48 V High-power Battery Pack for Mild-hybrid Electric Powertrains

Christian Vogler, Stephen Borman, Jonathan Hall,

Mike Bassett, Simon Reader and Martin Berger

MAHLE Powertrain

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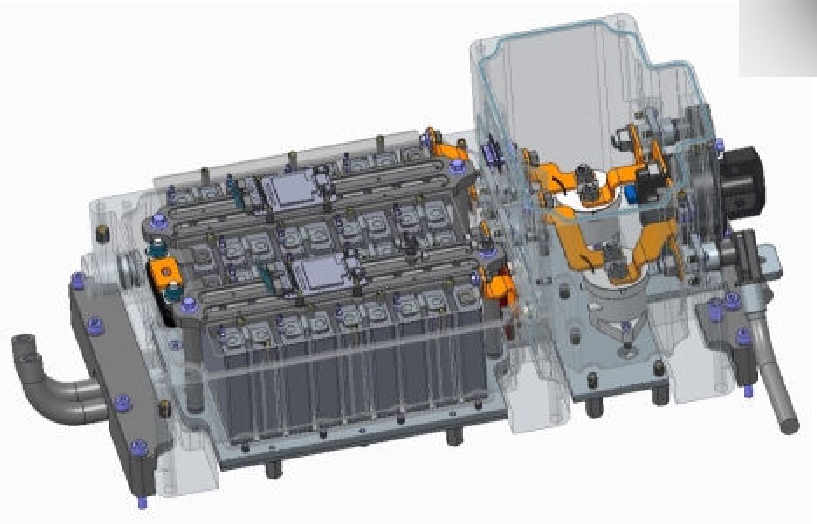
Overview

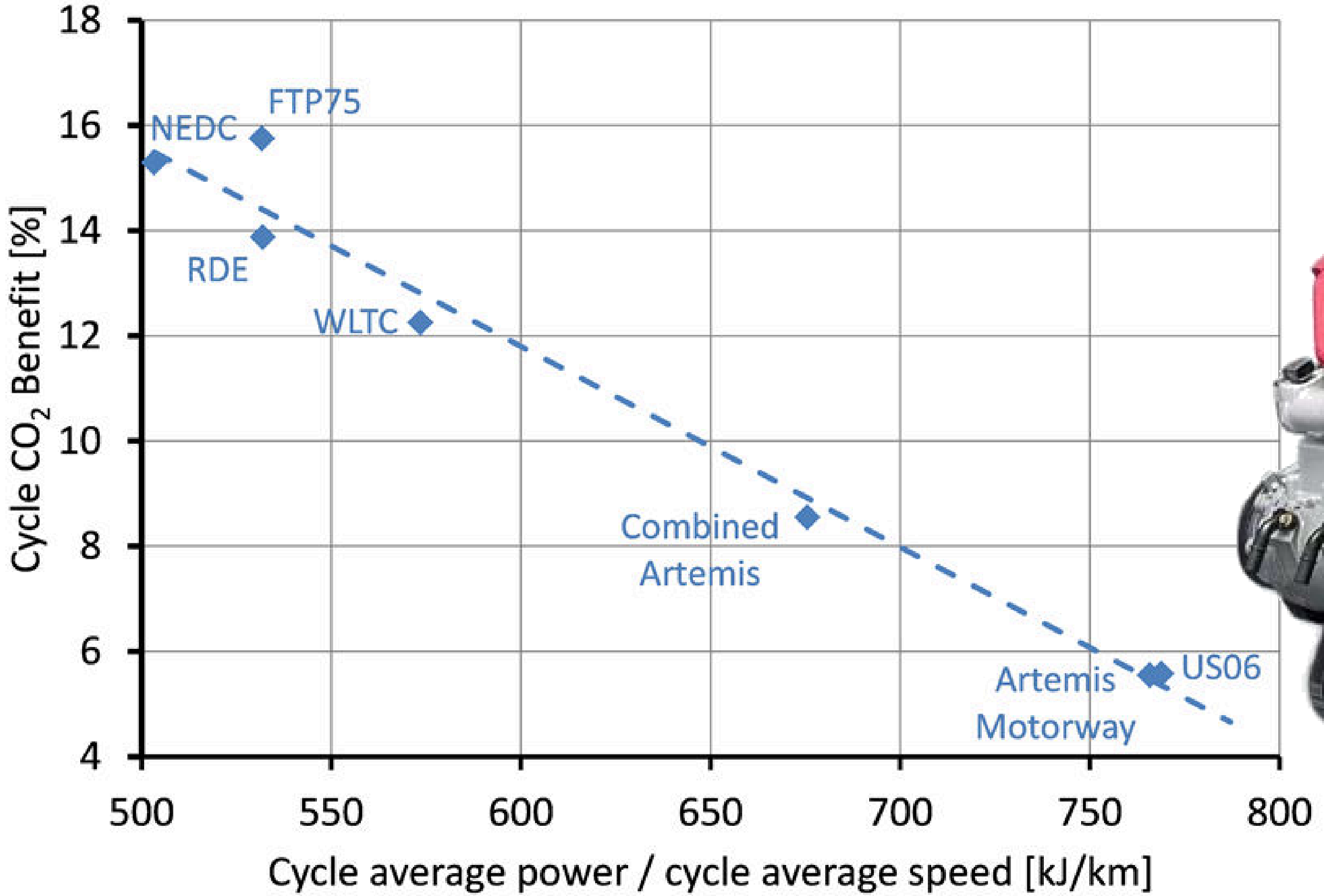
- Introduction
- Hybrid system power requirement
- Battery pack
  - Performance targets
  - Cell selection
  - Cooling plate concept
  - Thermal analysis
- Battery pack performance
- Detailed design
- Summary



