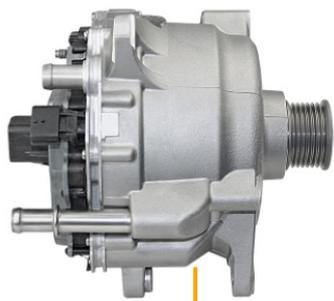




## Benefits of a 48V P2 Mild Hybrid

Brian McKay, Ph.D.  
Powertrain Technology & Innovation

# 48V Hybrid System Component Overview



## Configuration

- › Belt Starter Generator
- › DC/DC Converter
- › Li-Ion Battery



- › 48V electric motor
  - › Belt starter generator (BSG)
  - › Integrated starter generator (ISG)
  - › Electric front/rear axle drive (eFAD/eRAD)
- › DC/DC converter & Li-Ion battery
- › Features:
  - › Energy recuperation
  - › Engine-off coasting. Advanced ESS (<20 km/h)
  - › Torque assist and electric driving
  - › Power 48V consumers

# 48V Topology

## Mild Hybrid System Roadmap

### P0 configuration

- › Low cost integration
- › BSG on front end accessory drive (FEAD)
- › Torque limited

### P2 configuration

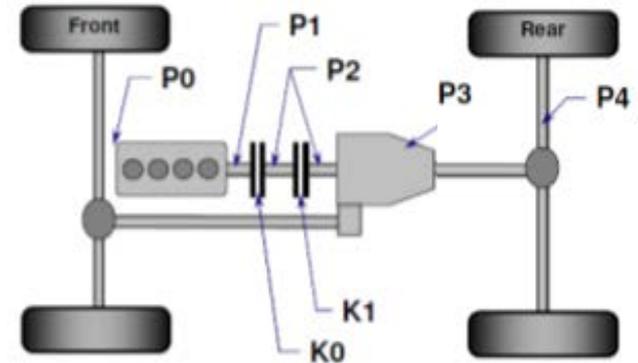
- › Side attached BSG or ISG
- › Higher cost and architectural changes
- › Additional hybrid functions
- › Eliminate engine drag loss

### P1 Configuration

- › Crankshaft mounted
- › High torque density
- › Axial length restrictions

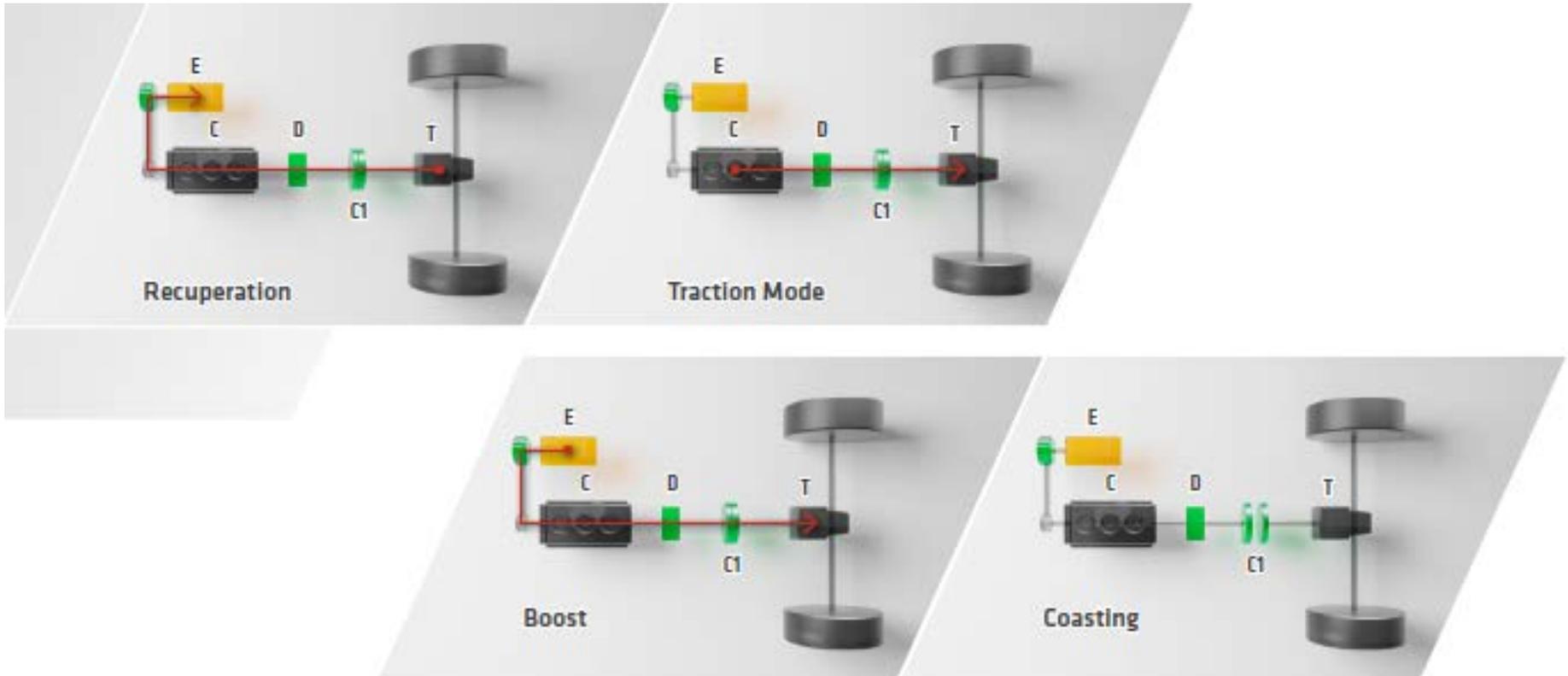
### P3 & P4 Configurations

- › P3: eMotor torque on gear output
- › P4: eMotor torque directly on axle drive
- › Highest recuperation potential



