Eco-Mobility 2024

Development and Field Test of a Fuel Cell Electric Tractor

TECHNISCHE UNIVERSITÄT WIEN

FCTRAC

Fuel cell tractor
fuelled with biogenic hydrogen

IFA Institut für Fahrzeugantriebe & Automobiltechnik

Johannes Konrad

Outline

Zero Emission Powertrains for Agricultural Tractors

Development of Fuel Cell Electric Powertrain

- Thermal System
- Hydrogen Storage System

Vehicle Benchmarking and Field Test

Conclusion and Outlook

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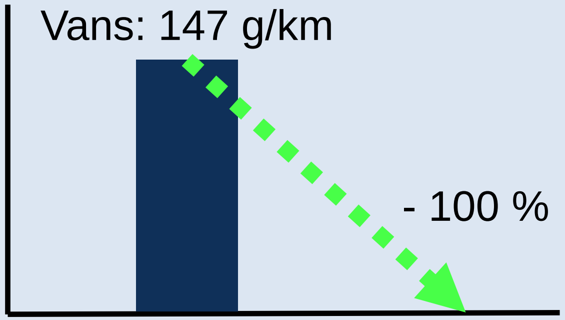
Zero Emission Powertrains for Agricultural Tractors
Framework Conditions

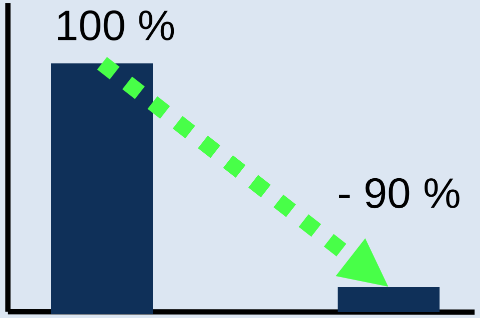
- Global efforts to limit climate change by reducing emissions of greenhouse gases
- **Legally binding climate targets** covering all key economy sectors:
  - **Paris Agreement:** hold average temperature increase to well below 2 °C above pre-industrial levels
  - **European Green Deal:** no net emissions of greenhouse gases by 2050

(Proposed) European CO_2 emission restrictions

Personal Cars and Vans



Heavy Duty Vehicles
(adopted)



Non Road Mobil Machinery

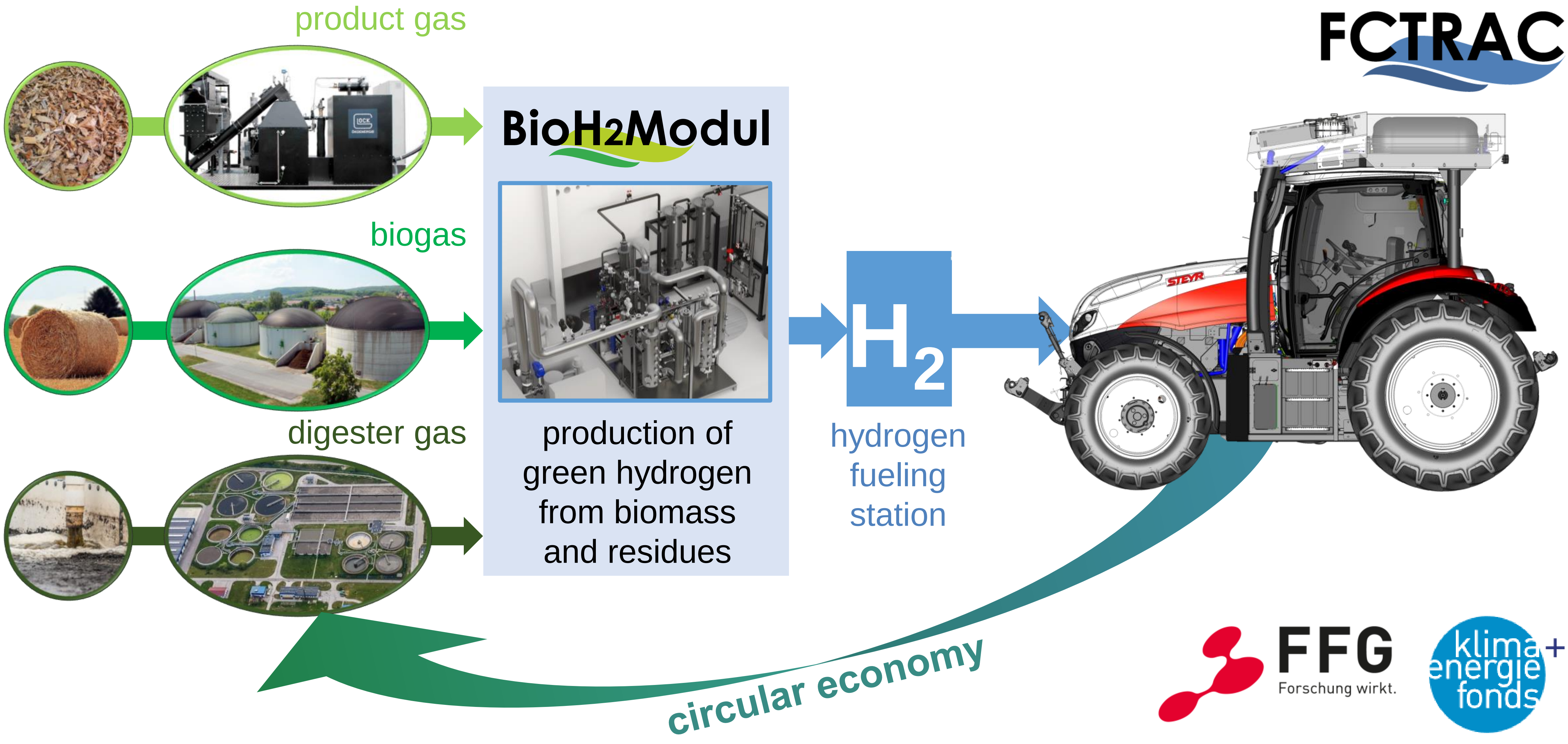
Which emission- & CO_2-regulations will be proposed?

