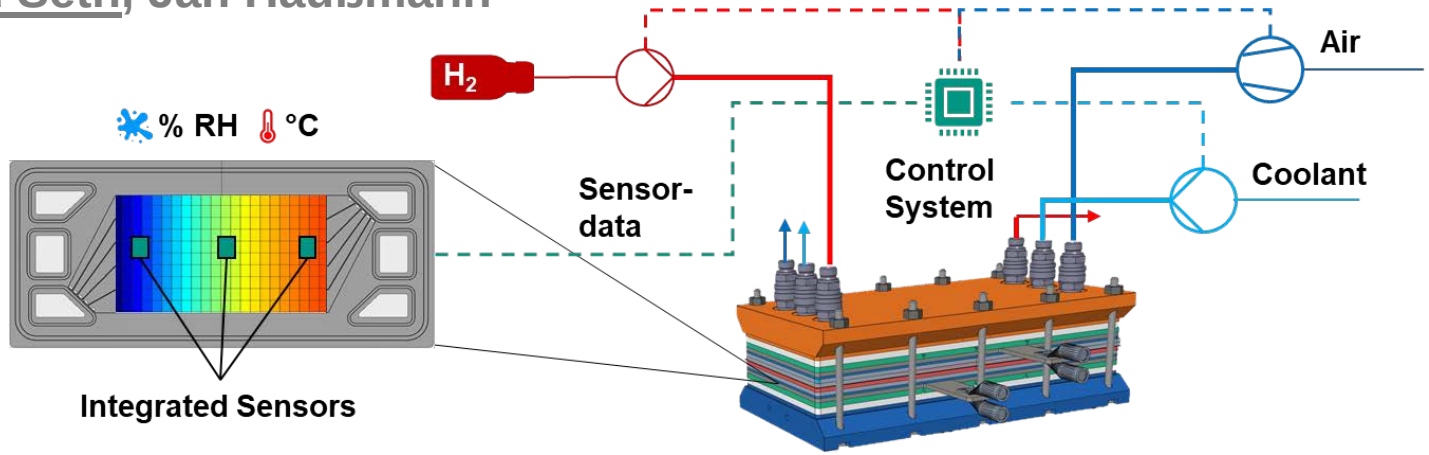
Sensor Integrated Fuel Cell for Real-time Spatially Resolved Observations Enabling Enhanced Control to Improve Fuel Cell Durability

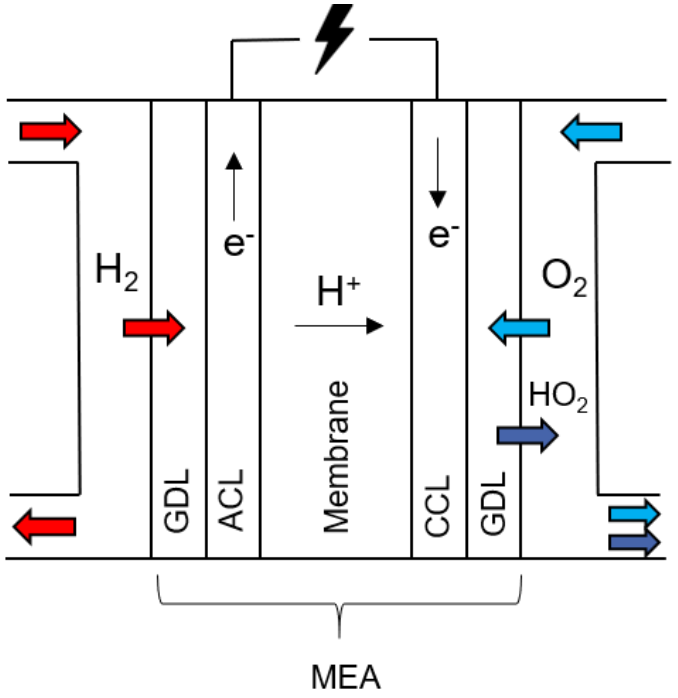
Bhanu Seth, Jan Haußmann



Motivation

What is a fuel cell?

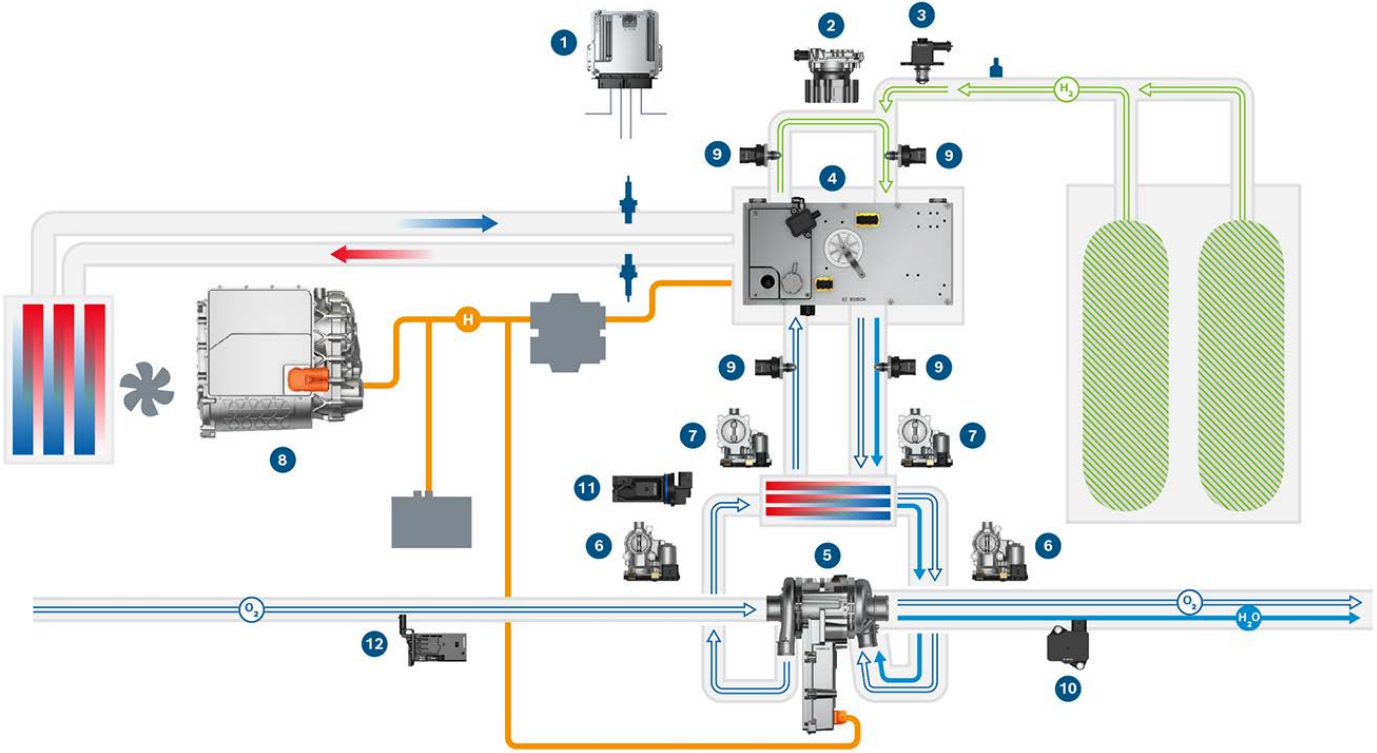
- Fuel cells convert chemical energy into electrical energy
- Low-temperature polymer electrolyte membrane (PEM) fuel cells are the focus of the automotive industry
- Maximum theoretical efficiency of the cell: 83 %.



