Waste Heat Recovery for Fuel Cell Electric Vehicle with a Thermochemical System

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The German Aerospace Center

Institute of Vehicle Concepts

DLR

The German Aerospace Center (DLR)
Overview

Research Topics:

Space

Aeronautics

Energy

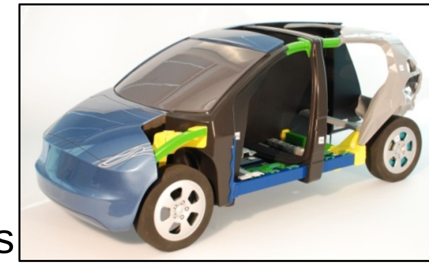
Transport

DLR has approximately 8.000 employees, 32 institutes, and facilities at 16 locations in Germany

- ■ 9 Site
- ● 7 Branches

DLR also has offices in Brussels, Paris, Tokyo and Washington D.C.

Institute of Vehicle Concepts (FK)
Research Areas

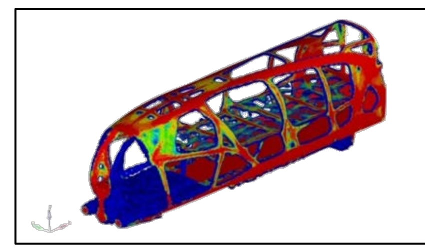


Road Vehicle Concepts

- Conception and demonstration of innovative vehicle concepts
- Exploration and holistic assessment of new technical solutions

Railway Vehicle Concepts

- Innovative multiple-unit train concepts
- Increasing energy efficiency



Lightweight Vehicle Design

- Lightweight construction concepts
- Integral processing of methods, materials ,and constructions

Alternative Drives

- Holistic modeling of vehicle energy architectures
- Improvement of future propulsion systems efficiency
- Novel energy conversion concepts

Contents

- Introduction
- The HT-PEFC range extender vehicle
- Development of novel waste heat recovery concepts
- Results of the overall vehicle simulation
- Conclusion

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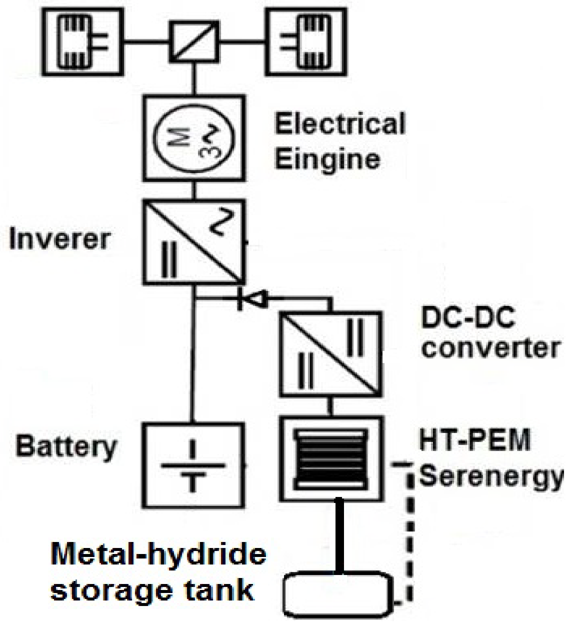
Introduction
Electric vehicle with fuel cell range extender (Research Demonstrator)

In a research project at the DLR Institute of Vehicle Concepts, a high temperature polymer membrane fuel cell (HT-PEFC) range extender for the smart fortwo electric car will be developed

A waste heat recovery system for the HT-PEFC range extender (REX) using thermochemical heat storages is investigated

Several issues are still open:

- Integration concepts of the thermochemical heat storages
- Evaluation of the integration concepts in the entire vehicle



