HYDROGEN REFUELING PROCESS FOR RAILWAY VEHICLES SIMULATION AND MODEL DEVELOPMENT

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Parallel Session 1 | Hydrogen Infrastructure for Transport, Distribution & Dispensing

06.03.2024 | 16:10 – 16:30

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EUROPEAN HYDROGEN ENERGY CONFERENCE

6 - 8 March 2024
Bilbao Exhibition Centre
Bilbao, Spain

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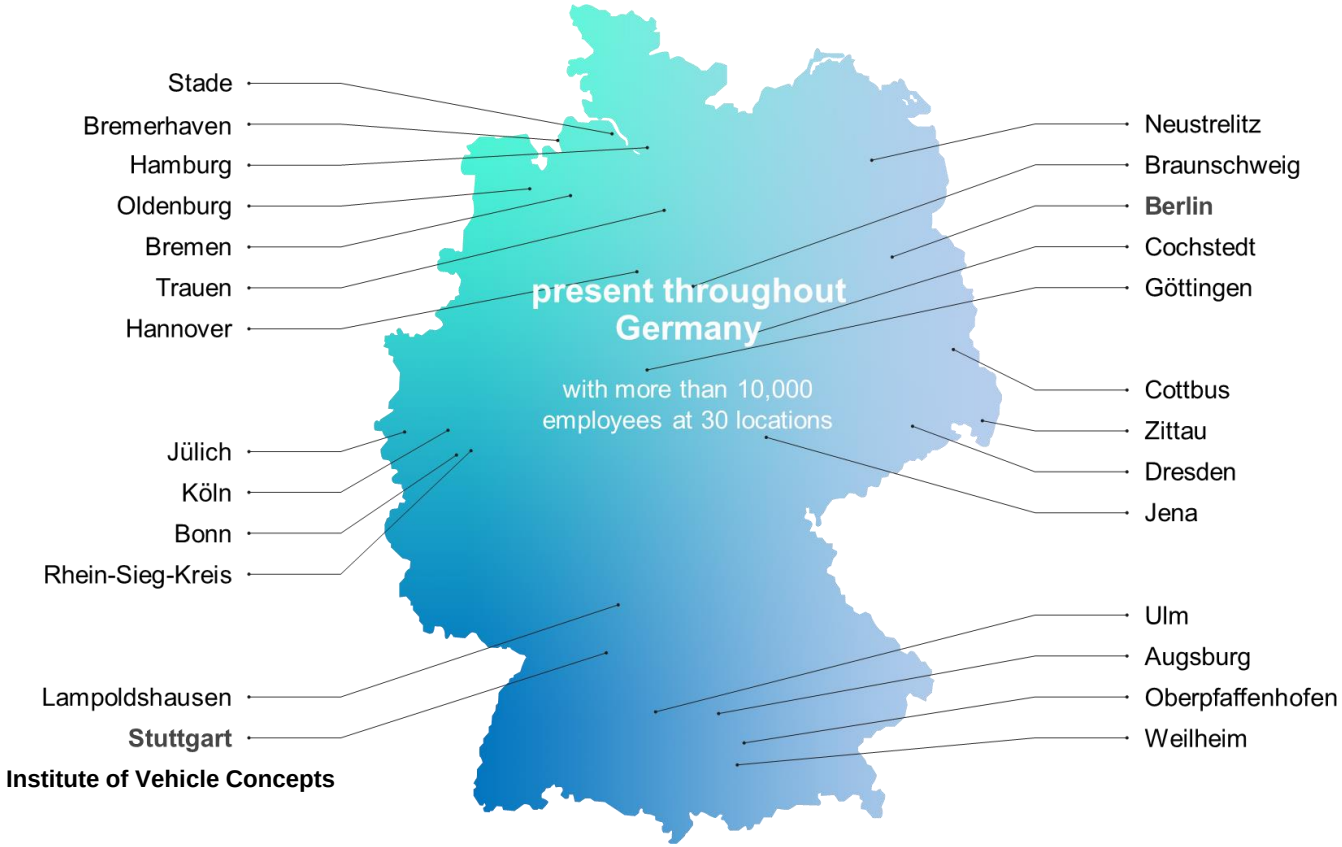
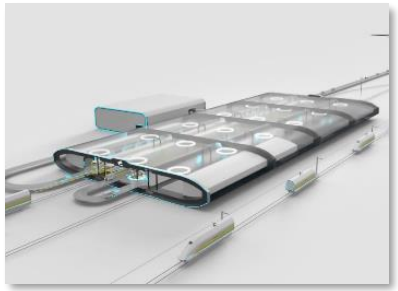
German Aerospace Center (DLR)

