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Waste energy analysis in hydrogen trains for increased system efficiency

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- Europe‘s Rail Rail4Earth Project
- Introduction: Hydrogen trains & Talgo TPH2 demonstrator
- Methodology: Measurement data analysis & waste energy technologies
- Results: Efficiency increase in hydrogen trains
- Conclusion

Rail4Earth project

A sustainable and green rail system

Project Partners:

Coordinator

ALSTOM

Other partners

Key Information:

- Funded by the European Union
- Part of the EU Joint Undertakings “Europe’s Rail”
- Budget: ≈ 95 million EUR
- Involved Partners: 73
- Duration: 48 months

Objectives:

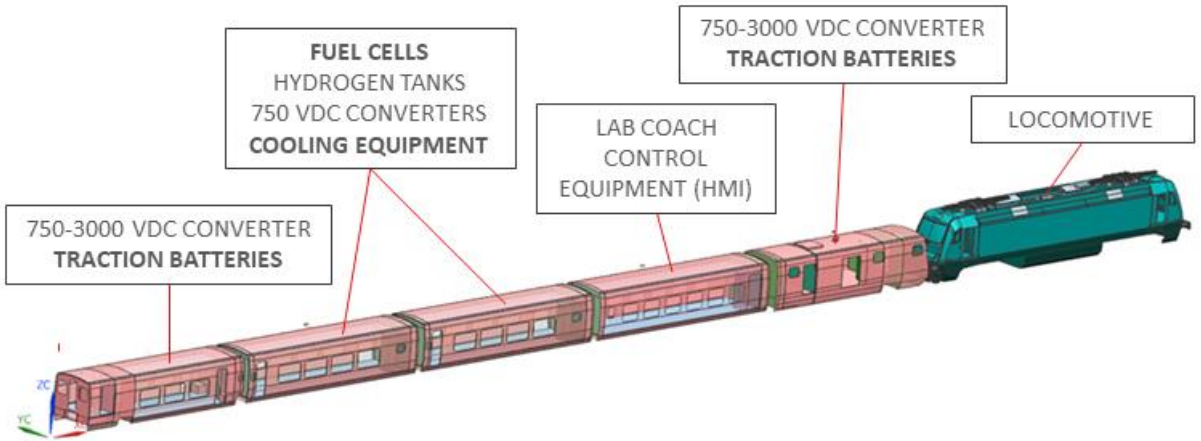
- Improve the existing **sustainability** performance of railways
- Build a more **attractive and resilient** transport mode
- Contribute towards the objectives of a **climate neutral Europe** for 2050

Introduction

Hydrogen trains & Talgo TPH2 demonstrator

- **25,000 diesel** rail vehicles in operation in Europe [1]
- Hydrogen rail vehicles for sustainable transport with overall efficiency of fuel cell **around 50 %**
- Research question/Objective:
  - Which technologies can be used to **increase efficiency in hydrogen trains**?
  - Quantify reduced energy demand of those technologies based on **hydrogen train demonstrator TPH2**

Parameter	Specification TPH2
Max. velocity	140 km/h
Max. power	1.4 MW
Power supply locomotive	3 kV DC
Batteries (NMC)	4 x 122 kWh
Fuel cells	8 x 70 kW
Hydrogen tanks (Type 4)	12 x 8.4 kg (350 bar)



[1] Chamaret et al., *Analysis, trends and expectations for low carbon railway*, 2023

NMC: Lithium Nickel Manganese Cobalt oxides DC: Direct Current

Methodology

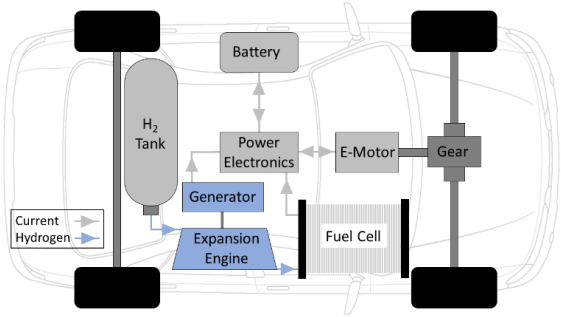
Measurement data analysis at hydrogen train demonstrator TPH2

- Measurement data recorded to **analyze energy flows** in the vehicle
- Relevant **parameters**
  - Vehicle velocity
  - Hydrogen mass flow
  - Power of motors, batteries, fuel cells, balance of plant
  - Generated heat fuel cell
  - Hydrogen pressure levels in tanks, piping and before fuel cell
- Two cycles of **vehicle operation** analysed
  - 0.5 h and 4 h on-site testing of the vehicle
- Identify **waste energy potentials** for electrical, thermal and pressure energy

