

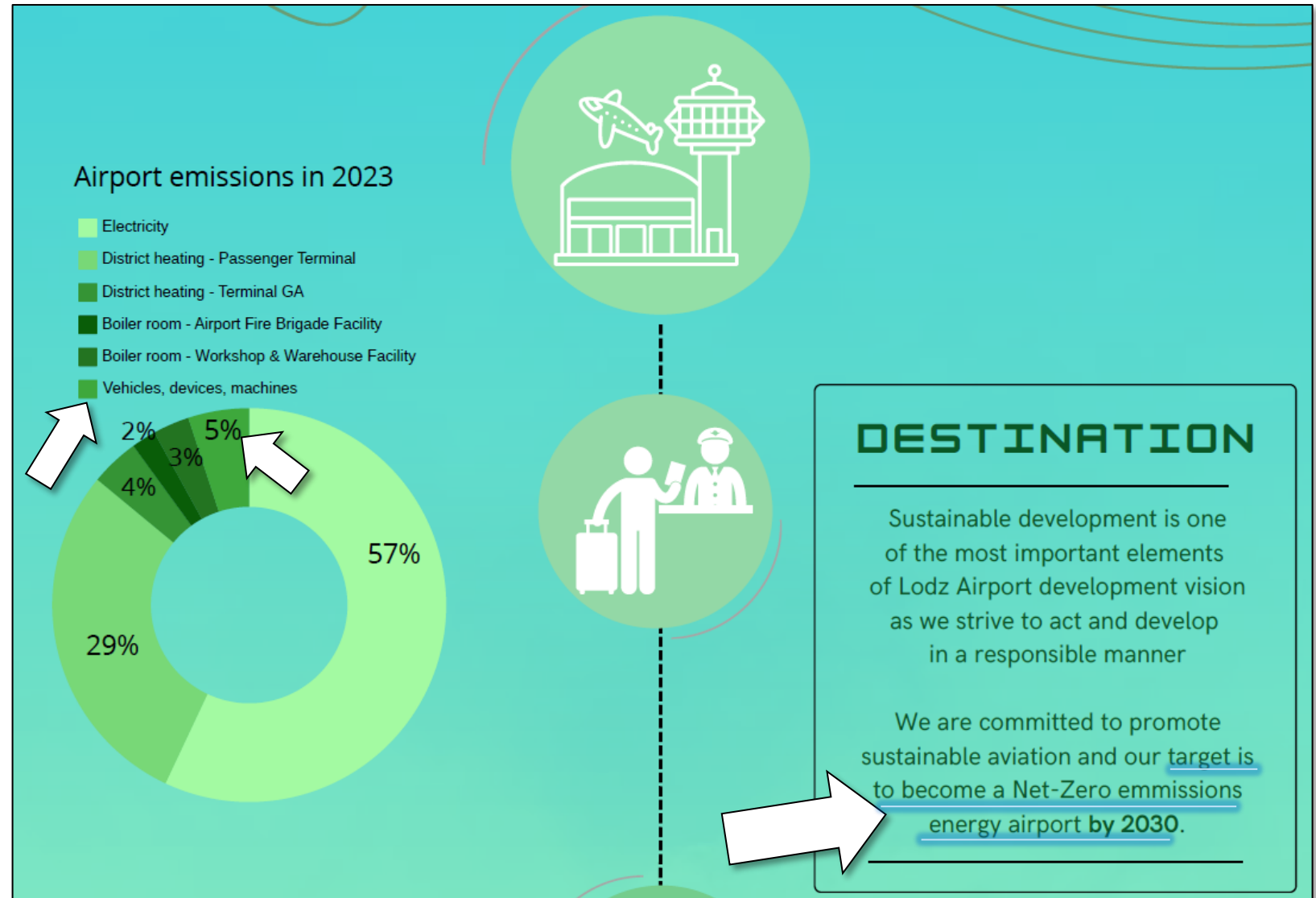


Thermal Management of a Fuel Cell Firetruck

Christian Doppler, Bernhard Lechner, Ana Romero,
Virtual Vehicle Research GmbH;
Wolfgang Luftensteiner, *Rosenbauer International AG*

Why should you put a **Fuel Cell into ARFFs???**
(Airport Rescue and Fire Fighting)

- Around 5% of airport emissions are from vehicles
- Airports want to become climate neutral until 2030
- But! What are airport emissions?
→ See next slide



<https://www.aci-europe.org/downloads/content/ZERO%20EMISSIONS%20ROADMAP%20d%20Airport.pdf>

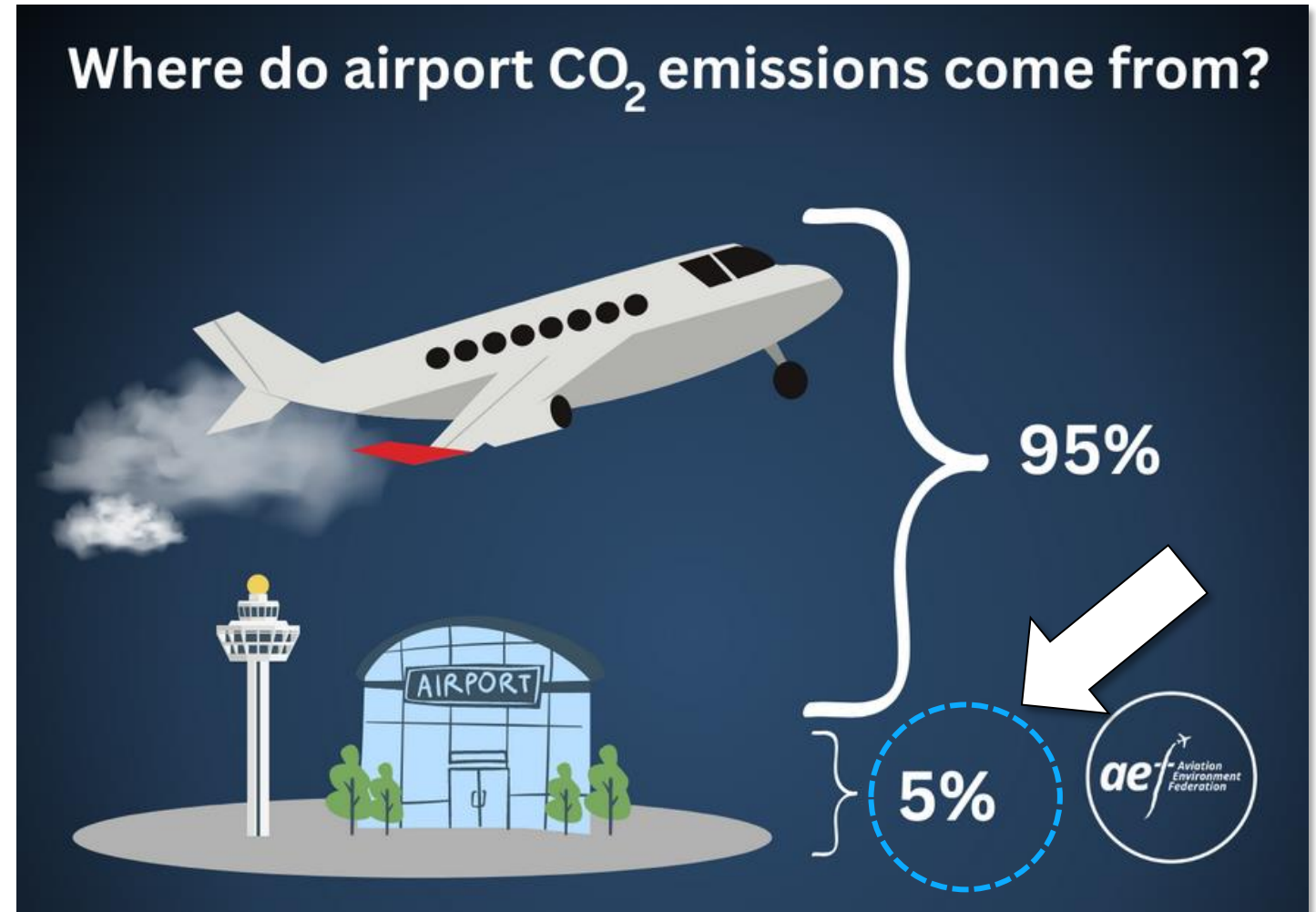
...A group of NGOs has written an open letter to the Secretary of State for Transport expressing concerns about the Government's proposals for a 'zero emissions airport' target.

The letter argues that using the phrase 'zero emissions airport' gives the misleading impression that all aviation emissions will be zero emission by 2040.

In reality, the proposed target would not include the emissions from flights, despite these being responsible for 95% of airports' total emissions...