High Downsized Demonstrator Vehicle

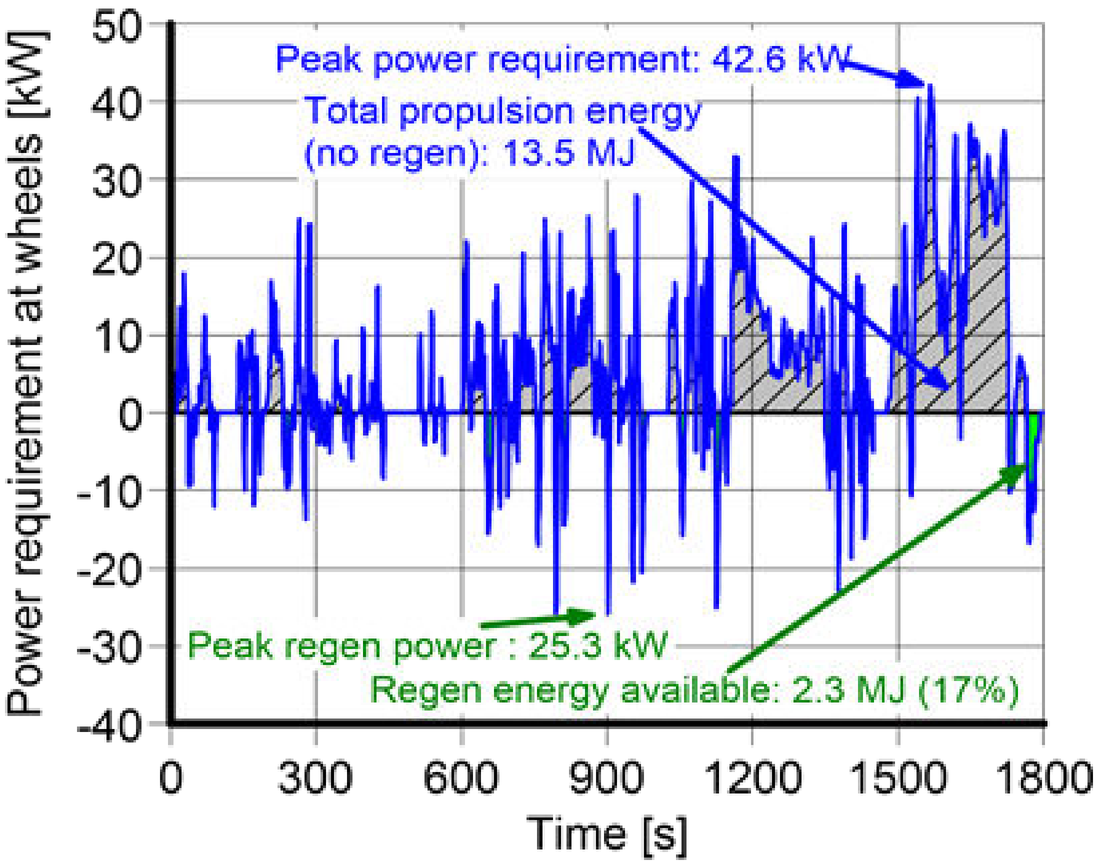
- Maintain dynamic performance of baseline vehicle
- CO_2 reduction through
  - Extreme downsizing (1.2 litre 3-cylinder engine)
  - 48V eSupercharger
  - 48V BISG recuperation
  - Down speeding
    - User specific shift-schedule

Downsizing Drive Cycle CO_2 Benefit Relative to 2.0 TGDI Baseline



Hybrid System Power Requirement

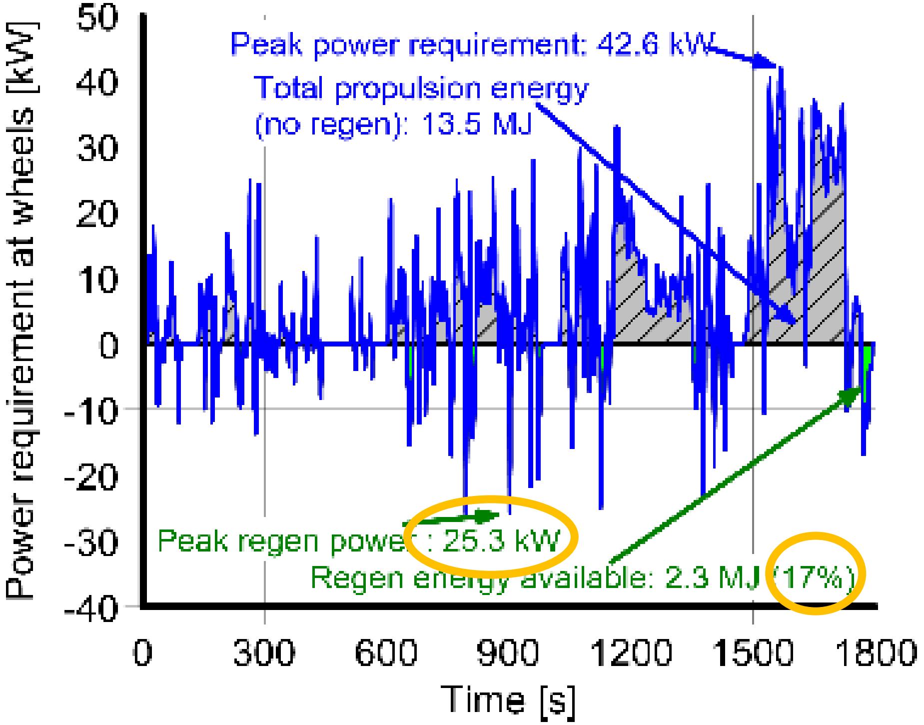
- Target application:
  - C-Segment car (high performance)
- Drive cycle:
  - WLTC

