FCH2RAIL

Fuel Cell Hybrid PowerPack for Rail Applications

Limitations in the Hydrogen Refueling Process of Railway Vehicles

DLR

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Agenda

- FCH$_2$Rail Project
- Motivation – Hydrogen vs. Diesel refueling
- Modeling Approach for Hydrogen Refueling Process
- Simulation Results for Hydrogen Refueling Time
- Limitations in Hydrogen Refueling and Recommendations

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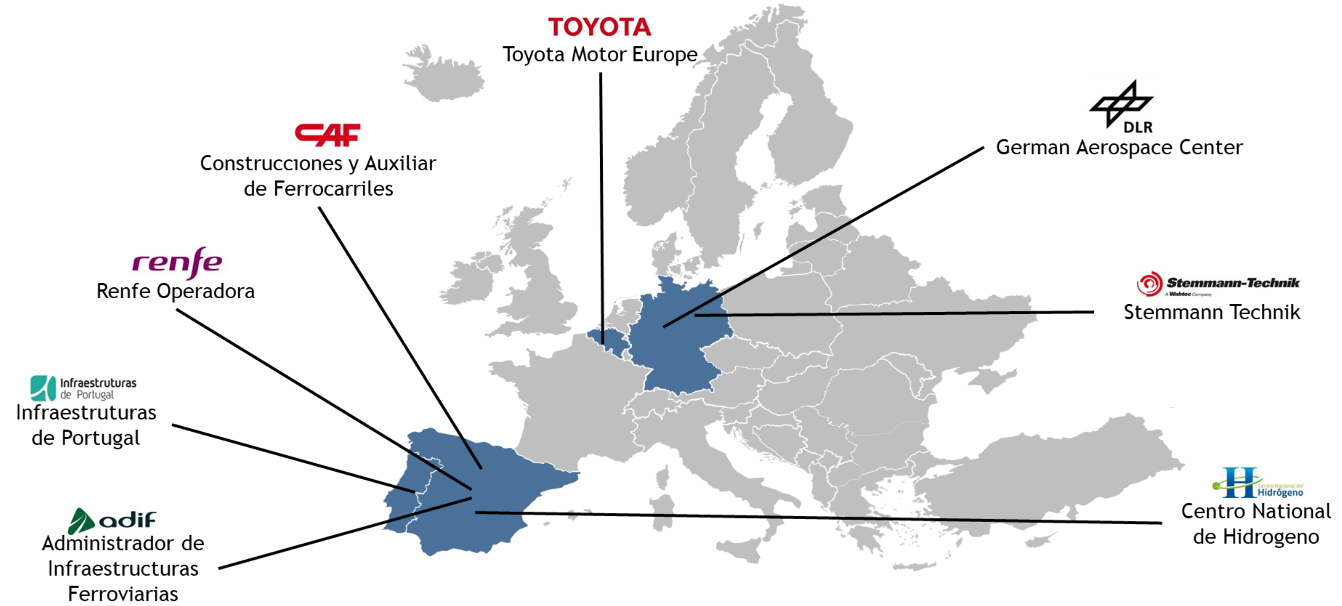
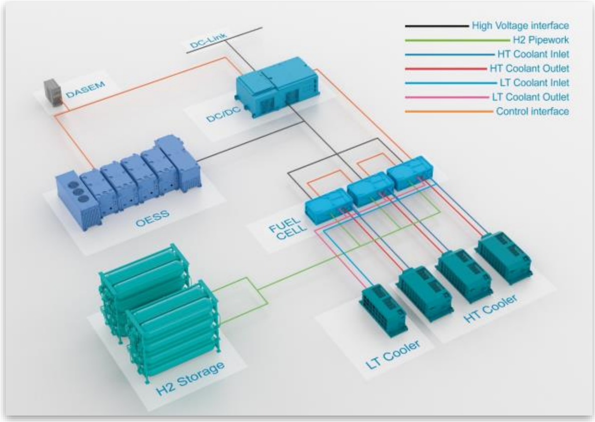
FCH$_2$RAIL Project

Overview & Consortium





Call Topic:

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

Main Objectives:

- Develop, build, test and homologate a multi-purpose Fuel Cell Hybrid PowerPack
- Demonstrate FCHPP in a Bi-mode Civia multiple unit
- Demonstrate competitiveness of fuel cell traction against existing diesel solutions

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Hydrogen Refueling Process for Railway Vehicles