# P0 Architecture

## Limited Hybrid Mode Capability



C = Combustion Engine

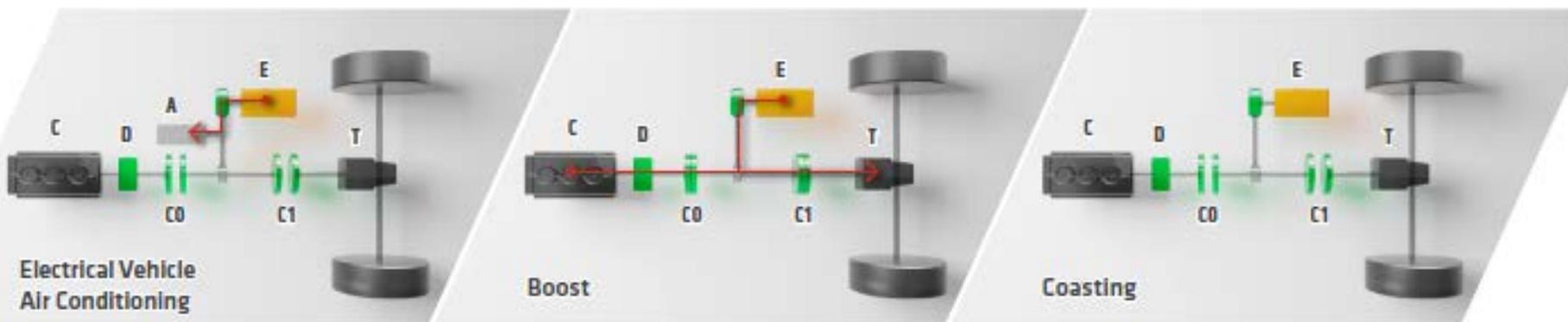
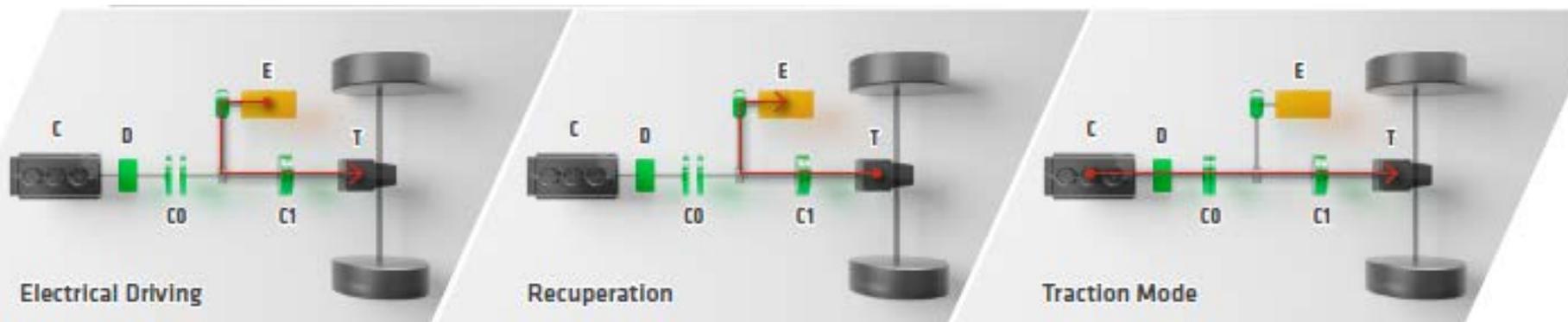
D = Dual Mass Flywheel

E = Electrical Machine

T = Transmission

# P2 Architecture

## Full Hybrid Mode Capability

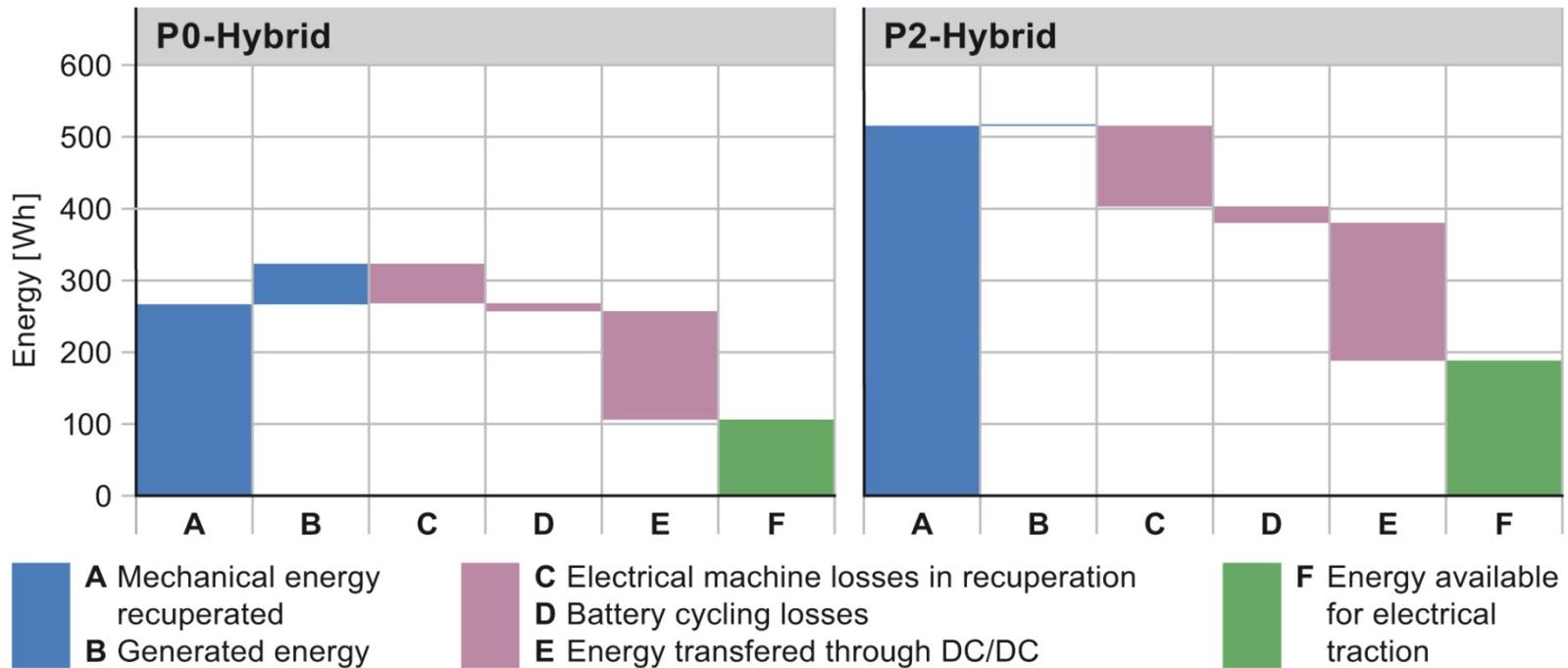


A = Air Conditioning Compressor    C = Combustion Engine    D = Dual Mass Flywheel    E = Electrical Machine    T = Transmission