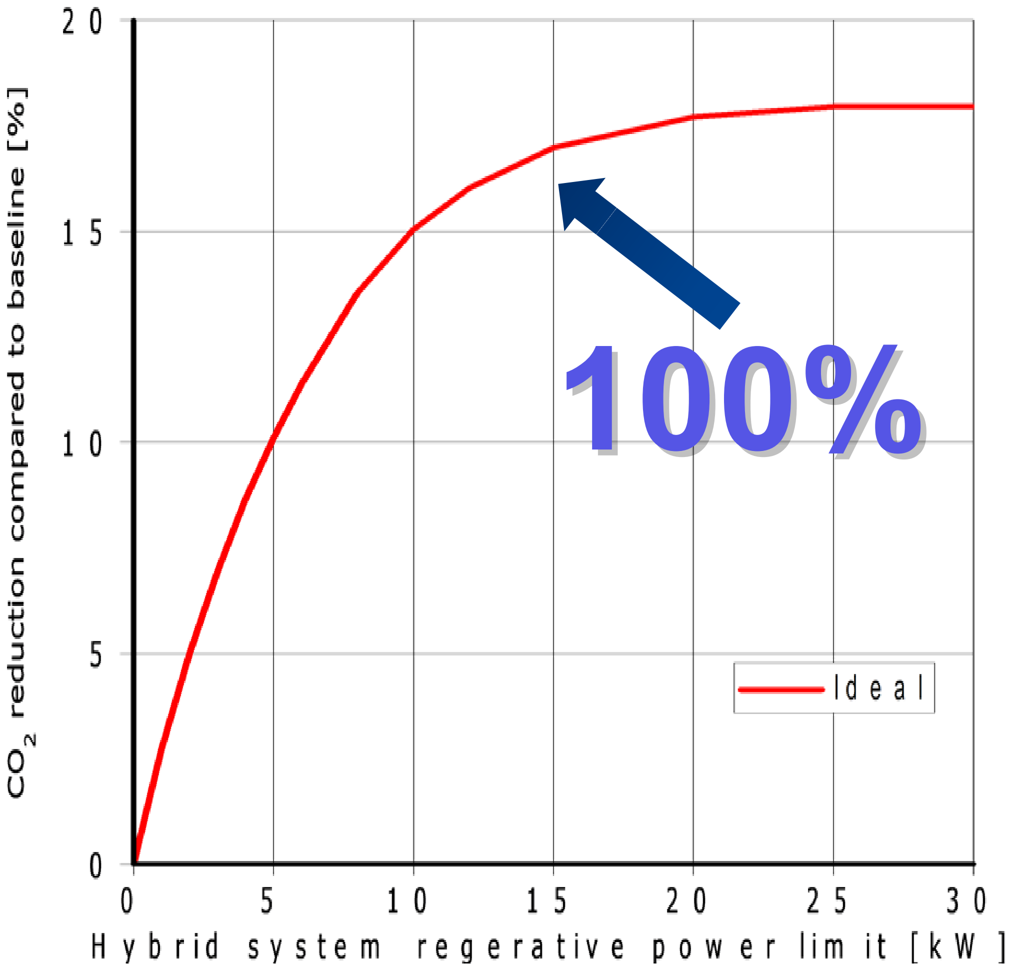


Up to 17% fuel consumption reduction possible

Hybrid System Power Requirement

- Understand the trade-off between:
  - (+) CO_2 emissions reduction
  - (−) Hybrid system power, package space and cost



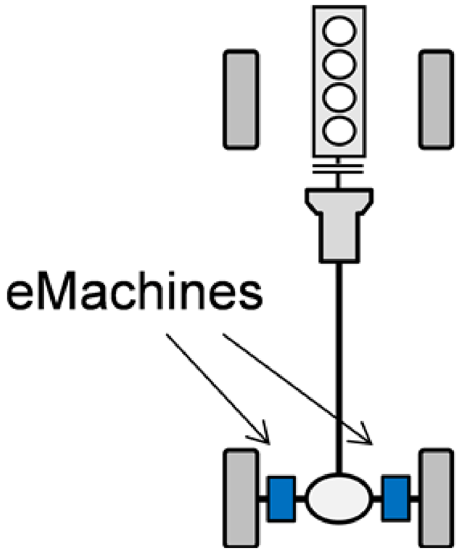


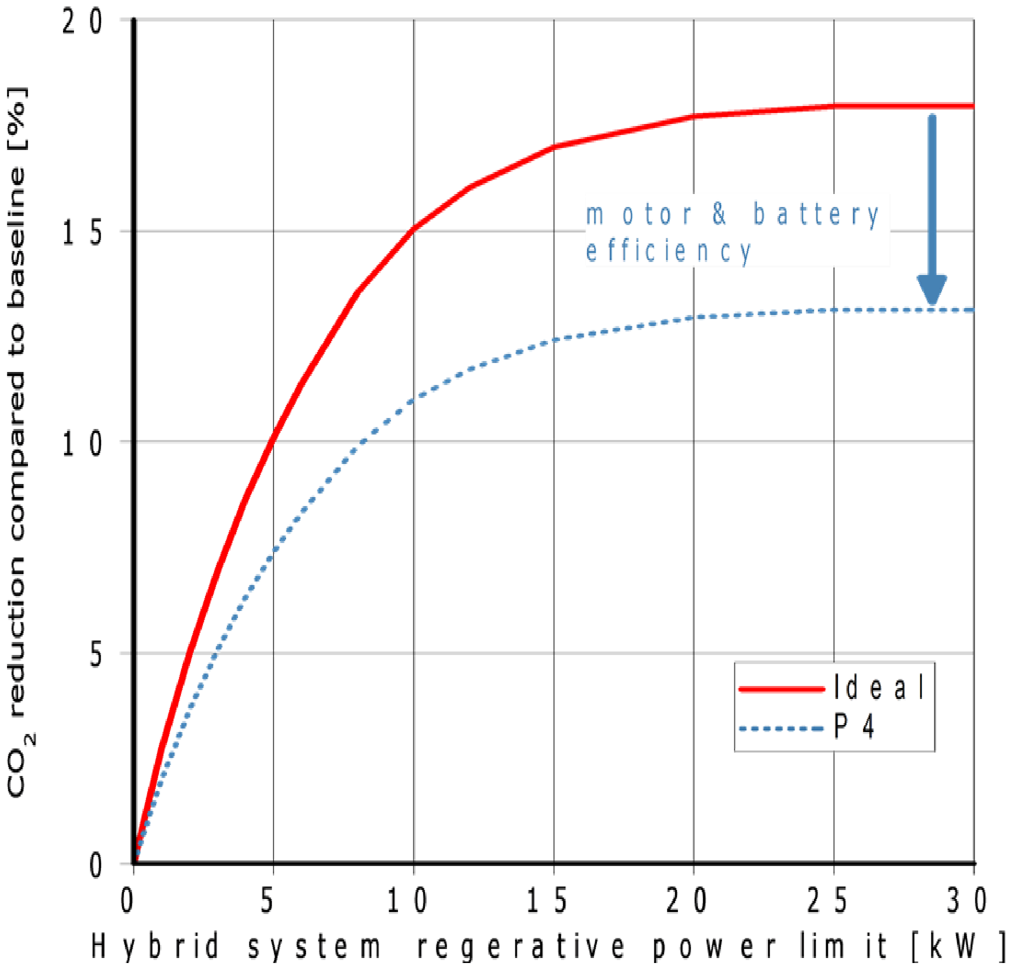
CO_2 benefit based on fixed engine efficiency

Hybrid System Power Requirement – P4/P3

- CO_2 reduction based on power at wheels
- Needed to actually utilise regenerative braking:
  - Motor / generator
  - Battery
- Both have inefficiencies
- Position of Motor closest to wheels:
  - Parallel hybrid configuration P4

