METU EE7566
Electric Drives in Electric and Hybrid Electric Vehicles

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Content

Electric Vehicle Topologies

1. Vehicle types overview
2. Battery electric vehicles (BEVs)
3. Hybrid electric vehicles
   - Series HEV
   - Parallel HEV
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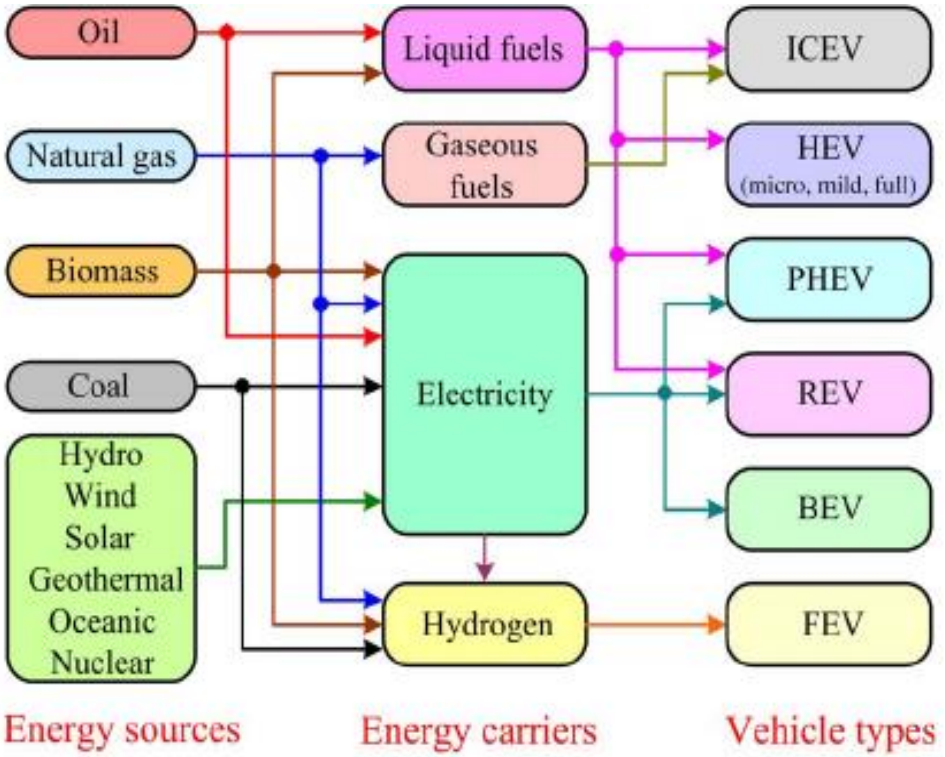
     - Speed coupler
   - Parallel-Series hybrid (Power-split)
   - Fuel cell EV
   - Plug-in HEV
4. Hybrid functions overview

Vehicle Types Overview – Electrification Level



Internal combustion engine vehicle

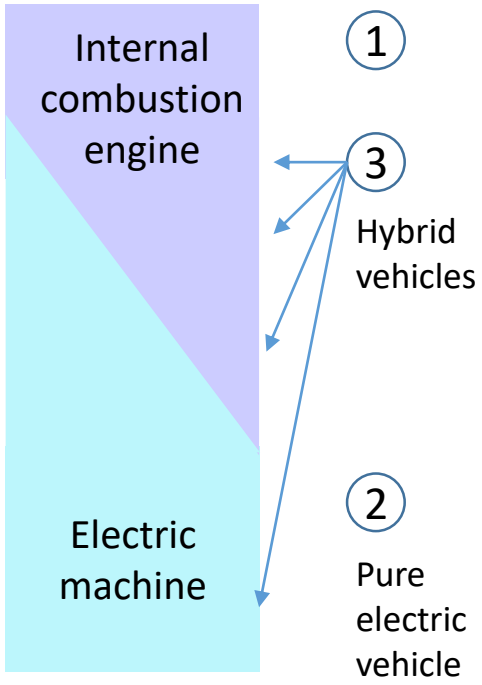
Hybrid electric vehicle

Plug-in hybrid electric vehicle

Range extender electric vehicle

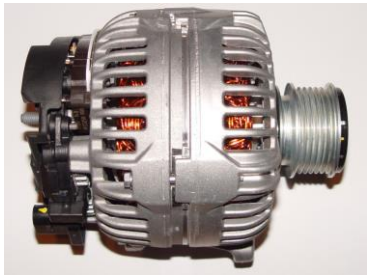
Battery electric vehicle

Fuel cell electric vehicle (FCEV)



Source: C. Liu, K. T. Chau, D. Wu and S. Gao, "Opportunities and Challenges of Vehicle-to-Home, Vehicle-to-Vehicle, and Vehicle-to-Grid Technologies," in Proceedings of the IEEE, vol. 101, no. 11, pp. 2409-2427, Nov. 2013.

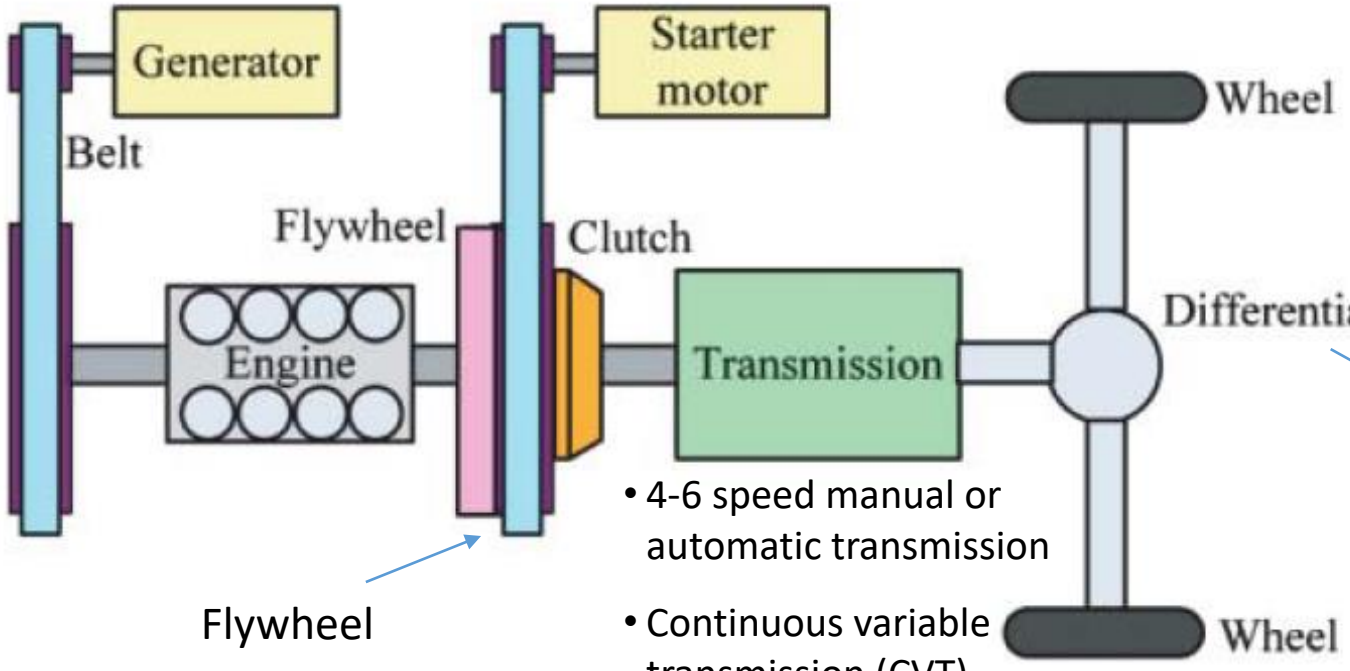
Internal Combustion Engine Vehicle



Generation:
12 V
100 A

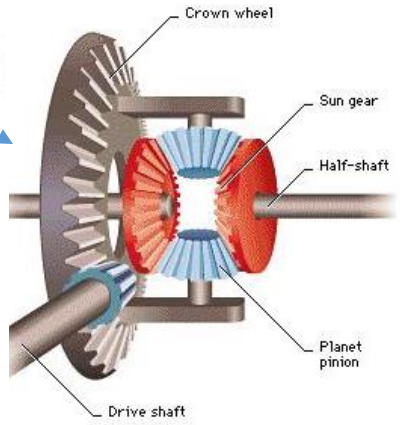
Cranking:
12 V & 150–200 A

Modes:
1. Engine propulsion
2. Mechanical braking

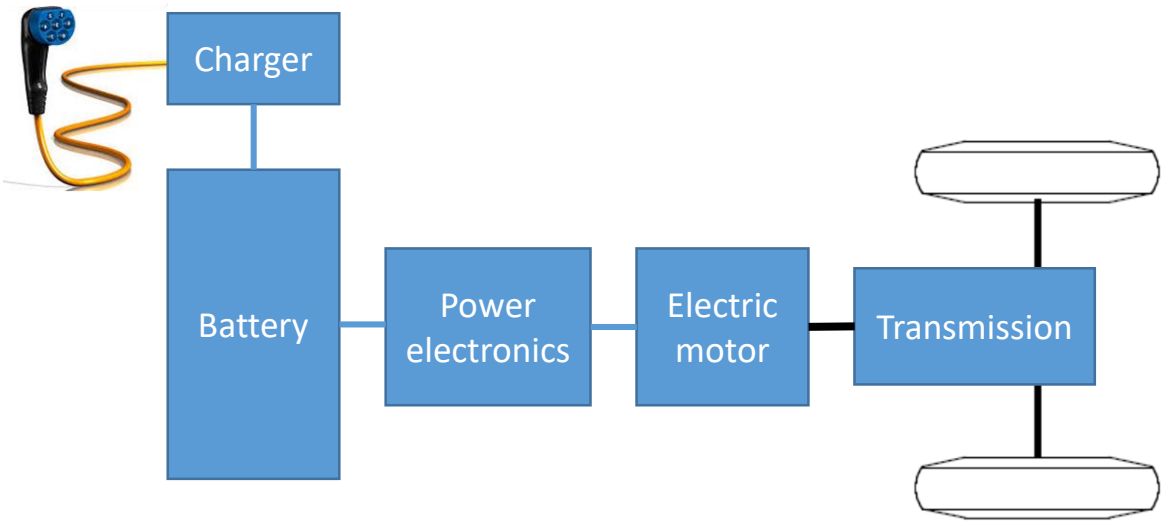


Flywheel

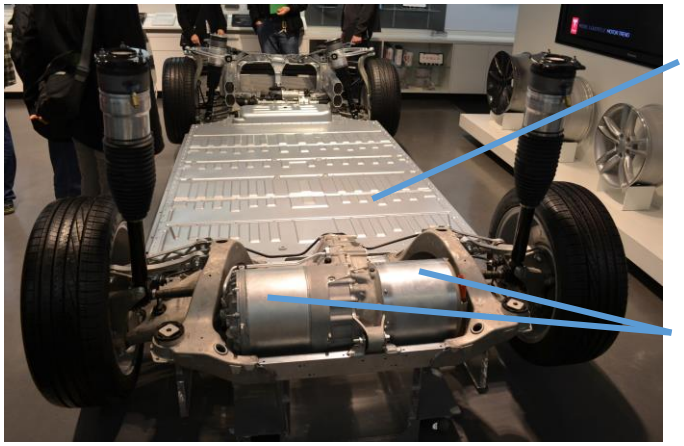
- 4-6 speed manual or automatic transmission
- Continuous variable transmission (CVT)



Vehicle Types –Battery Electric Vehicle

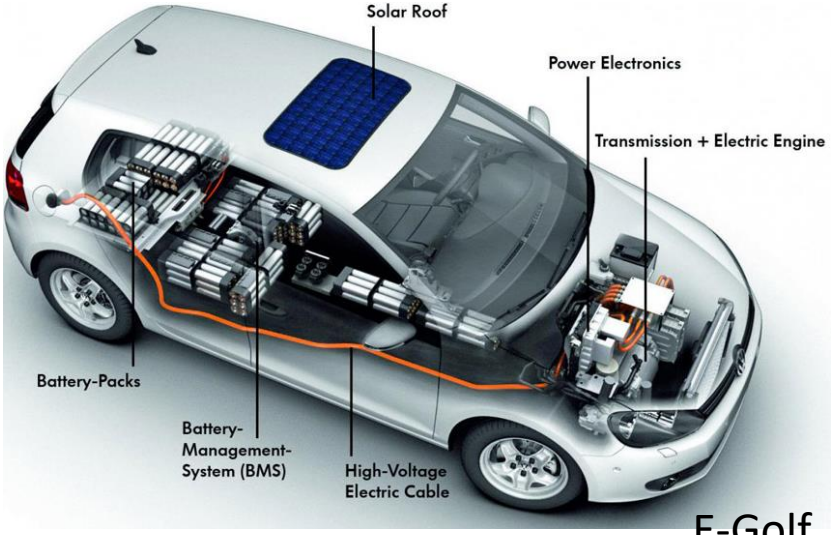


Modes:
1. Electric motor propulsion
2. Regenerative & mechanical braking



Battery pack

Electric motor and inverter

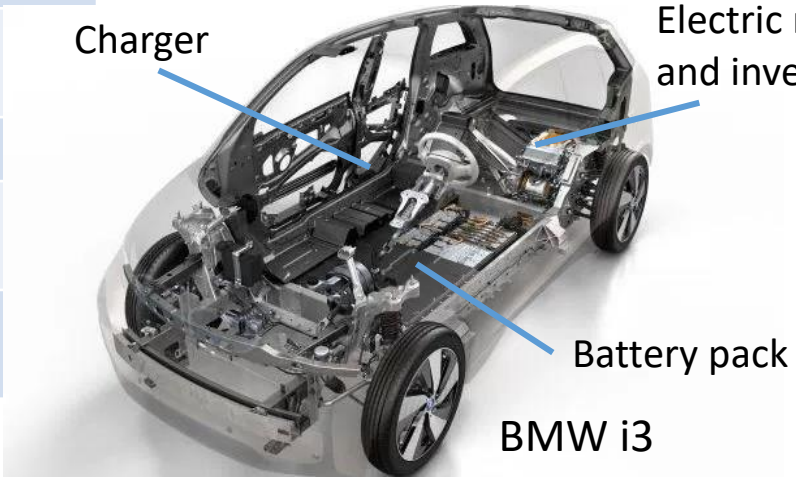


E-Golf

Tesla Model S: Rear drive, also there are dual drive options

Battery Electric Vehicle

	Tesla Model S 60 kWh	BMW i3
Electric motor	285 kW / 430 Nm	125 kW / 250 Nm
Battery	60 kWh / 225 kW	18,8 kWh
Gear ratio	9.73	9.7
Range	EPA: 335 km NEDC: 375 km	EPA: 130 km NEDC: 130 to 160 km
Max. speed	190 km/h	150 km/h
Empty weight	1961 kg	1195 kg
Base Price	$69.900	$42.275
Acc. 0-100 kmh	5.9 sec	7.2 sec
Fuel economy	88 mpg (EPA)	124 mpg (EPA)