The HT-PEFC range extender vehicle
Characteristics

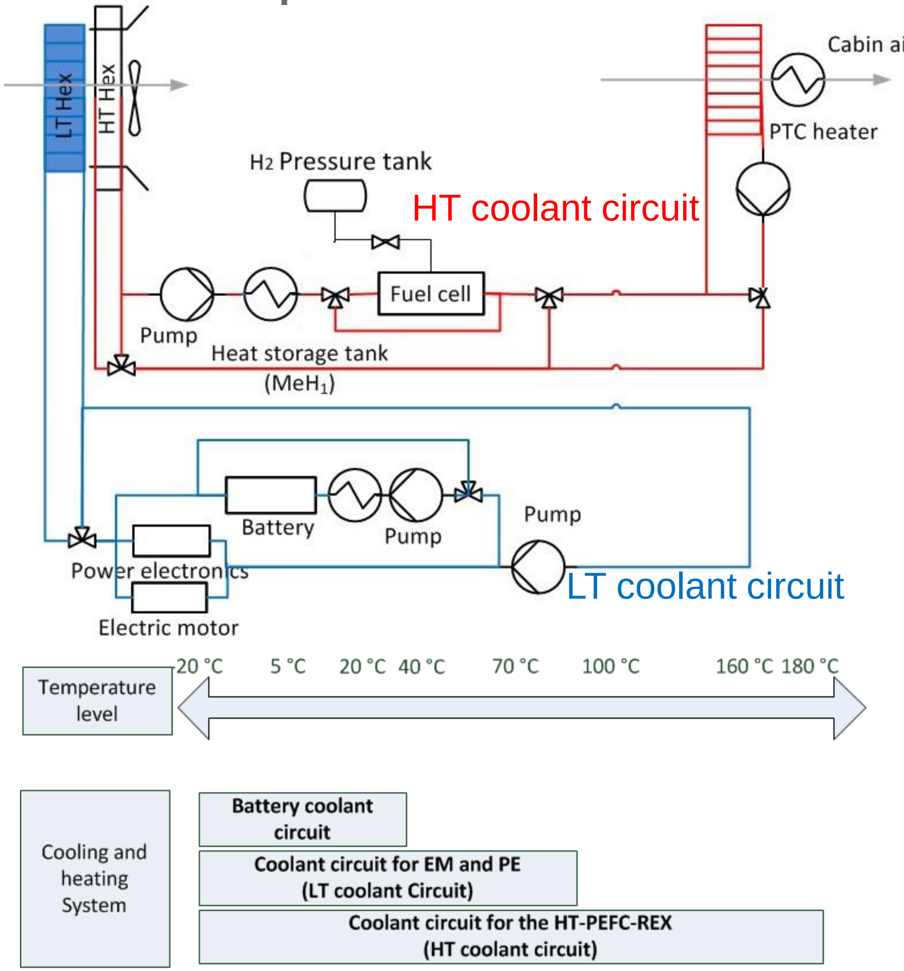
Maximum vehicle weight	1150 kg
Continuous output	35 kW
Max. power	55 kW
Max. torque	130 Nm
Battery type	Lithium-ion
Battery capacity	17.6 kWh
Battery weight	174 kg

Fuel cell type	HT PEFC
Maximum electrical power of the fuel cell	6 kW
Maximum current of the fuel cell	130 A
Fuel cell total mass	68 kg
H_2 tank storage capacity	0.9 kg

The HT-PEFC range extender vehicle
Cooling and heating system for the powertrain

The Cooling and heating system for the powertrain components consists of

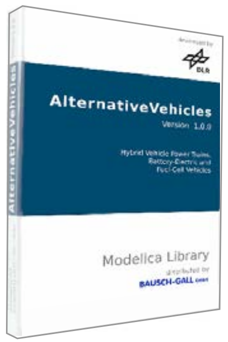
- Battery coolant circuit with coolant temperature < 40 ° C
- EM und LE coolant circuit with coolant temperature < 100 ° C
- Fuel cell coolant circuit with coolant temperature < 180 ° C