P4: Up to 13% CO_2 reduction



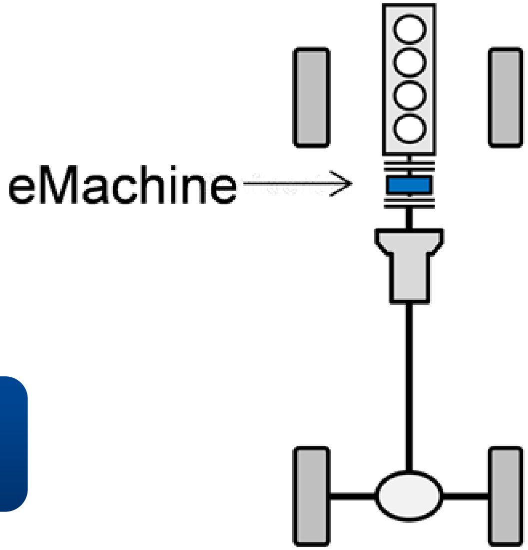


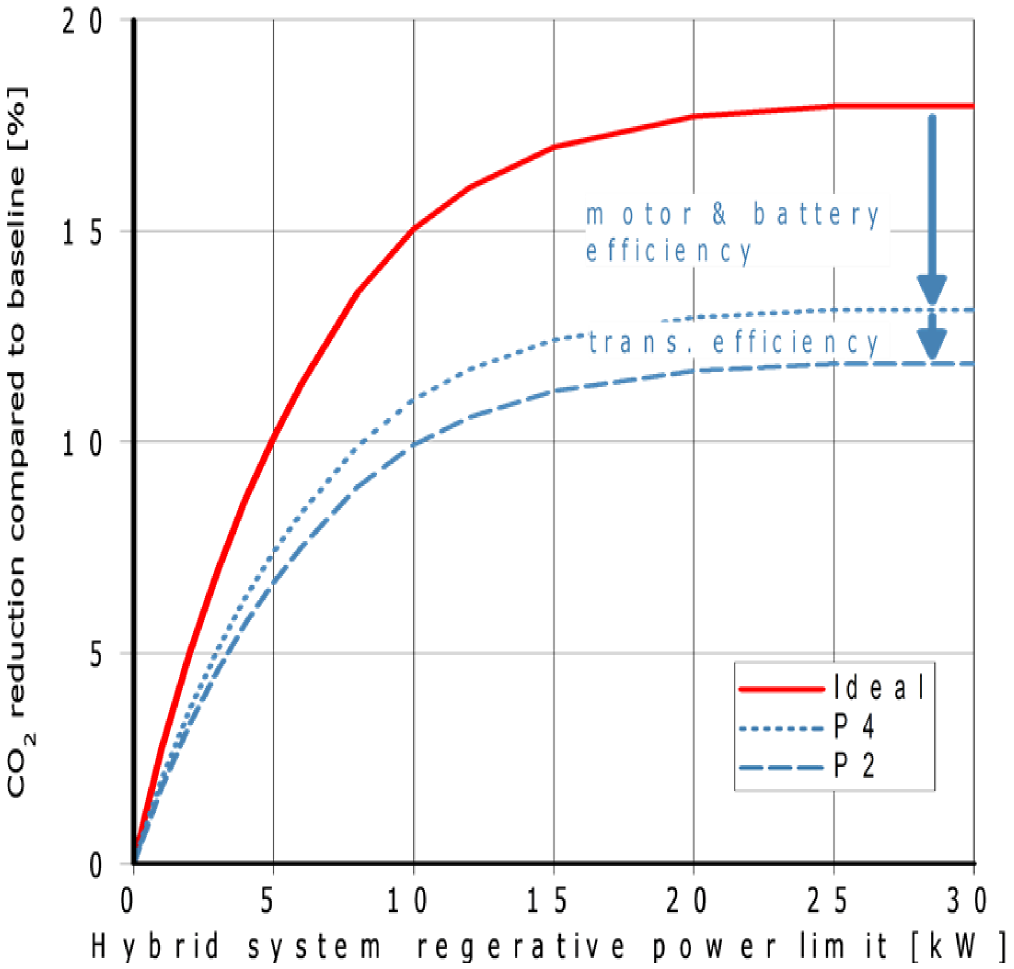
CO_2 benefit based on fixed engine efficiency

Hybrid System Power Requirement – P2

- Electric machine cost reduction possible with reduced maximum speed:
  - Electric machine speed linked with engine speed
- Transmission and final drive inefficiencies
- Position of Motor between engine and transmission:
  - Ability to declutch eMachine from engine
  - Parallel hybrid configuration P2

P2: Up to 12% CO_2 reduction



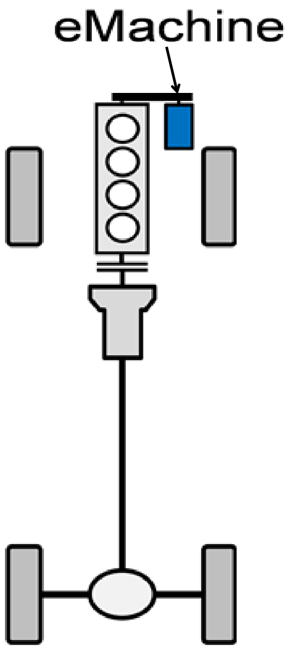


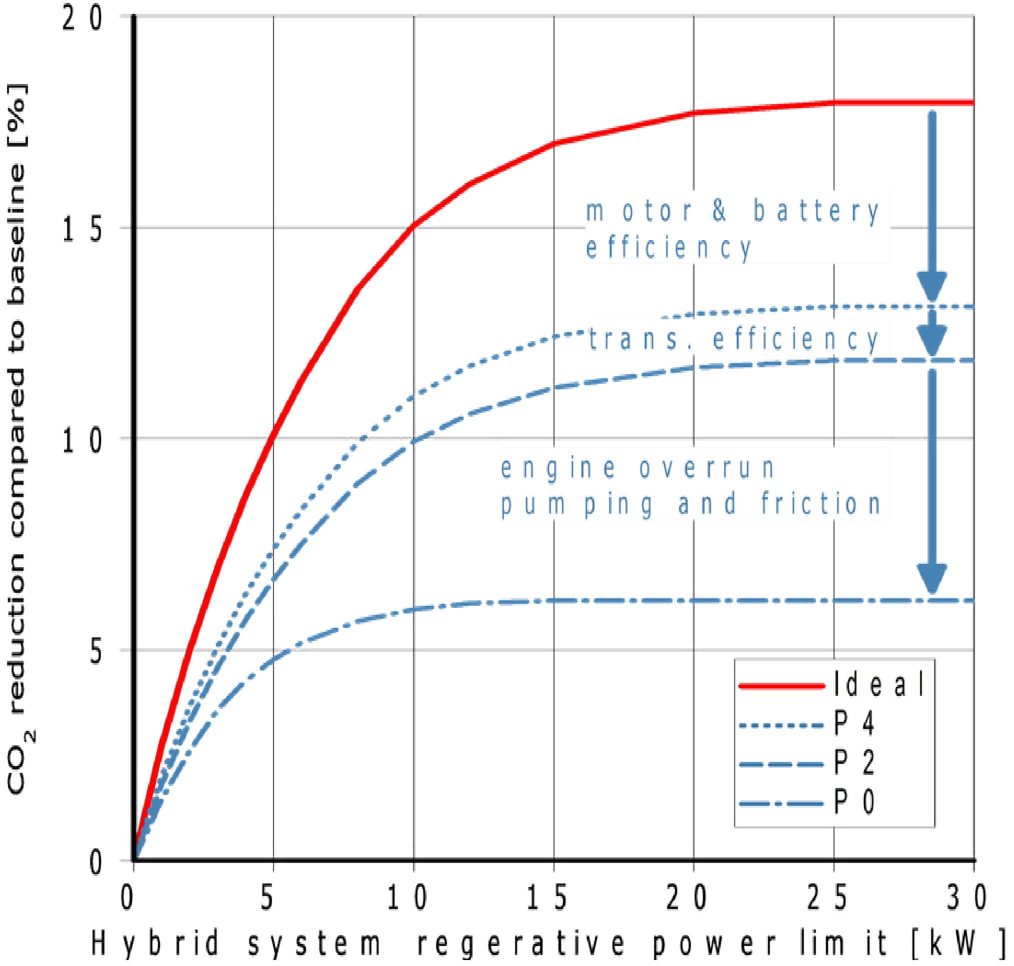
CO_2 benefit based on fixed engine efficiency

