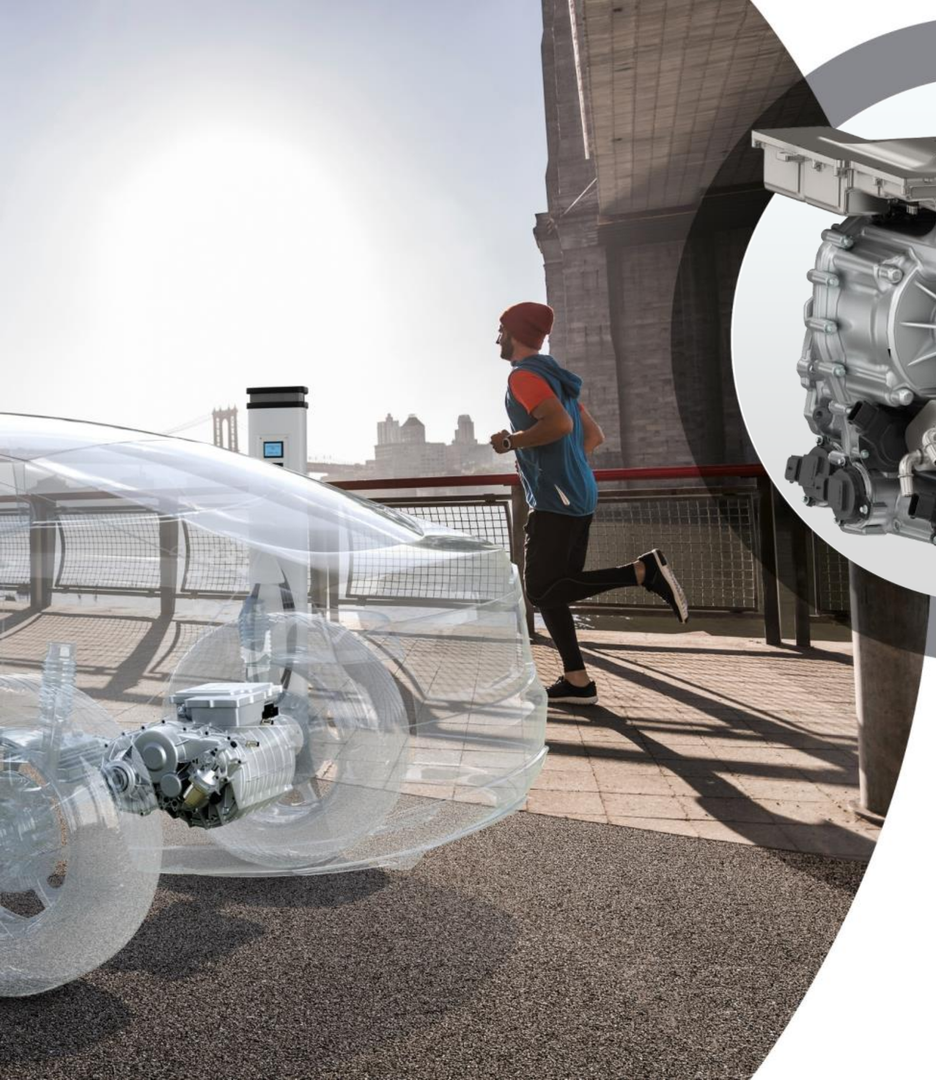
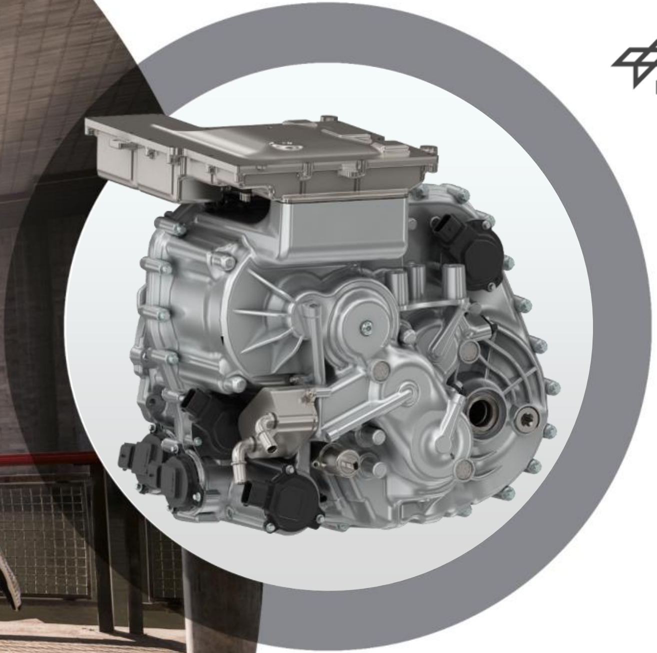




Benefit studies of an innovative metal hydride air-conditioning system for FCEVs by using thermal management simulation

Markus Kordel, DLR

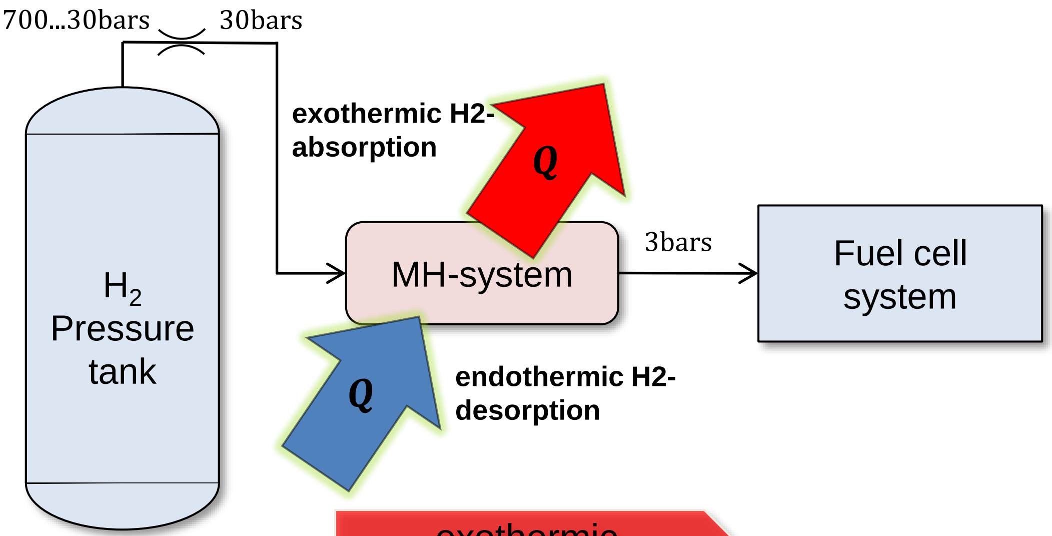
Joshua Pöhl, Magna

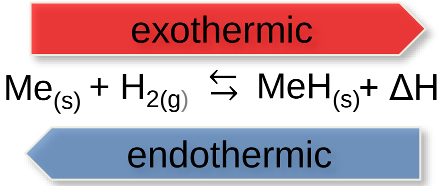
Agenda

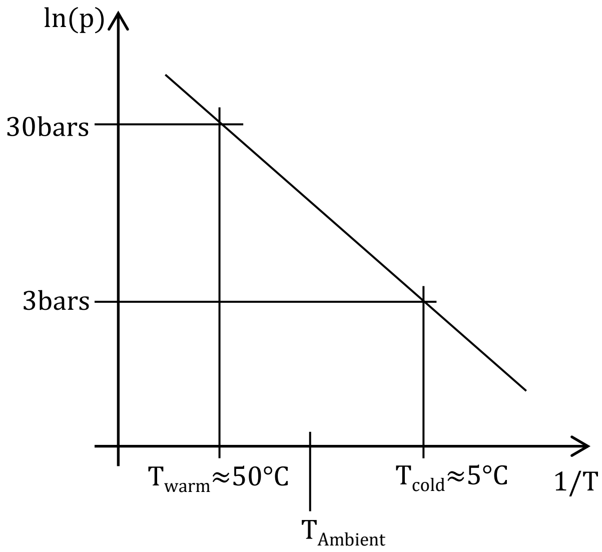
- Metal-Hydrid-Reactor (MeH-Reactor)
- Simulation of MeH-Reactor
- Simulation Model Overview
- Virtual Vehicle Integration
- Results
- Summary and Outlook

