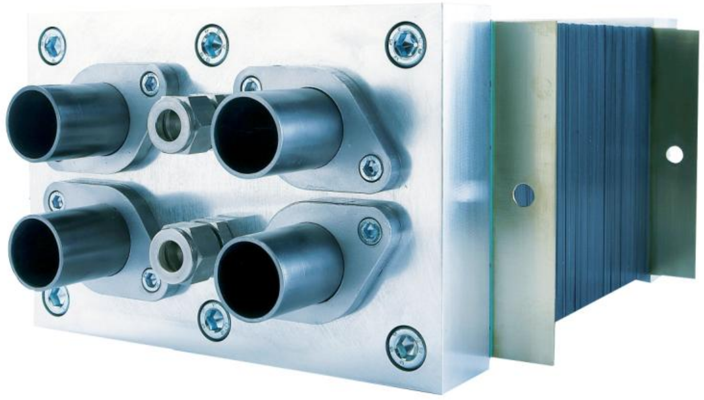
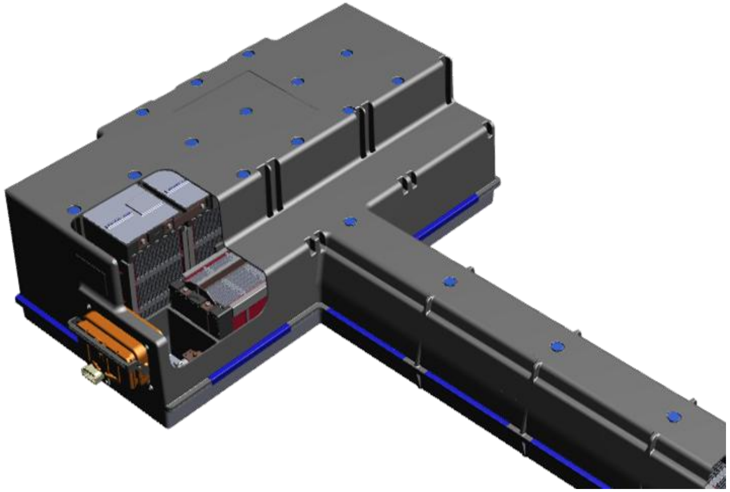


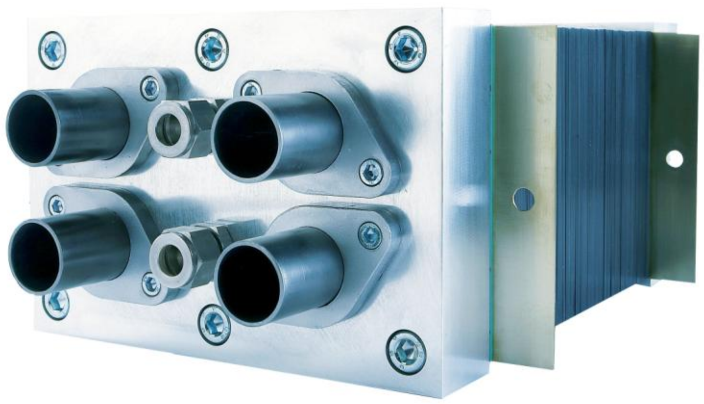
# Energiequellen für EVs: Brennstoffzelle und? - oder? Batterie

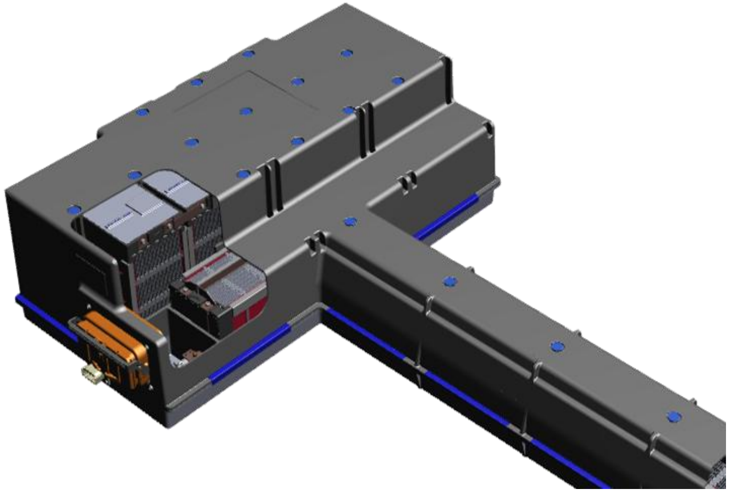


# Energy Sources for EVs: Fuel Cell and? - or? Battery

**Peter Prenninger**
AVL List GmbH

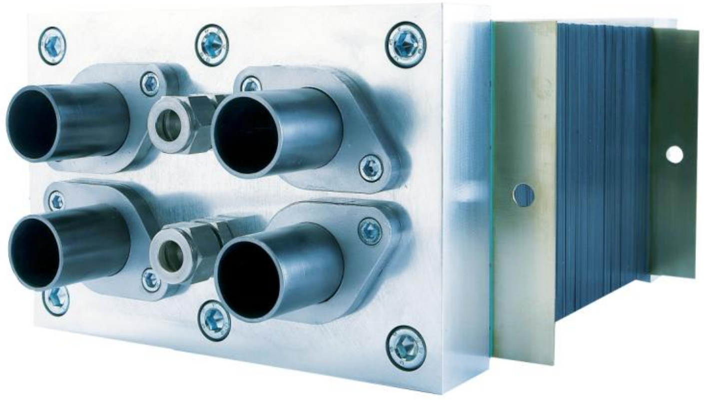
# CONTENT

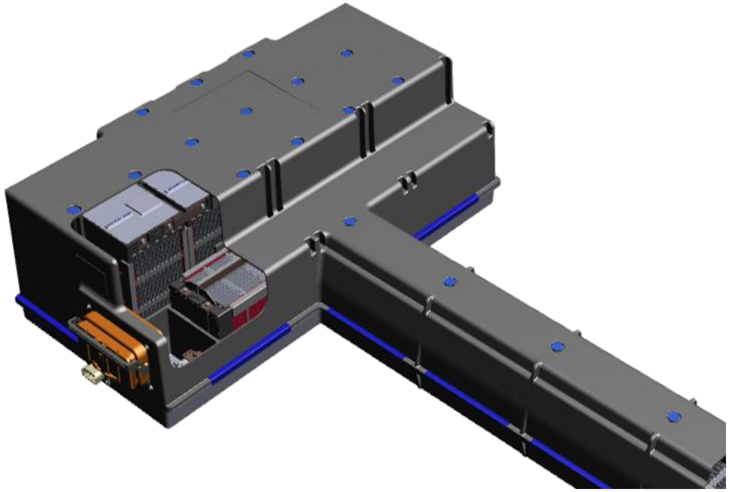




- **Fuel cell systems for automotive applications**
- **Braking energy recovery – general powertrain requirements**
- **Fuel cell – battery – hybrids for passenger car application**
- **Fuel cell – battery – hybrids for commercial transport applications**

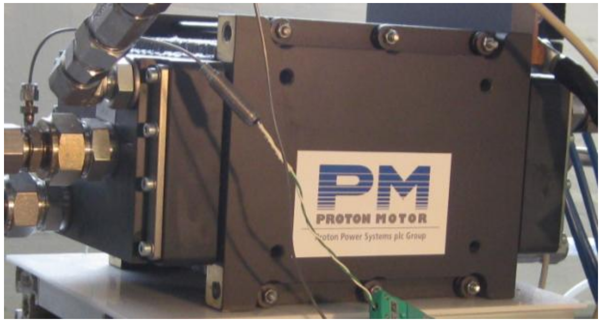
# CONTENT

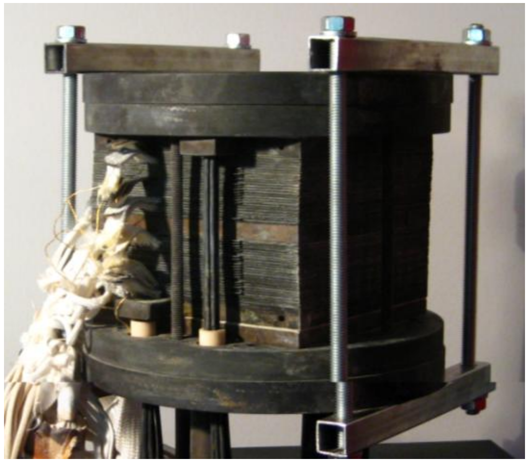




- **Fuel cell systems for automotive applications**
- **Braking energy recovery – general powertrain requirements**
- **Fuel cell – battery – hybrids for passenger car application**
- **Fuel cell – battery – hybrids for commercial transport applications**

# FUEL CELLS FOR AUTOMOTIVE APPLICATION



**Proton Exchange/Polymere Electrolyte Membrane Type**

- High efficiency particularly at partload (>> 50%)
- Pure H2 as fuel
- Operating temperature < 100 °C
- Main challenges: costs and durability

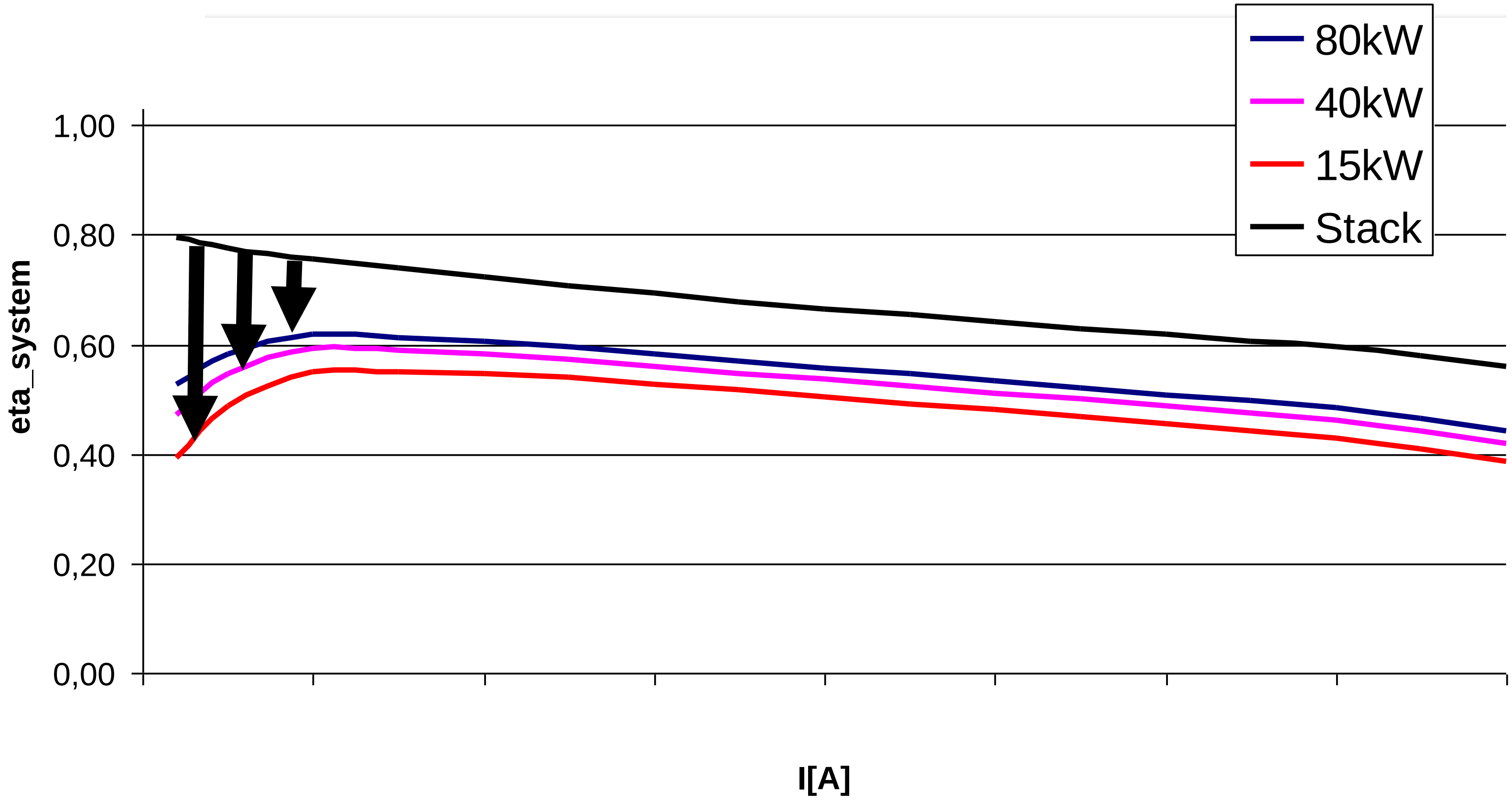
**High-Temperature PEMFC**

- Operating temperature 120-180 °C
- No humidification & water management
- Limited CO tolerance – coupling with fuel reformer feasible
- Power density currently < standard PEMFC