Motivation and Targets

39% of German / 46% of EU rail network **without overhead lines**

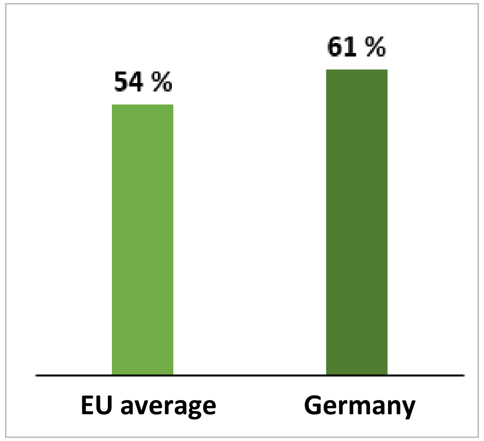
- Diesel as a fuel is state-of-the-art, H_2 one possible alternative

Hydrogen in railway vehicles:

- Storage pressure at 350 bar CGH2
- Capacity of 160 - 320 kg hydrogen in regional trains
- Target refueling time: **15 min**

Problem:

- **Competitiveness** of the technology concerning refueling time
- Refueling with **gaseous H_2 technically more challenging** than with liquid diesel
- H_2 heats up due to **compression** and **Joule-Thomson effect**



Share of electrified line sections in 2017/19
Source: BMDV

Target:

- Identify limitations in the hydrogen refueling process of railway vehicles in **simulations and measurements**

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Refueling process in FCH_2RAIL

Mobile refueling station

Demonstrator of **mobile refueling station**

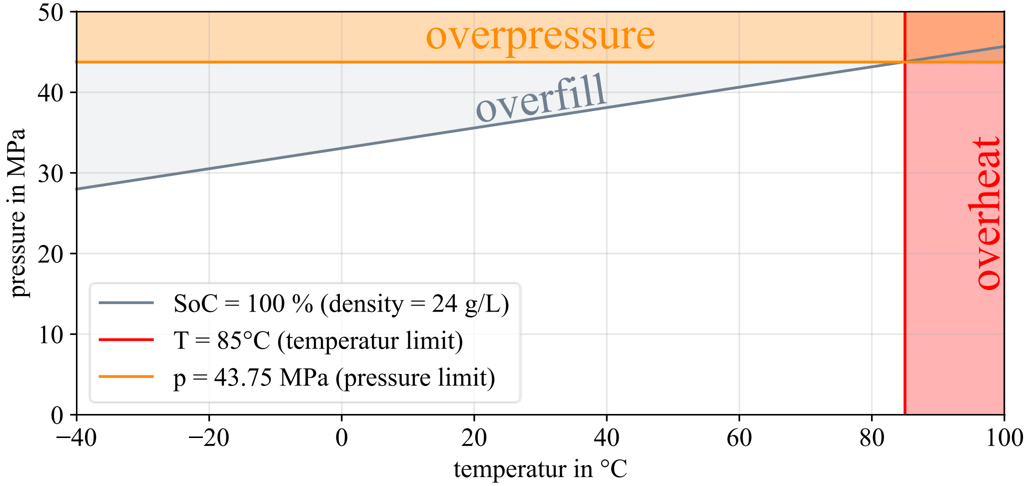
- Consists of 4 containers, operated by CNH2
- Refueling options: Intermediate storage or trailer

Pressure, temperature and mass flow **limitations from refueling standard SAE J2601-2**

- T = 85°C
- p = 43.75 MPa
- SoC = 100%
- Mass flow = 120 g/s

Measurement of refueling parameters

- Station: Temperature, pressure and mass flow in dispenser and other components
- Vehicle: Temperature and pressure in tanks



SAE: Society of Automotive Engineers
SoC: State of Charge

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Modeling of Hydrogen Refueling

