EVTC Electric Vehicle Transportation Center

2016 EV & Technology Workshop

Electric Vehicle Architectures

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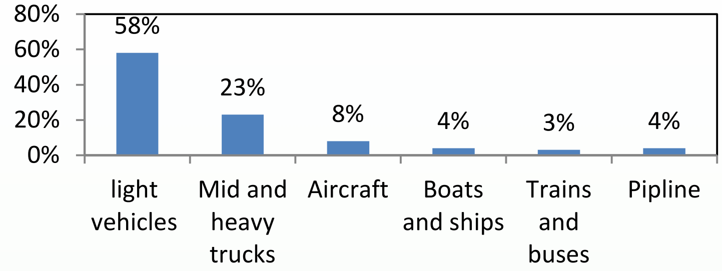
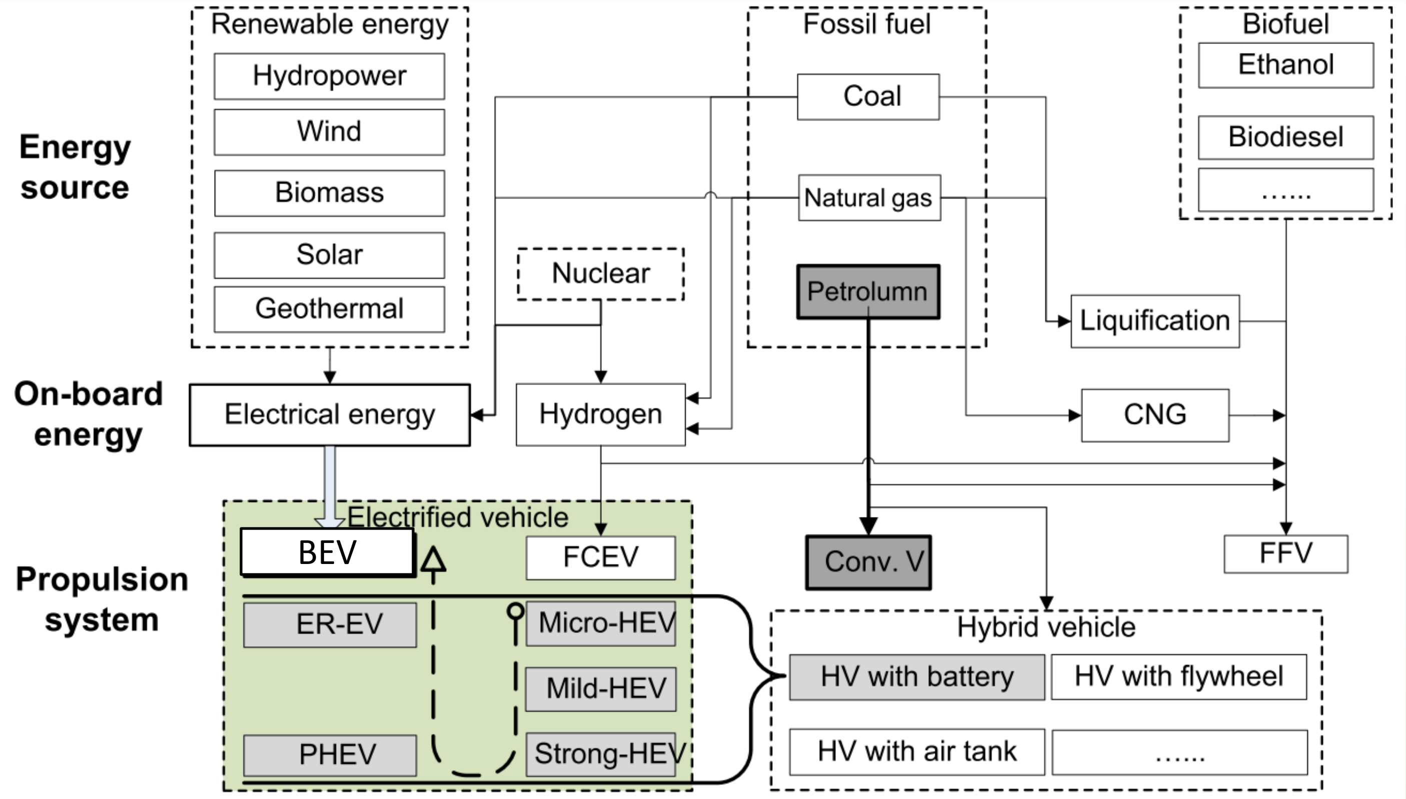
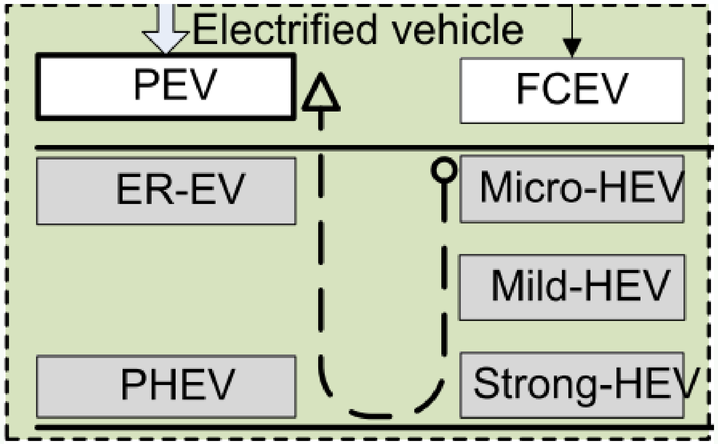
Powertrain Solutions for a Better Future





Reference 1

Electric Vehicle Characteristics



- Must have One or more electric machines (EMs)
- Must have an energy storage system (ESS) other than the fossil fuel tank.
- The EMs must provide propulsion power (partially or full)

Outline

- Key components of an EV powertrain:
  - Electric Machines (EM)
  - Power electronics
  - Energy management system (EMS)
  - Energy Storage system (ESS)
- EV classification and their electrification levels.
- Powertrain architecture design philosophy.
- EV powertrain architectures:
  - Battery Electric vehicle (BEV)
  - Hybrid electric vehicle (HEV)
  - Plug-in hybrid vehicle (PHEV)
  - Fuel cell electric vehicle (FCEV)

Some Useful Terminology

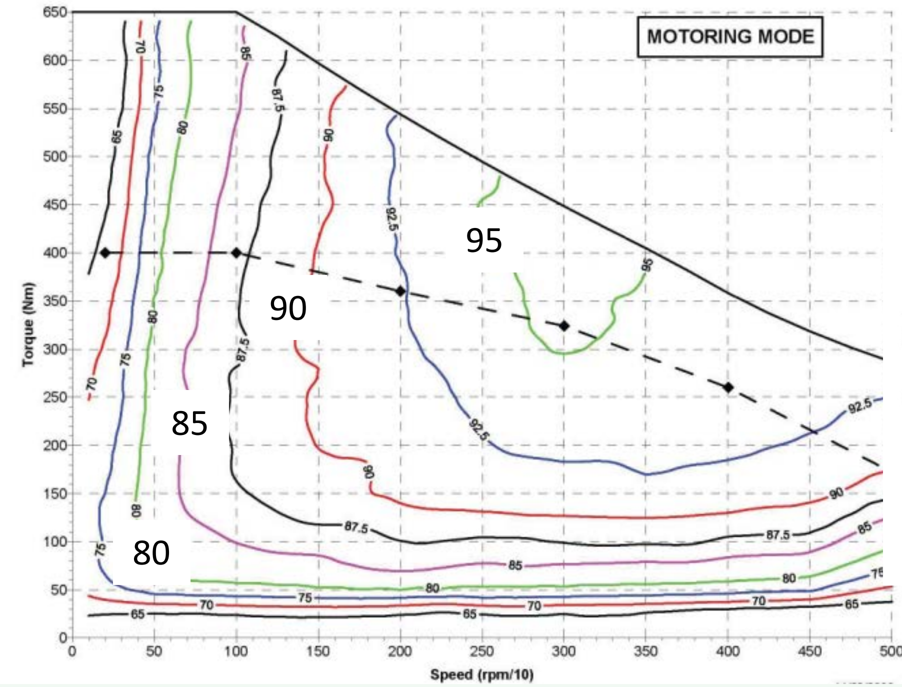
- **Internal combustion engine (ICE):** an engine that drives a piston by the hot air produced by the burning of gasoline, oil, or other fuel with air inside.
- **Transmission**: A gearbox that use gears and gear trains to provide speed and torque conversion between one rotating power source to another.
- **Differential (D)**: a geartrain that splits the torque two ways, allowing each output to spin at different speed when vehicle is turning.
- **Clutch**: a mechanism for connecting and disconnecting a vehicle's engine from its transmission system.
- **Electric machine (EM)**: a general term for electric motors and electric generators.
- **Energy management system** (EMS) : A system that controls the flow of energy from multiple energy sources.