**Solid Oxide Fuel Cell (SOFC)**

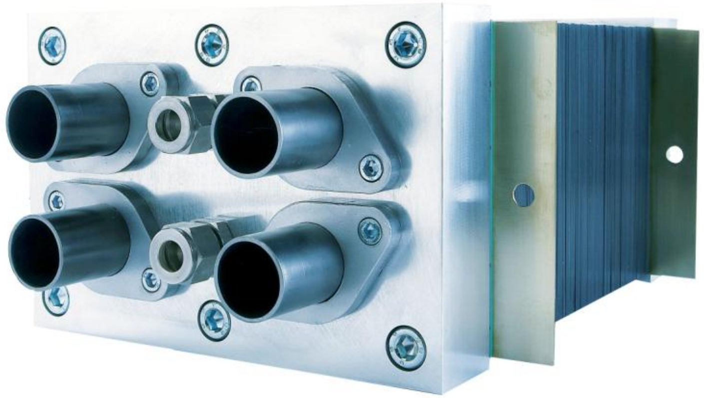
- Operating temperature > 650 °C
- O-Ion conductor – suitable for various fuels
- Simple system also if Diesel fuelled
- Main challenge: durability, corrosion, integration

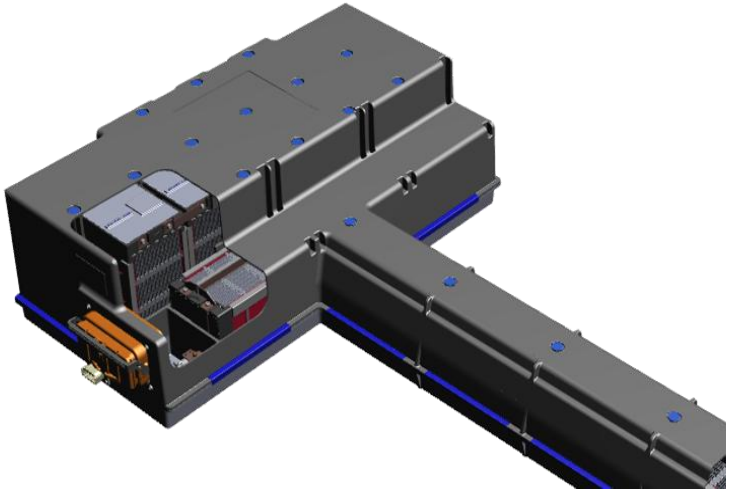
# TYPICAL FC SYSTEM EFFICIENCIES




- **Higher relative power demand of auxiliaries of lower power systems**
- **Decreasing efficiency of lower power systems**

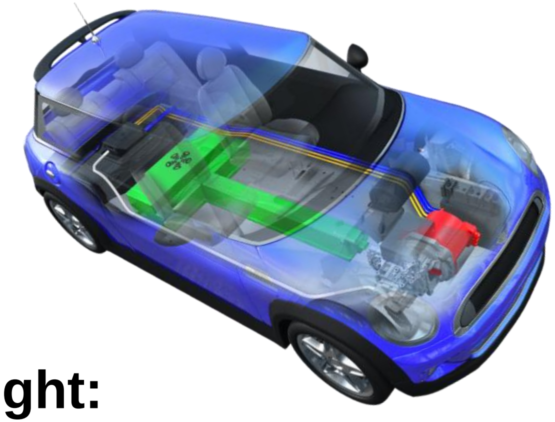
# CONTENT





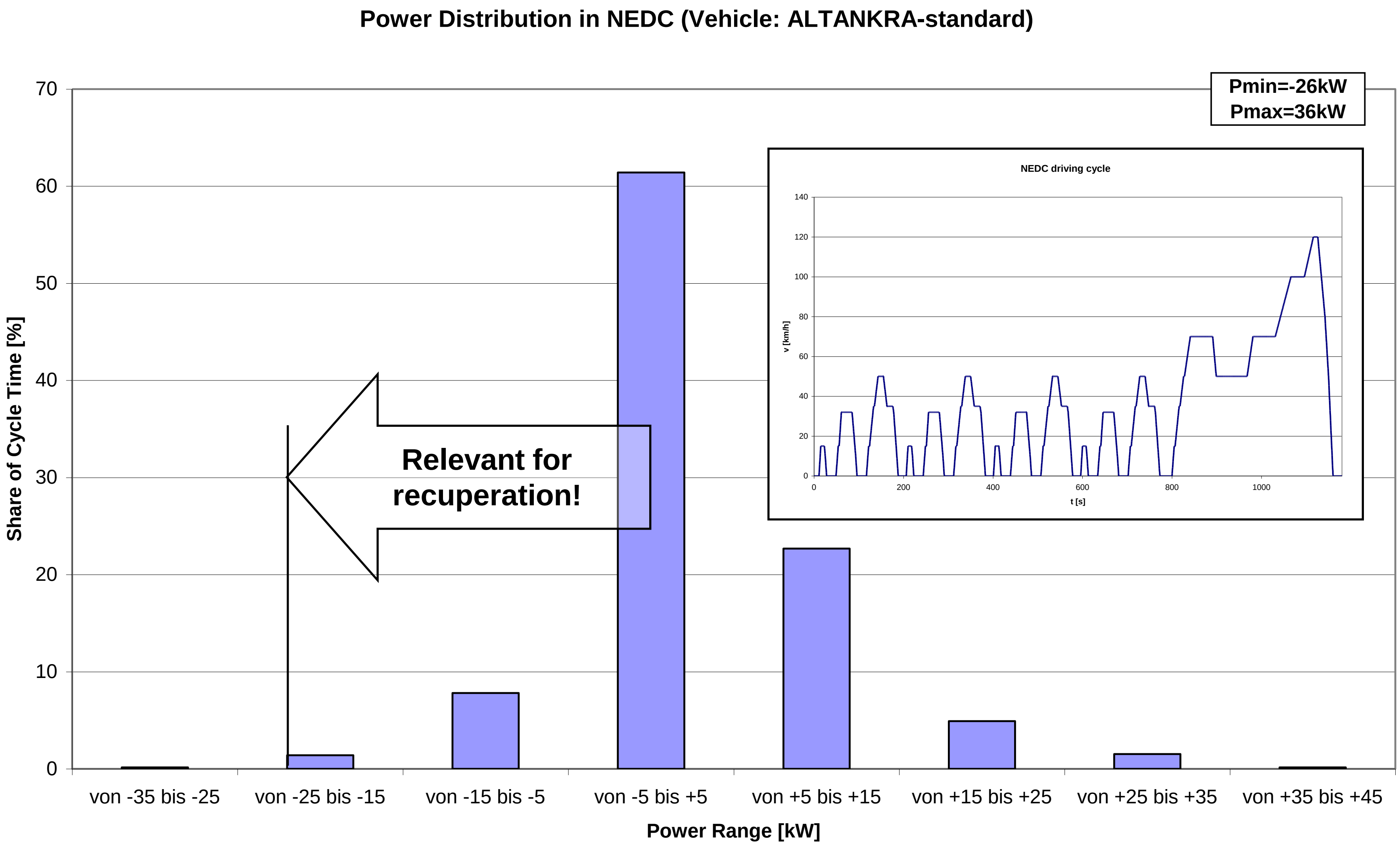
- Fuel cell systems for automotive applications
- **Braking energy recovery – general powertrain requirements**
- Fuel cell – battery – hybrids for passenger car application
- Fuel cell – battery – hybrids for commercial transport applications

# TYPICAL MID-CLASS CAR (REFERENCE CASE)

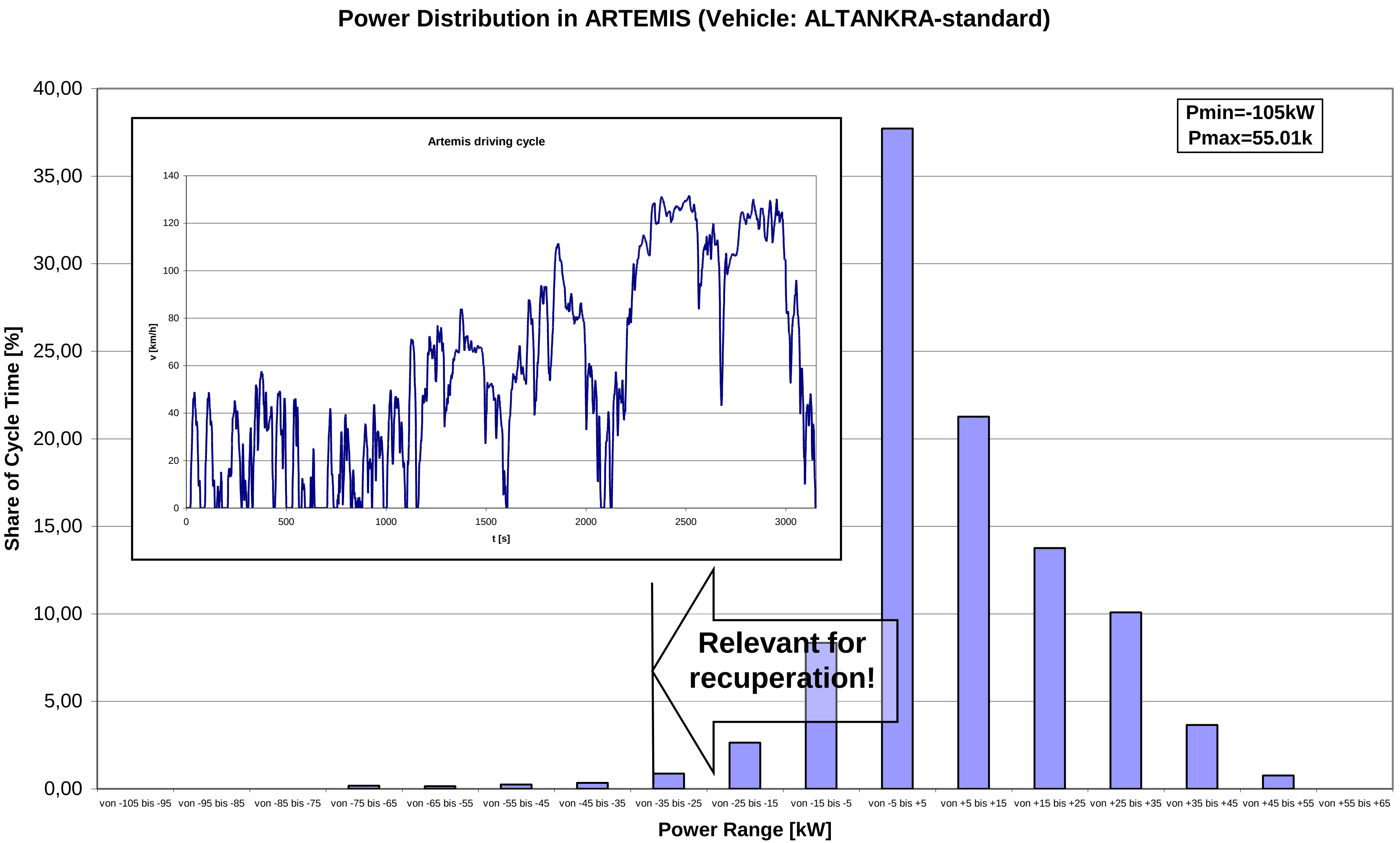


| | |
|---|---|
| ▪ **Weight:** | **1470 kg during test** |
| ▪ **Wheelbase:** | **2,7 m** |
| ▪ **Peak propulsion power:** | **80 kW** |
| ▪ **Drag coefficient:** | **0,31** |
| ▪ **Frontal area:** | **2,25 $m^2$** |
| ▪ **Time for 0-100 km/h:** | **<12 s** |
| ▪ **Top speed:** | **180 km/h** |