# Kinetic Energy Regeneration by Architecture

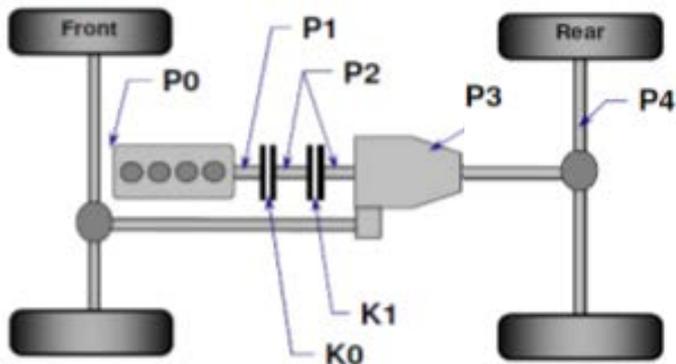
## P0 vs. P2

- › Architectures evaluated in WLTC for a C-segment vehicle class (inertia 1250 kg)
- › P2 configuration offers significantly higher energy regeneration benefit of up to 40%



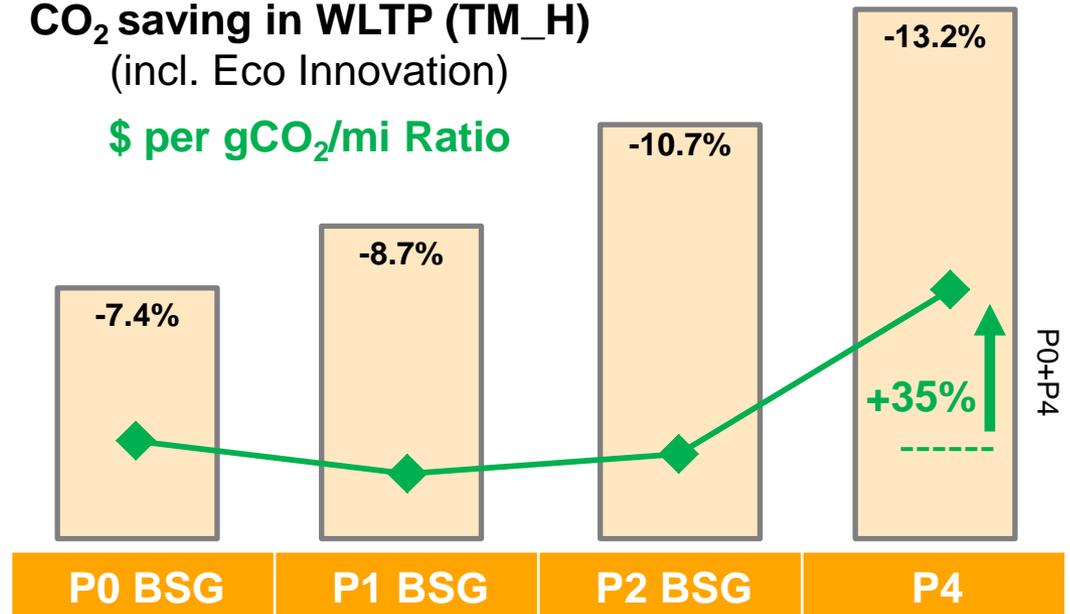
# 48V Topology

## Fuel Economy Benefit



CO<sub>2</sub> saving in WLTP (TM\_H)  
(incl. Eco Innovation)

\$ per gCO<sub>2</sub>/mi Ratio



	P0 BSG	P1 BSG	P2 BSG	P4
Recuperation, electric torque assist, "change-of-mind", engine-off coasting	✓	✓	✓	✓
Engine-off climate control	✗	✗	✓	✗
eCreeping	✗	✗	✓	✓

# System Level Approach

## P0 vs. P2

### Gasoline Technology Car I

- › Ford Focus 1.0L 3cyl Eco-Boost, CR=10,
- › No geometrical changes on the engine
- › Fuel Injection System XL3.1 with 200 bar
- › 48 V P0 architecture: Belt-driven Starter Generator (BSG)
- › Manual transmission with eClutch
- › CO<sub>2</sub> emission = 95 g/km (NEDC), Euro 6c



### Gasoline Technology Car II

- › Ford LINC 1.0L 3cyl Eco-Boost, raised CR=12
- › modified intake camshaft, RAAX™ turbocharger
- › Fuel Injection System XL3.1 with 200 bar
- › 48 V P2 architecture: BSG between combustion engine and transmission
- › Manual transmission with eClutch
- › CO<sub>2</sub> emission target < 85 g/km (NEDC), Euro 6c