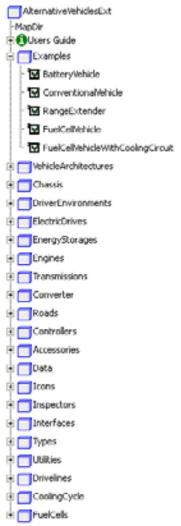


Modelling of the HT-PEFC range extender vehicle

An overall vehicle simulation model is build using

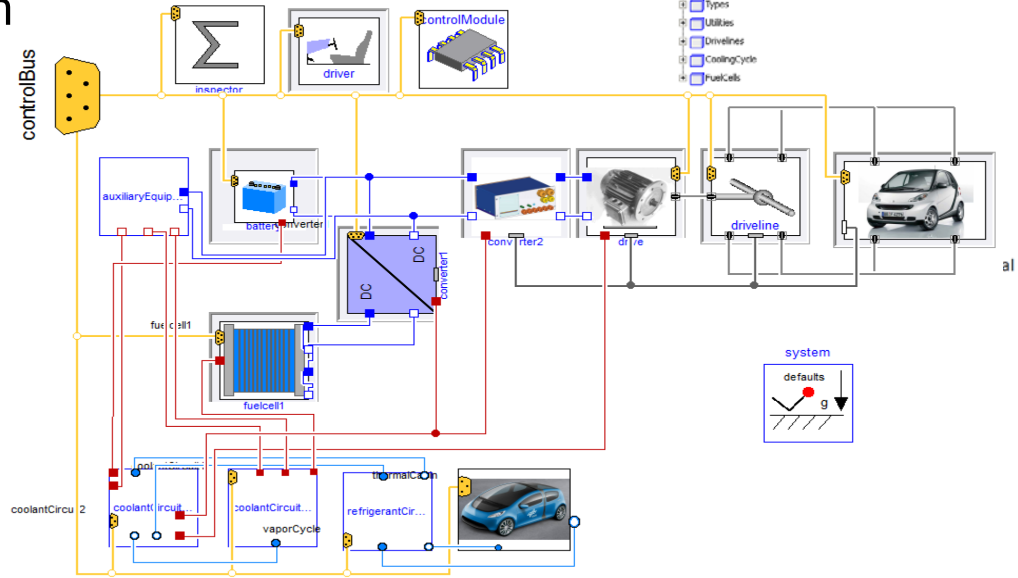
- The Modelica Standard Library
- The AlternativeVehicles Library





The overall vehicle simulation model consists of

- The powertrain
- Coolant circuits
- HVAC
- Cabin
- Control system



Development of novel waste heat recovery concepts
Background and goals

1. Storage of the unused waste heat during normal operation

   →Support of the cooling systems

2. The re-use of the stored waste heat for heating purpose before the drive

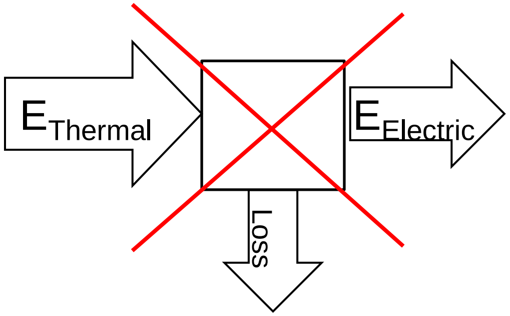
   →Substitution of the preheating systems

   →Increasing the energy efficiency

3. The use of one component (metal hydride storage) which is able to store the thermal energy and release it back when needed

   →No additional energy conversion

   → Reduction of the number of systems



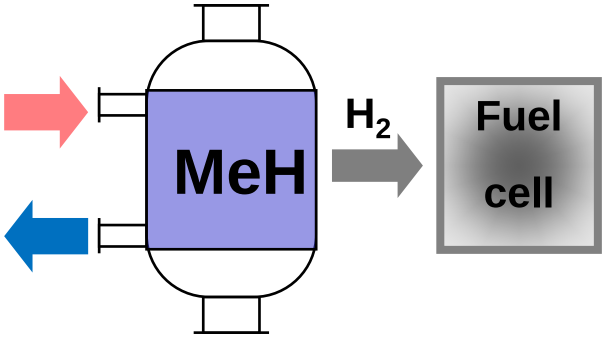
Principle of the metal hydride storage systems

