Vehicle Drivetrains

ECI 189G: Lecture 3

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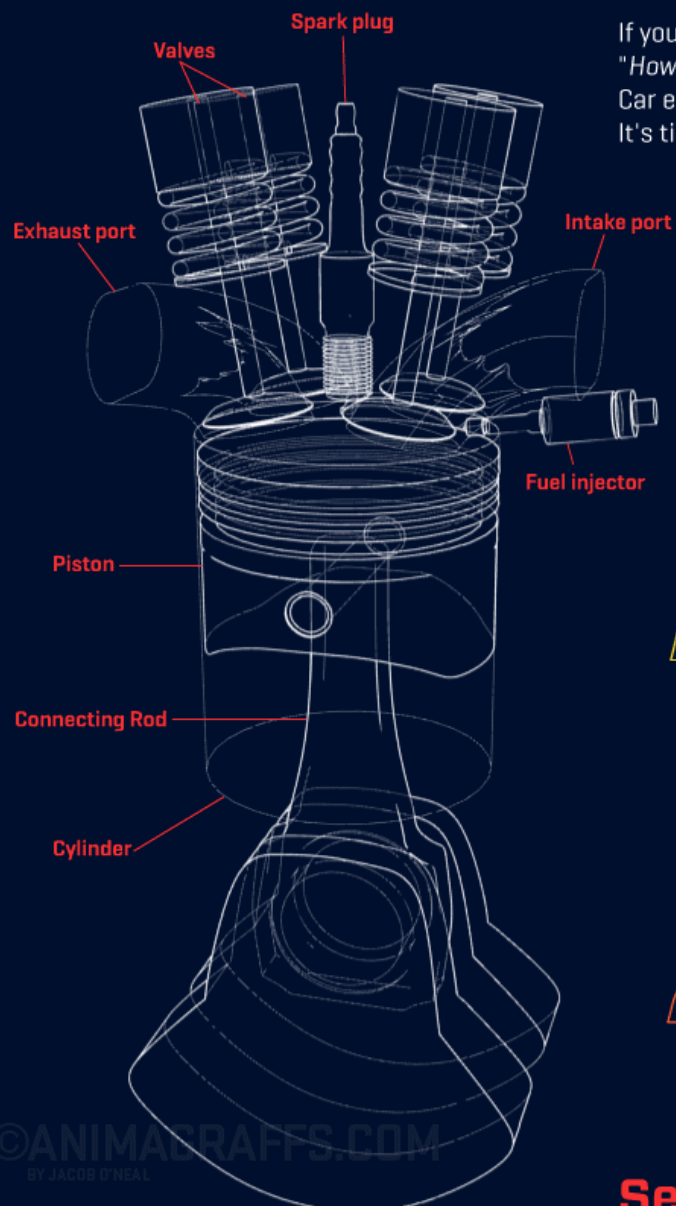
How does a gas car work?

DESIGN & RESEARCH BY JACOB O'NEAL NEED DESIGN? VISIT ANIMAGRAFFS.COM

HOW A CAR ENGINE WORKS

[And a note about hybrid gas-electric cars too]



If your only experience with a car engine's inner workings is "*How much is that going to cost to fix?*" this graphic is for you! Car engines are astoundingly awesome mechanical wonders. It's time you learned more about the magic under the hood!

The 4 Stroke Cycle

Let's take a look inside just one cylinder.

1 2 3 4

INTAKE STROKE

The piston descends, sucking air into the cylinder through open intake valves as fuel is injected.

COMPRESSION STROKE

With all valves closed, the piston comes back up, compressing the fuel-air mixture. Compressing the mixture delivers better power and efficiency.