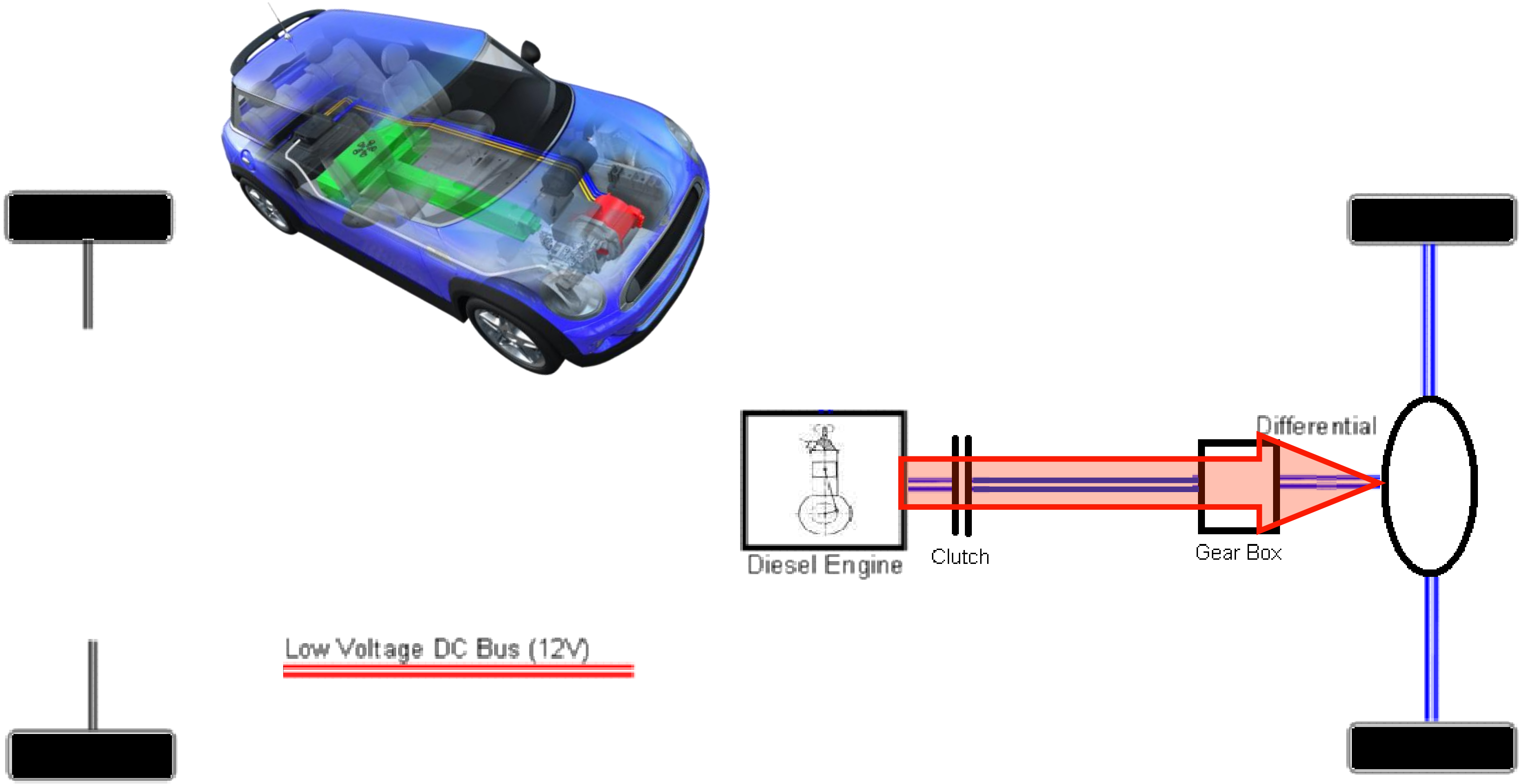
# BRAKE POWER IN NEDC



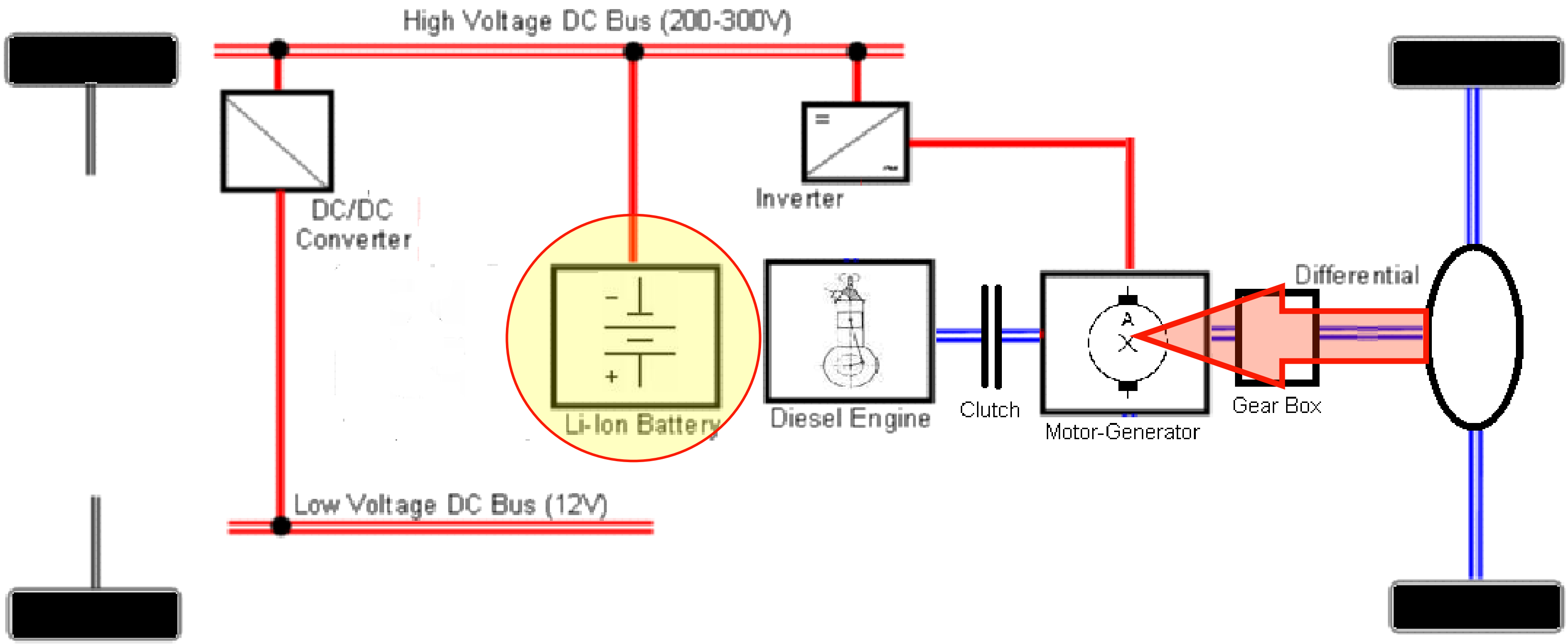
# BRAKE POWER IN ARTEMIS CYCLES



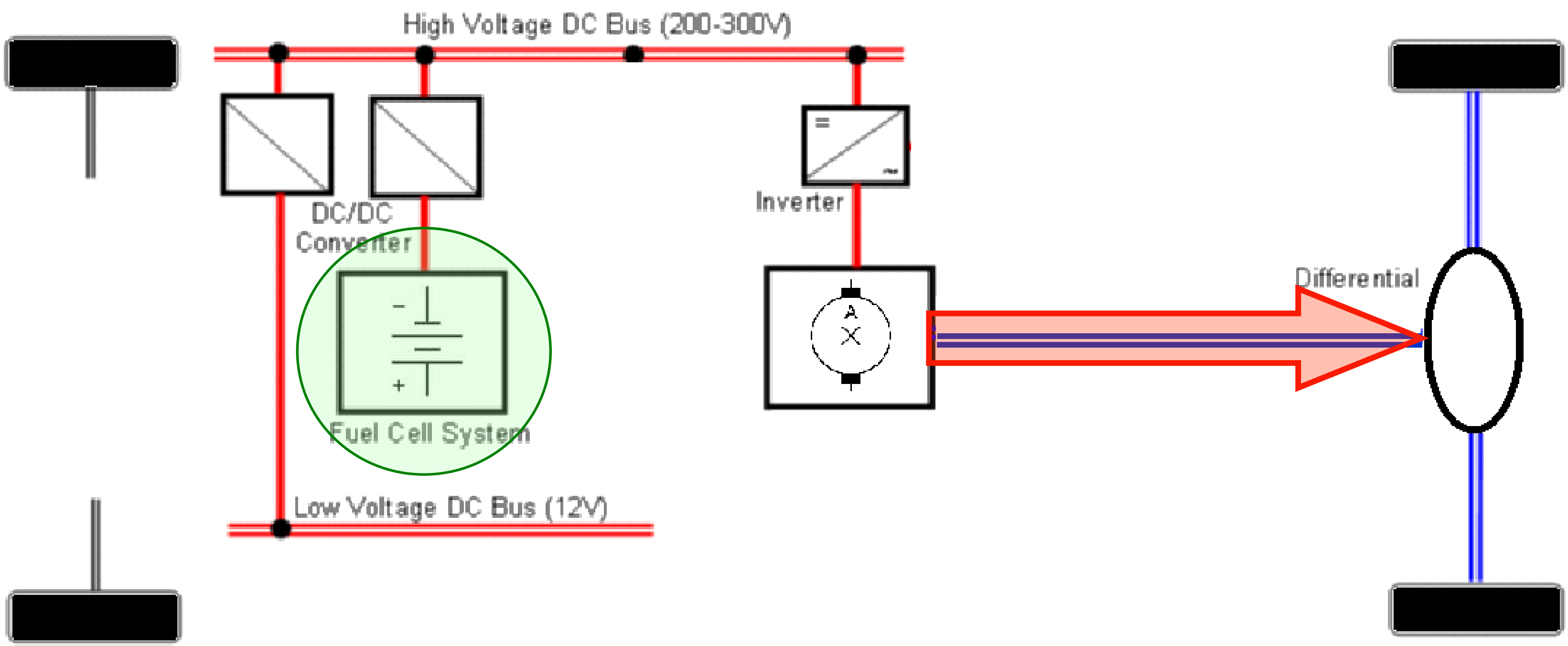
# TYPICAL PASSENGER CAR POWERTRAIN



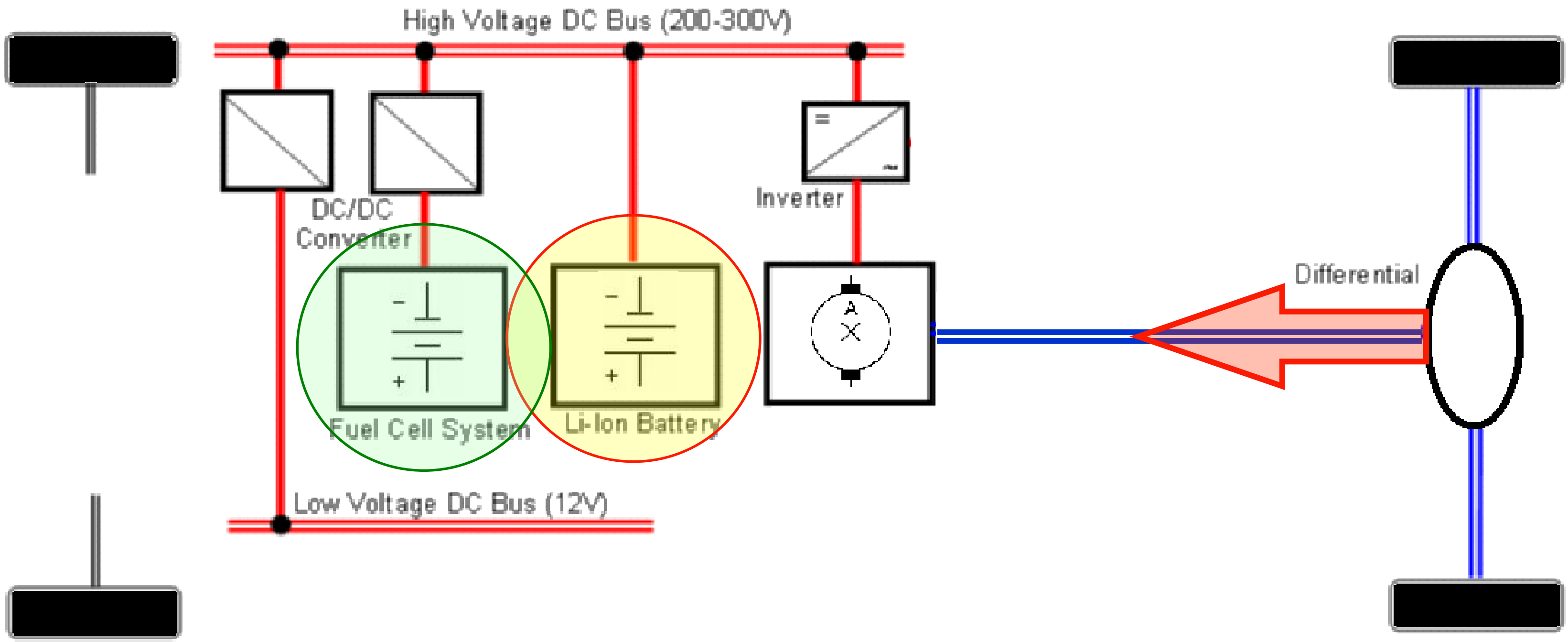
# SYSTEM REQUIREMENTS FOR HYBRIDIZATION



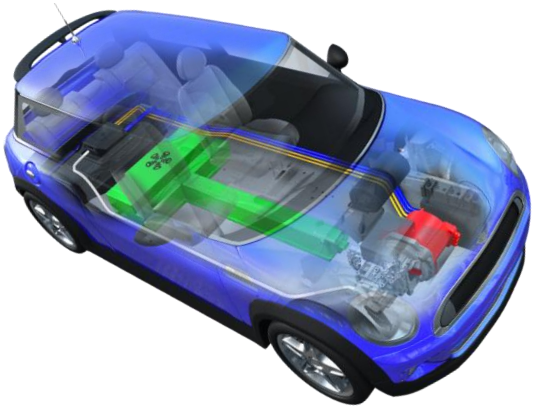
# TYPICAL FC POWERTRAIN FOR CARS



# BATTERY AS COMMON ELEMENT IN HEV!



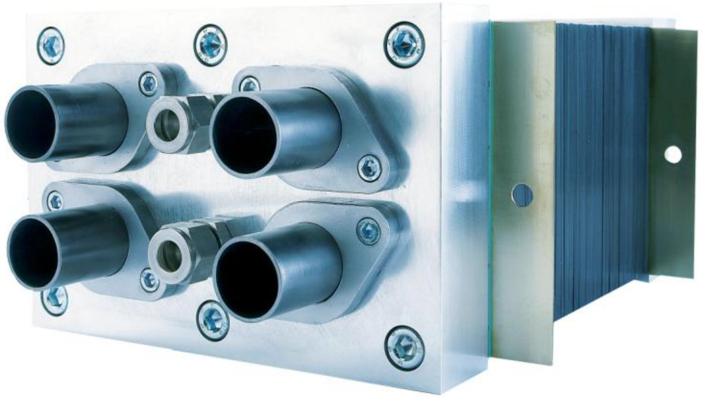
# BRAKE ENERGY RECOVERY IN NEDC

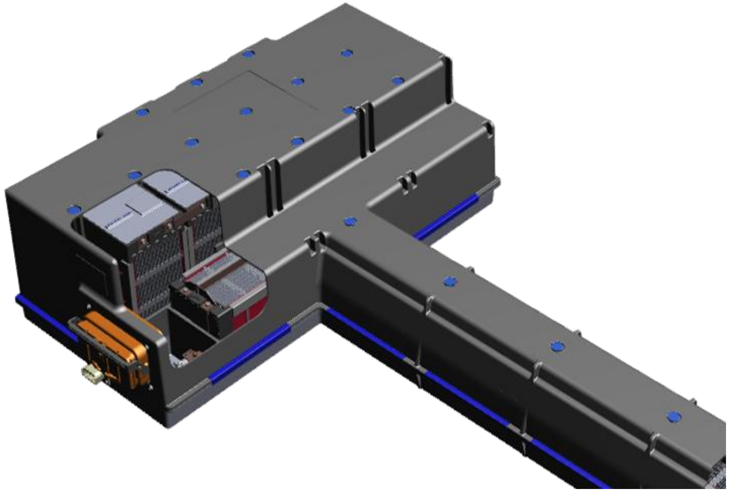


**Reference car (1470 kg test weight, 80 kW peak power)**

- **Normalized energy demand for driving approx. 45 MJ/100 km in NEDC – independent of powertrain architecture and type!**
- **Normalized braking energy approx. 12 MJ/100 km in NEDC – independent of powertrain architecture and type!**
- **Full recovery of braking energy would reduce the overall energy consumption by 27%**
- **Hybrids – either ICE or FC based – make use of this potential!**

# CONTENT





- Fuel cell systems for automotive applications
- Braking energy recovery – general powertrain requirements
- **Fuel cell – battery – hybrids for passenger car application**
- Fuel cell – battery – hybrids for commercial transport applications