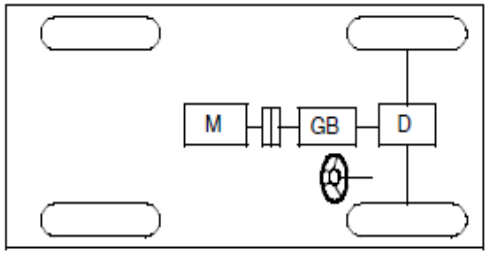


Check for newer models:
https://www.tesla.com/models/design#battery

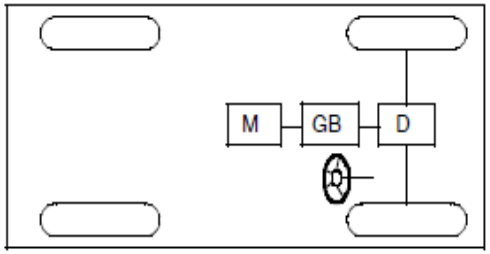
Battery Electric Vehicle Configurations

Possible front wheel drive drivetrain configurations:

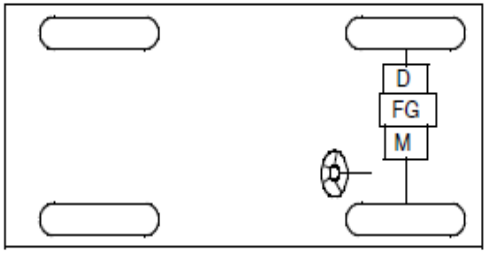
Configurations with differential



(a)

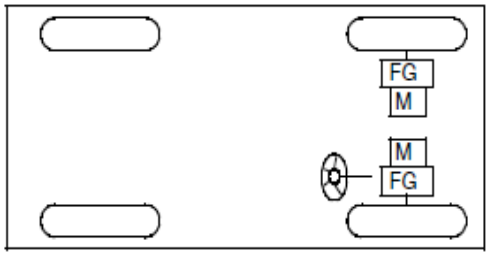


(b)

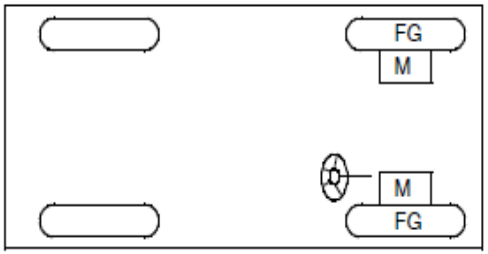


(c)

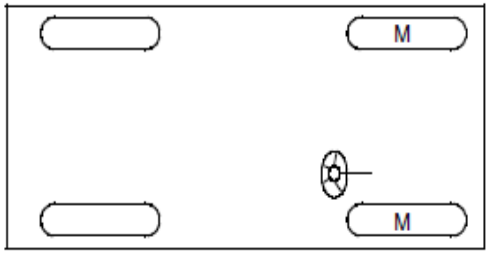
Configurations without differential



(d)



(e)

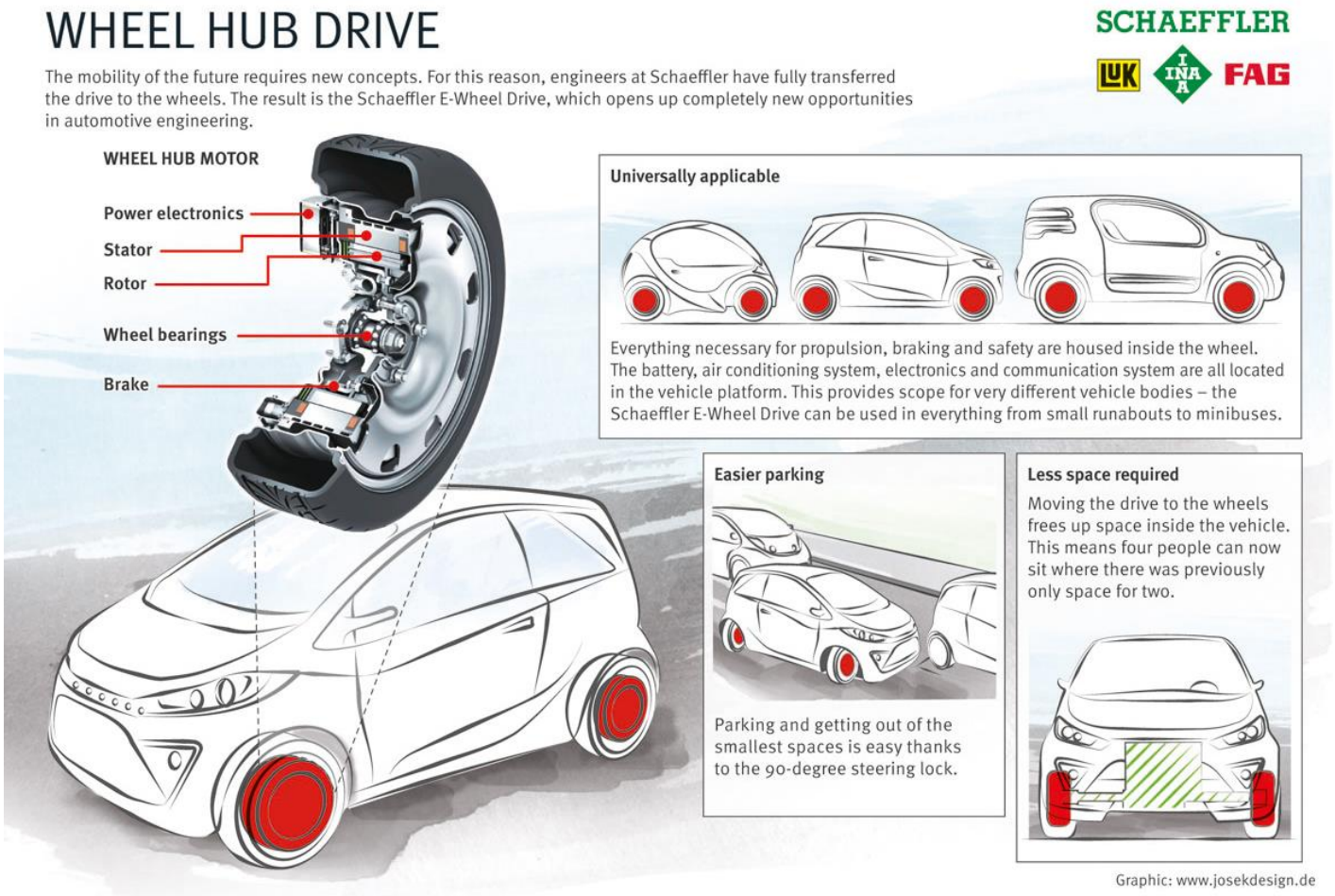


(f)

M: Electric motor
GB: Gearbox
D: Differential
C: Clutch
FG: Fixed (single speed) gearing

These configurations can be extended for only rear and rear & front wheel drives.

Battery Electric Vehicle with In-Wheel Drive



<u>Drawbacks:</u>

- Electric motor with higher torque requirement to start and accelerate
- Low power/torque density

- No mechanical gearing between the electric motor and the driving wheel
- Outer-rotor of a low-speed electric motor is be directly connected to wheel
- The speed of electric motor is equivalent to wheel speed

Hybrid Electric Vehicle (HEV) Modes

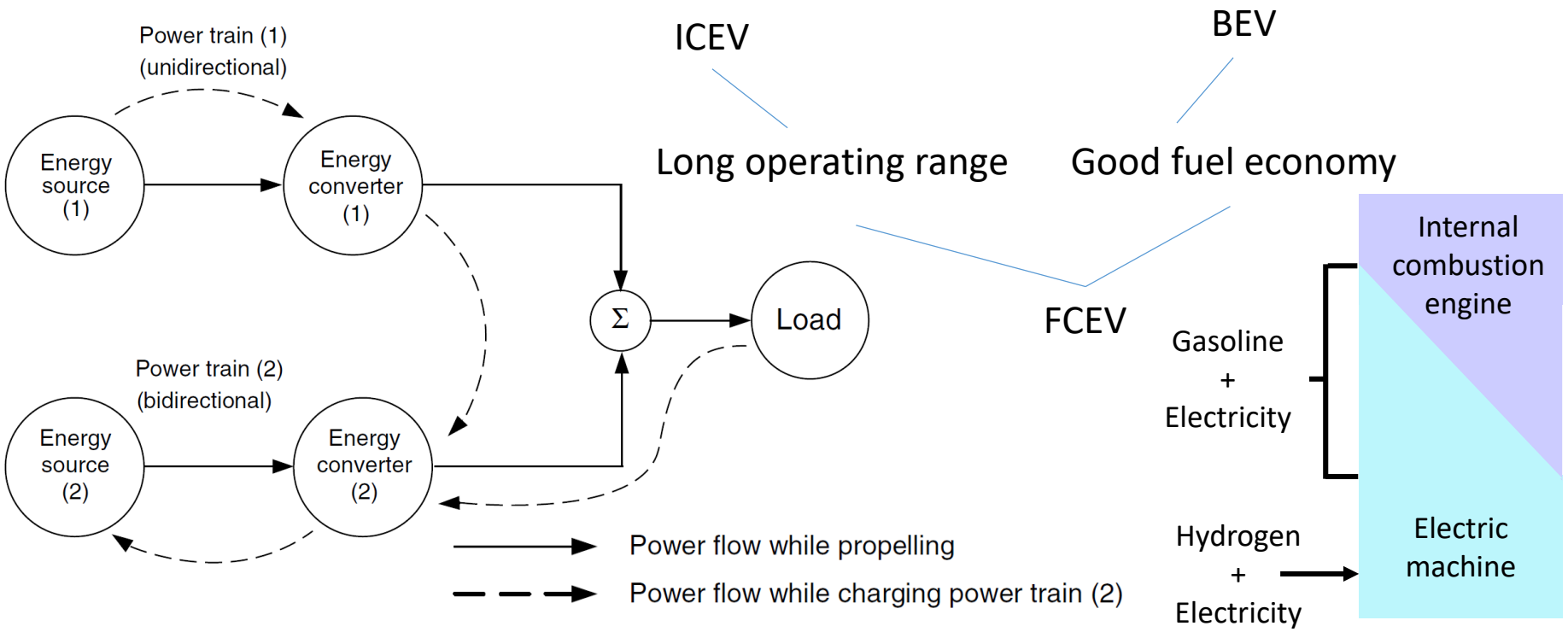
Hybrid: a thing made by combining two different elements; a mixture.

Hybrid vehicle: A vehicle with more than one form of onboard energy to achieve propulsion.

Hybrid electric vehicle: A hybrid vehicle with one of the onboard energy sources is electricity.

Current HEV application: Gasoline + Battery or Battery + Hydrogen

Motivation: Combine the good features of two different technologies



Hybrid Electric Vehicle (HEV)

Classification of HEVs

Hybridization level
- Micro
- Mild
- Full
- Plug-in (PHEV)
- Range extender (REX)

Power flow
- Series
- Parallel
- Series-parallel
- Complex

Energy sources
- Gasoline + **Electricity**
- Hydrogen + **Electricity**
- Gasoline + Hydraulic
  (not covered, refer to link below)

	Start-stop	Regenerative braking	Propulsion assist	Pure electric drive
Micro	✓	✓		
Mild	✓	✓	✓	
Full	✓	✓	✓	✓

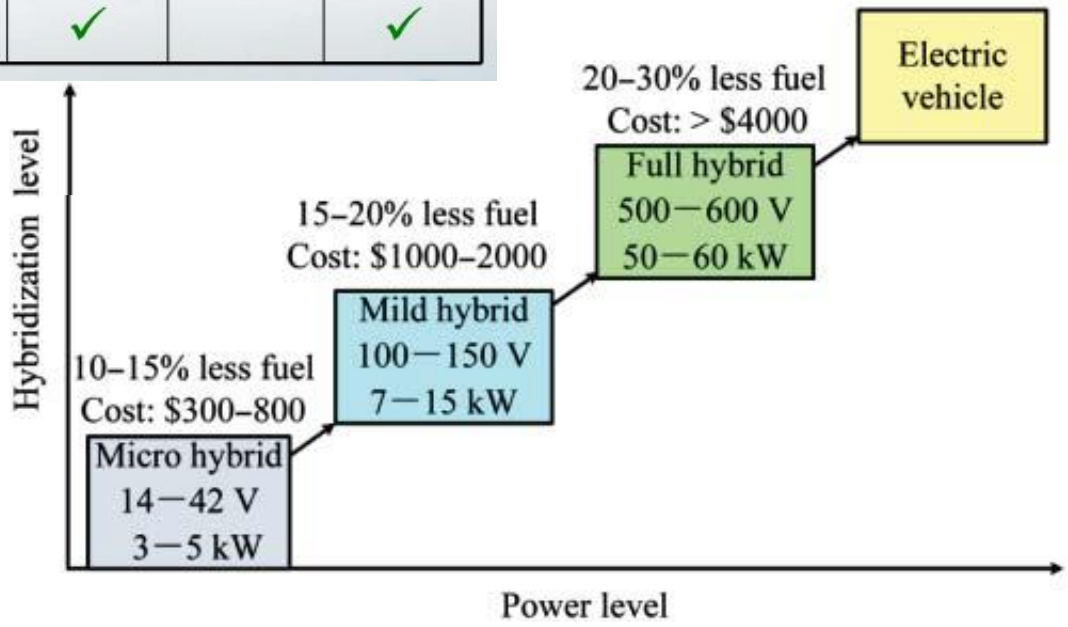
https://archive.epa.gov/otaq/technology/web/html/how-it-works-parallel.html