POWER STROKE

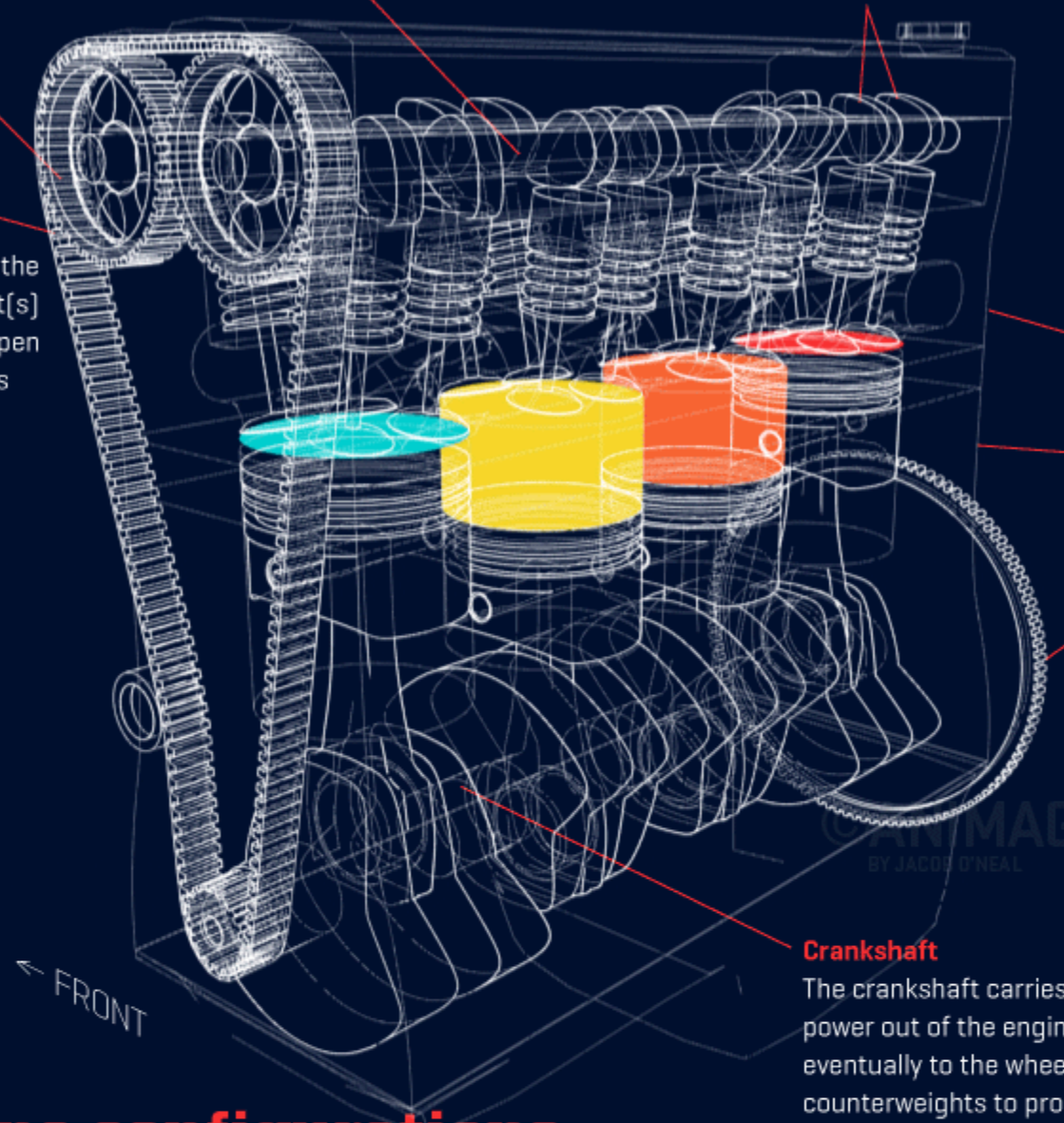
A spark ignites the compressed fuel-air mixture, and the resulting combustion forces the piston to the bottom of the cylinder again.

EXHAUST STROKE

The piston comes back up, pushing the spent mixture out through open exhaust valves.

Select engine parts

Unless your main ride is a lawn mower (no disrespect), your engine probably has more than one cylinder. Here's a 4 cylinder setup.



Timing belt (or chain)
A timing belt or chain synchronizes the rotation of the crankshaft and the camshaft(s) so that the engine's valves open and close at the proper times during each cylinder's intake and exhaust strokes. It also prevents the piston from striking the valves.

A timing belt (shown) is a rubber belt that usually features teeth on the inside surface, while a timing chain is a metal roller chain.

RPM
RPM means Revolutions Per Minute. If your engine is running at 3,000 RPM, that's 50 full crankshaft revolutions per second!

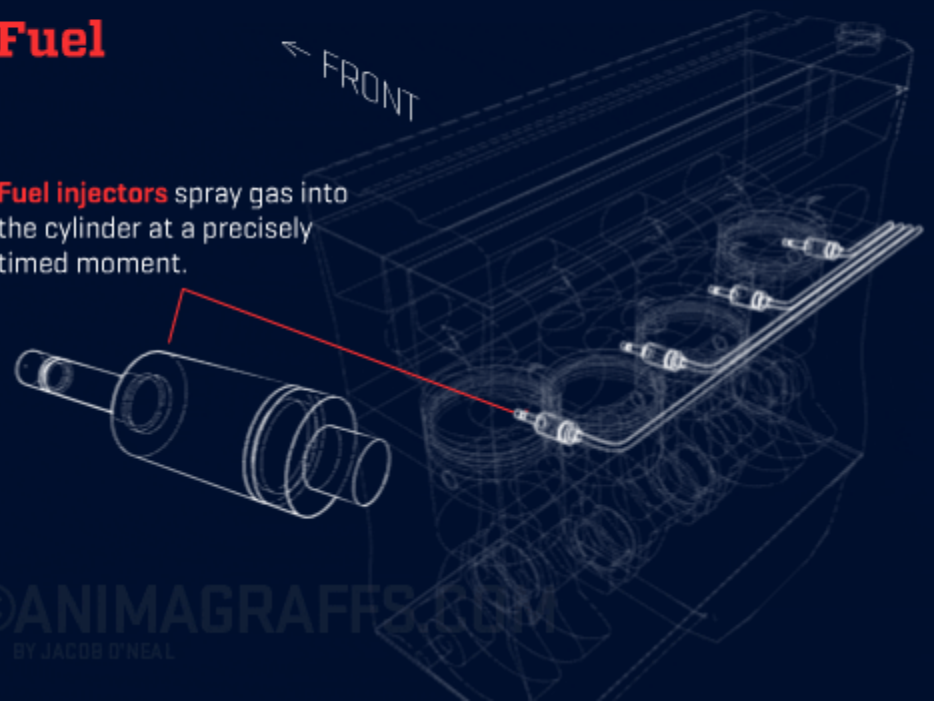
Crankshaft
The crankshaft carries piston power out of the engine and eventually to the wheels. It has counterweights to produce a balanced spin.