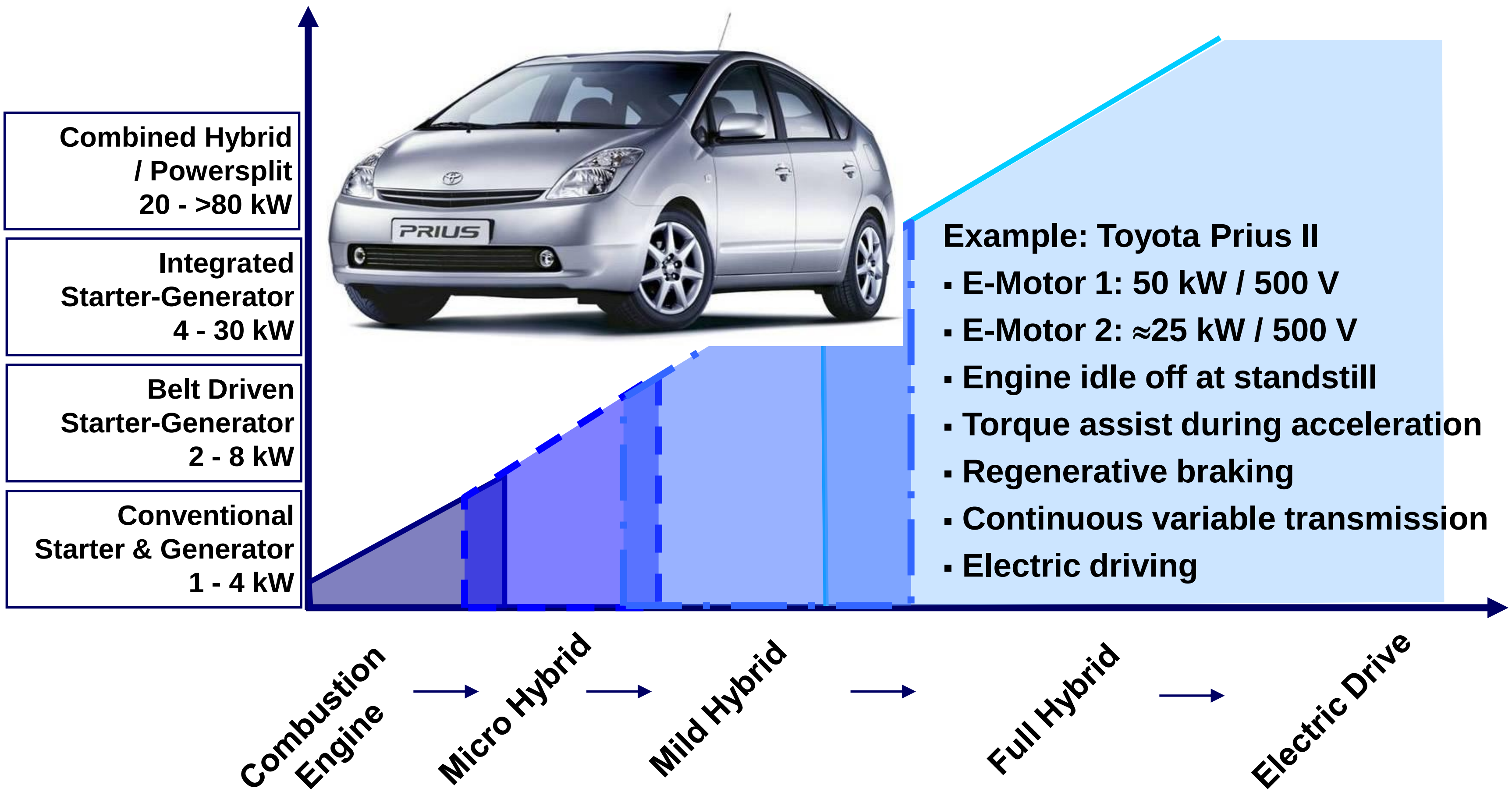
# DEGREE OF HYBRIDIZATION: ICE-HEV

**Hybrid**

**=**

**Combination Combustion Engine and E-Motor**

# DEGREE OF HYBRIDIZATION: ICE-HEV



# DEGREE OF HYBRIDIZATION: FC-HEV

**Hybrid**

**=**

**FC-System and Battery**

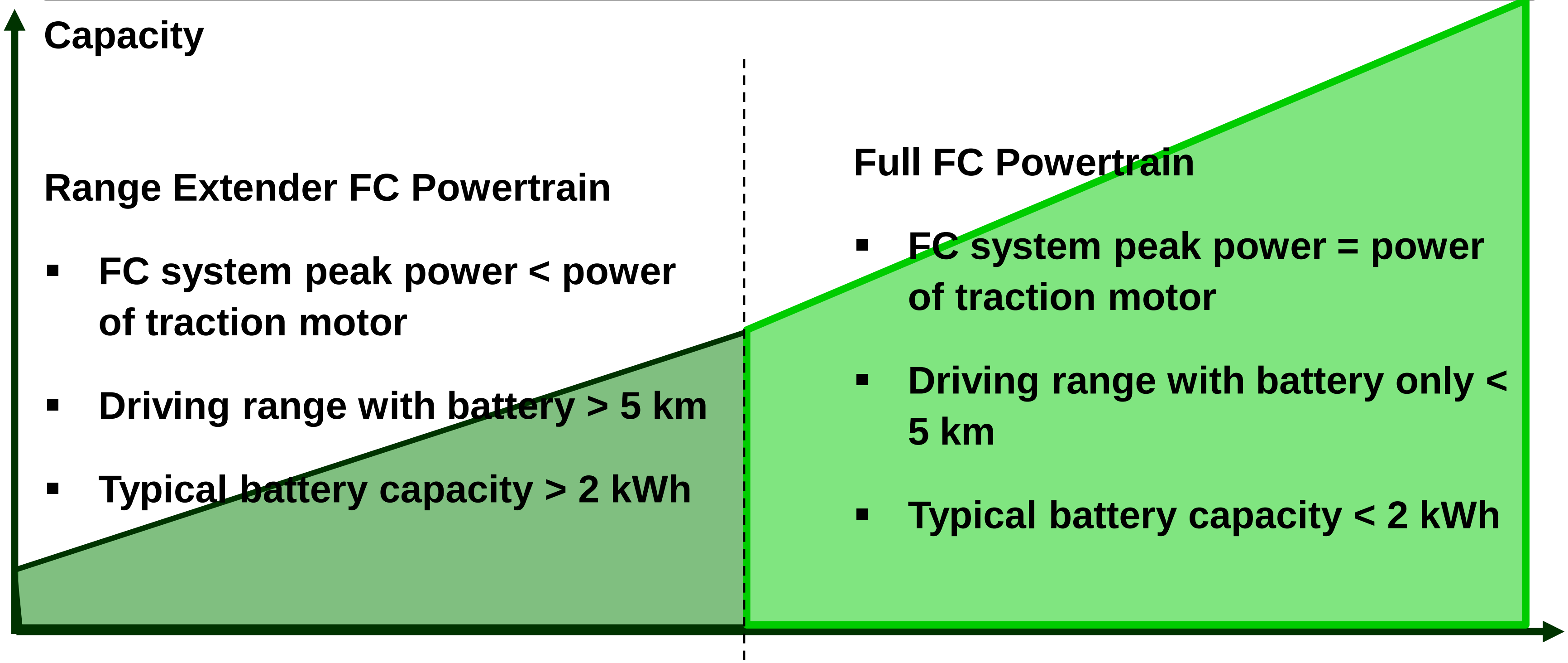
- **FC vehicle = EV!**
- **Higher battery capacity needed for fast FC system start-up – synergy in view of brake energy recovery!**
- **Peak power of battery determined by target brake energy recovery!**
- **Full FC powertrain if FC system peak power = maximum driving power**

# DEGREE OF HYBRIDIZATION: ICE-HEV

**Hybrid**

**=**

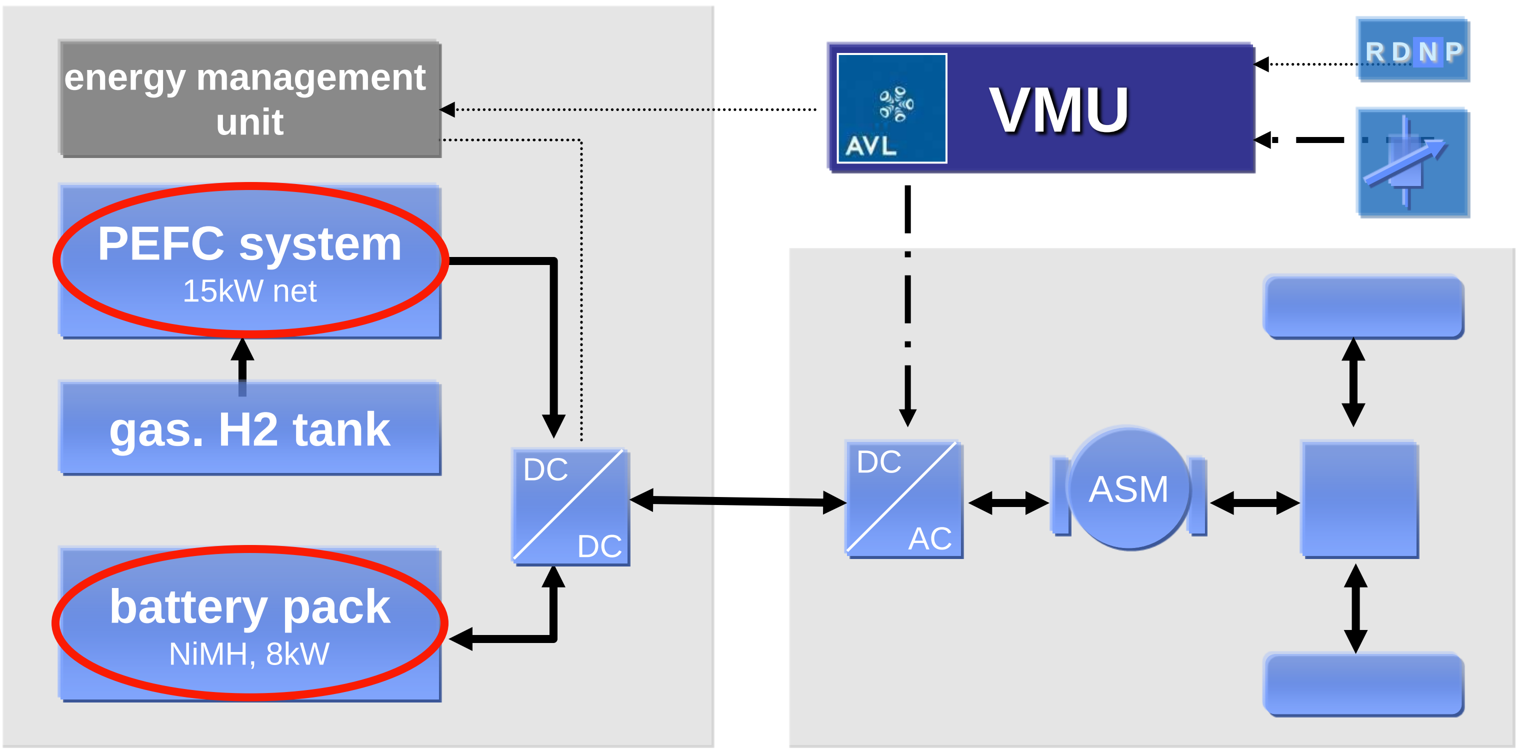
**FC-System and Battery**



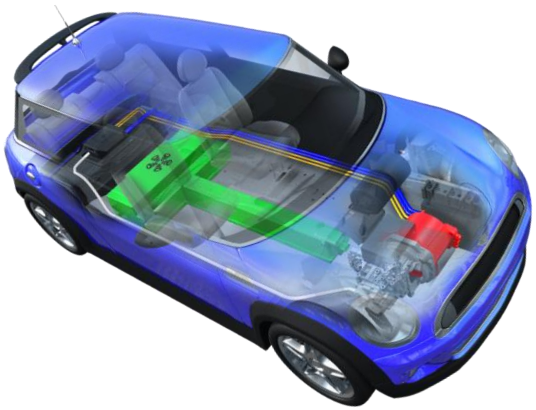
# FC-BATTERY HYBRID VEHICLE


- **Test and Validation of components**
- **Demonstration of FC-Battery Hybrid Powertrain**