Hybrid System Power Requirement – P1/P0

- Even more electric machine cost reduction possible reduced power and limited functionality:
  - Usage as stop-start motor / generator
- Engine friction and pumping losses
- Position of Motor on engine accessory drive:
  - Parallel hybrid configuration P0

P0: Up to 6% CO_2 reduction





CO_2 benefit based on fixed engine efficiency

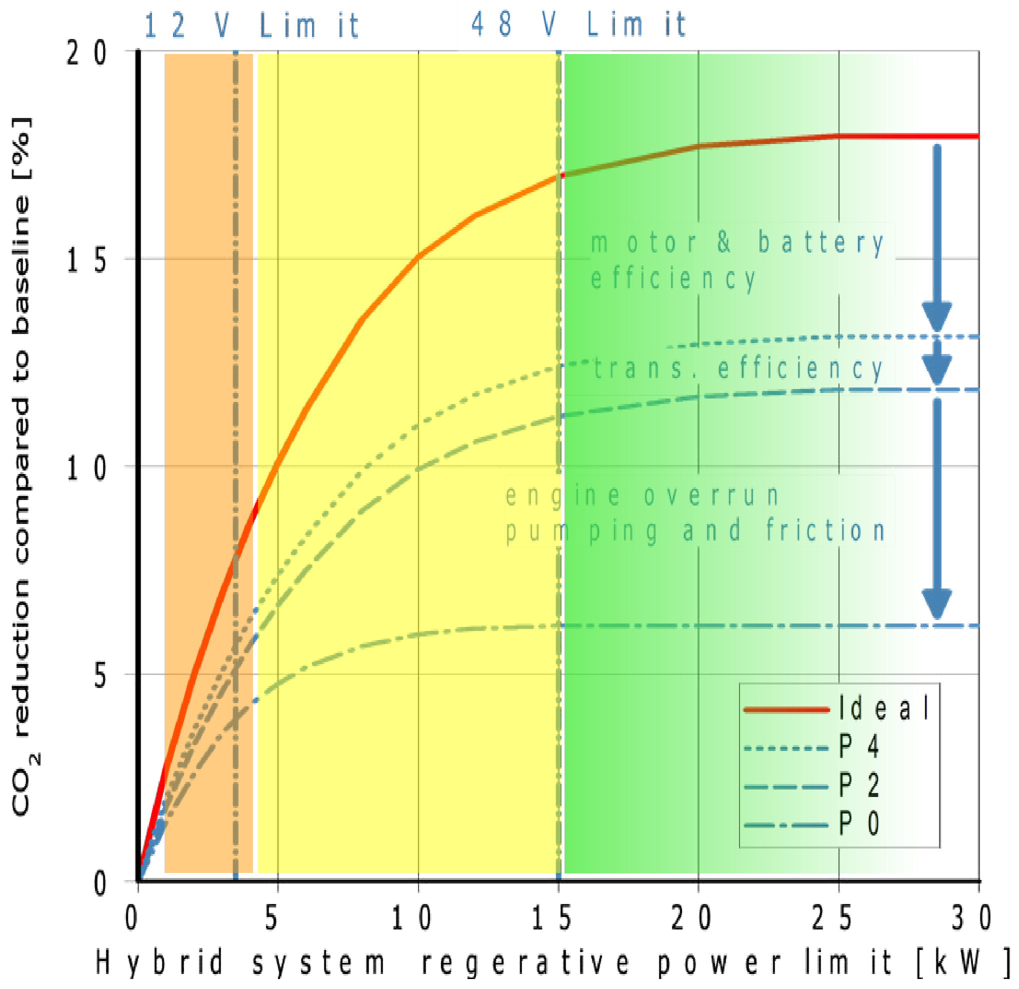
Hybrid System Power Requirement

- With 300A current limit:
  - 12V system max. regenerative power of ~ 4kW (4-6% CO_2 benefit)
  - 48V system max. regenerative power of ~ 15kW (6-12% CO_2 benefit)

- Maximum utilisation of mild hybrid system in P4 configuration
  - CO_2 benefit: 12-13 %
  - DC maximum currents: 300-500 A

Main development targets:

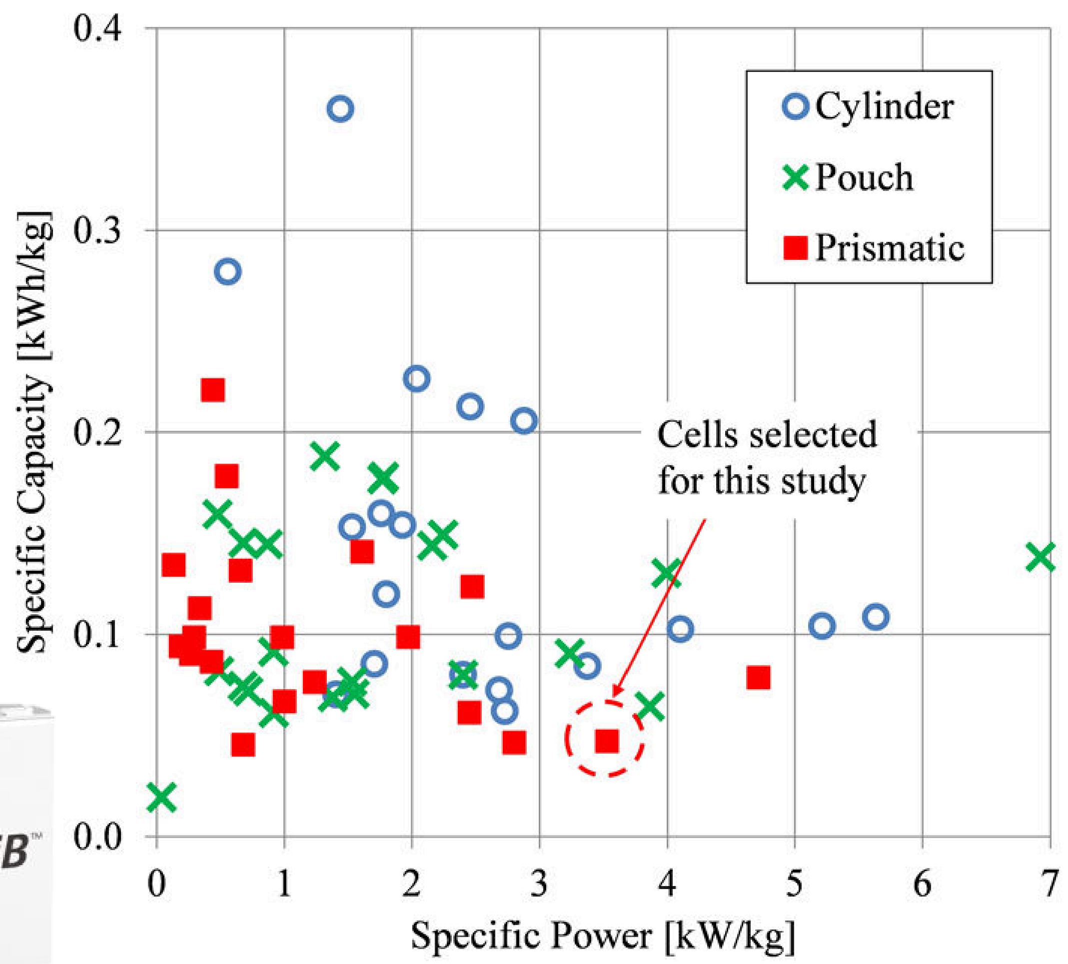
1. 500 A maximum battery charge current
2. Maximum power density for low battery mass