MeH-Reactor

Functional Principle



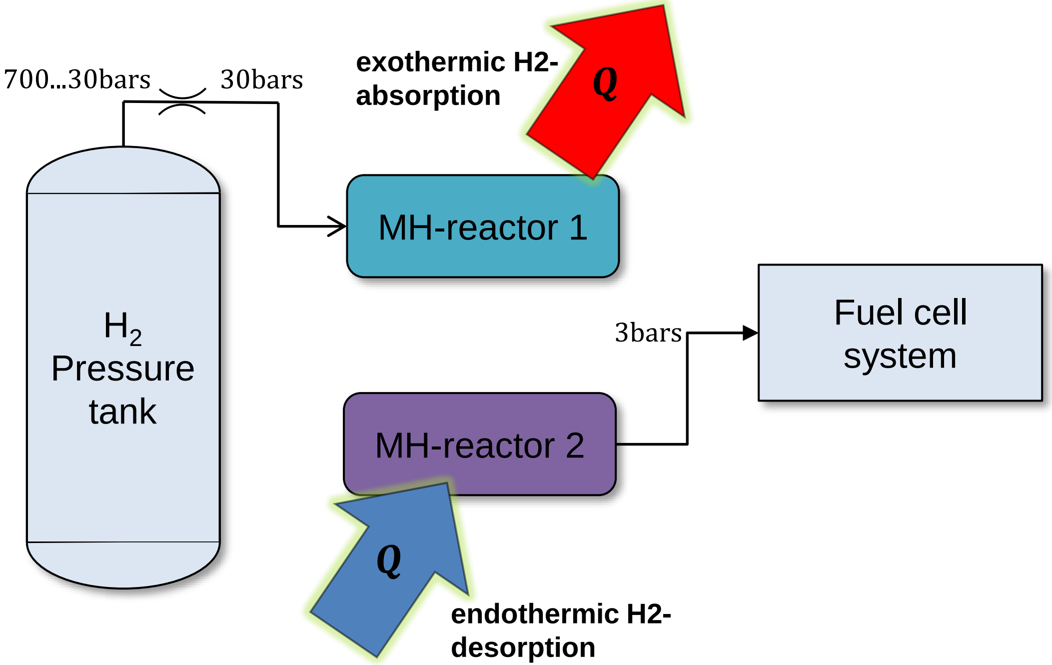


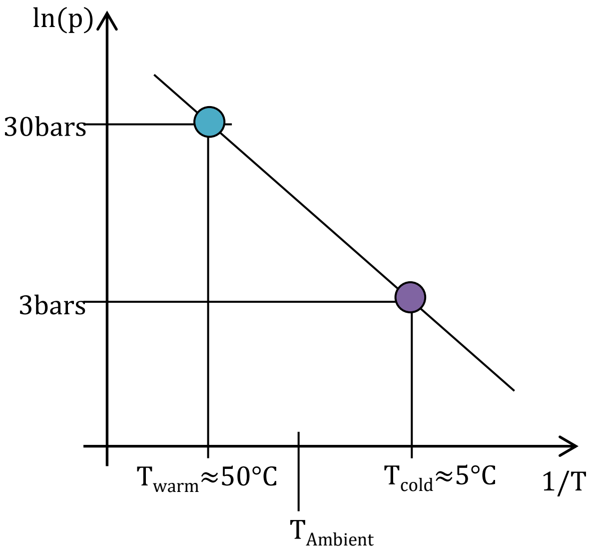


$$\ln\left(\frac{p_{eq}}{p_0}\right) = \frac{\Delta H_{abs/des}}{R \cdot T_{eq}} + \frac{\Delta S_{abs/des}}{R}$$