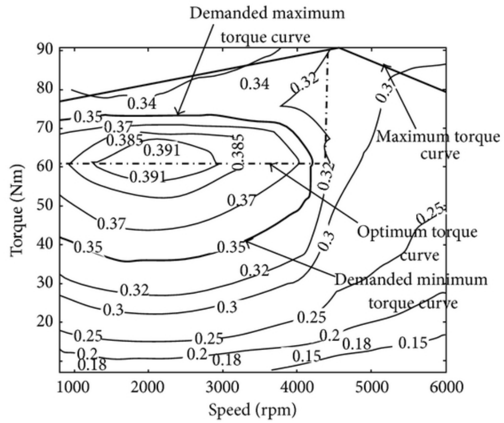
Key Powertrain Components

-Electric Machines (EM)

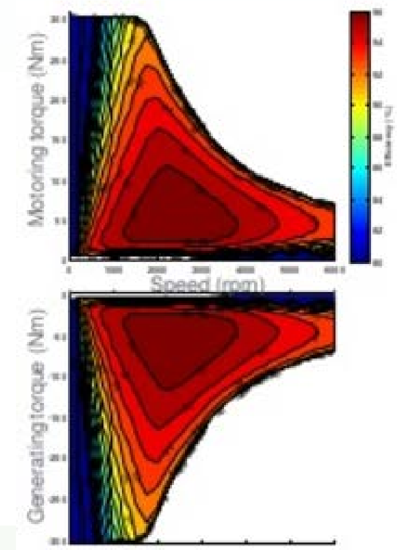
EM Type	Current	Image	Usage in EVs	Pros and Cons
Permanent magnet (PM) motor	3 phase AC		Used in most EVs	High efficiency, high torque short constant power range
Induction motor	3 phase AC		Tesla, Toyota RAV-4 EV	Simple, robust, wide speed range Less efficient than PM motors
Switched Reluctance motor	DC		Not yet widely used in EVs	Capable of extreme high speed Costly

Characteristics of Electric Motors





Motoring mode



Generator mode

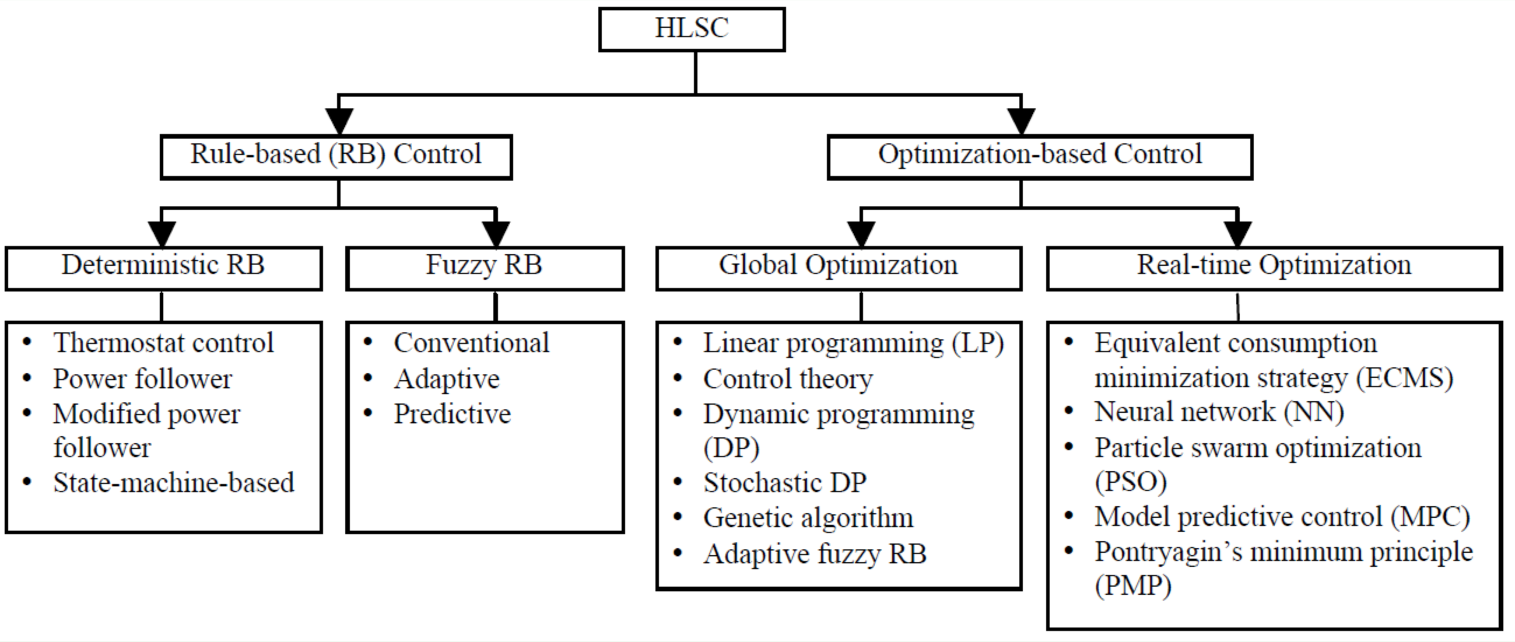
- large speed ranger of EM - no need for higher gears
- High torque output at low speed - no need for lower gears
- Launch vehicle at zero speed-no need to idle at low rpm
- High efficiency in the wide operating range.

Key Powertrain Components
-Power Electronics

- Inverter: convert DC to AC
- DC/DC converters: increase or decrease battery voltages
- Rectifiers (on-board chargers): convert AC from electric grid to DC.

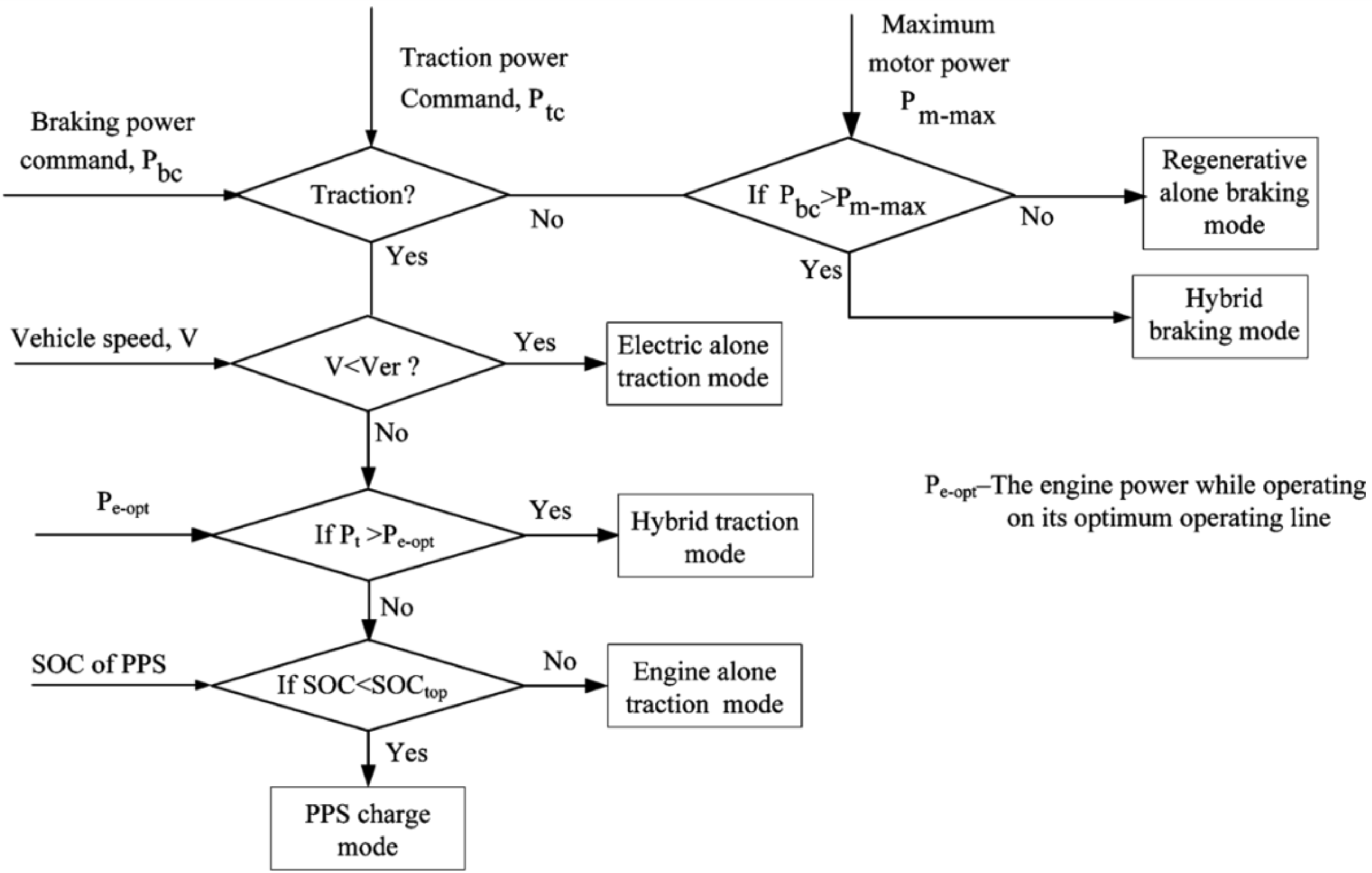
Key Powertrain Components
-Energy Management System (EMS)

- EMS uses hardware and software controls to optimize the energy efficiency and drivability.
  - Software-based high level supervisory control (HLSC)