Source: PEM Fuel Cell System (MathWorks)

Motivation

Fuel cell system

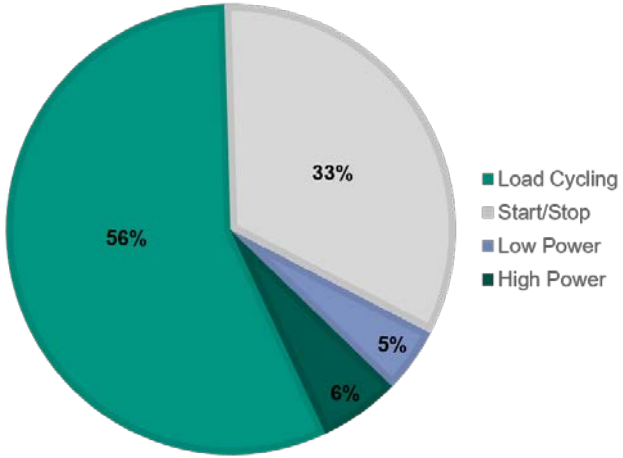


Source: Brennstoffzellenelektrischer Antrieb (bosch-mobility.com)

Motivation

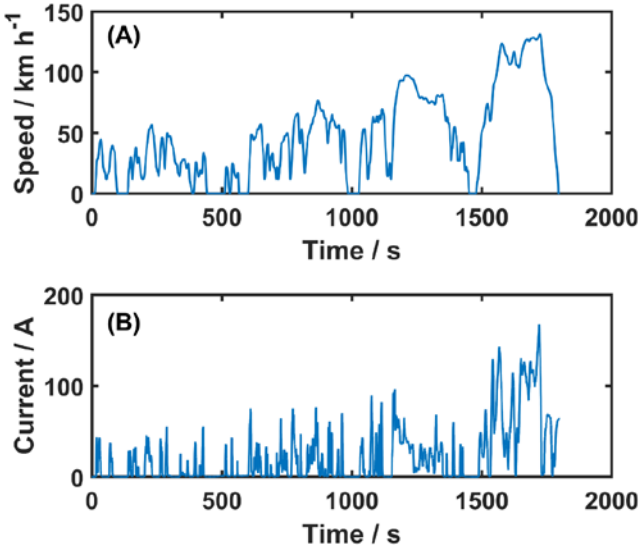
Dynamic load and fuel cell degradation

Influence factors: Degradation of fuel cells



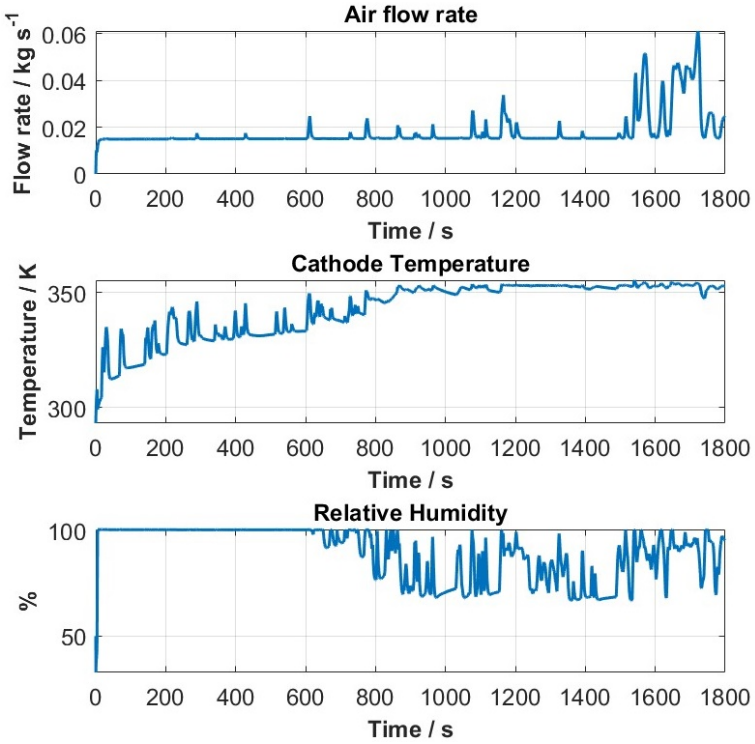
Source : Adapted from PEI, P., CHANG, Q., & TANG, T. (2008). A quick evaluating method for automotive fuel cell lifetime. International Journal of Hydrogen Energy, 33(14), 3829–3836. https://doi.org/10.1016/j.ijhydene.2008.04.048