$$\dot{Q}_{abs/des} = \frac{\dot{m}_{H_2}}{M_{H_2}} \cdot \Delta H_{abs/des}$$

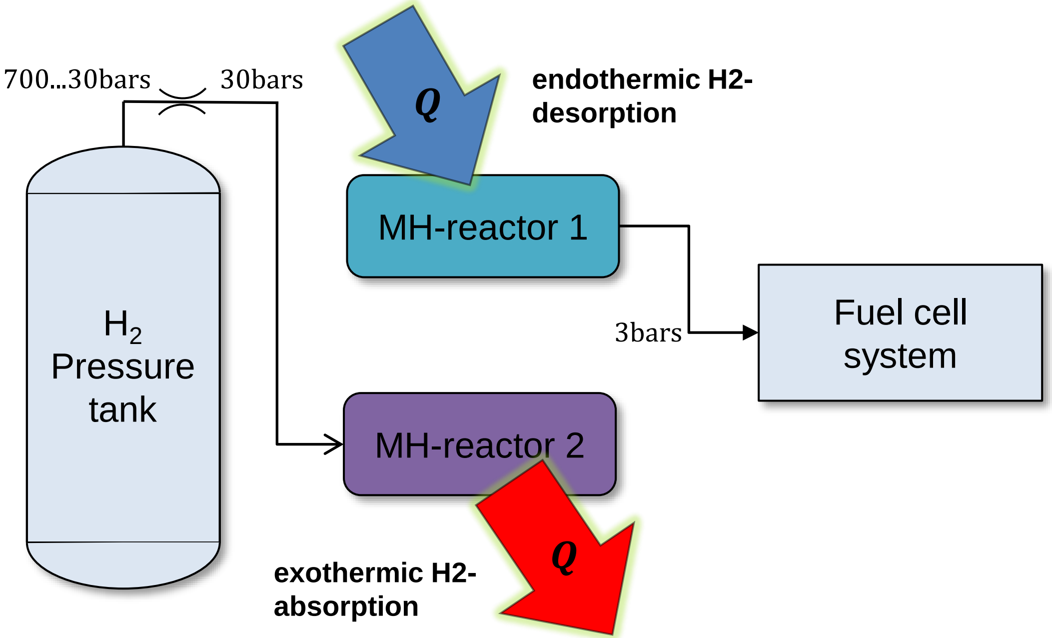
Quasi-continous Batch Operation

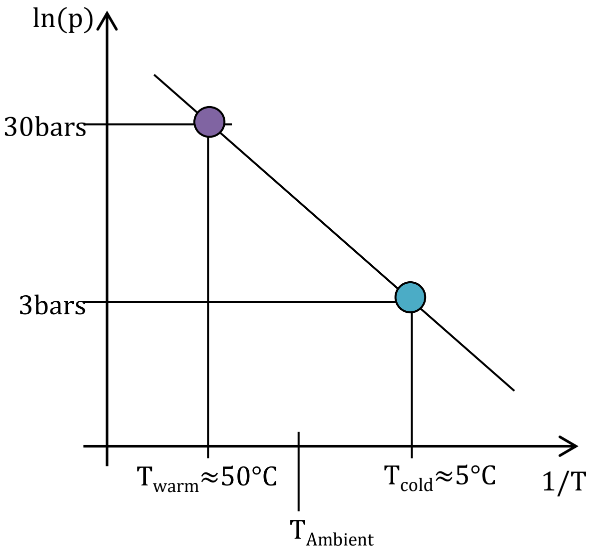




Q

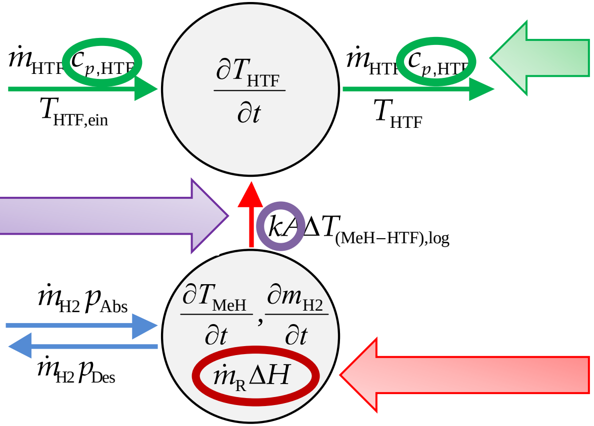
Quasi-continous Batch Operation





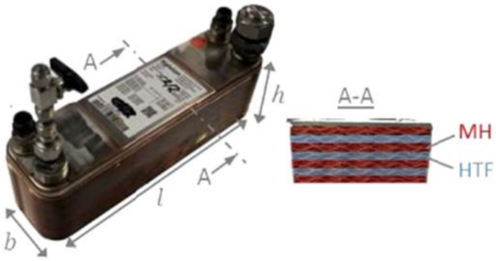
Reactor Model

Heat transfer modeling in 0D-Model



HTF-Material Characteristics

Reactor Characteristics

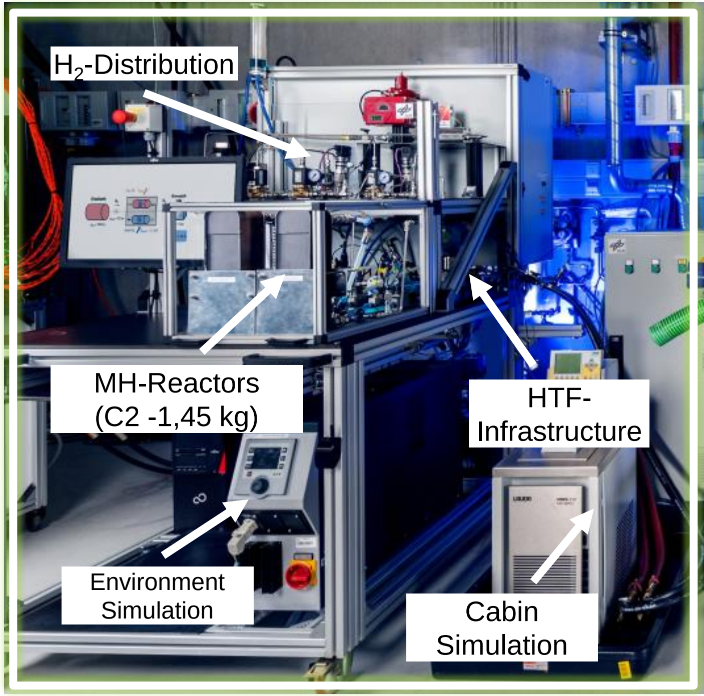


MH-Material Characteristics:

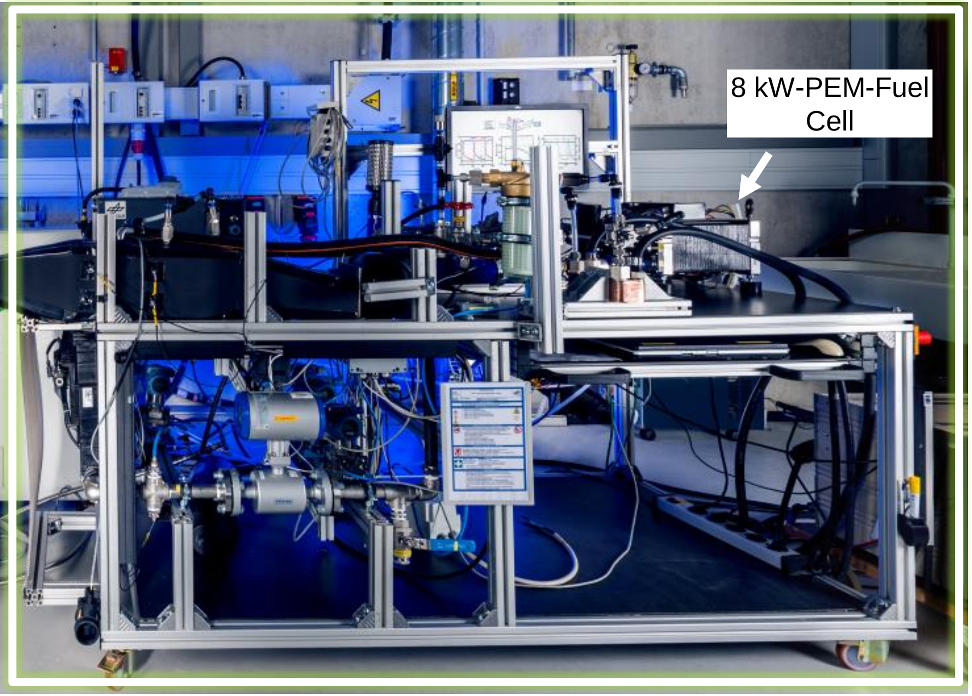
- Intrinsic kinetics
- chemical equilibrium characteristics

Experimental Setup

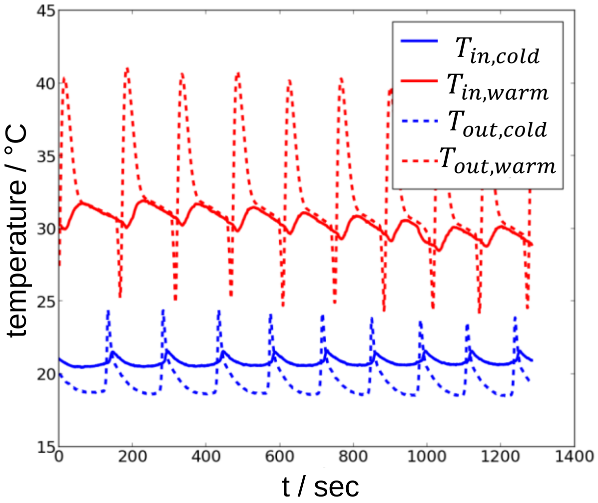
Metalhydride-Testbench



Fuel Cell Testbench



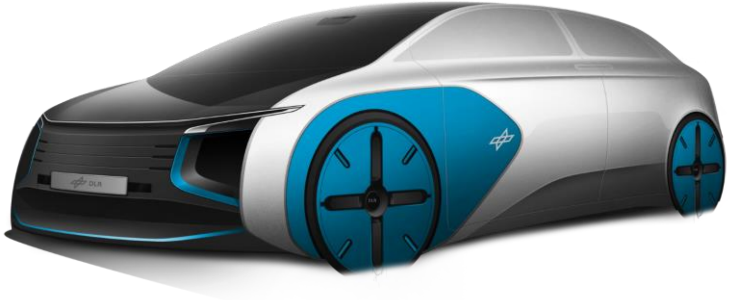
Experimental Setup



Temperature course of hot and cold flows with quasi continous behaviour

What are the effects of Metalhydrid-Climatisation on „Real Life Operation“?