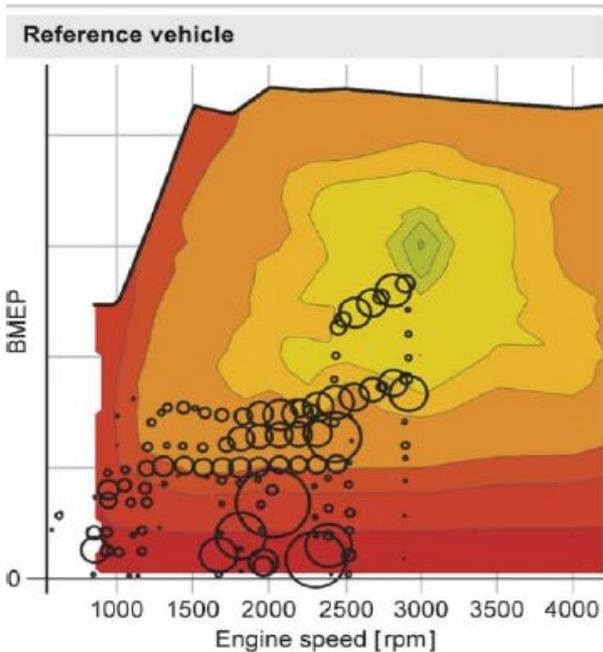


# 48V Hybrid

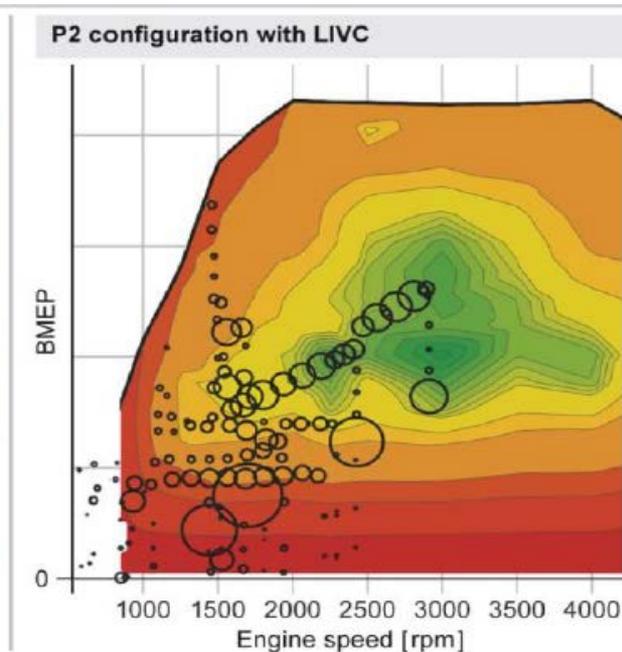
## CR & LIVC Opportunities

- › Increase CR from 10 to 12. Rematch turbocharger.
- › Utilize electric driving and downspeeding to address low end torque/turbo lag while minimizing enrichment.

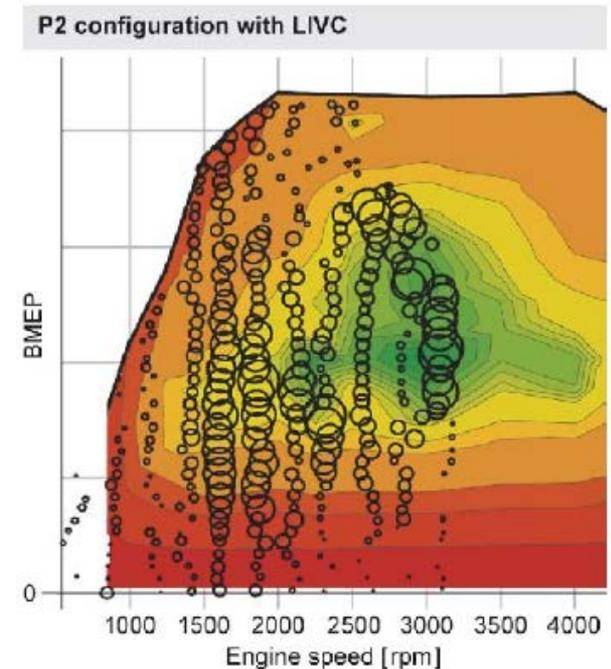
48V P0 + CR10, NEDC



48V P2 + CR12, NEDC

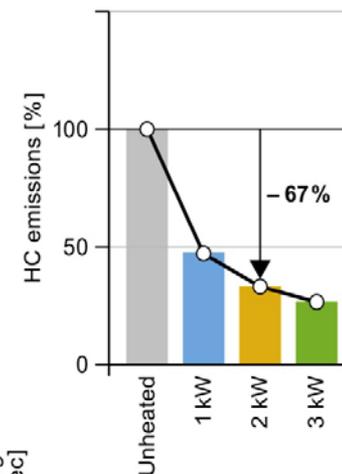
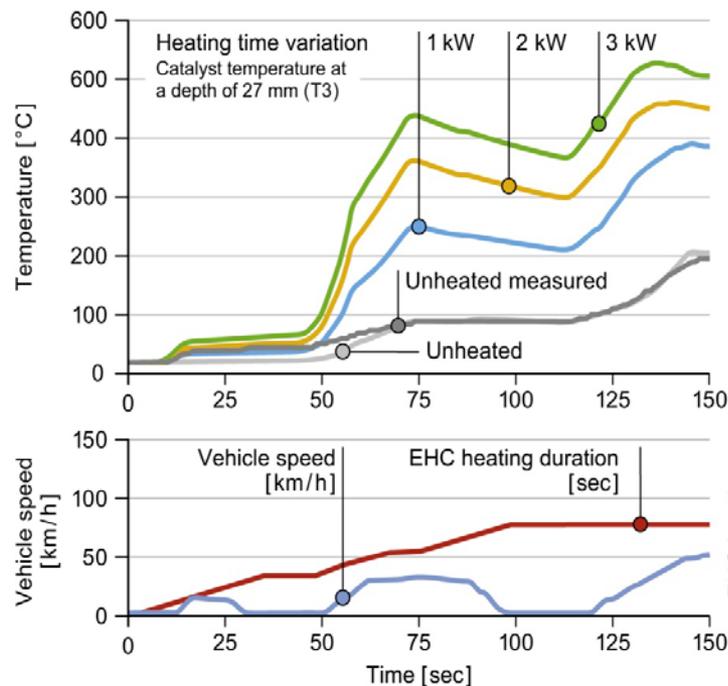
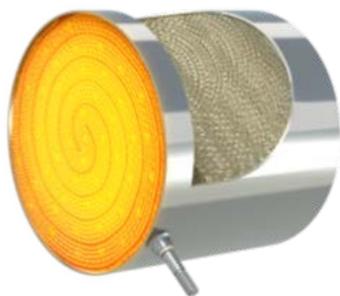


48V P2 + CR12, WLTC



# Electrically Heated Catalyst Cold Start Emission Strategy

- › Compliance to SULEV 30 and PM/PN limits requires a balance of catalyst light off with minimal particulate formation.
- › Turbocharged engines struggle with catalyst light-off duration.
- › Further exacerbated with durations of engine-off.