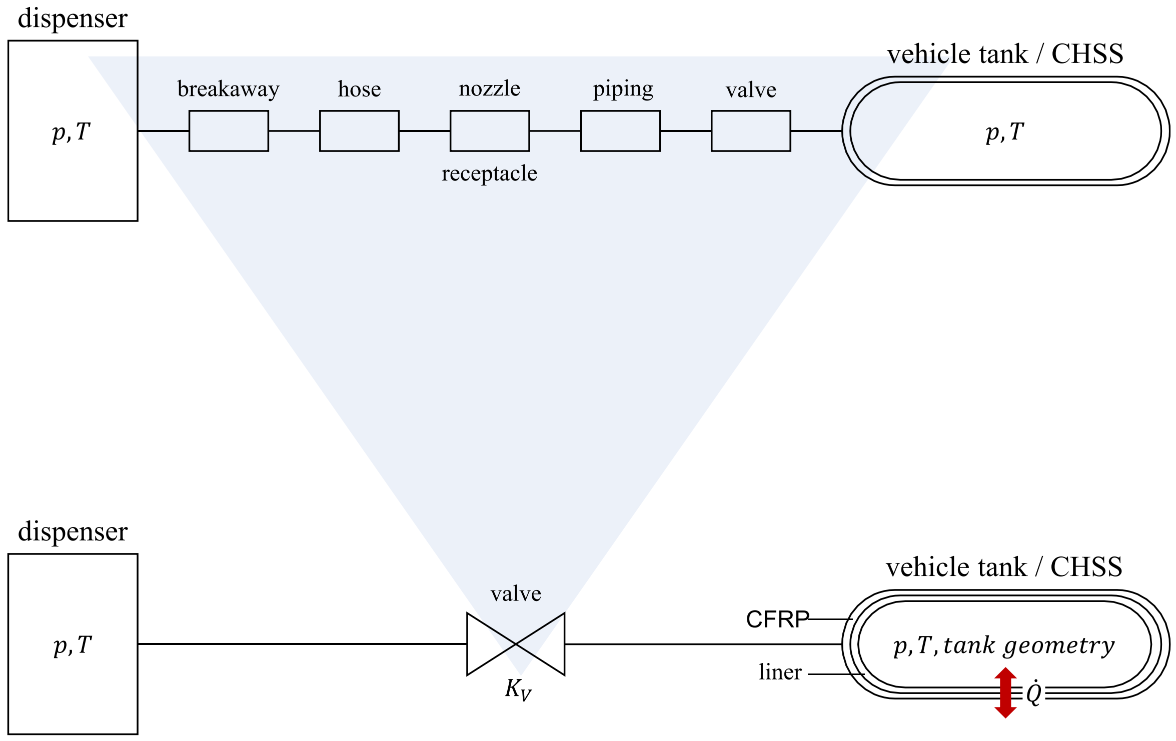
Flow Resistances and Heat Transfer

Components of hydrogen refueling process

- Refueling station: Dispenser, breakaway, hose, nozzle
- Vehicle: Receptacle, piping, valves, tanks

Abstraction of components for **modeling**

- Summarize **flow coefficient** K_v
- **Heat transfer** from tanks to environment



CHSS: Compressed Hydrogen Storage System
CFRP: Carbon Fiber Reinforced Polymer

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Modeling of Hydrogen Refueling