+



Base Vehicle

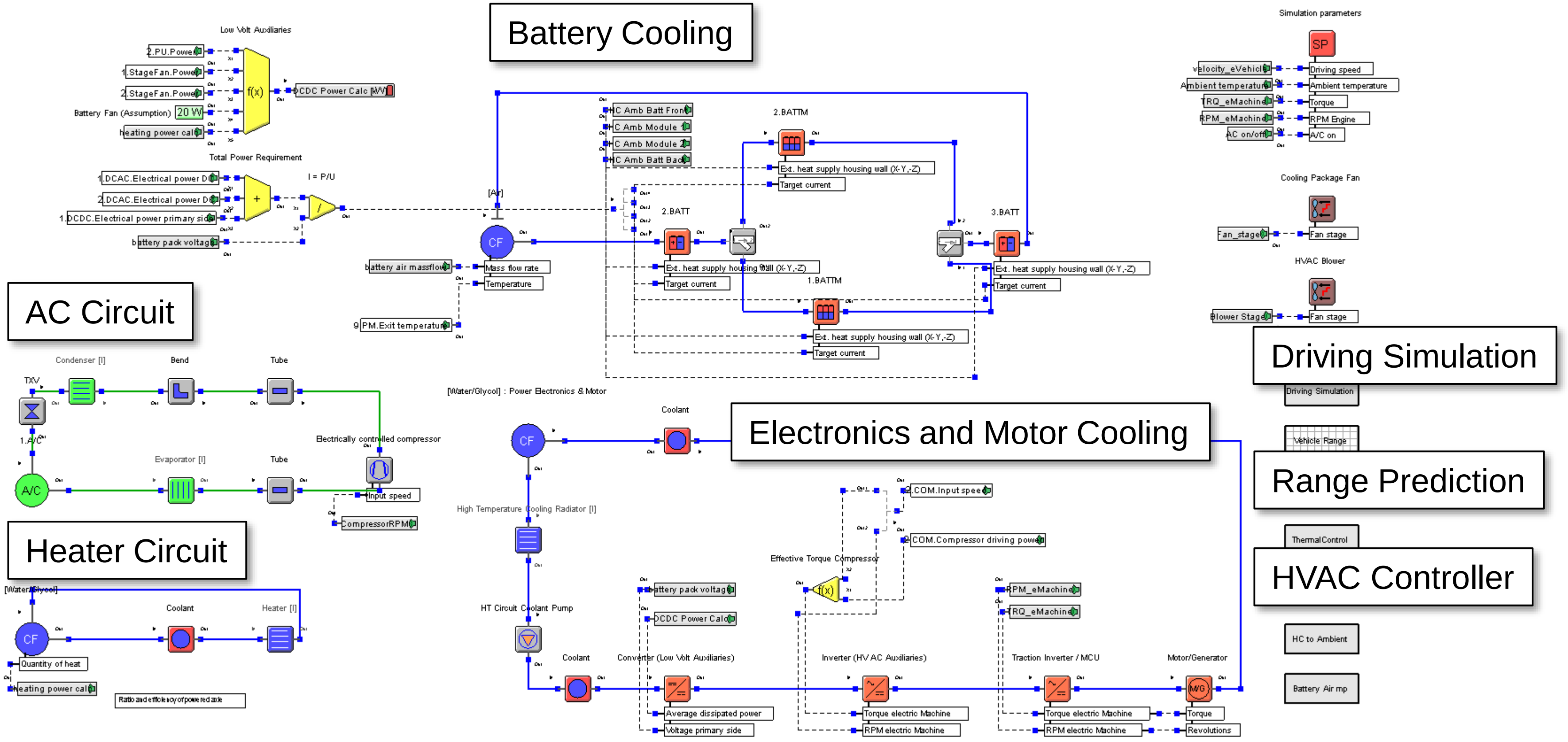
The Mitsubishi i-MiEV – Vehicle Overview

- Compact sized passenger car (Japanese K-car)
- 16kWh battery pack
- 49kW electric motor
- NEDC range 160km (OEM spec)

“Real life operational range” influenced by:

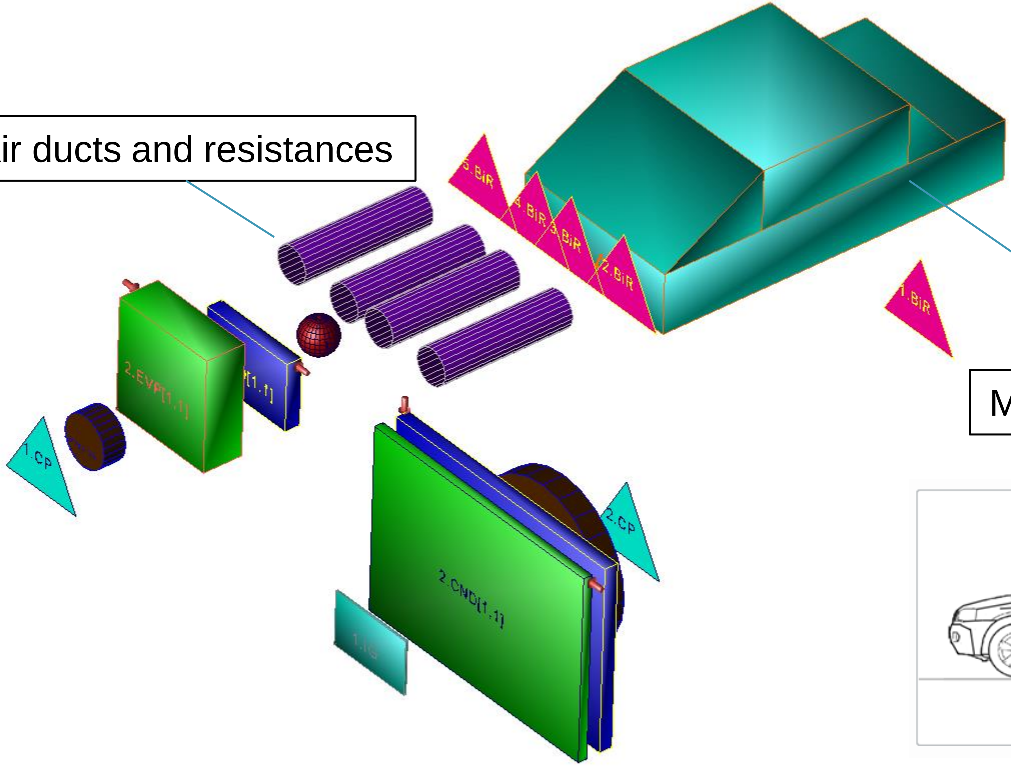
- Customer driving profiles
- Heating in winter
- Air conditioning in summer

Model Overview



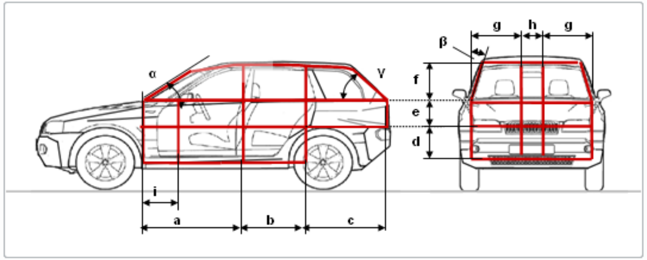
Multi-Zone Cabin Model

Air ducts and resistances



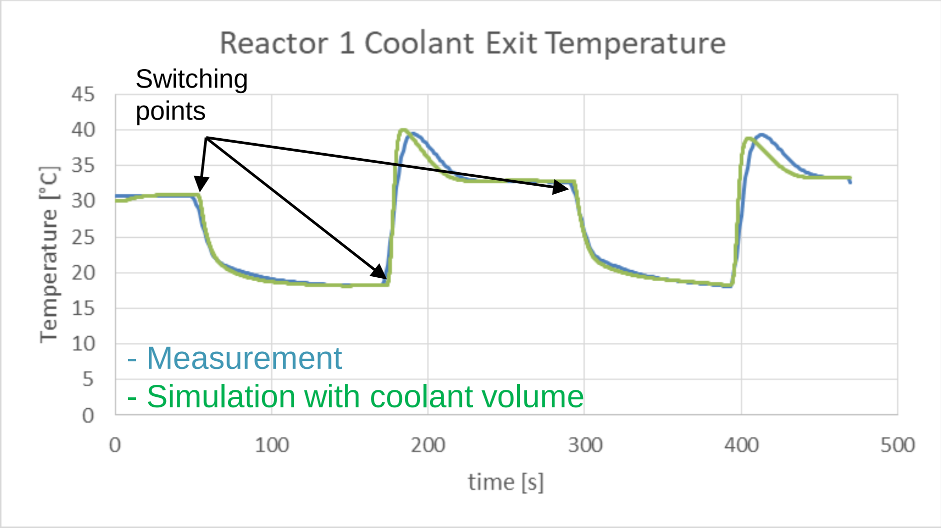
Detailed HVAC air path and passenger cabin to evaluate the passenger comfort.