# HYLITE POWERTRAIN CONCEPT

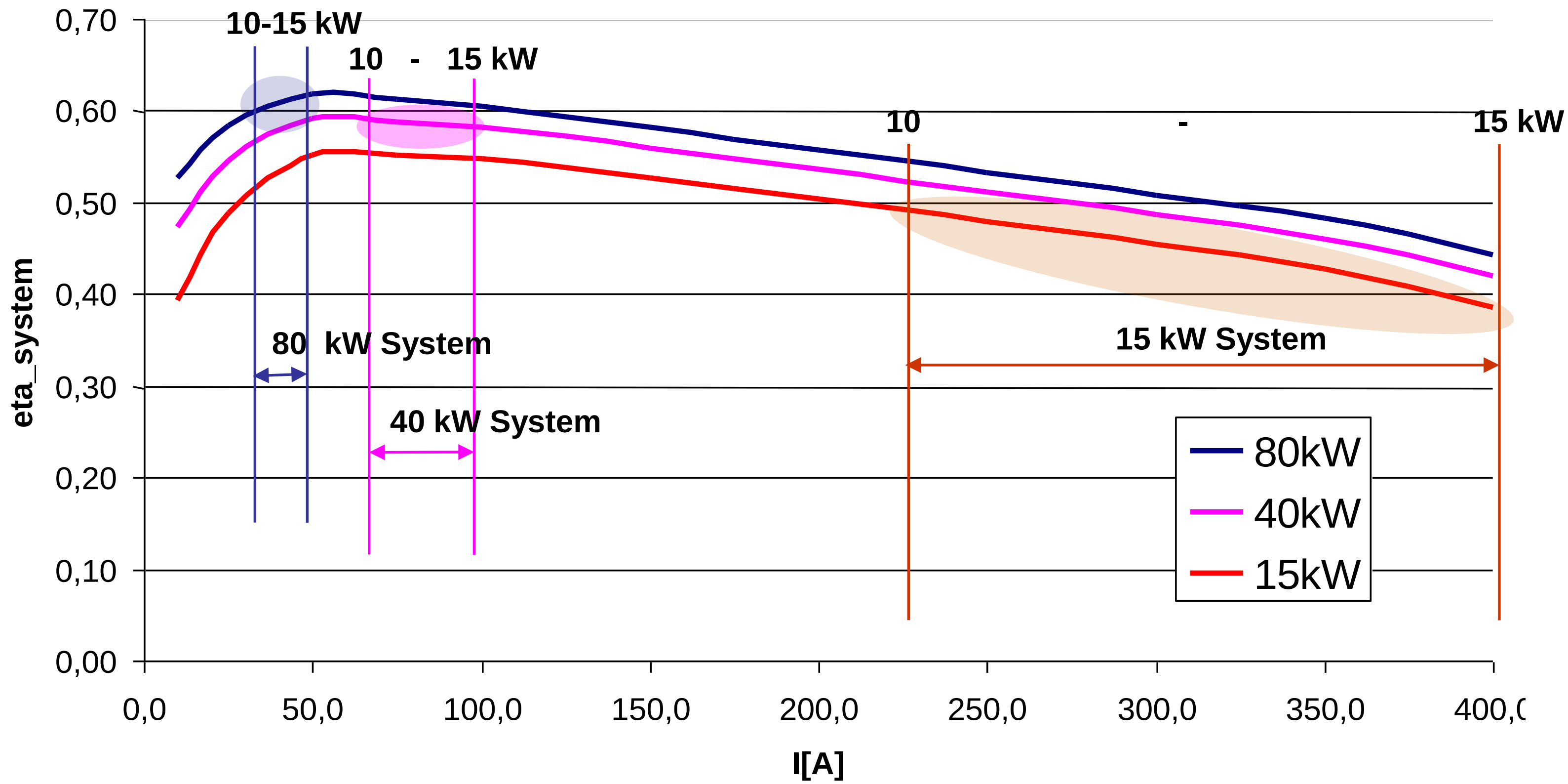


# TYPICAL MID-CLASS CAR (REFERENCE CASE)

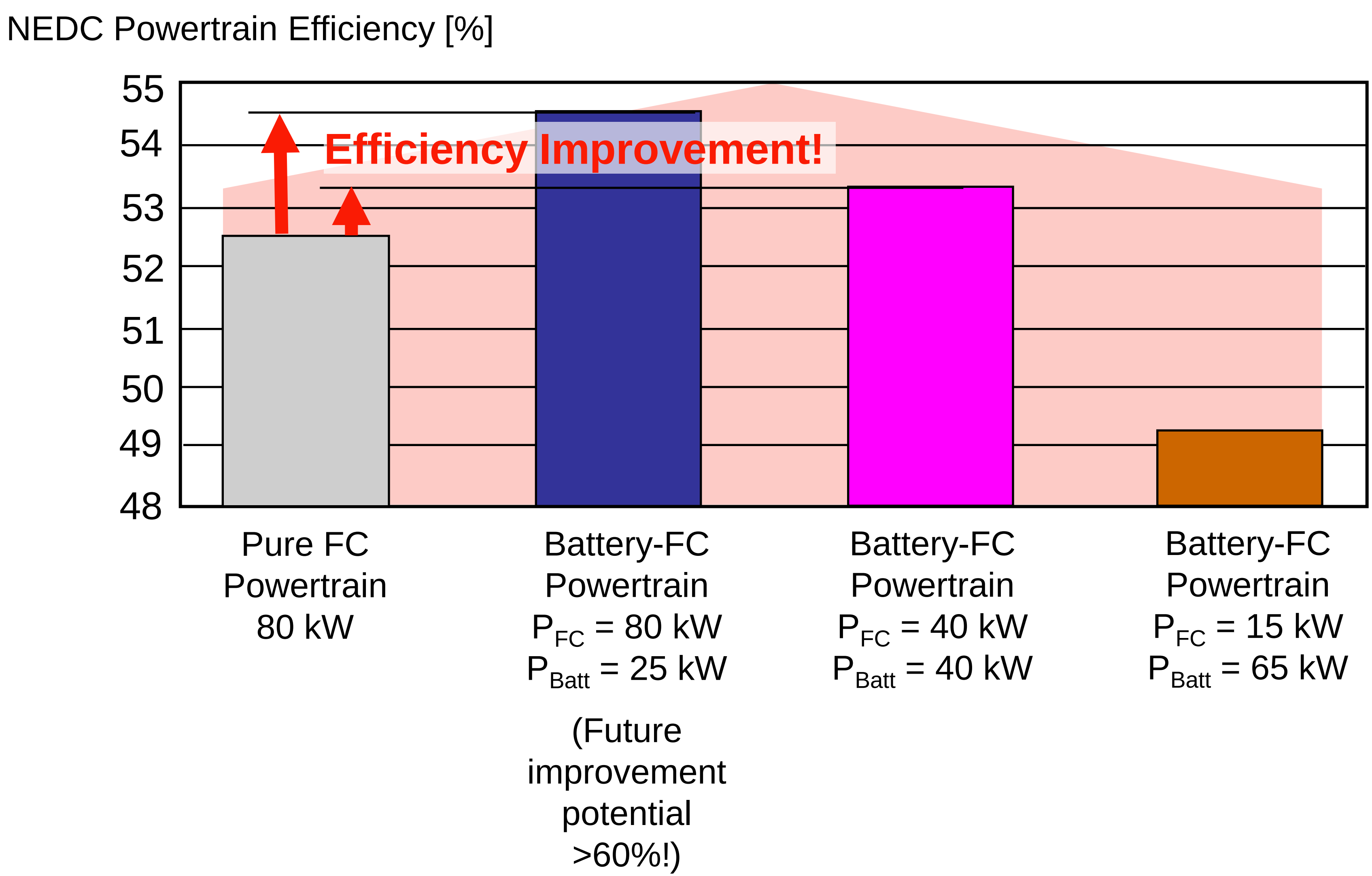


| | |
|---|---|
| ▪ **Weight:** | **1470 kg during test** |
| ▪ Wheelbase: | 2,7 m |
| ▪ **Peak propulsion power:** | **80 kW** |
| ▪ Drag coefficient: | 0,31 |
| ▪ Frontal area: | 2,25 $m^2$ |
| ▪ Time for 0-100 km/h: | <12 s |
| ▪ Top speed: | 180 km/h |

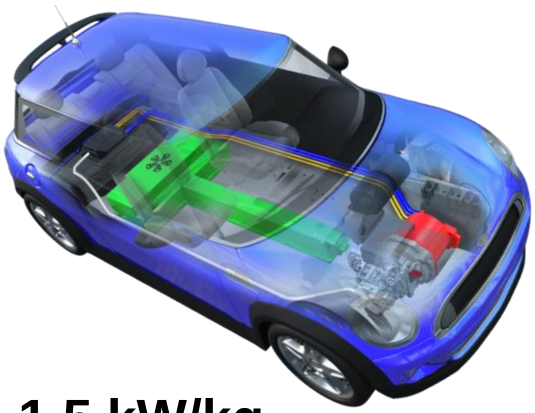
# TYPICAL FC SYSTEM EFFICIENCIES FOR REFERENCE VEHICLE



# FC & BATTERY-FC-HYBRID EFFICIENCIES



# FURTHER ADVANTAGE OF FC-BATTERY HYBRID

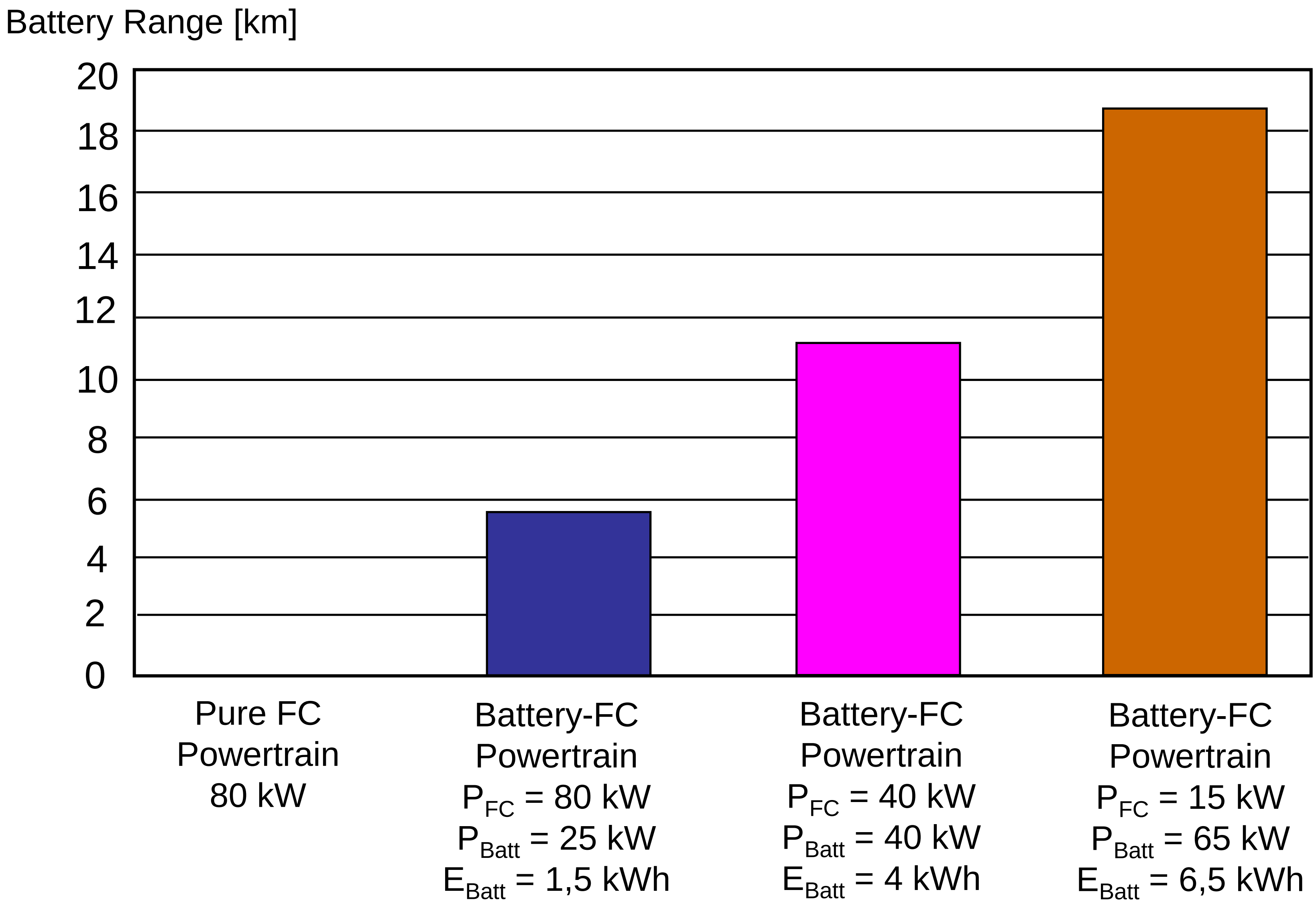


**Assumption (incl. Improvements):**

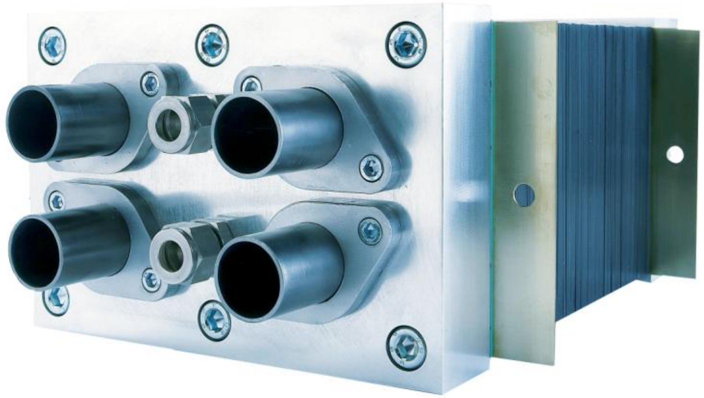
- **Battery system power density approx. 1,5 kW/kg**
- **Battery system energy density approx. 100 Wh/kg and 60% usable SOC range**

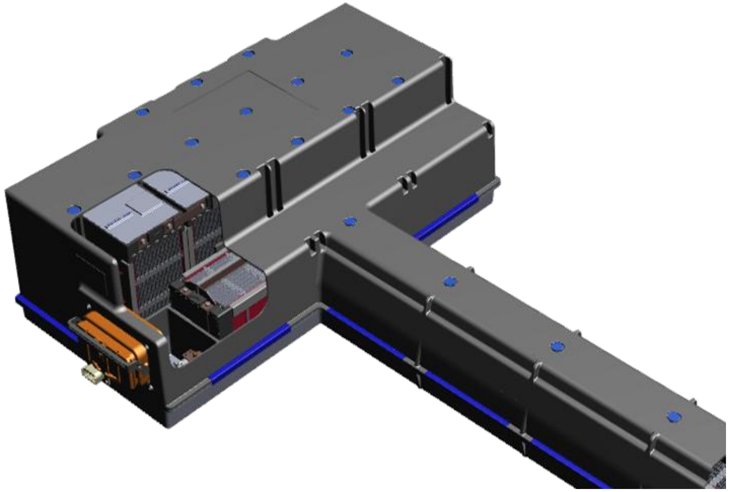
- **Net energy demand of EV powertrains (with recuperation) approx. 0,14 kWh/km**
- **Pure battery driving range = plug in hybrid function!**