Reference 4

EMS-Example

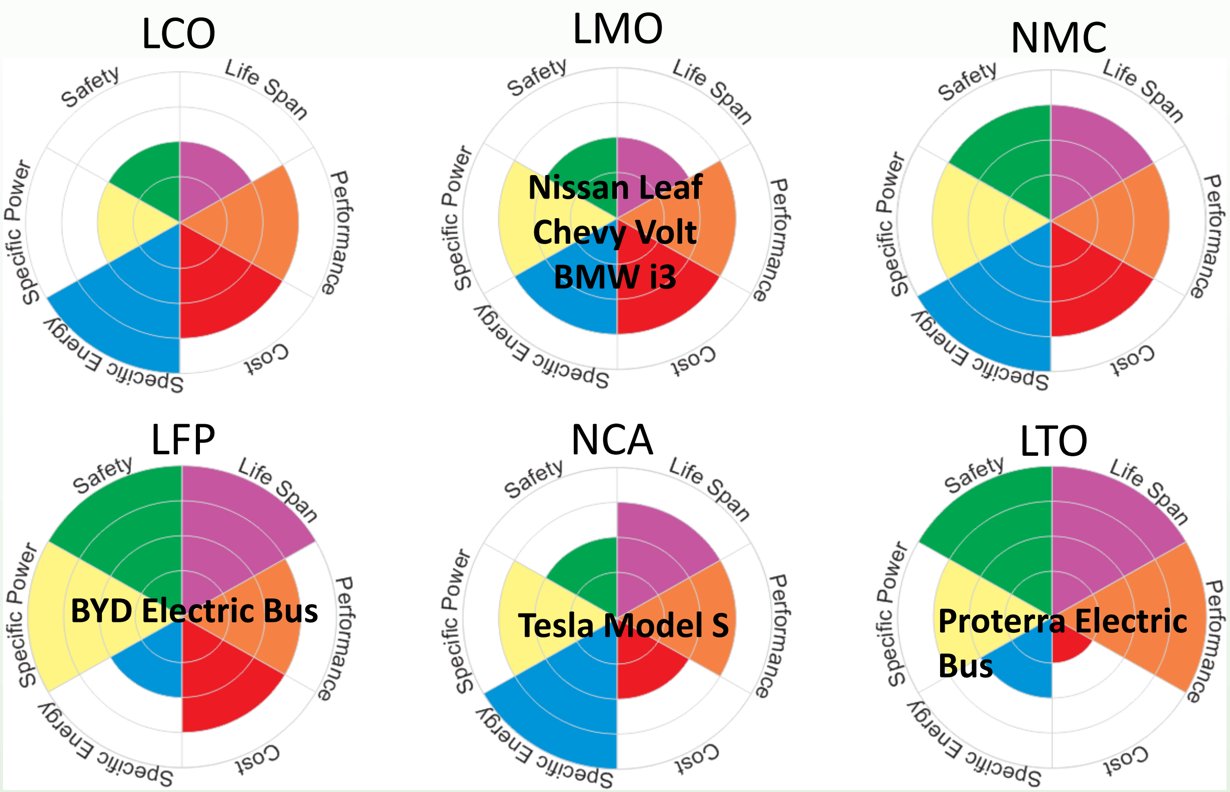


Reference 5

Key Powertrain Components

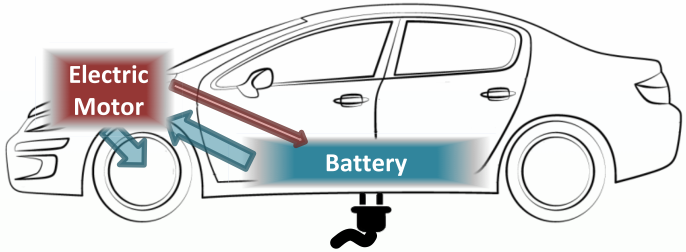
-Energy Storage Systems

- The ESS could be battery, ultracapacitor, and hydrogen tank (for fuel cell).
- Battery types used in EVs: Lead-acid, Nickel-metal hydride, Lithium ion.

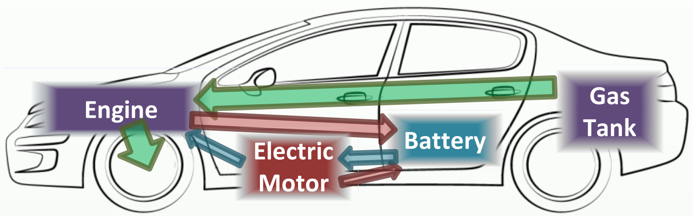


EV Types

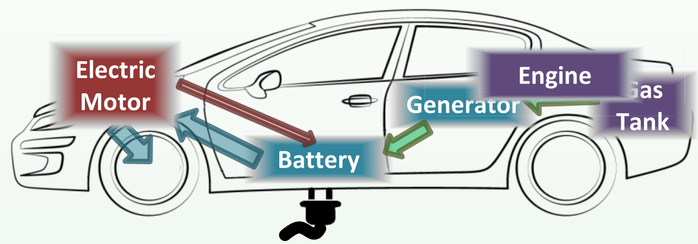
- Battery electric vehicle (BEV):



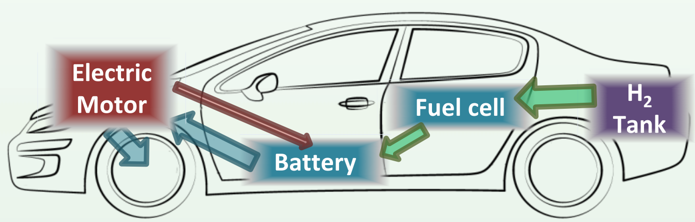
- Hybrid electric vehicle (HEV):



- Plug-in hybrid vehicle (PHEV):



- Fuel cell electric vehicle (FCEV):



Electrification Level of EVs

Micro HEV


BMW 1 and 3 series hybrid


Smart

Mild HEV


Honda Insight


Chevy Malibu Hybrid

Strong HEV


Toyota Prius


Ford Escape

PHEV


Honda Accord Plug-in


Toyota Pruis Plug-in

ER-EV


Chevy Volt

BEV


Nissan Leaf


Tesla Model S

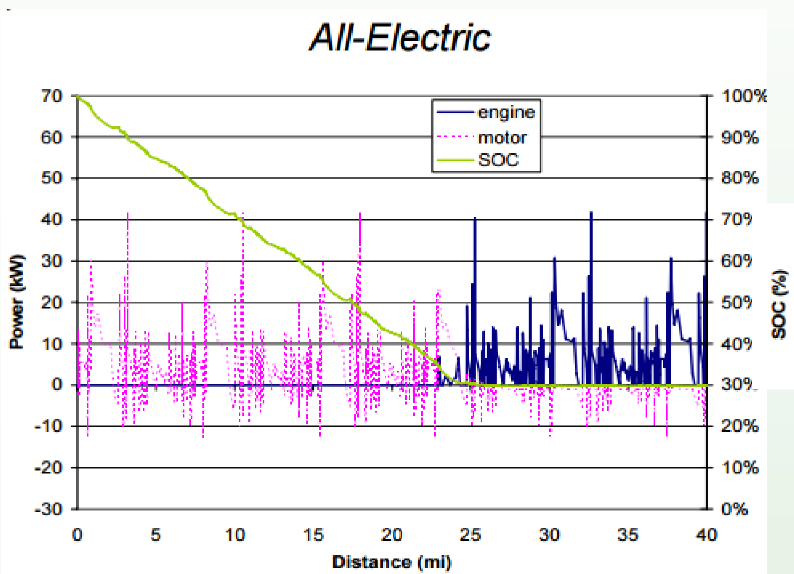
	Micro HEV	Mild HEV	Full HEV	PHEV	ER-EV	BEV
Start-stop	●	●				
Power assist		○	●	●	●	
Regen Braking		○	●	●	●	●
BEV driving			○	●	●	●
Plug				●	●	●
Voltage (V)	12	48+	200-300	300+	300+	300+
Power (kW)	2.5	10-20	50	60+	60+	60+
Efficiency improvement (%)	2-4	8-11	20-35	50-60	>60	>60

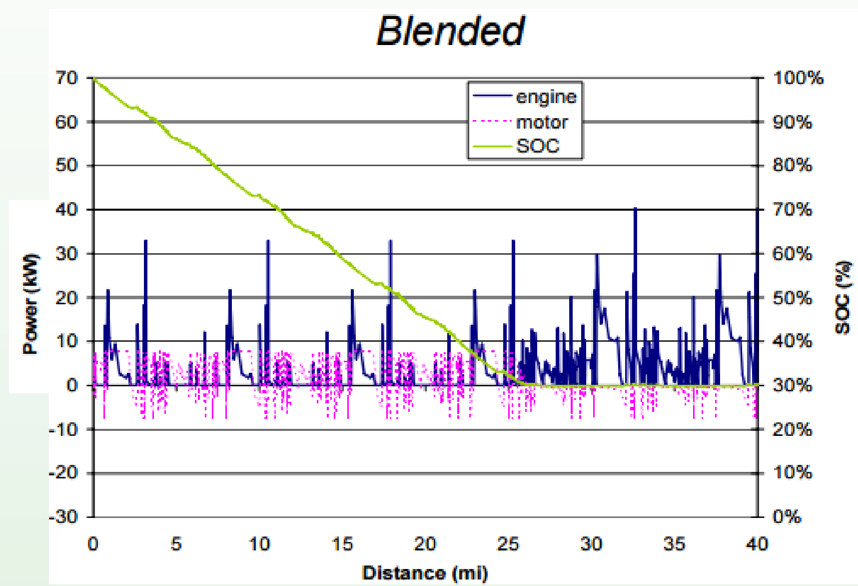
SOC Management for EVs

Charge sustaining mode

Micro HEV	Mild HEV	Full HEV	PHEV	ER-EV	BEV

Charge depleting mode





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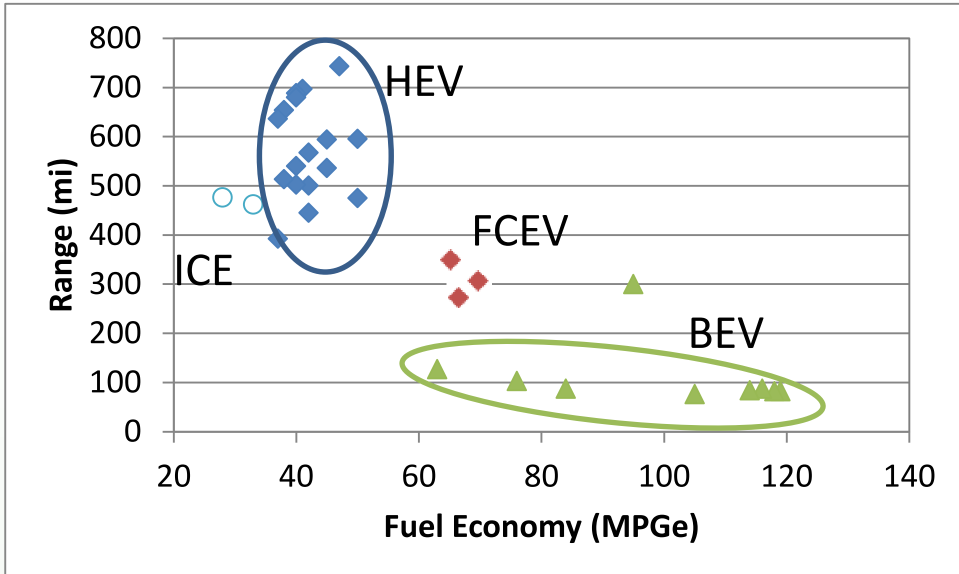
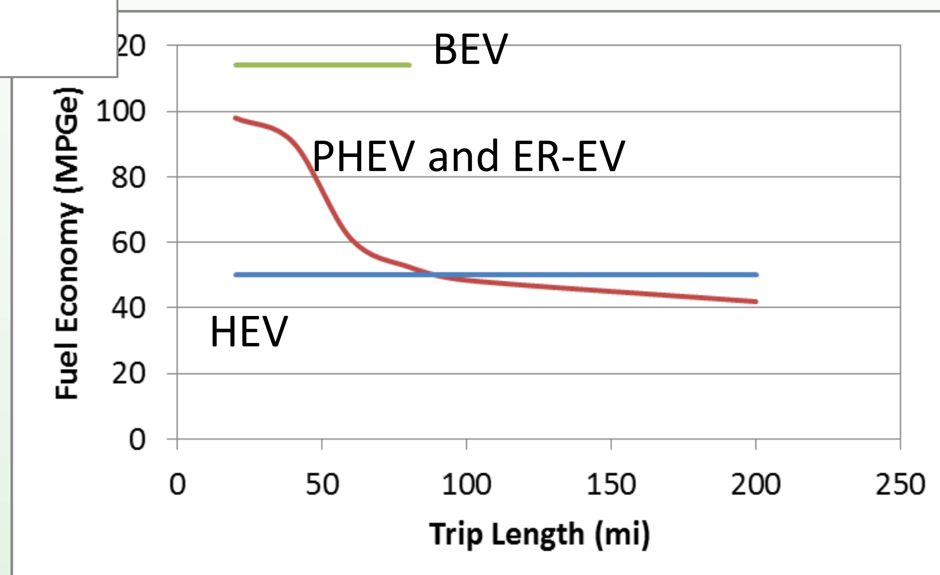
Fuel Economy and Range of EVs