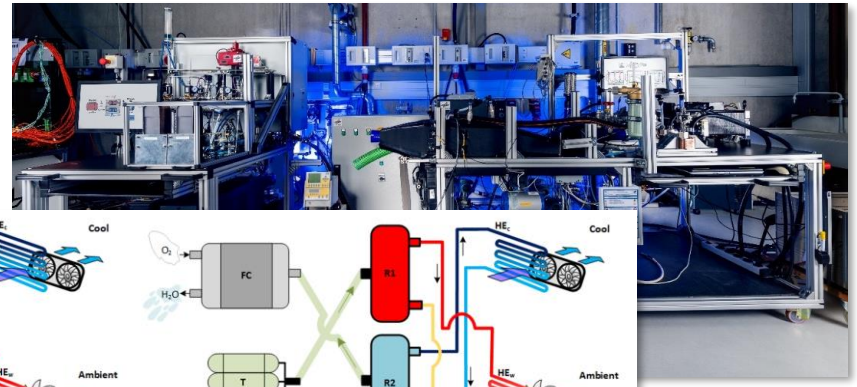
Methodology

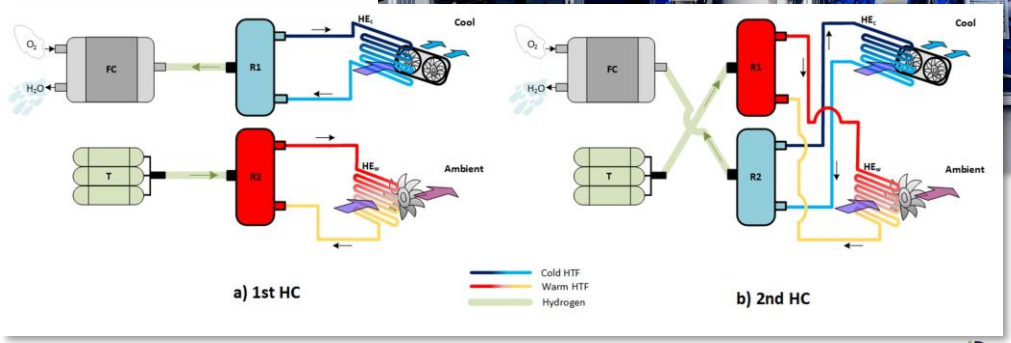
Waste energy technologies for hydrogen trains

- Identified **waste energy potentials**: Hydrogen pressure & waste heat of fuel cell
- Technologies to use **hydrogen pressure**
  - Hydrogen expansion engine
  - Hydrogen powered air conditioning
- Technologies to use **waste heat from fuel cell**
  - Absorption air conditioning
  - Direct heating with waste heat



Efficiency technology	Waste energy	Usage
Hydrogen expansion engine	Hydrogen pressure level	Electrical energy for traction or auxiliaries
Hydrogen Powered Air Conditioning – HyPAC	Hydrogen pressure level	Air Conditioning
Absorption Air Conditioning	Waste heat of fuel cell	Air Conditioning
Heating with waste heat	Waste heat of fuel cell	Heating of passenger compartment





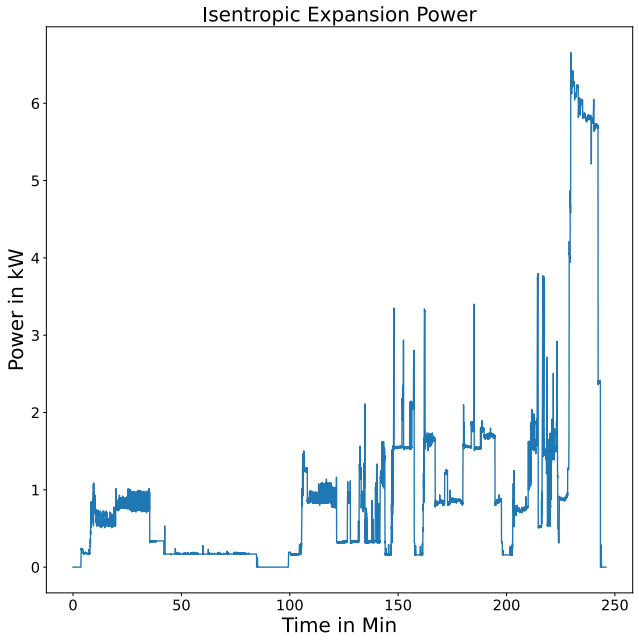
FC: Fuel cell
T: Tank
R: Reactor
HC: Half cycle

Results: Energy demand in hydrogen trains

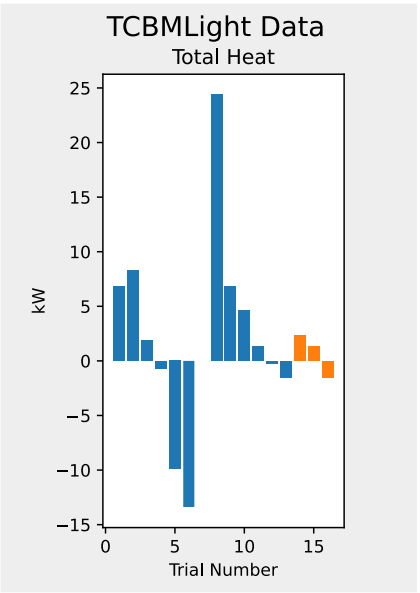
Hydrogen expansion engine & fuel cell waste heat

