Powertrain Topologies

4AT060 / 5AT010

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Powertrain Topologies

Contents:

- **Basic Vehicle Modelling Electric Vehicles Topology**
- **Hybrid Electric Vehicles Topology**

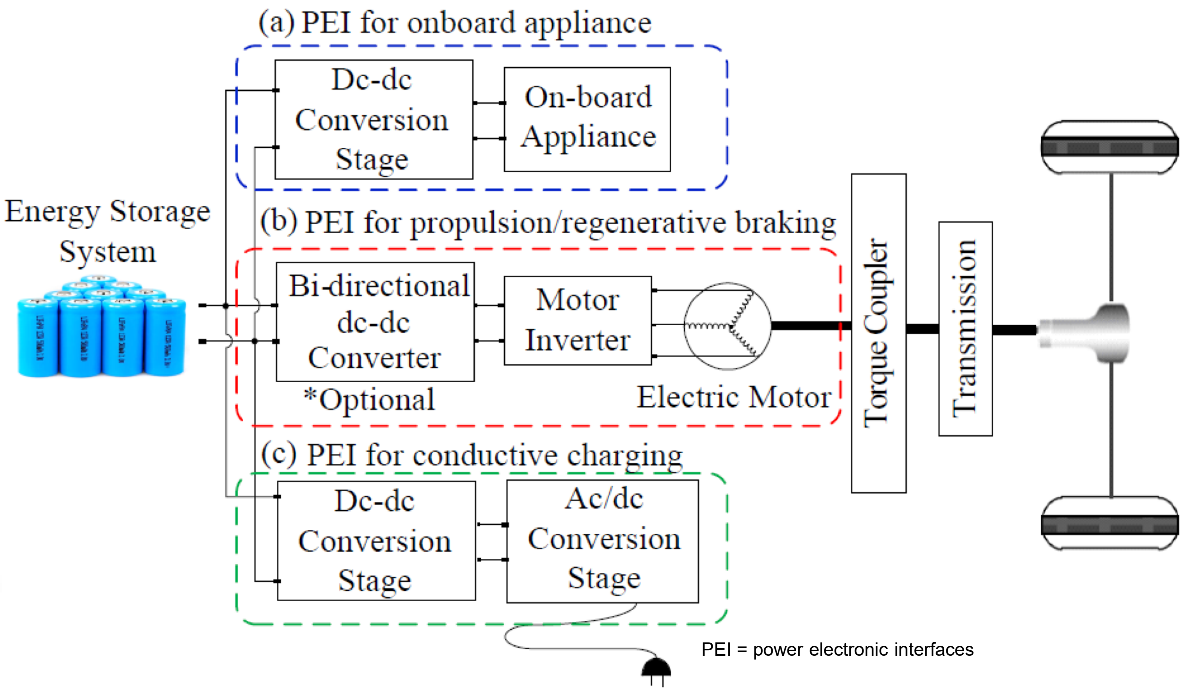
Recommended Reading:

- **Chapter 2 ('***Types of Electric Vehicles – EV Architecture'***), Electric Vehicle Technology Explained,** *Second Edition, James Larminie, John Lowry*
- **Chapter 3 ('***Electric Vehicles'***), Modern Electric, Hybrid and Fuel Cell Vehicles, Fundamentals,** *Theory, Design, Second Edition, Mehrdad Ehsani, Yimin Gao, Ali Emadi*
- **Chapter 4 ('***Hybrid Electric Vehicles'***), Modern Electric, Hybrid and Fuel Cell Vehicles, Fundamentals,** *Theory, Design, Second Edition, Mehrdad Ehsani, Yimin Gao, Ali Emadi*

Electric Vehicles Topology

Classic Full Electric

Powertrain Architecture →



PEI = power electronic interfaces

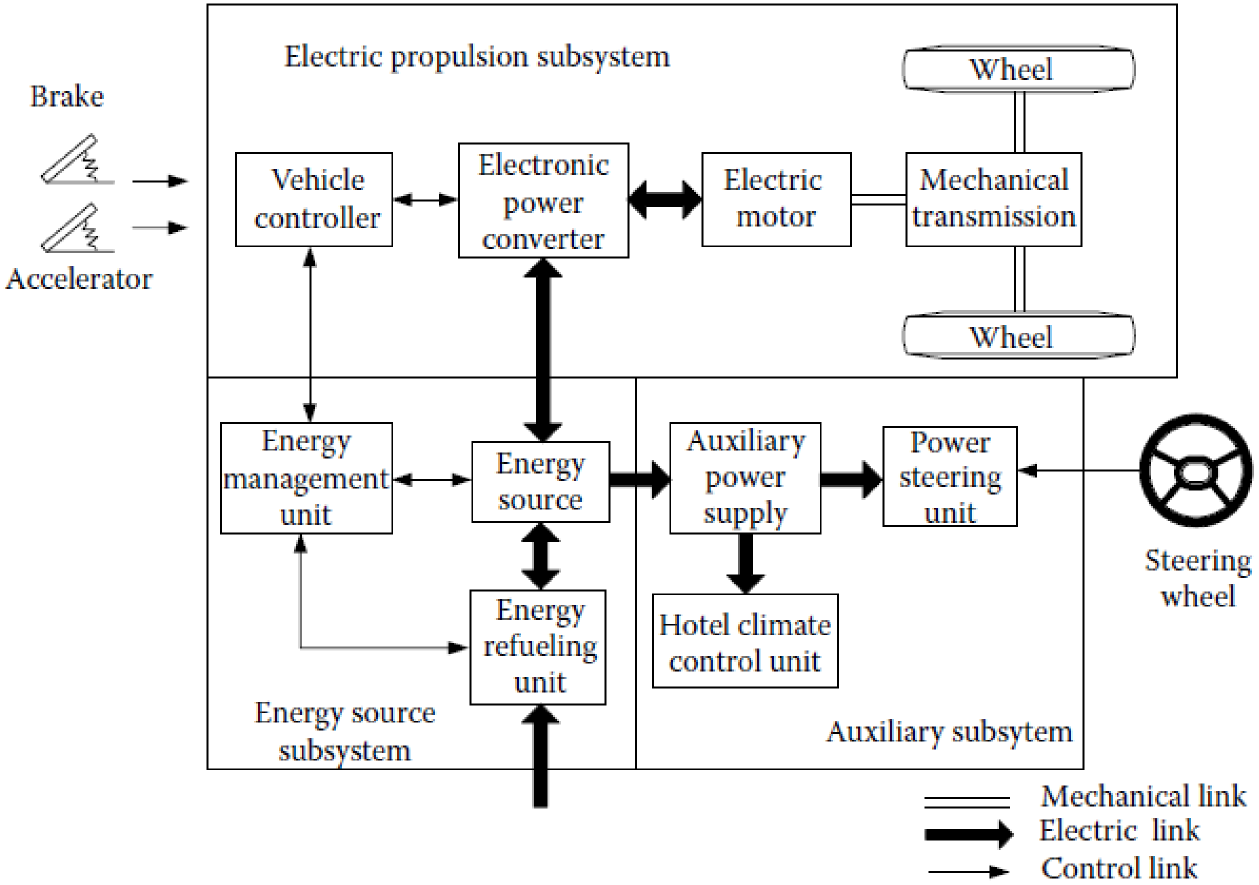
←Full Electric Refuse Truck
DAF/VDL

Source: J. Shen, Energy management of a battery-ultracapacitor hybrid energy storage system in electrical vehicles, PhD Thesis, University of Maryland, USA, (2016)

Primary EV Topology

- Typical EV also includes:
  - Energy management
  - Management of auxiliaries
  - Management of charge control
  - Thermal management of the complete vehicle
  - Driver support / vehicle control functions

More in week 8



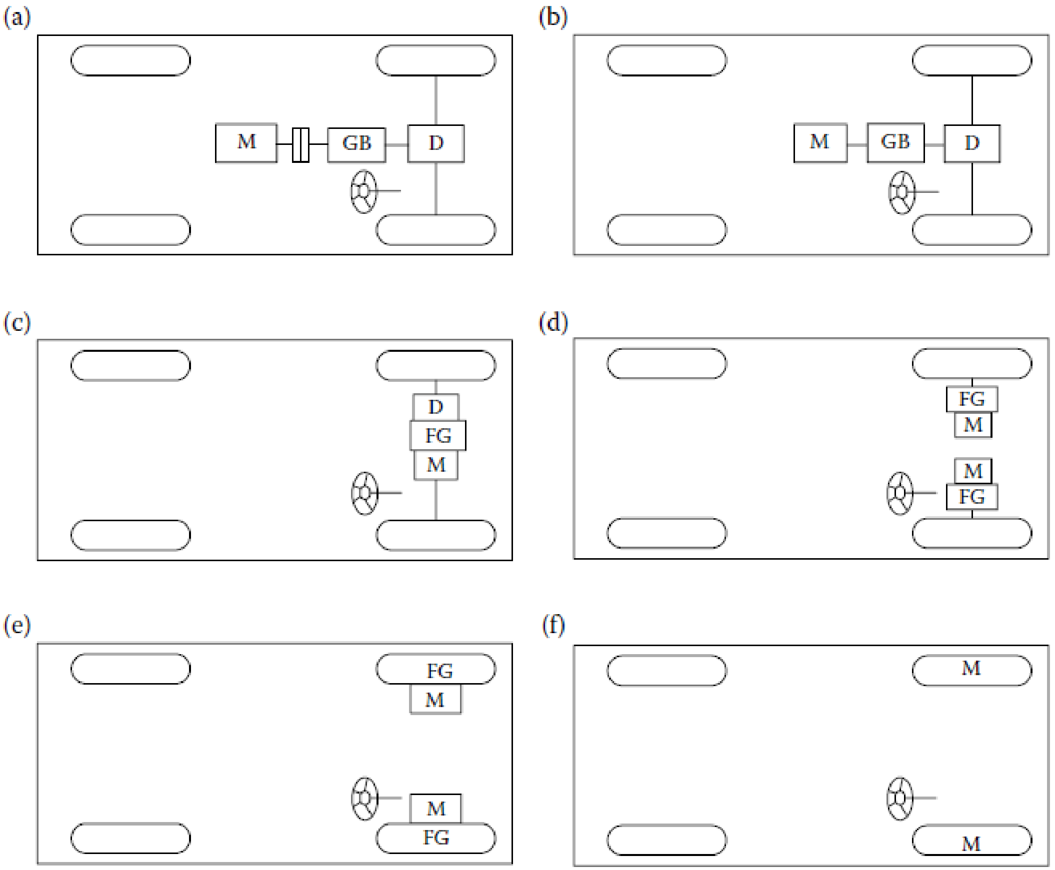
Electric Vehicle Topology Variants

- Electric machines can be combined within the driveline to support different performance and energy efficiency characteristics
- Includes another level of mode/control
- Very important considering ‘e-axles’
- Front and rear axles also possible (next slide) – consider Tesla D

- Question:

  Is the same true for HD trucks?