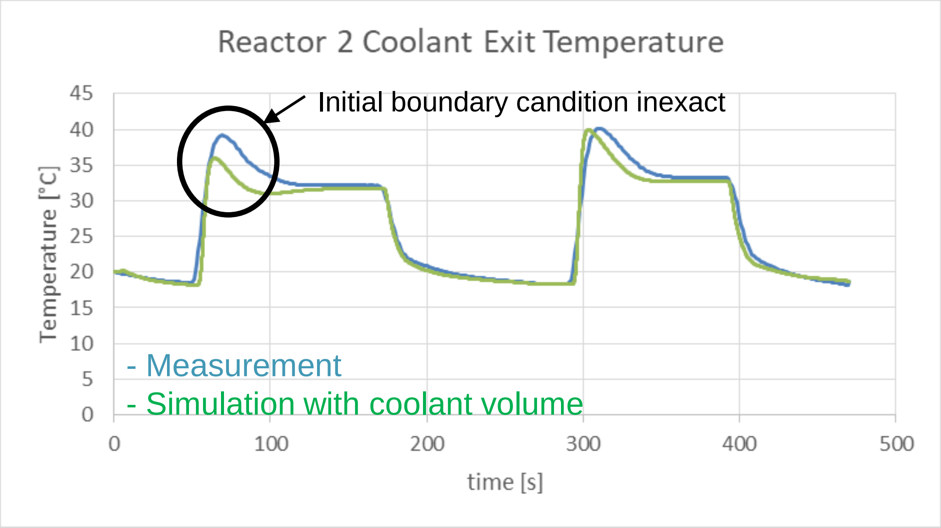
Multi zone cabin model



Calibration MeH Reactor

Model Calibration
Results Coolant Temperature

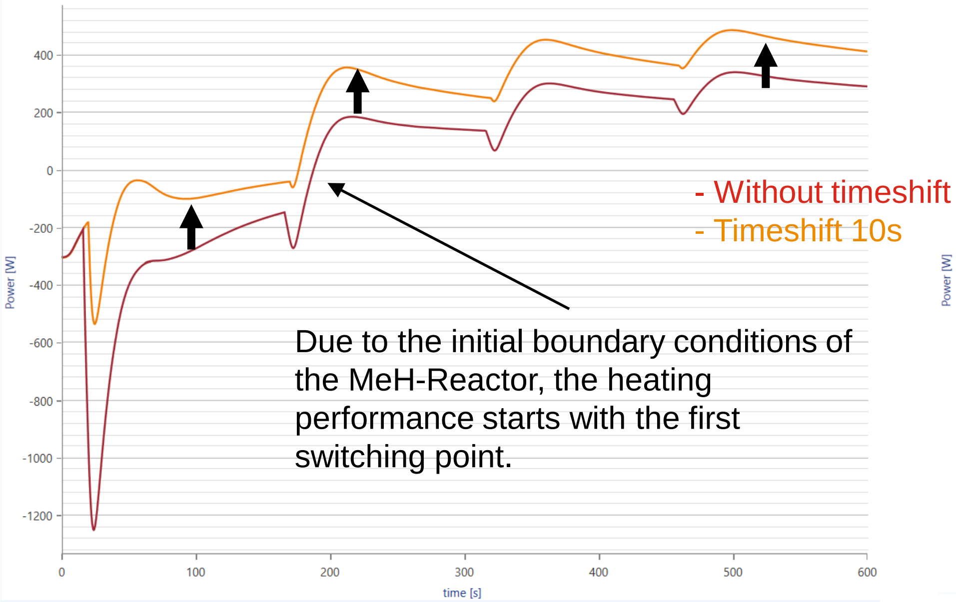




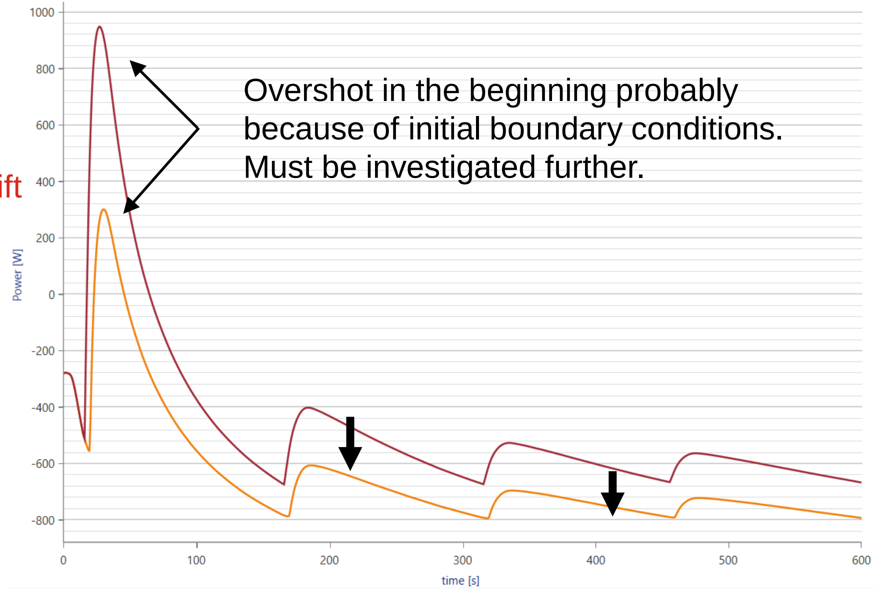
→ After engaging of the second reactor very good fit of coolant temperatures.

Valve Time Shifting
Results Heating and Cooling Power

Average Heating Capacity



Average Cooling Capacity



Valve control (valve time-shift) is very important to increase the average heating and cooling capacity

Virtual Vehicle Integration

Mitsubishi i-MiEV → i-MiFC

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Base Vehicle

- Compact sized passenger car (Japanese K-car)
- 16kWh battery pack (~160kg)
- 49kW electric motor
- NEDC range 160km (OEM spec)

Changes

Fuel Cell Vehicle

- 3.2 kWh battery pack (~32kg)
- 49kW electric motor
- 7 kW Fuel Cell (~7kg)
- No packaging investigation

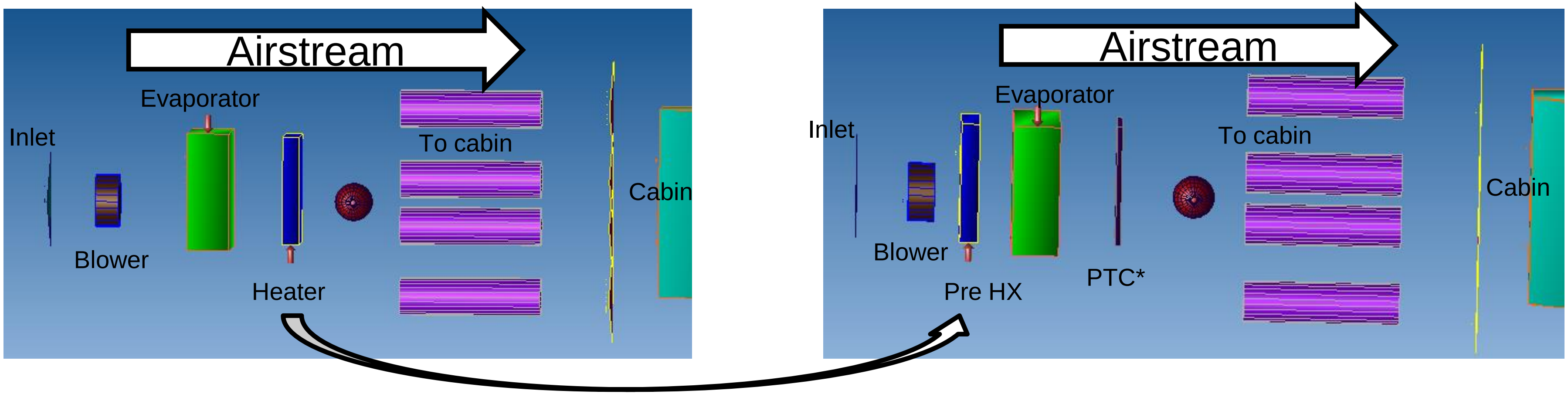
Operating Strategy

The FC is running at constant power.