Dynamic load changes



Motivation

Dynamic load and fuel cell degradation



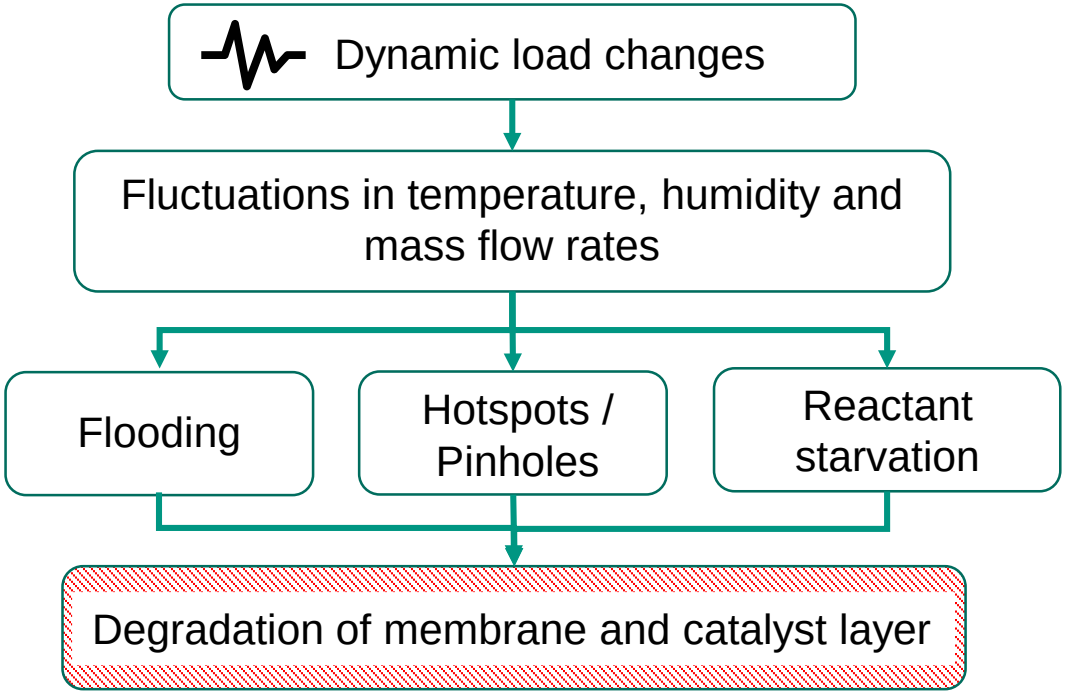
Dynamic load changes

↓

Fluctuations in temperature, humidity and mass flow rates

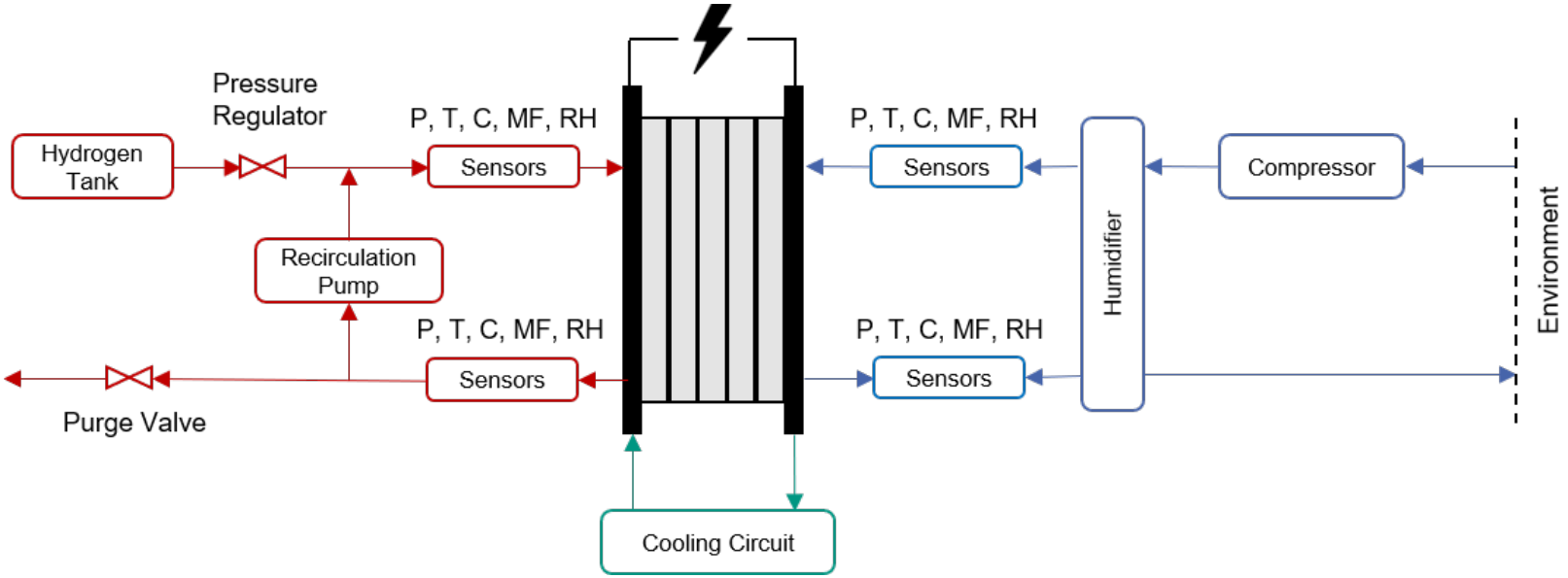
Motivation

Dynamic load and fuel cell degradation



Motivation

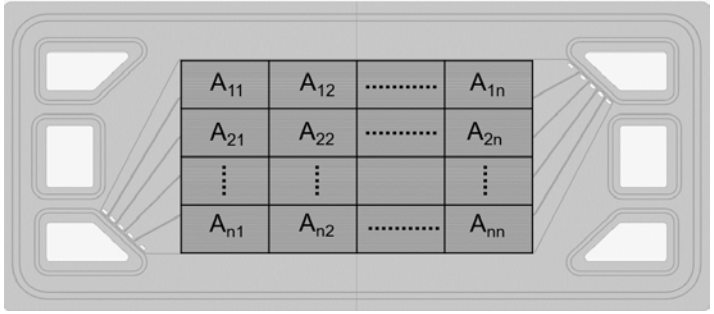
State of the art: Fuel cell sensors



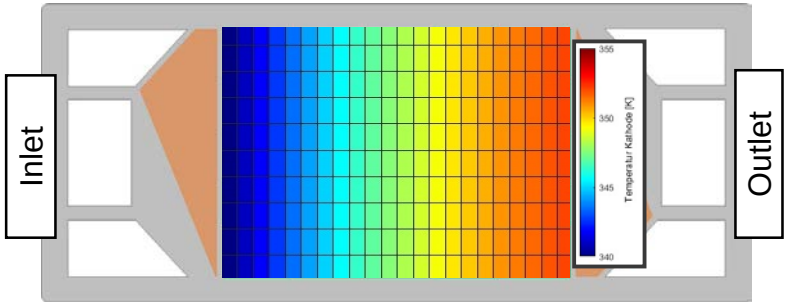
Source : Adapted from Wang, H [Hanqing], Morando, S., Gaillard, A., & Hissel, D. (2021). Sensor development and optimization for a proton exchange membrane fuel cell system in automotive applications. Journal of Power Sources, 487, 229415. https://doi.org/10.1016/j.jpowsour.2020.229415