  What other options are there?



C: Clutch
D: Differential
FG: Fixed gearing
GB: Gearbox
M: Electric motor

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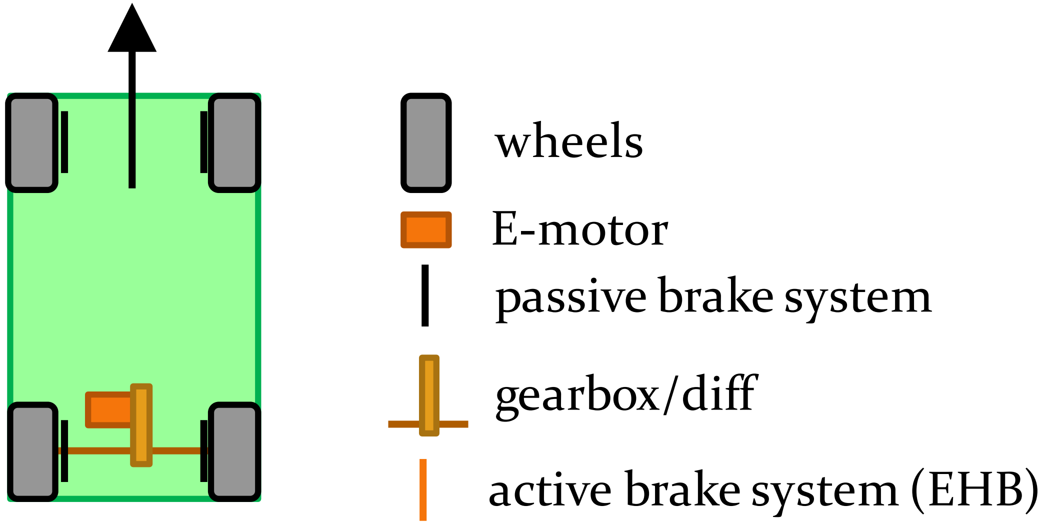
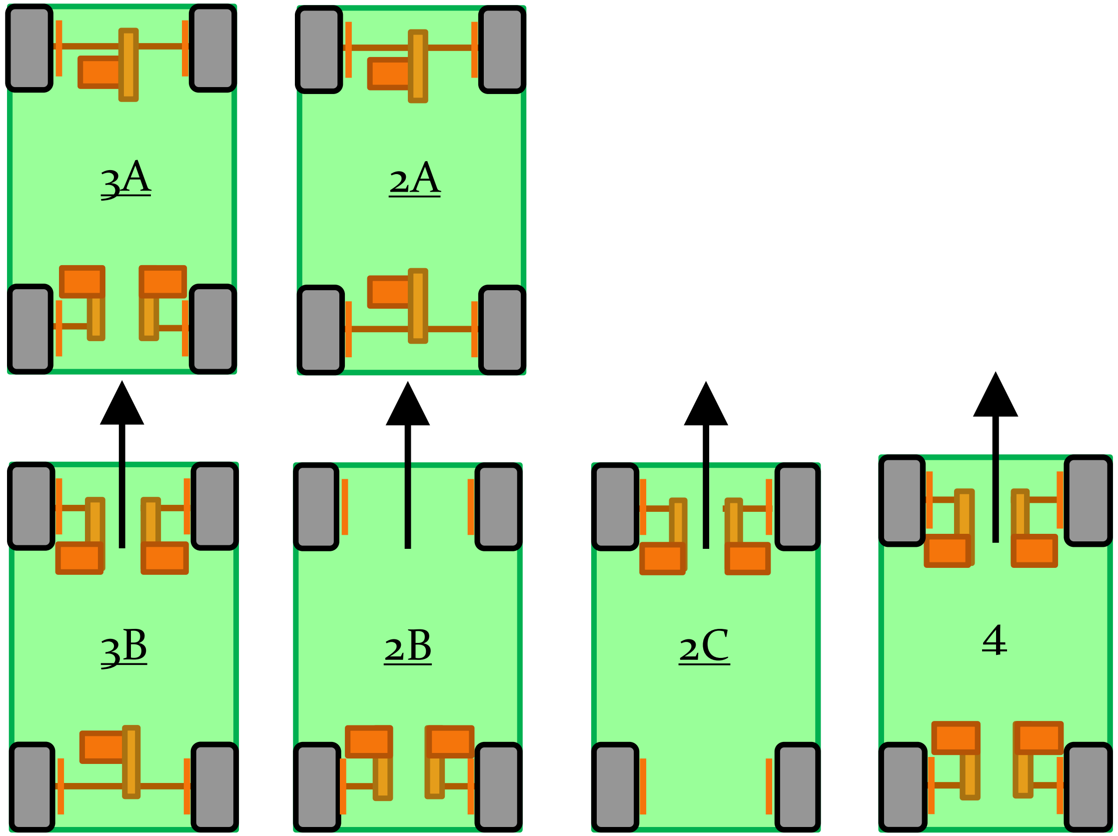
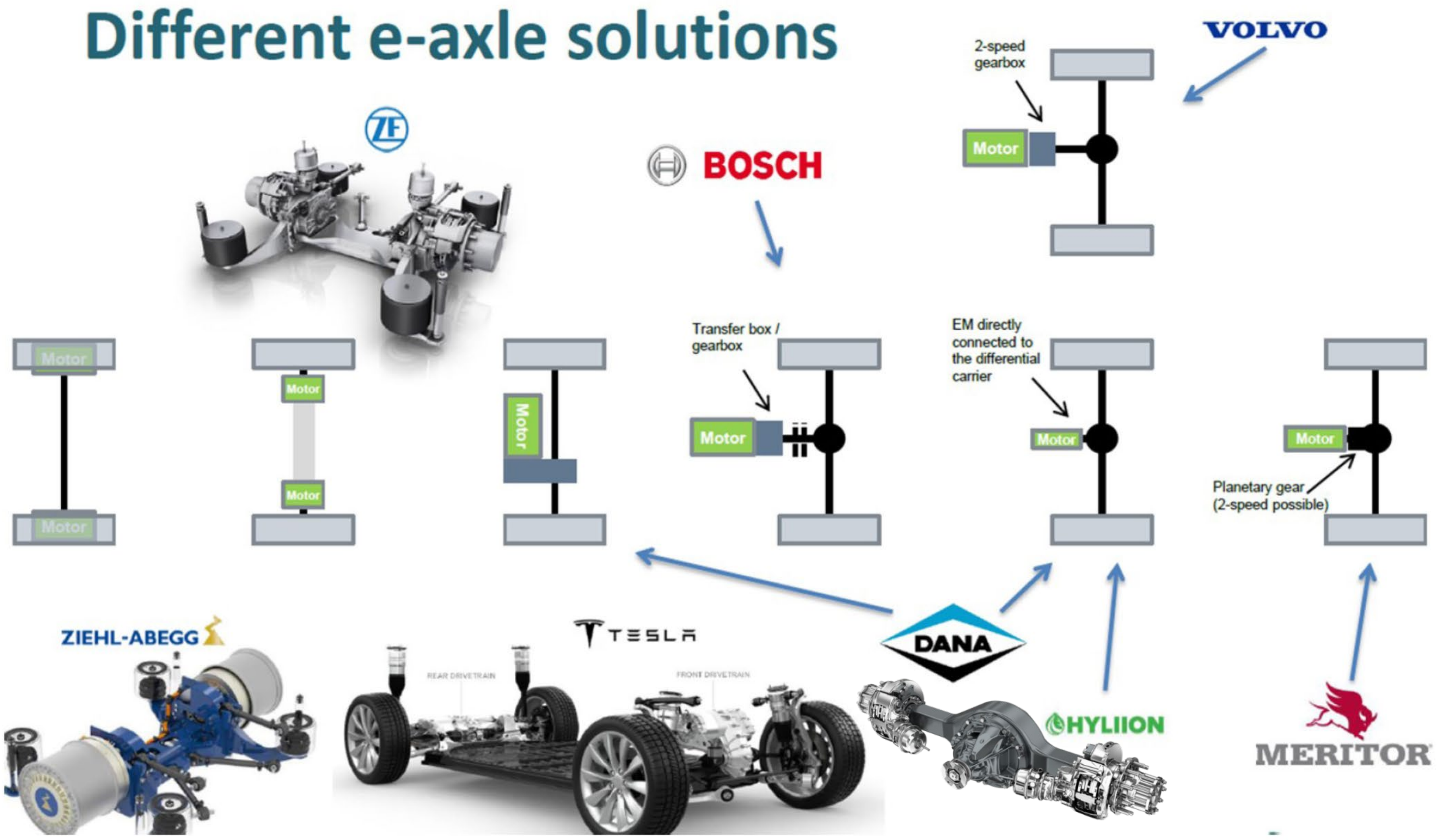
Electric Vehicle Topology Variants (continued)

- Analysis between vehicle dynamics and efficiency (regen, torque control)
- Combination with performance requirements





Electric Vehicle Topology Variants (continued)