Integration of MeH-Reactor HVAC-Box

Original

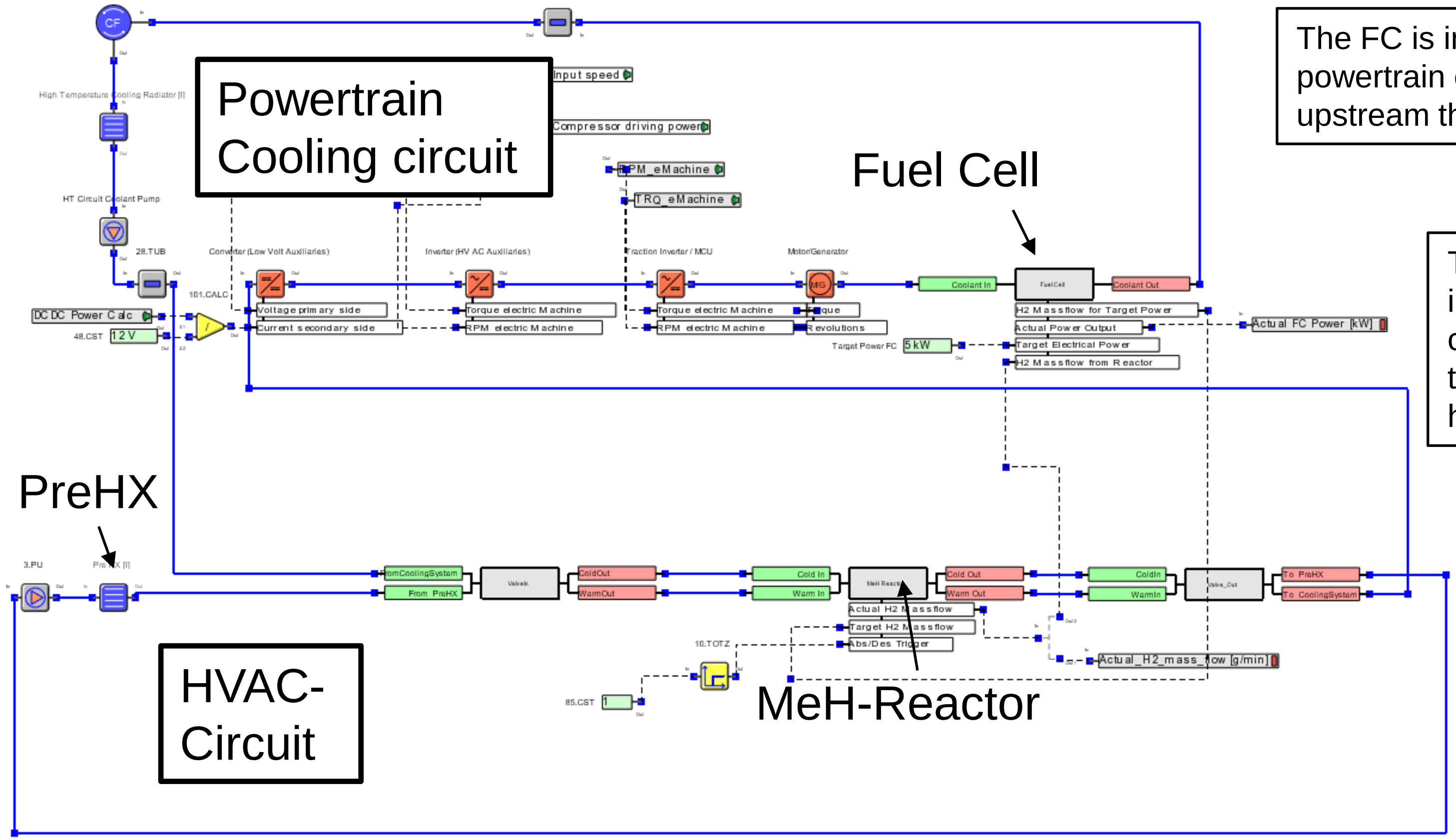
Modified



The existing heater core from the electric water heater will be used as pre HX and is placed in front of the evaporator.
An air side PTC* replaces the electric water heater.

*Air PTC is necessary for re-heat configuration.

Thermal Layout
Integration MeH-Reactor and Fuel Cell

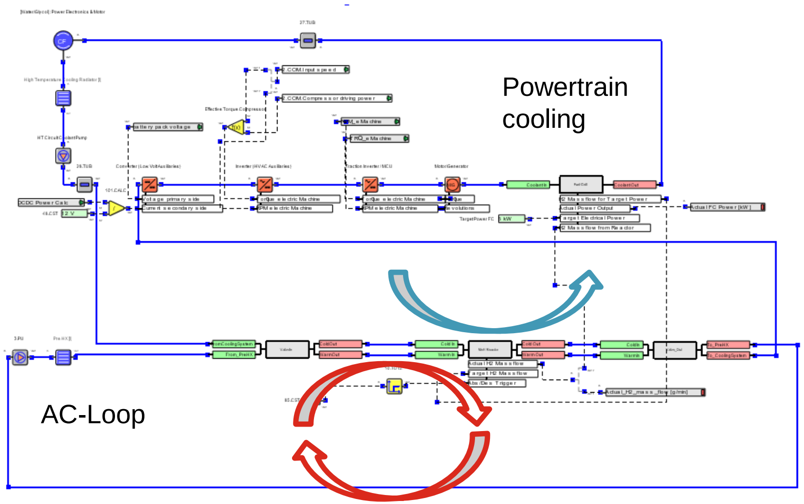


The FC is integrated in the powertrain cooling circuit upstream the E-Motor.

The MeH-Reactor is integrated in the Powertrain cooling circuit as well as in the HVAC circuit (old heating circuit).

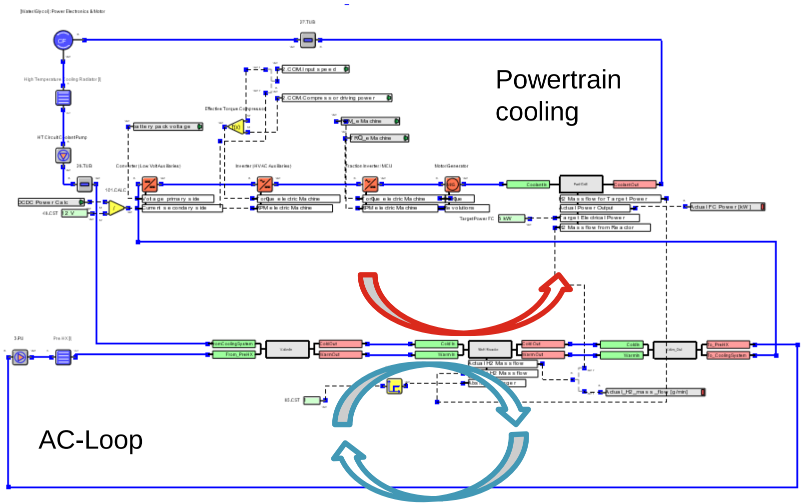
Heating vs. Cooling Mode

Cabin Heating



Warm reactor (absorption) is used for HVAC-Circuit to heat up the cabin air.
Cold reactor (desorption) is connected to the powertrain cooling circuit.