Motivation

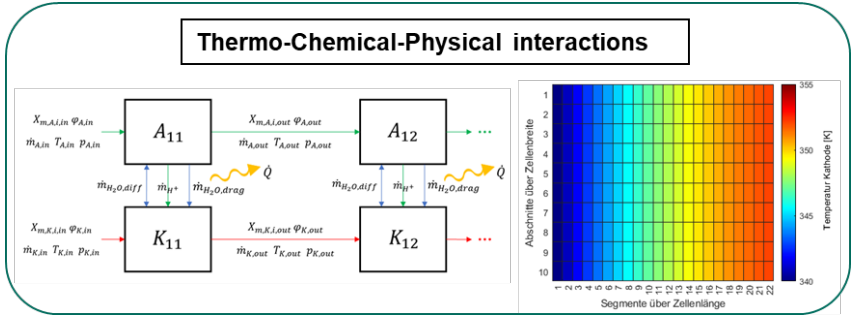
Gradient



Automotive bipolar plate with ~ 300 cm² active area



Simulated temperature gradient

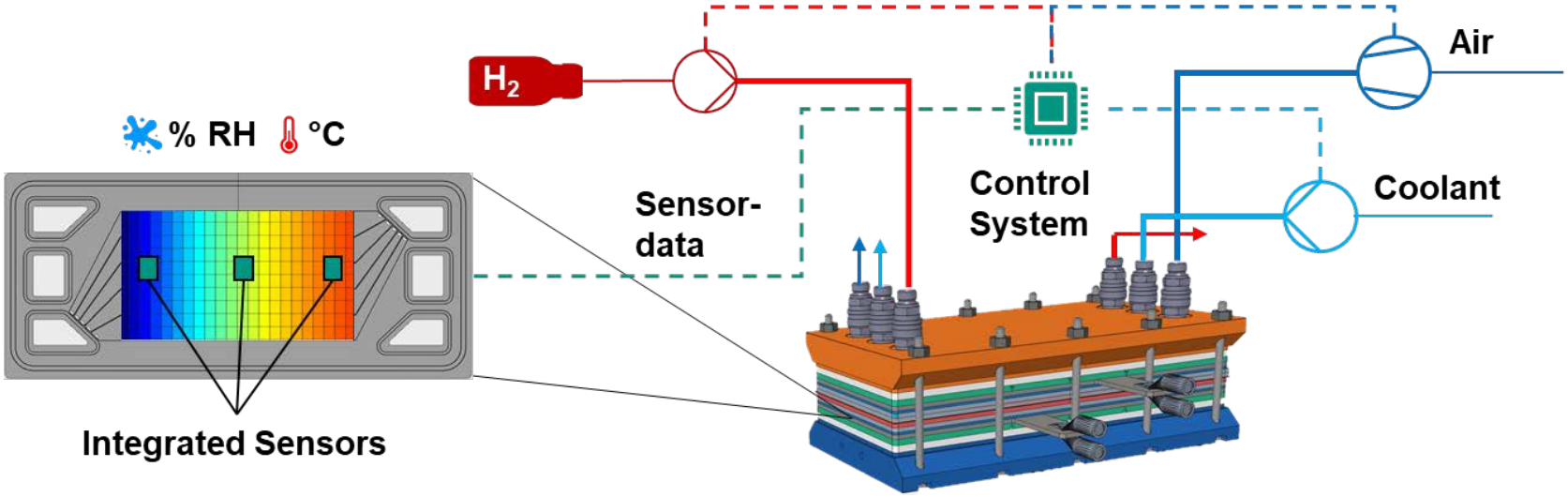


Gradients: Temperature, Humidity, Pressure, Concentration, etc.

Sensor based fuel cell approach

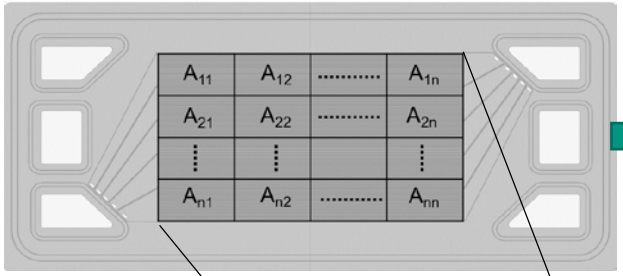
Future fuel cell control systems

Inclusion of spatially resolved data can enhance fuel cell control

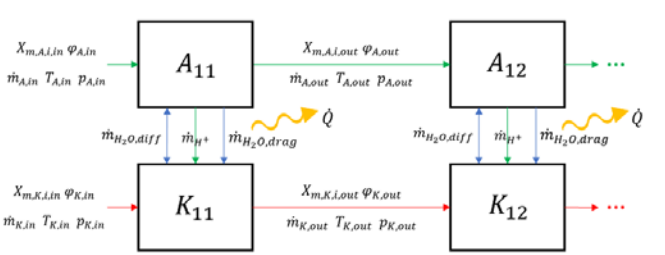


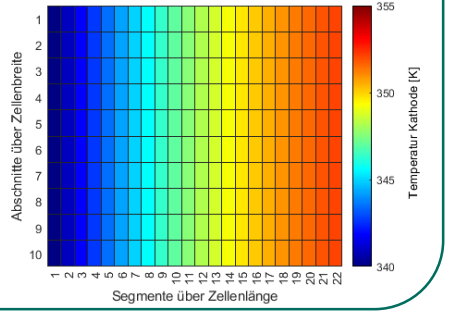
Sensor based fuel cell approach

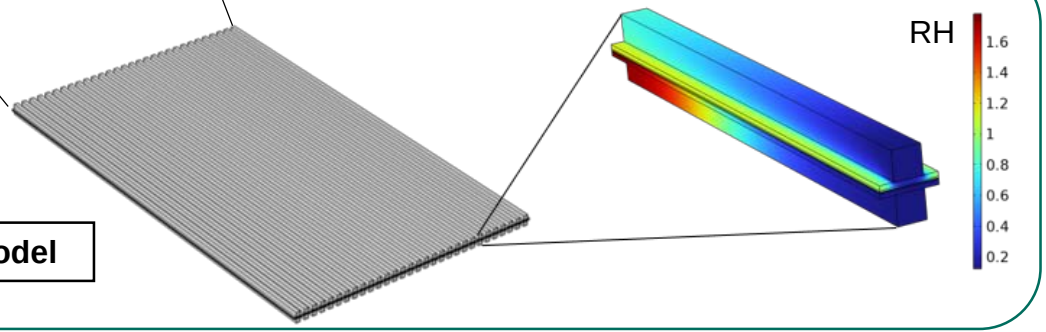
Spatially resolve fuel cell simulation model