Institute of Vehicle Concepts

- 5 fields of innovation
  - Vehicle architecture
  - Energy concepts
  - Drive trains
  - System analyses
  - Materials & process engineering
- 3 principles
  - Protecting the climate
  - Securing mobility
  - Shaping transformation
- System, concept and technology research for road and rail vehicles





DLR: Deutsches Zentrum für Luft- und Raumfahrt (engl.: German Aerospace Center)

Agenda

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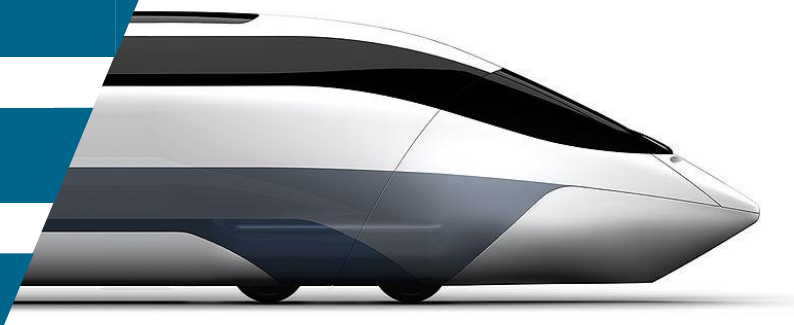
1 Motivation & Targets in Hydrogen Refueling of Railway Vehicles

2 Heidekrautbahn-Project

3 Norms and Standards for Hydrogen Refueling

4 Modeling of Refueling Process

5 Simulation Results for Pre-Cooling Temperatures



Hydrogen Refueling Process for Railway Vehicles

Motivation and Targets

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

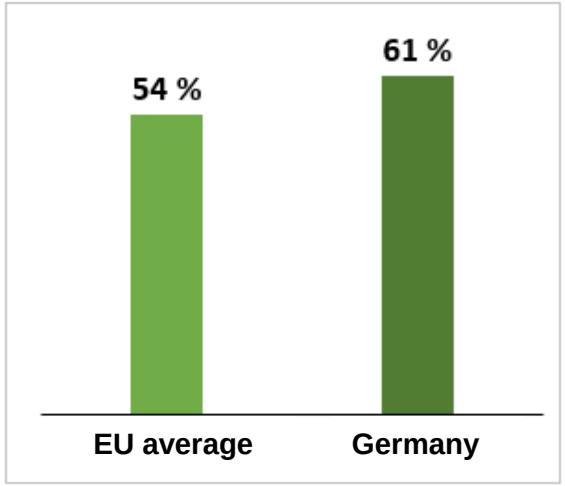
- Diesel as a fuel is state-of-the-art
- **H_2 one possible solution** to reduce greenhouse gas emissions

Hydrogen in railway vehicles:

- Storage pressure at 350 bar CGH_2
- 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
  - → **Temperature increase** of the H_2 due to compression and Joule-Thomson effect
  - → Conflict: Refueling time and H_2 temperature