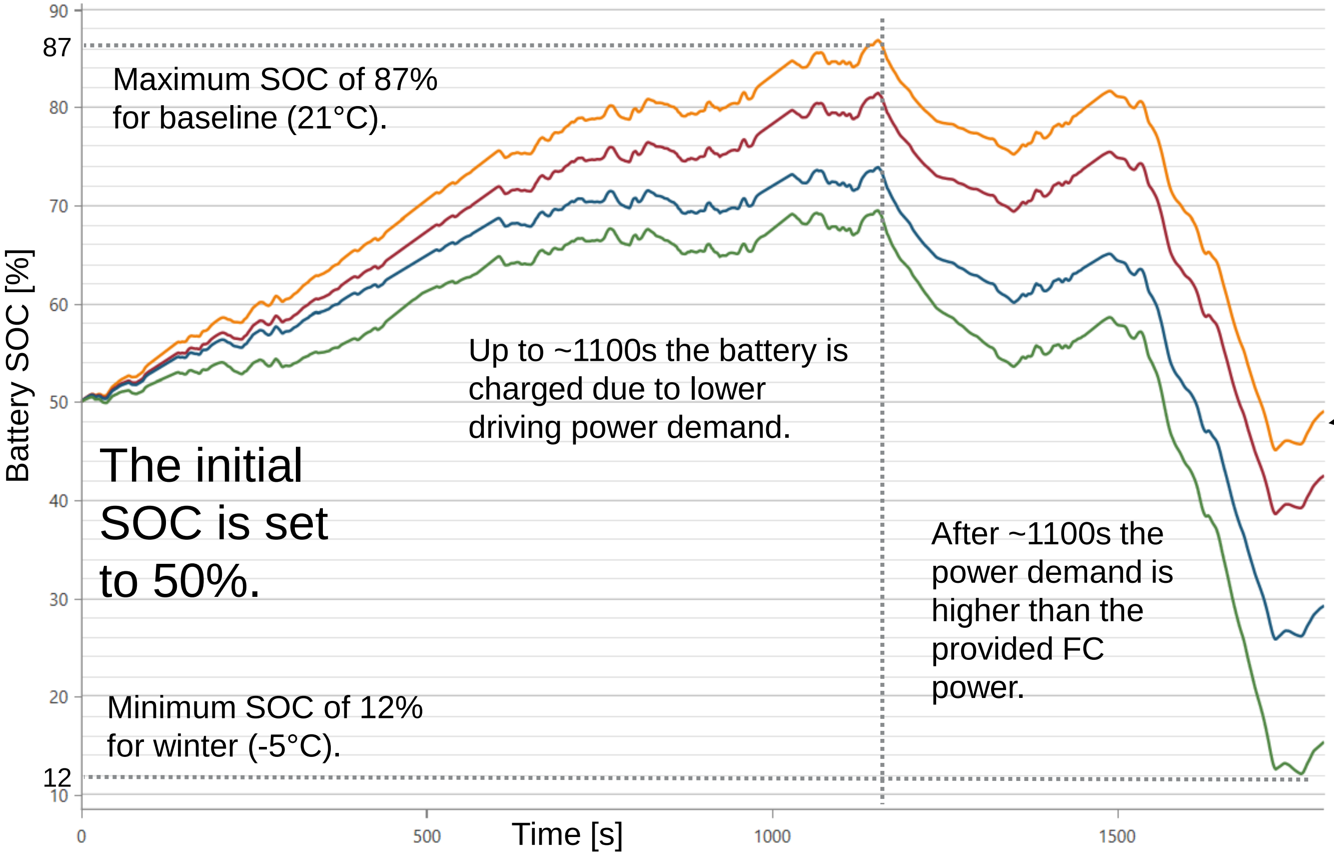
Cabin Cooling



Cold reactor (desorption) is used for HVAC-Circuit to cool down the cabin air.
Warm reactor (absorption) is connected to the powertrain cooling circuit.

Simulation Results

Simulation Results WLTC
Battery SOC (3.2 kWh)

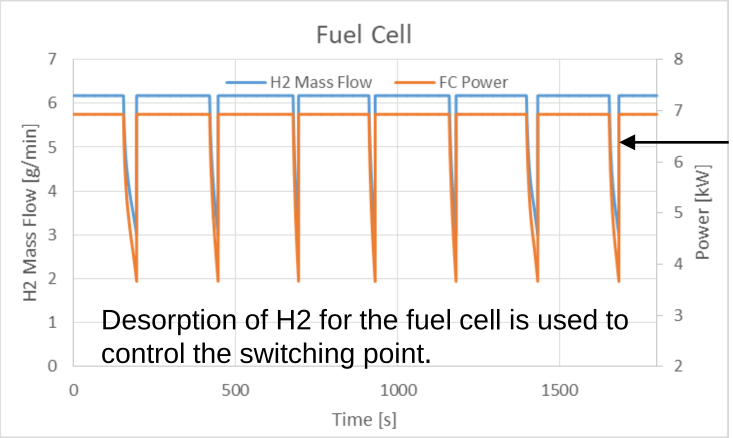


Ambient Conditions:
Baseline 21°C
Summer 30°C
Summer 40°C
Winter -5°C

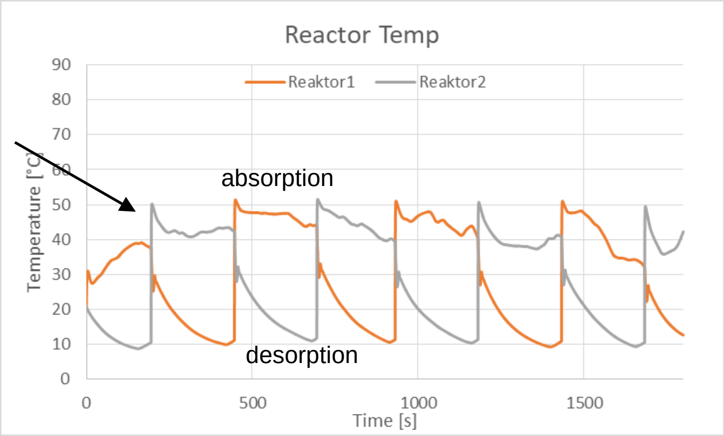
For baseline the SOC is almost initial SOC

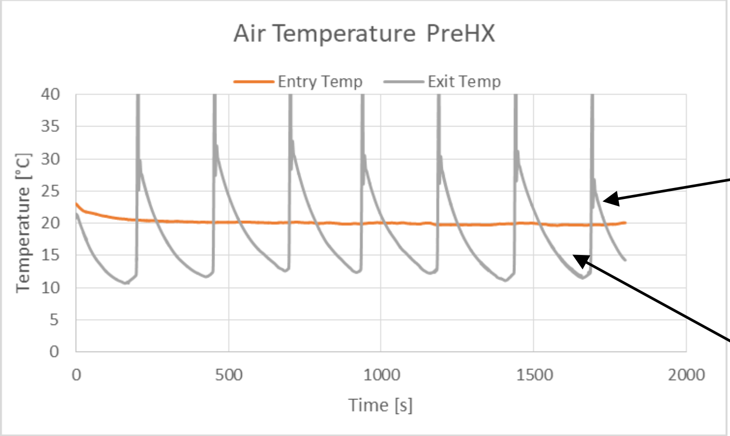
The range of SOC of the 3.2 kWh battery pack is necessary for all ambient conditions.

Simulation Results
MeH-Reactor Baseline 21°C



Switching point between absorption and desorption.



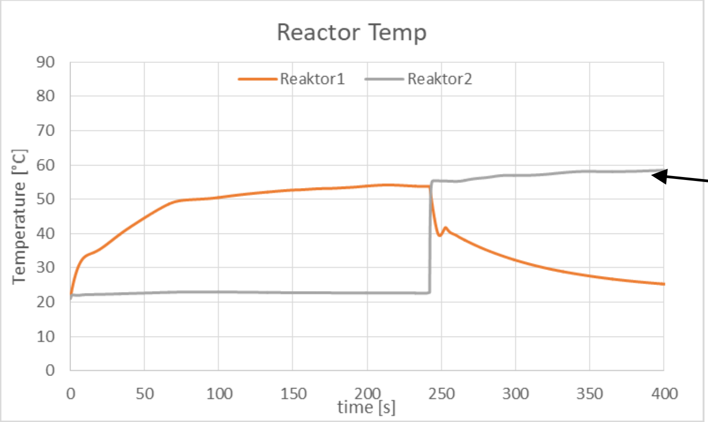


Small time with negative cooling performance after switching points.

Supported cooling performance of MeH reactor.

The FC application with MeH-reactor works on vehicle level and supports cooling @21°C. Optimization of controls necessary to reduce the overshoot.