Battery Pack Cell Selection

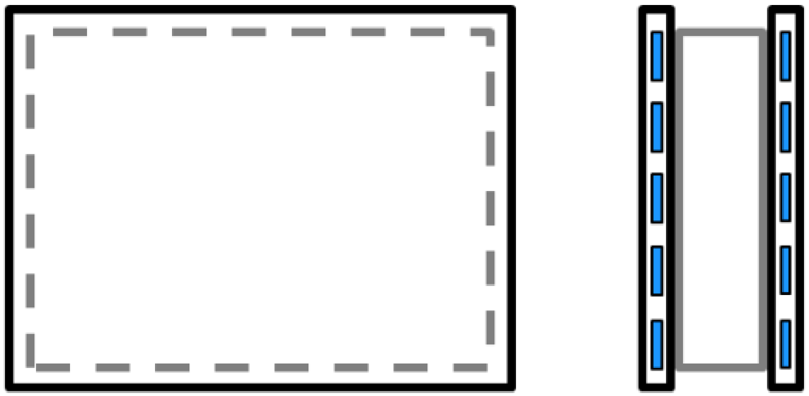
- No restrictions were set regarding:
  - Cell chemistry
  - Cell topology (cylinder, pouch, prismatic)
- Selection of prismatic cells with:
  - high specific power
  - low specific capacity
- Resulting module specification:

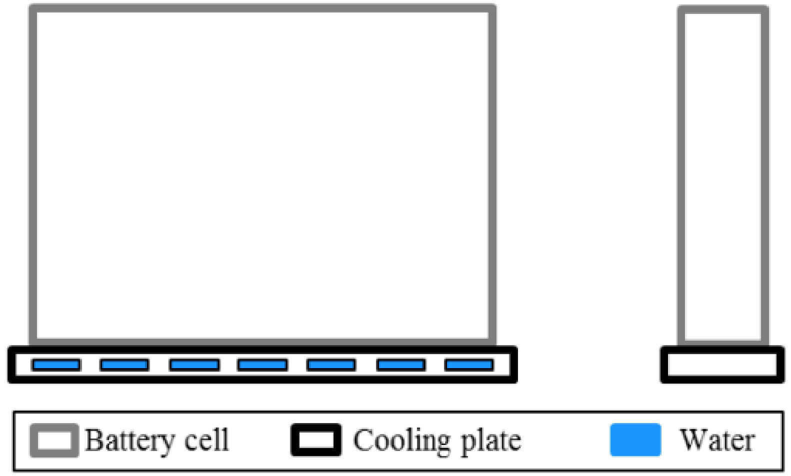
Parameter	Value
Cell configuration	18S 1P
Nominal voltage	46.8 V
Minimum voltage	36 V
Maximum voltage	50.4 V
Capacity	0.5 kWh
Peak current	500 - 650 A
Continuous current	250 A



Battery Pack Cooling Plate Concept

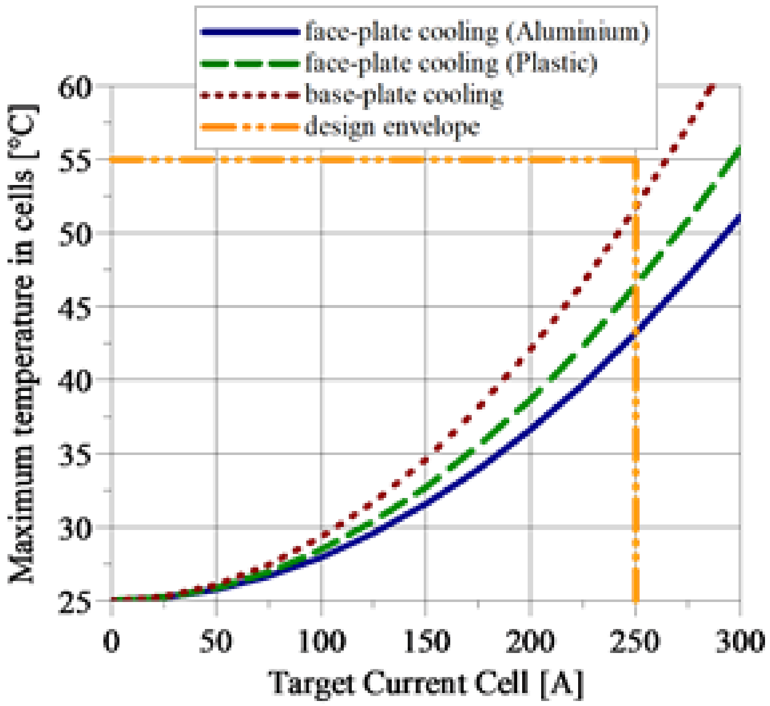
- Two concepts investigated:
  - Face-plate cooling:
    - (+) Large contact area
    - (+) Shortest distances for heat flux
    - (−) Lowest thermal conductivity in cell due to design
    - (−) High amount of plates necessary
  - Base-plate cooling
    - (+) Highest thermal conductivity in cell due to design (factor 100 better)
    - (+) Only one cooling plate
    - (−) Small contact area
    - (−) Long distances for heat flux