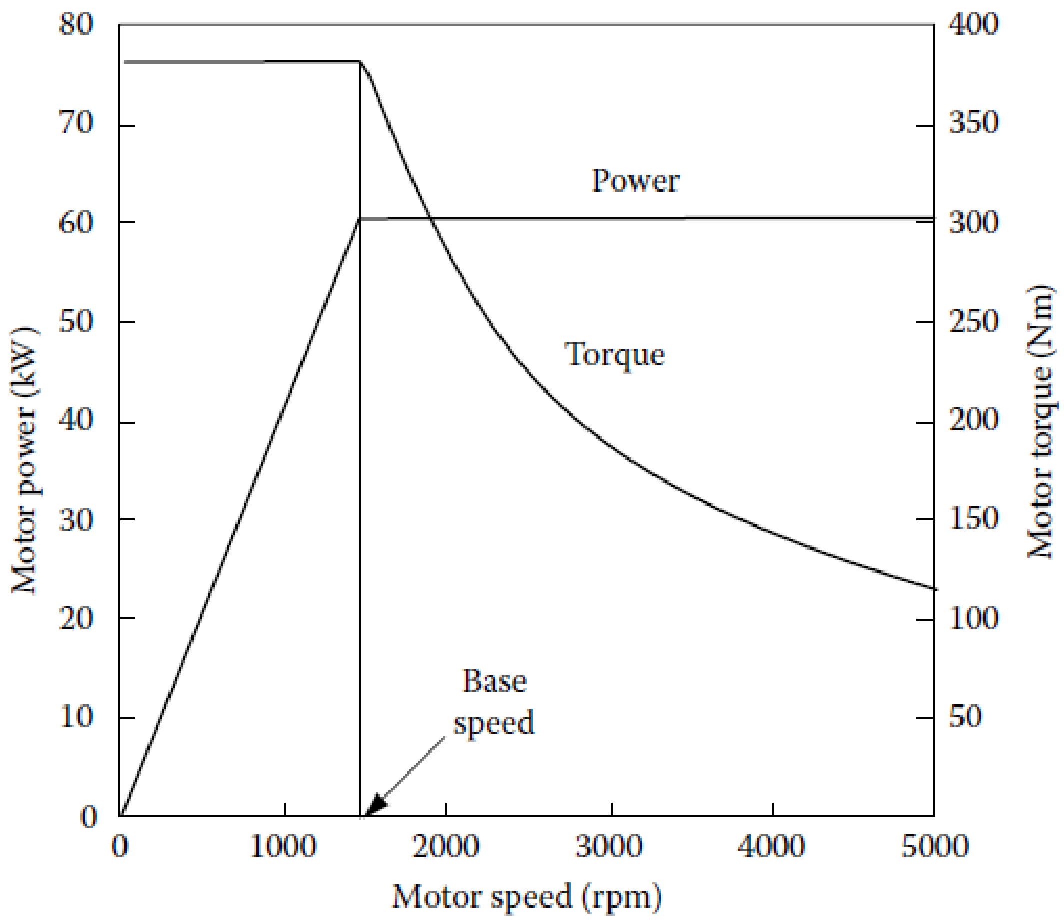


Source: *http://h2020-orca.eu/news/first-internal-orca-workshop-on-hybrid-electric-vehicles/*

Simplified Motor Performance

- Simplified motors can be considered to have an operational envelope:
  - Maximum torque
  - Maximum power
  - Maximum speed

Gearing allows for changing maximum torque vs. speed (maximum power ~constant)



Typical Motor Spec Sheet

HVH250-115 Electric Motor

Product Sheet

The HVH250 Series motors come in various stack length, cooling and winding configurations.

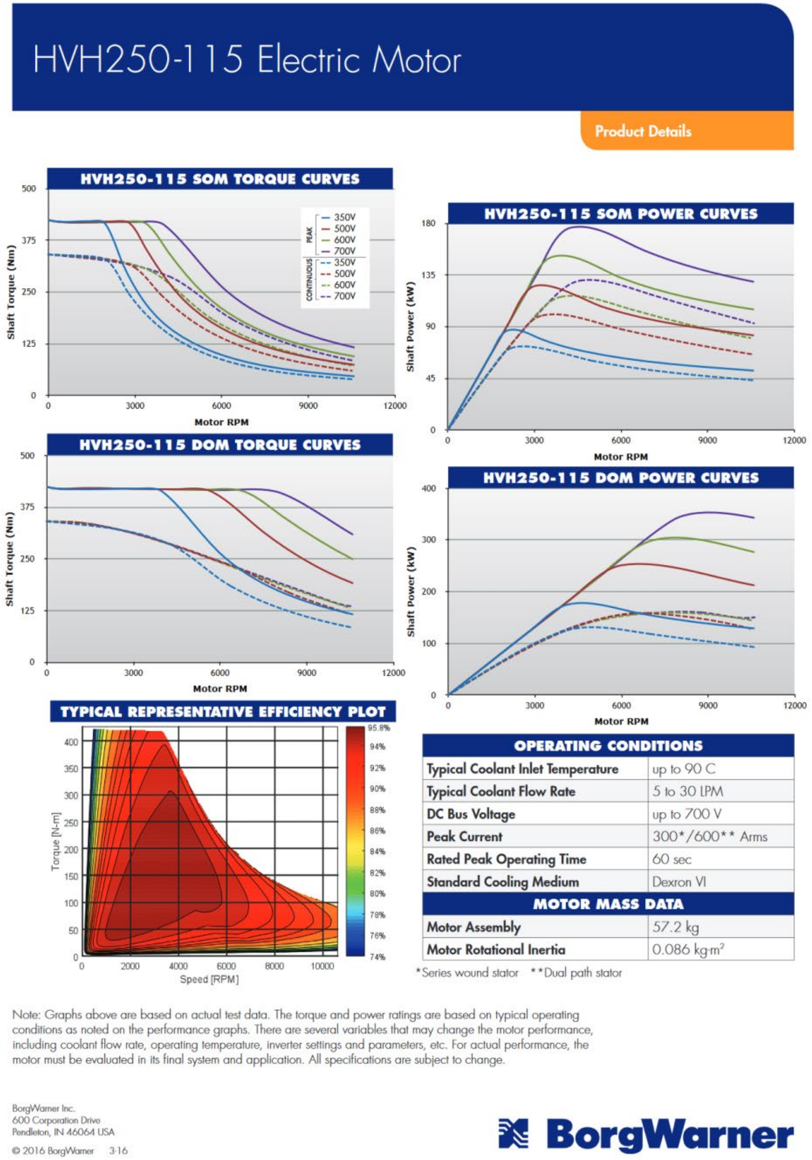
They are available as fully housed motors or as rotor/stator assemblies. The HVH250 is a powerful, durable and rugged electric motor/generator for use in on- and off-highway vehicles, power generation and other special high power demand applications.

With billions of kilometers of proven reliability, the HVH motors are supported by the largest independent electric motor test and R&D facility in North America.

Features & Benefits

- Peak efficiencies > 95%
- Designed with 120 years of automotive experience for ultimate reliability
- World class power density
- More than 10 years of continuous production and more than 100,000 motors in service
- Global sales and tech support
- Production capacity of up to 80,000 HVH motors per year

BorgWarner



HVH250-115 Electric Motor

Product Details

OPERATING CONDITIONS	
Typical Coolant Inlet Temperature	up to 90 C
Typical Coolant Flow Rate	5 to 30 LPM
DC Bus Voltage	up to 700 V
Peak Current	300*/600** Arms
Rated Peak Operating Time	60 sec
Standard Cooling Medium	Dexron VI
MOTOR MASS DATA	
Motor Assembly	57.2 kg
Motor Rotational Inertia	0.086 kg·m²

*Series wound stator **Dual path stator

Note: Graphs above are based on actual test data. The torque and power ratings are based on typical operating conditions as noted on the performance graphs. There are several variables that may change the motor performance, including coolant flow rate, operating temperature, inverter settings and parameters, etc. For actual performance, the motor must be evaluated in its final system and application. All specifications are subject to change.

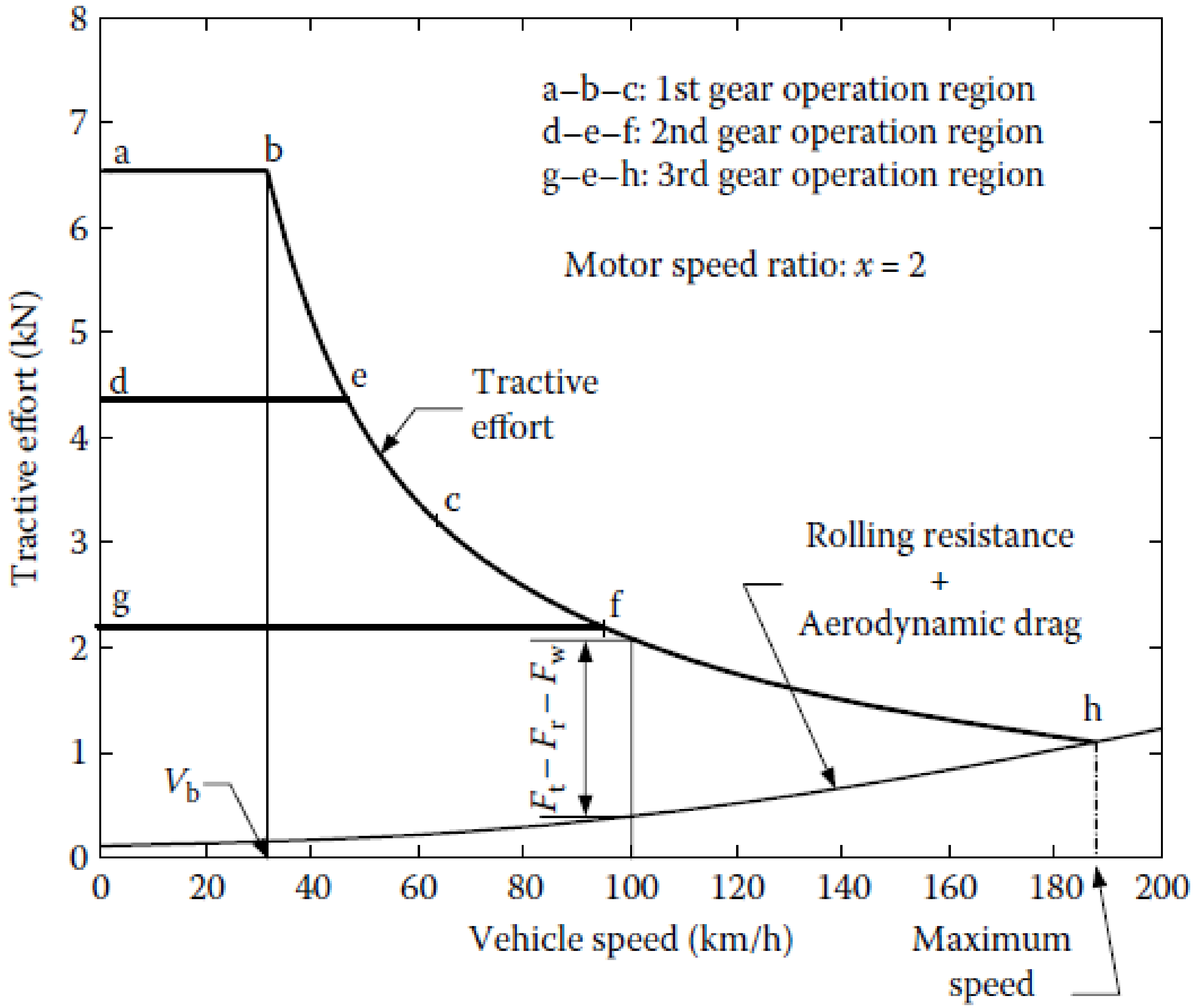
BorgWarner Inc.
600 Corporation Drive
Pendleton, IN 46064 USA