# BATTERY RANGE OF BATTERY-FC-HYBRID



# CONTENT





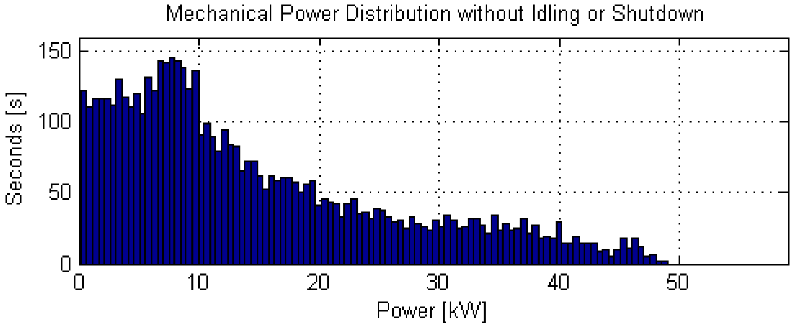
- Fuel cell systems for automotive applications
- Braking energy recovery – general powertrain requirements
- Fuel cell – battery – hybrids for passenger car application
- **Fuel cell – battery – hybrids for commercial transport applications**

# HT-PEM POWERED FORKLIFT - SIMULATION STUDY

Forklist used for simulation study

| | |
|---|---|
| Electric Motor Efficiency | 85% |
| Battery Efficiency | 90% |
| Fuel Cell Efficiency | Simulated Curve |
| IC Engine Efficiency | Recorded map |
| Hydraulic Pump | 90% |
| Hydraulic Motor | 90% |
| Battery Size | 12.000 kJ |
| LHV of Diesel | 42500 kJ/kg |

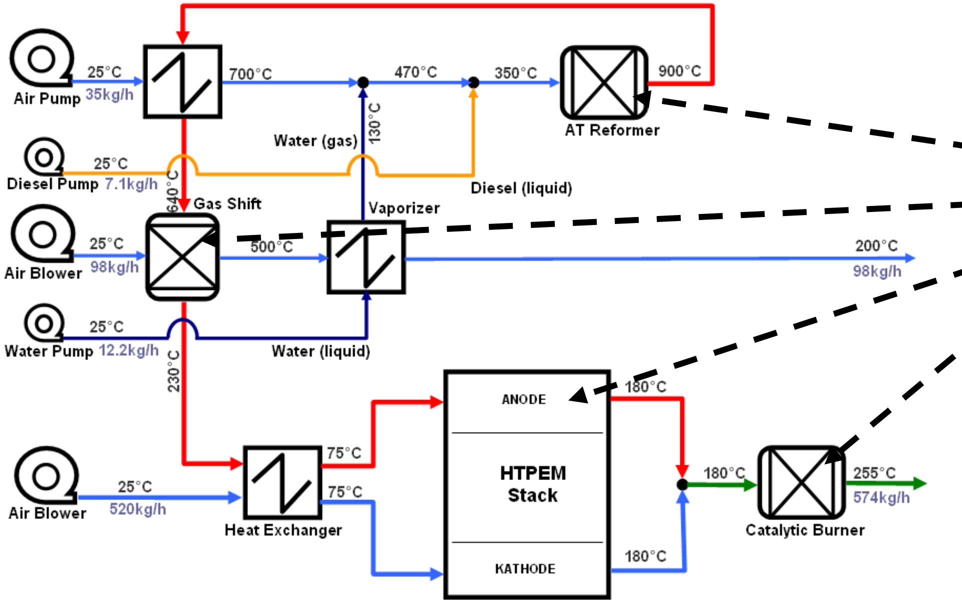
FC-battery hybrid powertrain



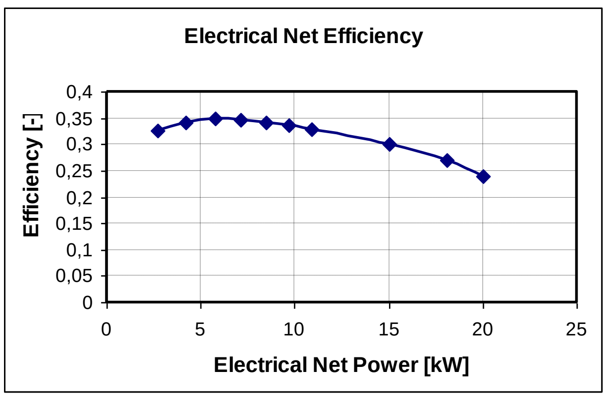

Recorded load profile (frequency chart)

- **Recorded a 5h load profile with a standard forklift at AVL facilities**
- **Process simulation of a 20kW HT-PEM fuel cell system (fuel: diesel)**
- **Simulation of the HTPEM system through the recorded load profile**
- **Comparison of the ICE powertrain with the fuel cell powertrain**

# HT-PEM MAIN POWER FOR FORKLIFT




- Autothermal Reforming
- Water gas shift for CO removal
- HTPEM stack technology
- catalytic off gas cleaning



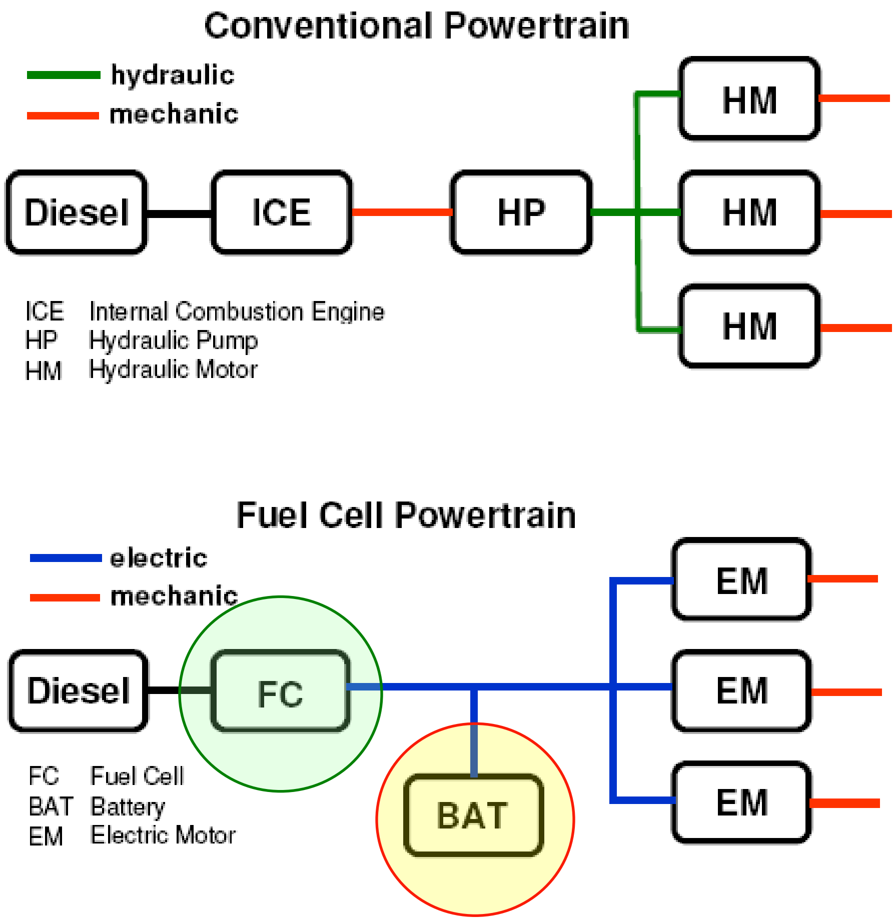

- **Facts:**
- **Fuel: Diesel**
- **$P_{net}$=20kW**
- **$P_{gross}$=23.9kW**
- **$\eta_{electr}$=24%**
- **CD=0.75A/cm²**
- **CV=0.53V**
- **Diesel=8.5L/h**
- **Water=12.2L/h**

CD…current density, CV…cell voltage

## Why HT-PEM ?

- **Membrane: Polybenzimidazole doped with phosphoric acid**
- **Temperature: 120-180°C**
- **CO tolerance: ~1mol% @ 160°C**
- **No humidification**
- **No liquid water issues**

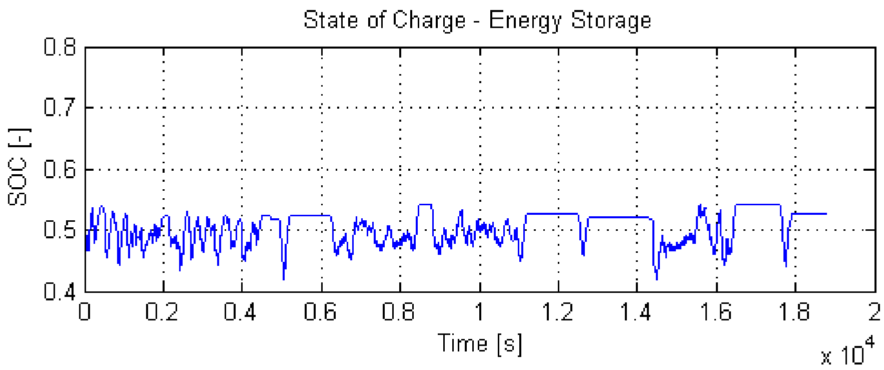
# HT-PEM POWERED FORKLIFT - SIMULATION STUDY

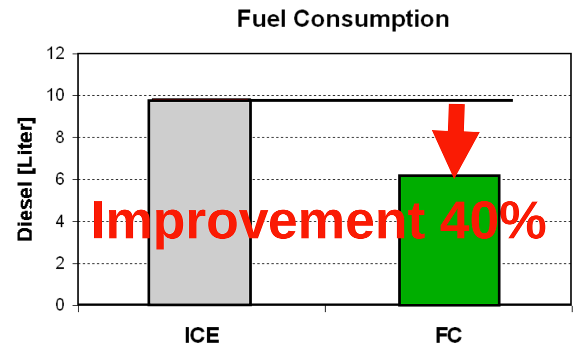


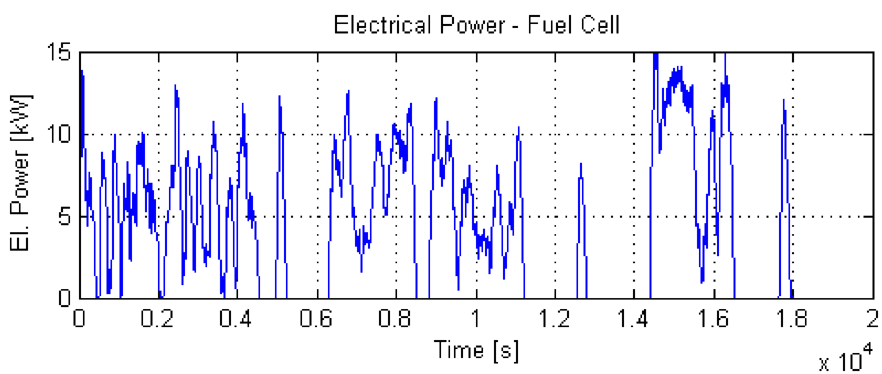

## Fuel cell powertrain advantages:

- Significant increase of overall efficiency
- Significant reduction of noise
- Most likely faster working movements due to the electric motor and hence reduced working time
- Recuperation of breaking energy
- No charging times (as for electrical forklifts)
- Moveably power supply of DC or AC power (power socket possible, incl. DC/AC inverter)
- No environmental concerns (leakages) due to the elimination of the hydraulic system