How will the future powertrain portfolio be composed?

→ To fulfil the legally binding climate targets: **On-, Off-, and Non-Road Powertrains need to become sustainable**

→ Non Road Mobil Machinery / Agriculture: **Competitive and sustainable zero emission powertrains are necessary**

Zero Emission Powertrains for Agricultural Tractors
Project Concept: FCTRAC and BioH2Modul



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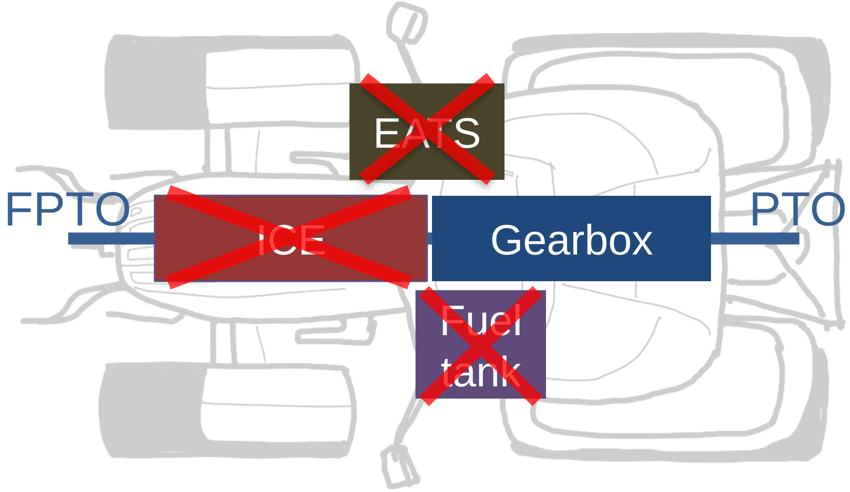
Development of Fuel Cell Electric Powertrain
Donor Vehicle and Powertrain Development Targets

FCTRAC donor vehicle
STEYR 4130 Expert CVT
rated power: 95 kW


[Picture: CNH]

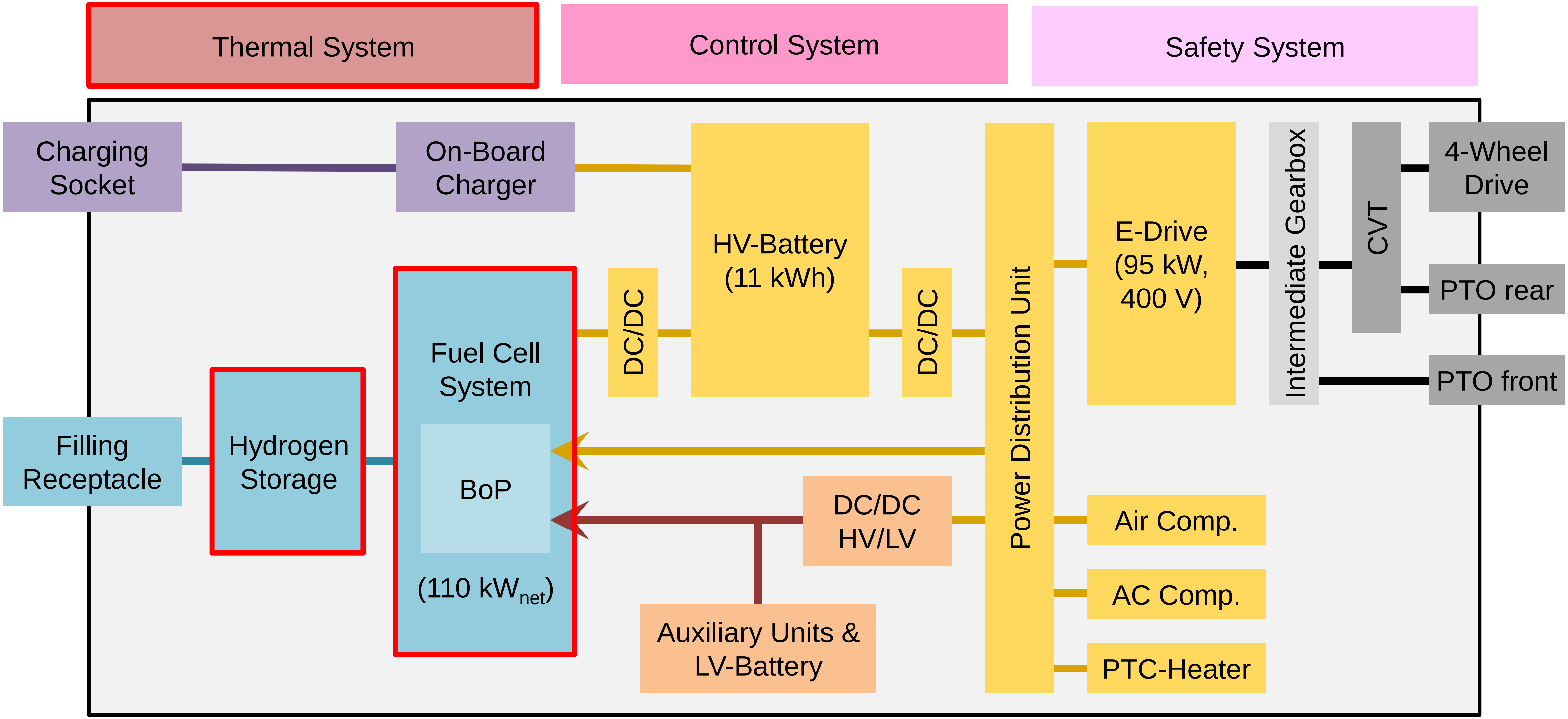
FCTRAC Basis:



Main development targets of FCTRAC powertrain:

- **Comparable performance to donor vehicle**: constant max. power of 95 kW & no derating up to 35 °C ambient temperature
- **Sufficient energy on board:** acceptable operation range and fast H_2 refueling
- **Driver's field view unchanged:** compact packaging

Development of Fuel Cell Electric Powertrain
System Architecture



Cooling of Fuel Cell System

PEM fuel cell system (110kW)

PEM stack

Electrochemical reaction
$2H_2 + O_2 \rightarrow 2\ H_2O$

- High-purity hydrogen
- Filtered air

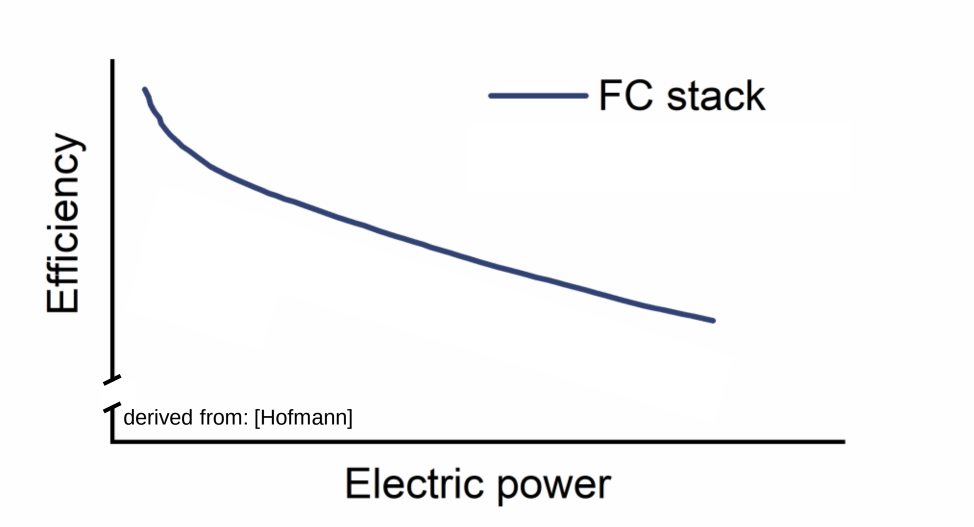
Operation temperature:
~ 80 °C

Balance of Plant (BoP)

- Hydrogen supply
- Air supply
- Water management
- Thermal system
- Control system