BorgWarner

Electric Vehicle Performance

- The tractive effort is considered in combination with the typical road load
- Design concerns:
  - Decisions on component sizing
  - Decisions on gearing (if any)
  - Optimisation for performance
  - Optimisation for energy efficiency and range
  - Tractive requirements (gradeability)
  - Acceleration times:

$$t_a = \int_0^{V_b} \frac{M\delta}{P_t/V_b - Mg\, f_r - 1/2\rho_a C_D A_f V^2}\, dV + \int_{V_b}^{V_f} \frac{M\delta}{P_t/V - Mg\, f_r - 1/2\rho_a C_D A_f V^2}\, dV,$$



Hybrid Electric Vehicles Topology

Levels of Hybridisation

Conventional Vehicles

Hybrid Electric Vehicles

Increasing electrical power →

Micro Hybrid	Mild Hybrid	Full Hybrid (Parallel / Power-Split / Serial)	Plug-in Hybrid vs. Range Extender Electric Vehicle

+ Electric drive
+ Electric take-off / auxiliaries
+ Engine Assistance (torque, e-turbo)
+ Kinetic Energy Recovery

Start / Stop

Hybridisation aiming at assisting the combustion engine

Hybridisation aiming at running the vehicle by electric propulsion

Battery Electric Vehicles

Fuel Cell Electric Vehicles

Increasing infrastructure considerations →

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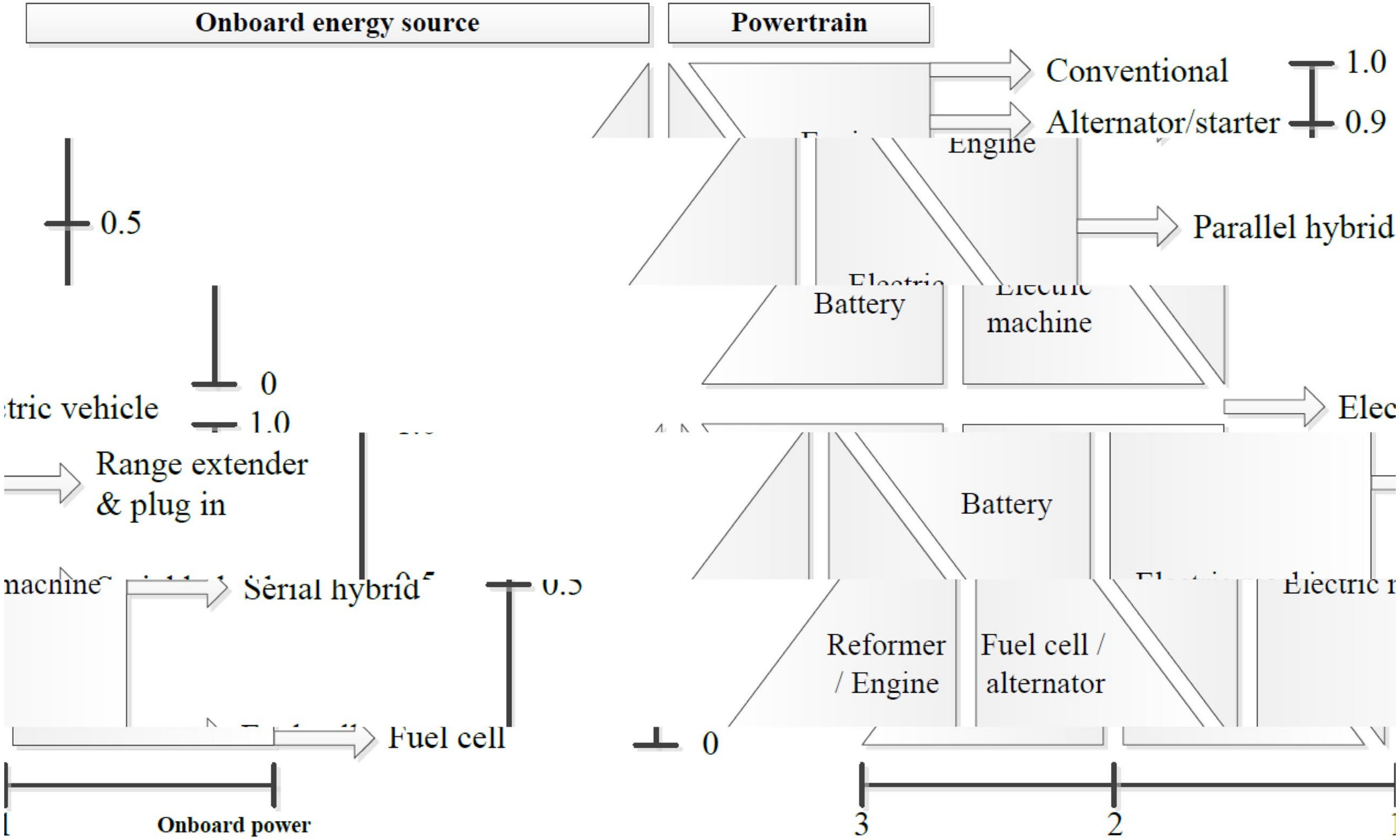
Classification by Energy and Powertrain



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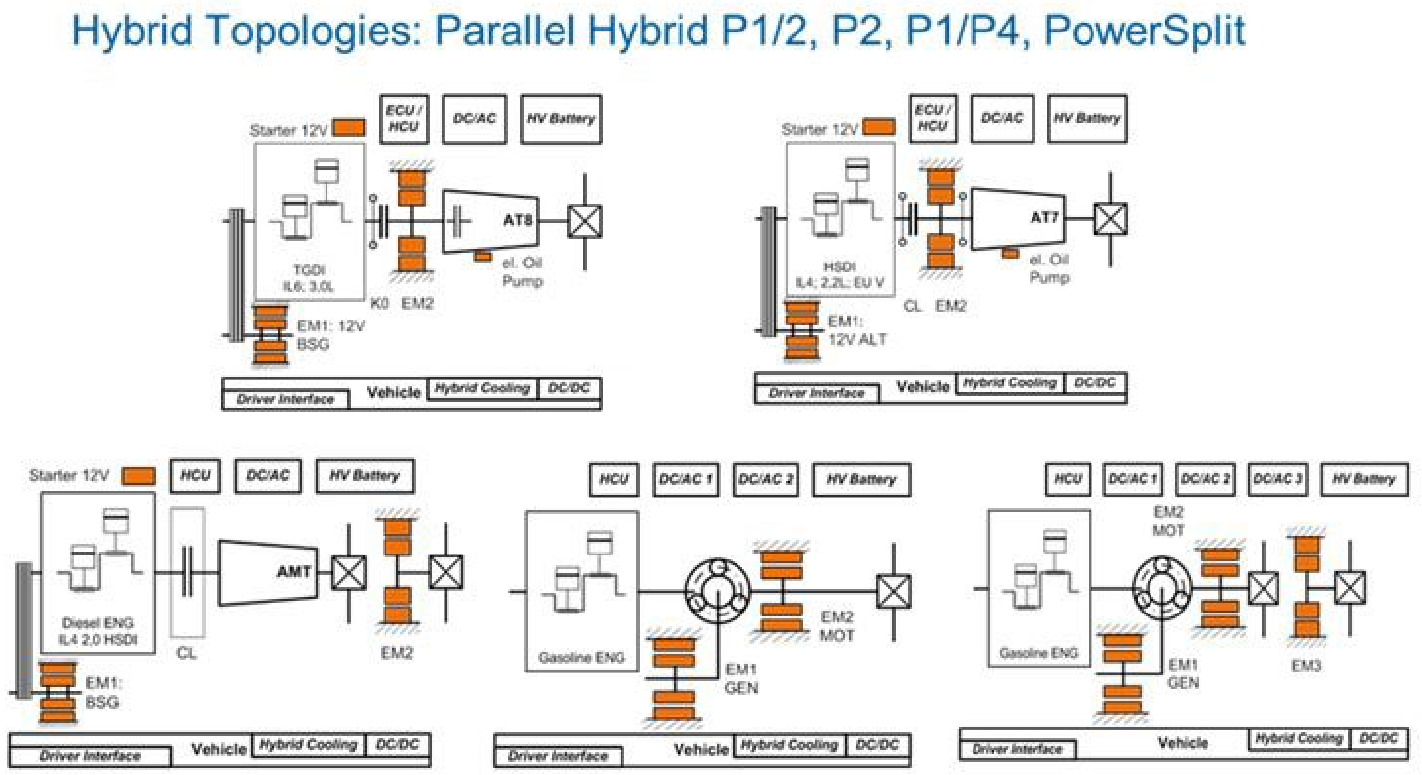
Hybrid Topologies