Analytical model







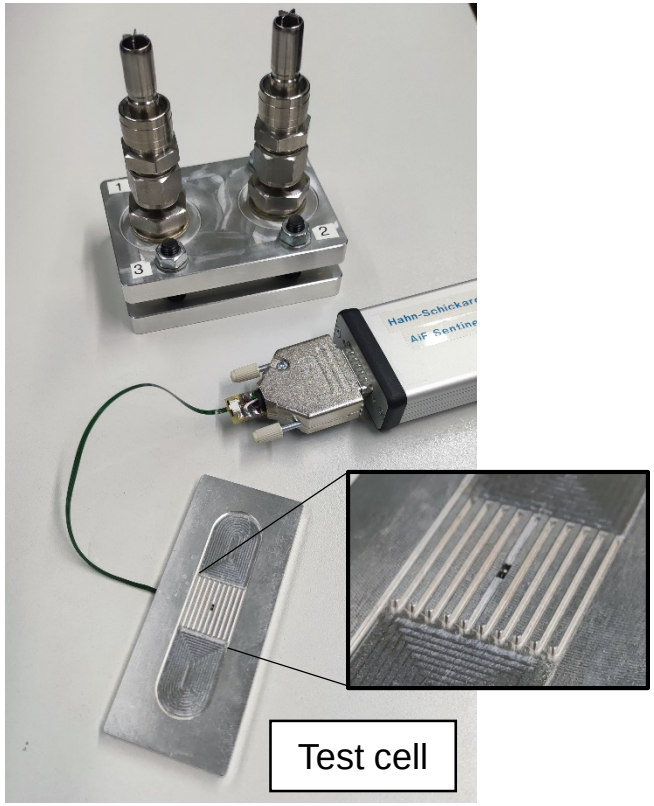
CFD Model

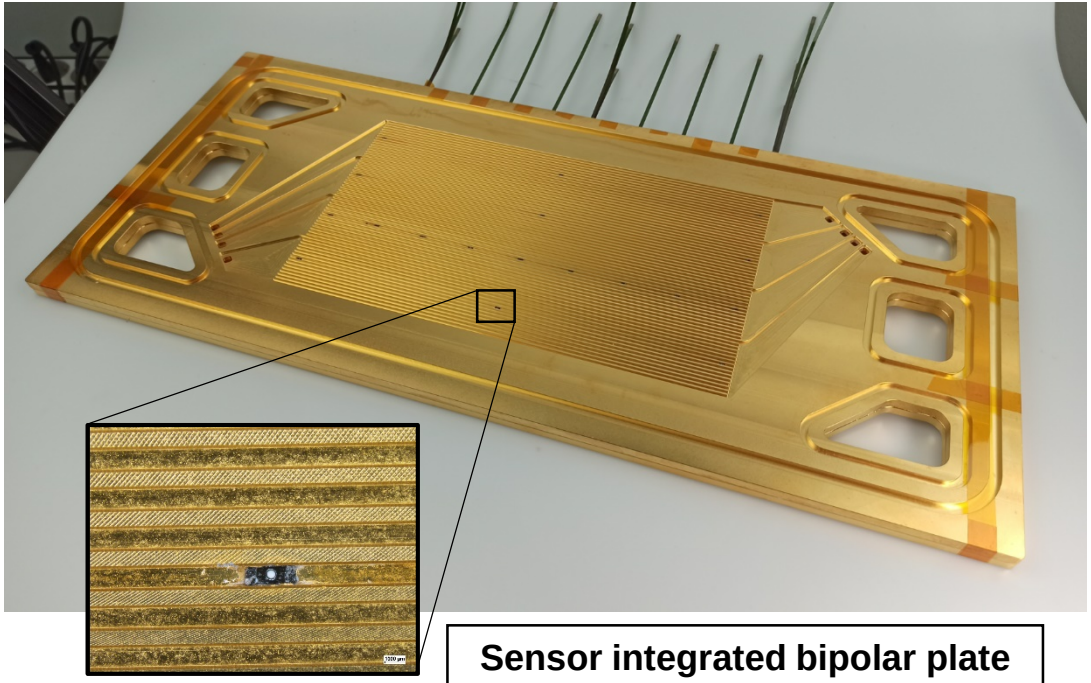
Influence of:

- Mass flow rates
- Pressure
- Humidity

Sensor based fuel cell approach

Experimental Setup - Sensor integrated bipolar plate



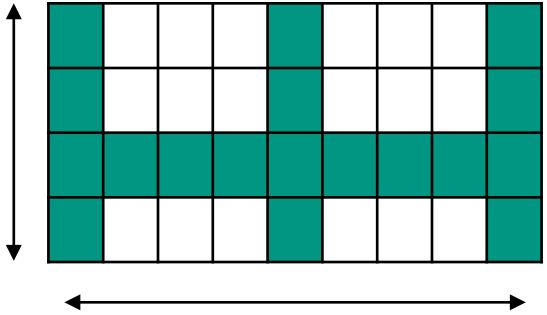


Sensor integrated bipolar plate
18 Temperature/Humidity Sensor

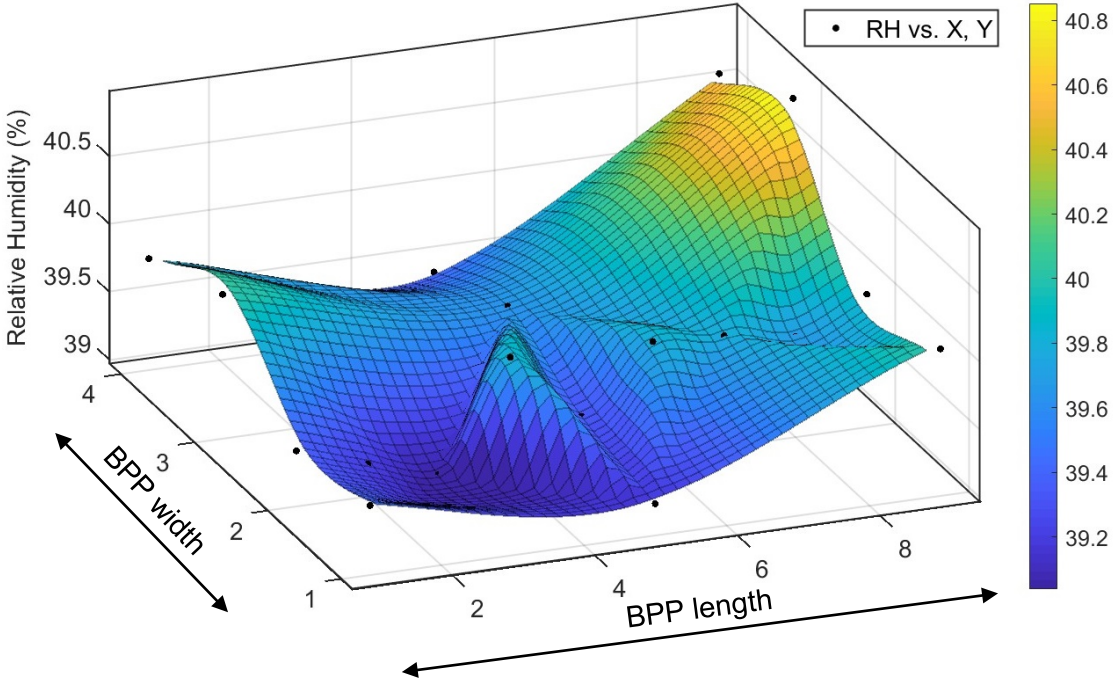
Sensor based fuel cell approach

Experimental Setup - Sensor integrated bipolar plate

Interpolation of values between sensor position to generate a continuous gradient

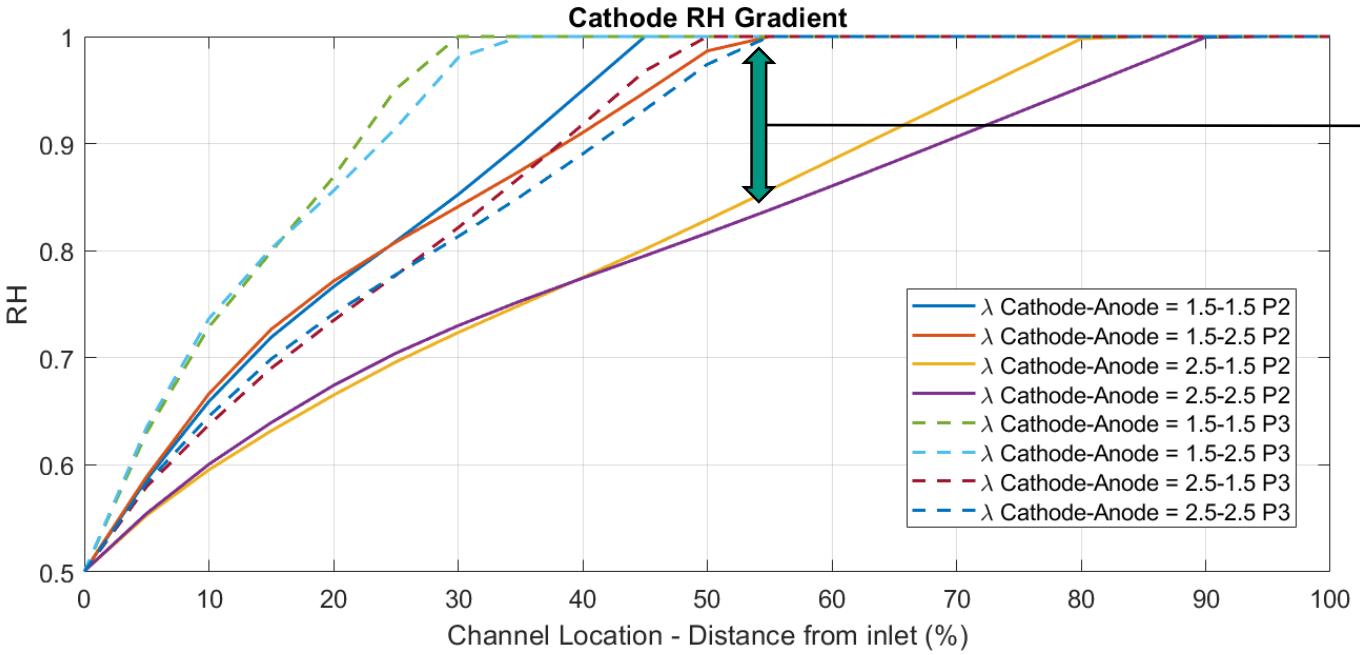


Sensor position grid on the bipolar plate (BPP)



Sensor based fuel cell approach

Operation strategy development



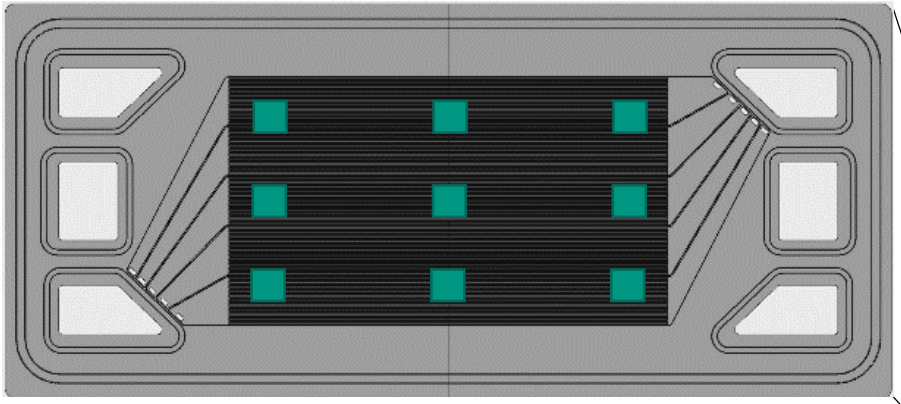
Stoichiometry and **operating pressure** as control parameters to regulate Relative Humidity.

