THERMAL MANAGEMENT CONCEPTS FOR FUEL CELL ELECTRIC VEHICLES BASED ON THERMOCHEMICAL HEAT STORAGES

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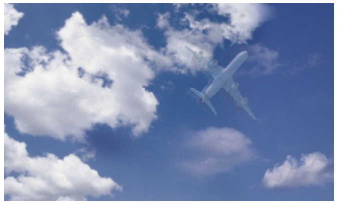
The German Aerospace Center (DLR)

Research Topics:

Space	Aeronautics	Energy	Transport
			

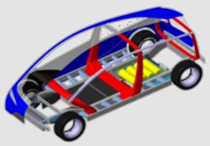
DLR has approximately 8.000 employees, 32 institutes and facilities at 16 locations in Germany

- 9 Site
- 7 Branches

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

The DLR Institute of Vehicle Concepts
Research Areas

1. Vehicle systems and technology assessment
2. Vehicle energy concepts
3. Alternative energy converters
4. Lightweight and hybrid design methods



Innovative concepts for road and rail vehicles

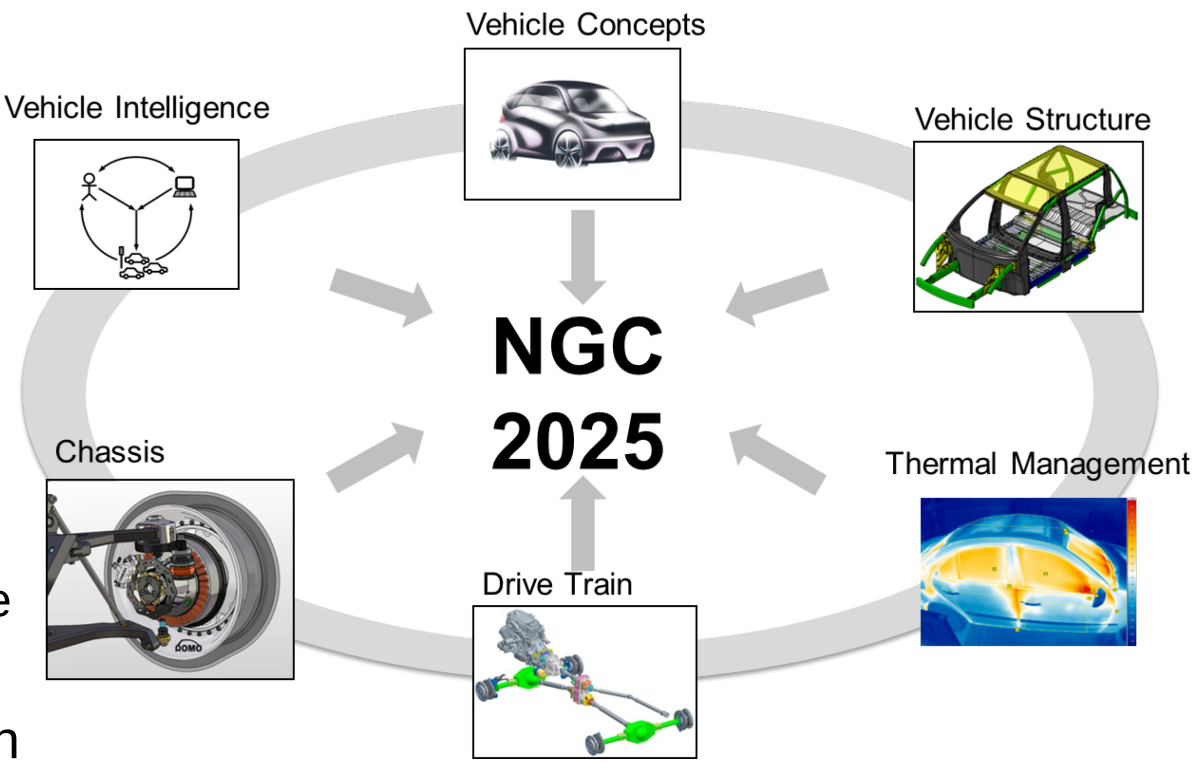
The Institute's fields of endeavour address the development of future technology systems for sustainable, safe and affordable generations of vehicles on road and rail

Contents

- Motivation and goals
- Methodology for the development of thermal management concepts based on thermochemical heat storages
- Simulation results
  - Reference vehicle
  - Thermochemical heat storages
  - Integration concepts of the thermochemical heat storages
  - Overall vehicle simulation
- Summary and outlook

Motivation
The „Next Generation Car (NGC)" Project

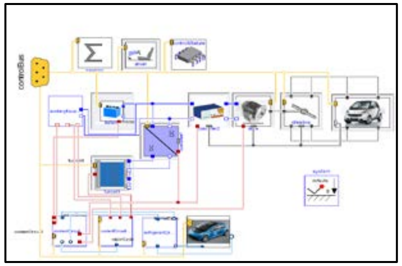
- Road research project within German Aerospace Center (DLR)
- Bundling DLR activities in the automotive field
- Technology demonstration in structured 6 working fields
- Assignment of the technologies to 3 vehicle concepts
  - Safe Light Regional Vehicle
  - Urban Modular Vehicle
  - Interurban Vehicle
- Joint usage of research hardware and test infrastructure



Contents

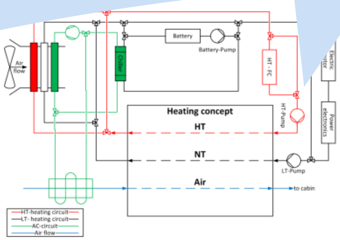
Methodology for the development of thermal management concepts based on thermochemical heat storages