Other engine configurations

Engine systems

Here's a look at the basic systems and elements that a gas engine needs to function. Unlike humans, they can't simply run on coffee and deadlines.

Fuel



OCTANE RATING

Using higher octane fuel in an engine designed for lower octane simply wastes money and can result in less complete combustion, resulting in lower fuel mileage.

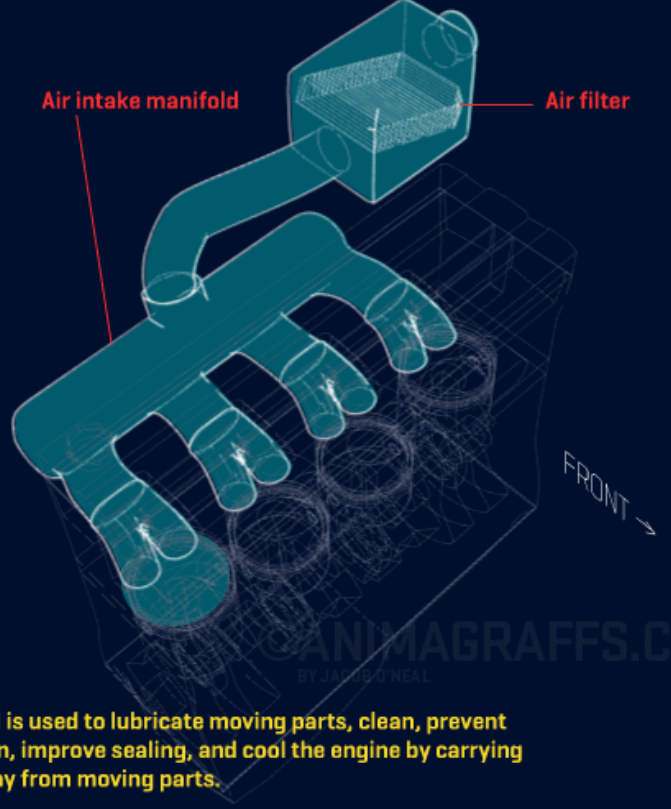
UNLEADED	PLUS	PREMIUM
87	89	93
PRESS	PRESS	PRESS

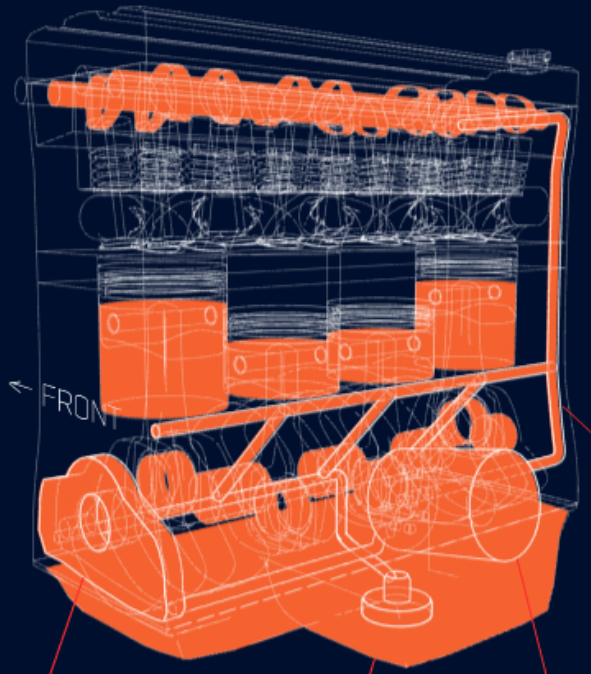
Gasoline's octane rating refers to its resistance to autoignition. Autoignition occurs when the fuel-air mixture is ignited by compression alone, without any spark. This can contribute to engine knock, and is generally destructive. High performance engines often have higher compression, which requires higher octane fuel to prevent autoignition.

Air (Oxygen)

The ratio of gas to oxygen an engine needs to run is about 1:14 — each part of gasoline requires fourteen parts oxygen.

On a 20 gallon tank, your engine will take in 20,000 cubic feet of oxygen (the equivalent of a 2,500 sq. ft. house)!





Oil

Motor oil is used to lubricate moving parts, clean, prevent corrosion, improve sealing, and cool the engine by carrying heat away from moving parts.