Metal hydrides (MeH) are metal powders which absorb and release hydrogen

- The hydrogen desorption consumes heat, since the reaction is endothermic

endothermic

$$\mathrm{MeH} + \mathrm{Heat} \rightarrow \mathrm{M} + \mathrm{H_2}$$

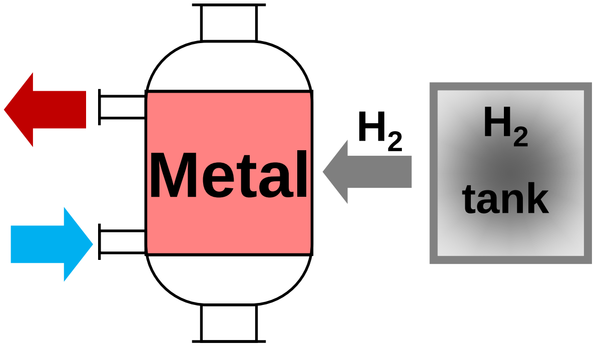


Storage of heat

- The hydrogen absorption generates heat, since the reaction is exothermic

exothermic

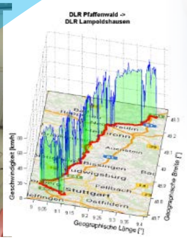
$$\mathrm{MeH} + \mathrm{Heat} \leftarrow \mathrm{M} + \mathrm{H_2}$$



Release of heat

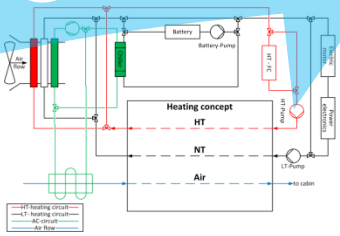
Methodological approach

Reference vehicle and operating conditions

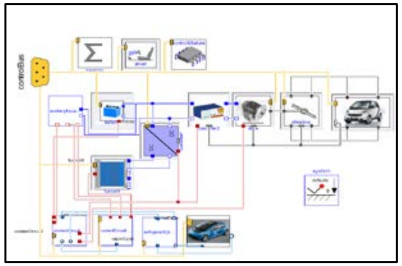


Thermochemical heat storages

Integration concepts



Overall vehicle Simulation



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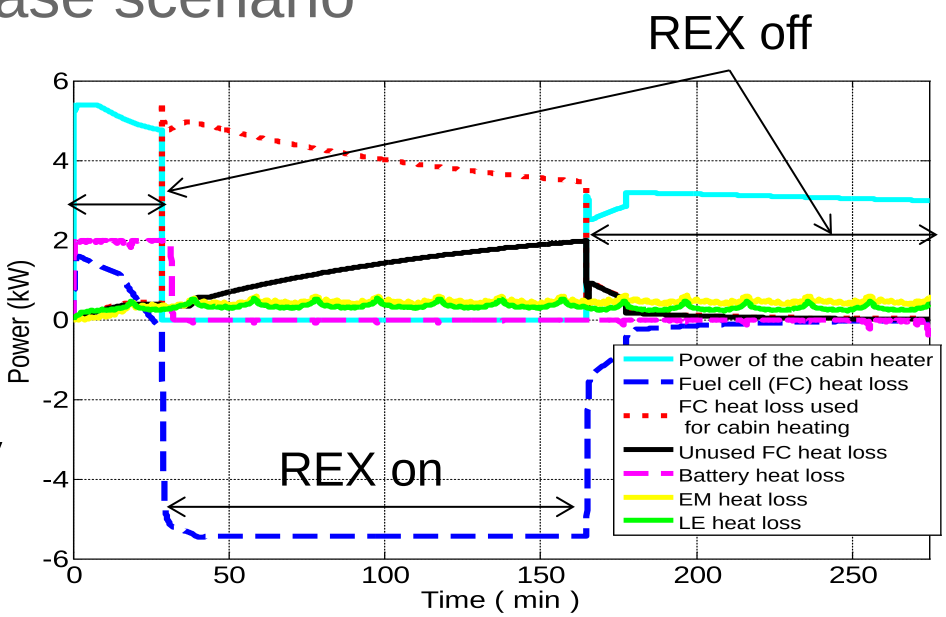
Determination of the waste heat energy
Simulation of the worst case scenario

- Ambient temperature: -20 ° C
- Humidity: 100 %
- Drive cycle : NEDC
- Electrical heating
    - 2,5 kW coolant heater for the fuel cell and the battery
    - 6 kW air heater
- Fuel cell waste heat is used for the cabin heating



Fuel cell waste heat energy	12.3 kWh
Cabin heat demand (REX operation)	9.3 kWh
HT waste heat energy	3.0 kWh
LT waste heat energy	3.3 kWh