HEV Classification wrt. Hybridization level

Hybrid Functions:

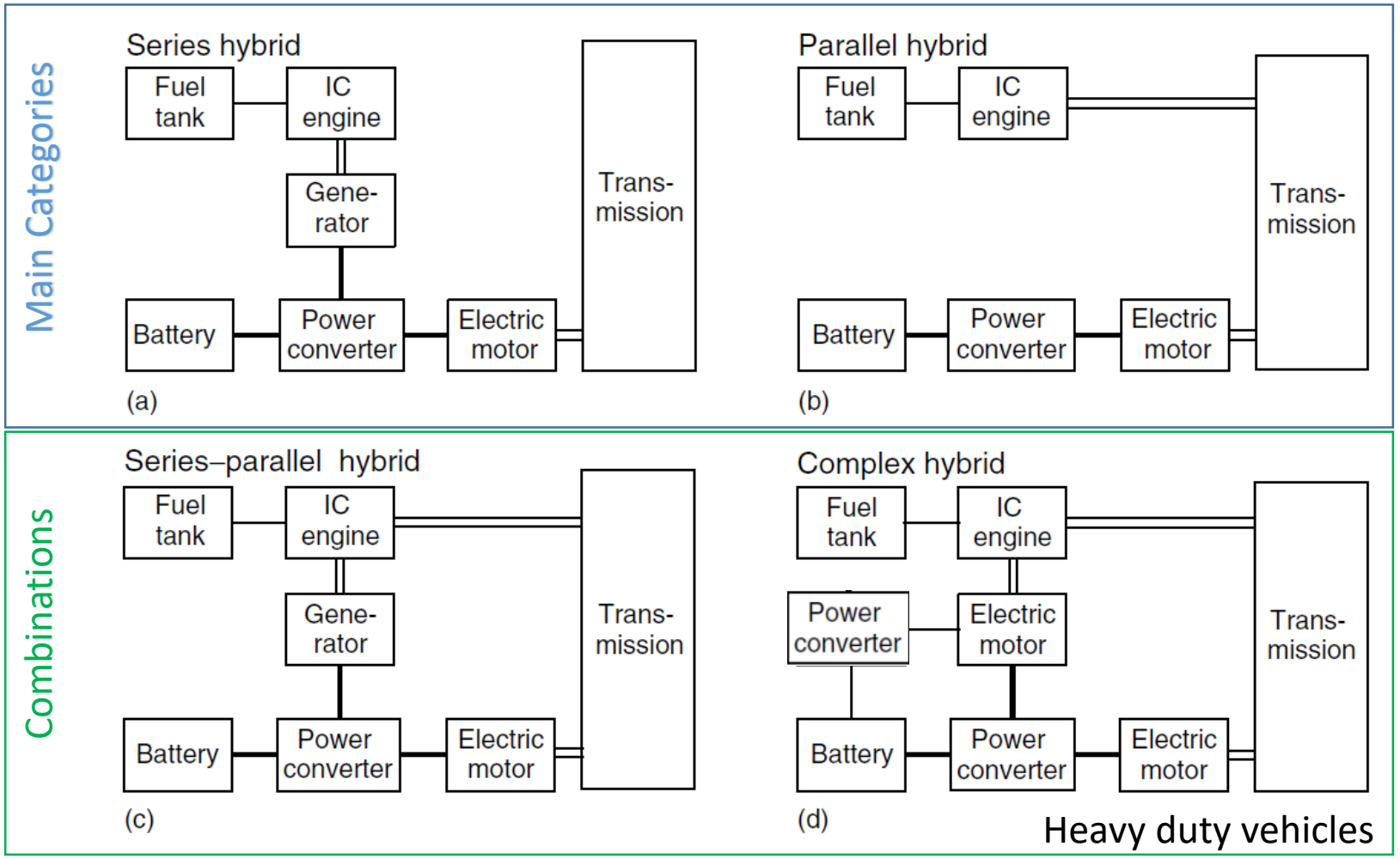
Increasing Electrical Capability

	IC Engine Stop/Start	Brake Energy Recovery	Electric Motor Assist	Pure Electric Drive
Micro-Hybrid	✓	✓		
Mild/Medium Hybrid	✓	✓	✓	
Full-Hybrid	✓	✓	✓	✓
Plug-In Hybrid	✓	✓	✓	✓
Range Extender	✓	✓		✓
Electric Vehicle		✓		✓



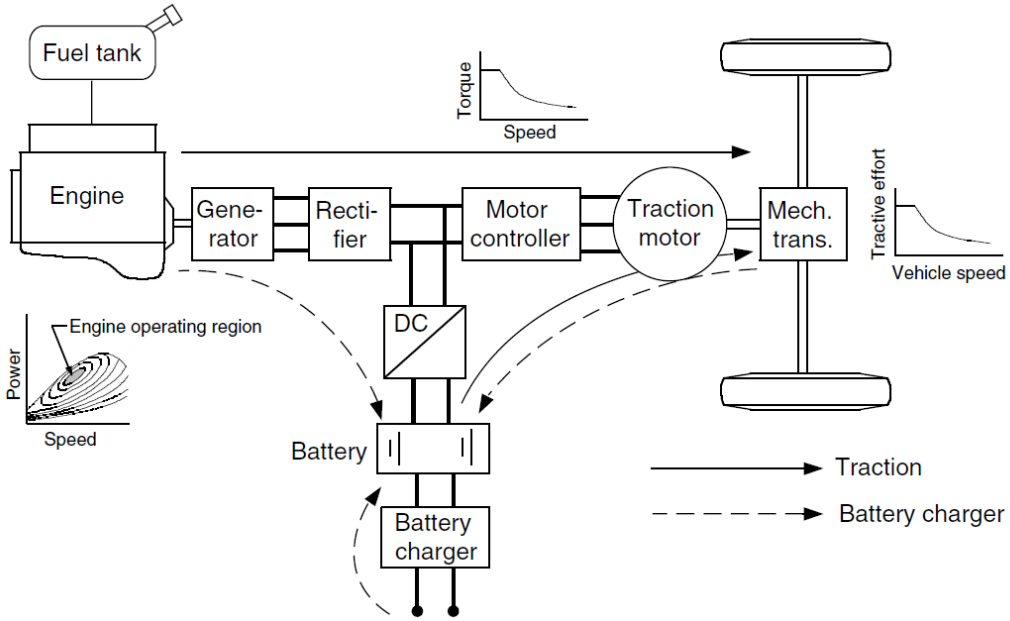
Volkswagen Bluemotion

HEV Classification wrt. Power Flow (Gasoline + Electricity)



HEV Classification wrt. Power Flow (Gasoline + Electricity)

Series Hybrid Electric Drivetrain



1. Pure electric mode: The vehicle is propelled only by the batteries.

2. Pure engine mode: The vehicle traction power only comes from the engine-generator.

3. Hybrid mode: The traction power is drawn from both the engine-generator and the batteries.

4. Engine traction and battery charging mode: The engine-generator supplies power to charge the batteries and to propel the vehicle.

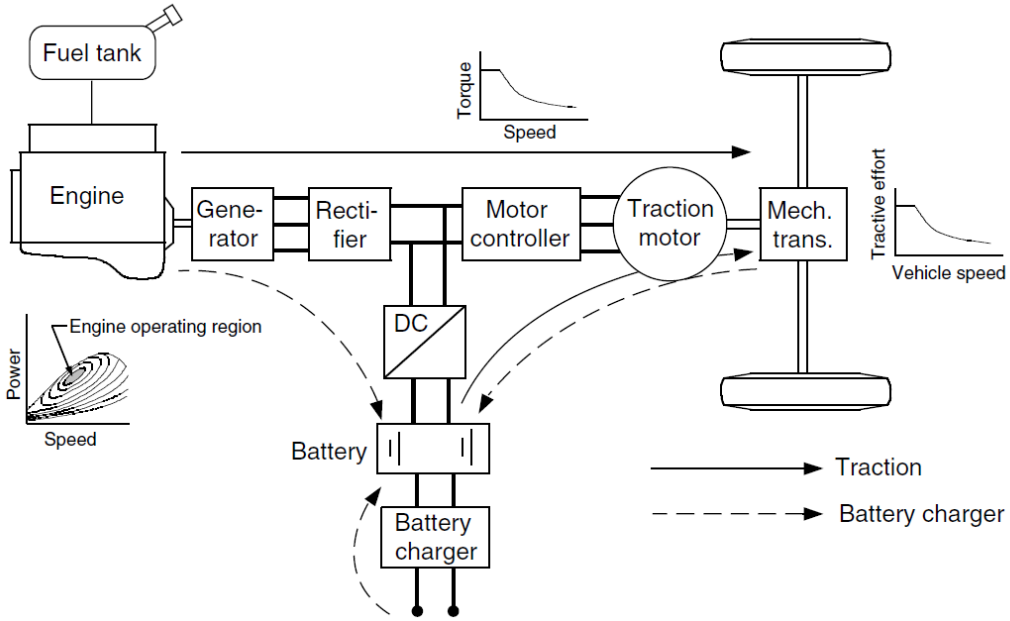
5. Regenerative braking mode: The engine-generator is turned off and the traction motor is operated as a generator.

6. Battery charging mode: The traction motor receives no power and the engine-generator charges the batteries.

7. Hybrid battery charging mode: Both the engine-generator and the traction motor operate as generators to charge the batteries.

HEV Classification wrt. Power Flow (Gasoline + Electricity)

Series Hybrid Electric Drivetrain



Advantages:

1. ICE's speed can be set individually
2. No complicated gear box and transmission
3. Easy design

Disadvantages:

1. The energy from the engine is converted twice, that causes low efficiency.
2. The generator adds additional weight and cost.
3. The traction motor, generator and ICE must be sized to meet maximum traction requirements.

Application:

Range extender (Gasoline range < Battery range)

- BMW i3 REX
- Chevrolet Volt REX

https://insideevs.com/u-s-bmw-i3-rex-actually-has-2-4-gallon-gas-tank-but-clever-software-limits-fueling-to-1-9-gallons/
https://www.greencarreports.com/news/1087888_2014-bmw-i3-electric-car-why-california-set-range-requirements-engine-limits

HEV Classification wrt. Power Flow (Gasoline + Electricity)

BMW i3 News

- https://insideevs.com/u-s-bmw-i3-rex-actually-has-2-4-gallon-gas-tank-but-clever-software-limits-fueling-to-1-9-gallons/
- https://www.greencarreports.com/news/1087888_2014-bmw-i3-electric-car-why-california-set-range-requirements-engine-limits

Chevrolet Volt

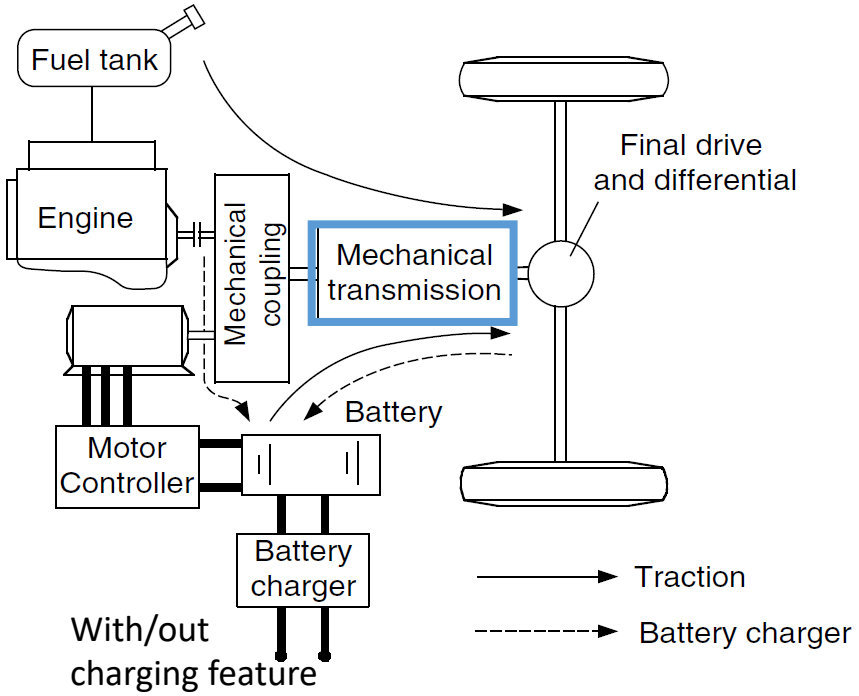
Powertrain	
Engine	1× 63 kW (84 hp) 1398 cc *EcoFLEX LUU* I4 (gasoline)[2]
Electric motor	1× 111 kW (149 hp) 1× 55 kW (74 hp) permanent magnet motor/generators
Transmission	*Voltec 4ET50* Multi-mode electric transaxle
Hybrid drivetrain	Series hybrid (GM Voltec)[3]
Battery	**First generation** 16.0 kWh lithium-ion (2011–2012)[4] 16.5 kWh lithium-ion (2013–2014)[5] 17.1 kWh lithium-ion (2015)[6] **Second generation** 18.4 kWh lithium-ion (2016)[7]
Range	**First generation** 380 miles (610 km) (EPA) (2011–2015)[8] **Second generation** 420 miles (680 km) (EPA) (2016)[7]
Electric range	**First generation** 35 miles (56 km) (EPA) (2011–2012)[9] 38 miles (61 km) (EPA) (2013–2015)[8] **Second generation** 53 miles (85 km) (EPA) (2016)[10]
Plug-in charging	120 V/15 A, 240 V/20 A AC[11]

https://en.wikipedia.org/wiki/Chevrolet_Volt

Chevy Volt Production Has Officially Come To An End

HEV Classification wrt. Power Flow (Gasoline + Electricity)