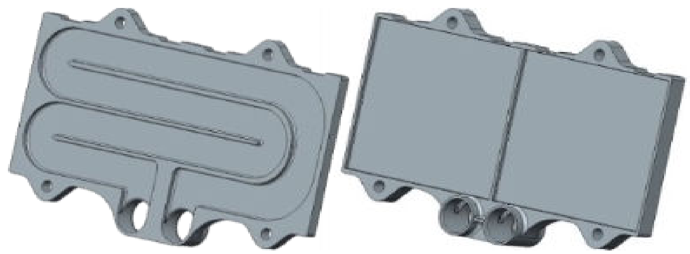




Battery Pack Cooling Plate Concept

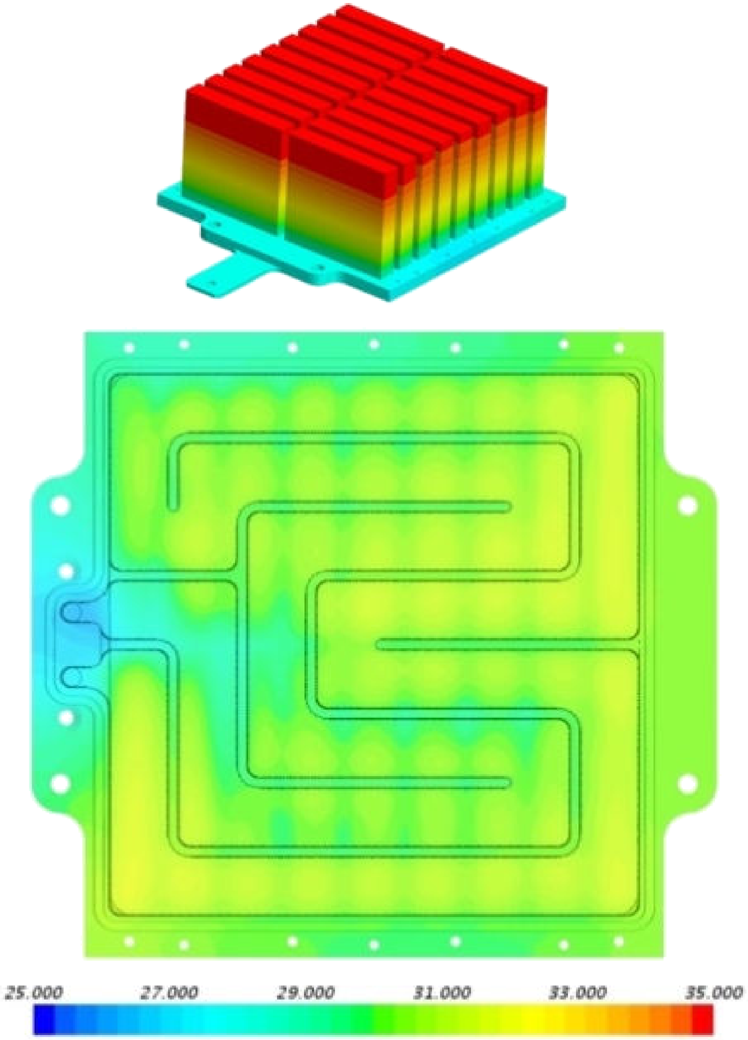
- Comparison of cooling concepts:
  - Face-plate cooling with aluminium plates with lowest temperatures, but
    - electrical isolation of cells difficult
  - Face-plate cooling with plastic plates with second lowest temperatures, but
    - High amount of coolant in channels (~900g)
    - High amount of connections to be sealed for coolant supply
  - Base-plate cooling within target temperature
    - Easy manufacturing
    - Low amount of coolant in channels (~130g)





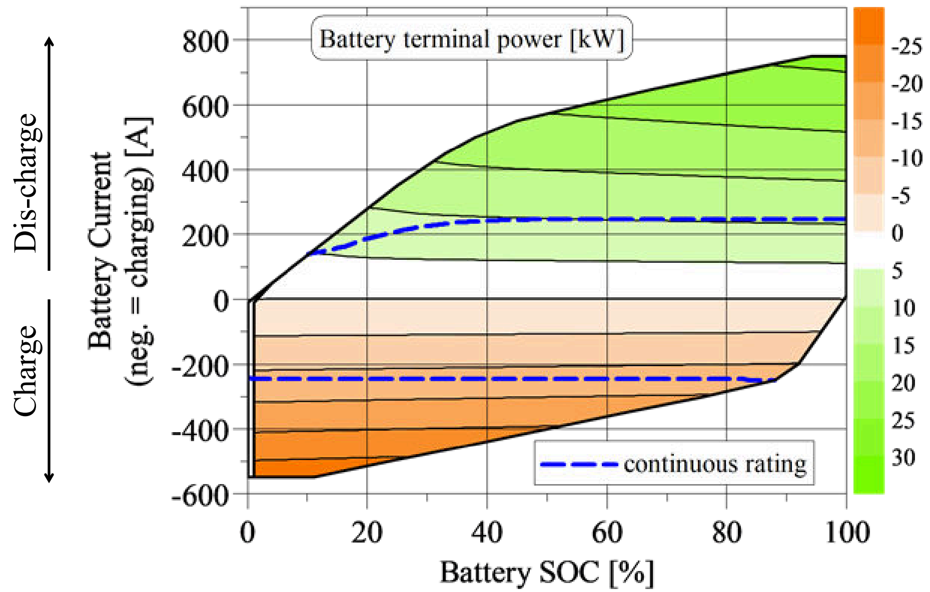
Battery Pack Thermal Analysis

- Detailed analysis and optimisation of base-plate cooling concept
  - All regions of all cells stay within temperature limits set by manufacturer @ 250 A
    - Coolant temperature: 25°C
    - Flow rate: 7 l/min
  - Even temperature distribution in contact surface between all cells
    - $\Delta T < 1.5°C$
    - Targeted to achieve homogenous aging of cell in module



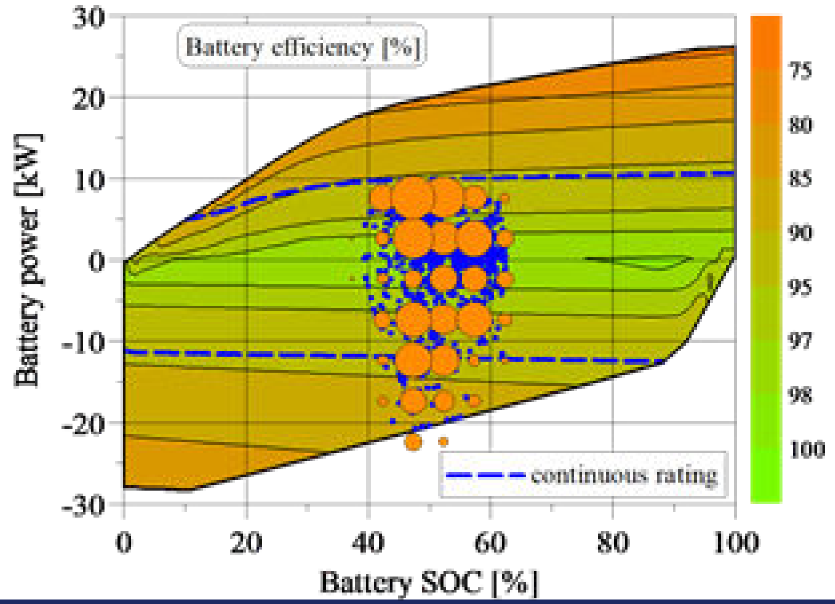
Module Performance Simulation

- Internal resistances of bus bars, fuse, contactors and current sensor
- Voltage limits applied
- Up to 25 kW peak power
- Continuous power: 10 kW discharging
  12 kW charging