- **Hydrogen expansion engine**
  - Input: Hydrogen mass flow, pressure in tanks
  - Pressure at fuel cell: 5 bar
  - Up to **6 kW additional power**
  - 2 % additional energy over the cycle at 90 bar
  - **Up to 4 % additional energy** possible at 300 bar

- **Waste heat** of fuel cell
  - Input: Heat dissipated by fuel cell
  - **Thermal HVAC energy demand** calculated with stationary thermal car body model (TCBMlight)
  - OP8 (-40 °C): Up to 25 kW → **> 1 car**
  - OP1 (-10°C): Up to 7 kW → **> 5 cars**



Operating points from EN 50591



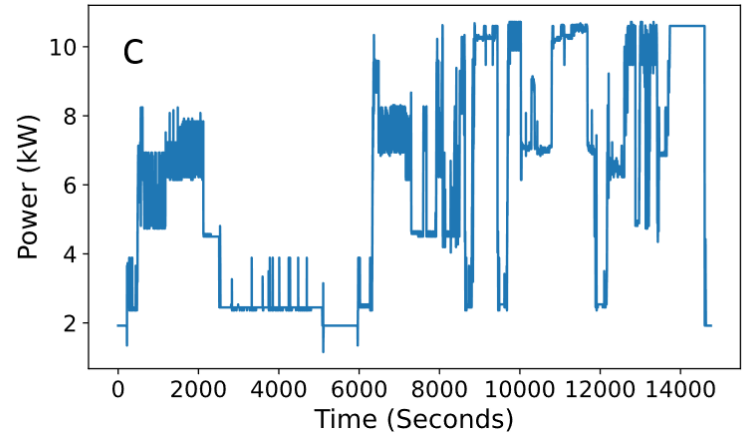
HVAC: Heating, ventilation, air conditioning
OP: Operating point

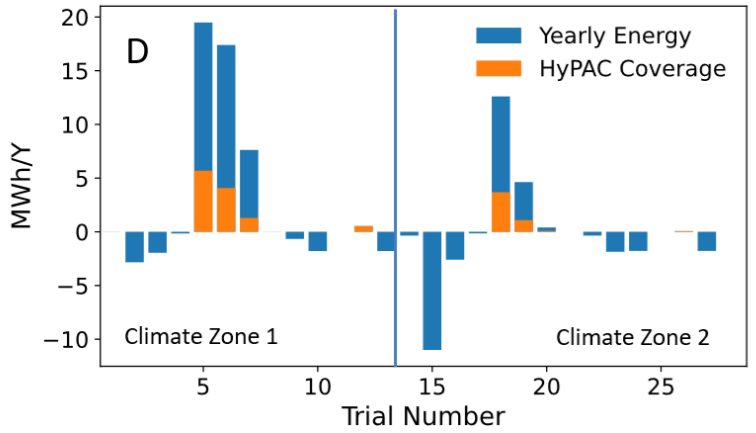
Results: Energy demand in hydrogen trains

Absorption air conditioning & hydrogen powered air conditioning

- Absorption air conditioning
  - Minimal waste heat temperature required is around 90 °C
  - Fuel cell waste heat maximum 75 °C
  - More suitable for **high temperature fuel cell systems**

- Hydrogen powered air conditioning (**HyPAC**)
  - Desorption of hydrogen from **metal hydrides** provides cooling capacity
  - Reduction of **power demand for HVAC** by 25 %
  - **Yearly energy demand** reduced…
    - by 5.2 MWh/year for climate zone II (Central Europe)
    - by 12.3 MWh/year for **climate zone I** (Southern Europe)





HVAC: Heating, ventilation, air conditioning
OP/Trial number: Operating point

Conclusion & Outlook

Waste energy analysis in hydrogen trains for increased system efficiency

Objectives:

- Which technologies can be used to **increase efficiency in hydrogen trains**?
- Quantify reduced energy demand of those technologies based on **TPH2 demonstrator**

Findings:

- Hydrogen expansion engine provides up to **4 % additional energy** from H_2 pressure
- Fuel cell waste heat enough to **heat one car at -40 °C** or 5 cars at -10 °C
- HyPAC with **metal hydride reactors** reduces HVAC energy demand by 25 % up to **12.3 MWh per year**

Outlook:

- HyPAC with 5 kW demonstrated in **DLR lab environment**
- System integration in **TPH2 demonstrator**
- Tests with existing HVAC system to **demonstrate energy savings**

HVAC: Heating, ventilation, air conditioning HyPAC: Hydrogen powered Air Conditioning

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Thank you for your attention!

Questions?

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