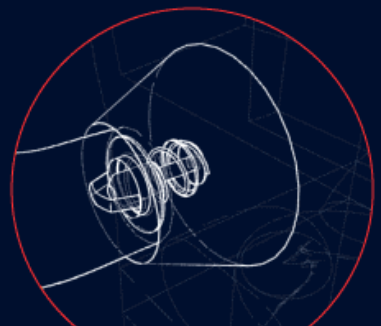
Rings around the top of the piston head keep oil out of the combustion process while otherwise allowing the cylinder to be lubricated.

Oil Galleries
Oil galleries are channels that carry oil to various engine parts.

Oil pump
The oil pump keeps oil properly pressurized and flowing through the engine.

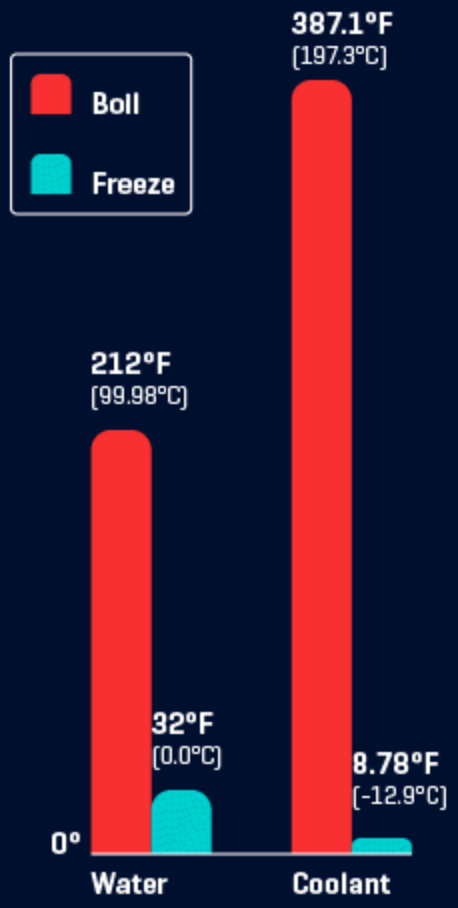
Oil filter
The oil filter removes unwanted material from engine oil.

Oil pan
The oil pan holds the engine oil.

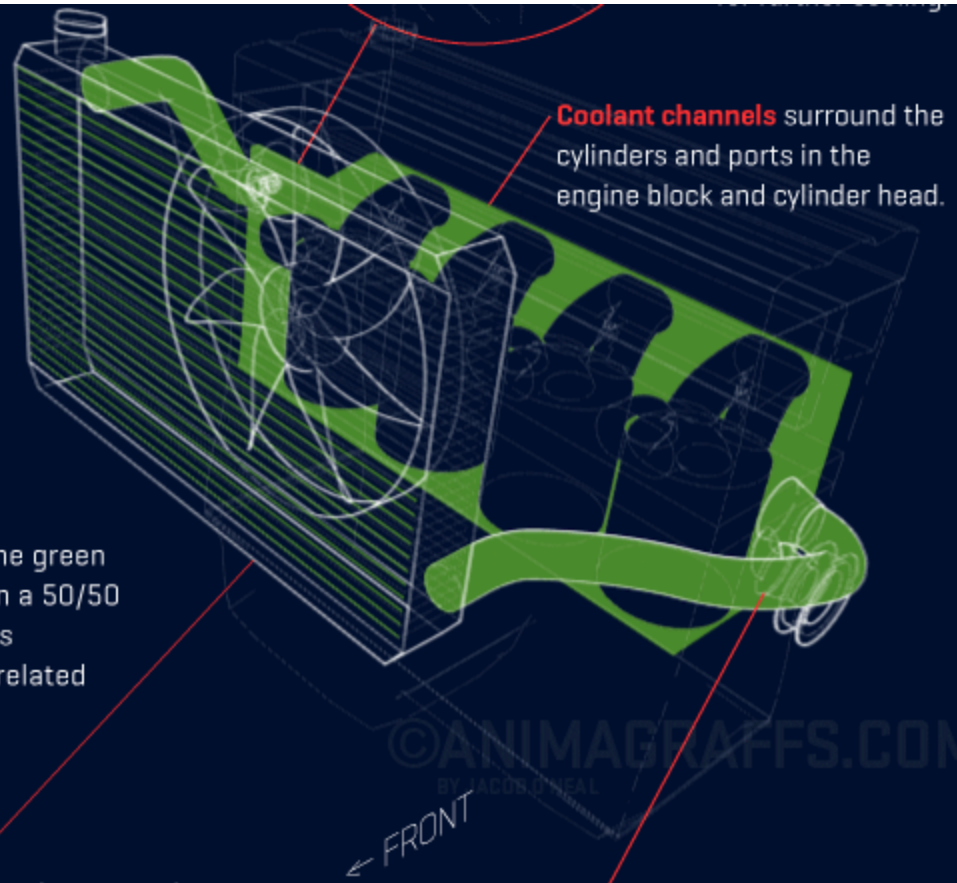


Thermostat
The thermostat regulates coolant temperature by either routing coolant back through the engine or to the radiator

Cooling



Engines get hot – the cooling system of a car going down the freeway dissipates enough heat to keep two average-sized homes warm!



Coolant channels surround the cylinders and ports in the engine block and cylinder head.