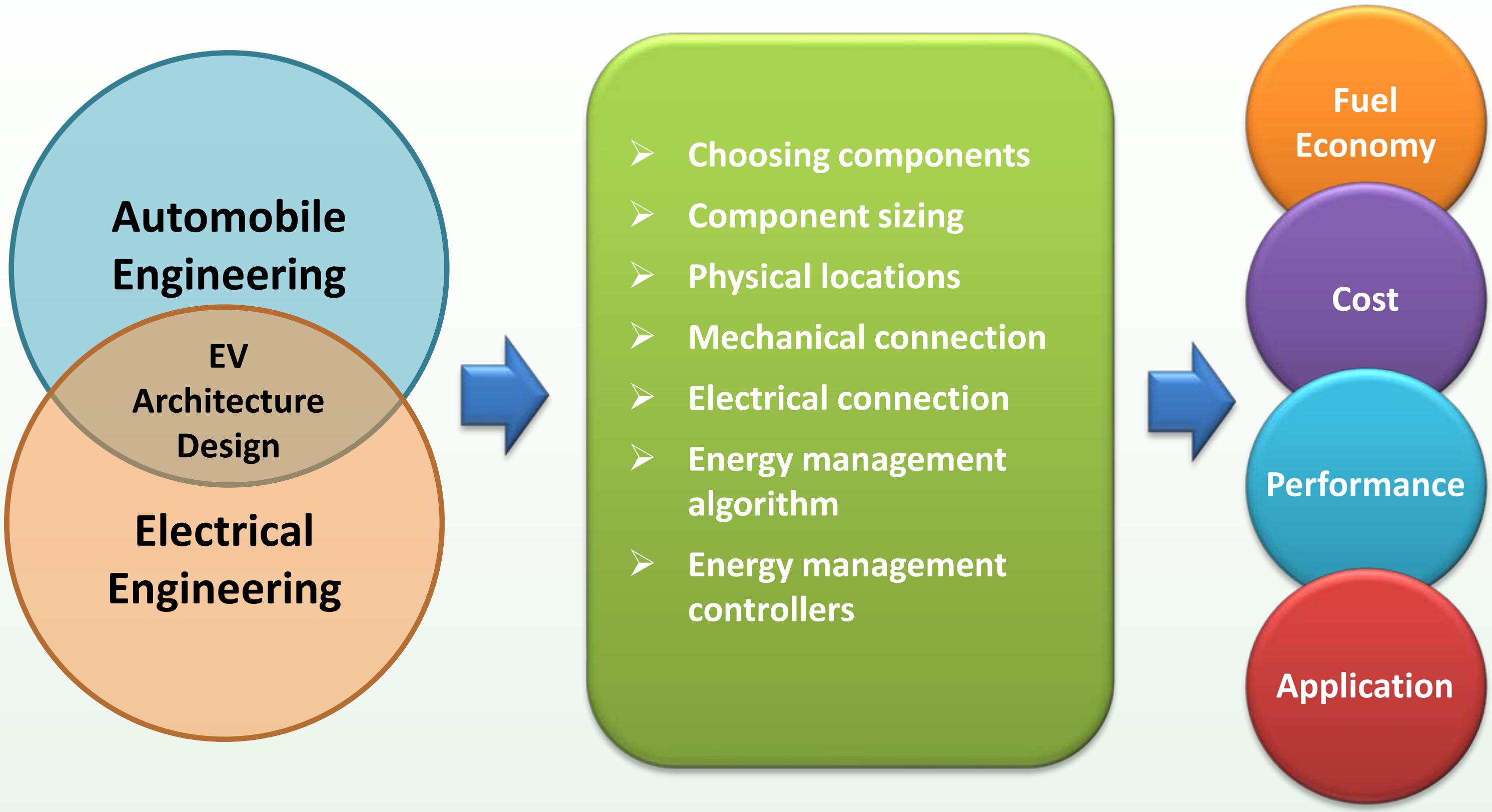


- BEV > FCEV > HEV > ICE

- The fuel economy of PHEV and ER-EV highly depends on driving behavior.



Powertrain Architecture Design Philosophy

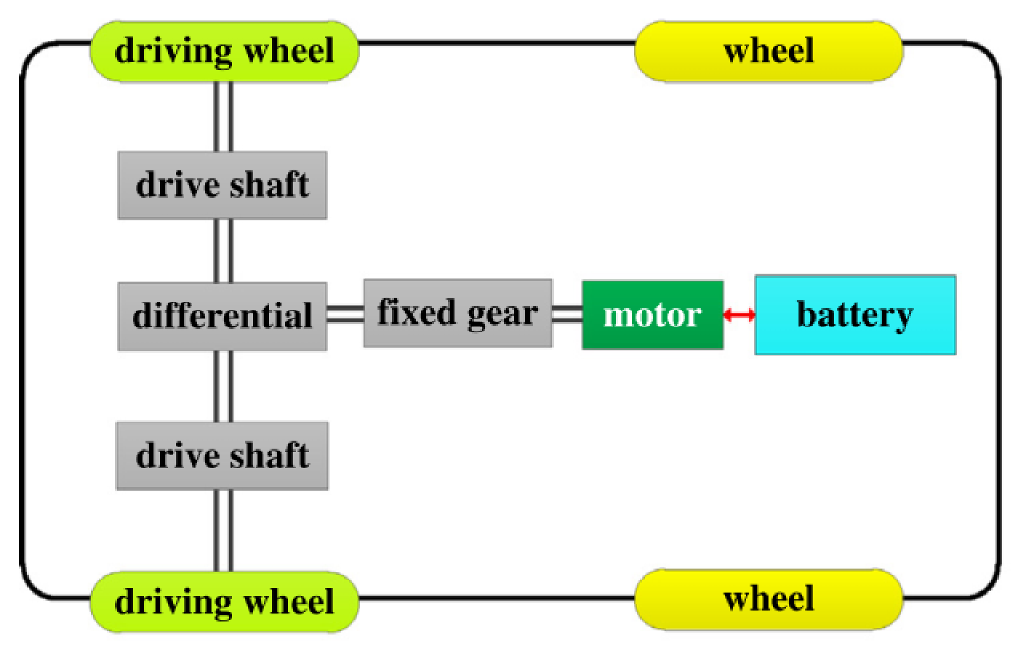


The best power system architecture for EVs is still the subject of ongoing investigation

BEV Architecture

Central Drive

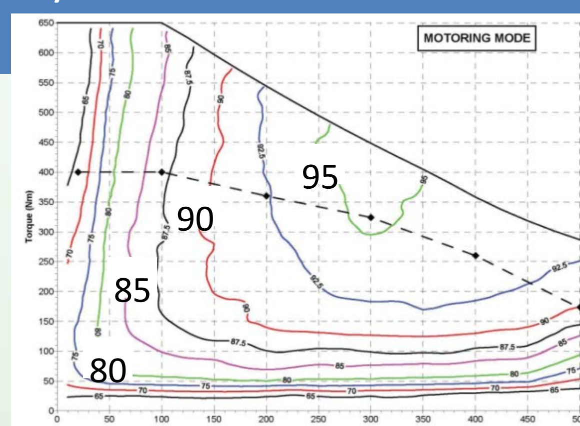
- Simplest layout
- Absence of clutch and transmission
- Employed by almost all BEVs on the market

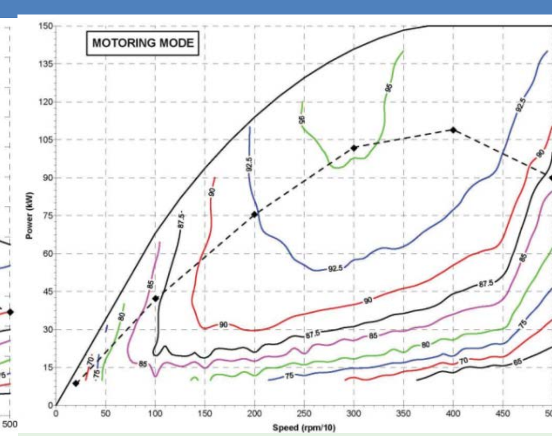


Nissan Leaf integrated e-powertrain

Central Drive: Pros and Cons

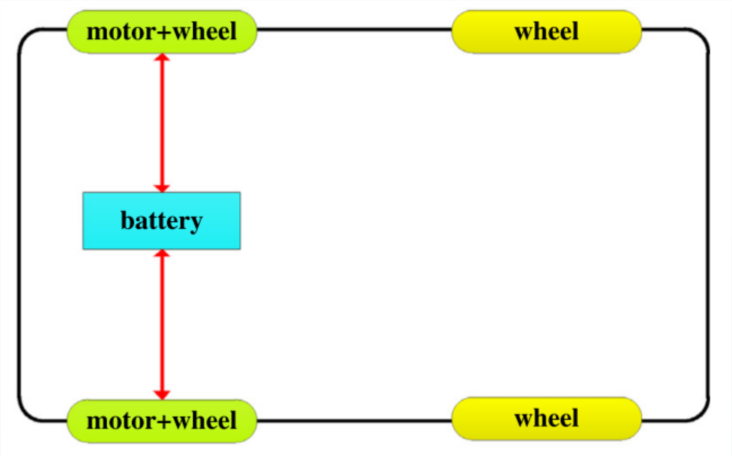
Pros	Cons
Reduced installation space and weight lighting	Efficiency drop near boundary conditions
Single-speed reduction gear is more cost effective	EM can only output a portion of its maximum power at low speed, reversely increases EM size and costs.
Efficiency loss can be further reduced due to fewer gear pairs and absence of transmission	
Control of gear shifts are totally eliminated	





BEV Architecture
Wheel-hub Drive

- Independent control of each driving wheel
- Elimination of differential and driving shafts.
- Popular design in electric scooters.