Dymola Simulation Model

Used **Dymola Libraries**

- Modelica Standard & Buildings Library

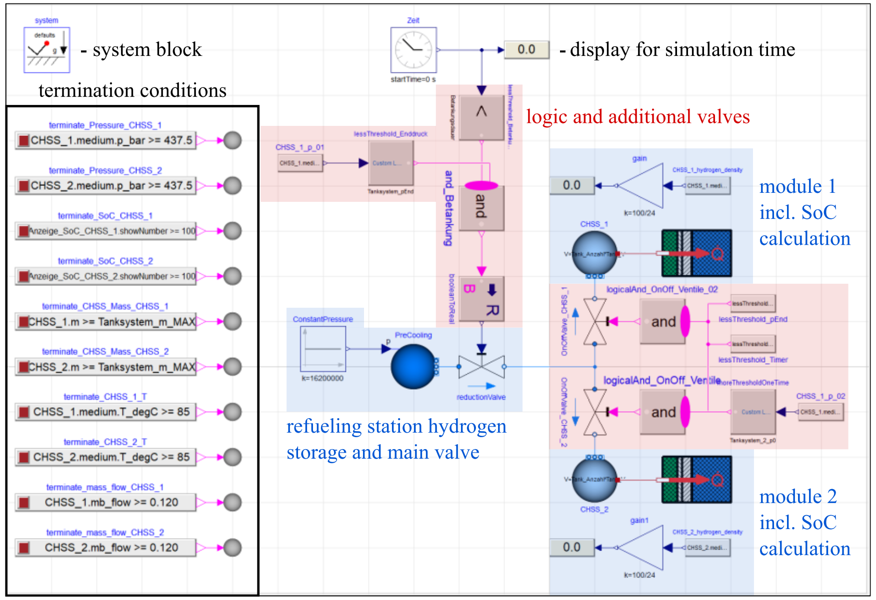
Hydrogen Refueling Model

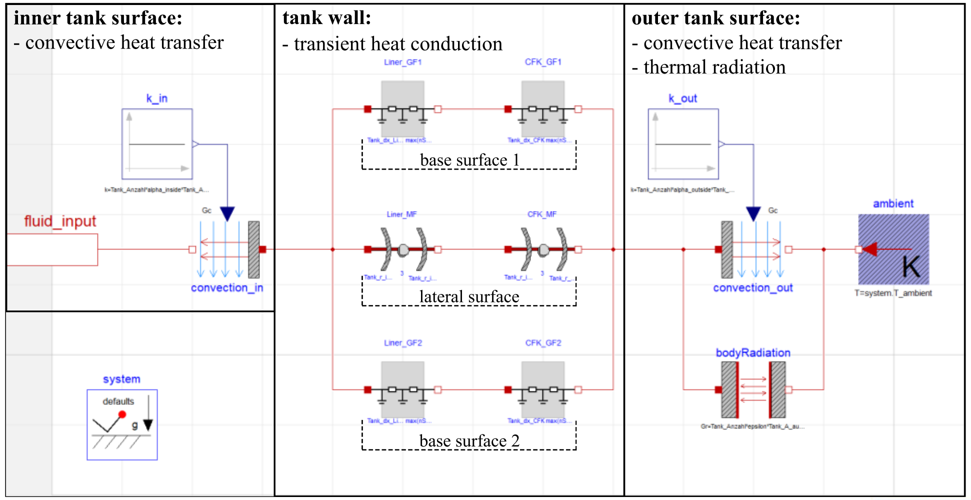
- **Termination conditions** for simulation
- Refueling Station: Pressure ramp rate, pre-cooling, valves
- Vehicle: Valves, storage tanks

Heat Transfer model

- Convective heat transfer
- Heat radiation
- Heat conduction

Lumped parameter model instead of CFD model for **fast simulation time**





CFD: Computational Fluid Dynamics
SoC: State of Charge

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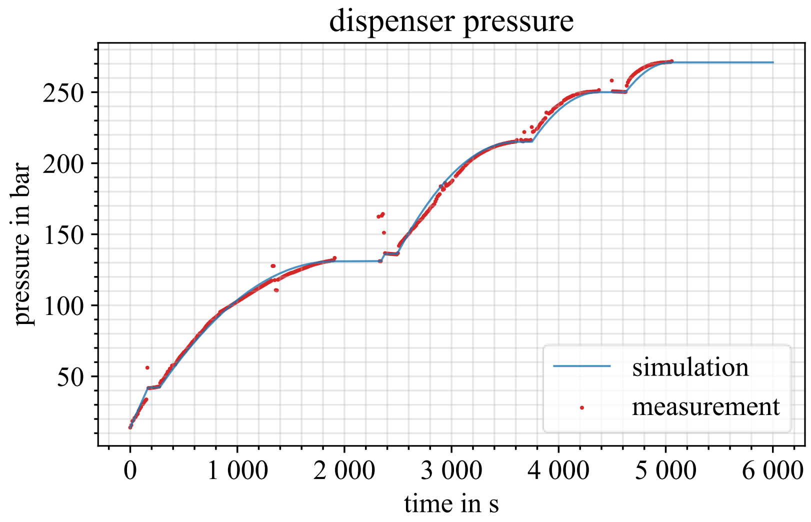
Modeling of Hydrogen Refueling

Validation with Measurement Data

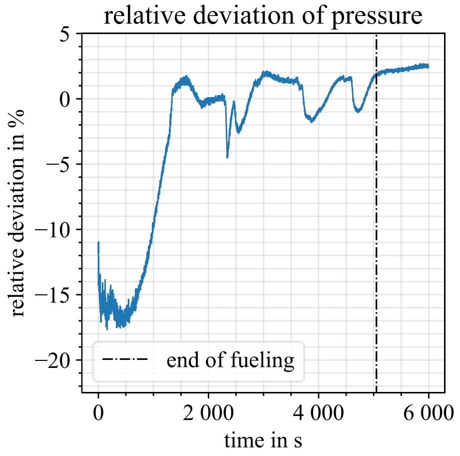
Measurement of **refueling data**

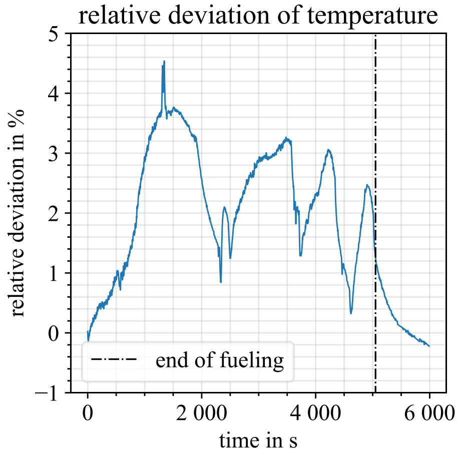
- Demonstrator refueling without pre-cooling
- Refueling in several **cascades**
- Measurement data of dispenser fitted as **input in simulation model**