The unused waste heat energy amounts 6.3 kWh

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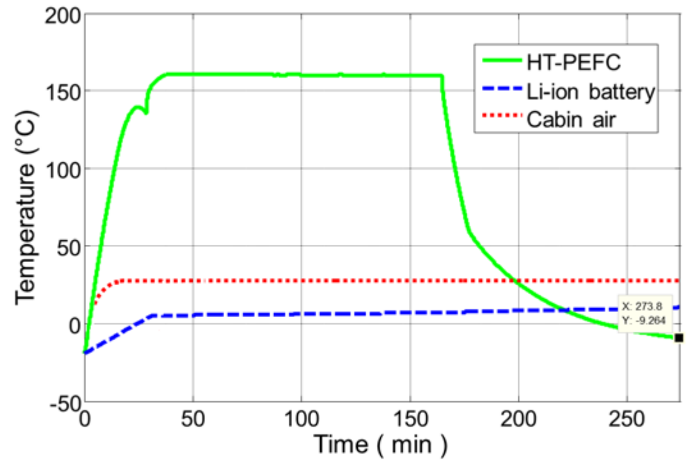
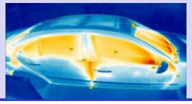
Determination of the heat demand for preheating

Simulation of the worst case scenario

- Ambient temperature: -20 ° C
- Humidity: 100 %
- Electrical heating during the cold start operation
    - 2,5 kW coolant heater for the fuel cell and the battery
    - 6 kW air heater



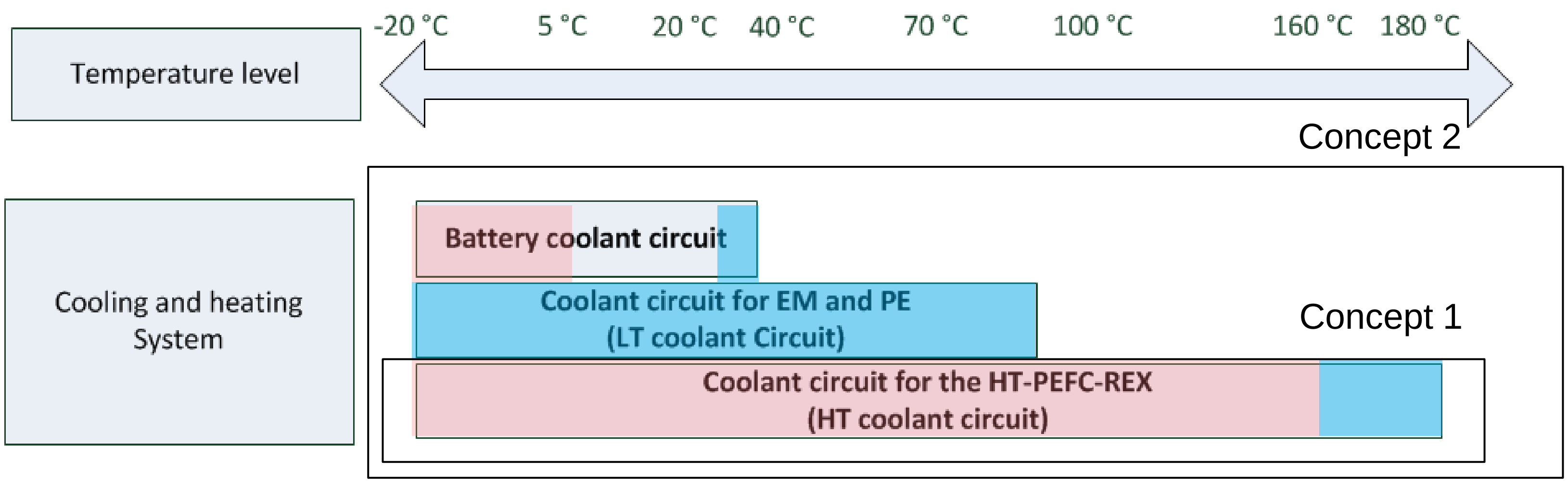
Component	Desired temperature	Electrical energy
	150 ° C	1.3 kWh
	5 ° C	1.4 kWh
	27 ° C	2.1 kWh

The total heat demand is around 4.8 kWh

Metal hydride waste heat recovery Concepts

The suggested concepts:

- Concept No. 1
  - High temperature waste heat recovery system
  - Storage and re-use of the fuel cell waste heat
- Concept No. 2
  - High and low temperature waste heat recovery system
  - Storage and re-use of the fuel cell, PE and LE waste heat



Metal hydride waste heat recovery concepts
Concept 1

Function

One MeH storage tank is used to store the HT waste heat and re-use it for

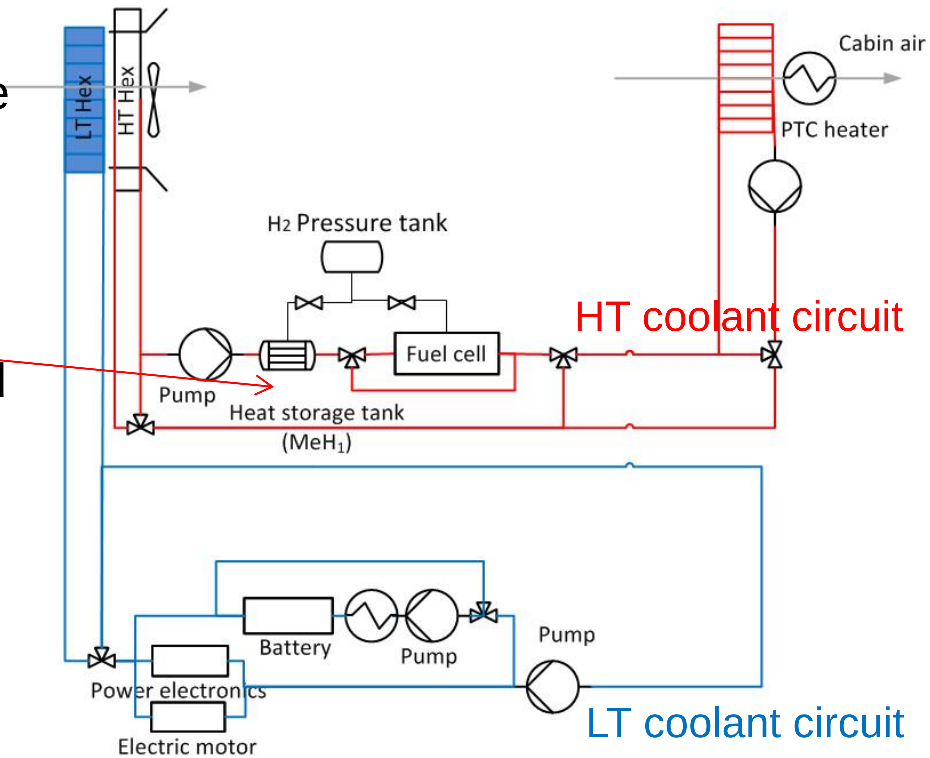
- Fuel cell preheating
- Cabin preheating

Integration concept

The MeH storage tank is integrated into the fuel cell coolant circuit

Thermochemical system

- Typ: a high temperature metal hydride ($LaNi_{4.75}Al_{0.25}$)
- Loading pressure: 35 bar
- Unloading pressure: 5 bar