# HT-PEM POWERED FORKLIFT - SIMULATION STUDY

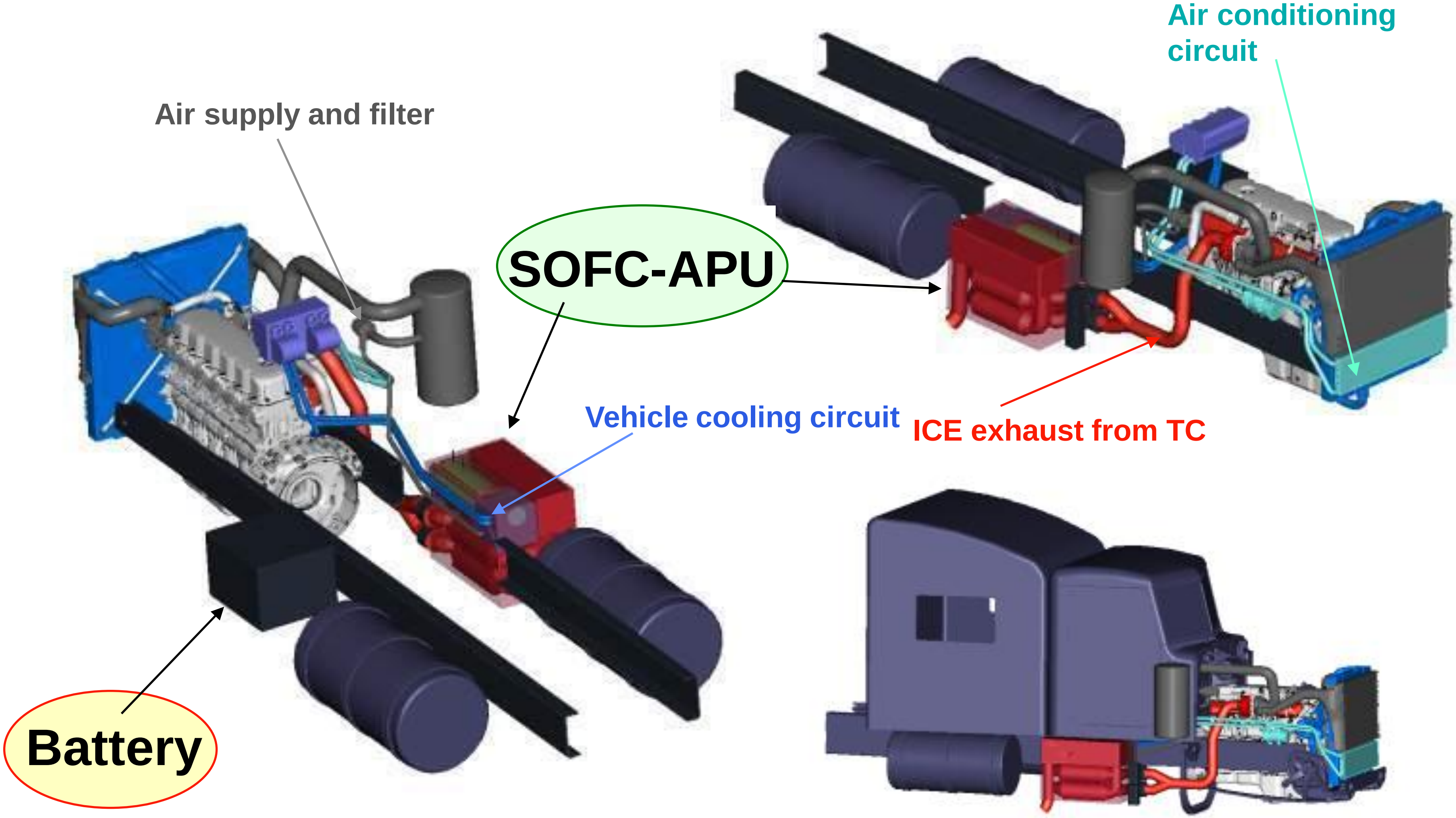


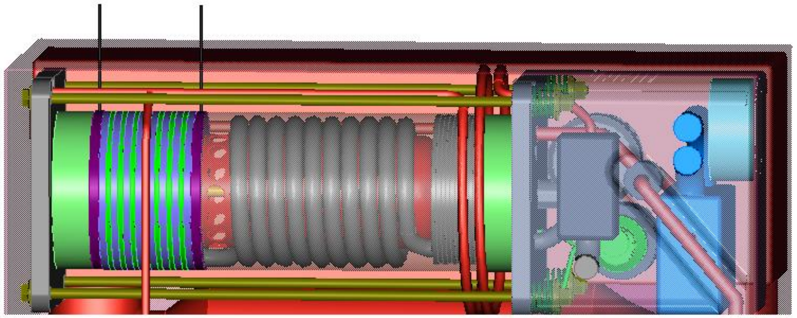

- 40% fuel consumption reduction (2.9L, 0.56L/h)
- **Battery needed for recuperation of energy!**
- **Factors of improvement:**
  - ✓ Very high fuel cell partload efficiency
  - ✓ Recuperation of braking and lowering of fork

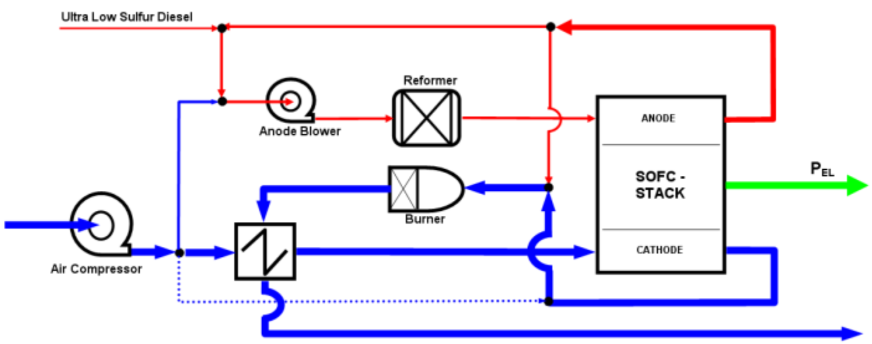
# SOFC-APU VEHICLE INTEGRATION STUDY




ICE…Internal Combustion Engine
TC…Turbocharger

# HYBRID FC-BATTERY SYSTEM FOR HD-TRUCK



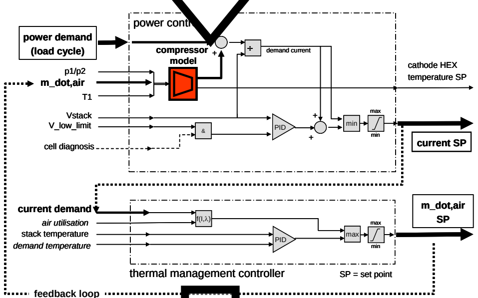


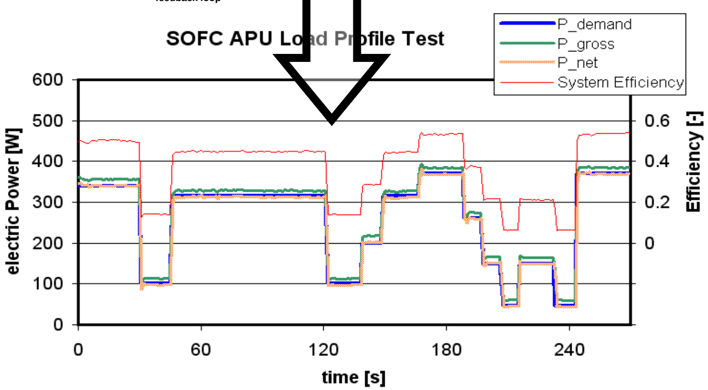

| | |
|---|---|
| Net Stack Power | 3kW |
| Gross Stack Power | 3.8kW |
| Efficieny @ max Load | 33% |
| Reforming Temp. | 800°C (ATR) |
| Weight | 70kg |
| Volume | 70L |
| Power Density | 45W/kg |

## Diesel SOFC APU

- Air conditioning and truck electrification during parking
- Cabin heating and engine pre-heating/conditioning

# SOFC-APU PERFORMANCE & INTEGRATION



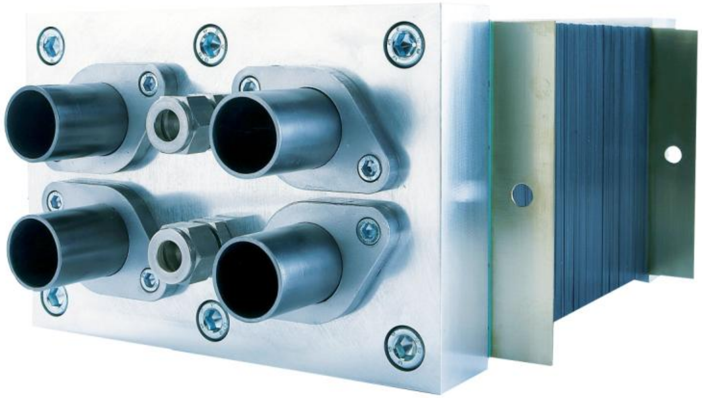




## SOFC APU System Integration

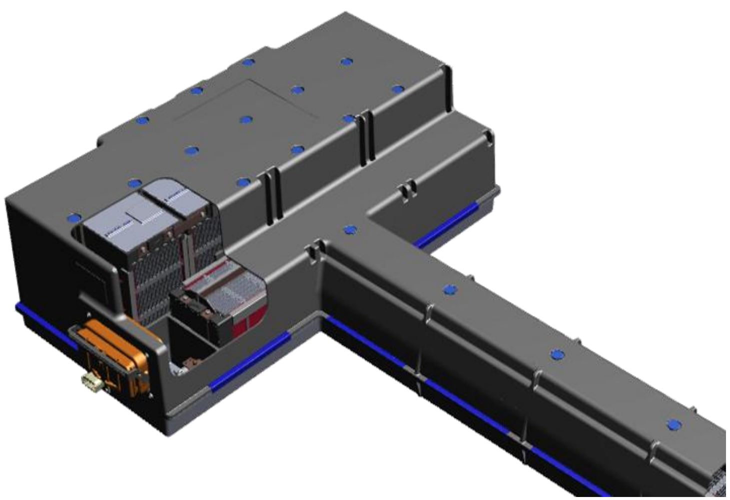
- 1 kW SOFC APU Proof-of-concept
- SOFC stack from TOFC
- High dynamics in „self-sustained“ mode
- System efficiency > 35%
- **Full hot box system integration**

# SUMMARY AND CONCLUSIONS

- ➔ „Fuel Cell Vehicles“ are EVs and ideally suited for recovery of brake energy – high voltage and high power board net available!
- ➔ Well designed architecture of a FC-battery hybrid powertrain improves overall system efficiency
- ➔ Battery provides plug-in function (bi-directional!)
- ➔ FC-battery powertrain provides additional benefits for customer – on-site high power electricity supply in LD vehicles
- ➔ Combination of FC-system and battery improves availability of former pure-battery off-road vehicles
- ➔ FC-APU in HD trucks offers additional benefits compared to energy supply based on pure battery solutions
- ➔ **Electric powertrains, batteries and fuel cells are natural allies!**



# Energy Sources for EVs:
# Fuel Cell
# and! - ~~or?~~
# Battery



**Acknowledgement:**

**The results were partly achieved with financial support from the Austrian Ministry of Transport, Innovation and Technology (Projects ALTANKRA, ELEKTRA, BREST and SOFC APU).**