# Powertrain Architecture

## Motivation for the 48 V P2 Topology

### P2 topology attributes

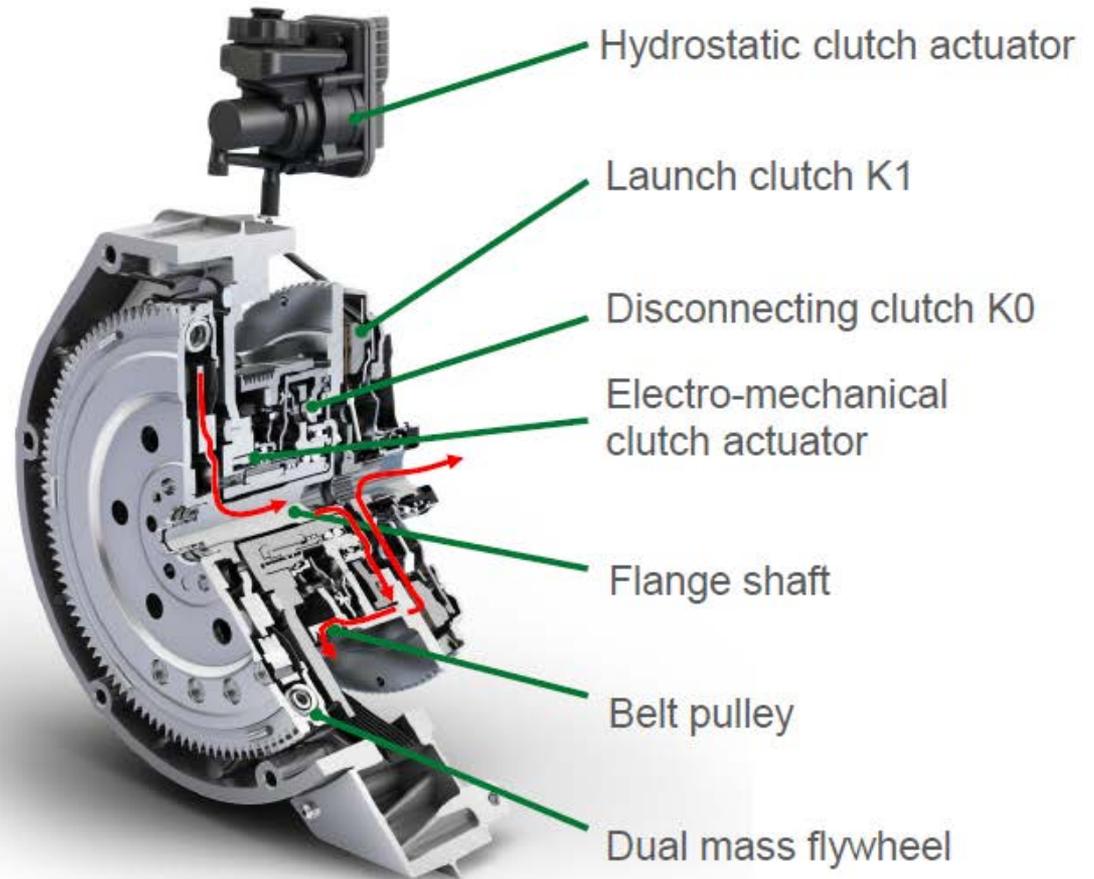
- › Located between ICE and transmission
- › Max. recuperation capability (reduced drag torque)
- › Engine-off coasting
- › Engine-off recuperation
- › Pure electric drive ('active' sailing)
- › Electric launch + electric creeping
- › Conservation of air conditioning (engine-off coasting, S/S phases)



# Hybrid Module Clutch Module

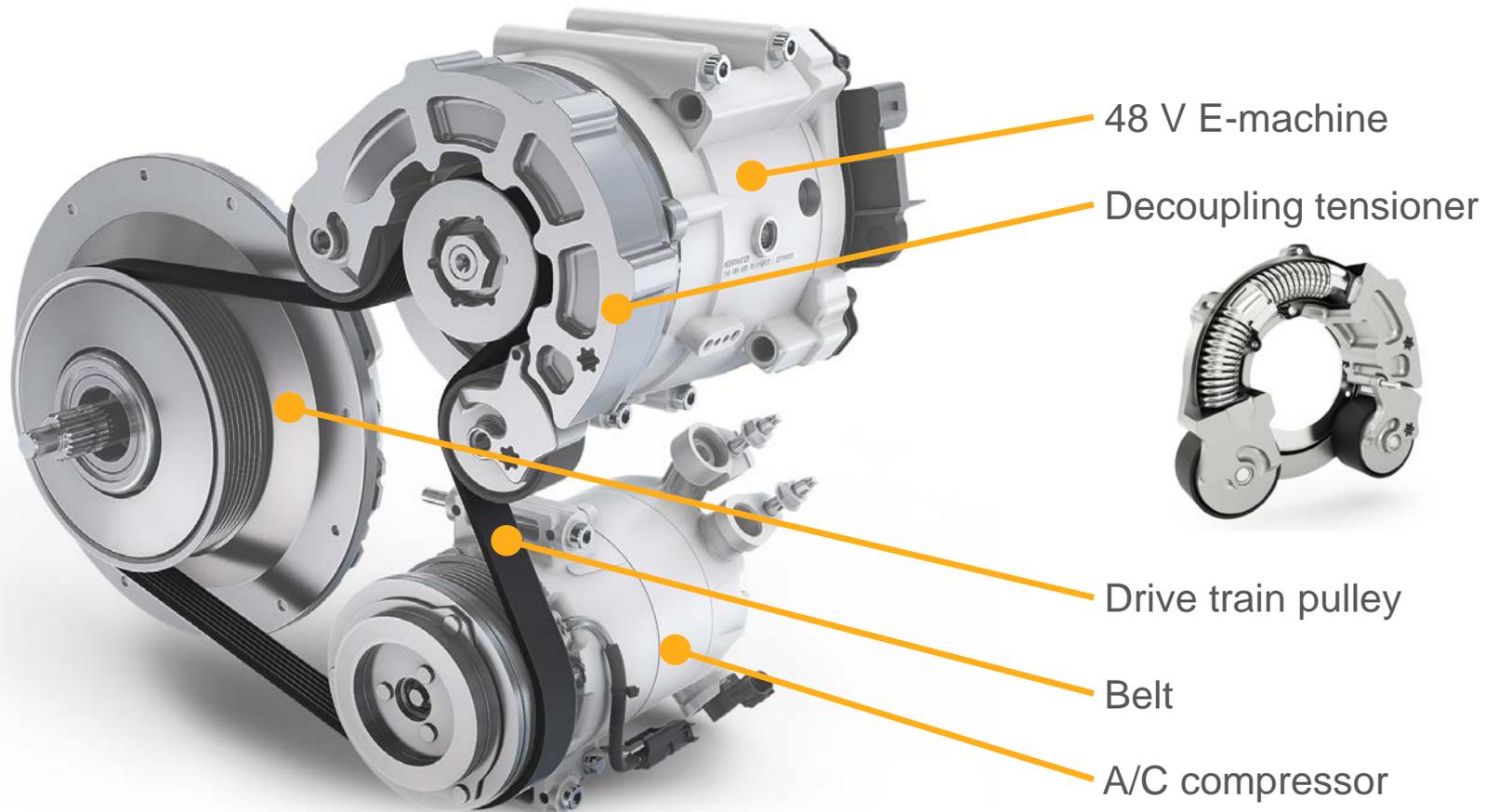
## Advantages

- High degree of integration
  - optimized axial package space
- Smart clutch modules
  - low functional integration effort
- Belt drive behind DMF
  - reduced torsional vibrations