Complete vehicle Integration

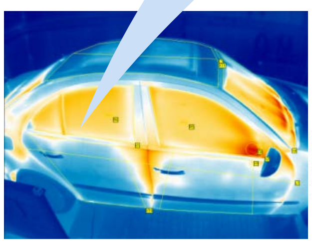


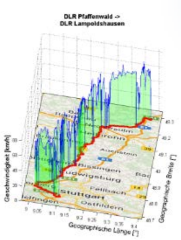
Integration concepts

Thermochemical heat storages



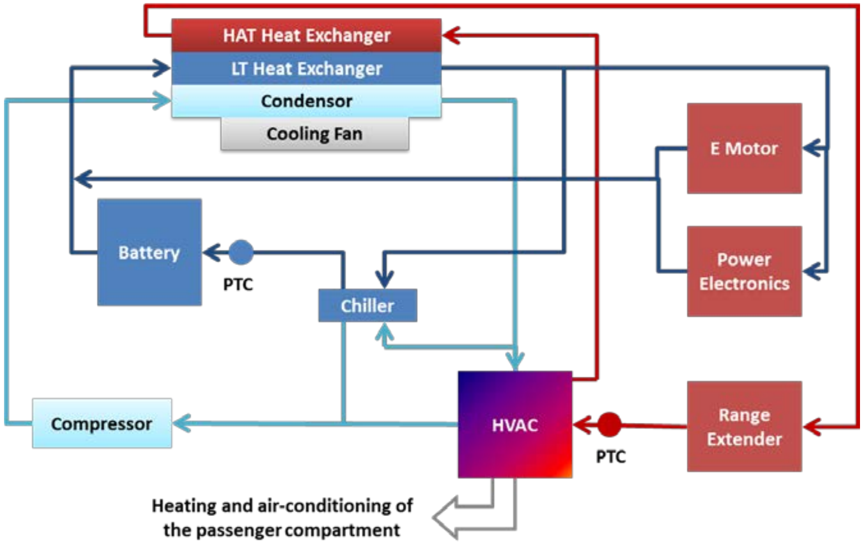
Reference vehicle and operating conditions





Methods and tools provided by the DLR Institute of Vehicle Concepts for the overall system design

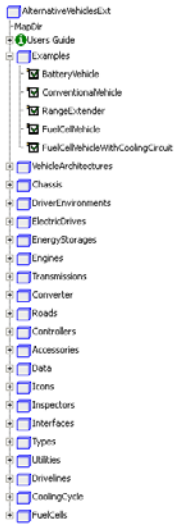
- Numerical methods
  - Digital prototypes (1D and 3D Simulation models)
- Experimental analysis
  - Real prototypes (test benches and demonstration vehicles)



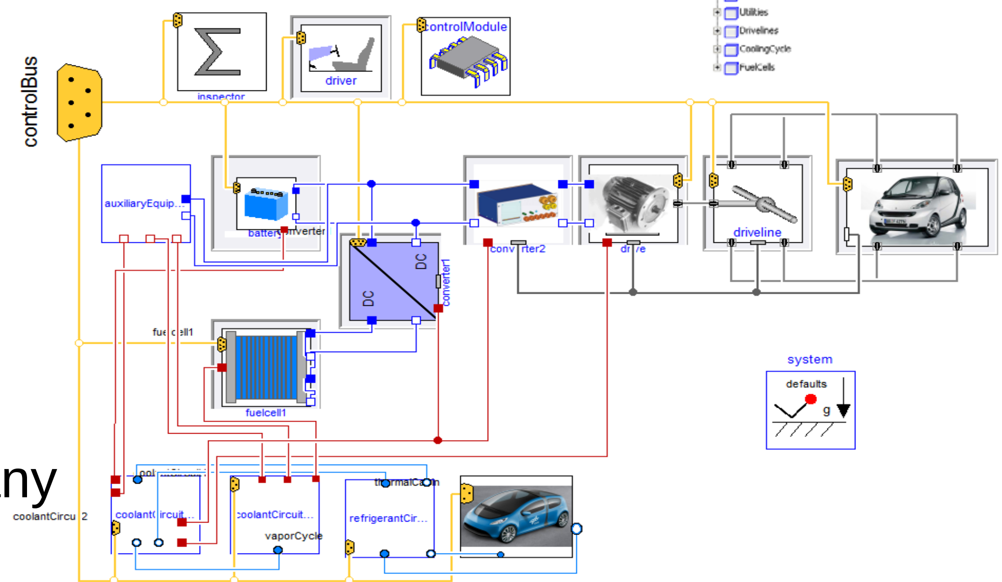
Simulation results ⟷ **Measurement data**

Methodology for the development of thermal management
Overall vehicle simulation model

- The overall vehicle simulation model uses
  - Modelica Standard Library
  - AlternativeVehicles Library



- The overall vehicle simulation model consists of
  - The powertrain
  - Coolant circuits
  - HVAC
  - Cabin
  - Control system



- The model can extended to any vehicle architecture

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Reference Vehicle
The High-temperature Fuel Cell Vehicle (HT-PEFC-REX)