Parallel Hybrid Electric Drivetrain



1. Pure electric mode: The vehicle is propelled only by the electric machine.

2. Pure engine mode: The vehicle is propelled only by the ICE (Engine).

3. Hybrid mode: The traction power is drawn from both the ICE and electric machine.

4. Engine traction and battery charging mode: The ICE supplies power to charge the batteries and to propel the vehicle.

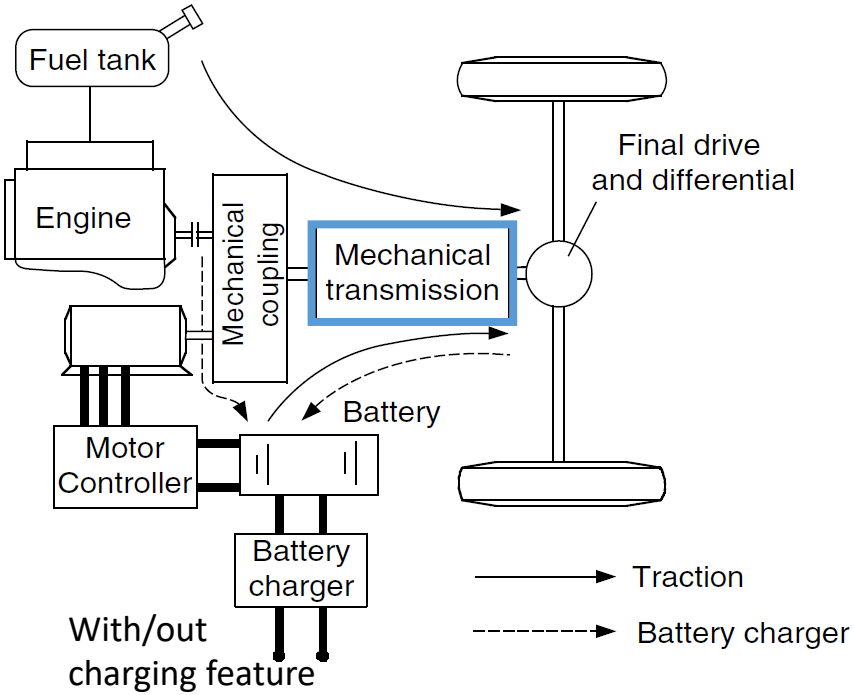
5. Regenerative braking mode: The electric machine is operated as a generator.

6. Battery charging mode: The electric machine receives power from the ICE and charges the batteries.

7. Hybrid battery charging mode: Both of the engine and wheels supply power to the electric machine to charge the batteries.

HEV Classification wrt. Power Flow (Gasoline + Electricity)

Parallel Hybrid Electric Drivetrain



Both internal combustion engine (ICE) and electric machine has a mechanical connection to wheels

Different configurations based on:

- Position of transmission (pre- or post transmission electric machine)
- Characteristics of mechanical coupling (multi or single gear transmission)
- Number of shafts (single or two shafts configurations)

There is a need for a mechanical coupling

Torque coupling

Speed coupling

HEV Classification wrt. Power Flow (Gasoline + Electricity)

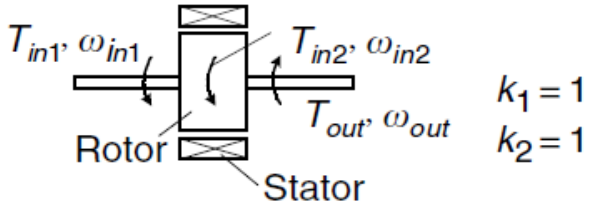
Parallel Hybrid Electric Drivetrain with Torque-Couplers

Torque coupler

$$T_{out} = k_1 T_{in1} + k_2 T_{in2}$$

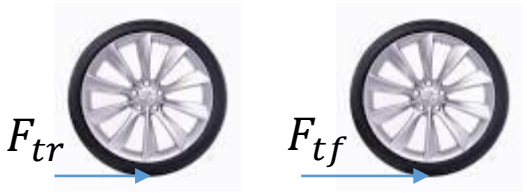
$$\omega_{out} = \frac{\omega_{in1}}{k_1} = \frac{\omega_{in2}}{k_2}$$

1. Single shaft configuration:

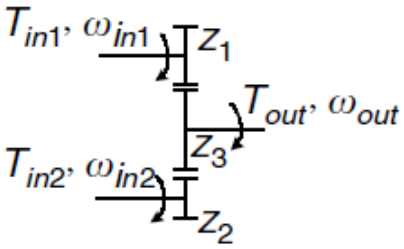


$k_1 = 1$
$k_2 = 1$

2. Vehicle wheels and road:



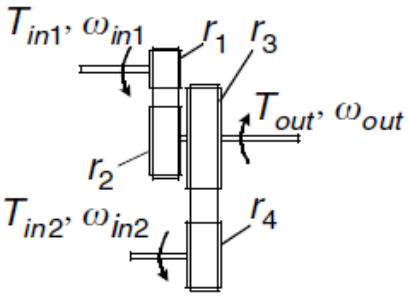
3. Gear box:



$$k_1 = \frac{Z_3}{Z_1},\ k_2 = \frac{Z_3}{Z_2}$$

z_1, z_2, z_3: Tooth number of the gears

4. Pulley or chain assembly:



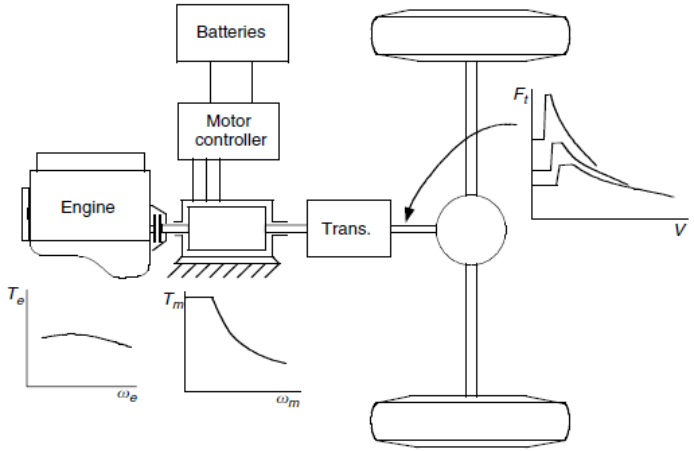
$$k_1 = \frac{r_2}{r_1},\ k_2 = \frac{r_3}{r_4}$$

r_1, r_2, r_3, r_4: Radius of the pulleys

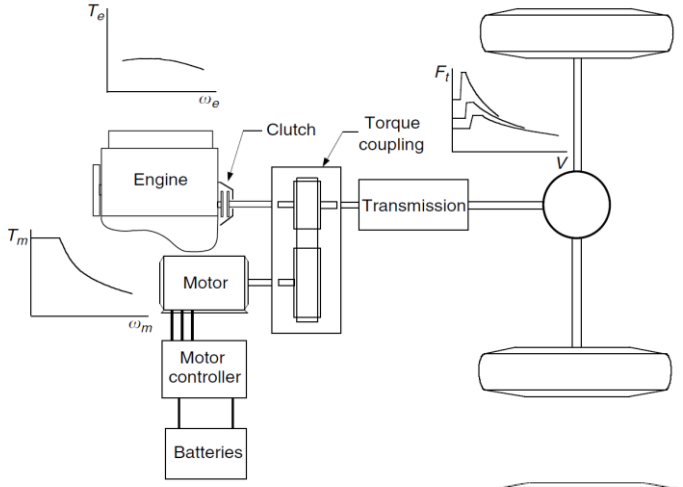
HEV Classification wrt. Power Flow (Gasoline + Electricity)

Parallel Hybrid Electric Drivetrain with Torque-Couplers

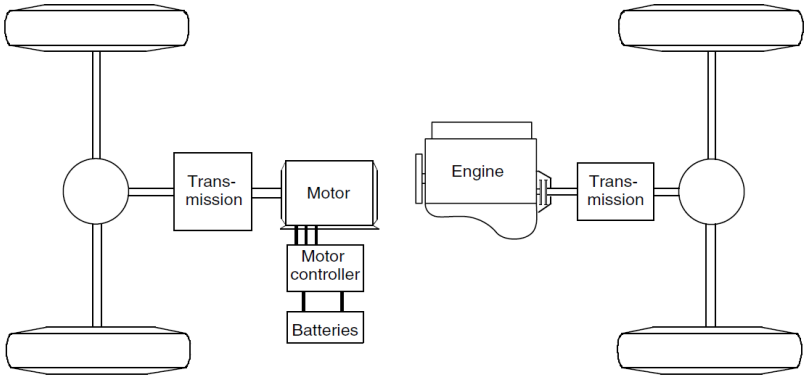
One-shaft configuration

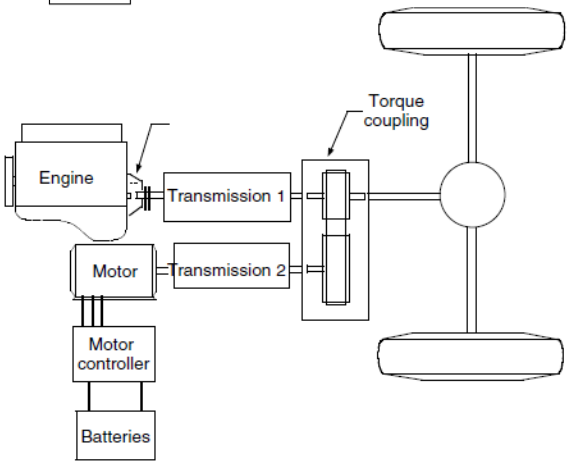


Two-shaft configurations



Separated axle torque combination

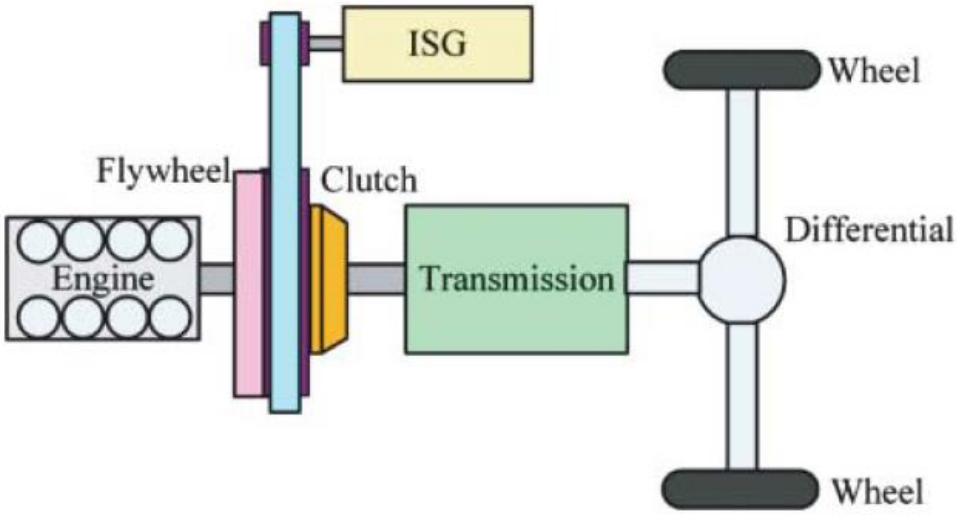




HEV Classification wrt. Power Flow (Gasoline + Electricity)

Parallel Hybrid Electric Drivetrain with Torque-Couplers

Application of two-shaft configuration: Micro hybrid with Integrated Starter Generator (ISG)

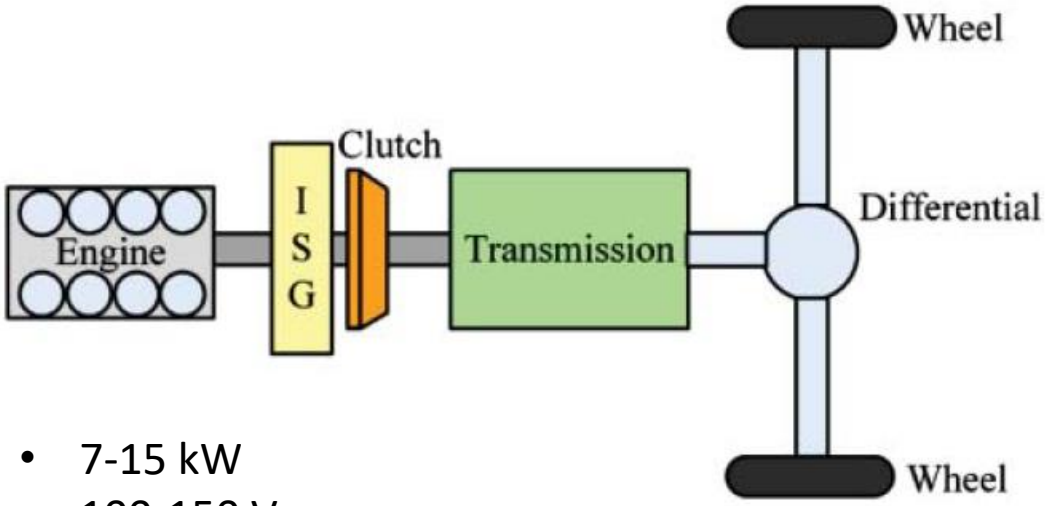


- 3-5 kW
- 12-42 V
- Modes:
  - Idle start-stop
  - Regenerative braking
- 10-15% improvement in fuel economy

HEV Classification wrt. Power Flow (Gasoline + Electricity)