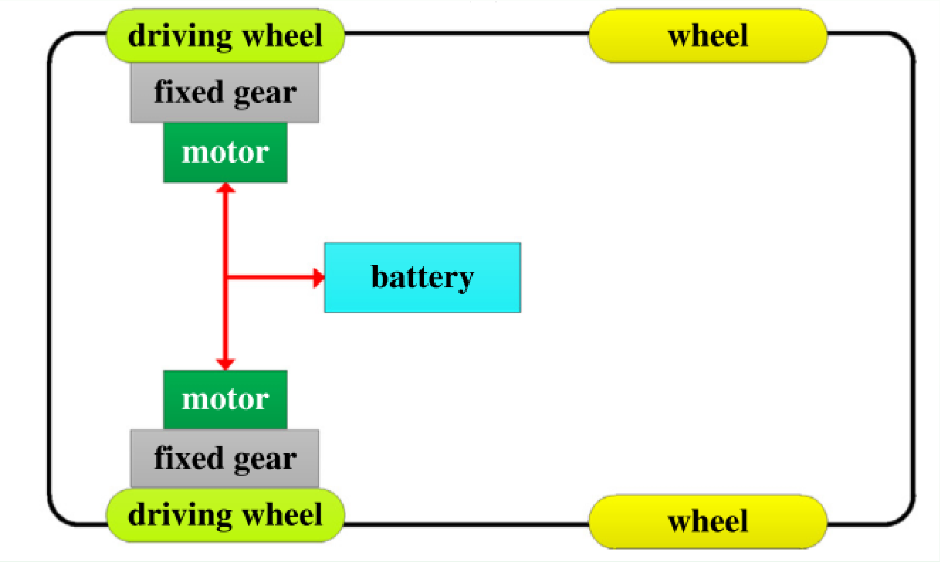
Brabus wheel-hub mounted electric motor

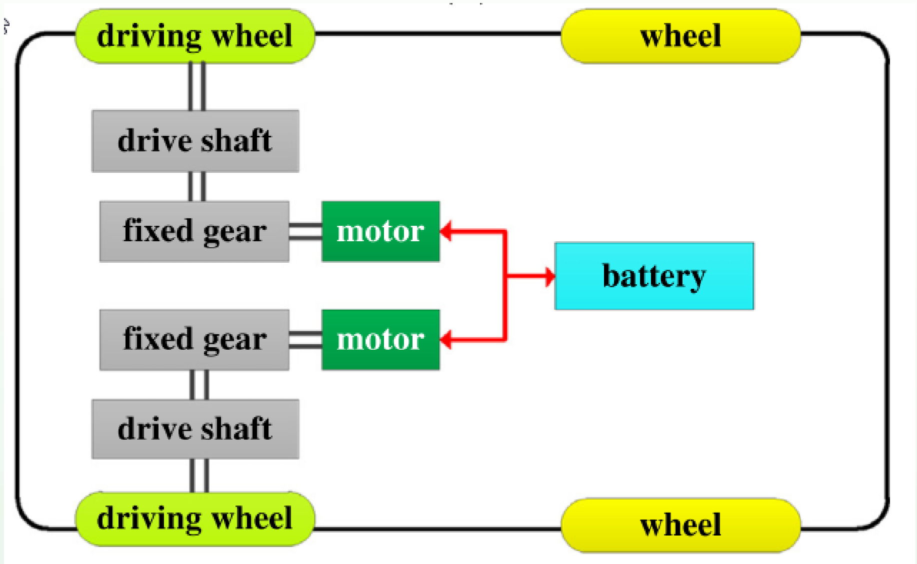
Pros	Cons
Weight and cost reduction	Electric motor works within low efficient region, restricted EM size

Reference 7

BEV Architecture
Wheel-hub Drive Derivatives

- The EMs are connected to wheels through reducer gears and drive shaft.





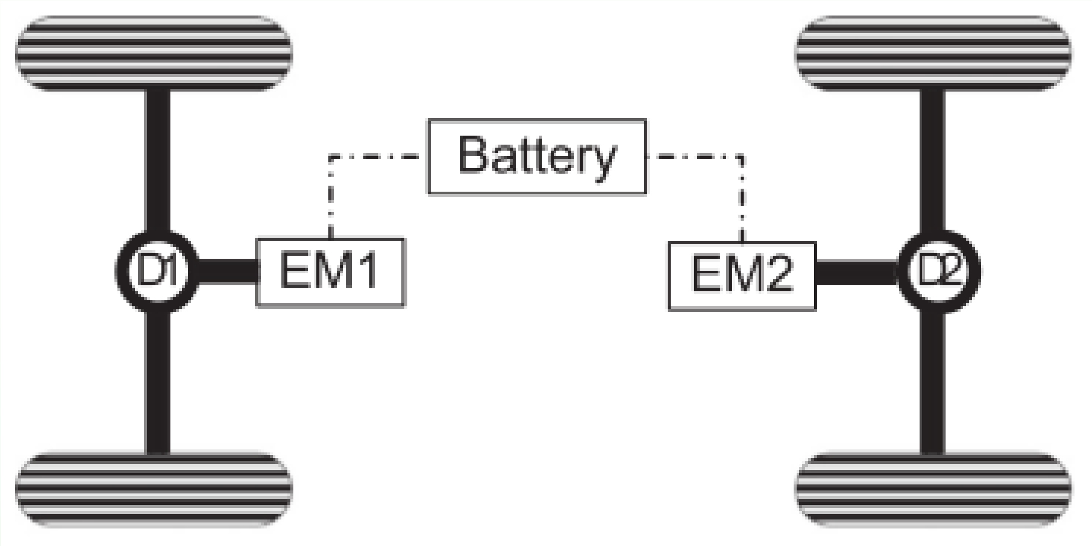
Mercedes-Benz SLS AMC E-Cell vehicle

Reference 7

BEV Architecture

Front and Rear Drive

- Capable of FWD, RWD, and AWD



HEV Architectures

Series hybrid

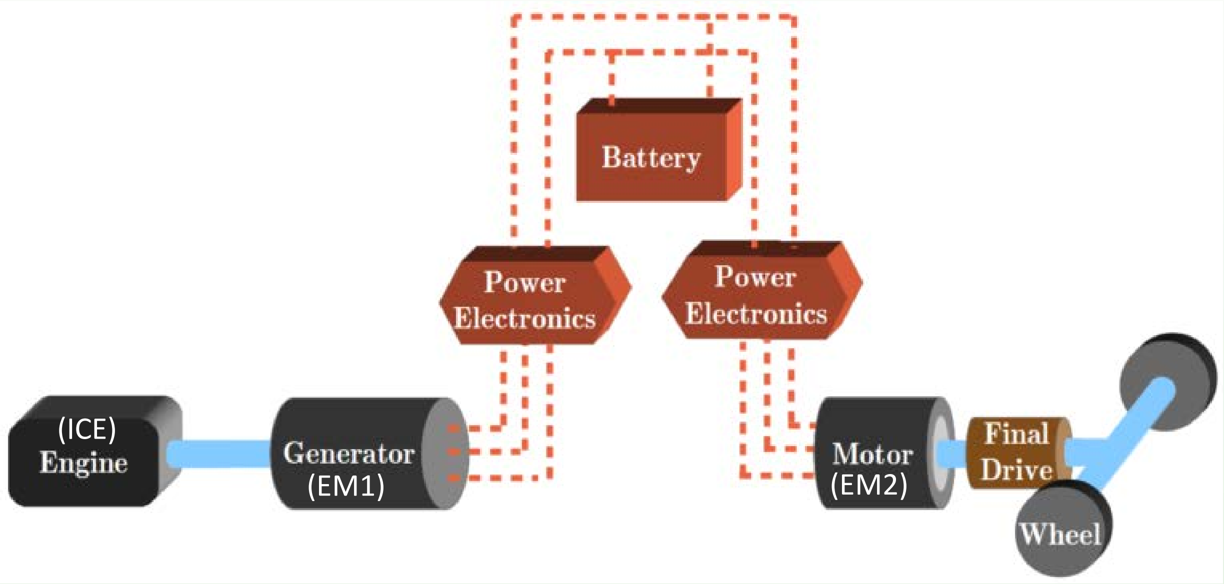
Parallel hybrid

Split-power hybrid

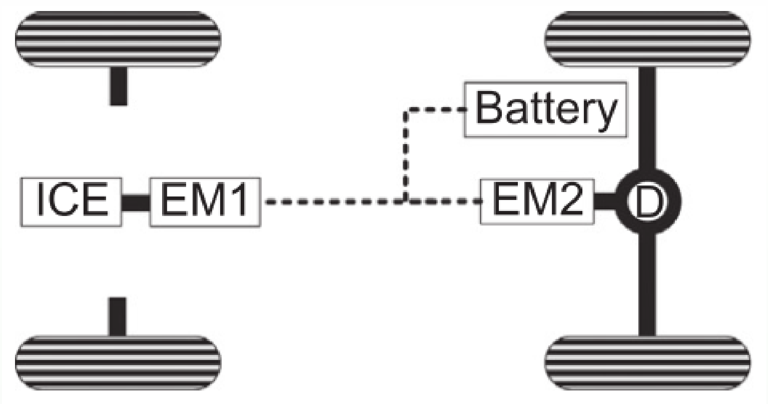
Compound hybrid

HEV Architectures
Series Hybrid

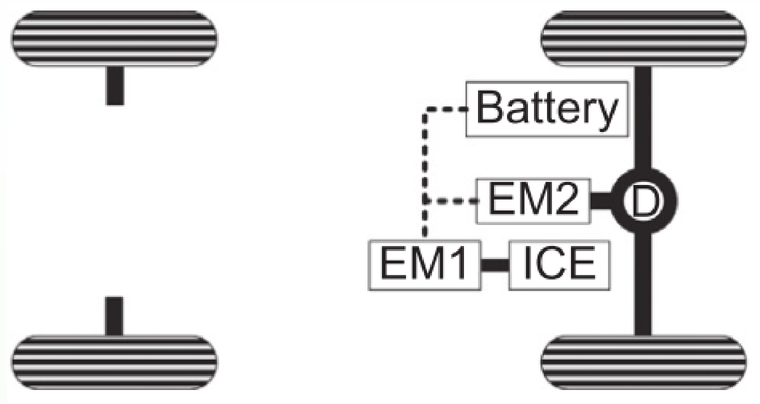
- ICE and EM are connected in series
- Basic components: ICE, electric generator (EM1), electric motor (EM2), and ESS (battery)
- Only EM provides torque to the final drive