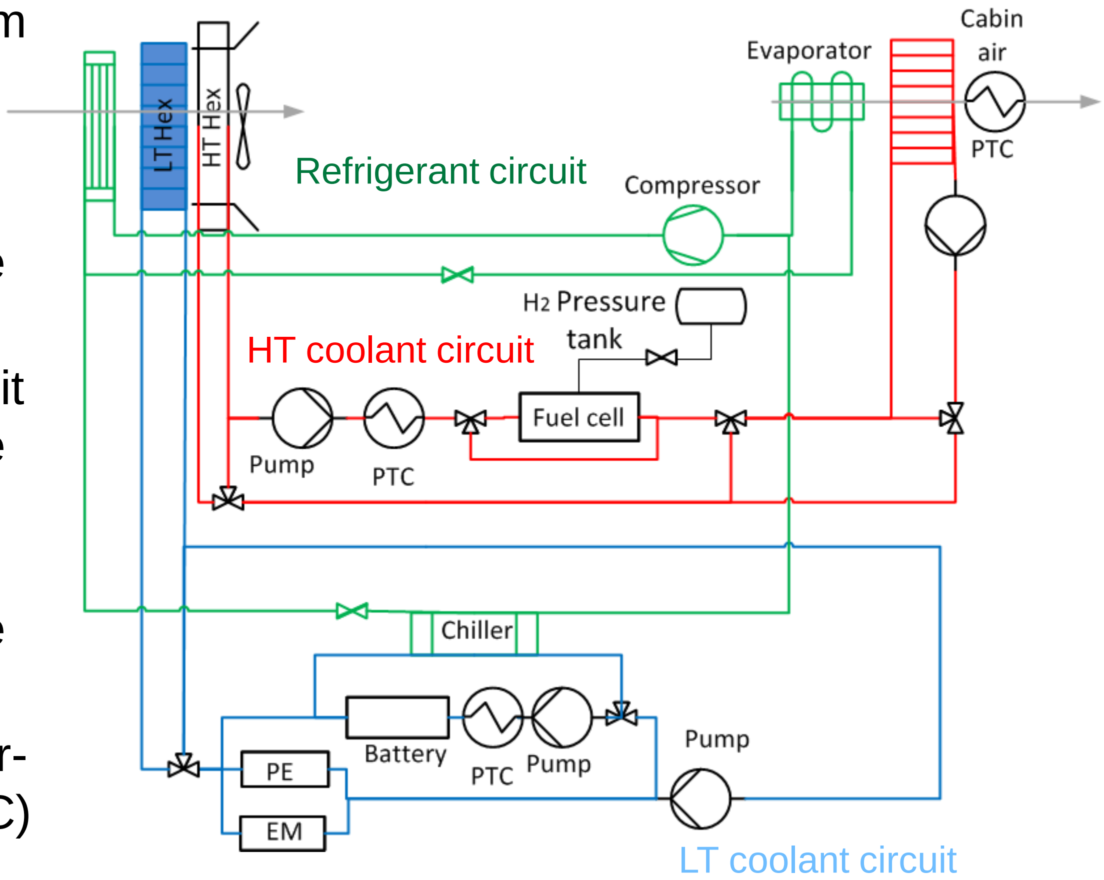
DLR's fuel cell demonstration vehicle, based on the battery electric vehicle Smart Fortwo electric drive manufactured by Daimler AG

Maximum vehicle weight	1150 kg (2535 lb)
Max. power	55 kW (73 hp)
Max. torque	130 Nm (95 ft lb)
Battery type	Lithium-ion battery
Battery capacity	17.6 kWh
Battery weight	174 kg (383 lb)

Fuel cell type	HT PEFC
Maximum electrical power	6 kW (8 hp)
Maximum current	130 A
Fuel cell total mass	68 kg (150 lb)
H_2 tank storage capacity	0.9 kg (2 lb)

Reference Vehicle
Thermal management system of the HT-PEFC-REX

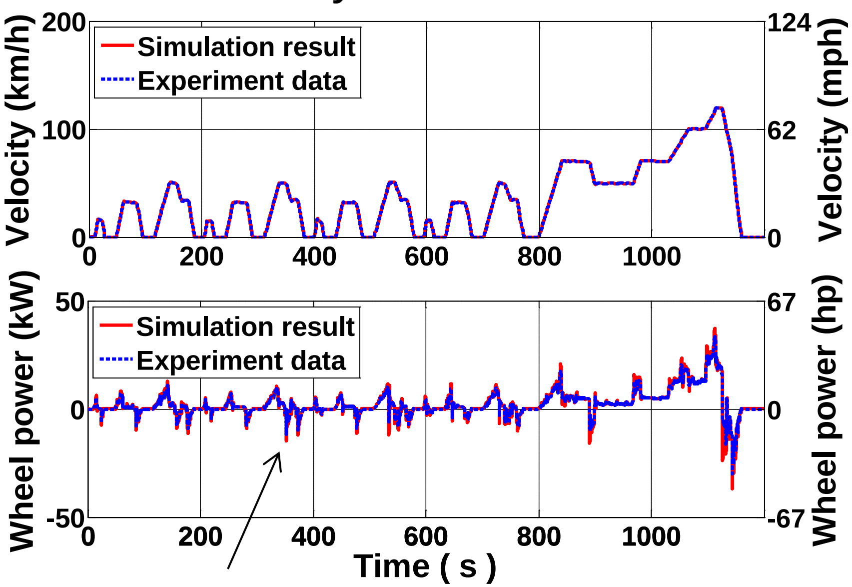
- Two systems are available
  - Cooling and heating system for the powertrain components
    - Battery coolant circuit with coolant temperature < 40 °C (104° F)
    - EM und LE coolant circuit with coolant temperature < 100 °C (212° F)
    - Fuel cell coolant circuit with coolant temperature < 180 °C (356° F)
  - Heating, Ventilation and Air-conditioning system (HVAC) for the cabin



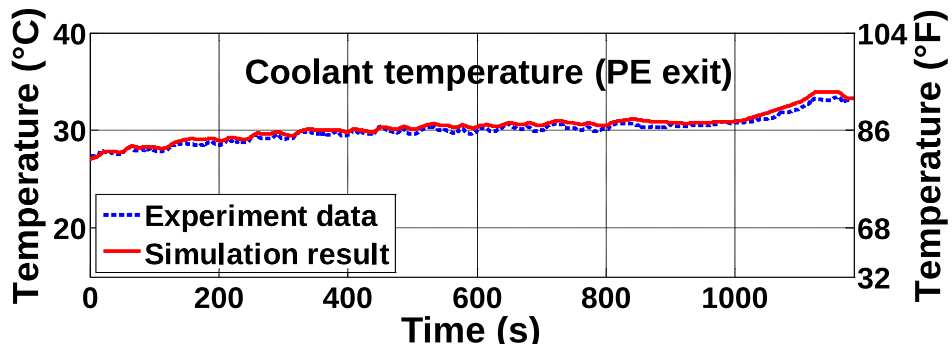
Reference vehicle
Comparison between measurements and simulations