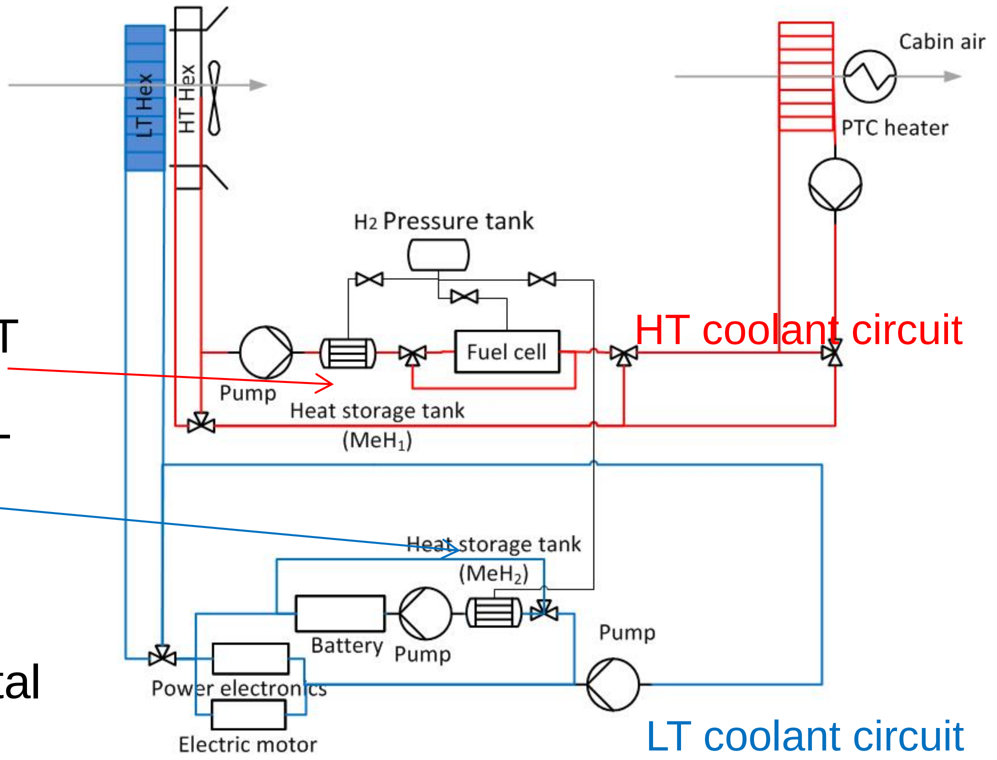


Metal hydride waste heat recovery concepts
Concept 2

Function
- MeH_1 is used to store the HT waste heat
- MeH_2 is used to store the LT waste heat

Integration concept
- MeH_1 is integrated into the HT coolant circuit
- MeH_2 is integrated into the LT coolant circuit

Thermochemical system
  - Typ: a HT metal hydride ($LaNi_{4.75}Al_{0.25}$) and LT metal hydride ($LmNi_{4.91}Sn_{0.15}$)
- Loading pressure: 35 bar for MeH_1 and 5 bar for MeH_2
- Unloading pressure: 5 bar for MeH_1 and 1 bar for MeH_2



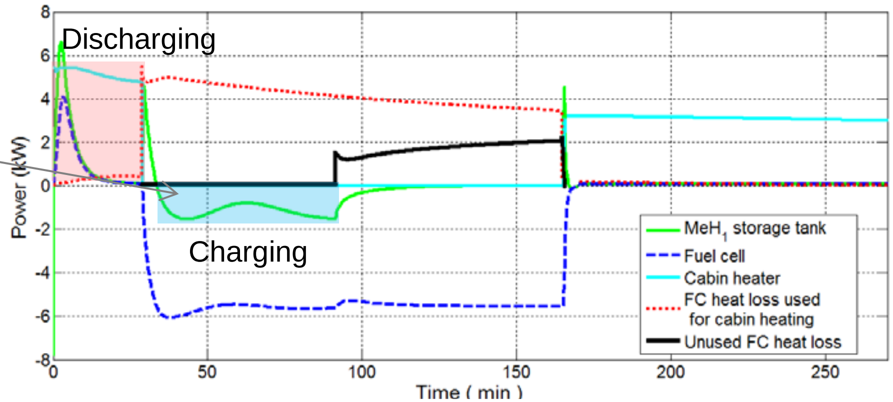
Overall vehicle simulation

Discharging and Charging of the heat storage tanks

Worst case scenario ($T_{ambient}$: -20° C, Drive cycle : NEDC)

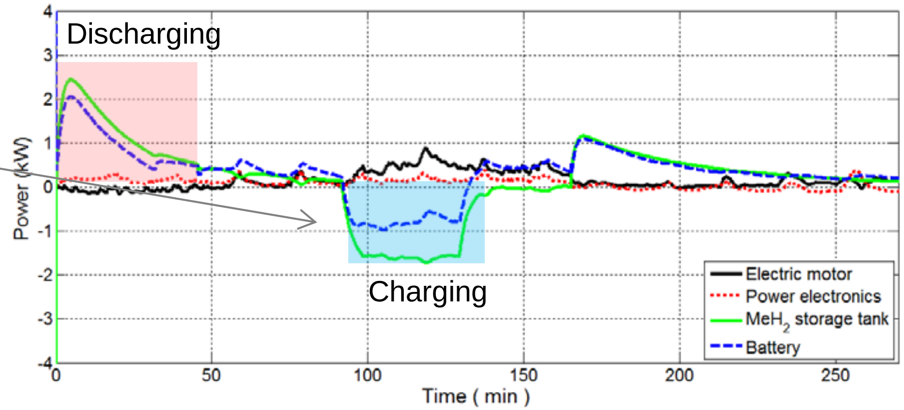
- Concept 1

  40 % of the HT waste heat can be stored for the preheating



- Concept 2

  40 % of the HT waste heat and 50 % of the LT waste heat can be stored for the preheating