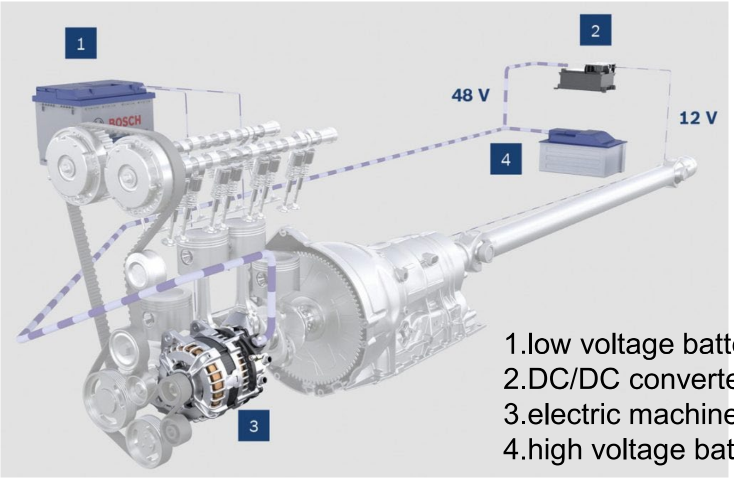
Many variants of topology exist:

- Typically classed as:
  - Series
  - Parallel
  - Series/Parallel / Powersplit

The level of electrification also has some influence on the designation of category

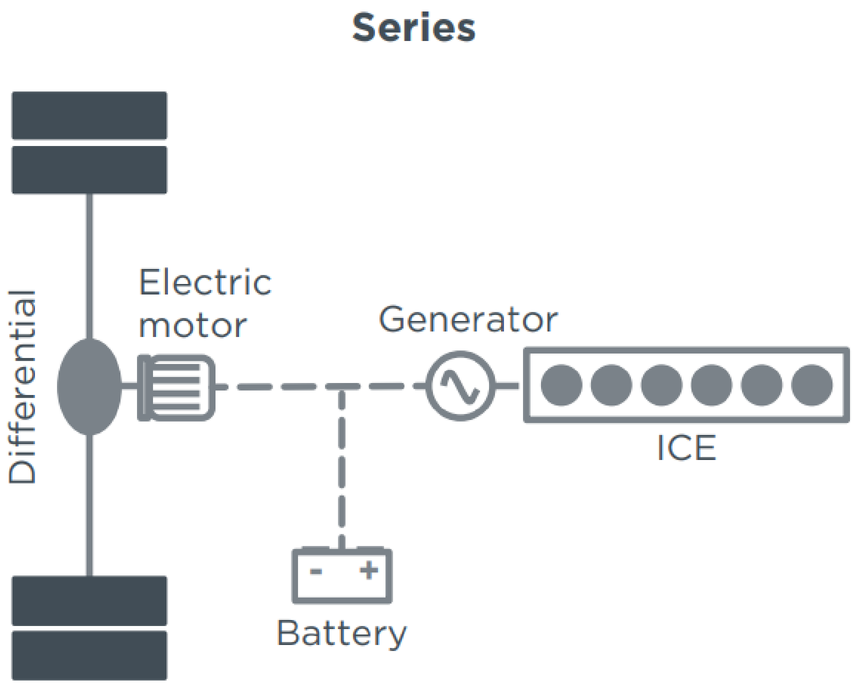


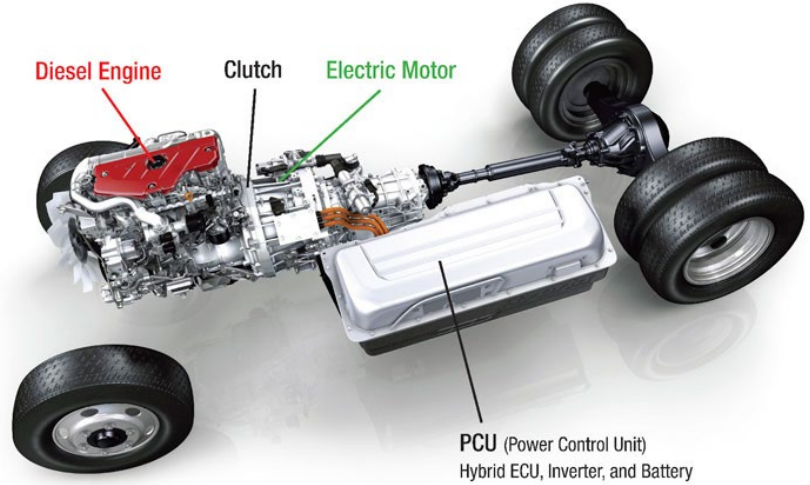
AVL.com



1.low voltage battery (12 V)
2.DC/DC converter
3.electric machine (motor & generator)
4.high voltage battery (48 V)

Series Hybrid





Series HD hybrid systems with electrical machines (currently used in specialized applications):

Advantage:

- High power density.
- No need for driveshaft.
- Simple mechanical system

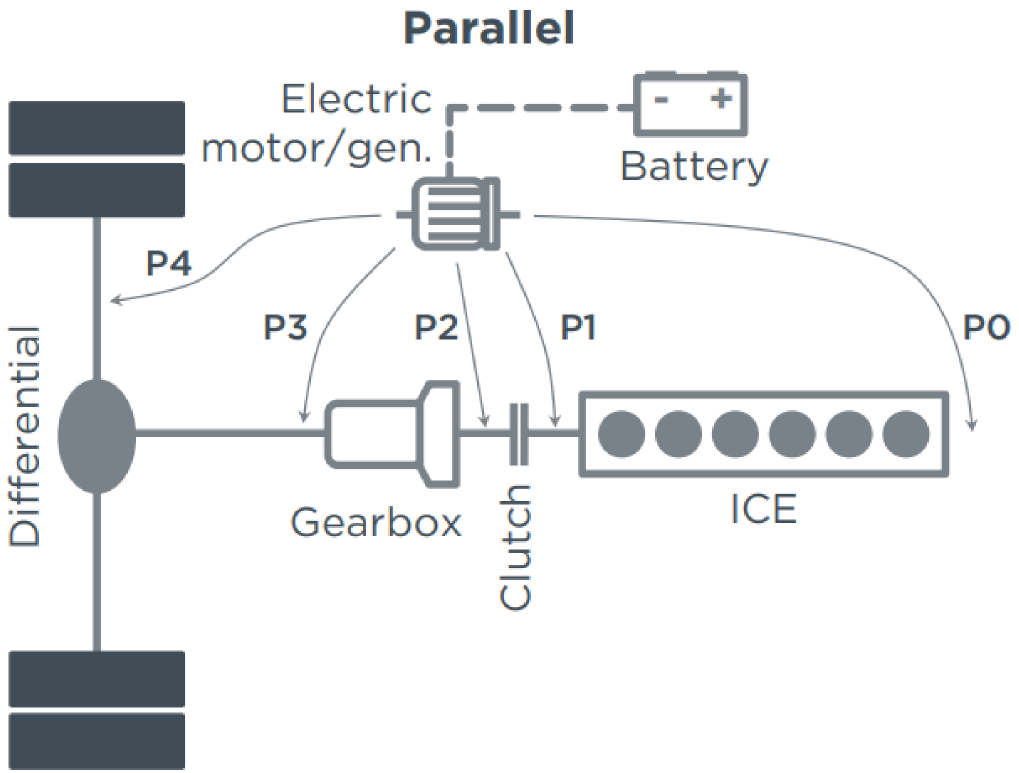
Disadvantage:

- Complex electrical system.
- Reliability, i.e. no mechanical fault tolerance.
- Costs

The future of VECTO: CO2 certification of advanced heavy-duty vehicles in the European Union (theicct.org)

Parallel Hybrid

Honda Insight Parallel Hybrid



Motivation:

Many commercial systems use parallel hybrid systems:

Advantage:

- Best balance between vehicle costs and fault tolerance.

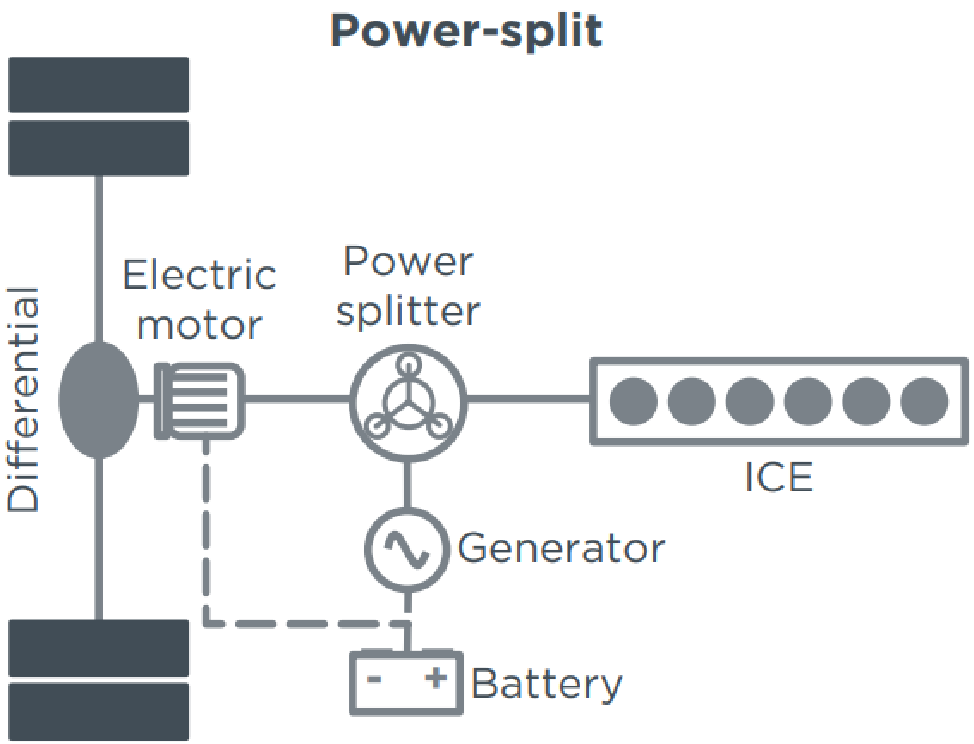
Can also be used to power auxiliary components.