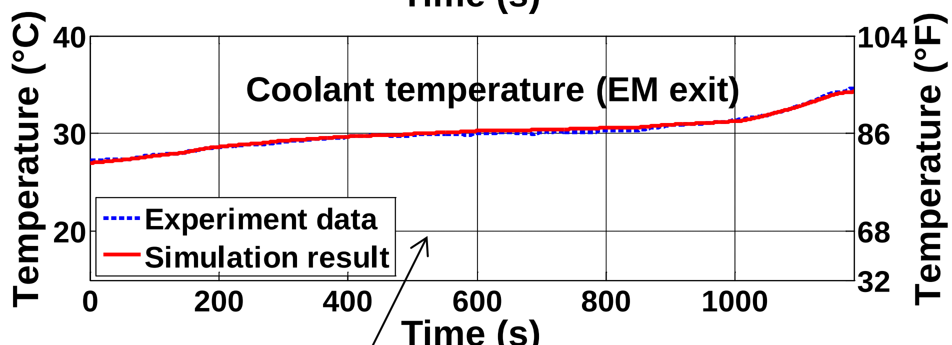
Boundary conditions used for the validation of the simulation models for the powertrain and low temperature coolant circuit

- Drive cycle : NEDC
- Ambient temperature: 25 ° C (77 ° F)
- Humidity: 50 %



The average absolute deviation values 30 W (0.040 hp)





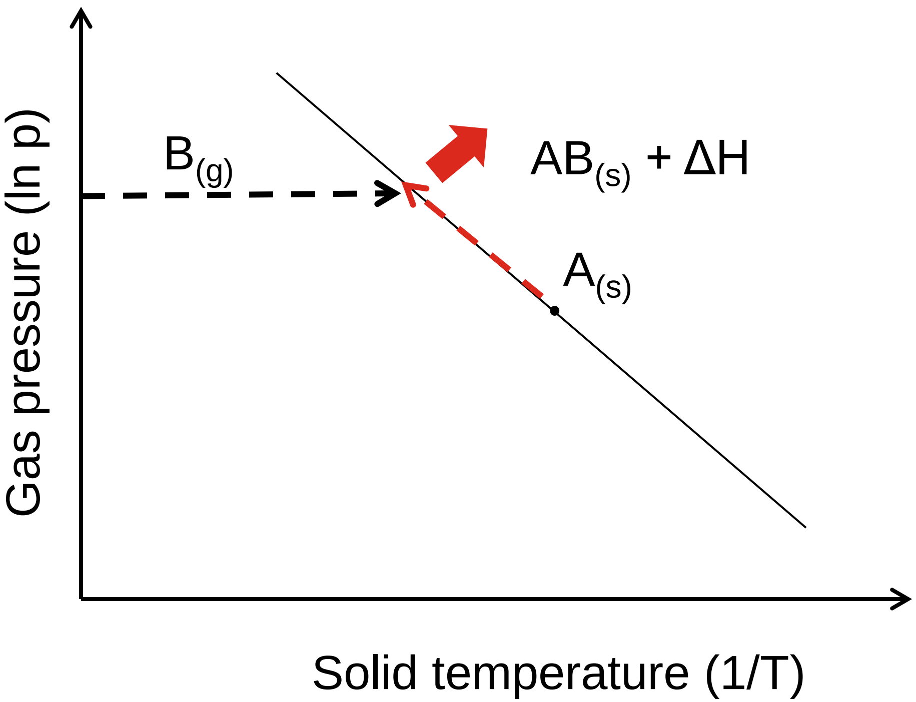
The average absolute deviation values
1,0 K at -10 ° C (14 ° F) Ambient Temp,
0,6 K at 25 ° C (77 ° F) and
2,0 K at 35 ° C (95 ° F)

Contents

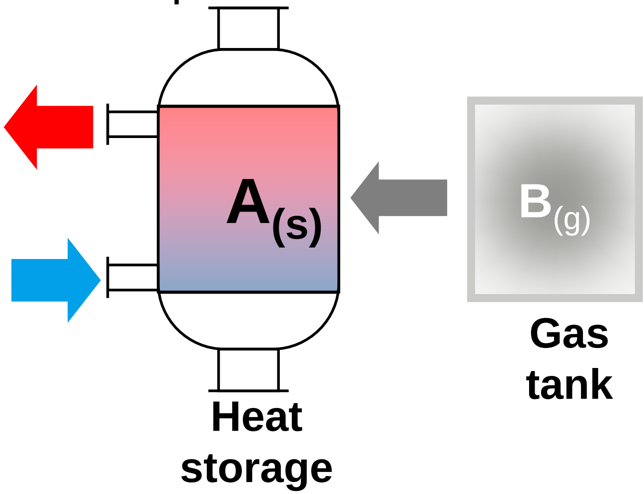
Thermochemical heat storage
The principle of the reversible gas/solid-reactions