Parallel Hybrid Electric Drivetrain with Torque-Couplers

Application of one-shaft configuration: Mild hybrid with Integrated Starter Generator (ISG)



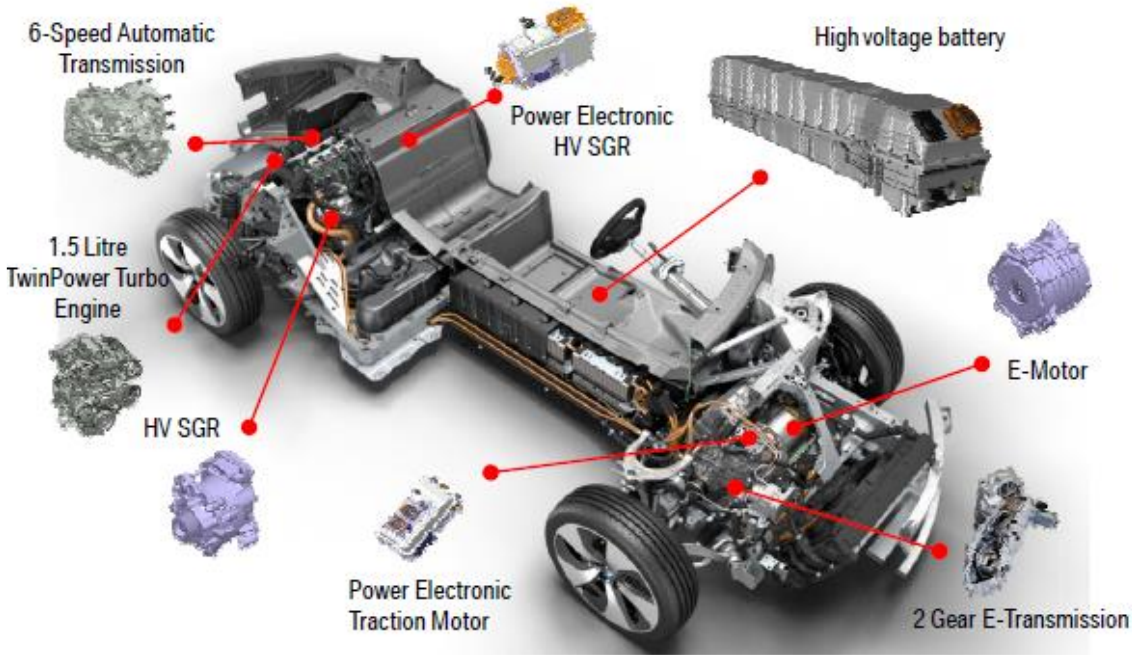
- 7-15 kW
- 100-150 V
- Modes:
  - Idle start-stop
  - Regenerative braking
  - Traction assist
- Downsized engine is possible

Honda Insight IMA, 1999.

HEV Classification wrt. Power Flow (Gasoline + Electricity)

Parallel Hybrid Electric Drivetrain with Torque-Couplers

Application of separated axle torque combination: Two axle traction full hybrid



http://hybridfordonscentrum.se/wp-content/uploads/2014/05/20140404_BMW.pdf

1. Pure electric mode: The vehicle is propelled only by the electric machine.

2. Pure engine mode: The vehicle is propelled only by the ICE (Engine).

3. Hybrid mode: The traction power is drawn from both the ICE and electric machine.

4. Engine traction and regenerative battery charging mode: The ICE supplies power to propel the vehicle and to charge the batteries.

5. Regenerative braking mode: The electric machine is operated as a generator.

BMW i8 will force fake engine noise and howl at pedestrians

https://www.bmwusa.com/vehicles/bmwi/bmw-i8/bmw-i8-coupe-features-and-specs/specifications.html

HEV Classification wrt. Power Flow (Gasoline + Electricity)

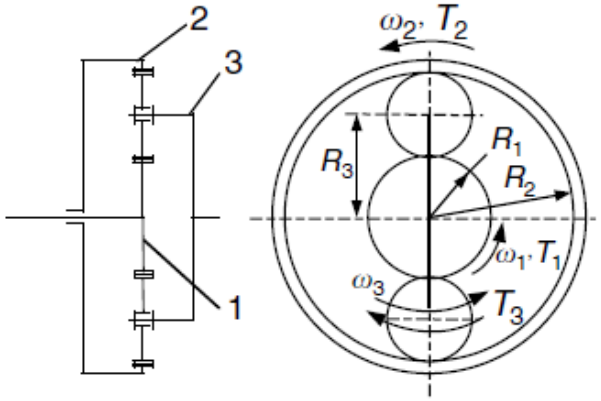
Parallel Hybrid Electric Drivetrain with Speed-Couplers

Speed coupler

$$\omega_{out} = k_1\omega_{in1} + k_2\omega_{in2}$$

$$T_{out} = \frac{T_{in1}}{k_1} = \frac{T_{in2}}{k_2}$$

1. Planetary gear unit:



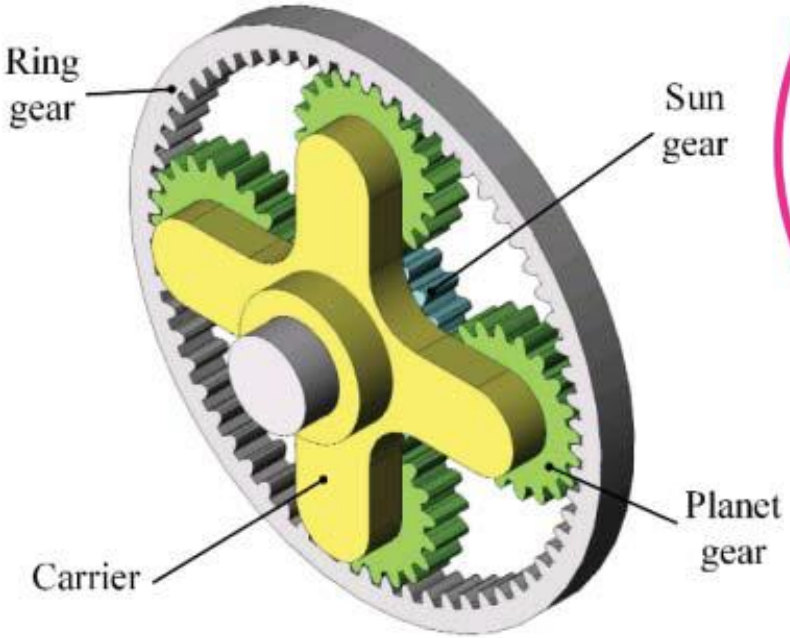
$$\omega_3 = \frac{R_1}{2R_3}\omega_1 + \frac{R_2}{2R_3}\omega_2 \qquad k_1 = \frac{R_1}{2R_3}$$

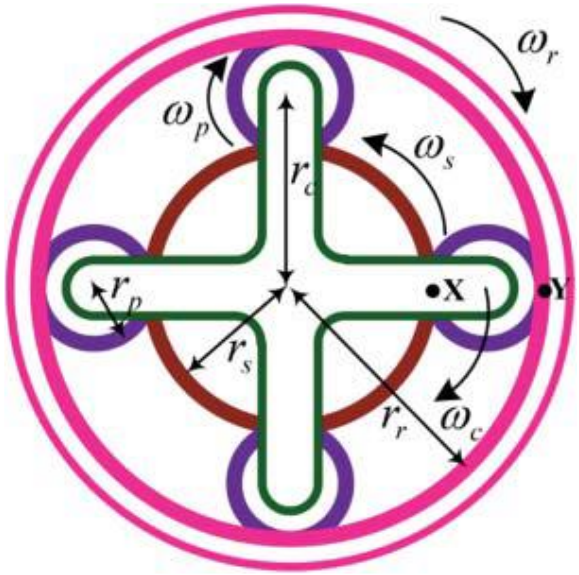
$$T_3 = \frac{2R_3}{R_1} \quad T_1 = \frac{2R_3}{R_2}T_2 \qquad k_2 = \frac{R_2}{2R_3}$$

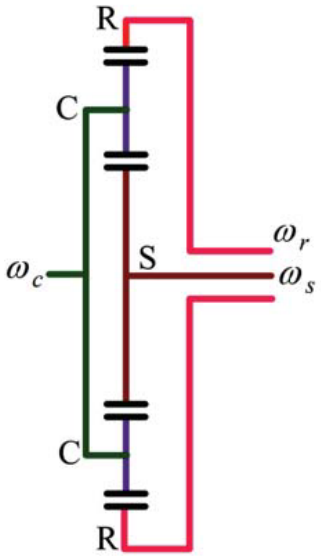
Understanding PLANETARY GEAR set !

HEV Classification wrt. Power Flow (Gasoline + Electricity)

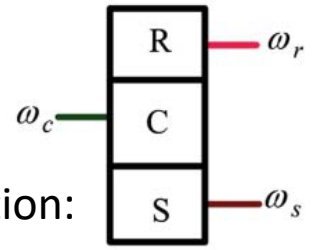
Planetary gear unit







Block representation:



Understanding PLANETARY GEAR set !

Tutorial: How to Derive the Formula for the Planetary Mechanism Gear Ratio

HEV Classification wrt. Power Flow (Gasoline + Electricity)

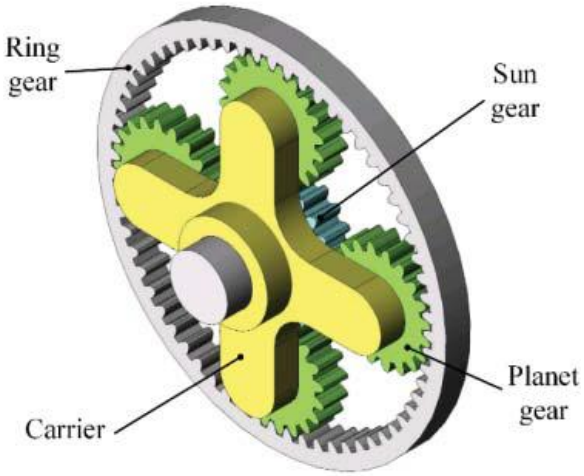
Planetary gear unit

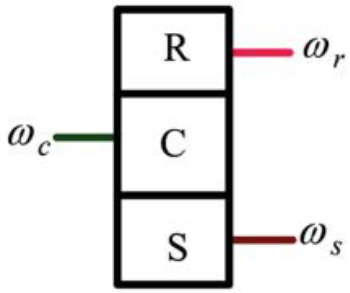
$$\omega_{out} = k_1\omega_{in1} + k_2\omega_{in2}$$

$$T_{out} = \frac{T_{in1}}{k_1} = \frac{T_{in2}}{k_2}$$

$$\omega_c = \frac{N_r}{N_r + N_s}\omega_r + \frac{N_s}{N_r + N_s}\omega_s$$

$$T_c = \frac{N_r + N_s}{N_r}T_r = \frac{N_r + N_s}{N_s}T_s$$





Example for N_r=72 and N_s=30:

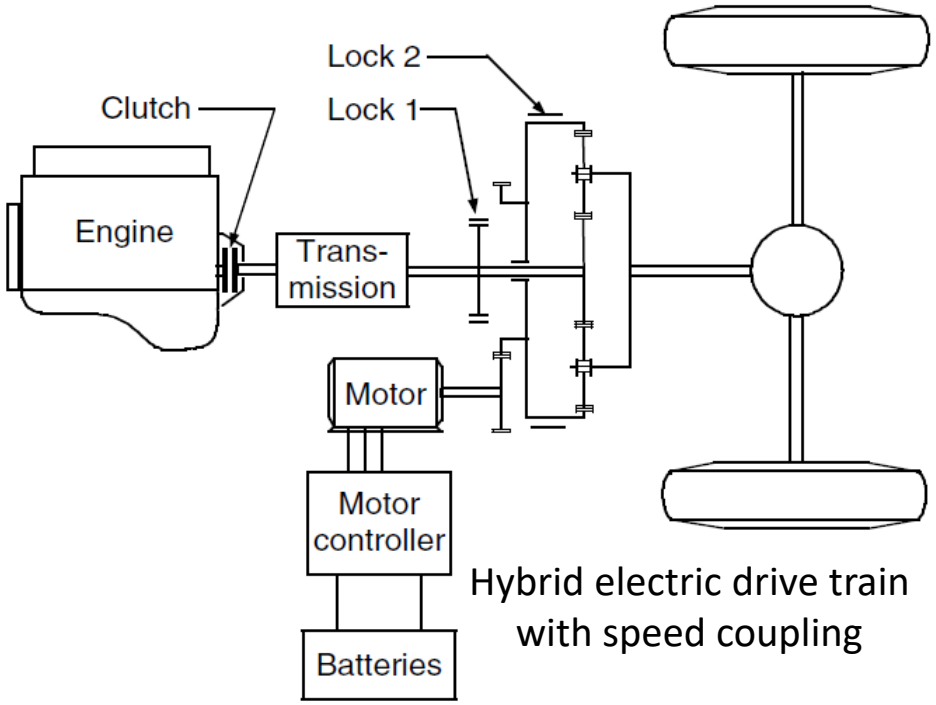
	Input	Output	Stationary	Calculation	Gear Ratio*
A	Sun (**S**)	Planet Carrier (**C**)	Ring (**R**)	$1 + \frac{N_r}{N_s}$	3.4:1 (Speed reduction)
B	Planet Carrier (**C**)	Ring (**R**)	Sun (**S**)	$1 / (1 + \frac{N_s}{N_r})$	0.71:1 (Overdrive)
C	Sun (**S**)	Ring (**R**)	Planet Carrier (**C**)	$-\frac{N_r}{N_s}$	-2.4:1 (Reverse direction speed reduction

*Gear ration=T_{out}/T_{in}= ω_{in}/ω_{out}

http://auto.howstuffworks.com/automatic-transmission3.htm

HEV Classification wrt. Power Flow (Gasoline + Electricity)

Parallel Hybrid Electric Drivetrain with Speed-Couplers



Hybrid electric drive train with speed coupling

1. Motor-alone mode: Lock 1 locks the sun gear to the vehicle frame (engine is shut off or clutch is disengaged) and lock 2 is released only the electric motor supplies its power to the driven wheels.

