Predictive energy management of heavy-duty fuel cell trucks

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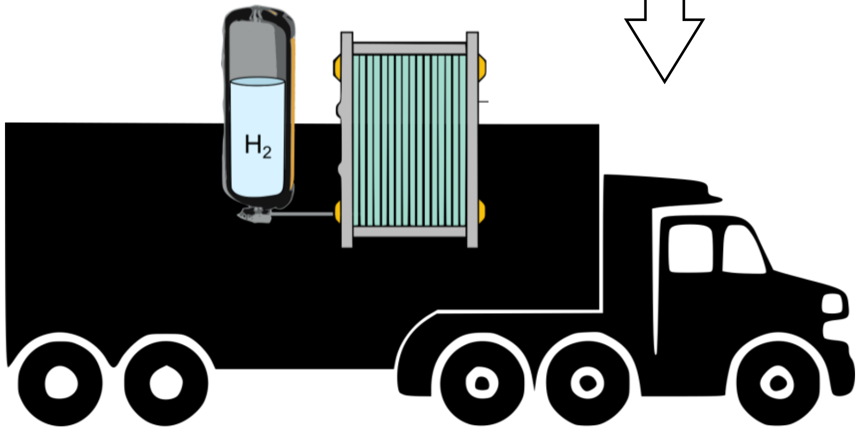
November 19, 2020

Fuel cell trucks

Electrification of road-freight transports

Battery vehicles | Fuel cell vehicles

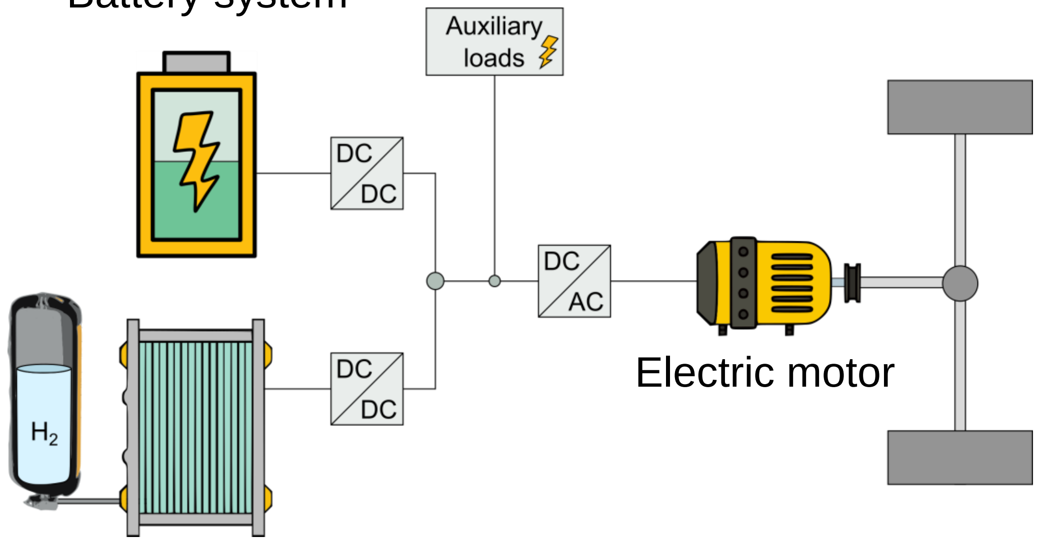
An energy management system is required to distribute the load to the fuel cell and battery systems