Operation temperature:
~ 60 °C

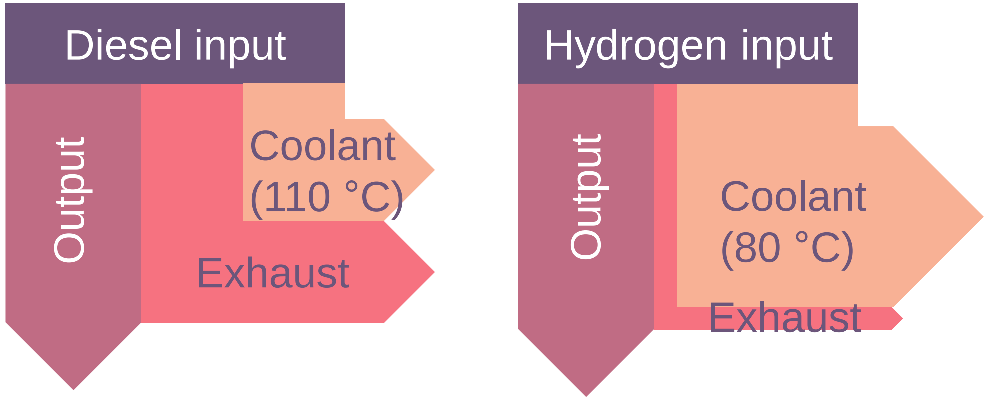
PEM fuel cell system efficiency

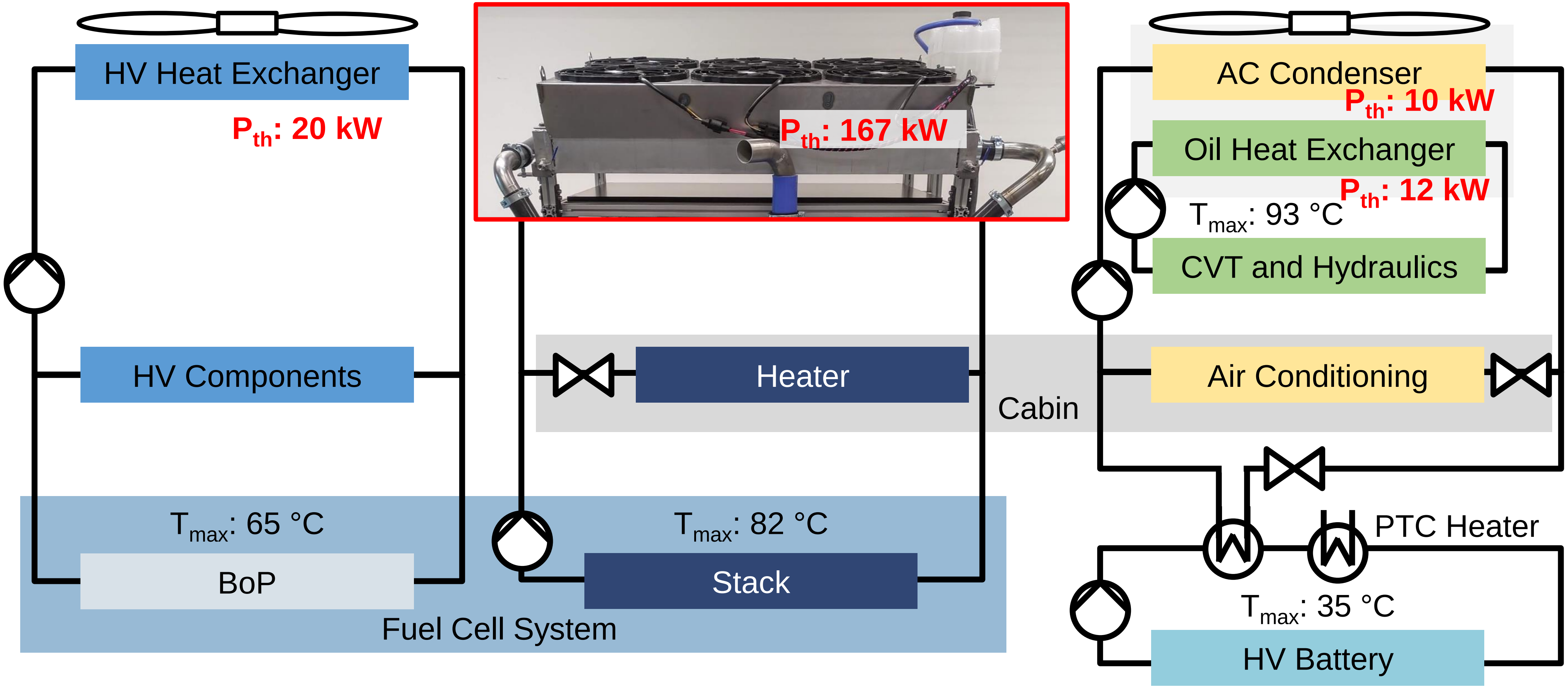


PEM fuel cell coolant system:

- Live parts of PEM stack are directly cooled:
  → Coolant liquid must be **electrically insulating**
- **Uniform operation conditions**: minimal temp. difference between stack outlet and inlet
- **Worst-case scenario at full-load:**
  waste heat approx. 50 % increased compared to diesel engine of donor vehicle