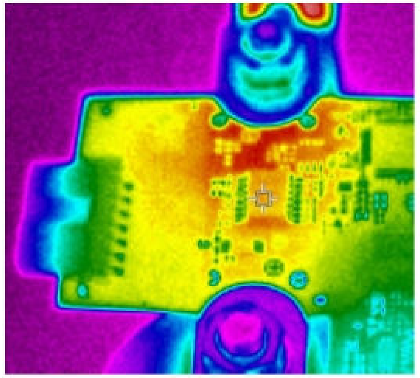
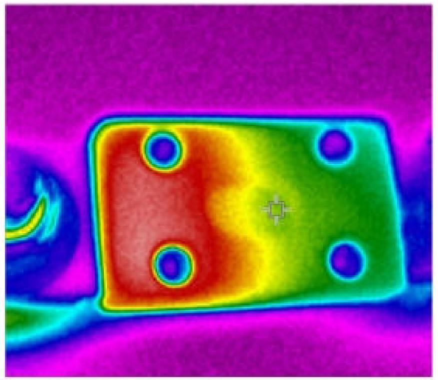
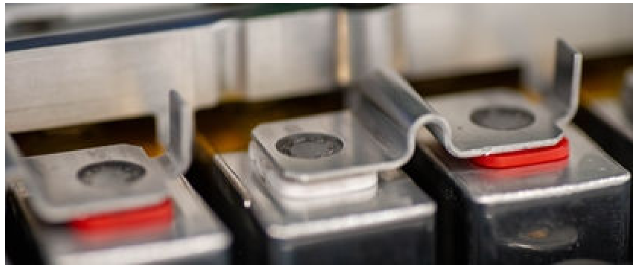
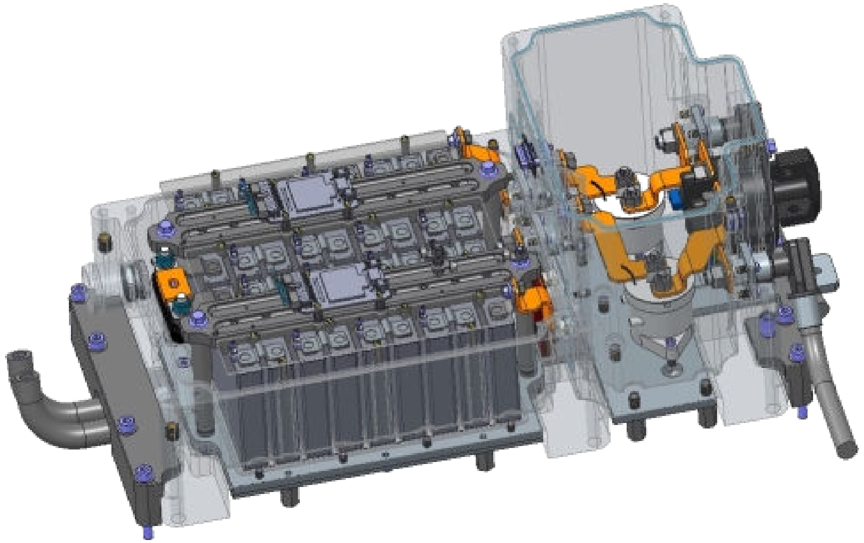
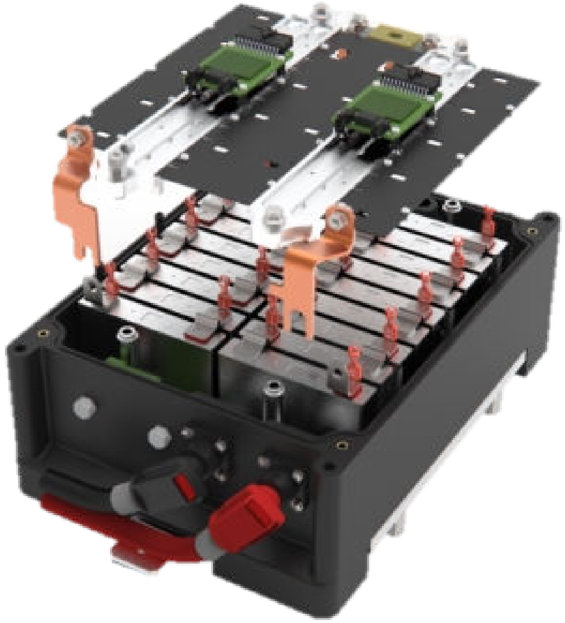
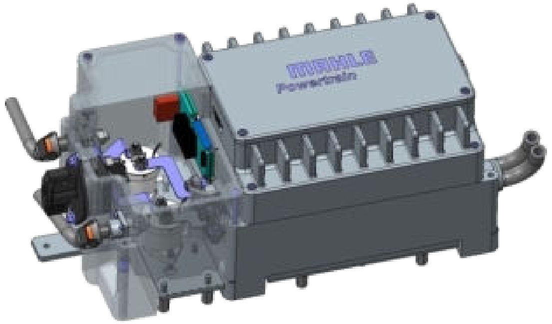
Drive-cycle Simulation in Target Application

- Main operation below continuous rating with efficiencies > 90%
- Peak power limited only when regenerating
- SOC operating window: 40 – 60 %



Detailed Design

- Detailed design study carried out
  - Package space in car under boot floor
  - Additional (detachable) safety module for prototyping (contactors, pre-charge, manual disconnect)
  - Basic crash simulation
  - Electromagnetic compatibility (EMC)

Summary

- Detailed analysis of performance requirements of mild hybrid systems
  - For maximum CO_2 benefit 25 kW of charging power required
  - Low capacity for minimum mass increase
- Design of battery module completed
  - Up to 25 kW charging and discharging power
  - Continuous power ratings of 10 kW discharging and 12 kW charging
  - Additional safety module for prototyping
- **5 – 15% CO_2 benefit in target application**
  - **Depending upon hybrid system architecture**
- **Battery module is currently built and prepared for testing**

Thank you for your kind attention!

Mike.bassett@gb.mahle.com