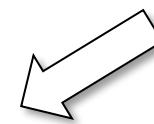
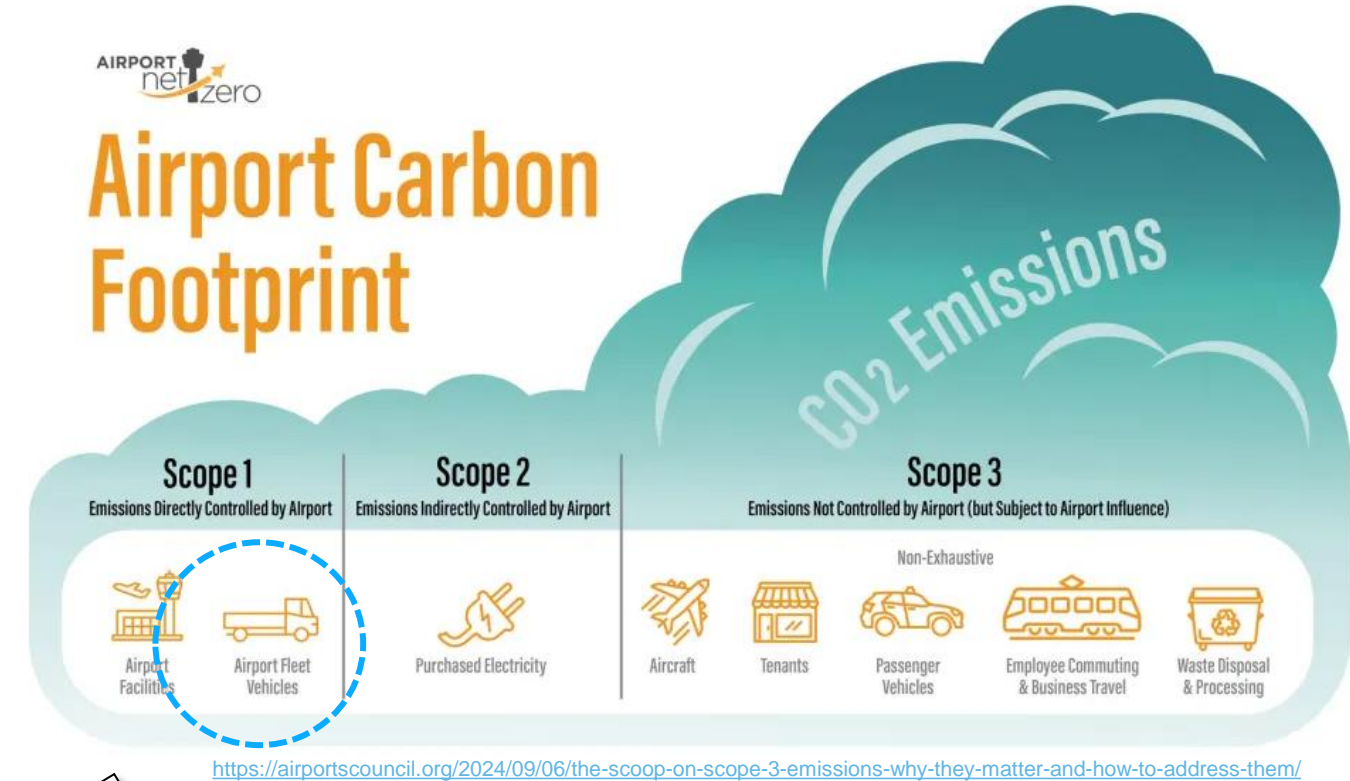
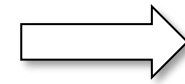
*But we also
need to cut
these 5%!*

*Airplanes are
another story!*

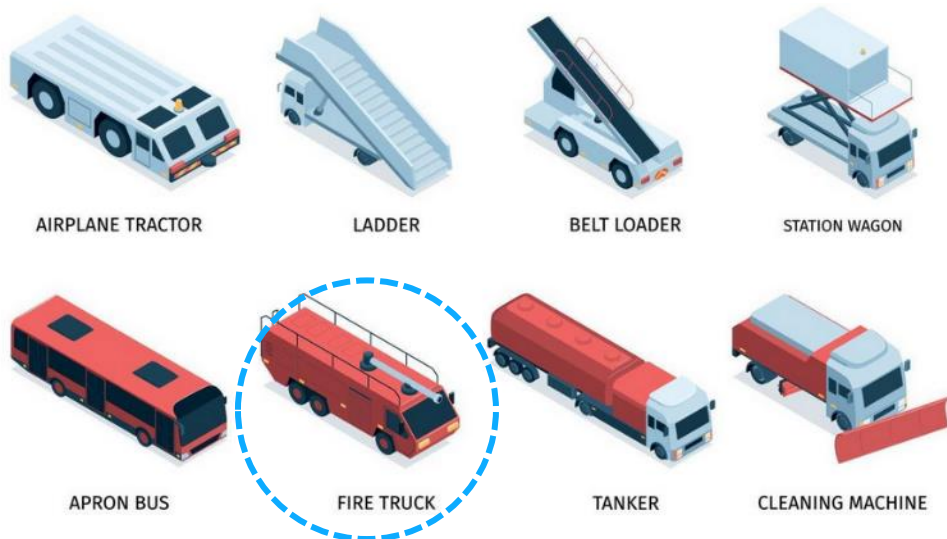


<https://www.aef.org.uk/2023/04/28/zero-emissions-airports-proposals-risk-misleading-the-public/>

- Different CO₂-reduction-initiatives are appearing
- Airport fleet vehicles should be addressed in the first step of free steps



AIRPORT FLEET VEHICLES



<https://www.vecteezy.com/vector-art/6846406-airport-transport-vehicles-set>

- Specific vehicles like in ARFF (Airport Rescue and Fire Fighting) have high power and energy demands
- New vehicle concepts/design are needed (battery, fuel cell)

Rosenbauer PANTHER

...The Rosenbauer PANTHER is one of the most successful, efficient, and variable ARFF vehicles worldwide...



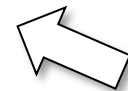
<https://www.rosenbauer.com/en/at/rosenbauer-world/vehicles/arff-vehicles/panther>

Rosenbauer Panther Electric 6x6

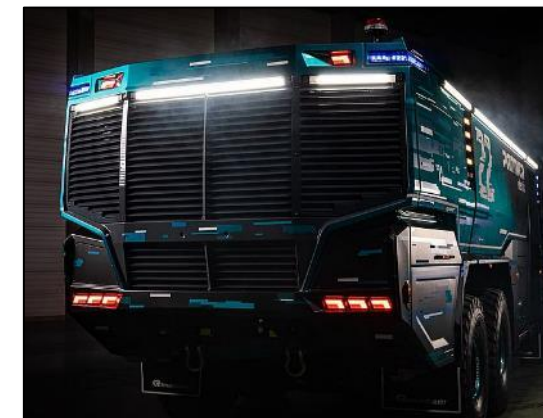
- Close to series concept, in transition to series development
- < 21 seconds from 0 to 80 km/h
- Fire water: 9,000 l/min normal pressure or 400 l/min high pressure
- Up to 100 m throw range
- Battery capacity is tailored to the area of application
- Integrated energy backup system (compact **Diesel engine**)



<https://www.rosenbauer.com/de/int/world/fahrzeuge/flughafenloeschfahrzeuge/panther-electric>



Let's replace ICE with **Fuel Cell** for local zero emissions



Key data of PEM FC system:

- System Power @ BOL: 300 kW
- System Efficiency @ BOL: ~ 60% @ part load & 50% @ full load
- T coolant: 55-70°C

Exemplary picture of PEM FC



<https://www.evdesignandmanufacturing.com/news/hyzon-motors-announces-milestone-producing-200-kw-single-stack-fuel-cell-system/>

Development process of Heat Exchanger (HX) model for FC Truck

Identification of Best-in-class ICE HX



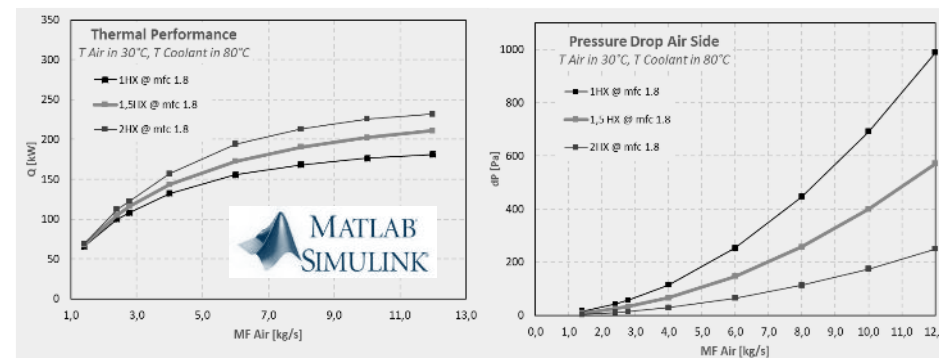
HX Measurements



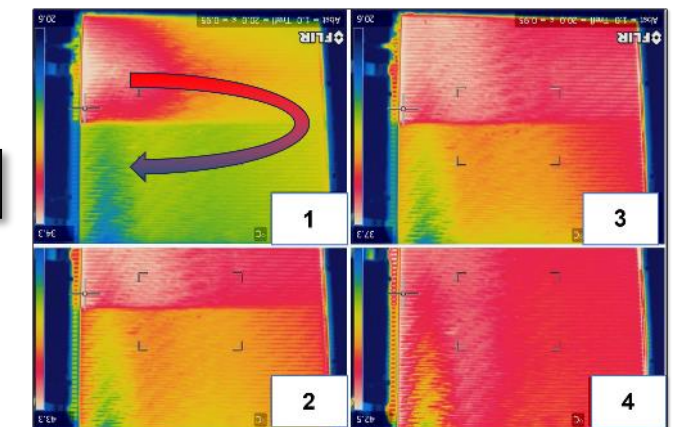
Characterization of coolant and air channel geometries



Analytical and empirical simulation models of HX



Evaluation of inner coolant flow: IR photos time laps (1...4)