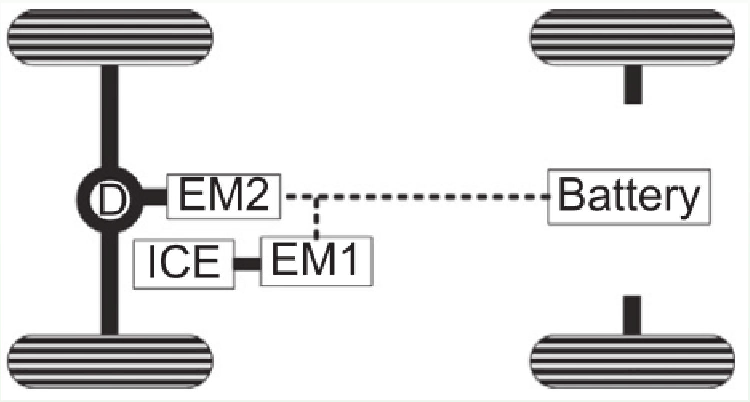
Series Hybrid Layouts



Front engine rear drive



Rear engine rear drive

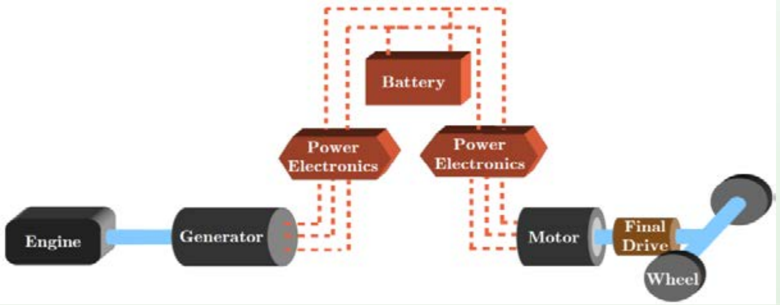


Front engine front drive

Reference 1

Series Hybrid: Pros and Cons

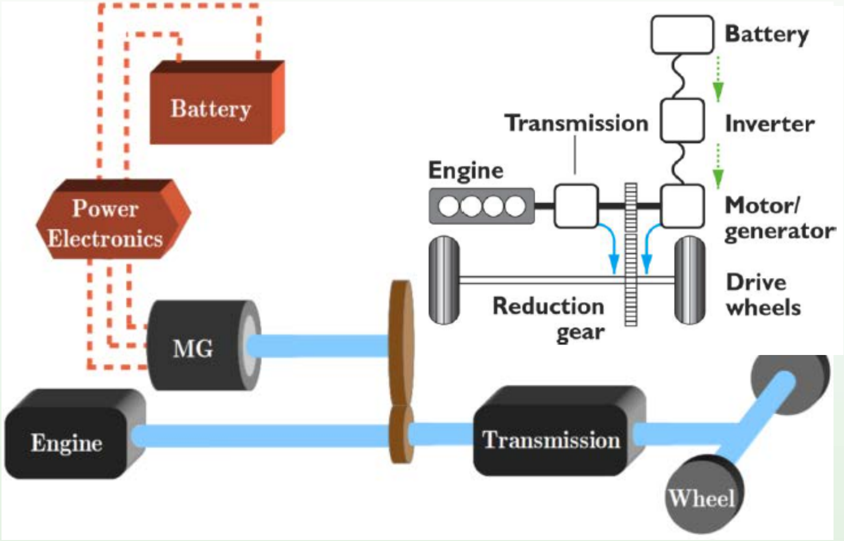
Pros	Cons
ICE always operates at peak efficiency range	Overall efficiency suffers especially at high speed
Efficiency loss can be further reduced due to fewer gear pairs and absence of transmission	EM can only output a portion of its maximum power at low speed, reversely increases EM size and costs.
Outstanding towing capacity at low speed	EM2 needs to meet all driving needs, increasing cost, weight, and installation space
Big EM2 motor is able to capture more regen braking	ICE is not engaged in final driving
Control system is relatively simple	

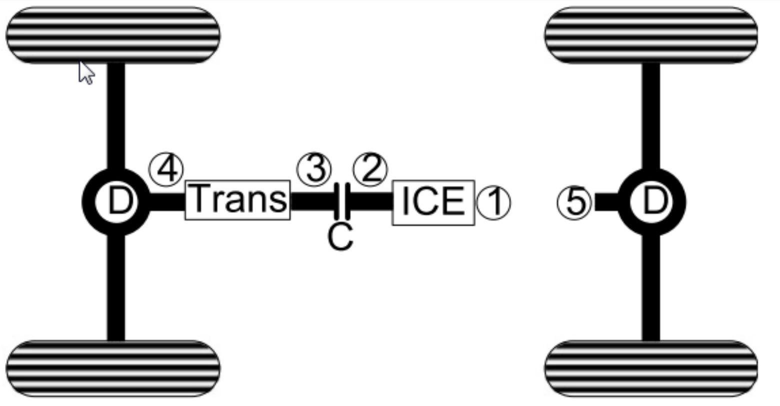


- Suitable for: mining vehicle, city bus (with frequent start-stop).

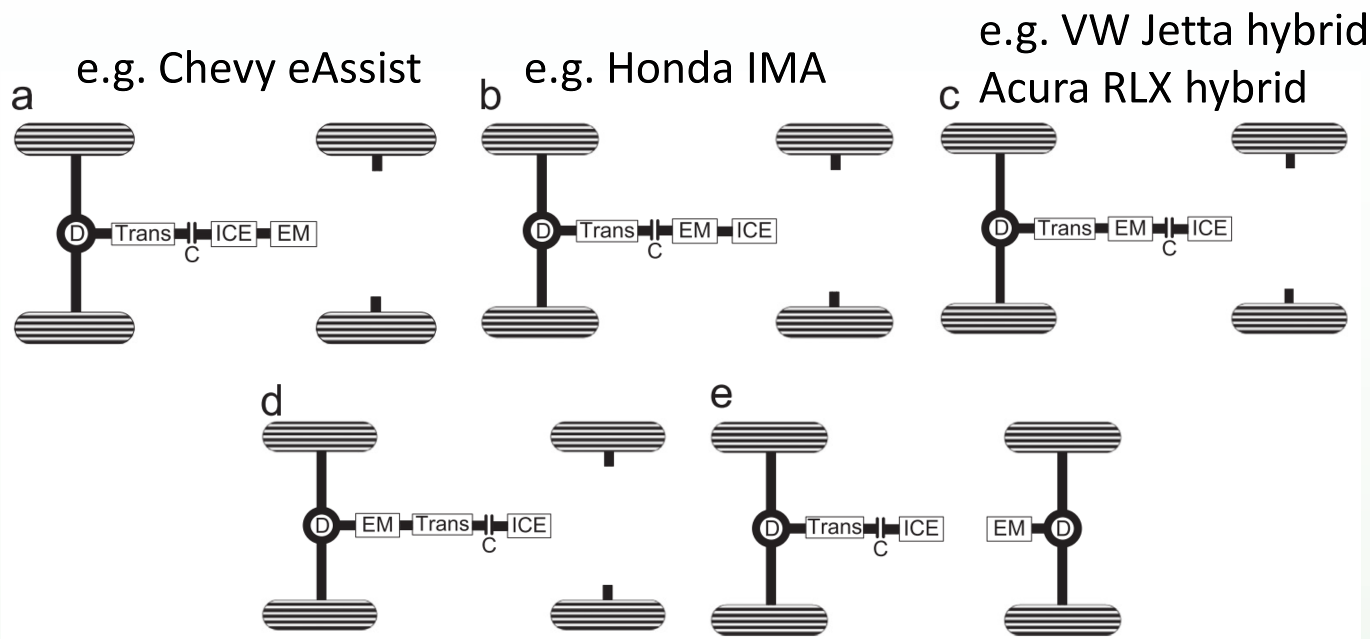
HEV Architectures
Parallel Hybrid

- Engine and electric motor are connected with fixed speed ratio.
- Both ICE and EM can provide torque to final driving, separately or together.
- Usually includes a transmission.