Zero emissions
Energy density
Fast refuelling

Cost
Lifetime
H_2 infrastructure

Battery system

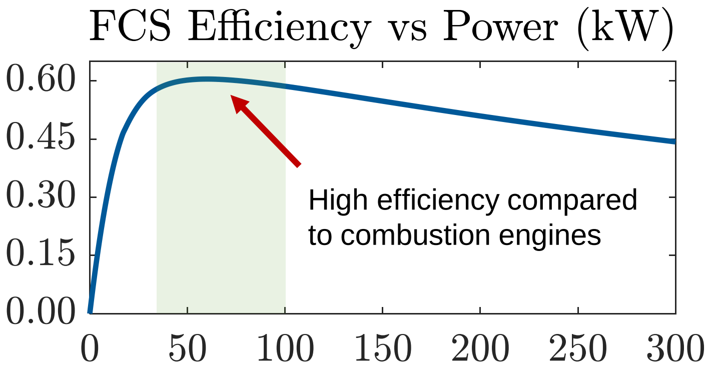


Fuel cell system

Targets of the energy management

Energy management has multiple targets

Maximize hydrogen economy



Mitigate fuel cell degradation

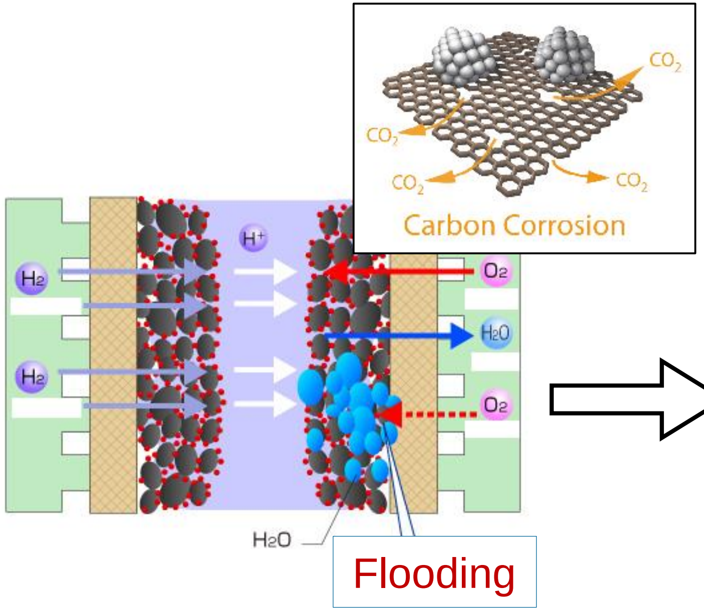
- Avoid frequent shutdowns
- Avoid low power operation
- Avoid transient loads

Sustain battery charge

- Avoid complete discharge
- Maximize regenerative braking

Critical conditions

- Reactant starvation
- High temperatures
- Dehydration/flooding



Fuel cell degradation


$\sim 1\ \mu V/h$


$\sim 100\ \mu V/h$

Prediction systems

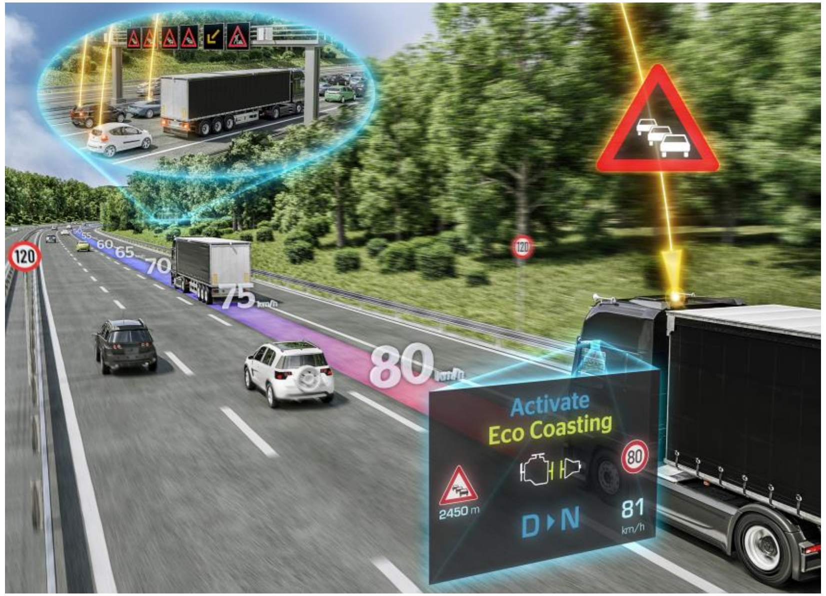
Predictive EMS: Use future driving information to improve performance of the vehicle