Energy-flows: ICE vs. PEM-FC



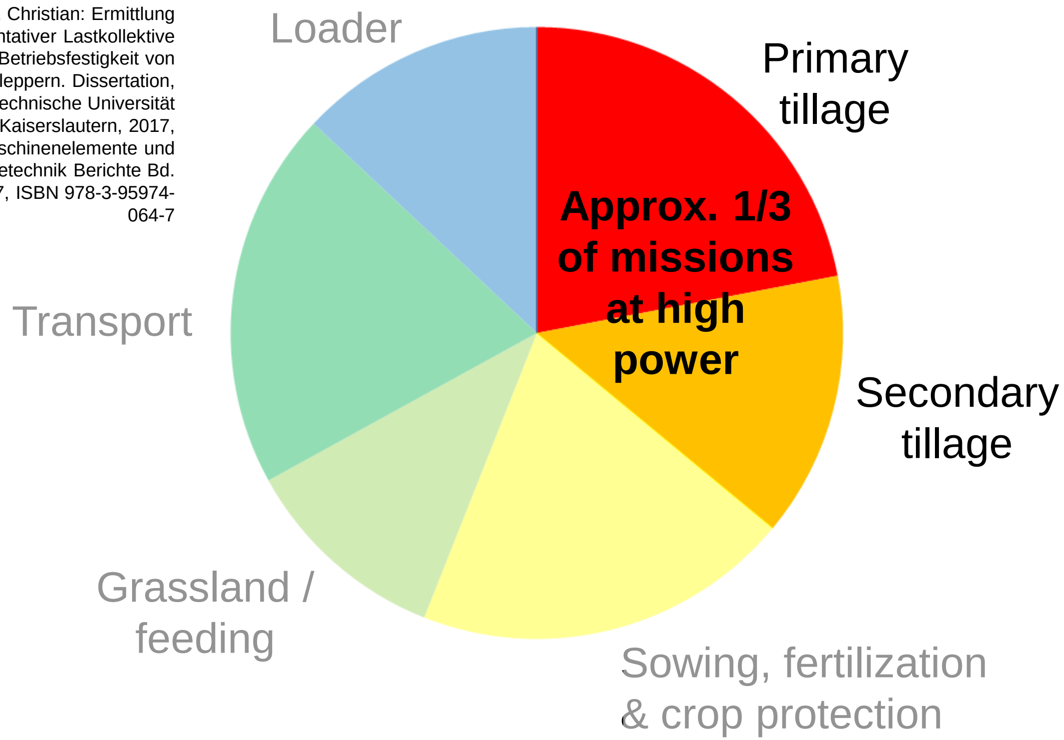


- Maximum dissipated waste heat: 209 kW
- FC heat exchanger volume approx. 2.3 larger than of diesel engine
- FC heat exchanger does not fit below hood → roof top solution developed

Hydrogen Storage System: Scaling

Average mission profile – percentage:
(vehicle class: 110 kW, farm size: 50-200 ha)

Eckstein, Christian: Ermittlung repräsentativer Lastkollektive zur Betriebsfestigkeit von Ackerschleppern. Dissertation, Technische Universität Kaiserslautern, 2017, Maschinenelemente und Getriebetechnik Berichte Bd. 26/2017, ISBN 978-3-95974-064-7



→ **High energy amount necessary**

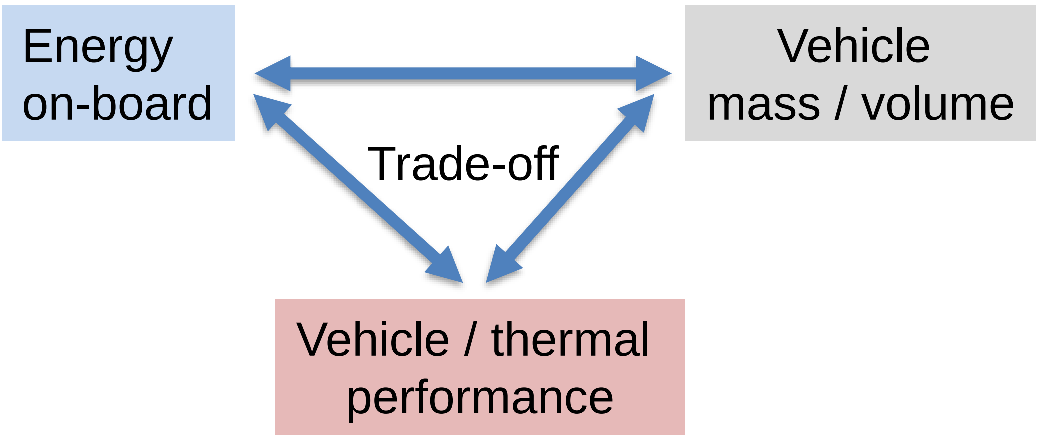
→ High power of coolant system necessary

Without high power coolant system: strong restrictions!

Compressed 700 bar hydrogen storage system:

- Reduced storage density compared to conventional liquid fuel
- Gravimetric energy density: at least more than 4 times higher than Li-Ion HV-batterypacks
- Applied in series produced personal cars
- Refueling time comparable to diesel-vehicle
- Cylindrical pressure vessels → roof top solution

Basic scaling of hydrogen storage system:



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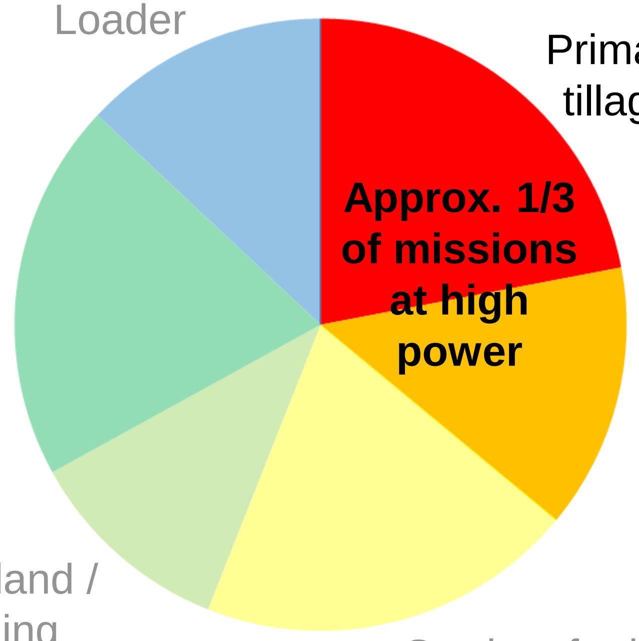