Types of Parallel Hybrid Architectures

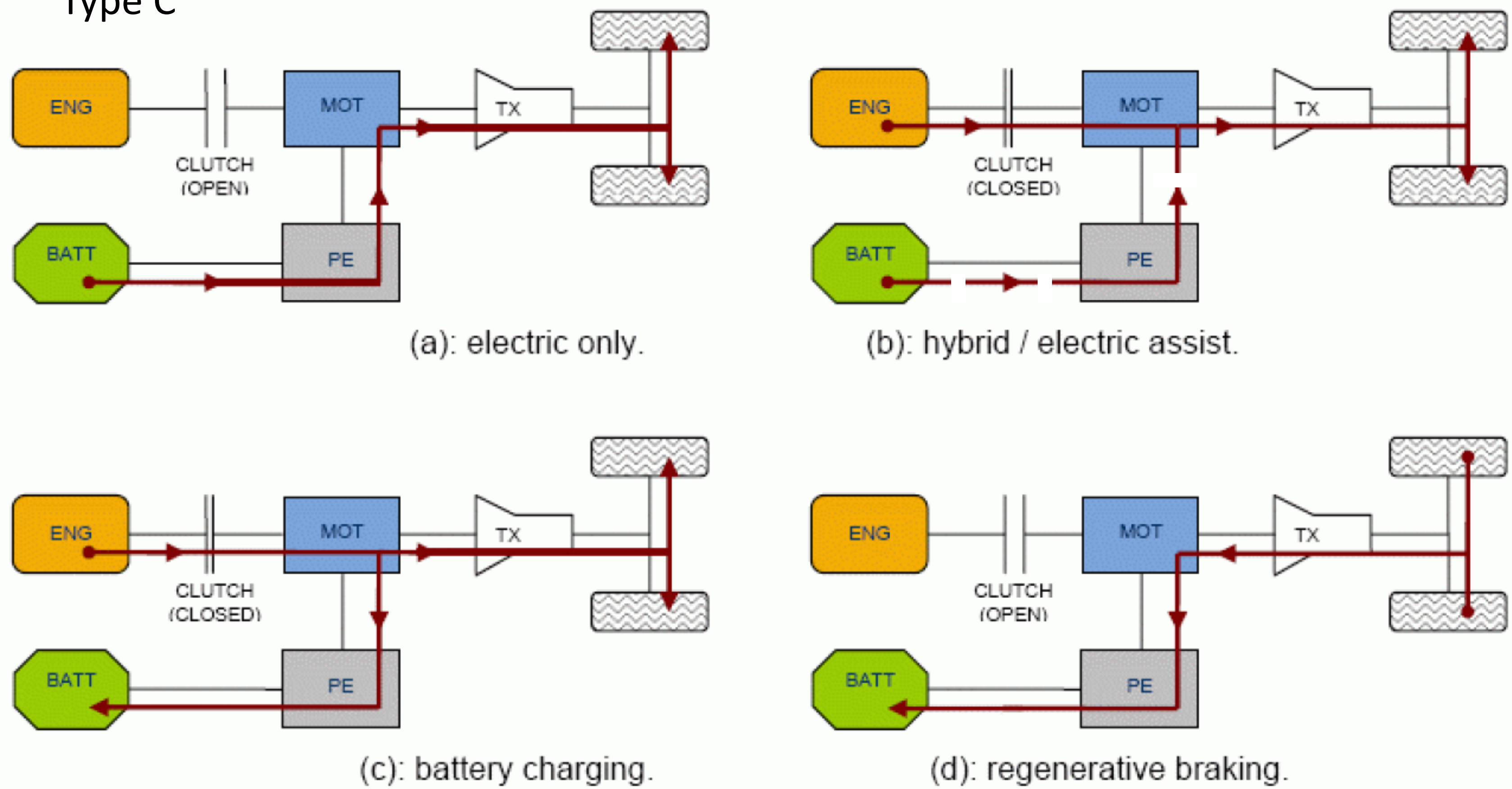


	Micro HEV	Mild HEV	Strong HEV	PHEV	ER-EV
Type-a	⊗	⊗			
Type-b		⊗			
Type-c		⊗	⊗	⊗	⊗
Type-d		⊗	⊗	⊗	⊗
Type-e		⊗	⊗	⊗	⊗

Reference 1

Operation Modes of Parallel Hybrid Architecture

Type C



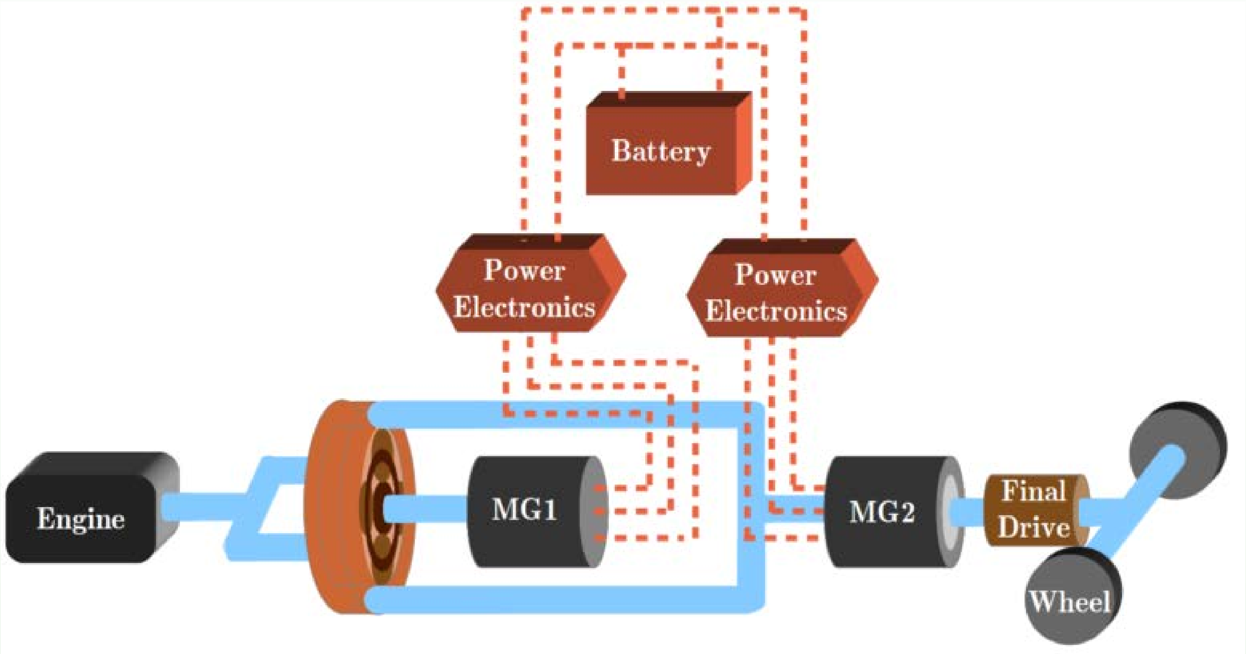
Parallel Hybrid: Pros and Cons

Pros	Cons
Total efficiency is higher doing cruising and highway driving	Complicated system with many variables
Required relatively small EM	ICE does not always operate at peak efficiency
Large design flexibility	Battery cannot be charged at standstill

- Example: Honda insight Hybrid, VW Jetta Hybrid, Acura RLX Hybrid, Nissan Pathfinder Hybrid

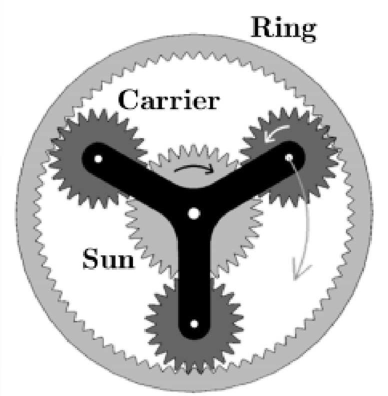
Power Split Hybrid Architectures

- Double connection between the engine and the final drive: mechanical and electrical.
- Consist of one or more power split device (PSD).

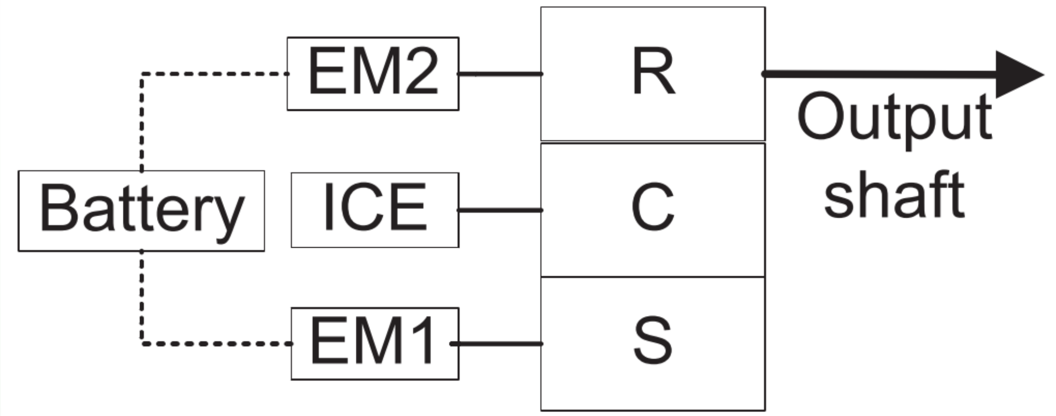


Reference 9

PSD Explained

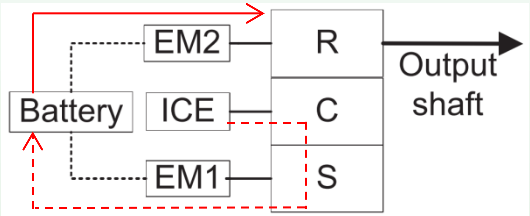


Planetary gear set

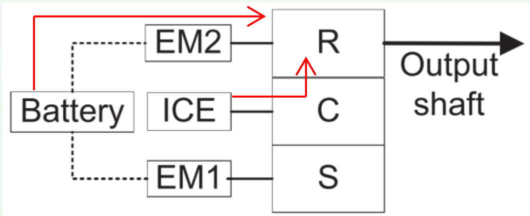


First generation Prius powertrain architecture

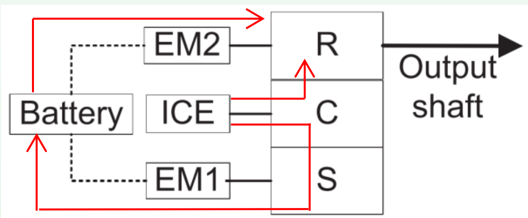
EM1: 10 kW electric machine
EM2: 50 kW electric machine



Coasting (low speed)



Acceleration



Cruising (high speed)

Reference 1

Power-Split Hybrid: Pros and Cons

Pros	Cons
Maximum flexibility to switch between electric and ICE power	Highly complex system, more expensive than parallel hybrid
Allows for a smaller, and more efficient ICE design	Efficiency transmitted over the electrical path is lower

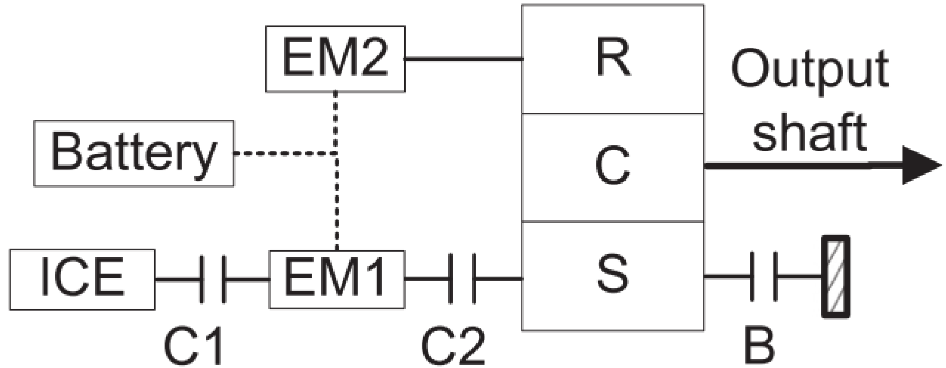
- Examples: Toyota Prius, Lexus CT200h, Lexus RX400h.