Long-term information

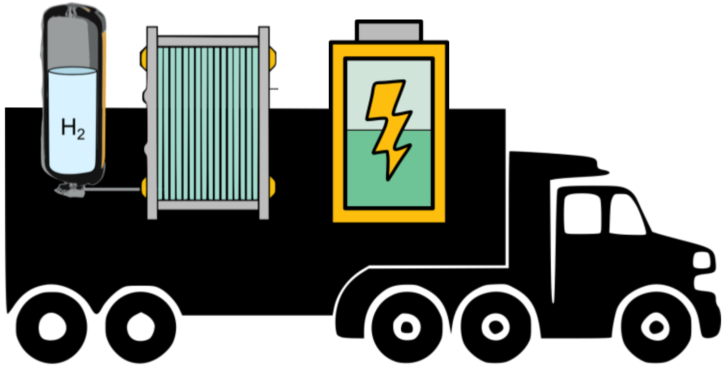
Basic driving information derived from knowing the planned destination. Elevation and average speed can be estimated based on the planned route.

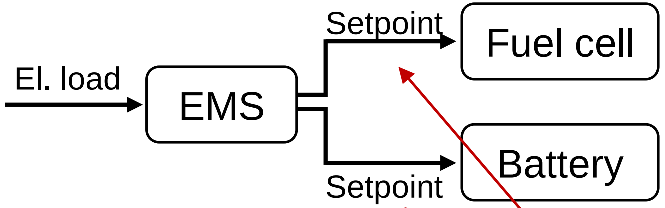
Short-term information

An on-board prediction system provides live driving information on the road ahead. For example: traffic speed, road slope/curvature, and road conditions in the next kilometre.



Predictive energy management





Predictive energy management

- Use predictive driving information to increase the hydrogen economy and fuel cell lifetime.

Short-term prediction

Use the load estimations to reduce fuel cell dynamics and meet the prescribed constraints.

Long-term prediction

Generation of optimal battery SoC reference on the estimated speed and elevation of the planned route.

Constraints

$$SoC_{min} \leq SoC \leq SoC_{max}$$

$$P_{fcs,min} \leq P_{fcs} \leq P_{fcs,max}$$

$$P_{b,min} \leq P_b \leq P_{b,max}$$

Setpoints are found minimizing a multi-objective cost function

Maximize H_2 economy	Reduce transients	Sustain charge

$$J = \int_{t_1}^{t_2} \left[\left(\eta_{fcs} - 0.61 \right)^2 + w_1 \cdot \left(\dot{P}_{fcs} \right)^2 + w_2 \cdot \left(SoC - SoC_{ref} \right)^2 \right] d\tau$$

Comparison with benchmark Pontryagin's minimum principle

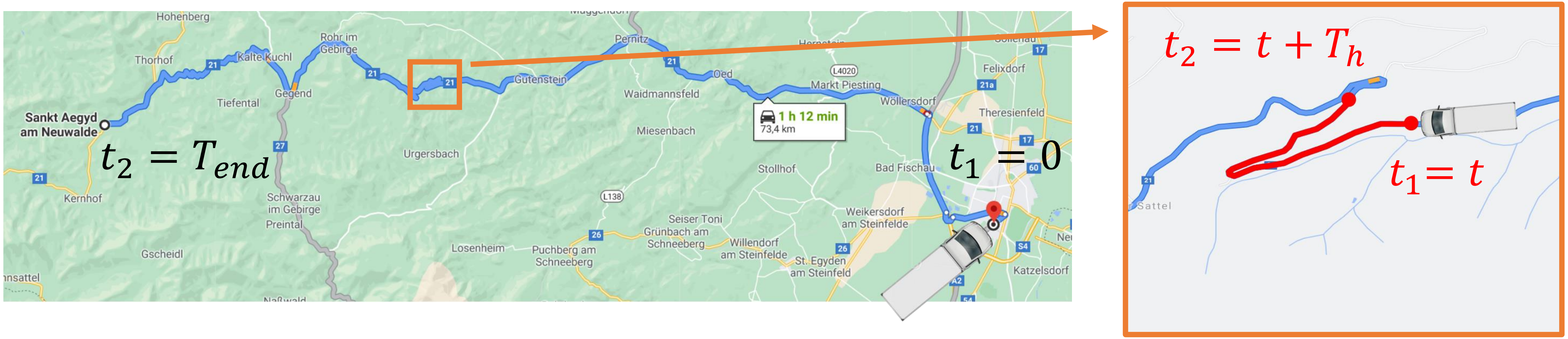
Pontryagin's minimum principle (PMP)

- Requires complete knowledge of the driving cycle.
- Benchmark for hydrogen economy: find the theoretical minimum consumption.
- Cannot be implemented in real vehicles.