Disadvantage:

- Complex mechanical system.
- Requires a drive-axle to the rear wheels.
- Does not allow for a redesign of current trucks, i.e. for specialized applications.

Series/Parallel or Combined or Full / Power-Split Hybrid

Toyota Prius Series/Parallel Hybrid



Motivation:

Many commercial systems use powersplit hybrid systems:

Advantage:

- Combines functional benefits of the series and parallel hybrids
- High control functionality

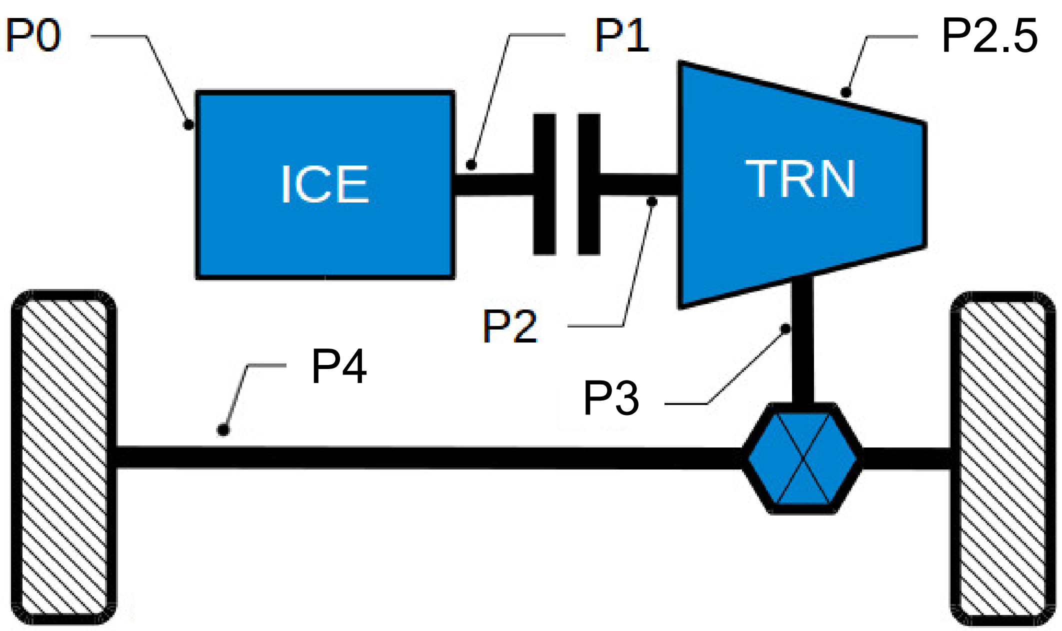
Disadvantage:

- Complex mechanical system and control.
- Difficult to realise for heavier vehicles in single stage power split.

48V?

Mild Hybrid Architectures and 48V

P0	The electric machine is connected with the internal combustion engine through a **belt**, on the front end accessory drive (FEAD)
P1	The electric machine is connected **directly** with the crankshaft of the internal combustion engine
P2	The electric machine is side-attached (through a **belt**) or **integrated** between the internal combustion engine and the transmission; the electric machine is decoupled from the ICE and it has the same speed of the ICE (or multiple of it)
P3	The electric machine is connected through a **gear mesh** with the transmission; the electric machine is decoupled from the ICE and its speed is a multiple of the wheel speed
P4	The electric machine is connected through a **gear mesh** on the rear axle of the vehicle; the electric machine is decoupled from the ICE and is located in the rear axle drive or in the wheels hub



https://x-engineer.org/automotive-engineering/vehicle/hybrid/mild-hybrid-electric-vehicle-mhev-architectures/

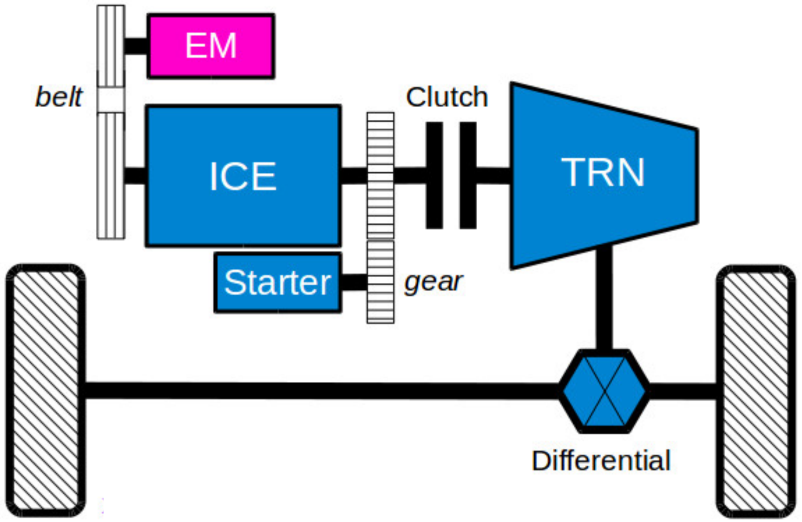
Hybrid Functionalities

- Idle Stop & Start – engine turns off when the vehicle is stationary
- Moving Stop & Start – engine turns off when driving
- Engine load shift – operating point of the engine is altered through torque
- Torque assist (fill) – additional torque is provided when engine cannot deliver
- Torque boost – additional torque is provided in addition to engine
- Sailing / Coasting – declutching of the powertrain when not required
- Energy recuperation – recovery of energy into battery through powertrain
- Brake regeneration – recovery of energy into the battery through braking
- Electric driving (P2-4 only) – engine turn off and pure EV mode

Belt Starter Generator Architecture (P0)

Advantages:
- Low cost of integration
- Air or liquid cooled electric machine
- Integrated inverter (with electric machine)
- Size modularity for the electric machine
- Speed / torque ratio possible between electric machine and ICE results in lower Power demand from the electric machine

Disadvantages:
- Limited torque capacity due to belt drive
- Energy recuperation affected by engine friction losses

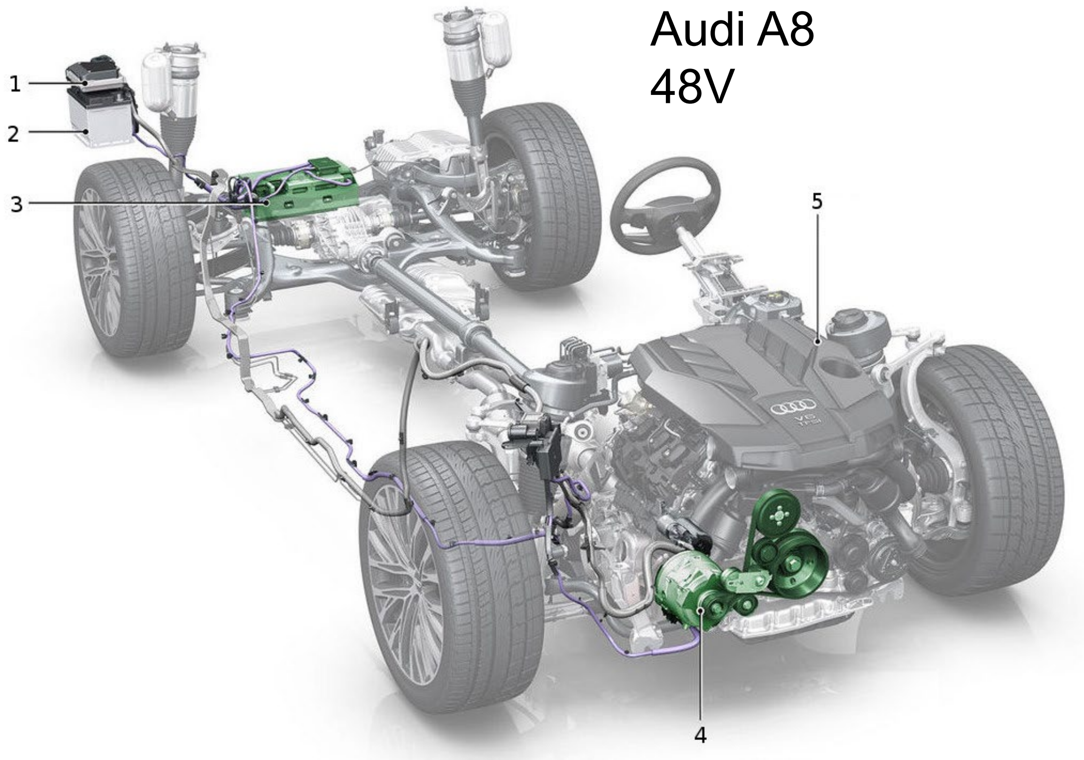


Overall Characteristics:
Torque Boosting Capability: **Medium** (limited by belt slip, durability)
Electrical Energy Recuperation: **Medium** (due to engine losses)
Driveability Improvements: **Medium** (due to limited torque boost)
Electrical Creep / Drive: **Not possible** (due to limited torque and belt drive)
Packaging: **Easy components integration** with limited impact on other components
System Efficiency: **Medium** (mainly due to belt-drive integration on the FEAD(1))

1 Front End Accessory Drive

https://x-engineer.org/automotive-engineering/vehicle/hybrid/mild-hybrid-electric-vehicle-mhev-architectures/