Anti-freeze

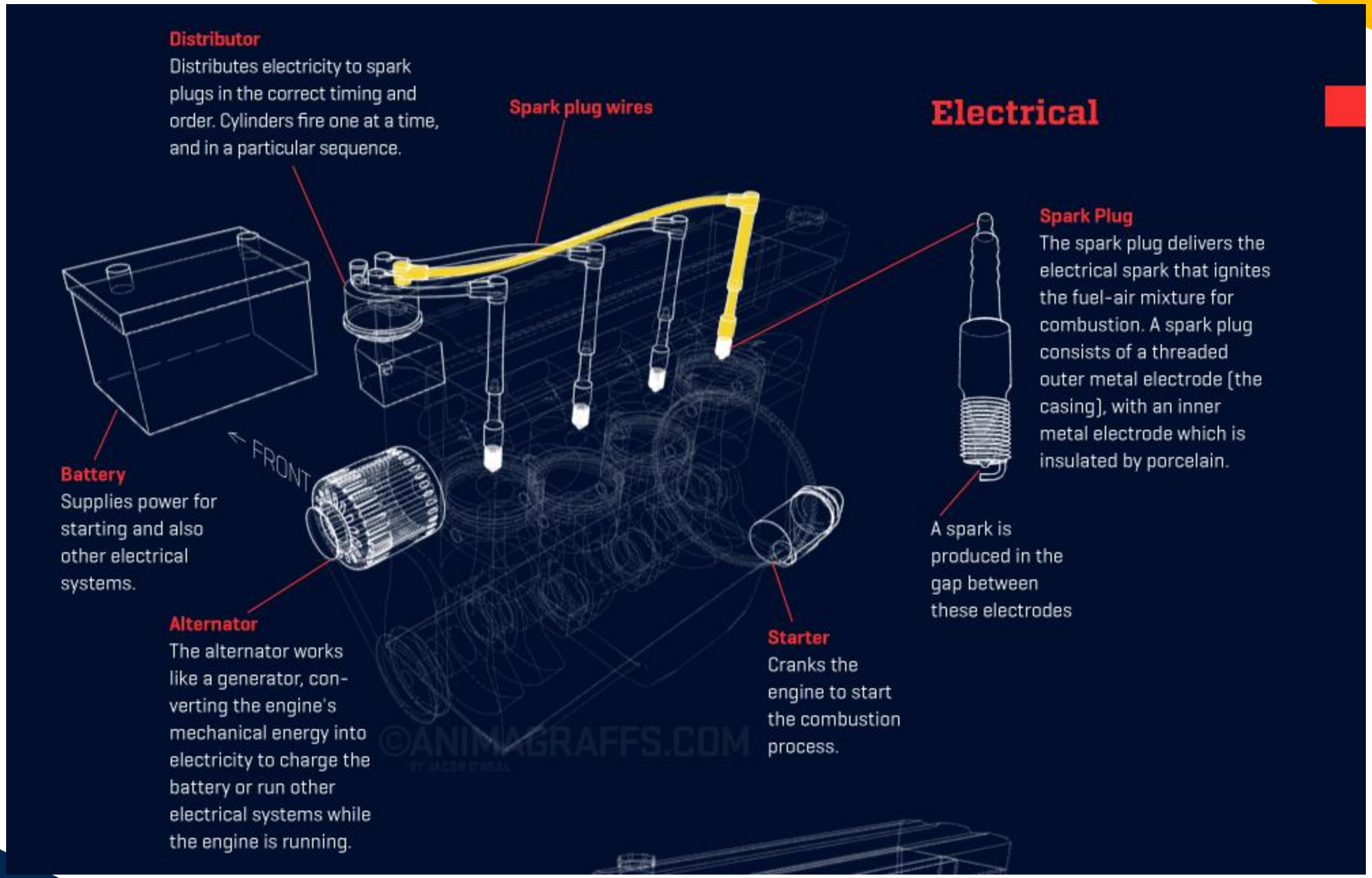
Anti-freeze (engine coolant) is the green liquid in your radiator, normally in a 50/50 mixture of coolant and water. It is designed to resist temperature-related changes like freezing or boiling.

Radiator and fan

The radiator is made of a series of metal tubes and fins. When the hot coolant returns from the engine block, it passes through the tubes. Air flowing through the radiator (over the fins) cools the coolant in preparation for another cycle through the engine.

Water Pump

The water pump keeps the coolant system flowing and properly pressurized.