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

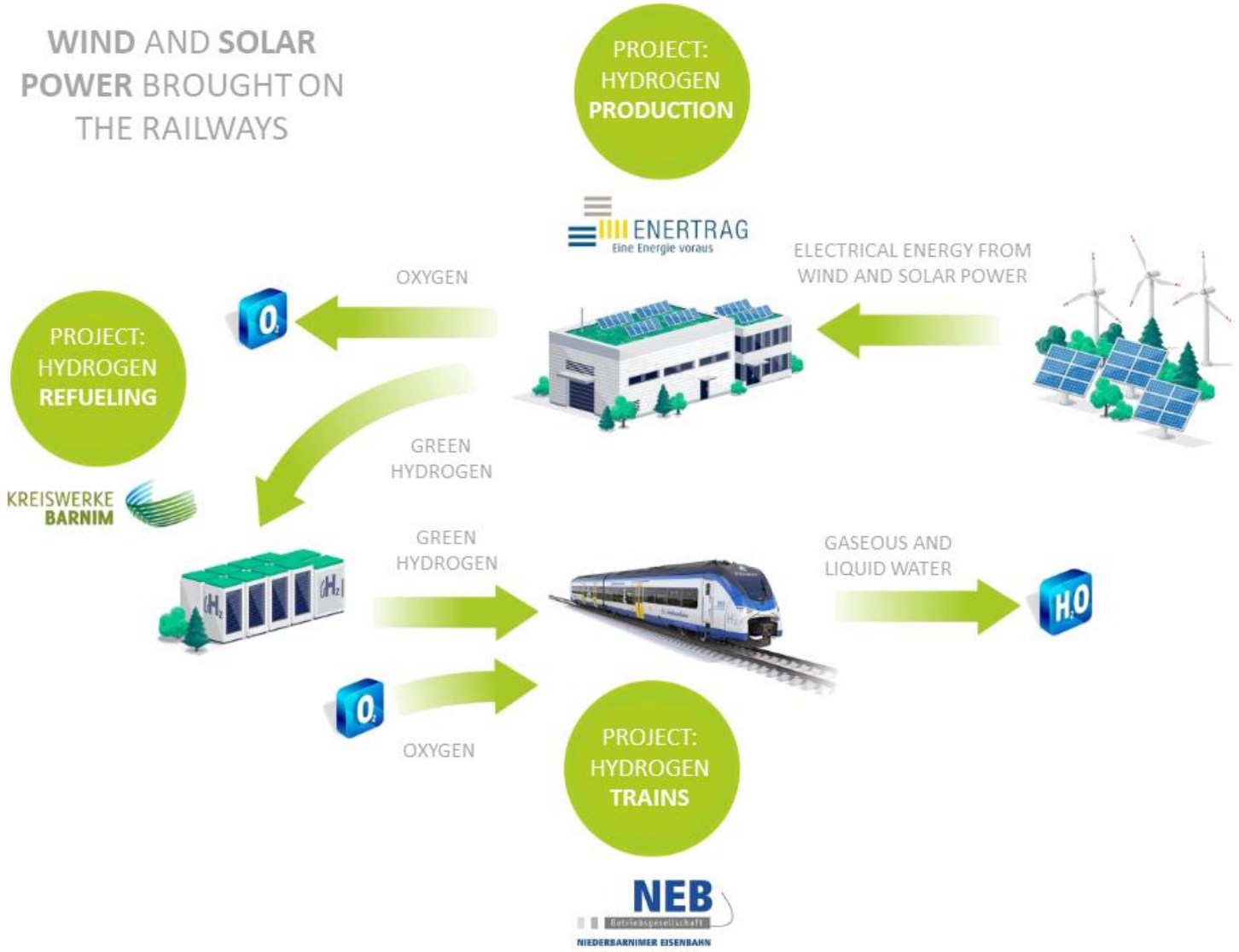
Siemens Mireo Plus H for Heidekrautbahn-Project

CGH_2: Compressed gaseous hydrogen

Heidekrautbahn-Project

Project overview and accompanying research

- **Green hydrogen** is produced by electrolysis from regionally generated, renewable wind and solar energy
- **1 hydrogen refueling station** in Basdorf, Germany
- **7 fuel cell hydrogen multiple units** Siemens Mireo Plus H replace existing diesel multiple units
- Start of operation in **December 2024**
- **Scientific research** accompanying the industrial project



Diesel vs. Hydrogen Refueling

Refueling stations in Basdorf, Germany

- **Diesel refueling station** in operation
  - Current diesel train refueling: 75 l/min
    - 2 x 750 l diesel on-board tank volume
  - Refueling time with diesel :
    - 1,500 l / 75 l/min = **20 min**
    - Calorific value of 1,500 l : **15,000 kWh**
- **Hydrogen refueling station** starting operation 12/2024
  - Maximum mass flow according to SAE J2601-2: 120 g/s
  - Refueling time with hydrogen:
    - 180 kg / 120 g/s = **25 min**
    - Calorific value of 180 kg H_2: **6,000 kWh**
  - Hydrogen refueling requires **more process effort** than diesel refueling
  - Use of two dispensers for **parallel filling of several on-board tank modules** shortens the refueling time

Top: Components of Diesel refueling station in Basdorf
Bottom: Location of current Diesel and future H2 refueling station