Model predictive control (MPC)

- Requires a load prediction system for the receding horizon optimization.
- Incorporates the advantages of short-term and long-term predictions to optimize the hydrogen economy and system lifetime.
- Can be implemented in real vehicles.

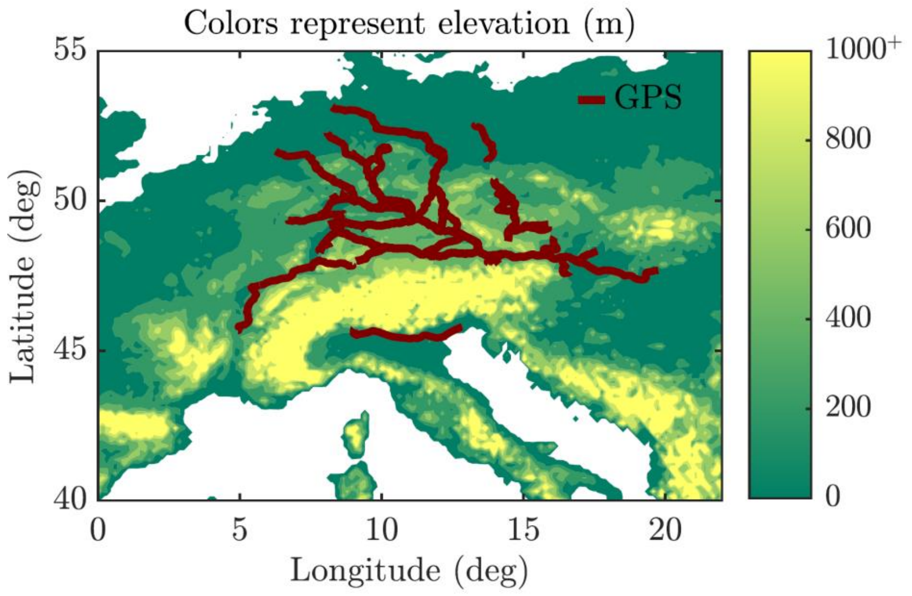
$$J_{MPC} = \int_{t_1}^{t_2} \left[\left(\eta_{fcs} - 0.61 \right)^2 + w_1 \cdot \left(\dot{P}_{fcs} \right)^2 + w_2 \cdot \left(SoC - SoC_{ref} \right)^2 \right] d\tau$$



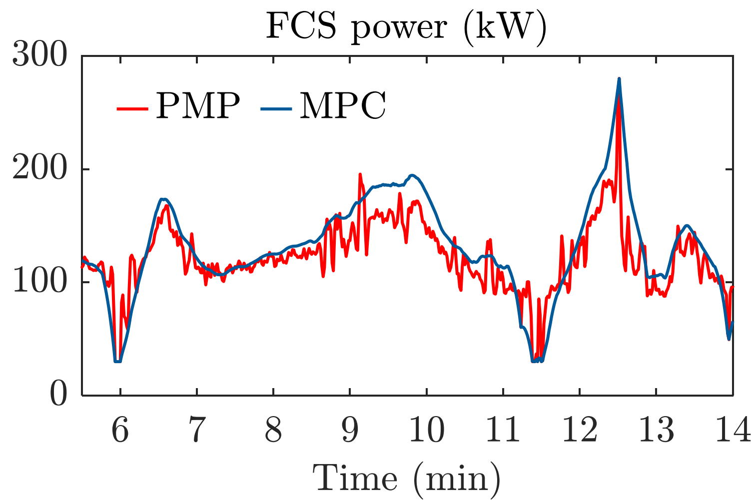
Simulation results

Simulations consider a realistic representation of the truck operation

- Real-world driving cycles (speed and elevation).
- Variable loading (15 - 40 tonnes).
- A total of 1750 driving hours (141,000 km).