P0 Examples



Audi A8
48V

1. DC/DC converter
2. low voltage battery (12 V)
3. high voltage battery (48 V)
4. 48V belt-drive starter-generator
5. 3.0 TFSI internal combustion engine

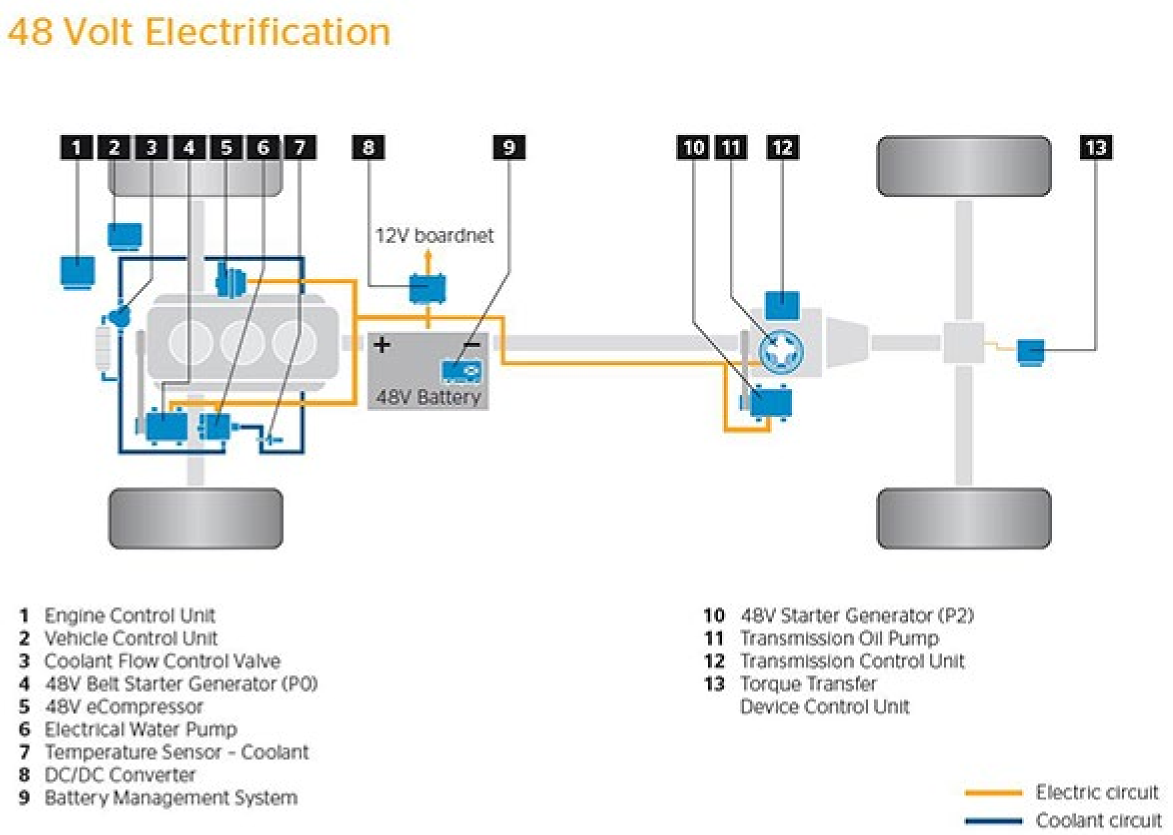
Valeo 48V
System

1. Powertrain Control Unit (PCU)
2. 14V battery sensor
3. Belt Starter Generator (BSG) 8 – 12 kW / 55 Nm Peak, with integrated inverter
4. DC/DC converter, 60 V / 12 V, 2 kW
5. 48V battery, 200 – 600 kJ

https://x-engineer.org/automotive-engineering/vehicle/hybrid/mild-hybrid-electric-vehicle-mhev-architectures/

P0 Examples

Continental

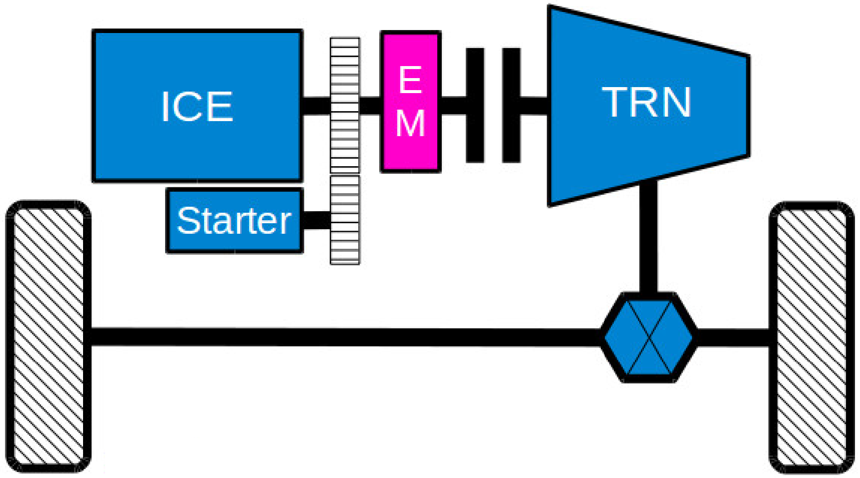


https://www.continental-automotive.com/en-gl/Passenger-Cars/Technology-Trends/Electrification/48-Volt-Technologies

Crankshaft Mounted Electric Machine (P1)

Advantages:
- Higher efficiency
- The 12V starter can be removed

Disadvantages:
- Output torque limited by the size of the electric machine
- Energy recuperation affected by engine friction losses
- High impact on existing vehicle architecture
- Higher overall cost of the electrical components
- Air cooling not possible for the electric machine



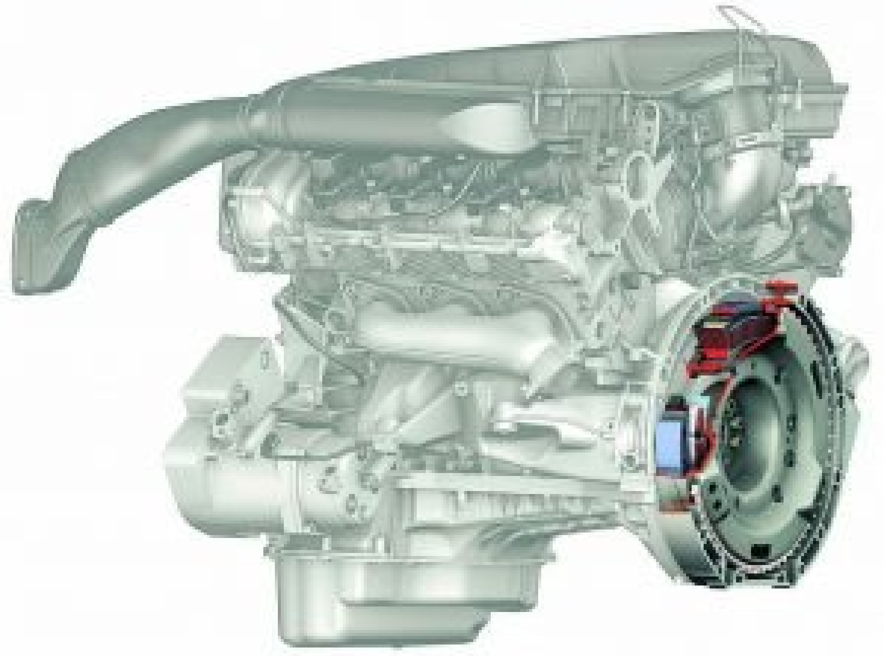
Overall Characteristics:
Torque Boosting Capability: High (if electric machine is capable)
Electrical Energy Recuperation: Medium (due to engine losses)
Driveability Improvements: Medium (depending on the torque capability of the electric machine)
Electrical Creep / Drive: Possible (depending on the torque capability of the e-machine)
Packaging: Difficult components integration (powertrain specially designed for this architecture)
System Efficiency: High (no gear mesh or belt losses)

https://x-engineer.org/automotive-engineering/vehicle/hybrid/mild-hybrid-electric-vehicle-mhev-architectures/

P1 Examples

Honda Insight Hybrid 2009 (with Integrated Motor Assist technology)

Mercedes Benz S400 BlueHybrid (MHEV)



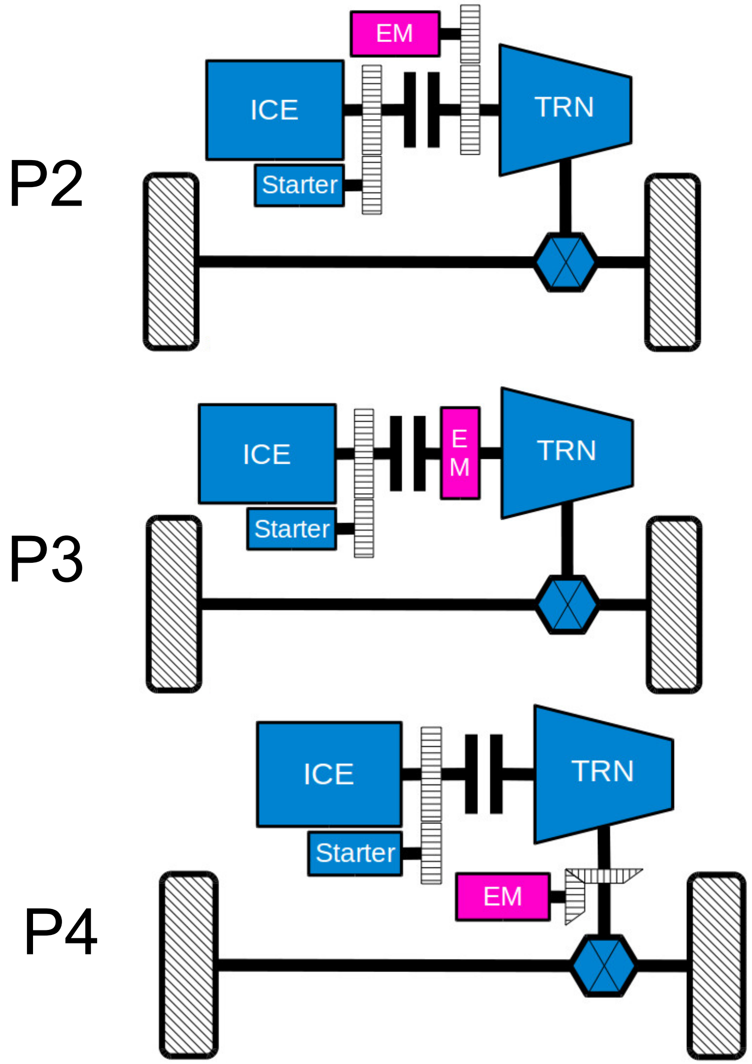
https://x-engineer.org/automotive-engineering/vehicle/hybrid/mild-hybrid-electric-vehicle-mhev-architectures/