SAE: Society of Automotive Engineers

Norms & Standards for Hydrogen Refueling

Parameters & Specifications

- Refueling protocol
  - Specifies the pressure for the refueling of the vehicle depending on various ambient conditions
- SAE J2601-1 defines refueling protocols for **passenger cars up to 10 kg** hydrogen capacity
- SAE J2601-2 (heavy-duty) defines **limits for refueling process** but no ramp rate specifications
- No specific standard available for refueling protocols in rail vehicles
  → **Project specific development** and validation
- SAE J2601-5 (02/24) & ISO 19885-1 (04/24) under development addressing **higher H_2-capacities**

SAE: Society of Automotive Engineers
ISO: International Standards Organization

General conditions for refueling according to **SAE J2601-2**

Validity	▪ 35 MPa ▪ H_2 capacity > 10 kg
Temperature	▪ -40°C to 85°C
Pressure	▪ 0.5 MPa to 43.8 MPa
Ambient temperature	▪ -40°C to 50°C
State of Charge (SoC)	▪ ≤ 100 %
Hydrogen mass flow	▪ ≤ 120 g/s

General conditions for refueling according to **SAE J2601-5 for H35**

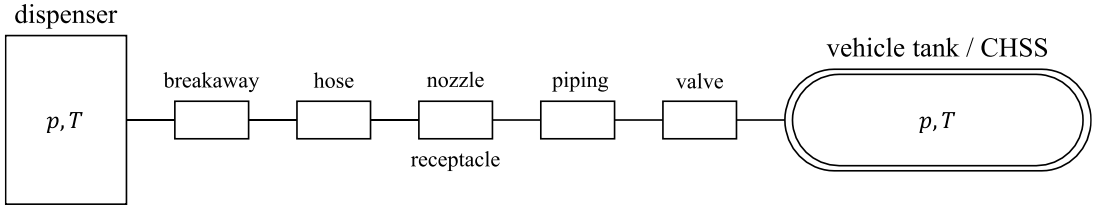
Validity	▪ 35 MPa ▪ H_2 capacity 5.97 – 180 kg
Single Tank Size	▪ 50 to 1,000 L
Fuel Delivery Temperature	▪ -40°C to 20°C
Hydrogen mass flow	▪ ≤ 120 g/s

Source: Clean Energy Partnership (CEP)

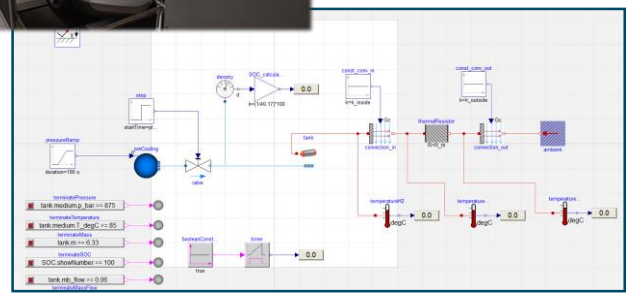
Modeling of Refueling Process

Simulation model in Dymola/Modelica

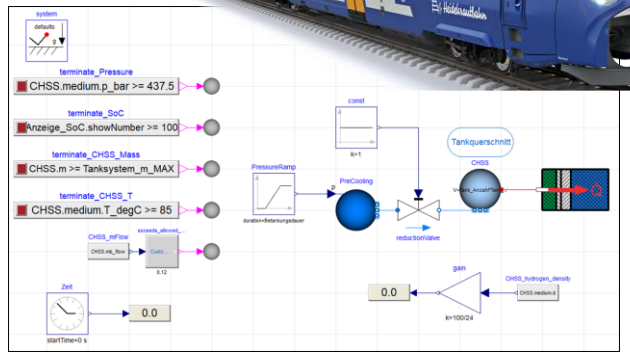
- Input: **Validated refueling model** for H_2 passenger cars according to SAE J2601-1
- Target: Adapt model for usage in H_2 trains to **derive optimization potential** for refueling process in vehicle operation
- Model Setup:
  - Models in Dymola/Modelica
  - Merging of the flow resistances of the individual components
  - Modeling hydrogen as a real gas