- Using the predictive energy management we can achieve the efficient operation of fuel cell trucks in realistic driving scenarios.
- The predictive SoC reference generation further improves the hydrogen economy up to 2%.
- MPC yields significant reduction of the transient operations retaining high hydrogen economy.
- Compared to PMP, MPC reduces transients of $\sim 50\%$ with a deviation from the maximum hydrogen economy below 1%.



Future research focus

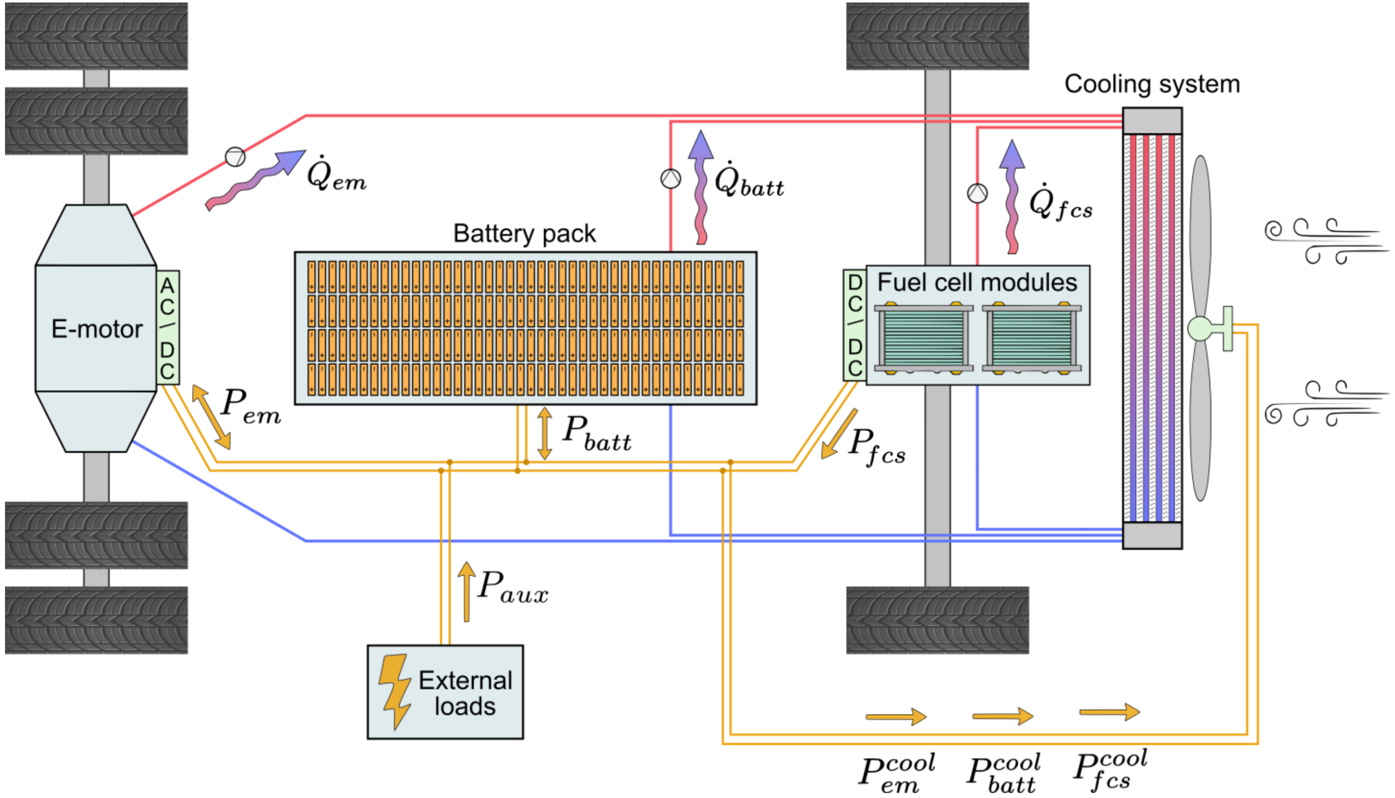
Main issues in fuel cell trucks

- Cooling is complex because the systems operate at different temperature levels and radiators require large cooling surfaces.
- During uphill sections the power absorbed by the cooling systems is significant (high losses).
- The degradation of fuel cell modules is increased by frequent starts and shutdowns.