Pressure ↑ RH ↑

Stoichiometry ↑ RH ↓

Sensor based fuel cell approach

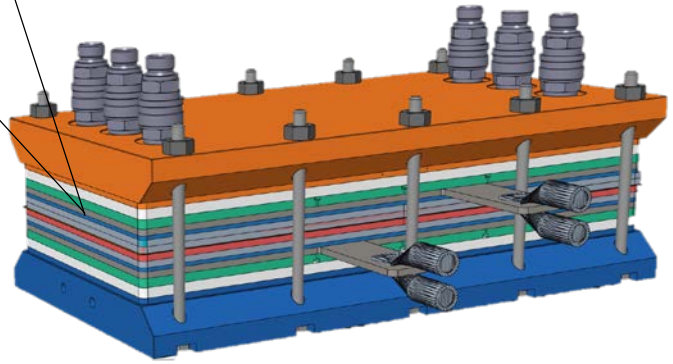
Sensor integration challenges



How many sensors do I need to place?

More Sensors → Better resolution

Enhanced system control



3 X 3 sensor matrix
~ 330 cells
9 x 330 = 2,970 sensors!
Each sensor with 2 cables ~ 5,940 cables!!

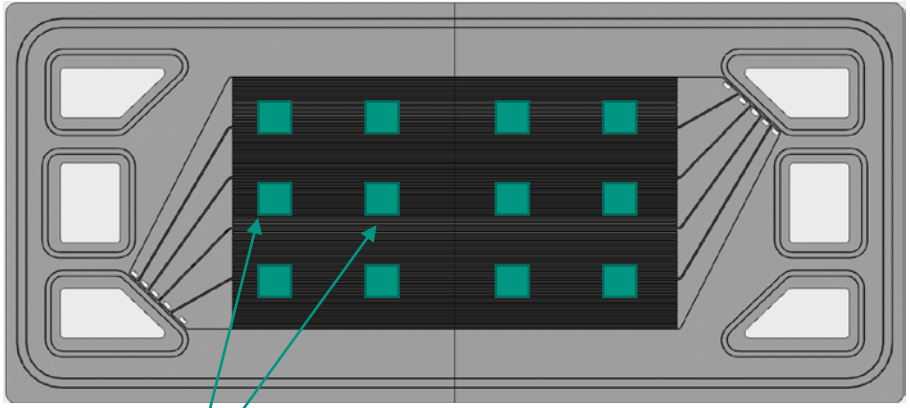
Costly and Complex!