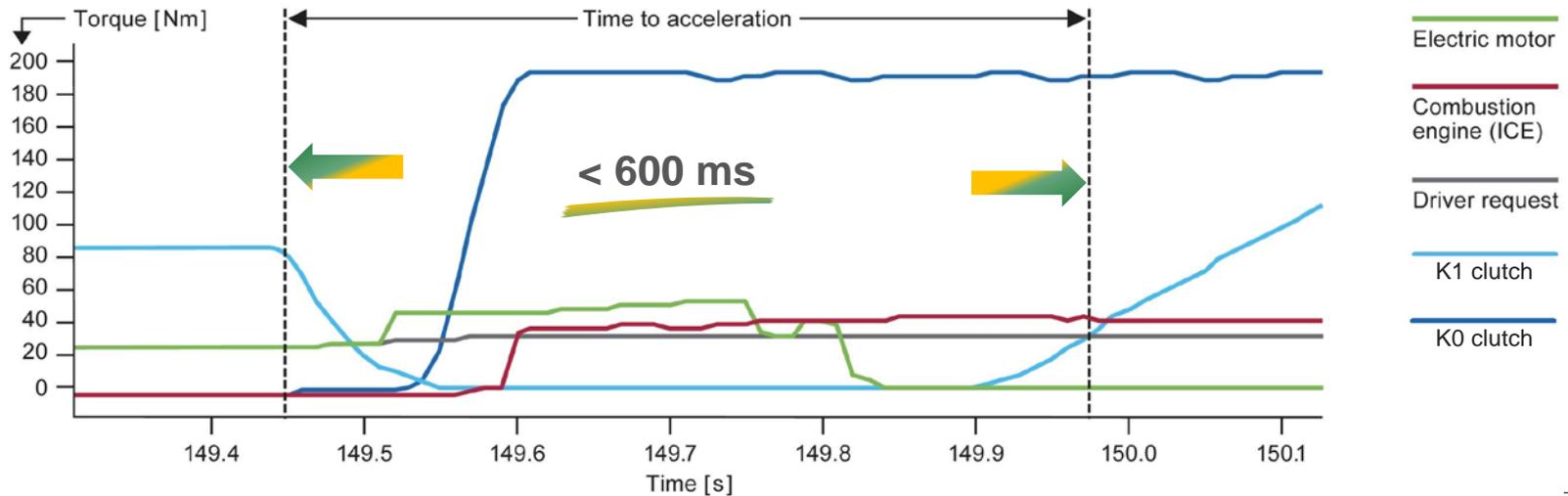
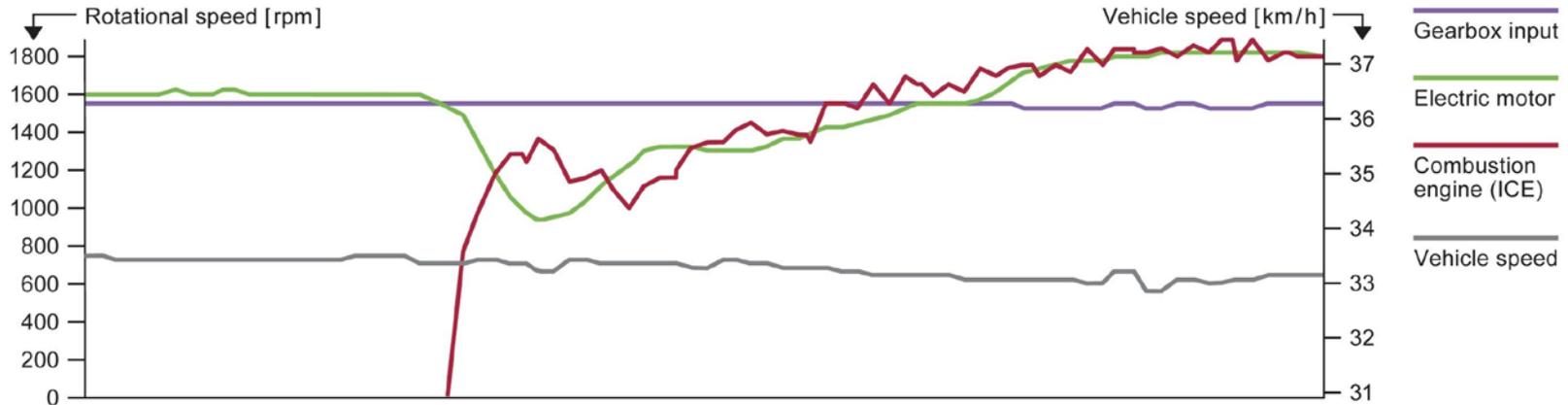
# Hybrid Module