Next Step:
Production

Longitudinal Dynamics

- 6x6 Panther, 40.5 tons GVW

Powertrain

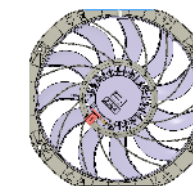
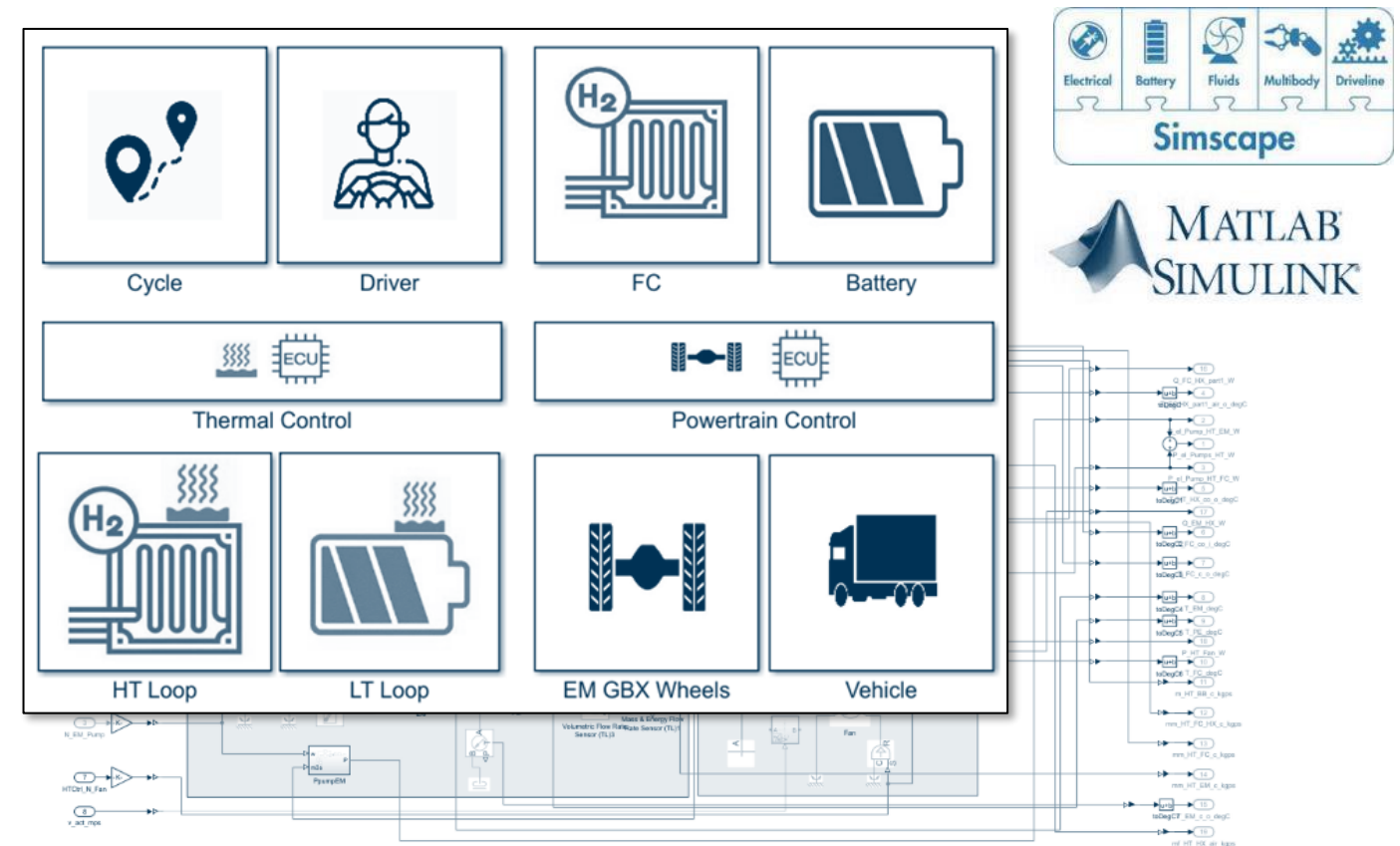
- Fuel Cell System 2x150 kW @ BOL
- 900 kW Electric Motors, 220 kW Pump
- 95 kWh Li-Ion NMC battery (2030 scenario)

- Short/long term C-rate: 10/5

Energy Management

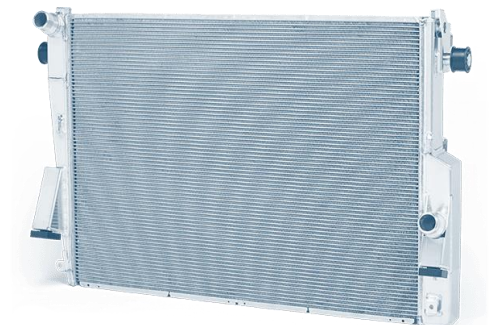
- FC thermal derating control
- SOC-sustaining control

High and Low Temperature Cooling Loops

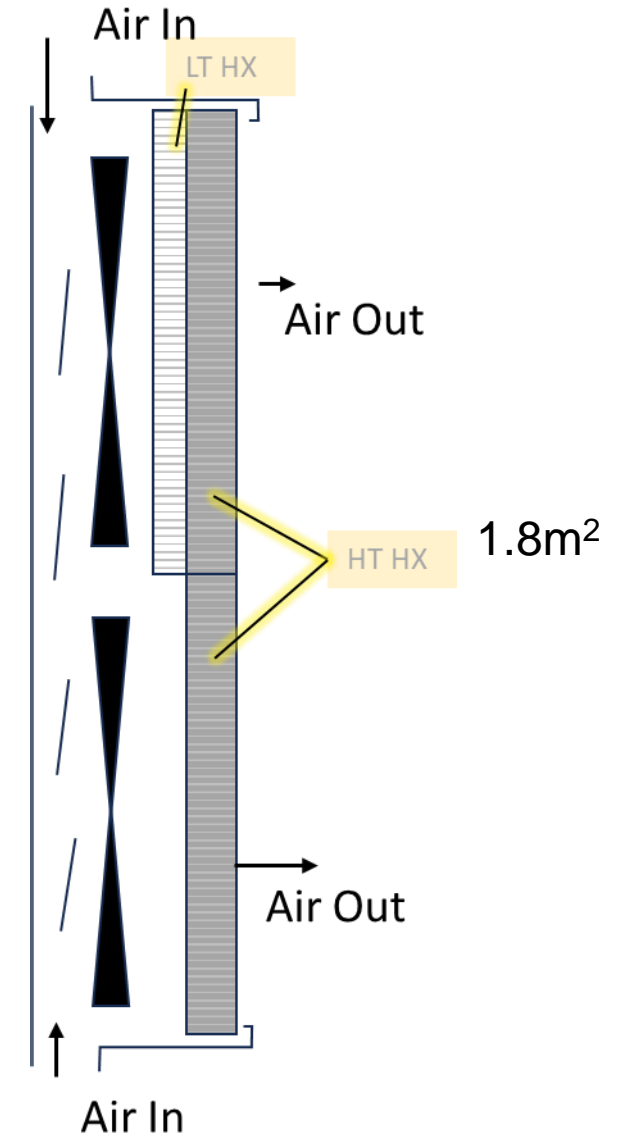
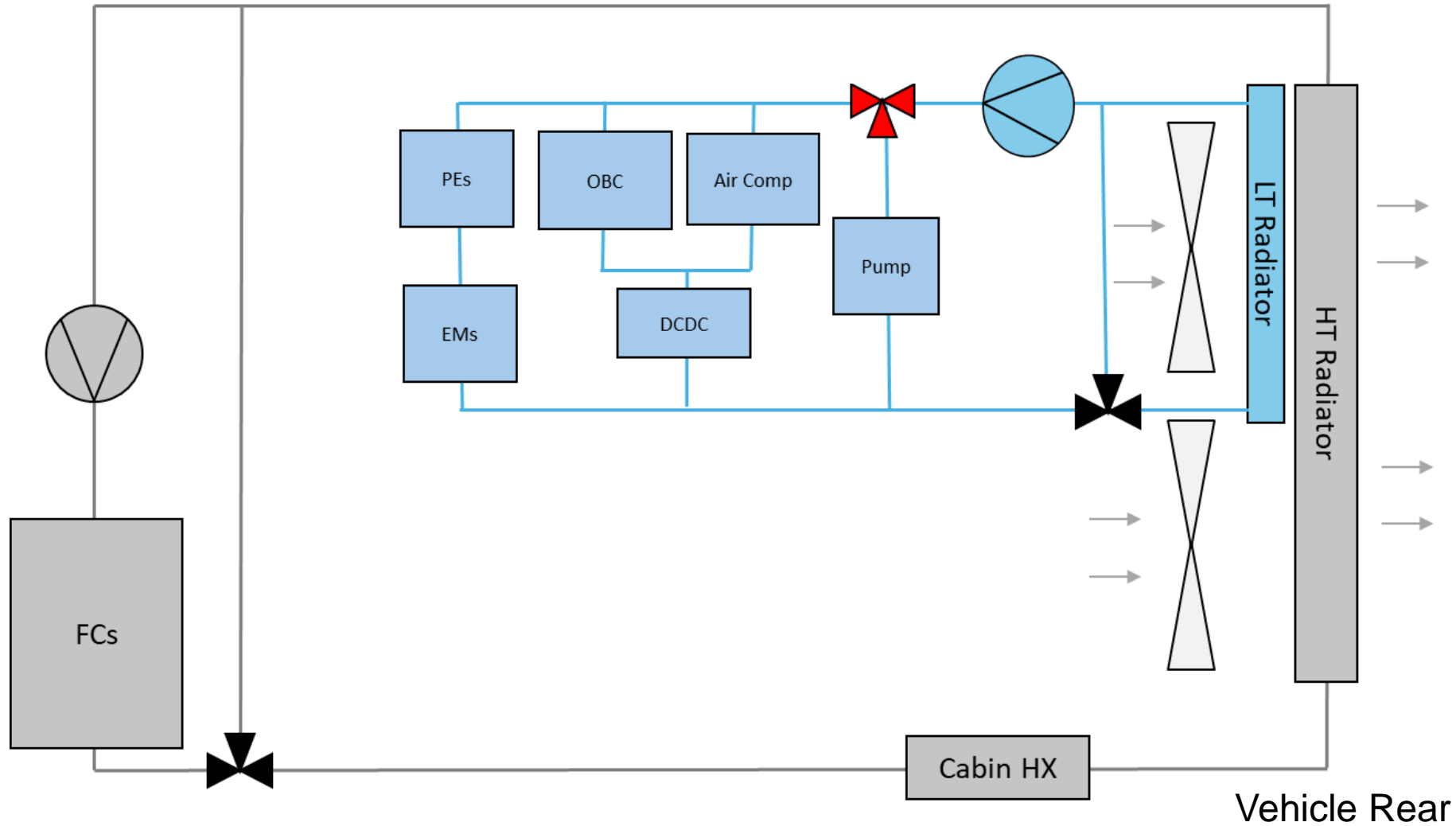