Sensor based fuel cell approach

Machine learning based ‚Soft Sensors‘

Data acquisition
from real sensors

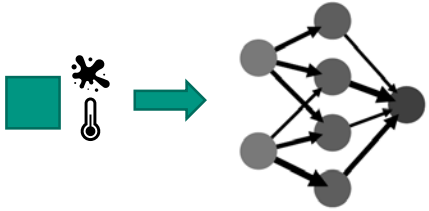
Real sensors



Real Sensors:
Real time data for measurement and soft sensor training

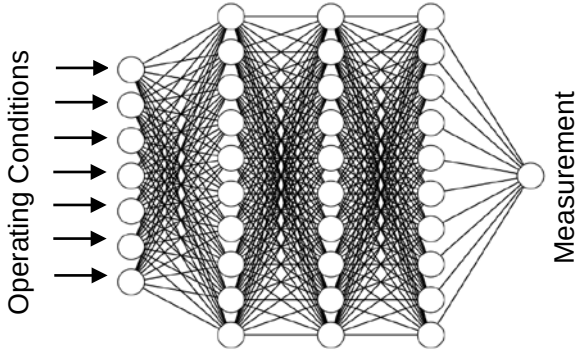
Sensor based fuel cell approach

Machine learning based ‚Soft Sensors‘



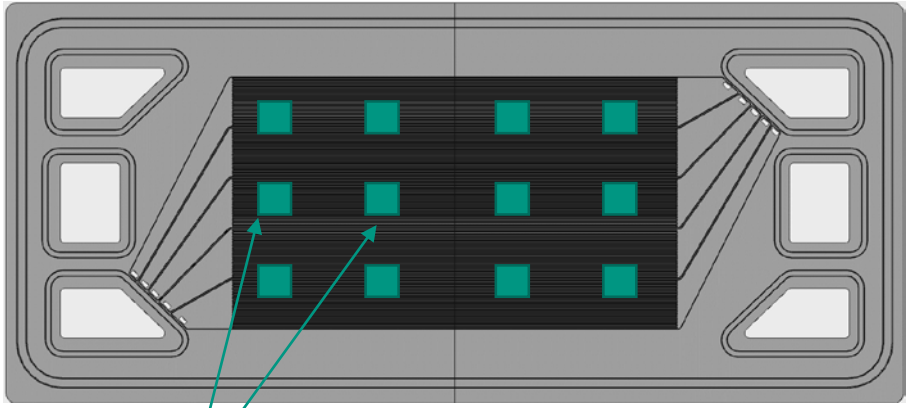
Data acquisition from real sensors

Training of neural network



Neural network based prediction

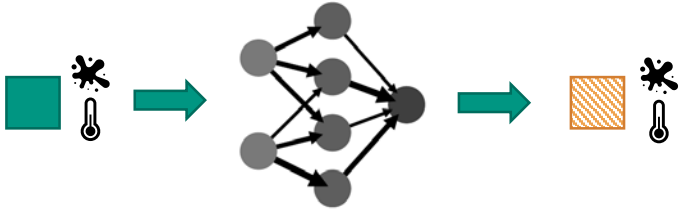
Real sensors



Real sensors:
Real time data for measurement and soft sensor training

Sensor based fuel cell approach

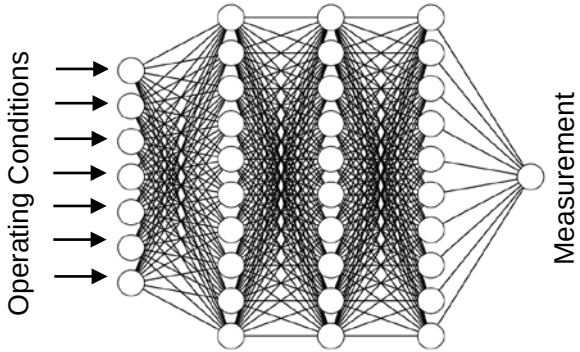
Machine learning based ‚Soft Sensors‘



Data acquisition from real sensors

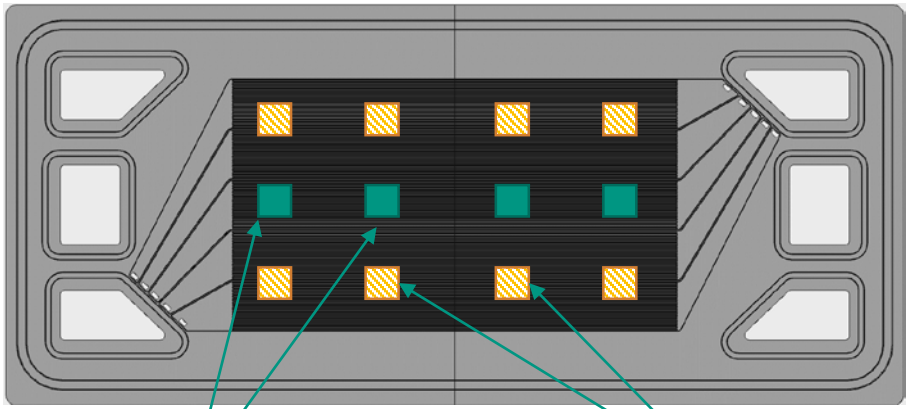
Training of neural network

Virtual sensor



Neural network based prediction

Matrix of real and soft-sensoren

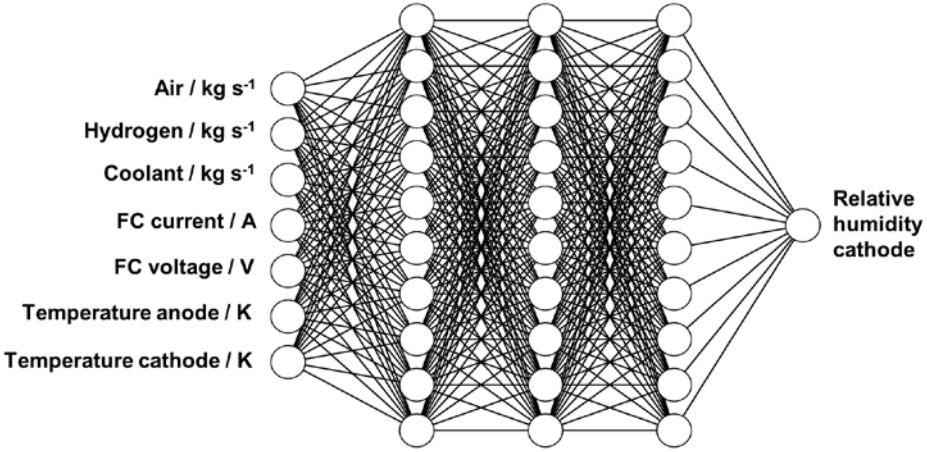


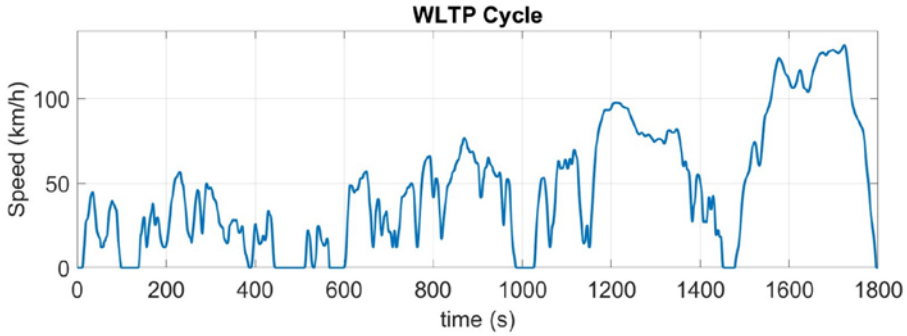
Real sensors:
Real time data for measurement and soft sensor training

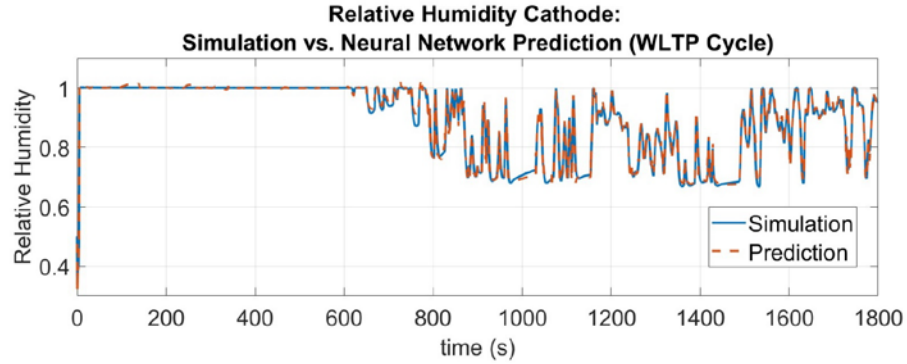
Soft-sensors: Improved resolution without increase in cost

Sensor based fuel cell approach

Machine learning based ‚Soft Sensors‘







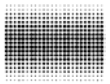
International Conference on Fundamentals & Development of Fuel Cells FDFC2023, Ulm, Germany.

FC3 Fuel Cell Conference Chemnitz 2024, Chemnitz, Germany.

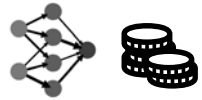
Sensor based fuel cell approach

Conclusion and scope of future work

- Sensor integrated approach can help in capturing **local conditions**

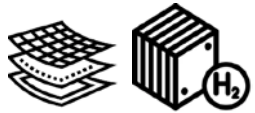


- Machine learning based ‚**soft-sensors**‘ can enhance spatial resolution without increasing the cost



- Integrating local conditions within control algorithm may **enhance** the **durability** of the fuel cells by reducing the critical states

- Further work in the direction of **thin film sensor** development, integration into commercial **metallic BPPs** and **short stack** testing to be carried out in the next steps



Thank you for your attention

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