→ **High energy amount necessary**

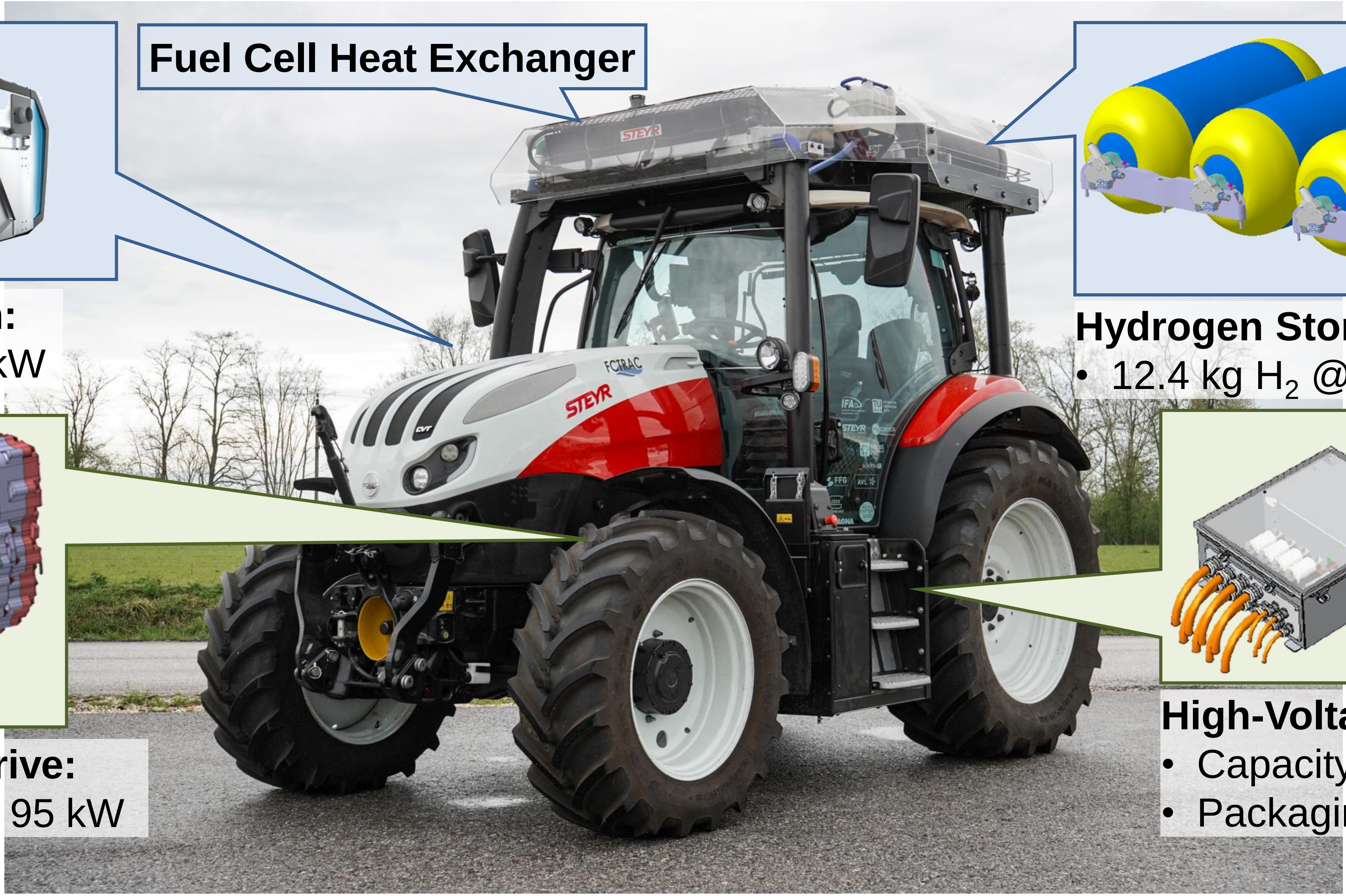
→ High power of coolant system necessary

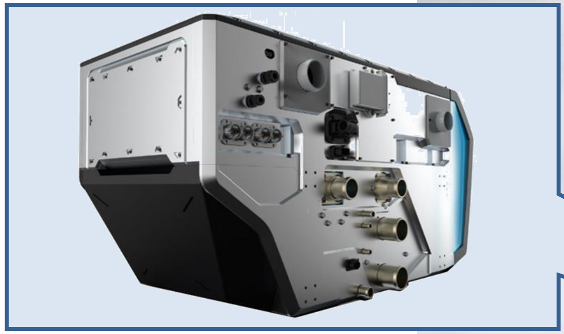
Without high power coolant system: strong restrictions!

Design of compressed 700 bar hydrogen storage system:

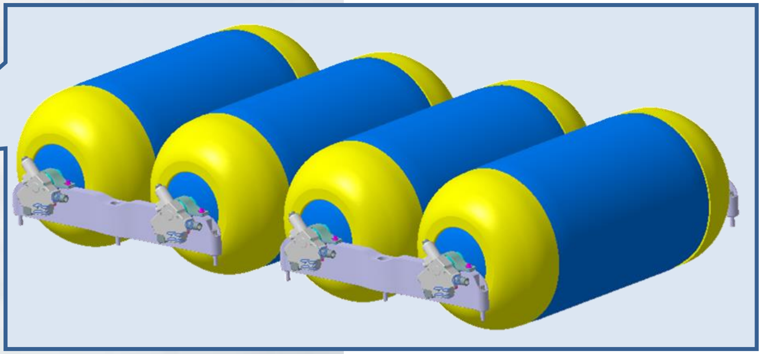
- 4 tanks with capacity of 12.4 kg hydrogen / 413 kWh of energy (approx. 43 L Diesel equivalent)
- Sufficient energy on board for mixed applications at medium load
- Operation at high load:
  - Fast refueling at BioH2Modul at farm
  - Future fleet solution: mobile refueler that provides hydrogen at operating side