HV-fan

© Borg Warner



HX

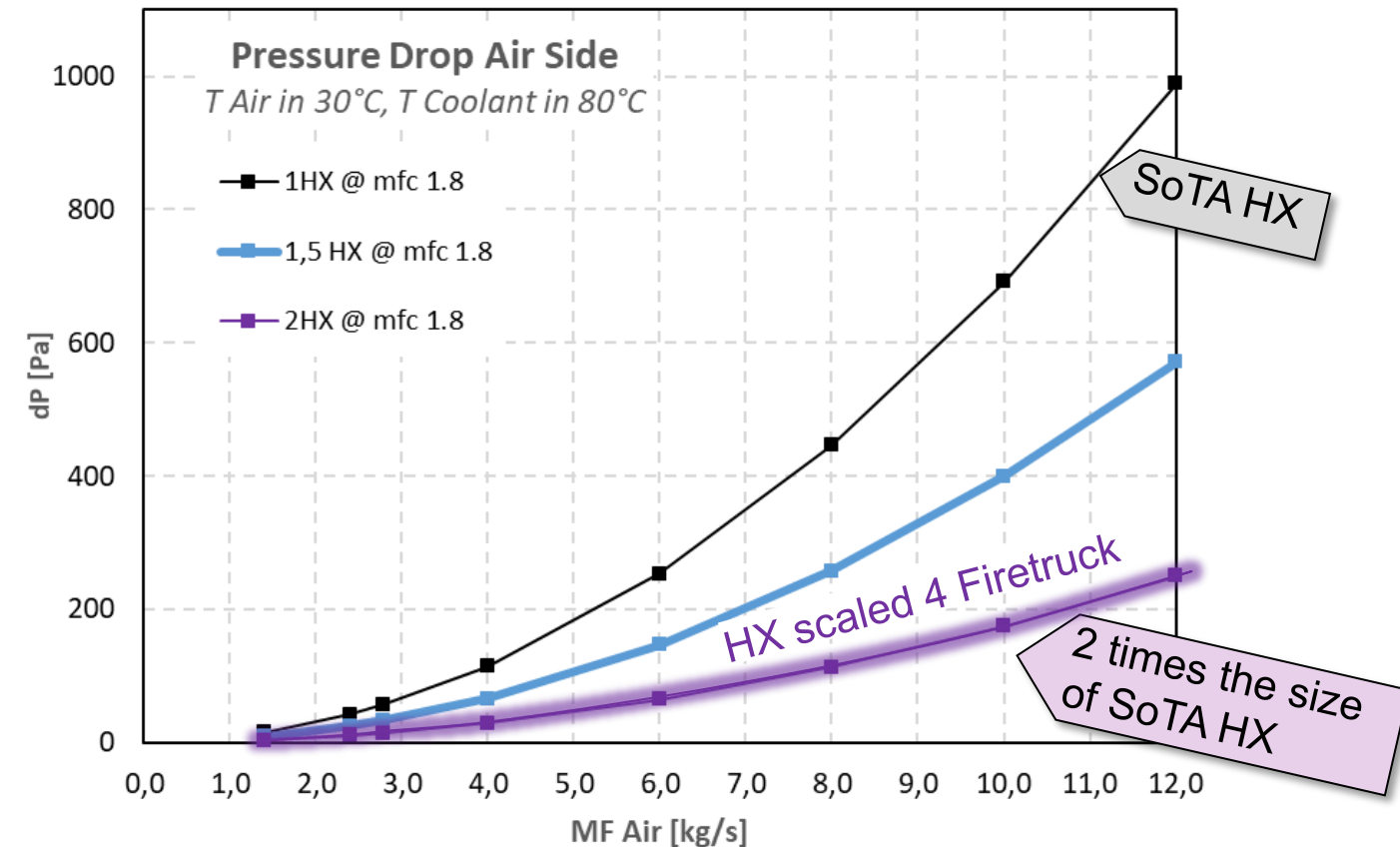
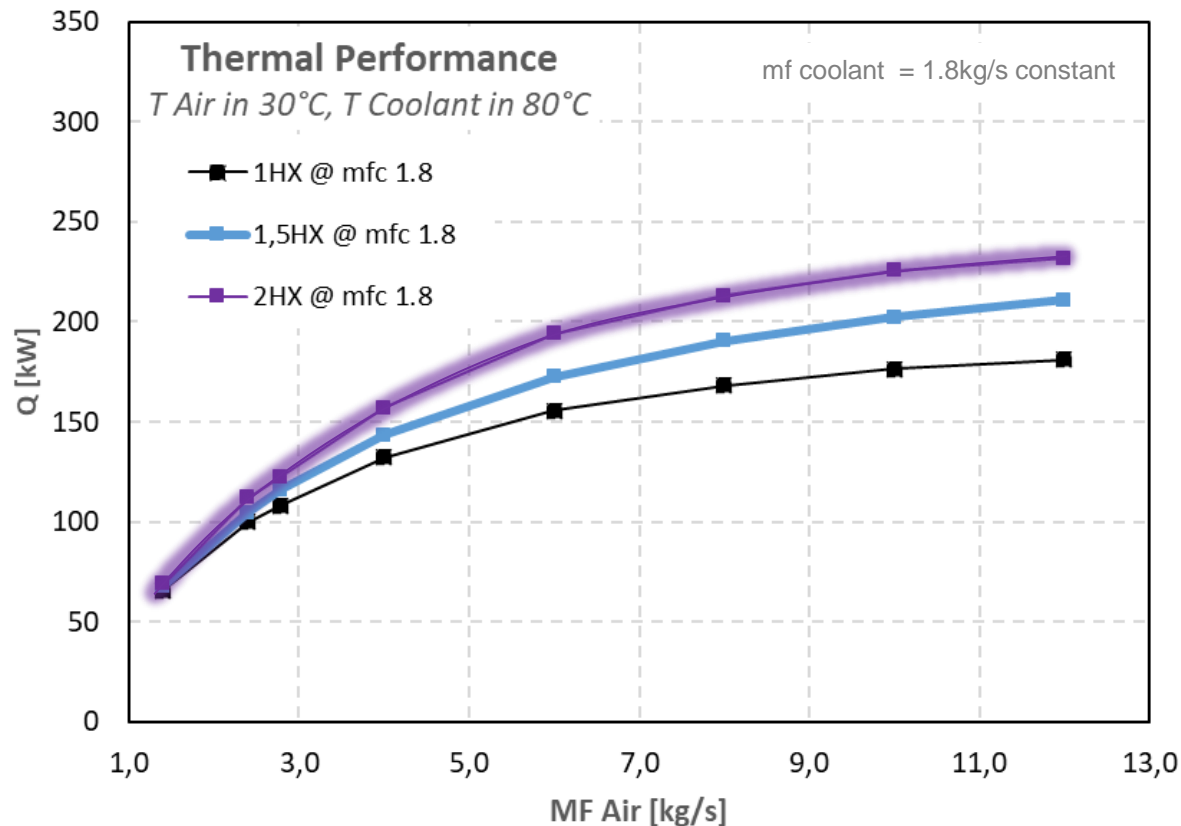


HX Configuration (Side View)

Results from HX characterization

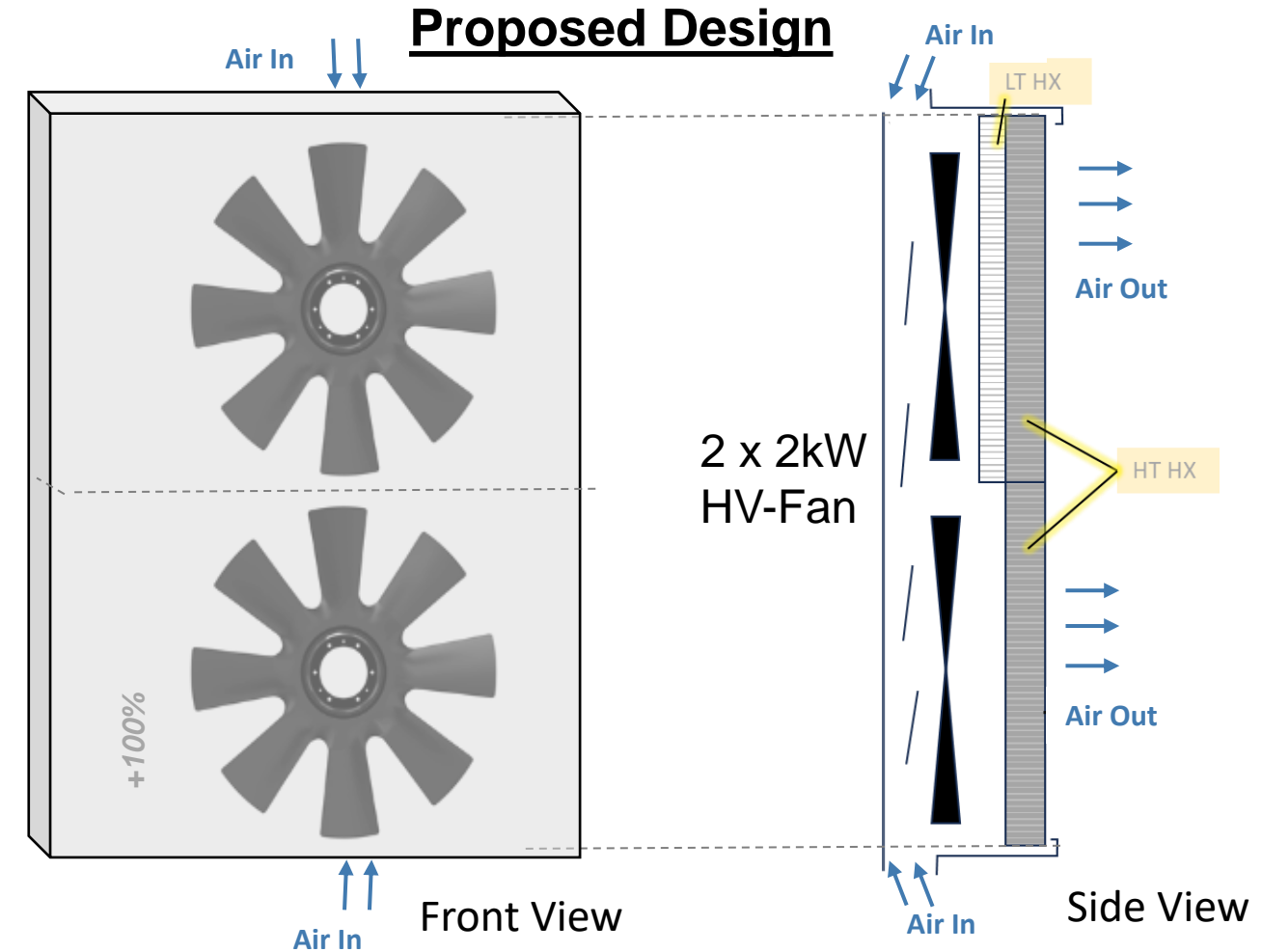
- Thermal performance
- Pressure drop air & coolant