exothermic

$$A_{(s)} + B_{(g)} \rightarrow AB_{(s)} + \Delta H$$



Discharging of the heat storage tank replaces a heater



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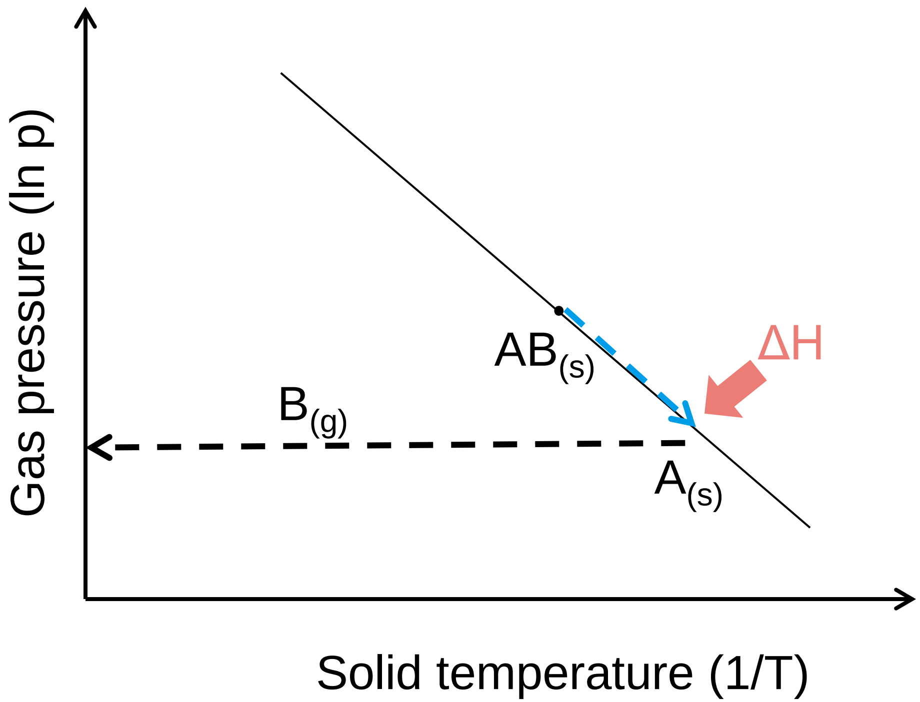
Source: eberspaecher.com

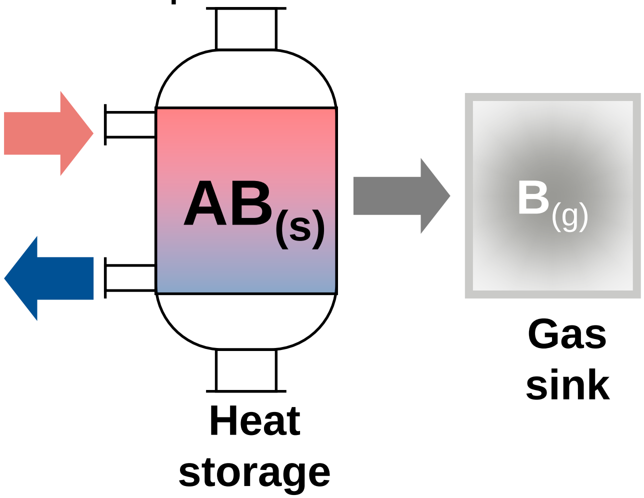
Thermochemical heat storage
The principle of the reversible gas/solid-reactions

endothermic

$$A_{(s)} + B_{(g)} \leftarrow AB_{(s)} + \Delta H$$



Charging of the heat storage tank replaces a cooler



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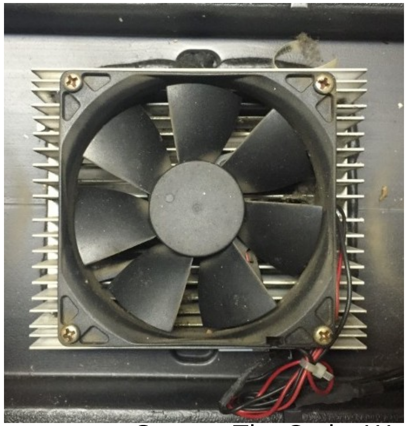

Source: The Cedar Workshop

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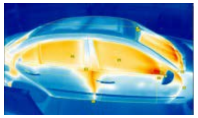
Integration concepts of the thermochemical heat storages (TCS)

The suggested concepts:

- Substitution of the HT-PEFC fuel cell pre-conditioning system (**Concept No. 1**)
- Substitution of the HT-PEFC fuel cell and battery pre-conditioning systems (**Concept No. 2**)
- Support of the continuous air-conditioning system (**Concept No. 3**)

Concept Nr.	Main function	Component	Temperature range
1	Preheating and cooling		150 °C – 180 °C (302 °F – 356 °F)
2	Preheating and cooling	 	150 °C – 180 °C (302 °F – 356 °F) 5 °C – 40 °C (41 °F – 104 °F)
3	Continuous air-conditioning		22 °C – 28 °C (71 °F – 82 °F)