Distributor
Distributes electricity to spark plugs in the correct timing and order. Cylinders fire one at a time, and in a particular sequence.
Spark plug wires
Electrical
Spark Plug
The spark plug delivers the electrical spark that ignites the fuel-air mixture for combustion. A spark plug consists of a threaded outer metal electrode (the casing), with an inner metal electrode which is insulated by porcelain.
FRONT
Battery
Supplies power for starting and also other electrical systems.
A spark is produced in the gap between these electrodes
Alternator
The alternator works like a generator, converting the engine's mechanical energy into electricity to charge the battery or run other electrical systems while the engine is running.
Starter
Cranks the engine to start the combustion process.
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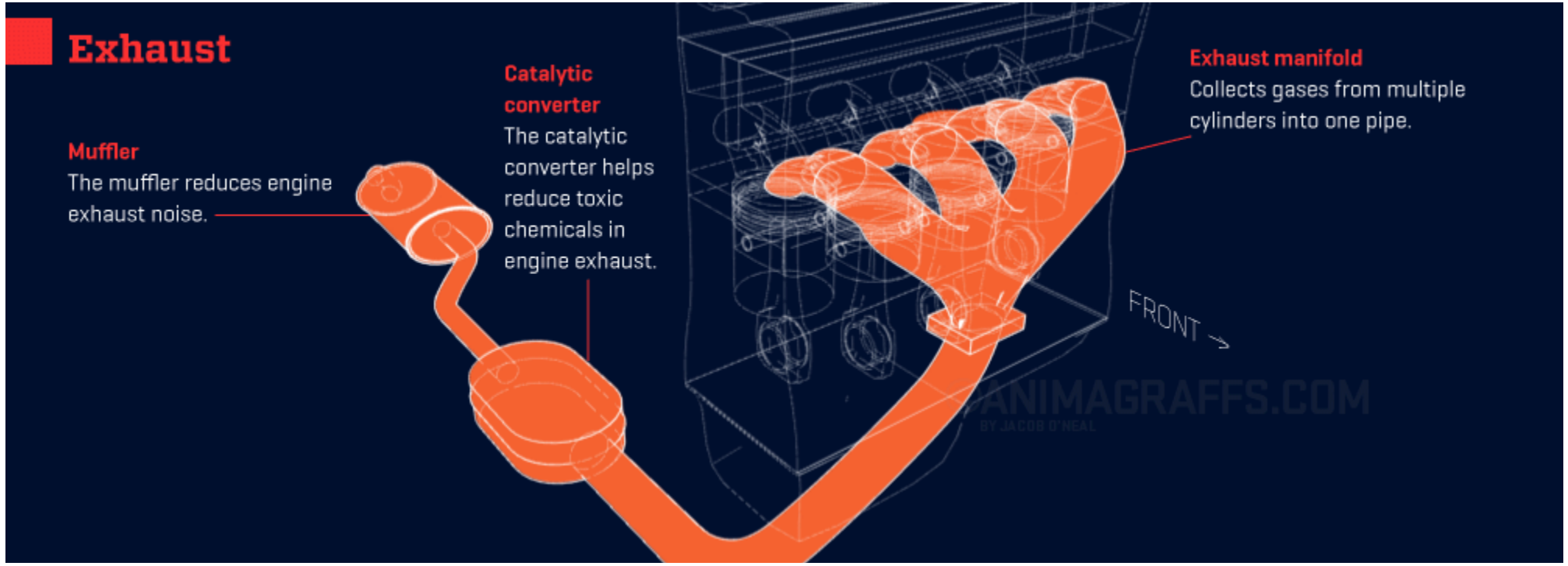
Exhaust
Muffler
The muffler reduces engine exhaust noise.
Catalytic converter
The catalytic converter helps reduce toxic chemicals in engine exhaust.
Exhaust manifold
Collects gases from multiple cylinders into one pipe.
FRONT
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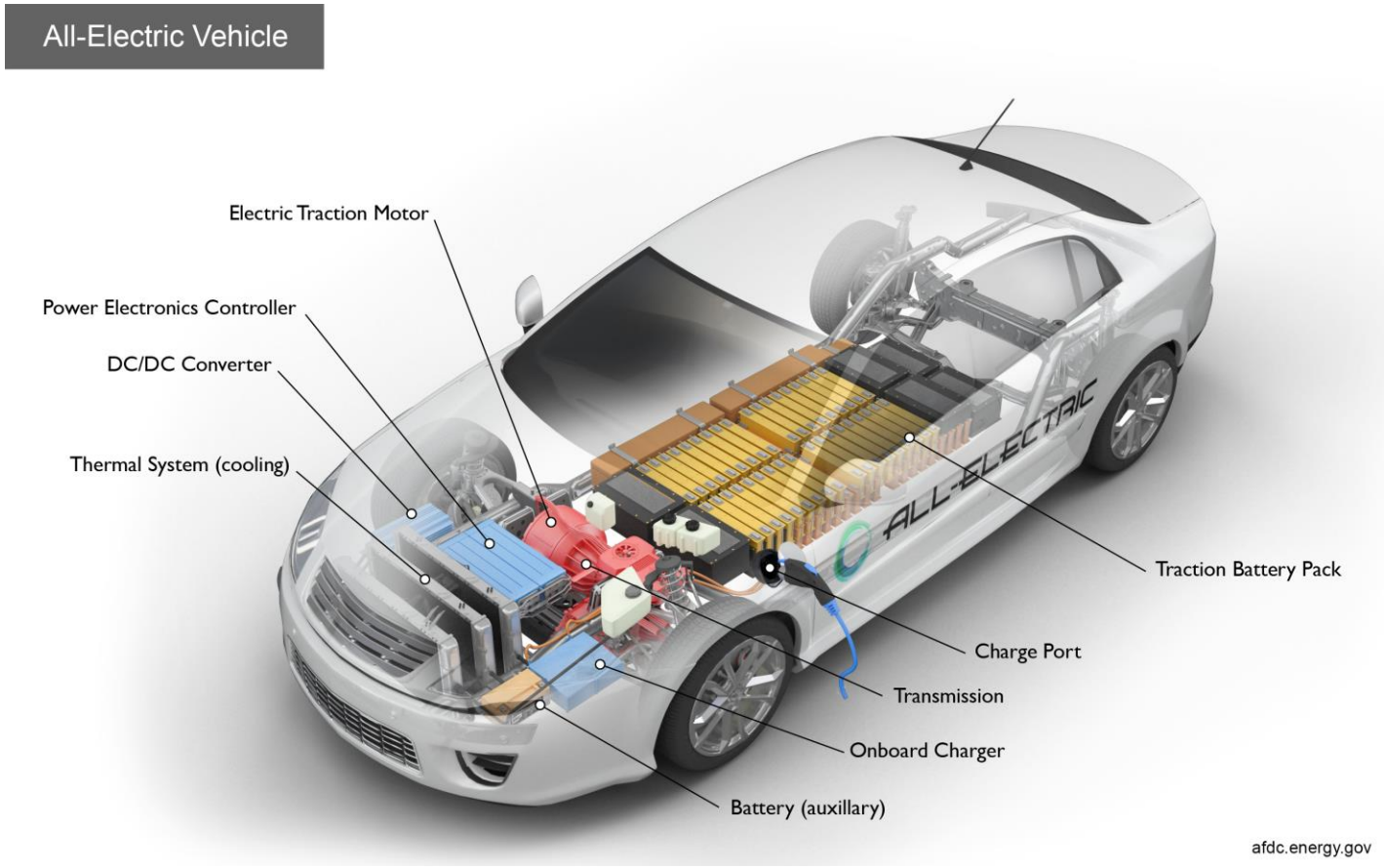
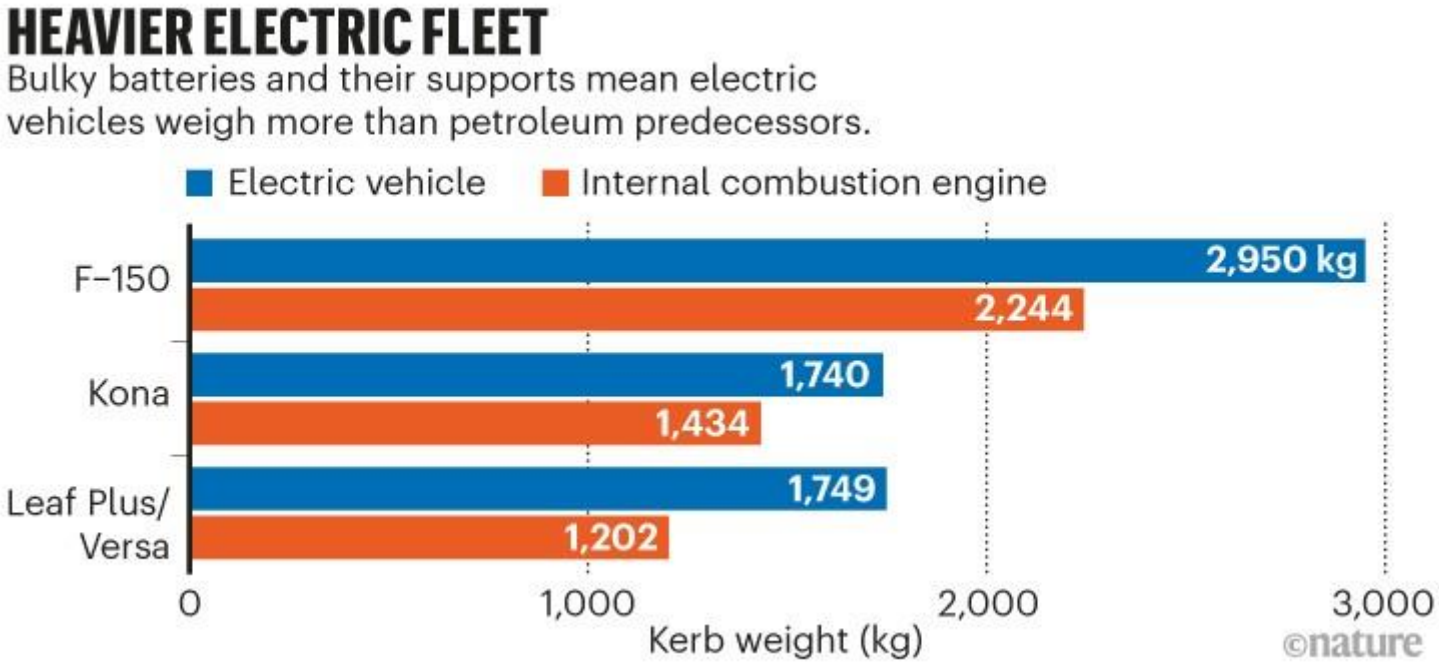
How do electric cars work?