2. Engine-alone mode: Lock 2 locks the ring gear to the vehicle frame and lock 1 is disengaged, only the engine supplies power to the driven wheels.

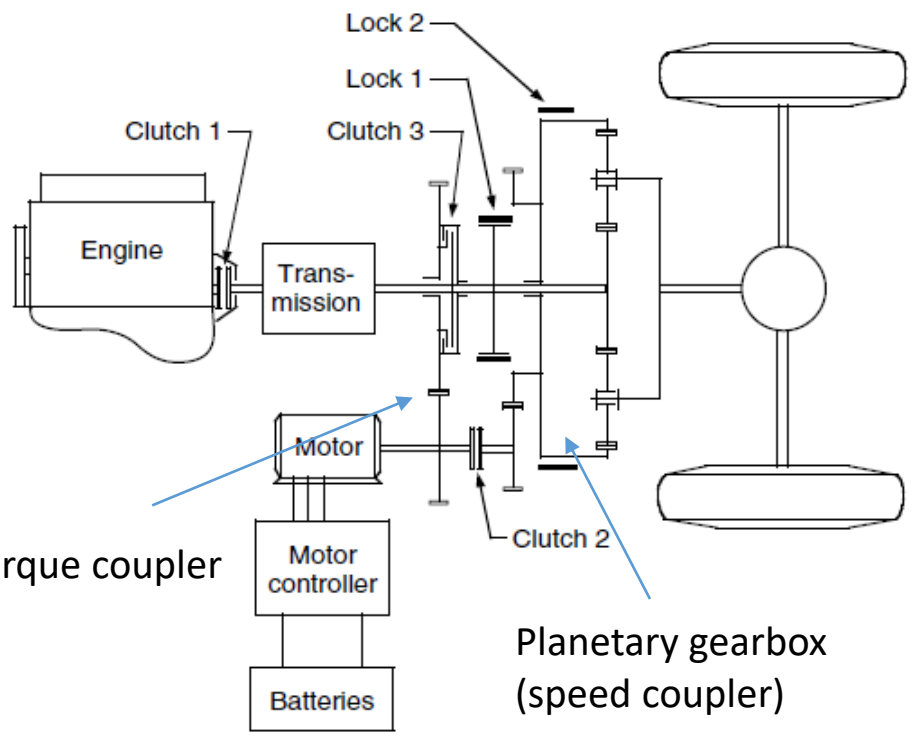
3. Hybrid mode: Locks 1 and 2 are released (the sun gear and ring gear can rotate) and both the engine and electric machine supply positive speed and torque (positive power) to the driven wheels.

4. Regenerative braking: Lock 1 is locked, the engine is shut off or clutch is disengaged, and the electric machine is controlled in regenerating operation (negative torque).

5. Battery charging from the engine: When the controller sets a negative speed for the electric machine, the electric machine absorbs energy from the engine.

HEV Classification wrt. Power Flow (Gasoline + Electricity)

Parallel Hybrid Electric Drivetrain with both Torque- and Speed-Couplers



Hybrid electric drive train with torque and speed coupling

Torque coupling mode:

Torque of ICE and EM decoupled but speeds have fixed ratio

- Lock 2 locked
- Clutch 1 and 3 engaged
- Clutch 2 disengaged

Used at low speeds for torque combination operation

Speed coupling mode:

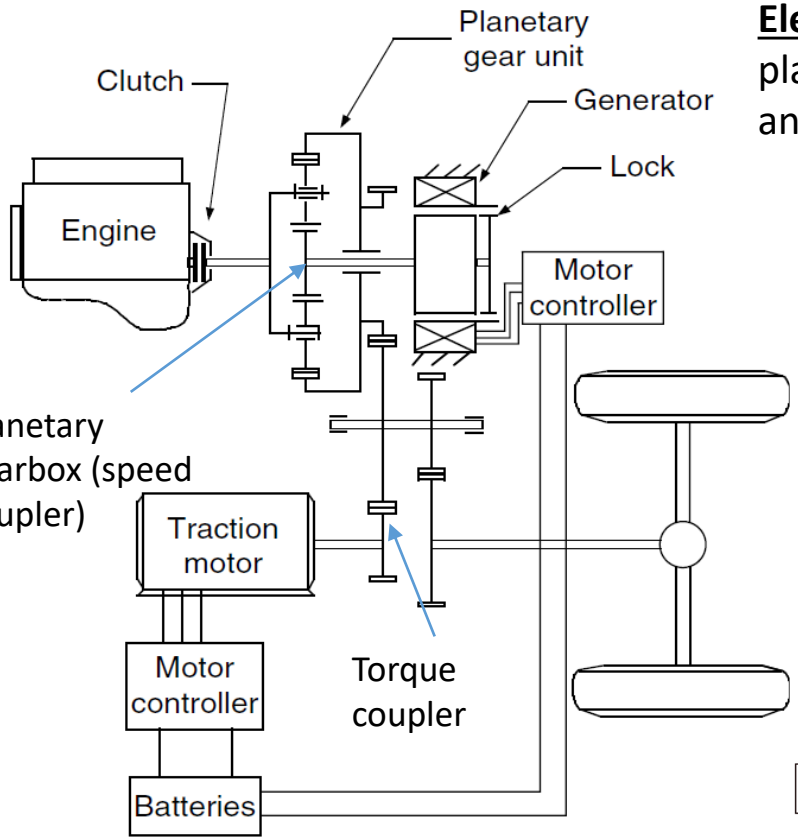
Speed of ICE and EM decoupled but torques have fixed ratio

- Lock 1 and 2 released
- Clutch 1 & 2 engaged
- Clutch 3 disengaged

Used at high speeds to speed engine speed close to optimum

HEV Classification wrt. Power Flow (Gasoline + Electricity)

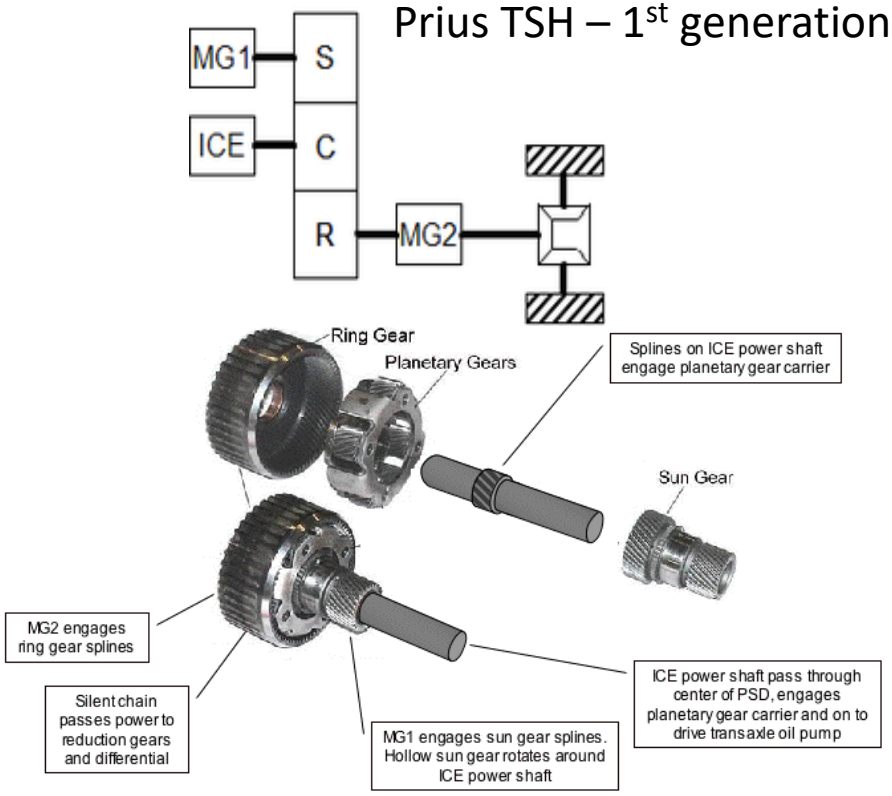
Parallel-Series Hybrid Electric Drivetrain (with Torque and Speed Couplers and a Generator)



Animation:
http://eahart.com/prius/psd/

Electrical variable transmission: Combination of a planetary gear unit (power split device), a generator and a battery pack

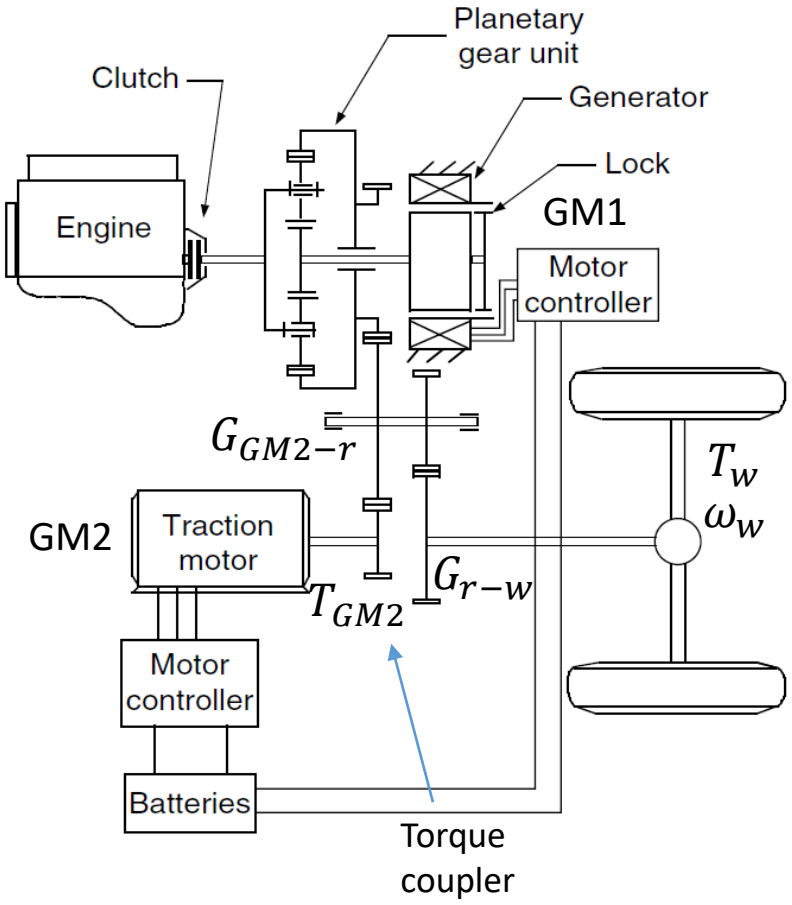
Prius TSH – 1st generation



http://priuschat.com/threads/introduction-to-prius-power-flow.29352/

HEV Classification wrt. Power Flow (Gasoline + Electricity)

Parallel-Series Hybrid Electric Drivetrain (with Torque and Speed Couplers and a Generator)

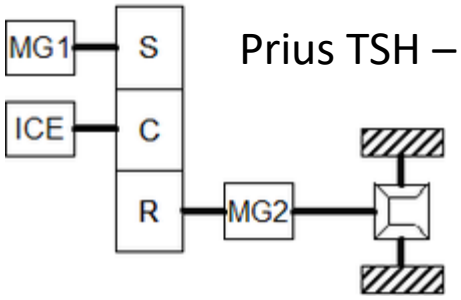


$$\omega_{GM2} = \omega_w G_{GM2-r} G_{r-w}$$

$$T_{GM2} G_{GM2-r} + T_r = \frac{T_w}{G_{r-w}}$$

$$\frac{\omega_{GM2}}{G_{GM2-r}} = (1 + \frac{N_s}{N_r})\omega_{engine} - \frac{N_s}{N_r}\omega_{GM1}$$

$$G_{GM2-r} T_{GM2} = \left(\frac{N_r}{N_r + N_s}\right) T_{engine} = \frac{N_r}{N_s} T_{GM1}$$



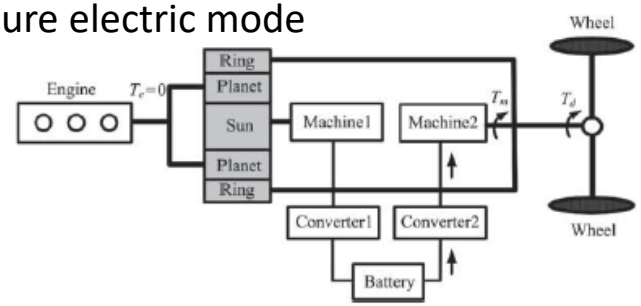
Prius TSH – 1st generation

G_{GM2-r}: GM2 to ring gear ratio and G_{r-w}: ring to wheel gear ratio (inc. differentail) ω_w:Rotational speed of wheels

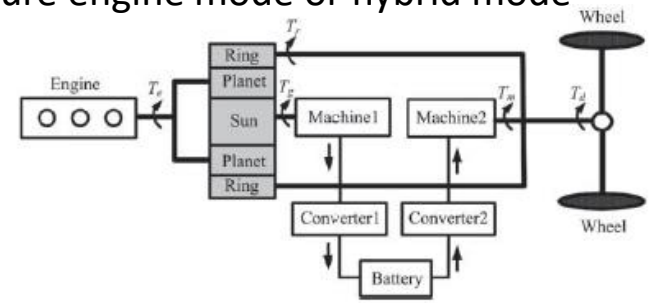
HEV Classification wrt. Power Flow (Gasoline + Electricity)

Parallel-Series Hybrid Electric Drivetrain (with Torque and Speed Couplers and a Generator)