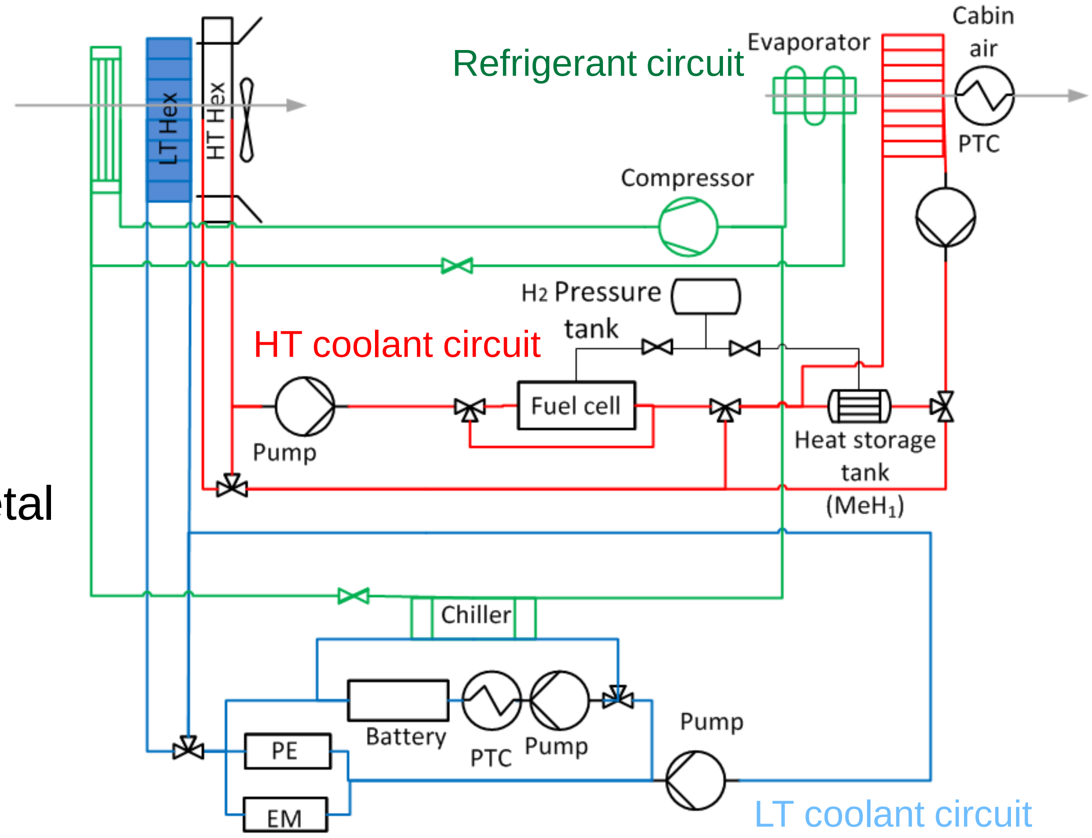
Integration concepts of the thermochemical heat storages (TCS) Substitution of the fuel cell pre-conditioning system

- Concept No. 1:

  Integration into the HT coolant circuit

- Function
  - Fuel cell preheating
  - Fuel cell cooling
  - Cabin preheating

- Thermochemical system
  - Typ: a high temperature metal hydride ($LaNi_{4.75}Al_{0.25}$)
  - Loading pressure: 35 bar (507 psi)
  - Unloading pressure: 5 bar (72 psi)



Integration concepts of the thermochemical heat storages (TCS) Substitution of the fuel cell and battery pre-conditioning systems

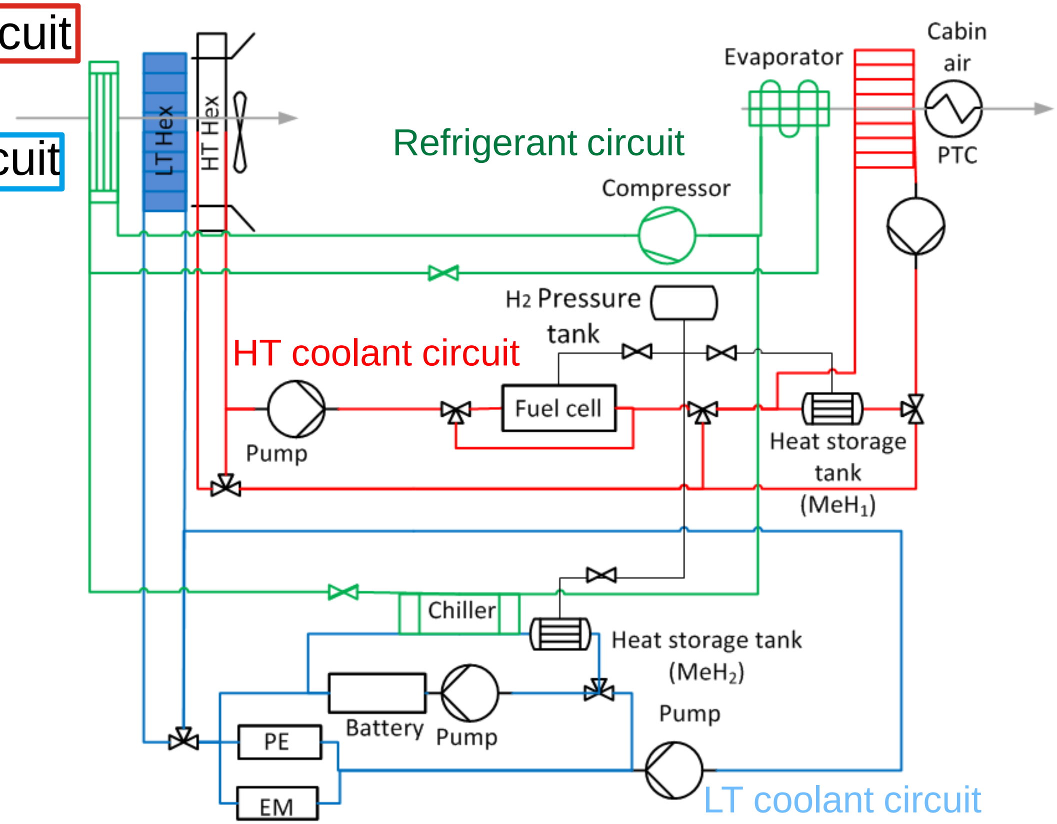
- Concept No. 2:

  Integration into the HT coolant circuit

  and

  Integration into the LT coolant circuit

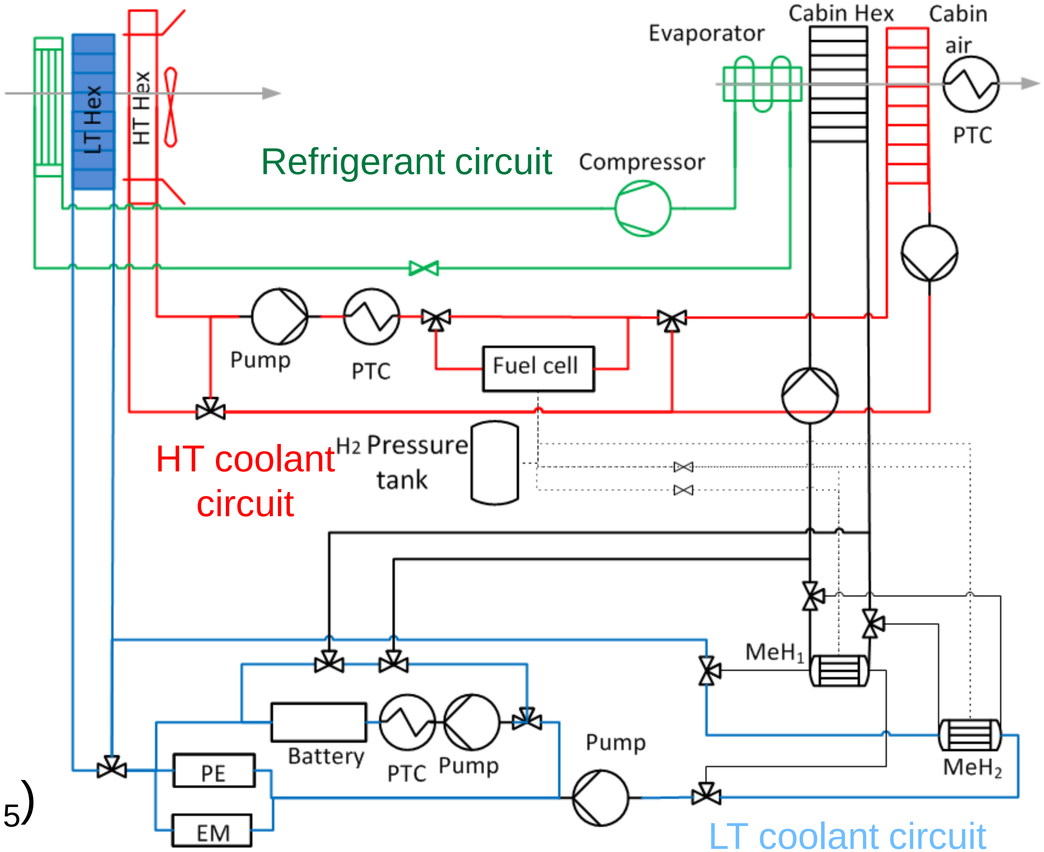
- Function
  - Fuel cell preheating/cooling
  - Cabin preheating
  - Battery preheating/precooling



- 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 (507 psi) for MeH_1 and 5 bar (72 psi) for MeH_2
  - Unloading pressure: 5 bar (72 psi) for the HT- TCS and 1.5 bar (21 psi) for the NT-TCS

Integration concepts of the thermochemical heat storages (TCS)
Support of the air-conditioning system

- Concept No. 3:
  Integration into the cabin and LT coolant circuit
- Function
  - Continous cabin heating
  - Continous cabin cooling
  - battery heating and cooling
  - LE and EM cooling
- Thermochemical system
  - Typ: 2 low temperature metal hydrides ($T_{0.99}Zr_{0.01}V_{0.43}Fe_{0.09}Cr_{0.05}Mn_{1.5}$)

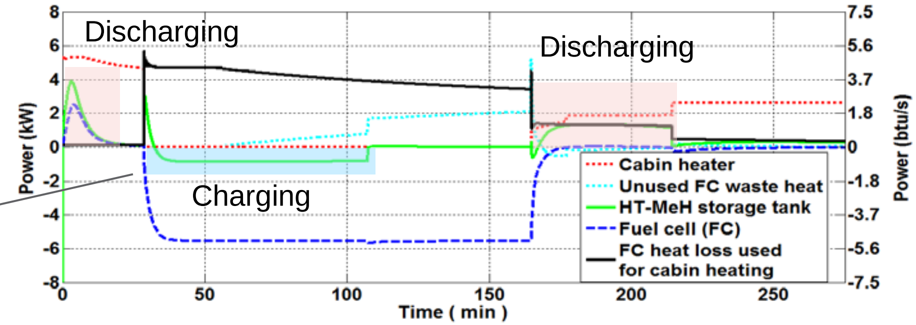


  - Loading pressure: 50-80 bar (725-1160 psi)
  - Unloading pressure: 1.5-5 bar (21-72 psi)

Overall vehicle simulation
Discharging and Charging of the heat storage systems in NEDC

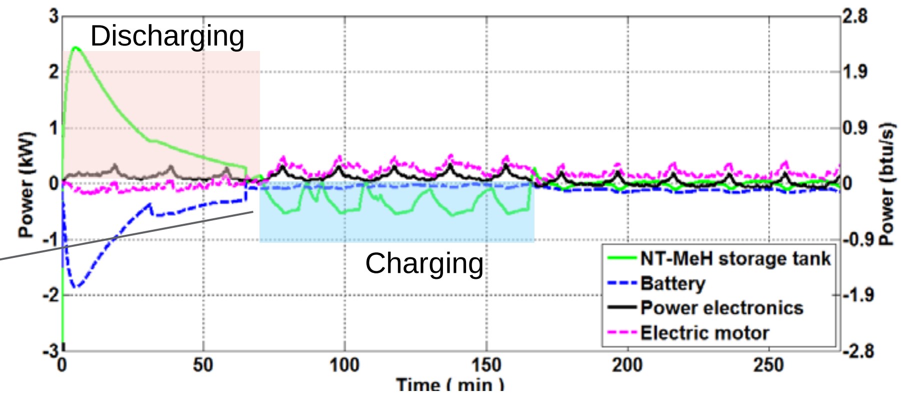
- Concept 1 ($T_{ambient}$ = - 20 ° C / - 4 ° F)