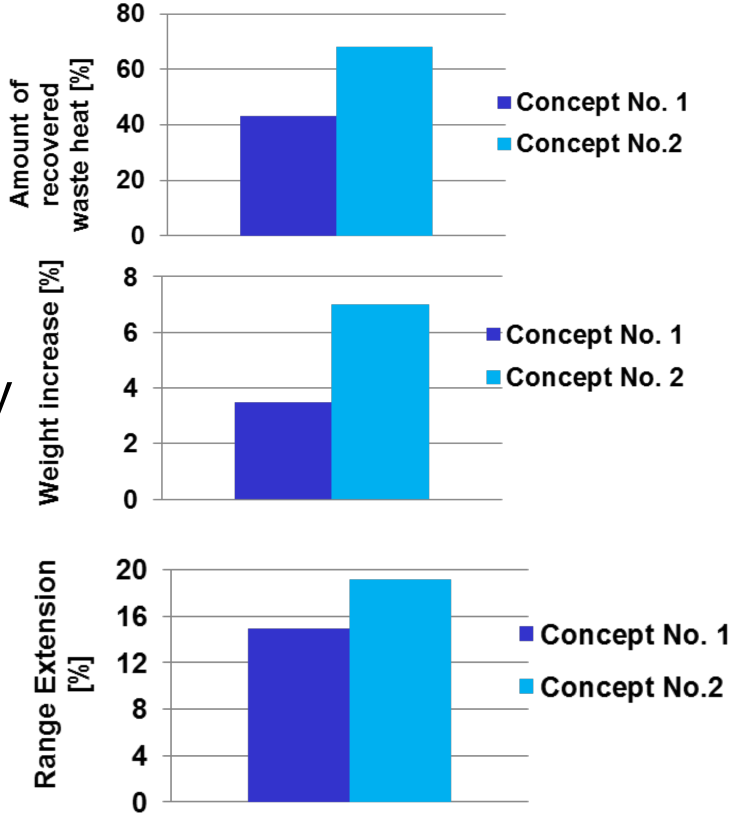


Overall vehicle simulation

Assessment and comparison

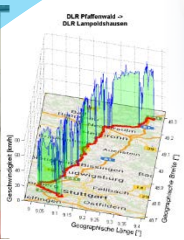
- The Reference case is the NEDC cycle with the conditioning system switched on
- The NEDC cycle is repeated several times in sequence until the battery SOC and H_2 tank are depleted

- At least 40 % of the HT-PEFC-REX waste heat can be recovered by the thermochemical systems
- The increase in mass caused by the metal hydride systems does not exceed 8 %
- A range increase by up to 17 % in comparison to the HT-PEFC-REX vehicle is possible



Conclusion

Reference vehicle and operating conditions

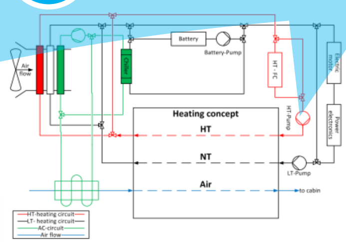


✓ Waste heat energy and heat demand for preheating are determined

Thermochemical heat storages

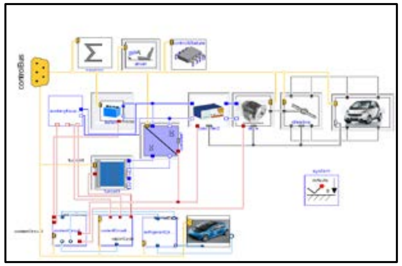
✓ The reaction system is designed

Integration concepts



✓ 2 Integration concepts are developed

Overall vehicle Simulation



✓ A range increase by up to 17 % is possible

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Thank you for your attention!

Questions?

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