Validated



Further development



SAE: Society of Automotive Engineers

Modeling of Refueling Process

Simulation model in Dymola/Modelica

Used Dymola Libraries

- Modelica Standard & Buildings Library

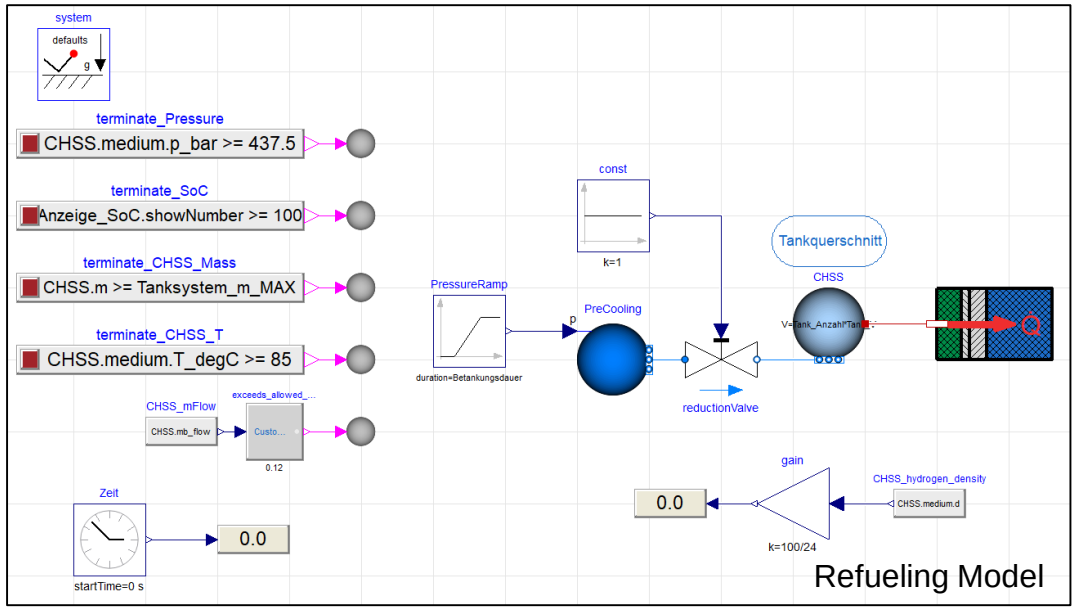
Hydrogen Refueling Model

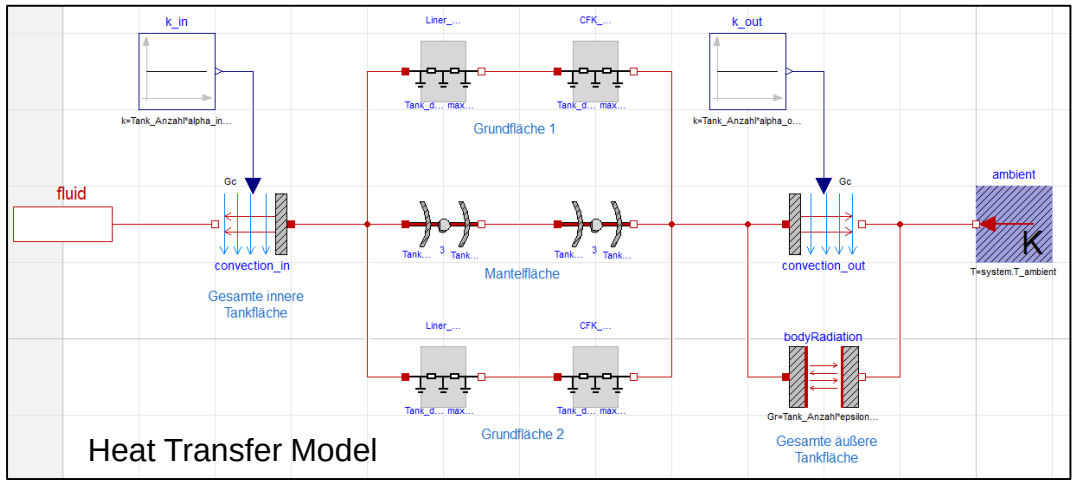
- Termination conditions for simulation
- Refueling Station: Pressure ramp rate, pre-cooling, valves
- Vehicle: Valves, storage tanks