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



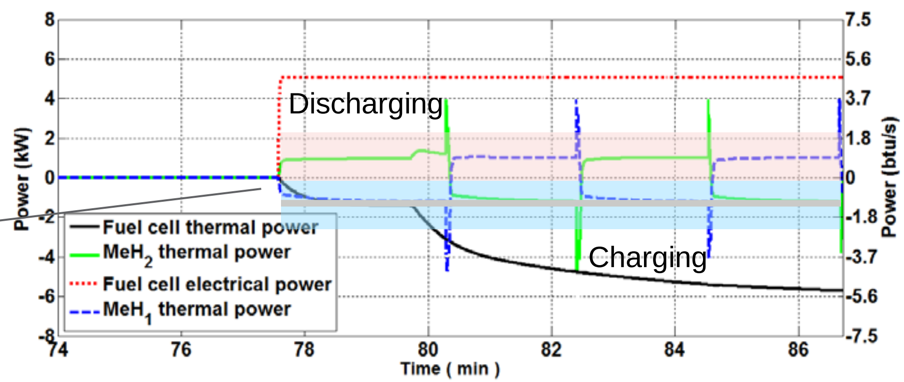
- Concept 2 ($T_{ambient}$ = - 20 ° C / - 4 ° F)

  40 % of the HT-PEFC-REX waste heat and 50 % of the EM and LE waste heat can be stored for the preheating



- Concept 3 ($T_{ambient}$ = 40 ° C / 104 ° F)

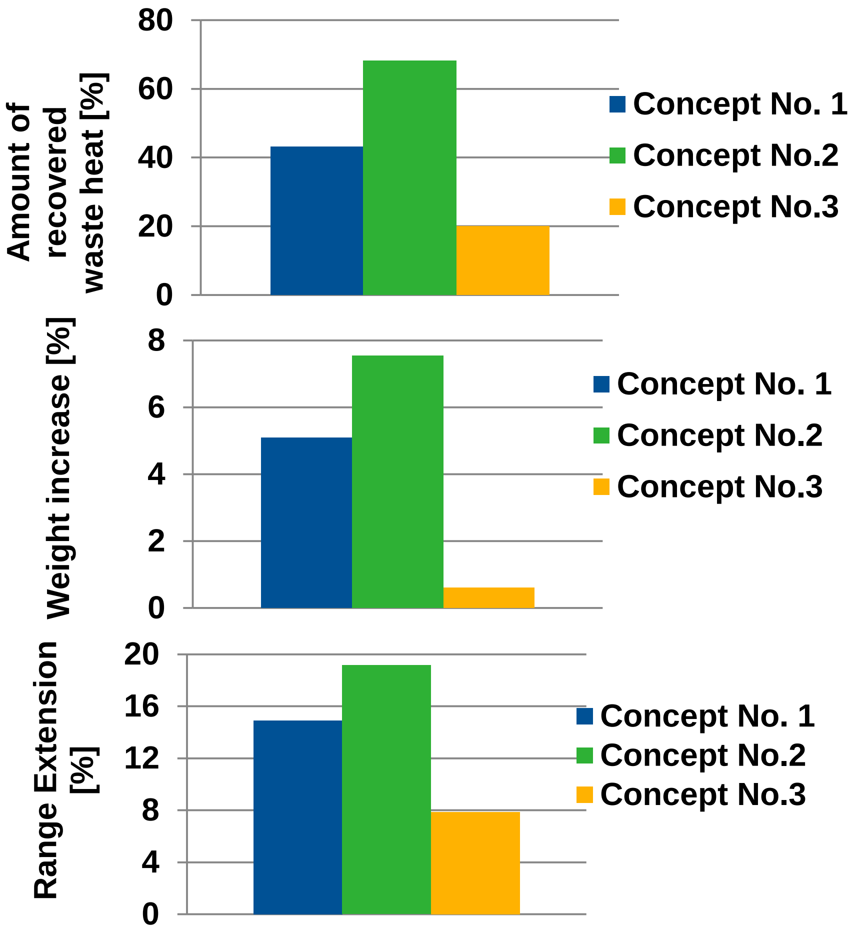
  MeH cooling energy corresponds to 20 % of the HT-PEFC-REX waste heat



Overall vehicle simulation
Assessment and comparison of the integration concepts

- 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 20 % 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



Summary

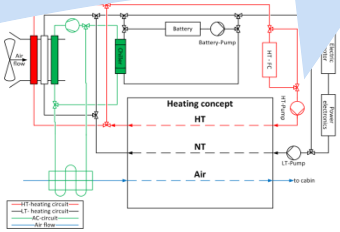
Reference vehicle
and
operating conditions

✓ The thermal management system is measured and modelled

Thermochemical
heat storages

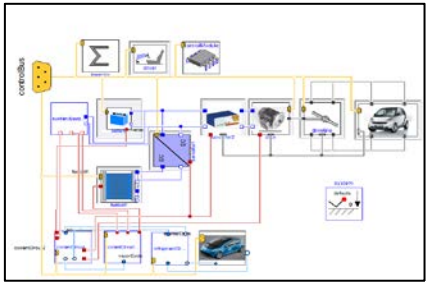
✓ The reaction system is selected and a simulation model is created

Integration
concepts



✓ 3 Integration concepts are developed

Complete
vehicle
Integration



✓ A range increase by up to 17 % is possible

Thanks for your attention!

Questions?

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