Validation evaluation

- High pressure deviation at the beginning of refueling
- Temperature and pressure **deviation around 5%** for the rest of the time
- Relative behavior of temperature and pressure during refueling is **similar in measurement and simulation**
- **Further validation** with more data sets is planned





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Analysis of Refueling Process

Simulation Results – Variation of Tank Type and Temperatures

Boundary conditions for refueling

- Starting pressure 60 bar
- Final temperature 85°C
- Final SoC 100% → 160 kg H_2

Temperatures

- Ambient, pre-cooling and starting temperature in tank on same level
- Refueling time **nearly triples** from -10°C to 30°C

Tank types

- Refueling time for type 4 **over 30% longer** than type 3
- Hybridization of tank system offers **faster refueling times** than type 4 and **higher energy density** than type 3

Simulated refueling time for different tank types & temperatures:

	Type 3	Type 4	Hybrid
$\mathrm{T} = -10°C$	**13.5 min** (± 0%)	**17.1 min** (+26.1%)	**15.3 min** (+13.1%)
$\mathrm{T} = 15°C$	**21.9 min** (± 0%)	**29.5 min** (+ 34.7%)	**25.7 min** (+ 17.3%)
$\mathrm{T} = 30°C$	**36.2 min** (± 0%)	**50.4 min** (+ 39.1%)	**43.3 min** (+ 19.6%)

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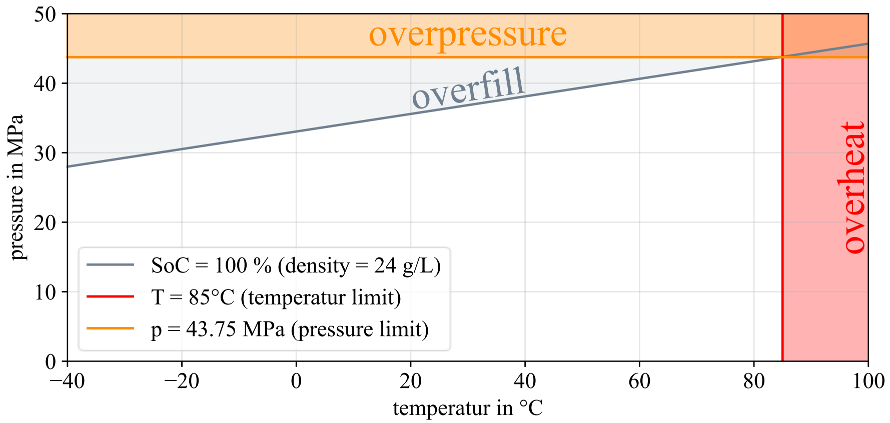
Conclusion

Limitations for Refueling Time and Recommendations

Identified limitations for the refueling time:

- **Temperature limitation** in tanks (85°C)
- Choice of temperature which is limited
- **Pressure loss** from refueling station to vehicle
- Mass flow limitation per dispenser (120 g/s)



Concluded **recommendations** for a **fast refueling** process in railway vehicles:

- Maximize average mass flow and **fast mass flow increase** (e.g. degressive pressure ramp rates)
- **Modularization** and simultaneous refueling of several tank systems
- **Active cooling** of the tanks
- Use of **type 3 tanks**
- Setting a **component temperature limit** instead of a hydrogen gas temperature limit (e.g. liner)
- Refueling at the **lowest ambient temperature**
- Refueling with maximum **pre-cooling** (-40°C)

Further work: Optimization of the refueling process

SoC: State of Charge

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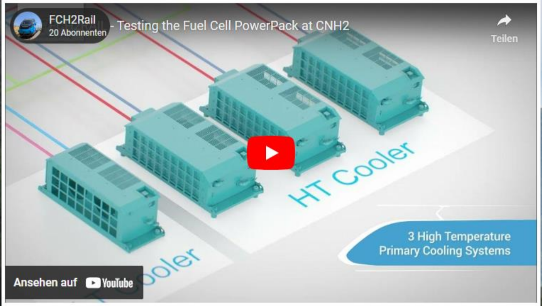
Testing the FCHPP



https://youtu.be/mC7EGb9VA7w

Train transformation

https://youtu.be/bFBR6nhyEVI

The Journey Begins!

https://youtu.be/s4JfnDbrLW8

HRS in service

https://youtu.be/RkGnYSADNO0

Thank you for your attention!

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