## Belt Drive



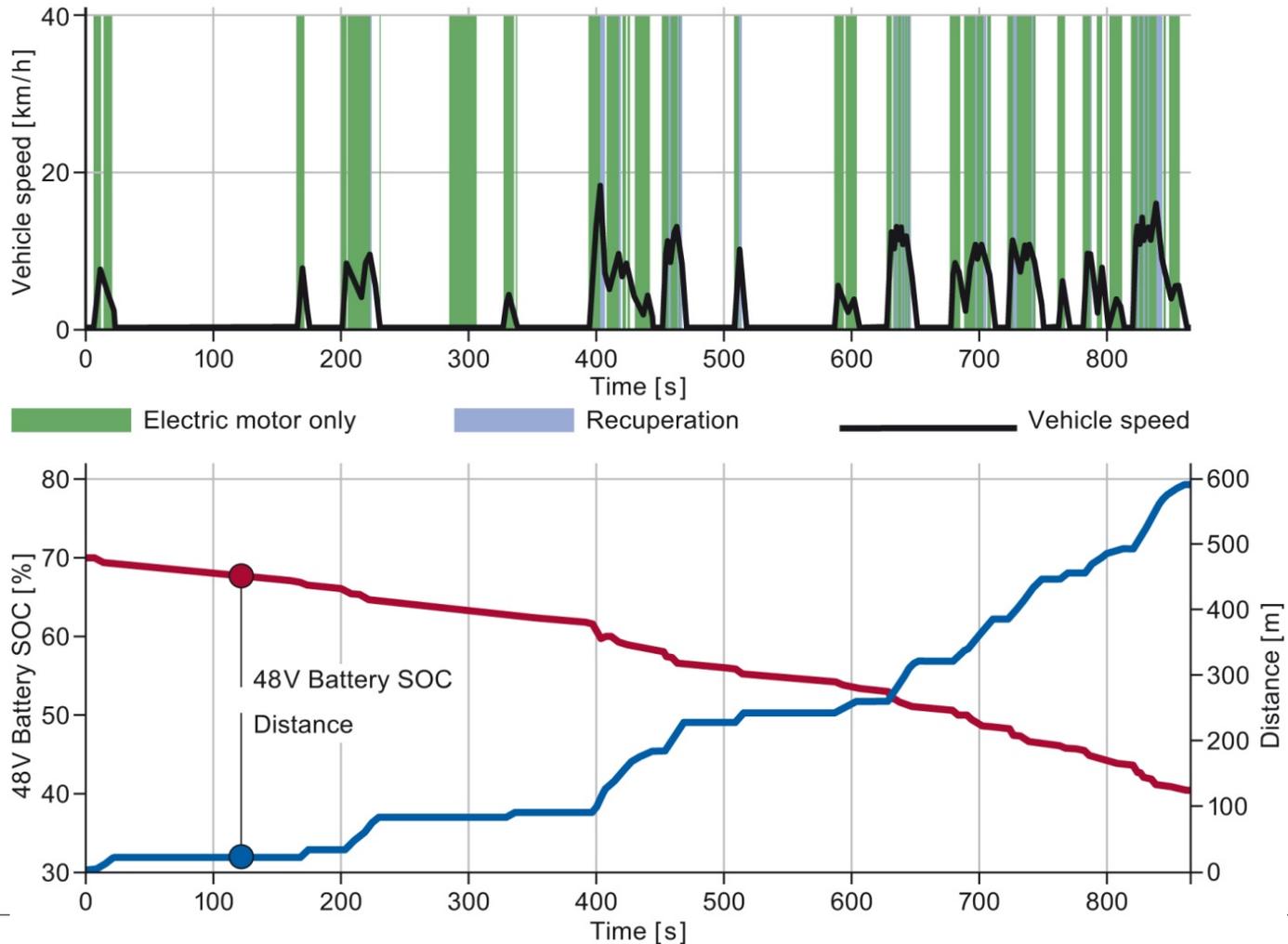
# Hybrid Module

## Engine Restart – Acceleration from Coasting Mode



# eCreeping

## Extended Functionalities – Traffic Jam

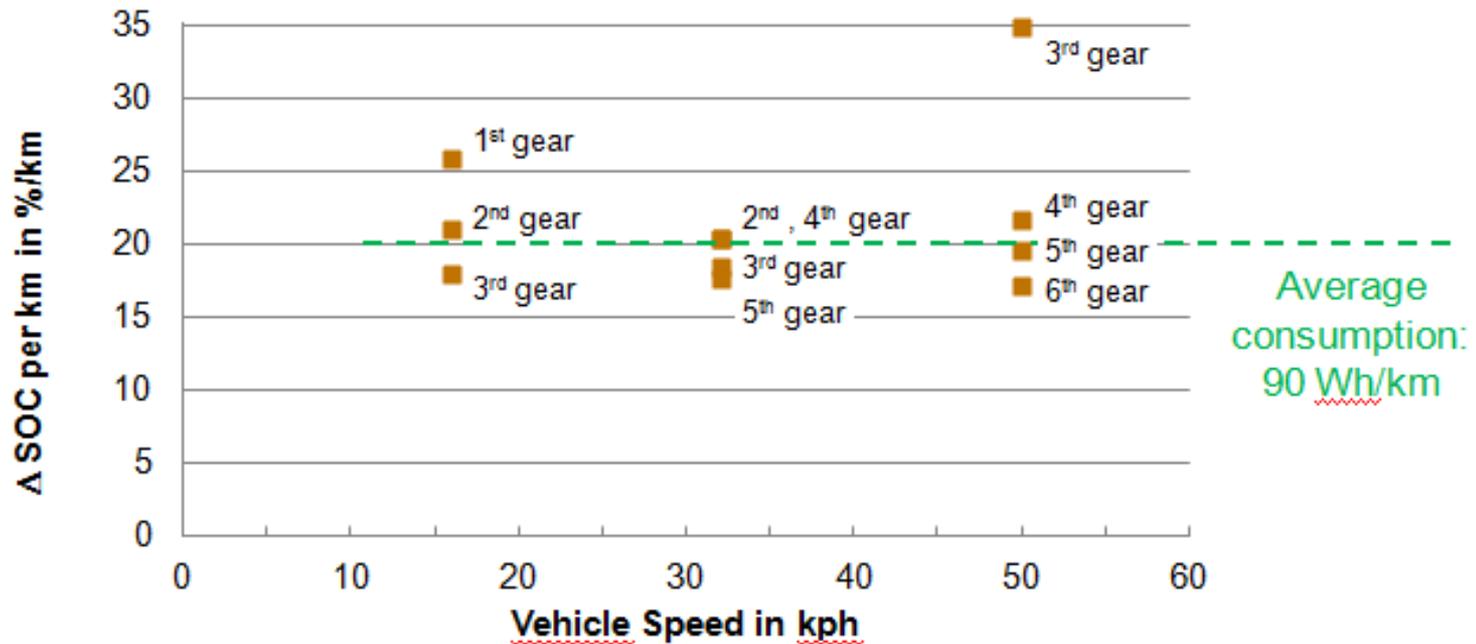


# eSailing

## Purely Electric Driving with 48V P2 Hybrid

### Results from a C-Segment vehicle (inertia 1250 kg)

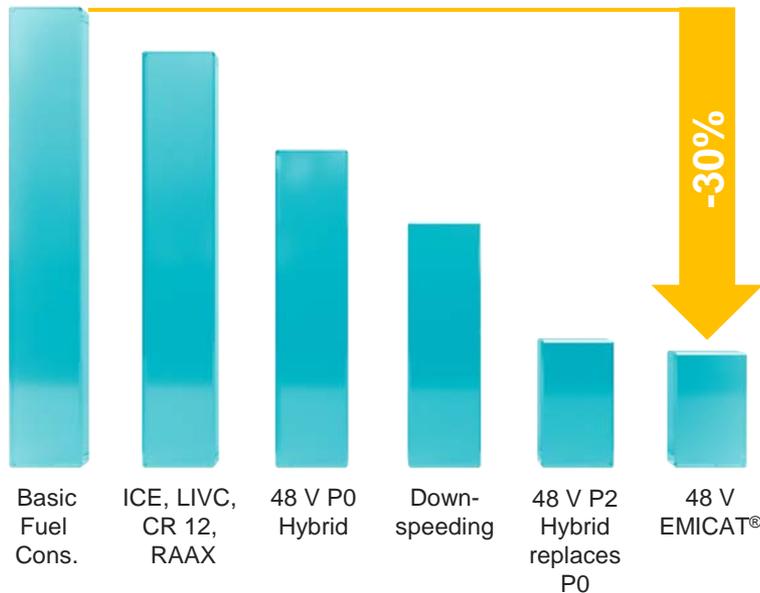
- › Keep vehicle speed constant purely electrically
- › 100% state-of-charge (SOC) corresponds to 460 Wh