Compound Hybrid Architectures

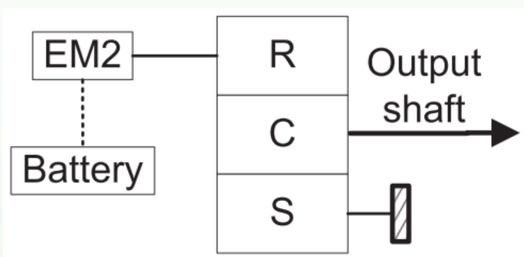
- Able to operate in more than one basic hybrid modes in a single architecture.
- May include Series/parallel, series/power-split, parallel-parallel and many other configurations.
- Increased cost and complexity.

Compound Hybrid - Chevy Volt 1st Gen

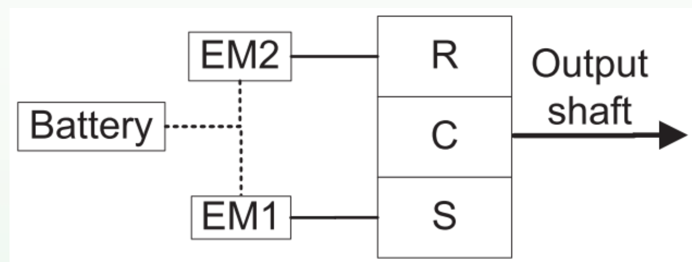
Chevy Volt



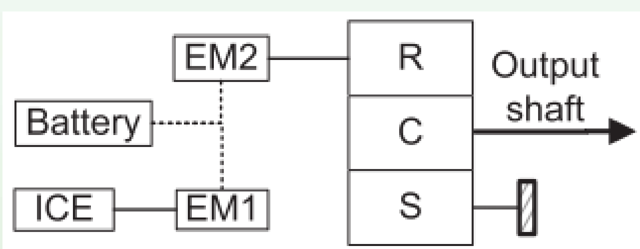
Volt powertrain architecture



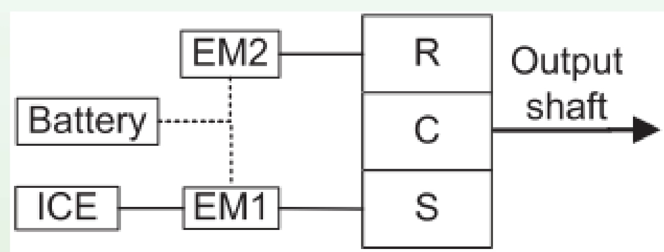
First BEV mode



Second BEV mode

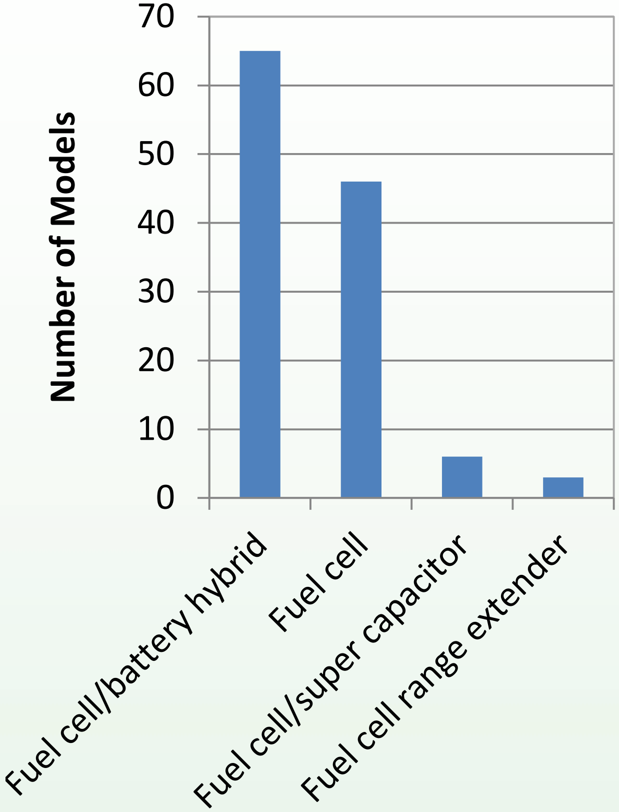


Series hybrid mode



Power-split hybrid mode

Fuel Cell Electric Vehicles



Commercially available FCEVs

Toyota Mirai

Hyundai Tucson

Reference 10

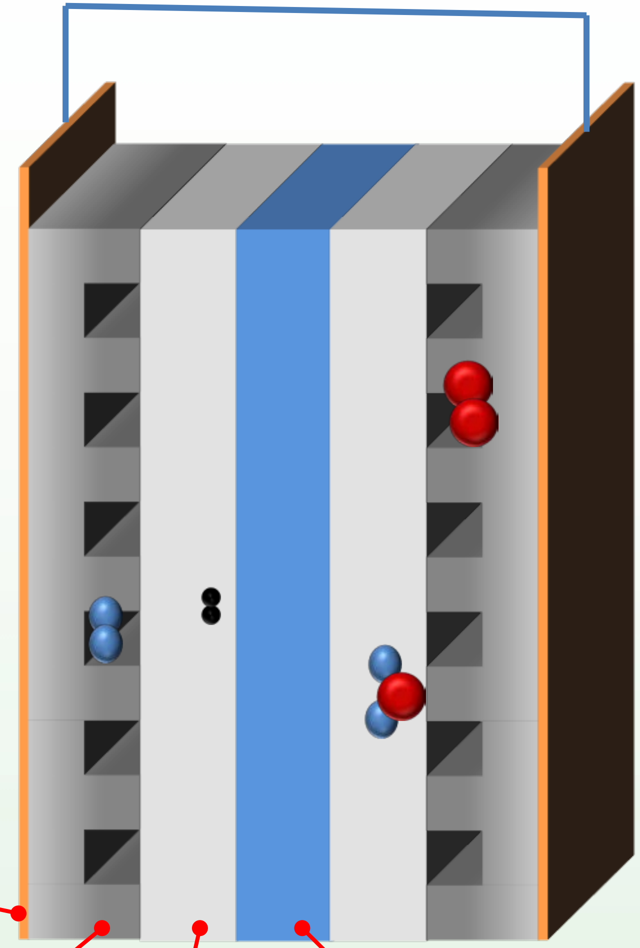
Proton Exchange Fuel Cell Mechanism

Anode
Fuel Oxidation

$$H_2 \rightarrow 2H^+ + 2e^-$$

Cathode
Oxidant Reduction

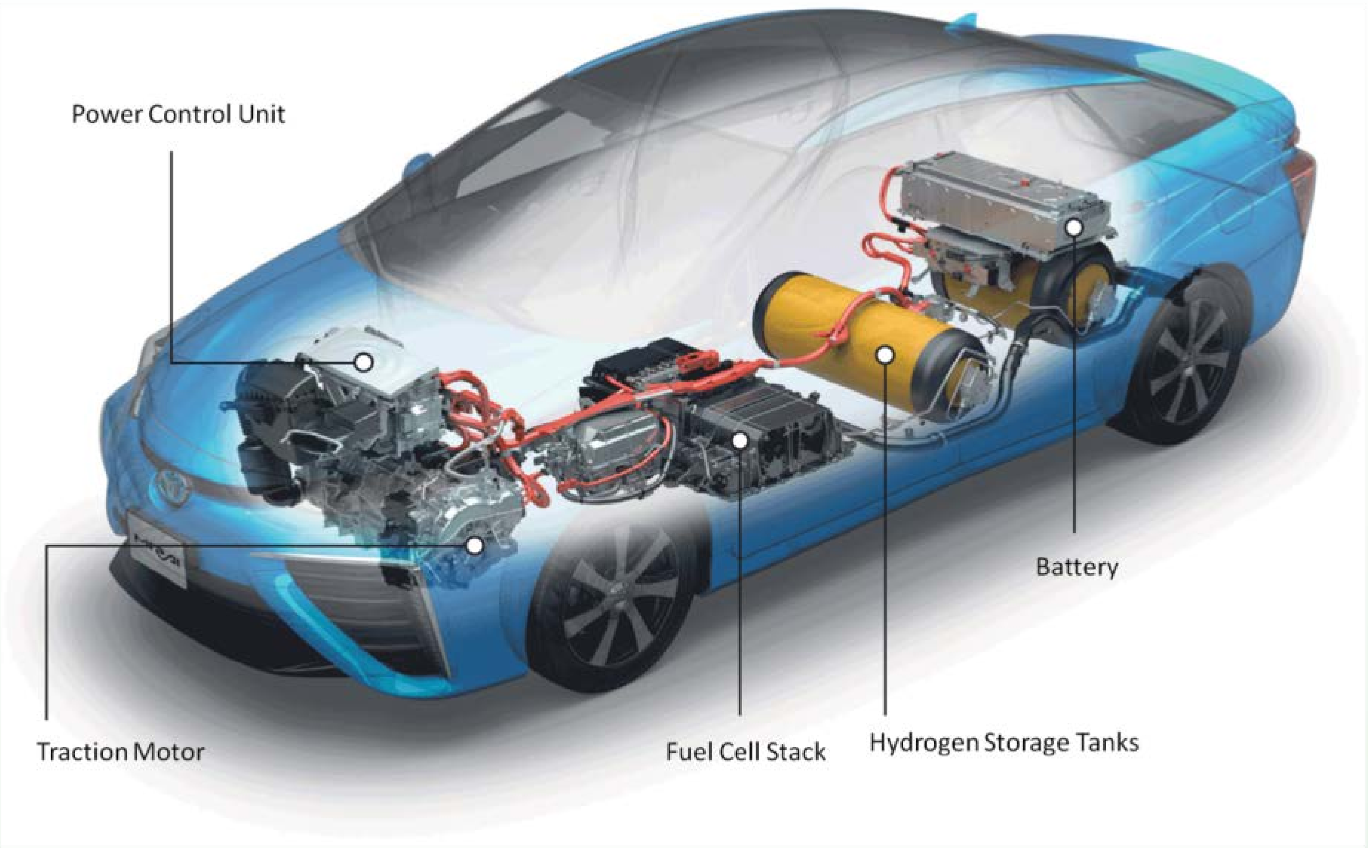
$$1/_2\, O_2 + 2H^+ + 2e^- \rightarrow H_2O$$



Total Reaction:

$$H_2 + O_2 \rightarrow H_2O + heat$$

Fuel Cell Electric Vehicle Architectures



Reference 11

Summary

- There are many EV architectures which exist in the market, and many more are being proposed and researched.
- There are many design decisions for producing a sensible EV architecture.
- There is no one-size-fits-all solution.
- EV engineering requires synergetic efforts from variety of fields.

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