Exponential pressure drop increase on air side → limited by required fan power





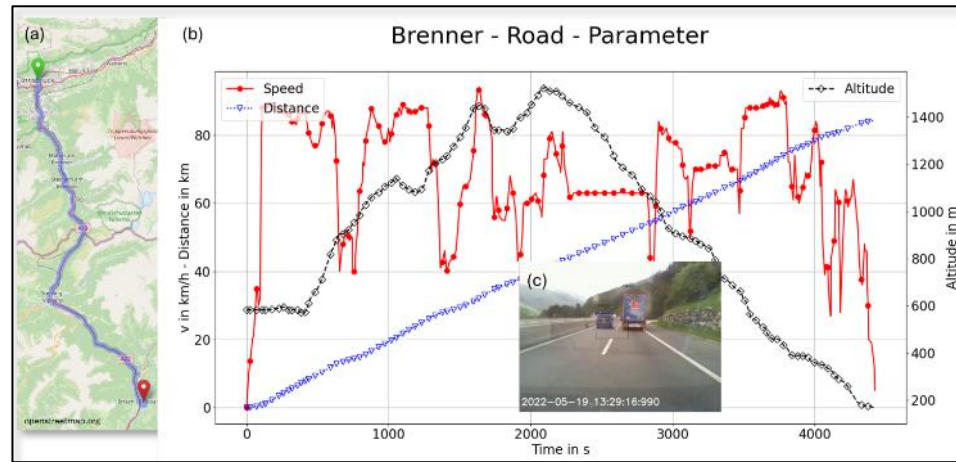
<https://30yearspanther.rosenbauer.com/en/everything-on-line/>



Engineering Target:

ThMgt design should fulfill 5 scenarios up to 43.3°C T Ambient without (major) derating:

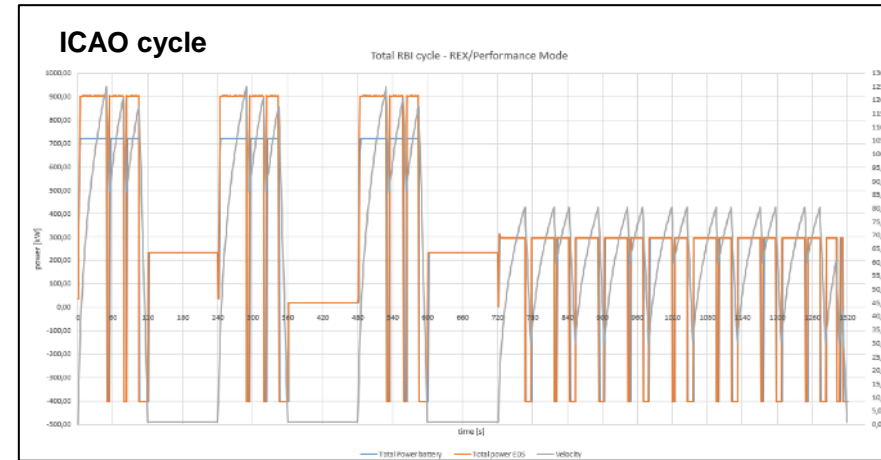
RBI Cycle, RBI Transfer Cycle, NFPA 414, NFPA 1901, Brenner Highway Cycle



Brenner Highway Cycle

85km, 1h13min

574m → 1375m

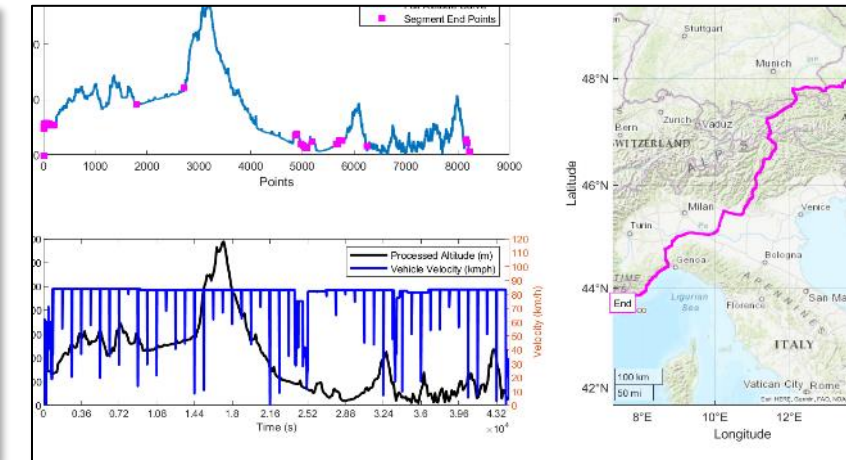


ICAO Cycle

>900kW Power Peaks

No derating allowed @

T Amb = 43,3°C and 50°C.



Transfer Cycle

1000km at 80km/h

without firefighting water

NFPA 414 Cycle:

Minimum energy content valid for ARFF, long-term pump operation for 2h @220kW + driving for 48.3km @88.5km/h

NFPA 1901 Cycle:

Minimum energy content valid for municipal trucks, long-term pump operation for 2.5h @210kW

Results: RBI Cycle @ 43,3°C T Ambient & EOL

Target Vehicle Velocity:

Achieved very well

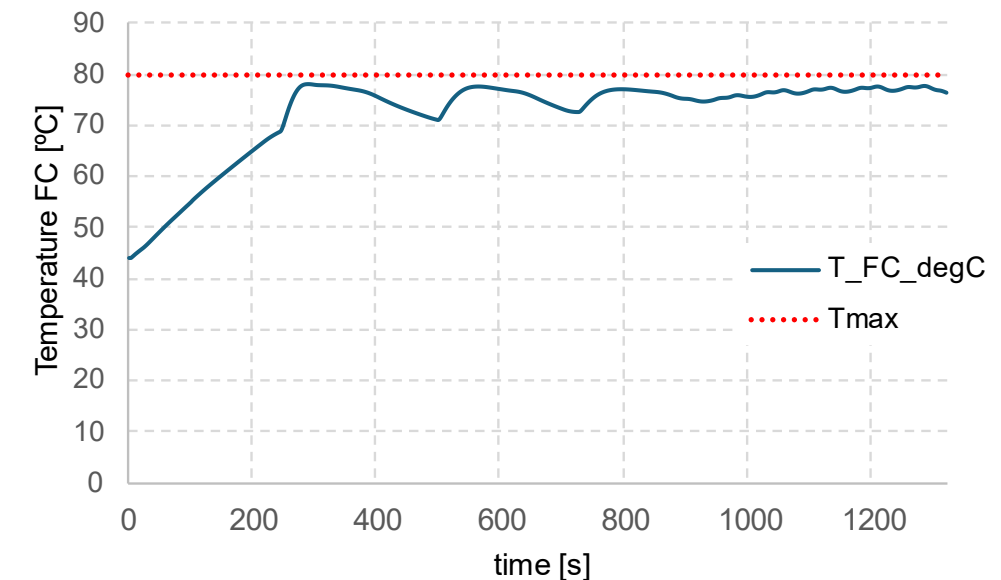
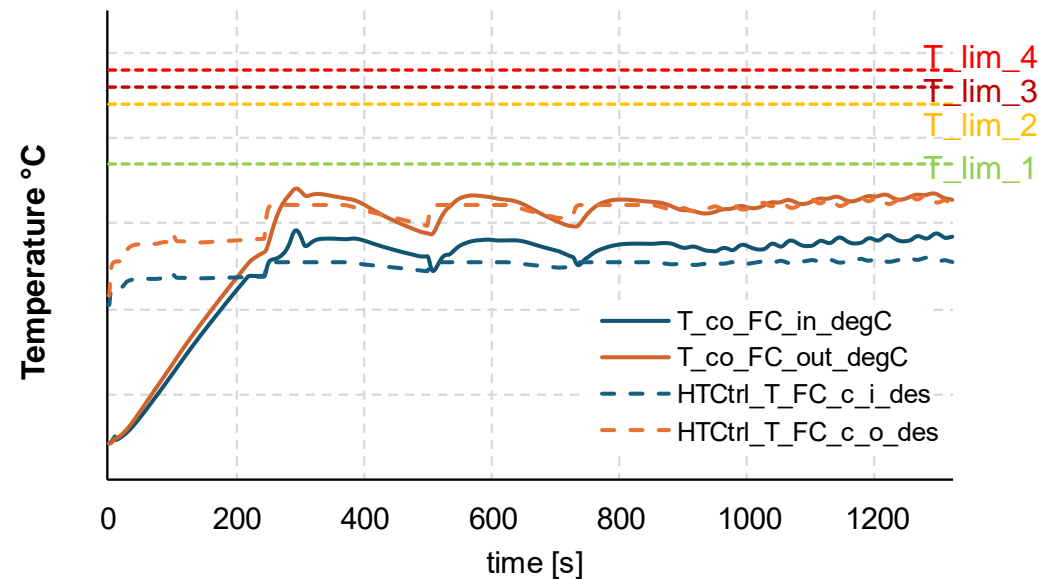
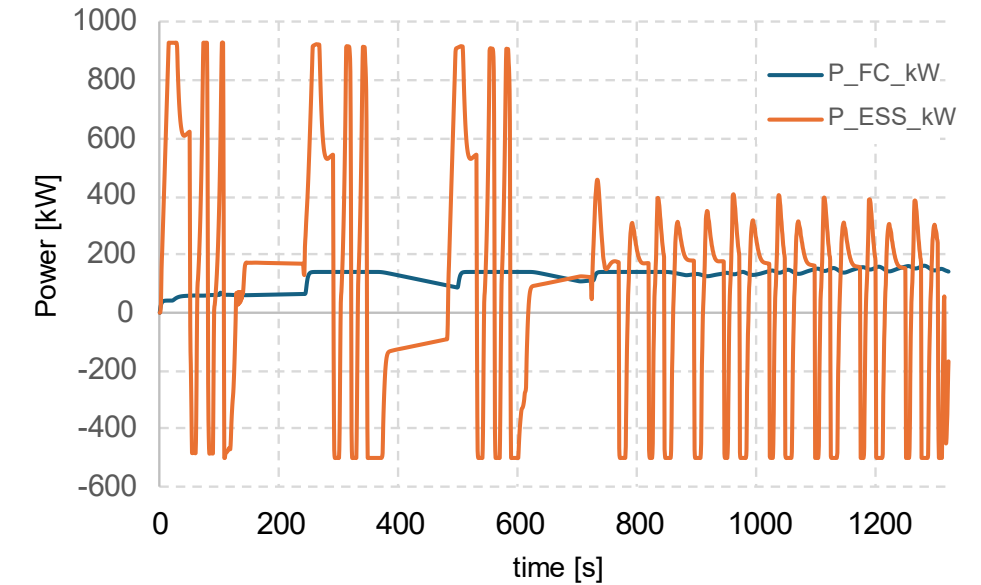
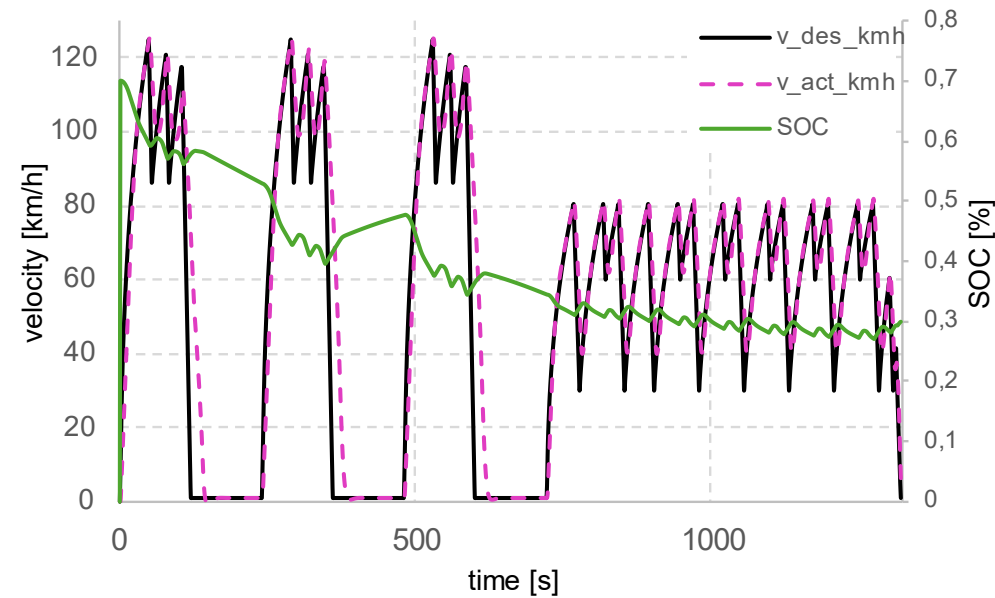
Target Coolant Temp.:

Achieved mostly well

FC-Derating:

No

The most important cycle for Rosenbauer at harshest conditions can be achieved very well



Results: NFPA 414 Cycle @ 43,3°C T Ambient & EOL

Target Vehicle Velocity:

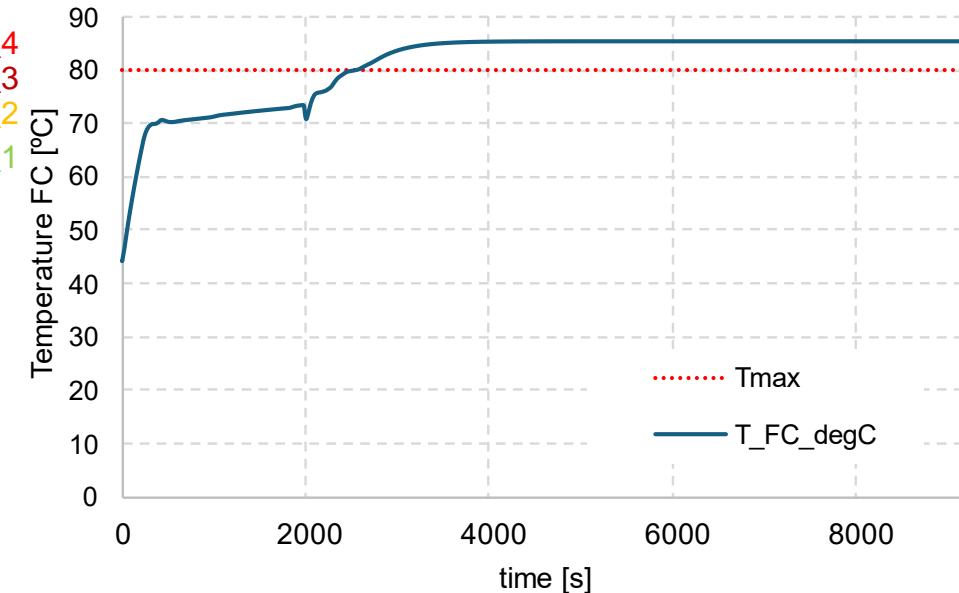
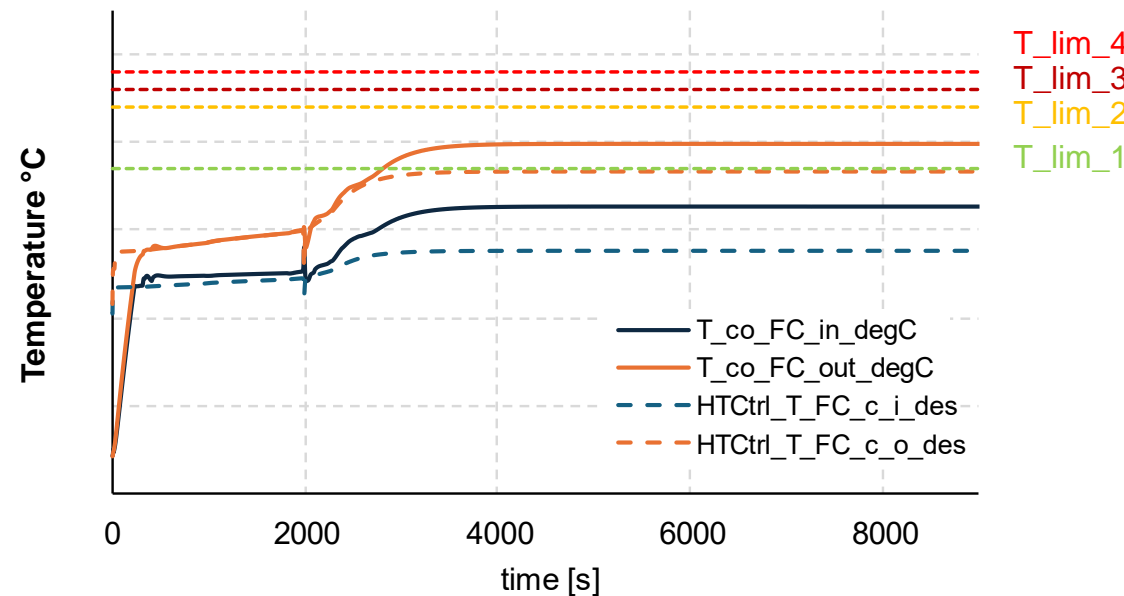
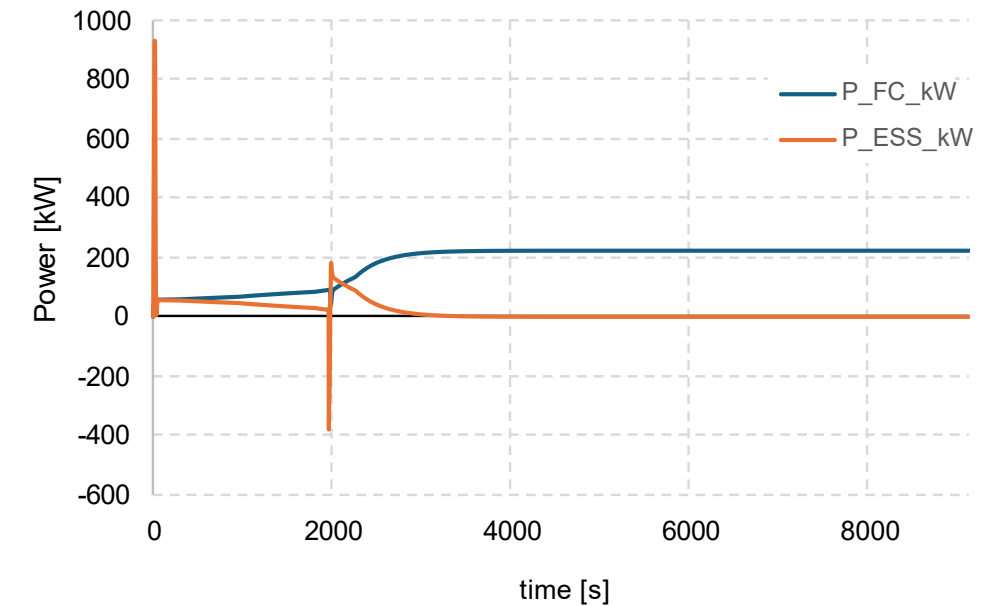
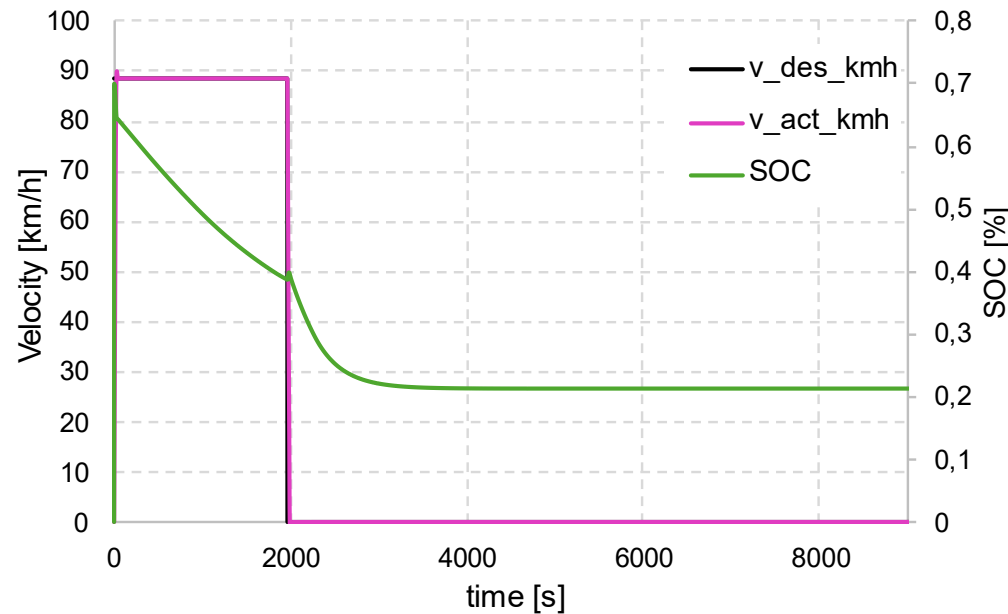
Achieved very well