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

Simulation Results for Refueling Process

Pre-cooling for fast refueling

Worst case: Refueling at 40 °C in summer

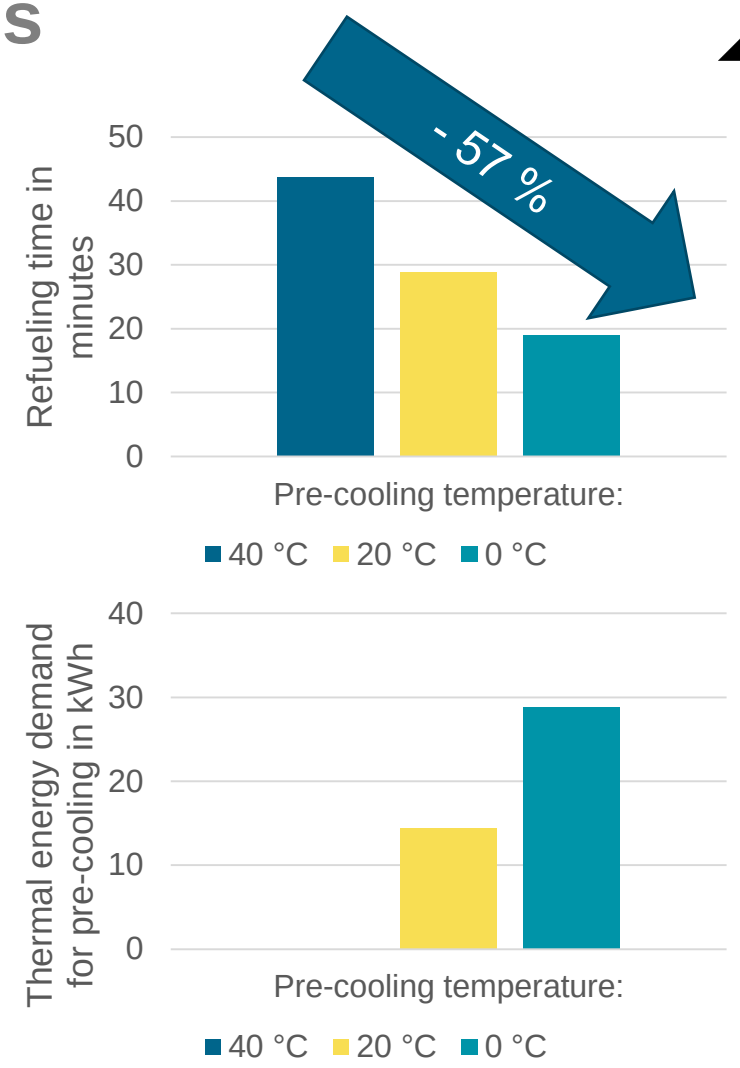
Evaluate different pre-cooling temperatures

- 2 x 90 kg hydrogen capacity
- Over **40 minutes of refueling time** without pre-cooling
- **Reduced refueling time** by 57% with pre-cooling to 0 °C

Energy demand for pre-cooling

- Pre-cooling is **energy and cost intensive**
- Thermal energy demand based on $c_{P,\,H2}$ = 14.4 J/gK
- Electrical energy demand dependent on system COP
  - COP depends on ambient and pre-cooling temperature

Next step: **Model validation** with measurement data



Fast refueling times must be weighed against energy and cost savings due to less pre-cooling effort to ensure **time and cost-optimized operation** with hydrogen trains

COP: Coefficient of Performance

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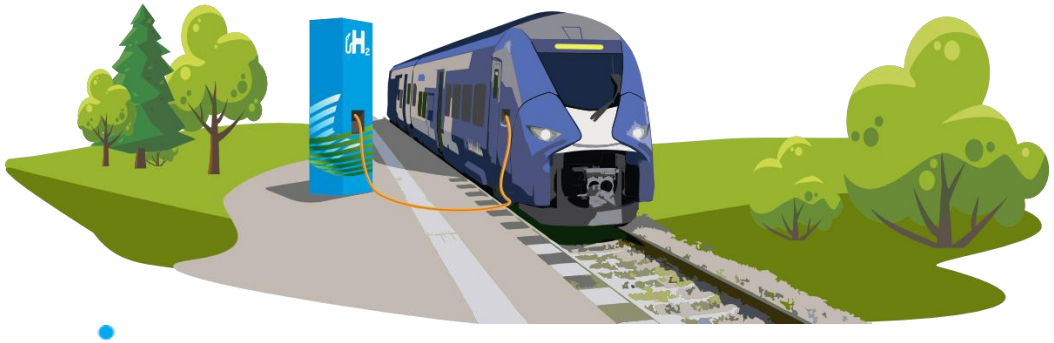

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VEHICLES AND REFUELING STATION

DLR Institute of Vehicle Concepts

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research

project information (German)

SIEMENS

vehicle manufacturer

VBB Verkehrsverbund Berlin-Brandenburg

transport association

nip Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie

Bundesministerium für Digitales und Verkehr

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