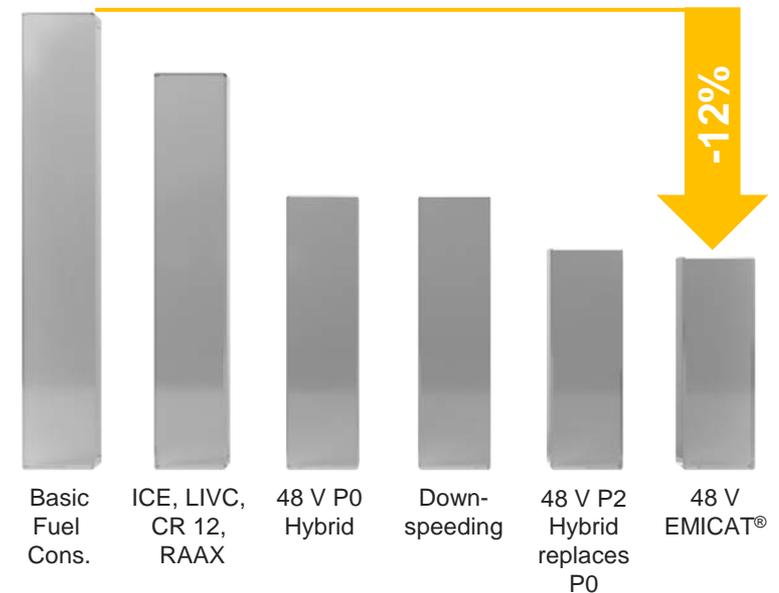
# CO<sub>2</sub> Reduction Potential

## Selection of System Configuration by Simulation

### NEDC



### WLTP



### Combustion Engine

- › Higher efficiency by high CR

LIVC: Late Intake Valve Closure  
CR: Compression Ratio

### Hybrid Concept

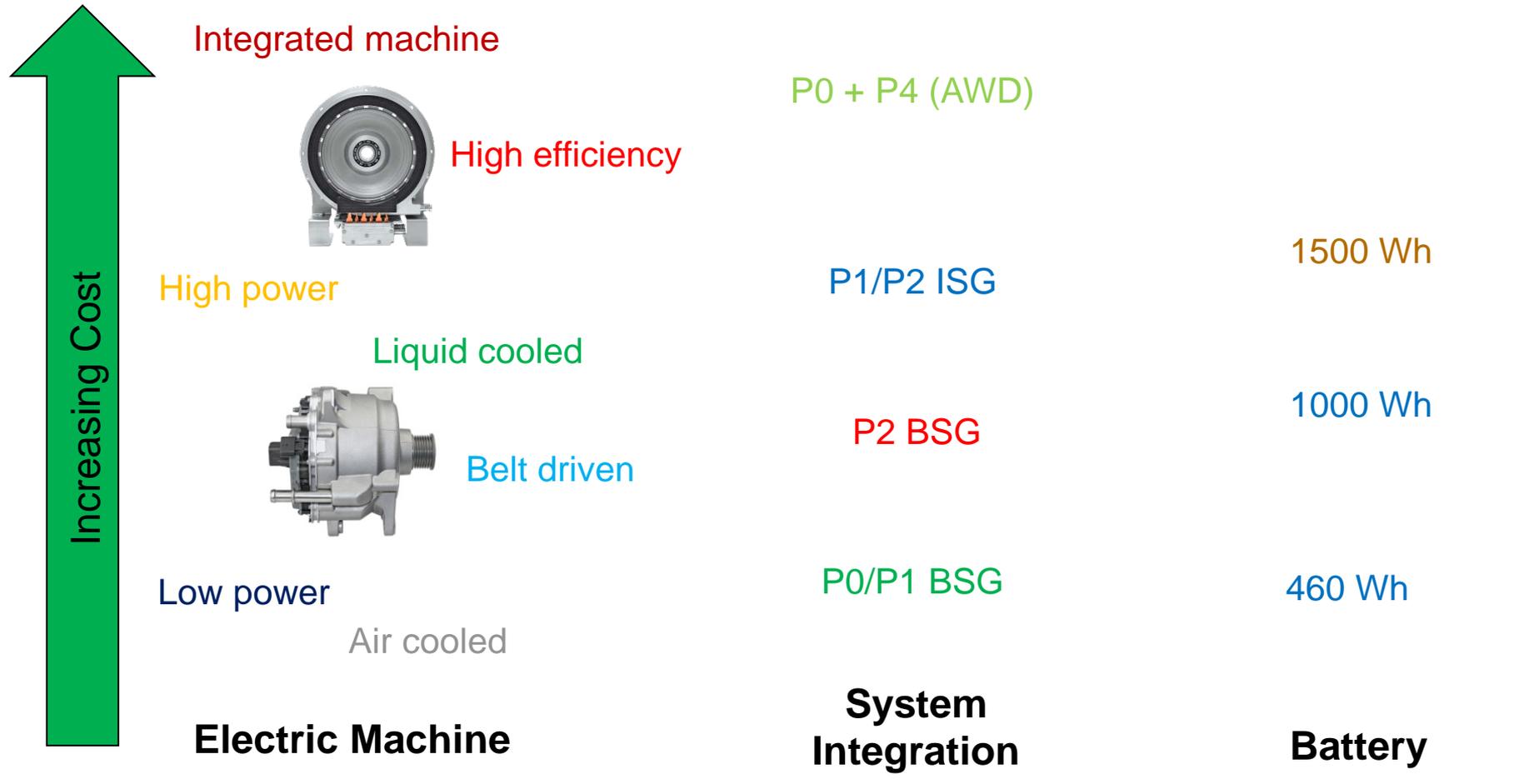
- › Increased recuperation capability
- › Electric drivability

### Operation strategy

- › System optimization (1+1=3)

# 48V Hybrid

## Cost Sensitivity



**Thank you!**

Questions?

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