P2, P3, P4 Topologies

Advantages:
- Highest efficiency
- Electric driving (creep)
- Four/All Wheel Drive Mode (P4 architecture)

Disadvantages:
- Requires an additional electric machine for engine Stop & Start
- High impact on existing vehicle architecture
- Higher overall cost of the electrical components
- Air cooling not possible for the electric machine

Overall Characteristics:
Torque Boosting Capability: **High** (if electric machine is capable)
Electrical Energy Recuperation: **High** (not affected by engine losses, partly by transmission losses)
Driveability Improvements: **Medium** (depending on the torque capability of the electric machine)
Electrical Creep / Drive: **Possible** (depending on the torque capability of the e-machine)
Packaging: **Difficult components integration** (powertrain specially designed for this architecture)
System Efficiency: **High** (only gear mesh losses)

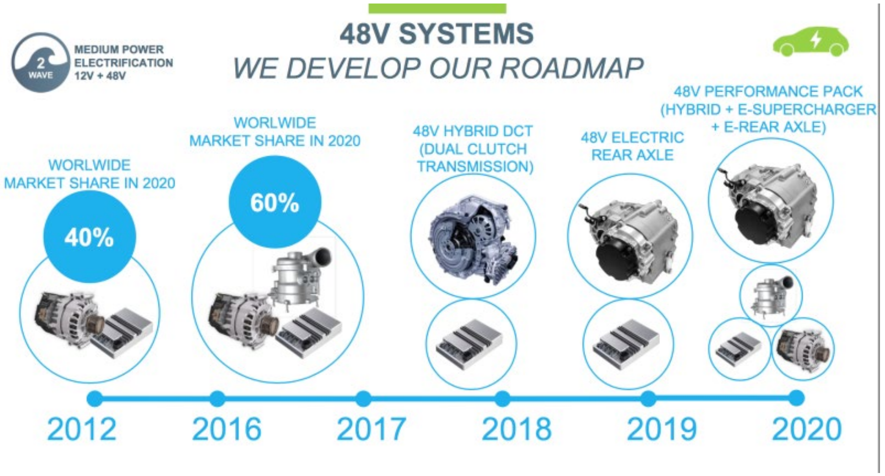


https://x-engineer.org/automotive-engineering/vehicle/hybrid/mild-hybrid-electric-vehicle-mhev-architectures/

P2, P3, P4 Examples

Getrag Hybrid Double Clutch Transmission

Valeo 48V Electric Rear Axle Drive (ERAD)



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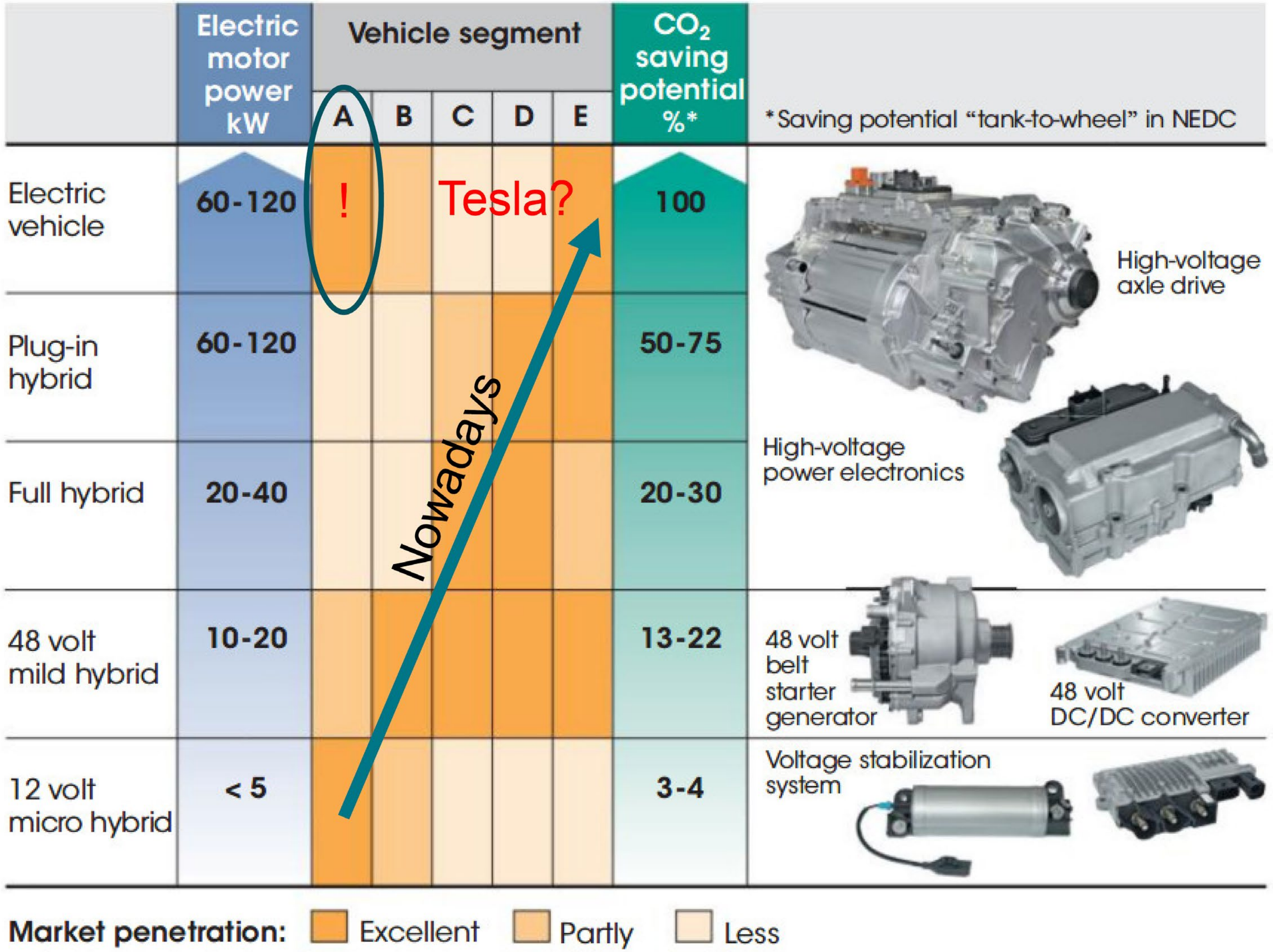
Electric Machine vs. CO2



A – Subcompact cars
B – Compact cars
C – medium cars
D – Large cars
E – Premium cars

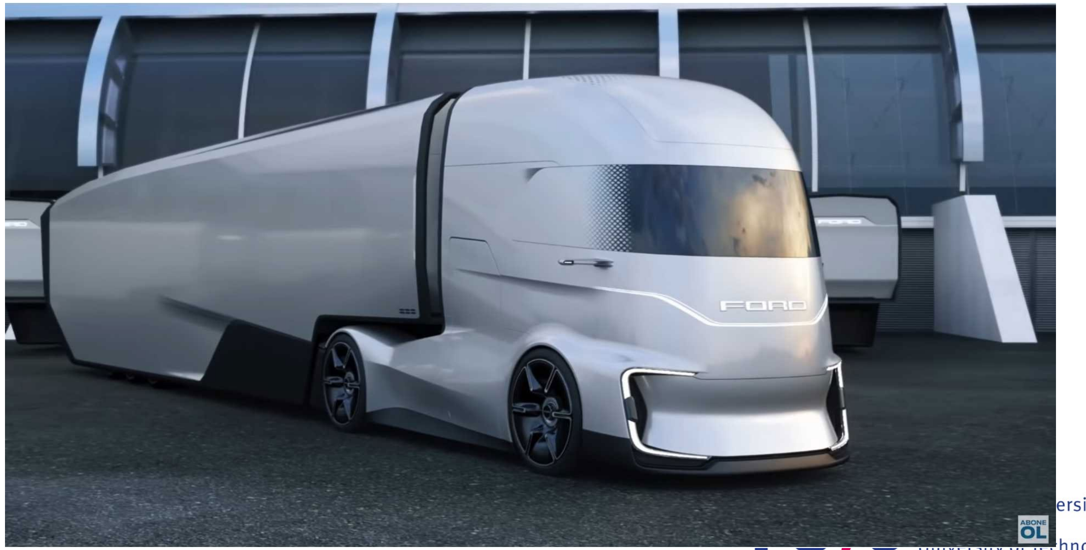
Hybrid Trends

- First mild hybrid systems introduced by vehicle manufacturers were P1 but they are currently being replaced by P0, P3 and P4
- the industry standard for MHEV is based on the 48V electric network
- the P0 architecture is the current most used mild hybrid solution
- the market is evolving towards P4 architectures due to higher benefits in terms of CO2 reduction and efficiency
- electrical supercharging is going to be integrated with most of the 48V MHEVs

https://x-engineer.org/automotive-engineering/vehicle/hybrid/mild-hybrid-electric-vehicle-mhev-architectures/

Are there other options?

Future of Trucks?



Summary

- Electric vehicle topologies
- Hybrid vehicle topologies


Questions