Test Bench Validation of Powertrain
Packaging



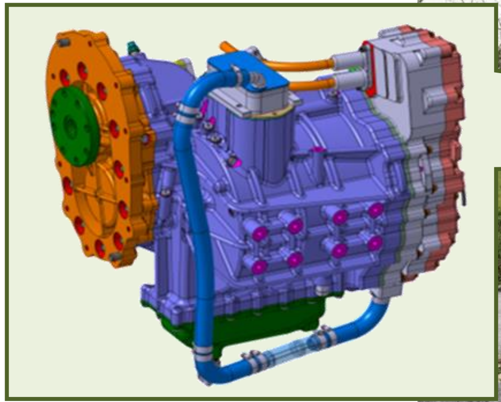


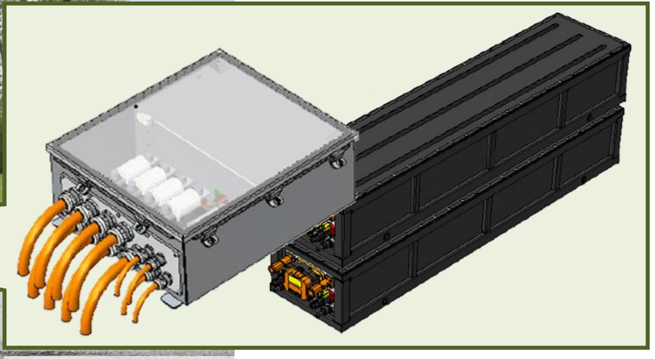
Fuel Cell Heat Exchanger



Fuel Cell System:
- Net power 110 kW

Hydrogen Storage System:
- 12.4 kg H_2 @700 bar





Inverter and E-Drive:
- Constant power 95 kW

High-Voltage Battery:
- Capacity 11 $kWh_{useable}$
- Packaging fit to vehicle

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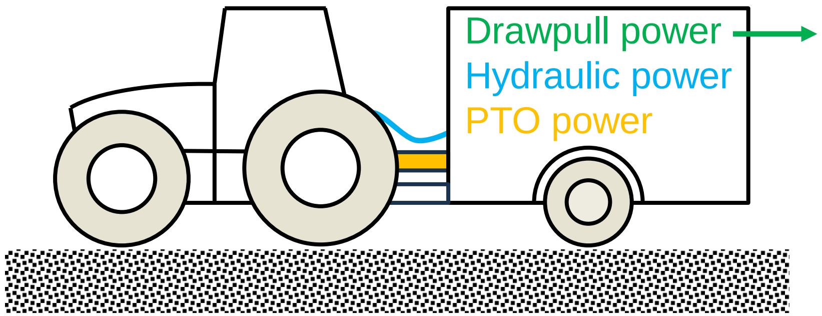
FCTRAC vs. Diesel-ICE-Vehicle: Benchmarking Setup

DLG-PowerMix Cycles:

- 14 standard cycles for agricultural tractors
- Replicate typical field and transport applications
- Hydraulic-, PTO- and drawpull-power requested



Test Setting:

- Testing with CNH´s mobile test rig by CNH: Simulation of farming cycles based on DLG cycles
- Reference vehicle STEYR 4140 Expert CVT (Model Year 2023) with identical rims and tires

Three Selected Test Cycles:

Harrowing (light)