Target Coolant Temp.:

Higher, but below threshold

FC-Derating:

No (Inlet Temp. below Threshold)



Results: NFPA 1909 Cycle @ 43,3°C T Ambient & EOL

Target Vehicle Velocity:

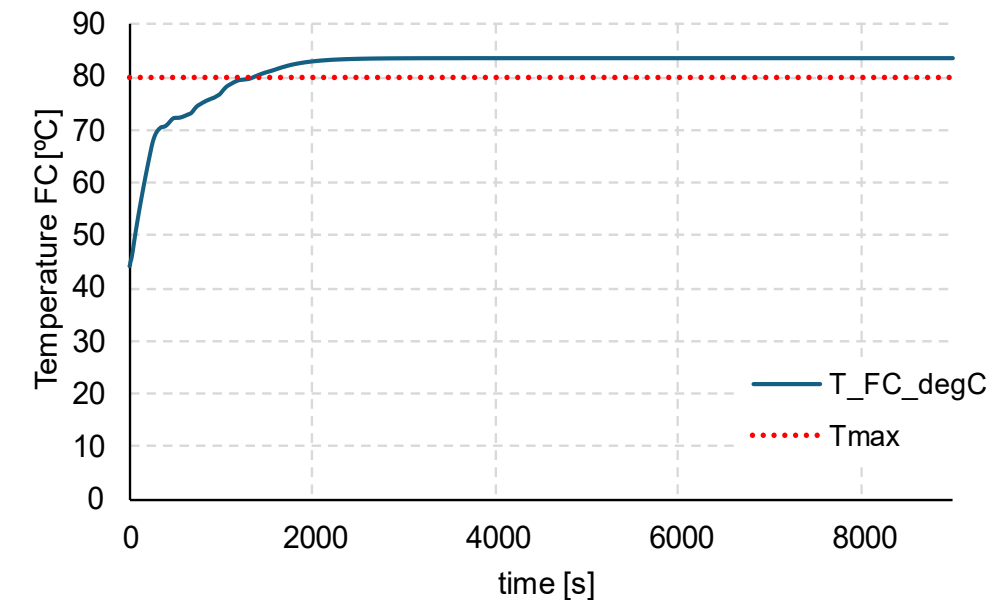
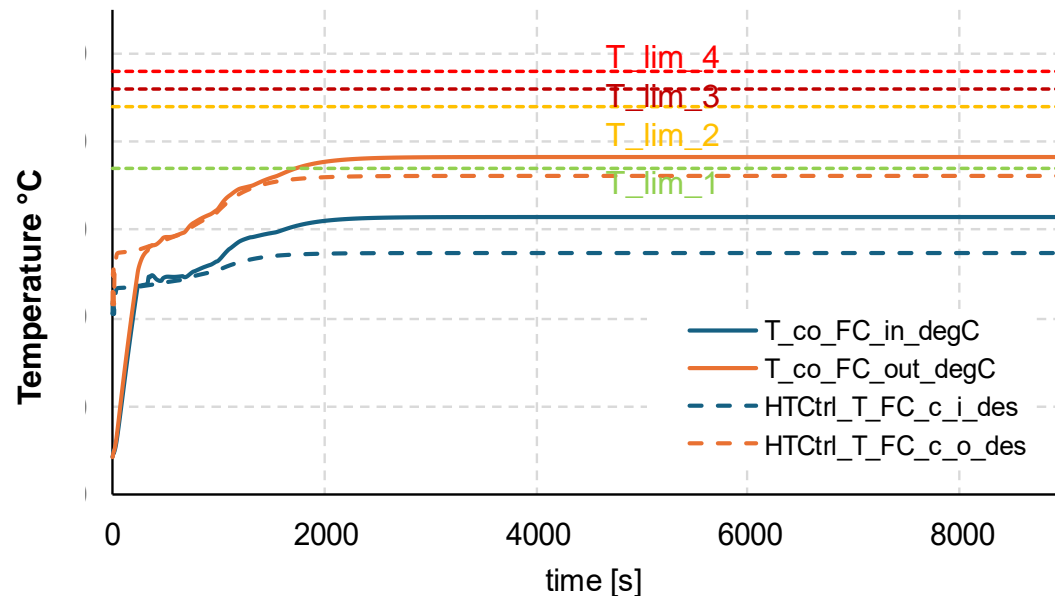
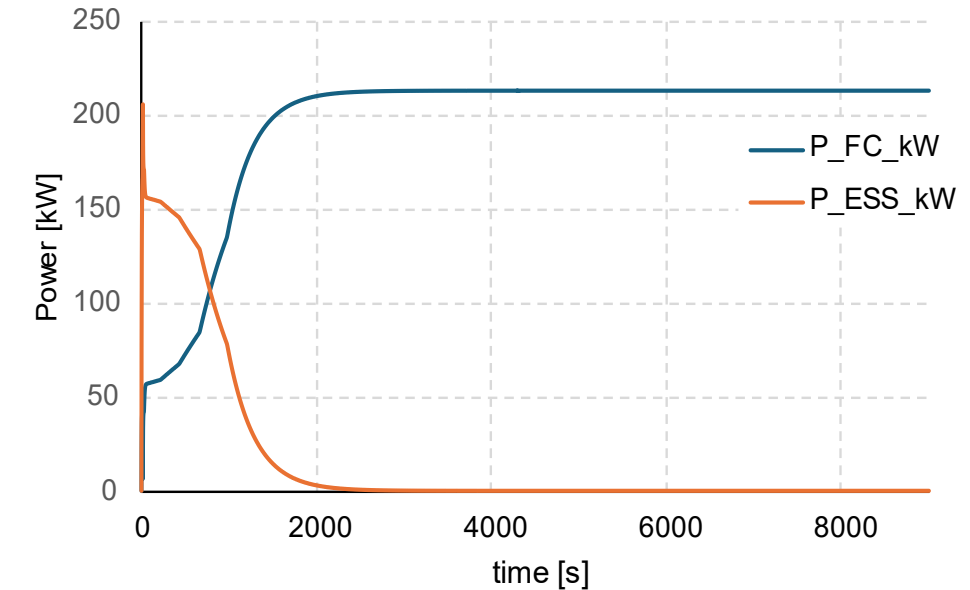
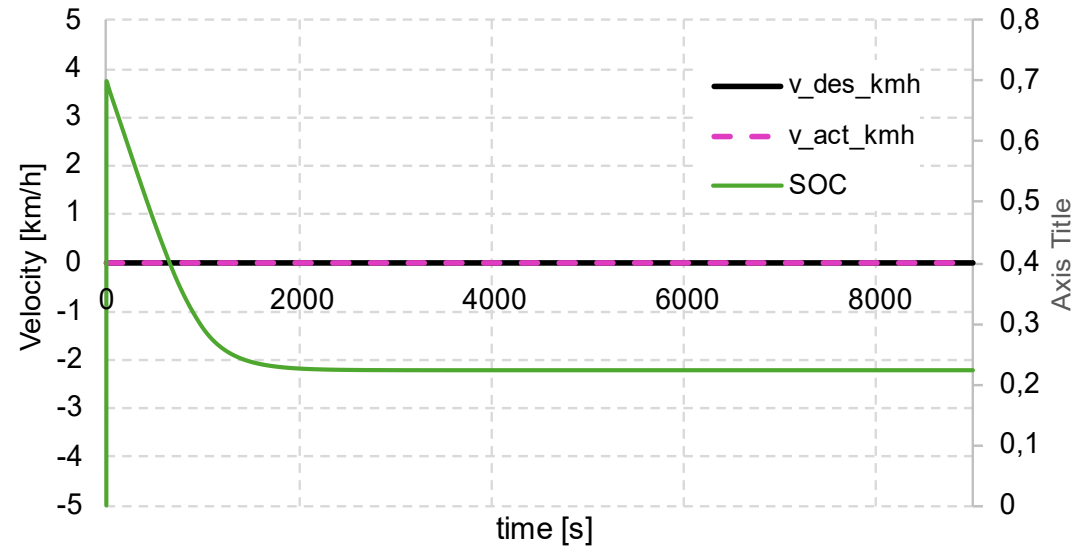
-

Target Coolant Temp.:

Higher, but below threshold

FC-Derating:

No (Inlet Temp. below Threshold)



Results: Brenner Highway Cycle @ 43,3°C T Ambient & EOL

Target Vehicle Velocity:

Achieved with some deviations
→ More fluctuations happen

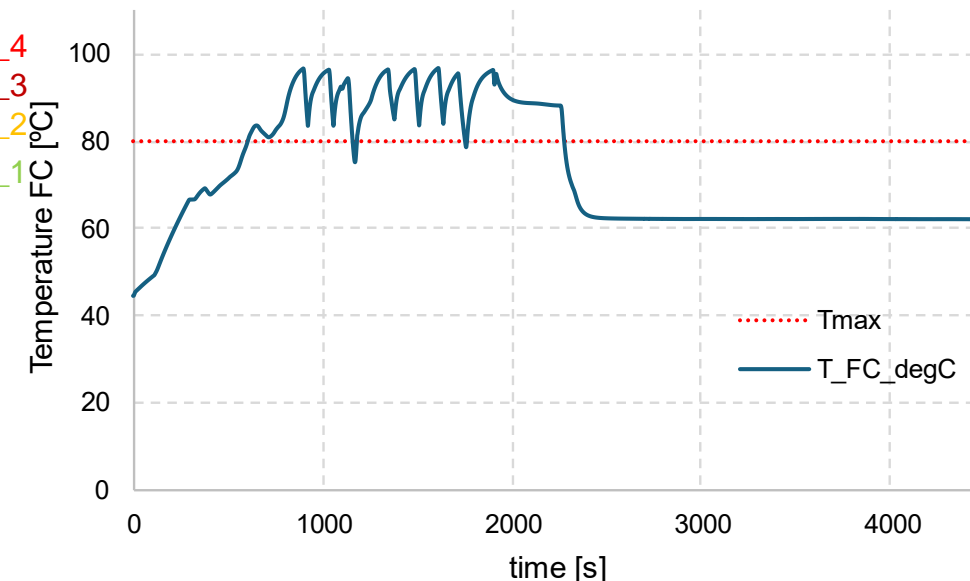
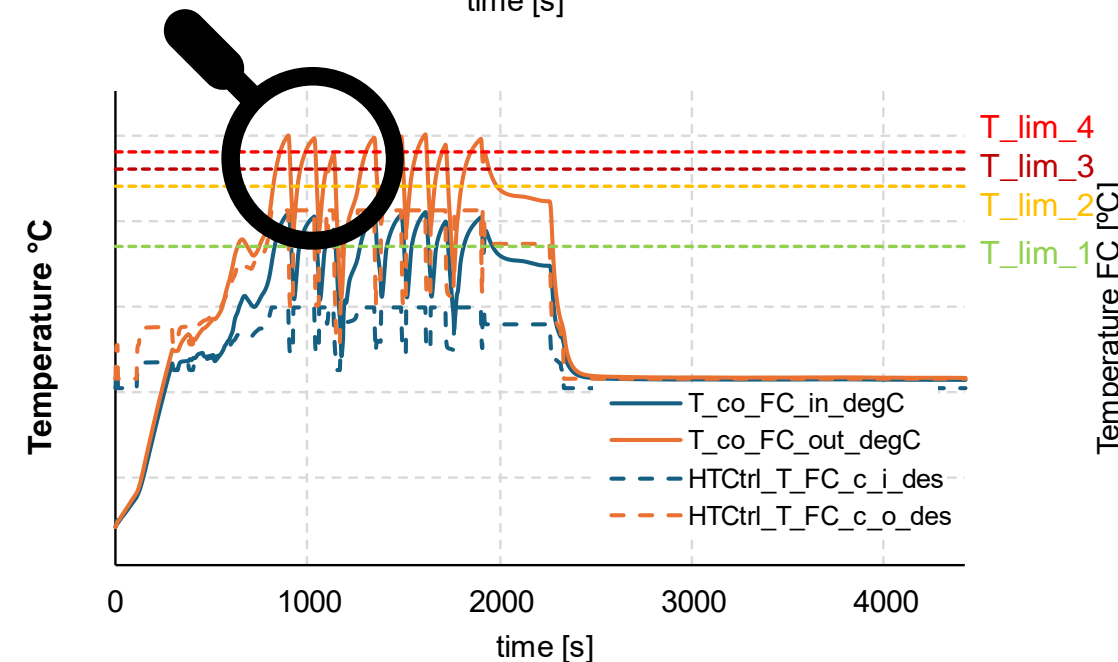
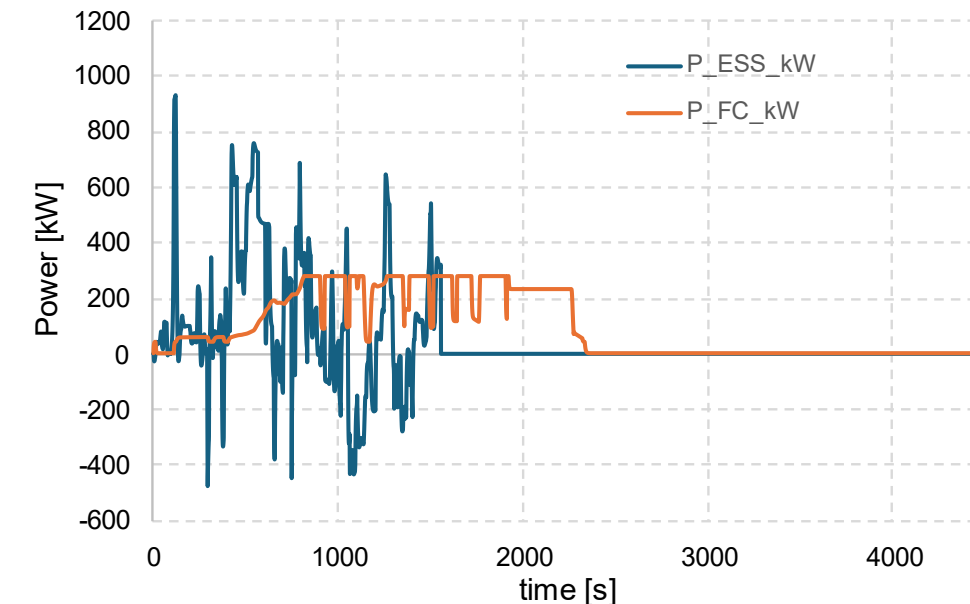
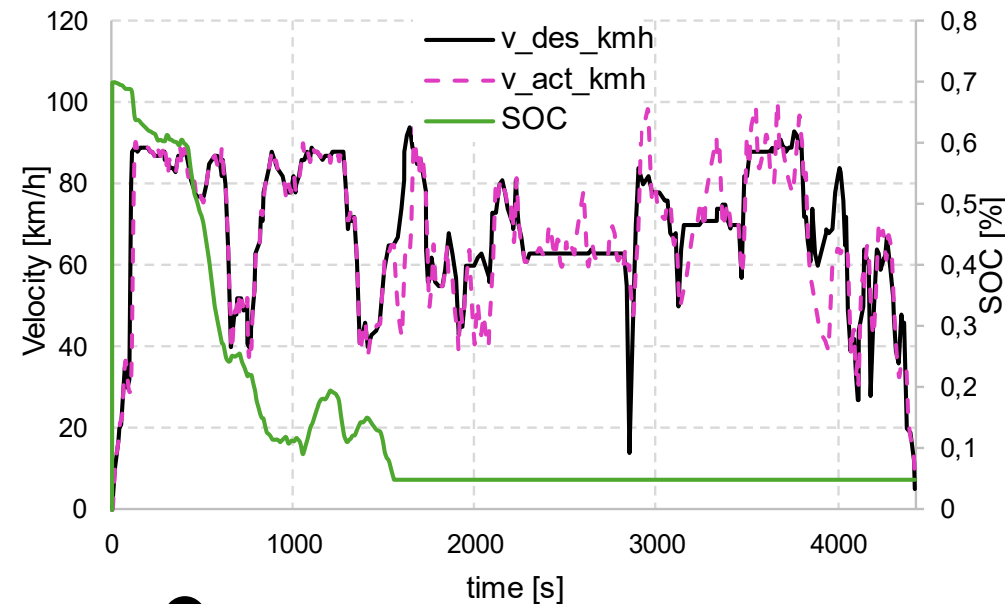
Target Coolant Temp.:

Higher and above Threshold 1 and 2

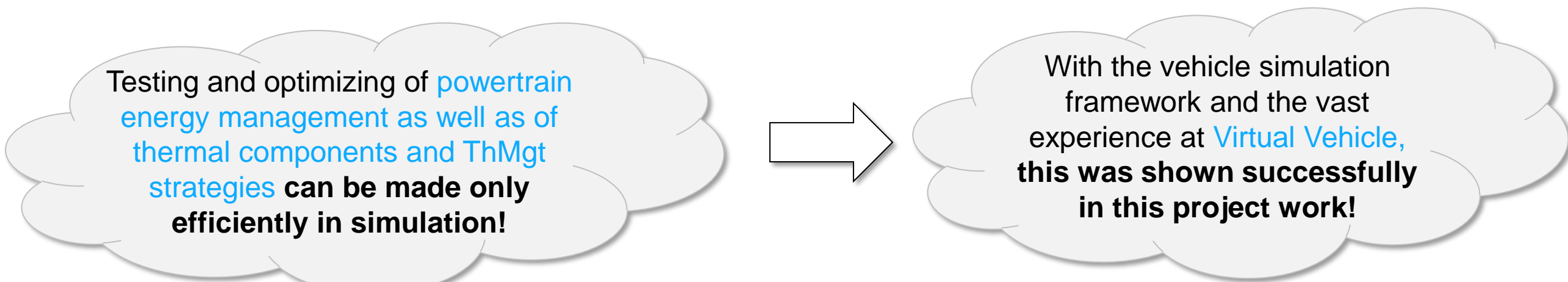
FC-Derating:

Yes, Temp. immediately drops

Btw: Brenner @
43.3°C is rather
unusual, but
achievable



- Different CO₂-reduction-initiatives are appearing in EU, requesting zero emission airports
- **ARFF vehicles** have **huge power and energy demands** requiring FC-based energy backup systems
- Concept for Rosenbauer Panther Electric: **2x150kW FC** and **95 kWh battery** (C-rate: 10/5)
- **FC HX size of 1.8m²** was finally identified with different cycle & scenarios
- Making sure of enough air mass flow with **2x 2kW HV-Fans** (no driving wind, HX is in the rear of vehicle)
- **Influence of the battery on FC-system** and hence on the heat losses is very significant (size and C-rate)
- A good powertrain energy management has huge influence on vehicle performance and thermal design aspects



Testing and optimizing of **powertrain energy management as well as of thermal components and ThMgt strategies** can be made only **efficiently in simulation!**

With the vehicle simulation framework and the vast experience at **Virtual Vehicle**, **this was shown successfully in this project work!**

THANK YOU!

Christian Doppler
christian.doppler@v2c2.at

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HyFiT partners



AC agility consulting

+2 associated
partners



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