWh/a and 13226 kWh/a for the Hydrogen Powered Air Conditioning (HyPAC) system. The absorption refrigeration system is more sensitive to fluctuating fuel cell loads, whereas the HyPAC shows similar improvements for both tracks. Reducing HVAC energy demand needs to be investigated further and especially further improvements in the system design (sizing, material selection) can increase the energy improvements in future.

Keywords: Rolling Stock, Fuel Cell Powertrain, HVAC, Metal Hydrides, Absorption AC, Hydrogen

1 Introduction

The analysis of air conditioning technologies in a waste heat perspective is part of the holistic energy efficiency improvement analysis objective to increase autonomous range within the *FCH2Rail* EU-Project's framework. A bi-mode powertrain is implemented in an existing vehicle in this project. Thereby, the advantages of both, catenary operation and autonomous operation with fuel cells can be utilized [1].

Fuel Cell Hybrid PowerPack for Rail Applications

Thank you for your attention

www.fch2rail.eu

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