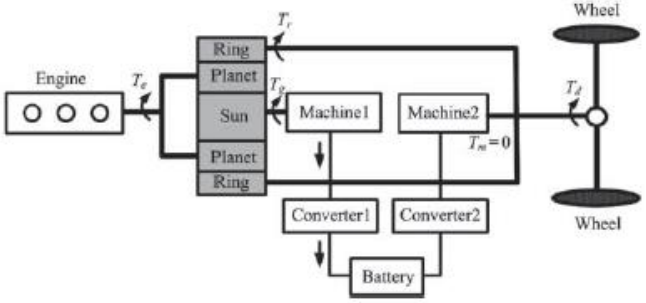
Pure electric mode



Pure engine mode or hybrid mode



Engine traction and battery charging mode



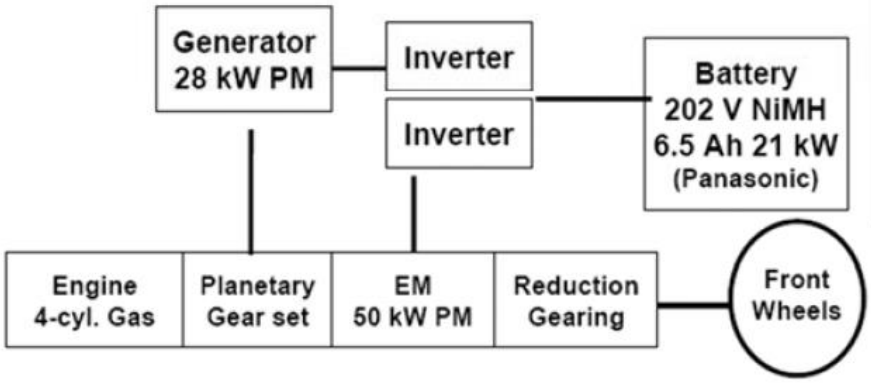
1. **Pure electric mode:** GM2 as traction motor, at starting, SOC of battery decreases.
2. **Pure engine mode:** Engine delivers power to wheels
   a. GM2 freewheels if speed of GM1 (generator) is zero.
   b. Engine delivers both power to ring gear (torque coupler) and to GM1 (generator). The power produced by generator is used by GM2 to produce positive torque, so SOC of battery is constant.
3. **Hybrid mode:** Both engine and GM2 deliver tractive power, SOC of battery decreases.
4. **Engine traction and battery charging mode:** The ICE supplies power to propel the vehicle and to charge the batteries, at cruising.
5. **Regenerative braking mode:** The electric machine GM2 operates as a generator to recharge battery, generator has 0 torque.
6. **Battery charging mode as stand still:** Engine supply power to GM1 to charge battery, GM2 is standstill.

HEV Classification wrt. Power Flow (Gasoline + Electricity)

Parallel-Series Hybrid Electric Drivetrain (with Torque and Speed Couplers and a Generator)

Prius (pronounciation: PrEE-uhs)

Engine:	1.5 L 4-cylinders DOHC 57 kW / 110 Nmt
Motor:	DC Brushless 500 V 50 kW / 400 Nm

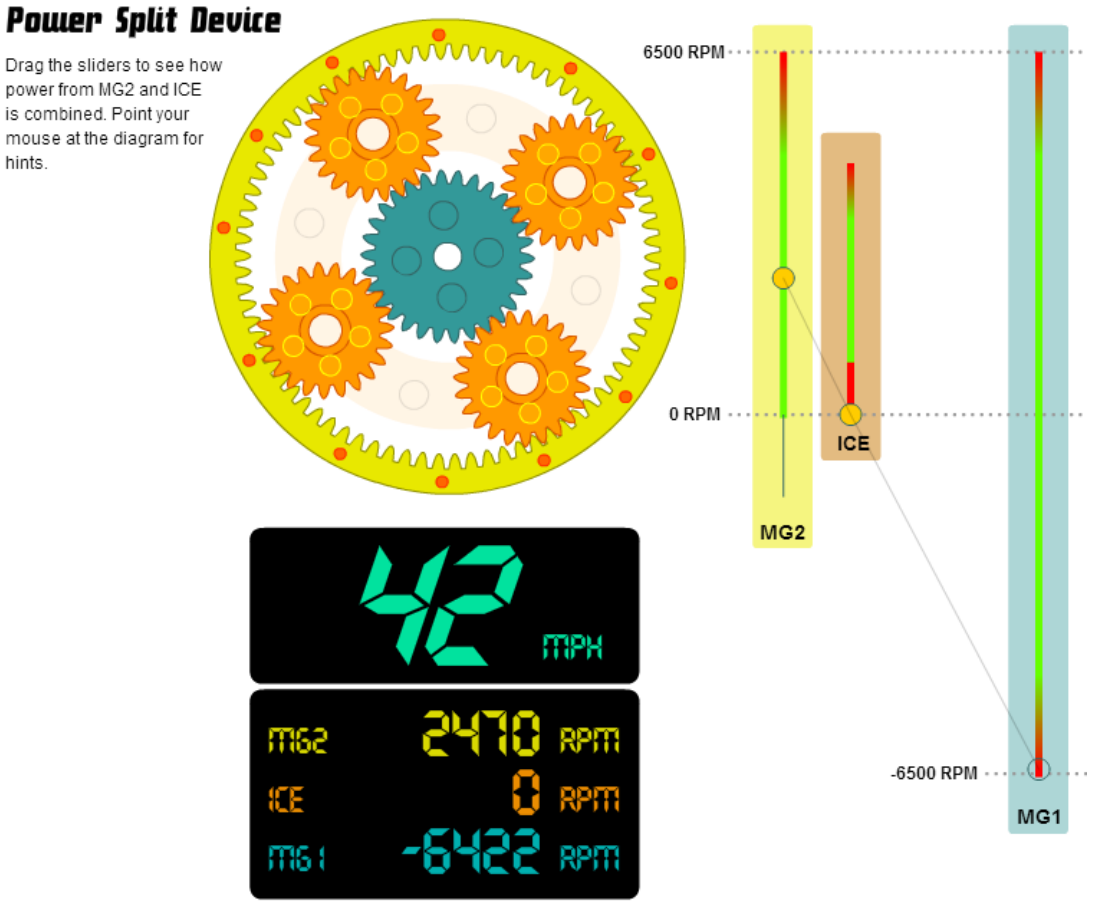


EPA MPG	1.8L AT Corolla	HEV	Gain (%)
City	30	60	100
Highway	38	51	34

Note Corolla 1.8L 130 HP 4-speed AT
Echo 1.5L 108 HP 4-speed AT
33/39 City/Highway MPG

HEV Classification wrt. Power Flow (Gasoline + Electricity)

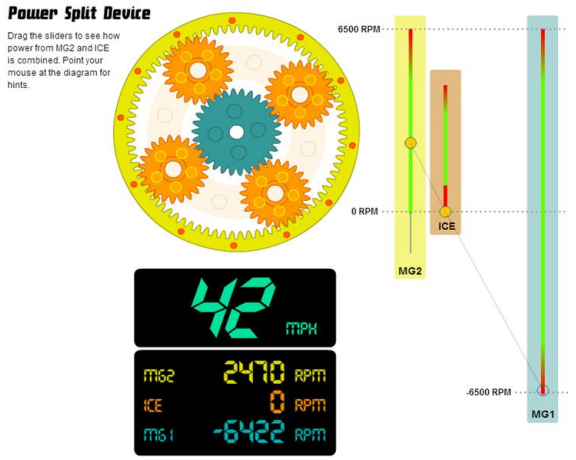
Parallel-Series Hybrid Electric Drivetrain (with Torque and Speed Couplers and a Generator)



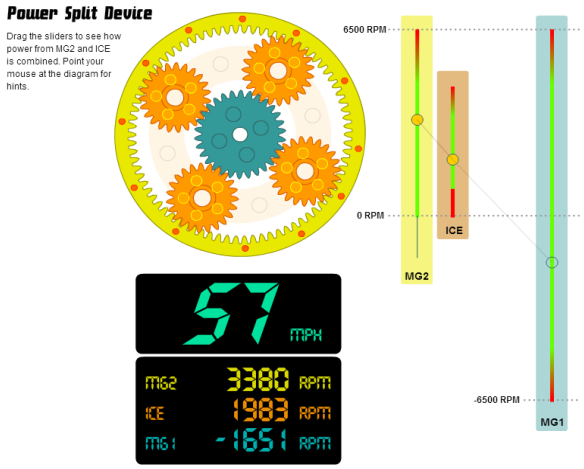
Animation:
http://eahart.com/prius/psd/

HEV Classification wrt. Power Flow (Gasoline + Electricity)

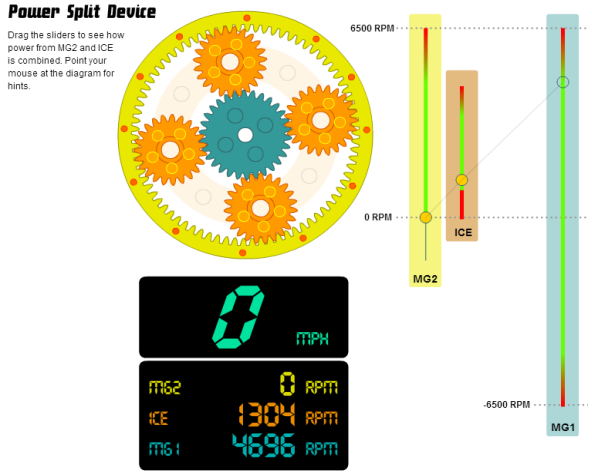
Parallel-Series Hybrid Electric Drivetrain (with Torque and Speed Couplers and a Generator)



Pure electric mode



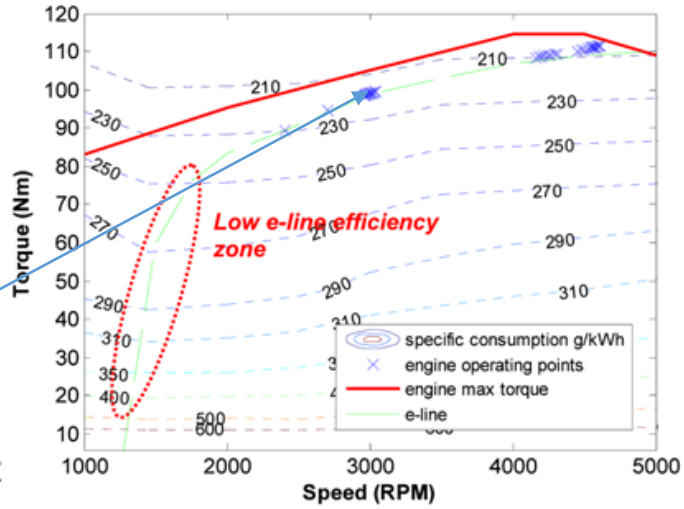
Hybrid mode



Battery charging mode at stand still

Better fuel economy due to:

- No clutches and shifting gears
- Idle stop-start operation
- Electric launch
- Regenerative braking
- Internal combustion engine works at its max. efficiency points

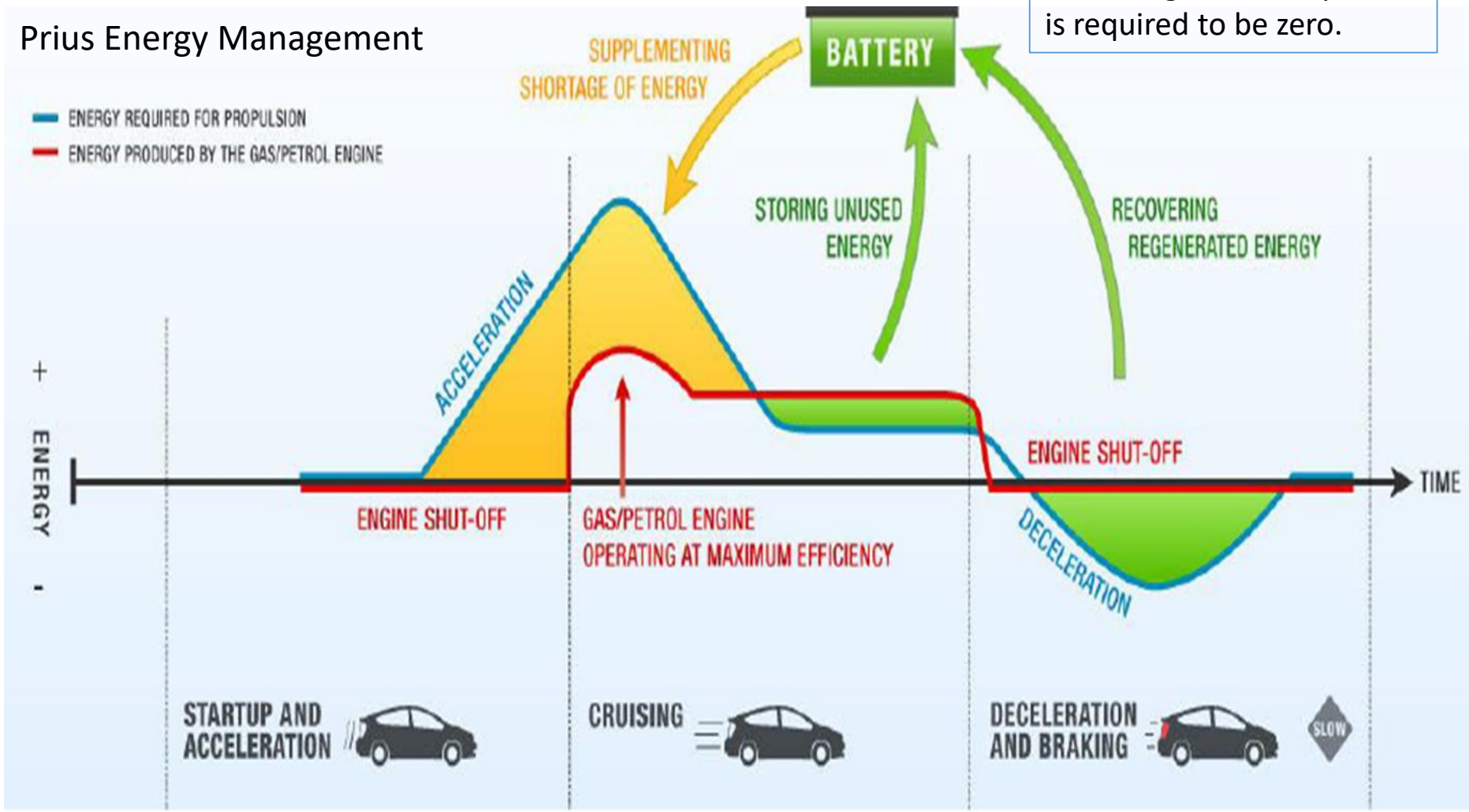


http://link.springer.com/article/10.1007%2Fs12239-012-0029-0

HEV Classification wrt. Power Flow (Gasoline + Electricity)

Without plug-in feature, net change in battery SOC is required to be zero.