Modification of MeH-Reactor
Changes compared to Test-bench

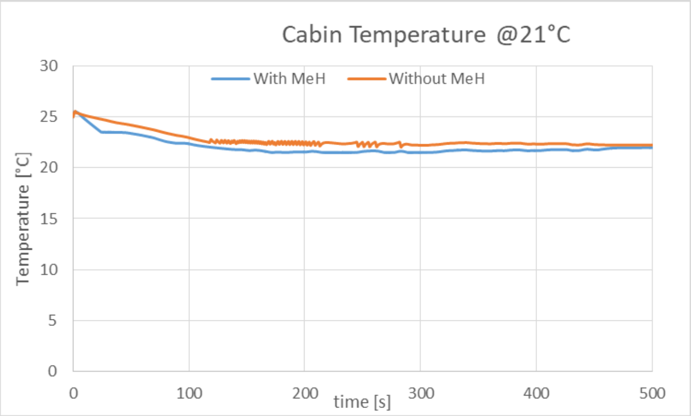


For higher ambient temperatures (40°C) the reactor temperature reaches saturation temperature of metalhydrid, because of the higher coolant temperatures. The absorption process would change over.

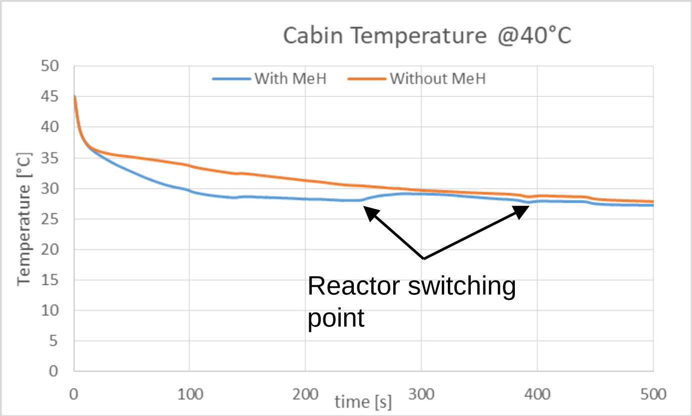
- The pressure of the MeH reactor is increased from 35 bar to 45 bar to increase the saturation temperature.
- Due to the higher pressure the de- and absorption process is faster. This leads to faster switching points.
- The mass of the MeH-reactor is increased from 1.49 kg to 2.5 kg.

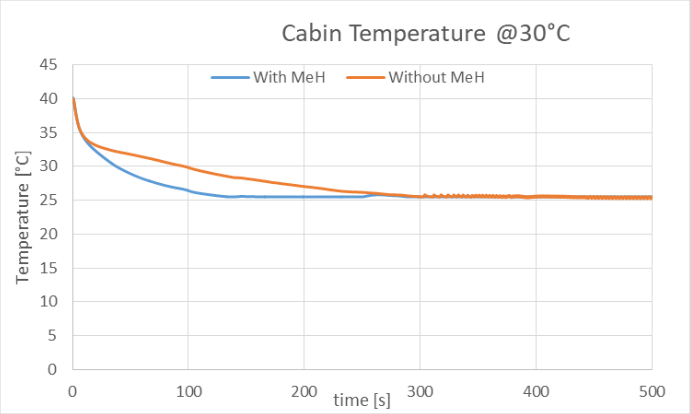
The following results are generated with this modifications.

Simulation Results WLTC
Cabin Temperature (Driver-Zone)

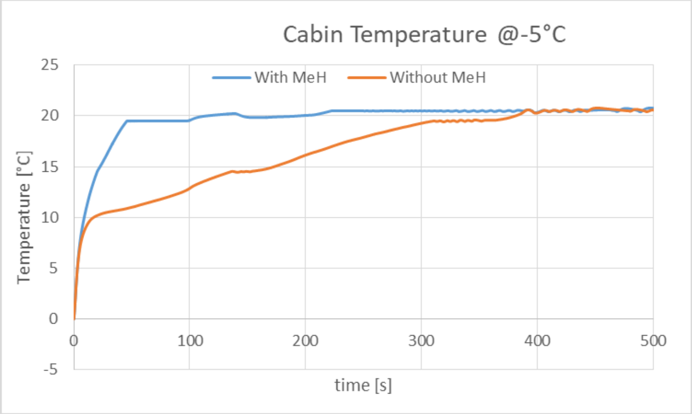


Faster warm-up and cool-down for the cabin in all cases with usage of MeH-reactor.

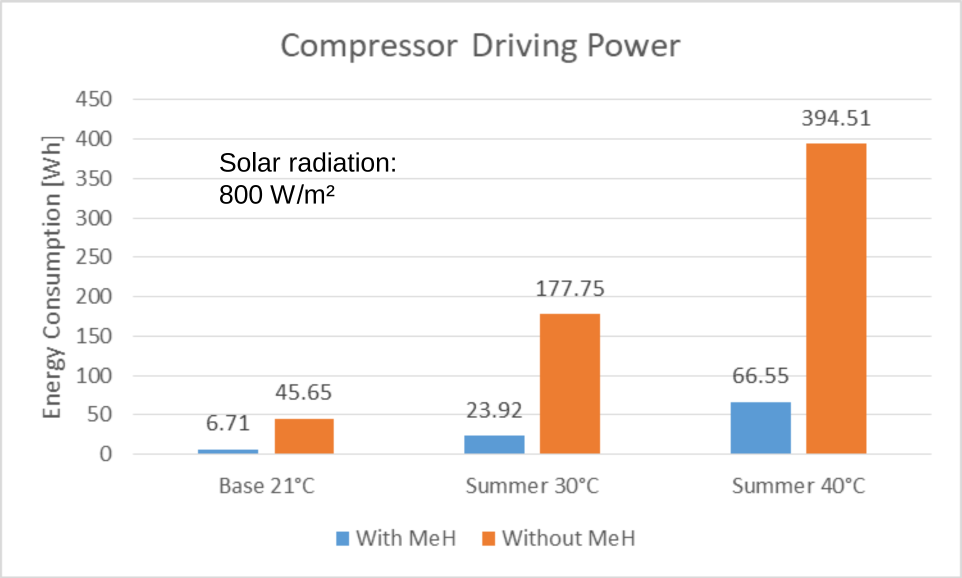


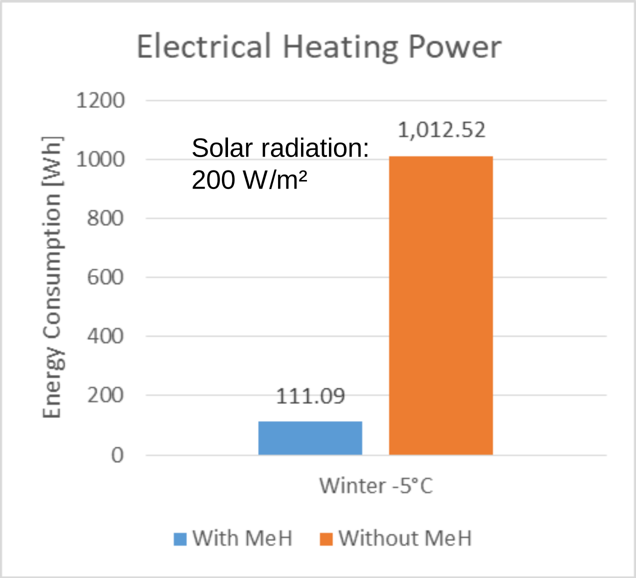


Optimized controls necessary to reduce the temperature variation due to the switching points.



Simulation Results WLTC
Comparison Power Consumption Auxiliaries





Significant energy savings for compressor and electrical heater with MeH-reactor.

Summary and Outlook

Summary and Outlook

- The MeH-Reactor can be simulated with KULI and after calibration the behavior from the test-bench is reached.
- The MeH-Reactor and simplified FC were implemented in the overall cooling system of the Mitsubishi iMiEV to simulate the WLTC.
- It could be shown that the MeH-Reactor can support the HVAC-System in warm and cold conditions significantly with a minimum of changes in the cooling system.
- Less power consumption for compressor and heater as well as faster cool down and warm up of the cabin.

- Optimization of MeH-Reactor size:
  - Mass of MeH, Mass of housing, Pressure levels
- More detailed modelling of FC
  - To optimize the control strategy for the interaction between MeH-reactor, FC and Cooling System

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INSPIRING **INNOVATION.**