- **Work:** Drawpull, PTO
- **Speed:** 9 km/h
- **Power:** medium

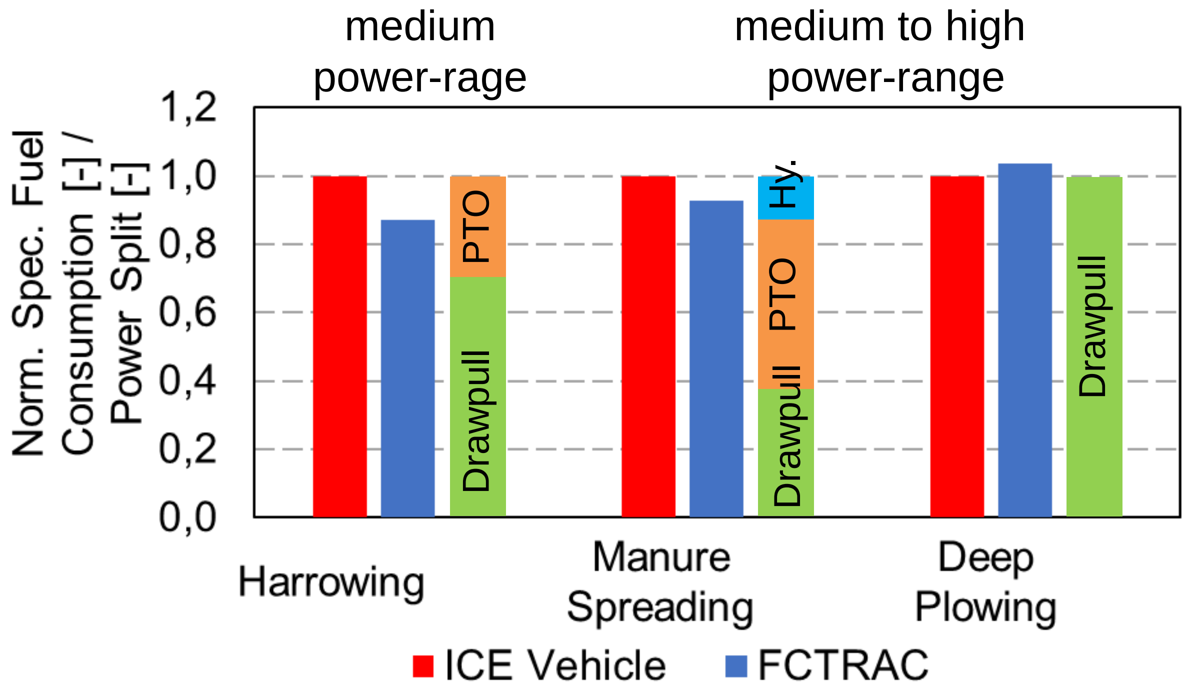
Manure Spreading

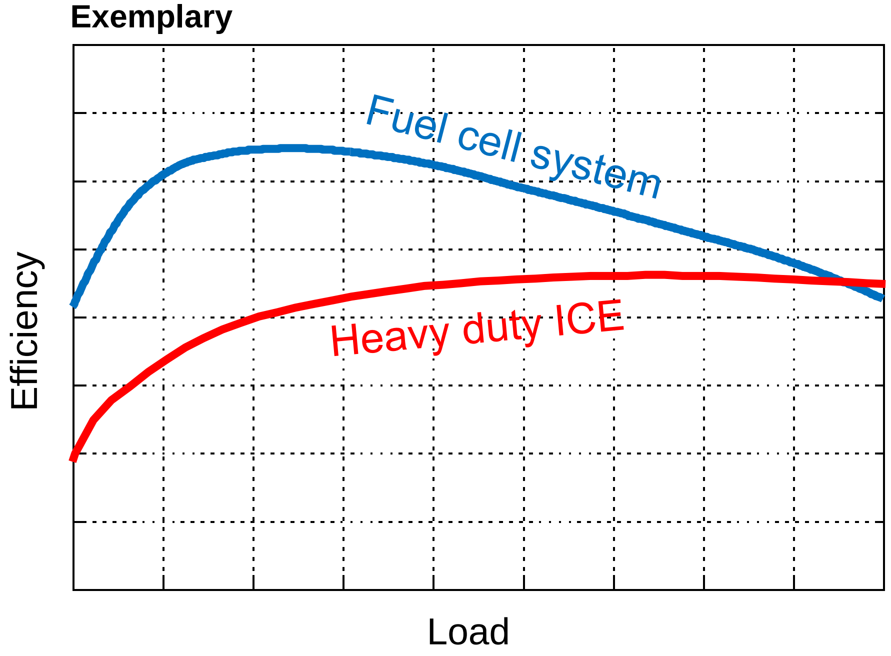
- **Work:** Drawpull, PTO & Hydraulic
- **Speed:** 7 km/h
- **Power:** medium - high

Deep Plowing

- **Work:** Drawpull
- **Speed:** 9 km/h
- **Power:** medium - high

Comparison of FCTRAC and Diesel-ICE-Vehicle:





- Opposed efficiency tendencies of ICE and FC
- FCTRAC has higher weight – increased rolling resistance and acceleration power demand
- Fixed CVT input speed – ICE efficiency significantly influenced
- Carry-over CVT without modifications (emulation of ICE behavior)

Potential: weight reduction, system architecture, operation strategy

Vehicle Benchmarking and Field Test
Field Test





Implement	**Cultivator**	**Disc Harrow**	**Rotary Harrow**	**Rake**	**Trailer (18 t) Hilly environment**
Avg. working speed	9.4 km/h	11.1 km/h	6.5 km/h	10.0 km/h	24.5 km/h
Avg. engine load	85 %	76 %	76 %	32 %	62 %

- FCTRAC with FC powertrain proved reliable operation in challenging environments
- FCTRAC (prototype vehicle) achieved comparable working performance to ICE-Diesel-Vehicle

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- **Fuel Cell Electric Powertrain for FCTRAC:**
  - Fuel cell system is main energy provider and HV-battery supports dynamics and allows battery-only operation
- **Thermal system:** Increased waste heat and at lower temperature levels compared to a diesel engine
  → **Fuel cell heat exchanger on roof top**
- **Hydrogen storage:** 700 bar compressed hydrogen storage system
- **Benchmarking against diesel vehicle:**
  - Reduced consumption in medium load range
  - Potential: weight reduction, system architecture, operation strategy
- **Field Test:**
  - FC powertrain proved **reliable operation** in challenging environments
  - **Comparable performance to diesel vehicle**
- **Outlook**
  - Further analysis and optimization with focus on powertrain architecture / software
  - Successor project in planning

This project is supported with funds from the Climate and Energy Fund and implemented in line with the "Zero Emission Mobility" program.

FCTRAC

Fuel cell tractor fuelled with biogenic hydrogen

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