Future research

Integration of thermal management within the predictive control framework

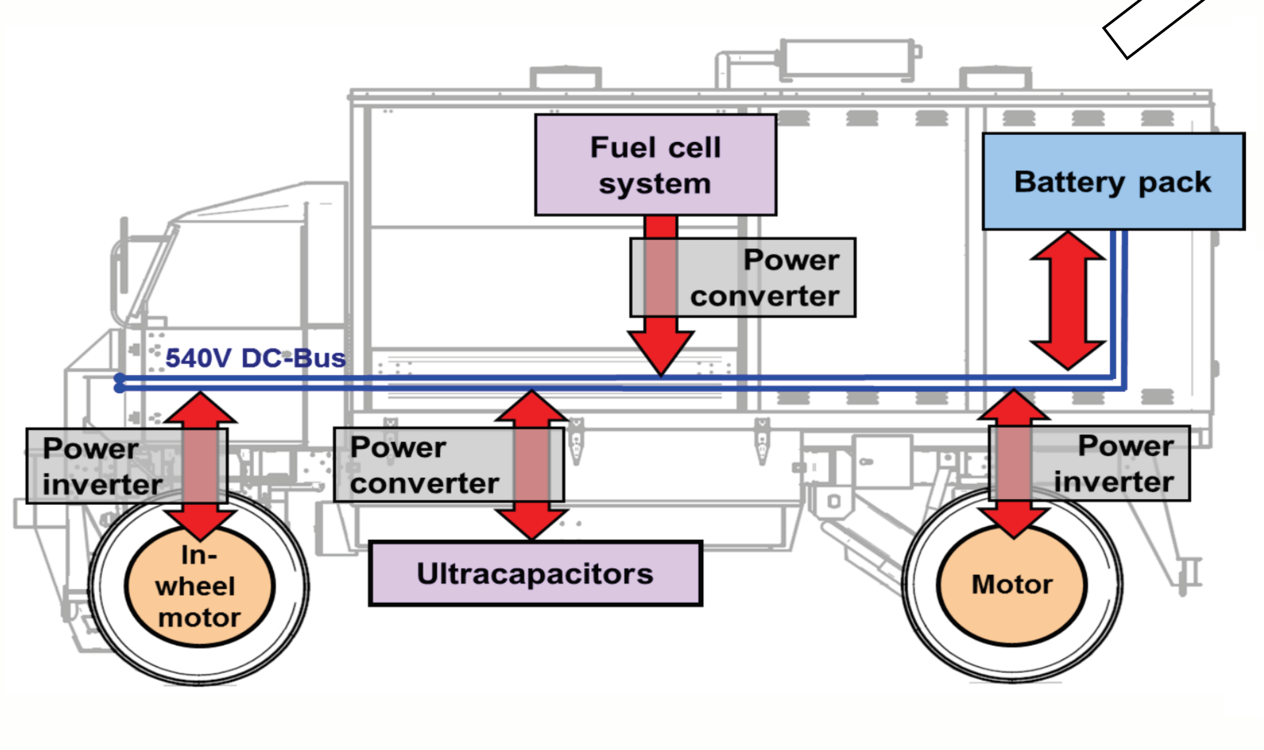
Predictive activation/shutdown of fuel cell modules



Additional research topic

Advanced FC powertrain configurations

Use of ultracapacitors to further reduce fuel cell dynamics, increase H2 economy, reduce FC starts, and consider battery lifetime as additional target.



IEEE VTS Motor Vehicles Challenge 2020

International energy management challenge won by our TU Wien team.

TU Wien – Energy management team

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