Prius Energy Management



http://www.slideshare.net/dasaramutt/electric-and-hybrid-vehicles

HEV Classification wrt. Power Flow (Gasoline + Electricity)

Prius Generations

		1st generation (From 1997)	2nd generation (From 2003)	3rd generation (From 2009)
Vehicle exterior				
Maximum system voltage	V	288	500	650
			Boost converter	
Battery voltage	V	288	202	202
PCU maximum total output	kVA	147 +10%	162 +10%	178
Motor maximum output	kW	33	50	60
10-15 mode fuel economy	km/L	28.0 +26%	35.5 +8%	38.0
Objective (Except for fuel economy)		First mass produced HV	Improved power performance	Compact units

HEV Classification wrt. Power Flow (Gasoline + Electricity)

Prius Generations

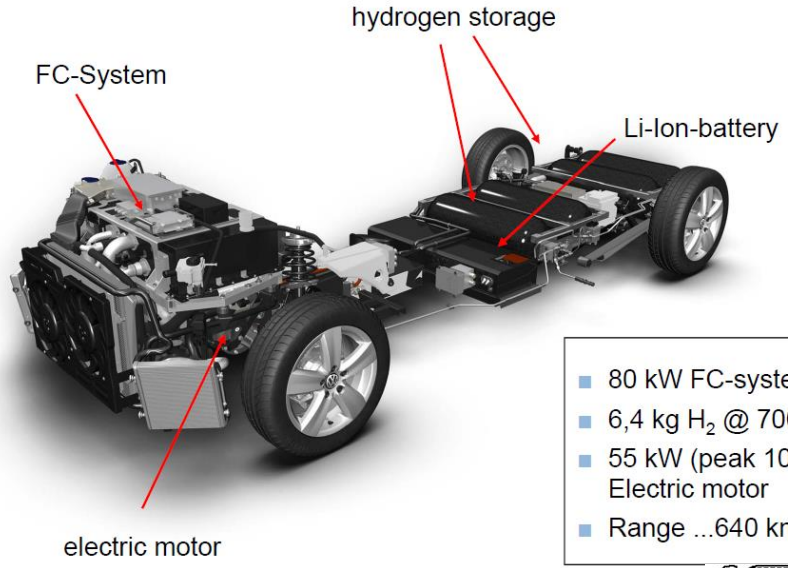
1st Gen. (1997–2003)	2nd Gen. (2003–2009)	3rd Gen. (2009–2012)	Plug-in Hybrid
ICE: 1,5 Liter (43–53 kW) EM: 30–33 kW	ICE: 1,5 Liter (58 kW) EM:50 kW	ICE: 1,8 Liter (73 kW) EM: 60 kW	ICE: 1,8 Liter (73 kW) EM: 60 kW Pure electric speed: 135 km/h
Battery: 1.3 kWh (NiMH)	Battery: 1.3 kWh (NiMH)	Battery: 1.3 kWh (NiMH)	Battery: 8.8 kWh (Li-Ion)
			Electric range: 50 km (NEDC)

https://ev-database.uk/car/1059/Toyota-Prius-Plug-in-Hybrid

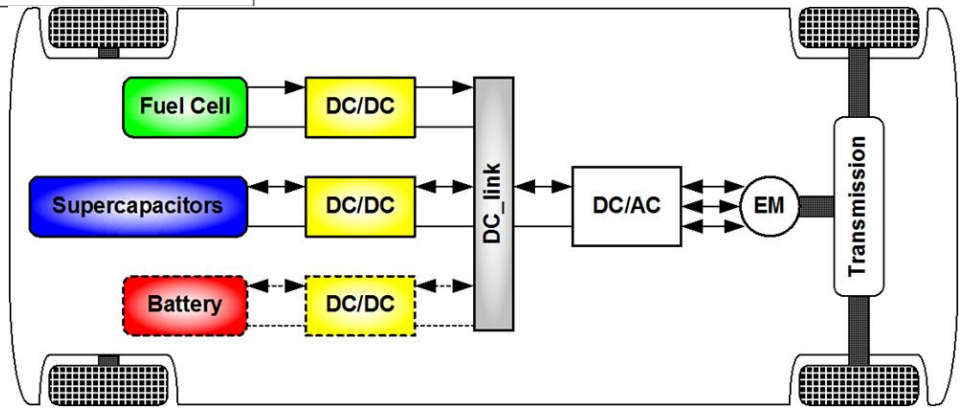



HEV Classification wrt. Power Flow (Hydrogen + Electricity)

Fuel Cell Electric Vehicles: Serial Hybrid Configuration or Range Extender



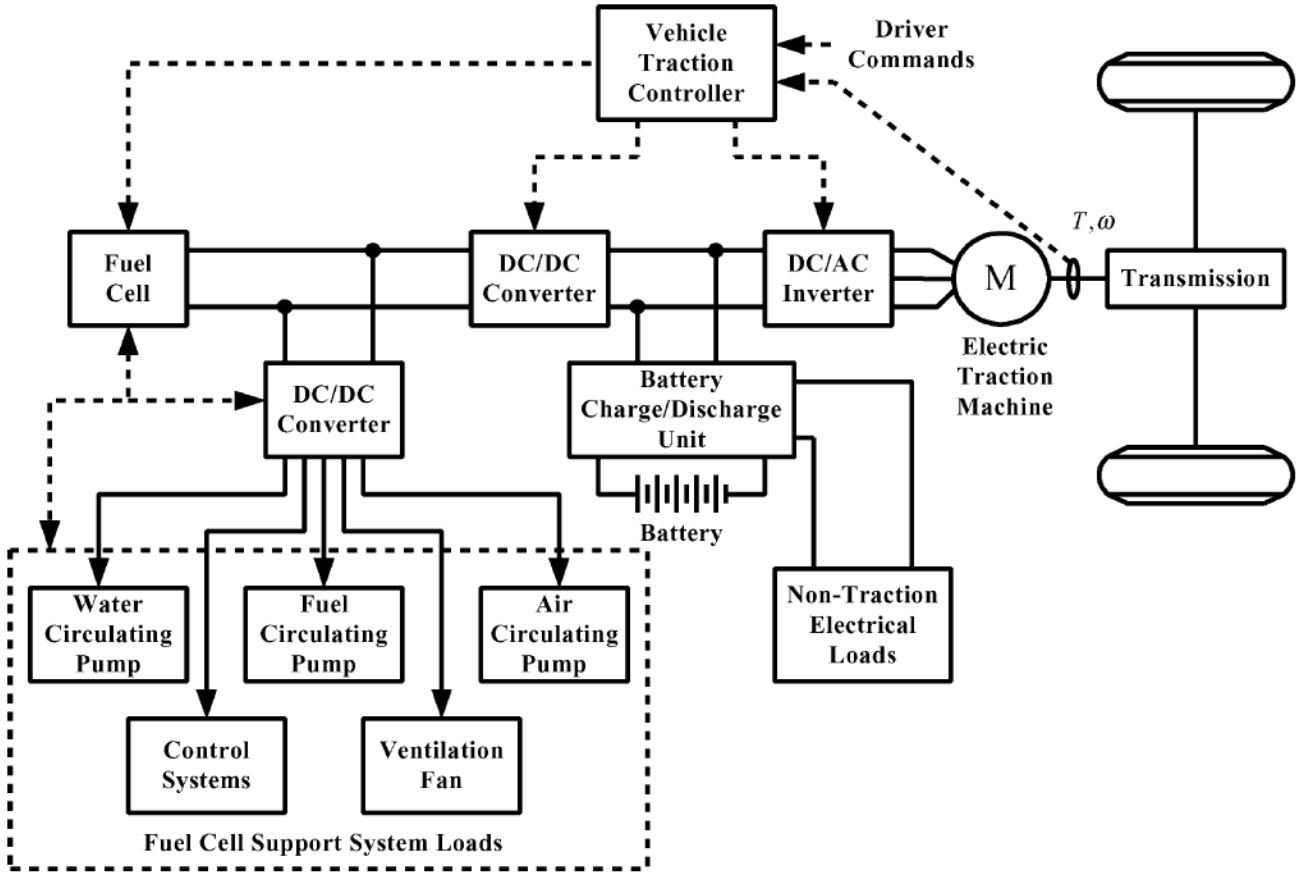
- 80 kW FC-system
- 6,4 kg H_2 @ 700 bar
- 55 kW (peak 100 kW) Electric motor
- Range ...640 km



- [VW HyMotion Fuel Cell Technology Explained]
- [Toyota Mirai, Volkswagen Passat HyMotion, Audi A7 H-Tron | Translogic]

HEV Classification wrt. Power Flow (Hydrogen + Electricity)

Fuel Cell Electric Vehicles: Serial Hybrid Configuration or Range Extender



HEV Classification wrt. Power Flow (Hydrogen + Electricity)

Honda, Hyundai and Toyota announced 2015/16 commercial launches

- Hyundai Tucson FCV
- Honda Clarity/FCV Concept
- Toyota Mirai
- Daimler, Ford, Renault/Nissan and GM Followers (by 2018)

Obama Administration has become more proactive

- Sec Chu reversed “four miracles” position
  - Expanded infrastructure
  - A more cost efficient way to make fuel cells
  - A cleaner way to derive hydrogen
  - A lighter, and less expensive hydrogen gas tank.
- DOE staff proactive, especially with respect to hydrogen from natural gas

Hyundai Tucson Fuel Cell

Honda FCV Concept

Toyota Mirai

HEV Classification wrt. Power Flow

Plug-in Hybrid Electric Drivetrain: able to be connected by means of a plug.

- Applicable to all full hybrid configurations
- Usually a battery with a higher capacity is installed
- All range extender electric vehicles must be with plug-in feature.
- All vehicles with no standstill battery charging mode (Some parallel HEVs, e.g. BMW i8)
- Nice to have for Fuel Cell HEV due to not widespread hydrogen infrastructure

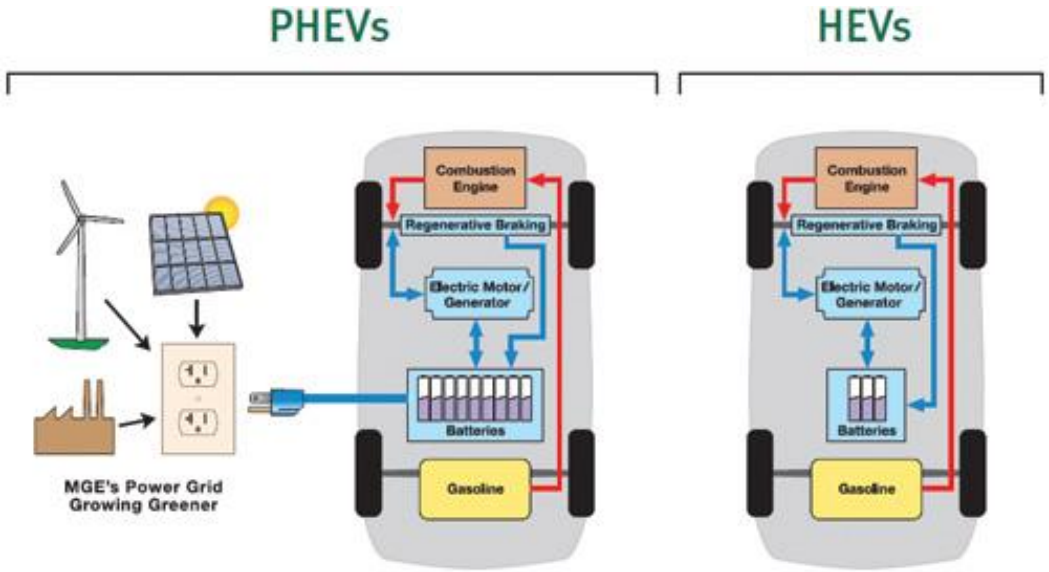
Advantages:

- Longer electric drive range
- Possibility of zero emission vehicle with renewable energy sources
- Better fuel economy

Disadvantages:

Heavier and more expansive powertrain due to:

- Increased battery capacity
- Charger



Hybrid Functions Overview

Start-Stop system automatically shuts down and restarts the internal combustion engine to reduce the amount of time the engine spends idling in order to reducing fuel consumption and emissions.

Regenerative braking is the energy recovery mechanism that is applied to convert the kinetic energy into a form that can be stored or used for another purpose.

Propulsion assist means that electric motor assists internal combustion engine when extra power is required.

In **pure electric drive**, electric motor propels the vehicle, which is applied at low speeds due to low efficiency of internal combustion engine.

	Start-stop	Regenerative braking	Propulsion assist	Pure electric drive
Micro	✓	✓		
Mild	✓	✓	✓	
Full	✓	✓	✓	✓

Videos

Hybrid System Technology

Hydrogen Cars - Toyota Mirai - Explained

TOYOTA FCV (Mirai) 2015 commercial video

Advertisement of the week:

Volkswagen-Darth Vader 2011 Super Bowl Commercial

Textbooks:

Reading assignments:

- **Chapters 4 & 5** *of* Ehsani, M. and Gao, Y. and Emadi, A., **"**Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design", 2nd Edition, CRC Press LLC, 2009.
- **Chapter 10** *of* Chau, K. T., "Electric Vehicle Machines and Drives: Design, Analysis and Application" Wiley-IEEE Press, August 2015.