BEV diagram

- Substantially fewer moving components in an EV
- Charge port replaces fueling valve and battery replaces gas tank
- No combustion byproducts with a battery = no tailpipe!

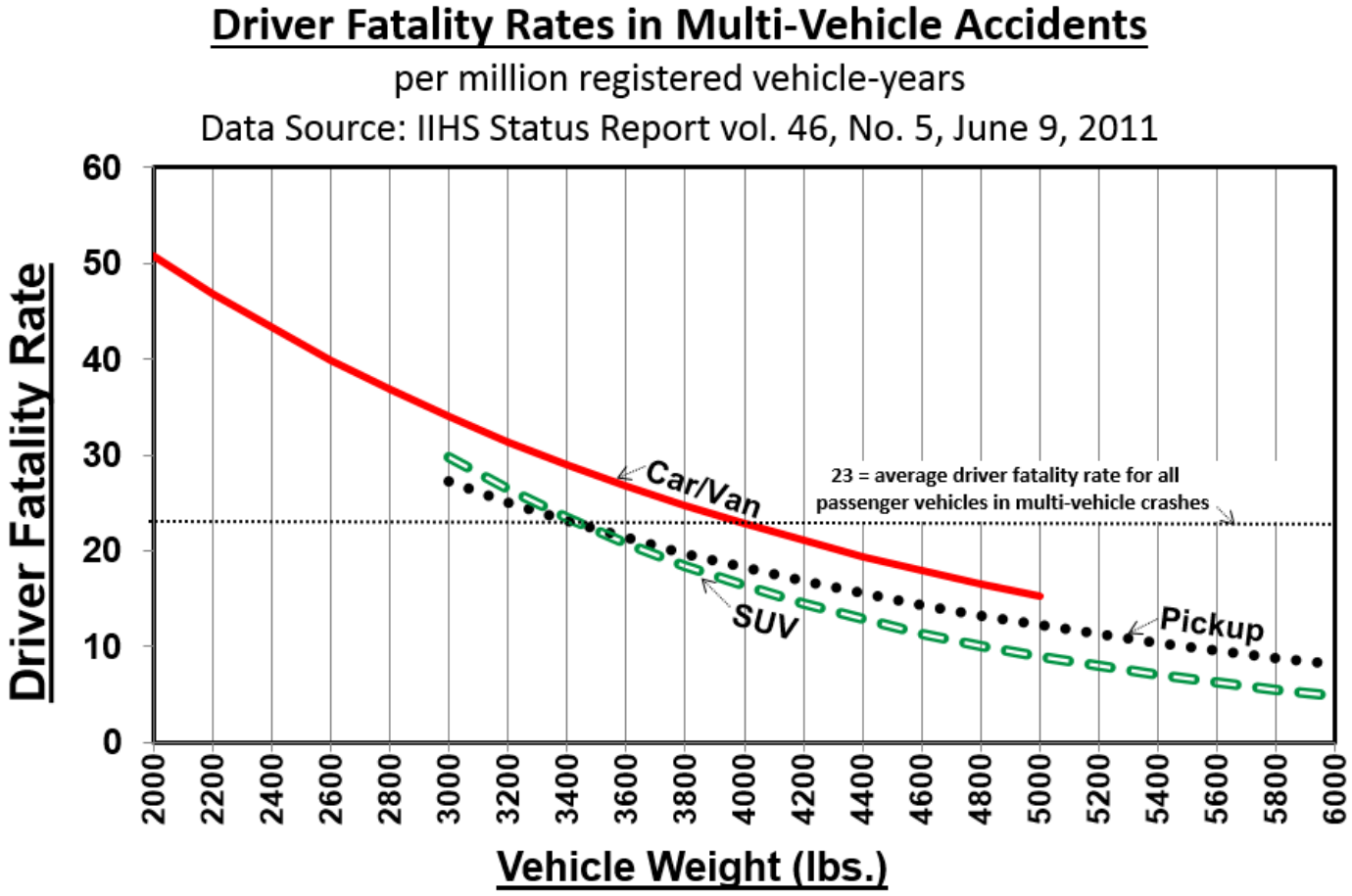


Vehicle weight: batteries are heavy!



Safety and Weight

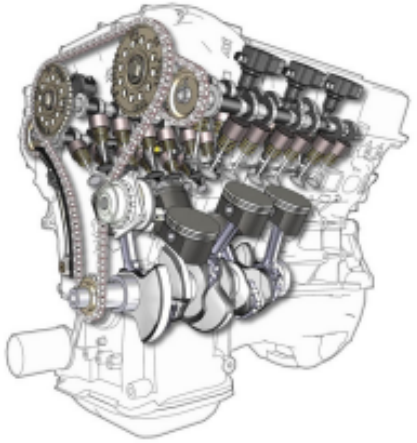
- A by-product of heavier vehicles is an “increase” in safety (heavier vehicles tend to lead to less fatalities and reduction in morbidity)
- Not so straightforward… differential in vehicle weight is what matters!



From a mechanical standpoint, EVs are *extraordinarily* simple

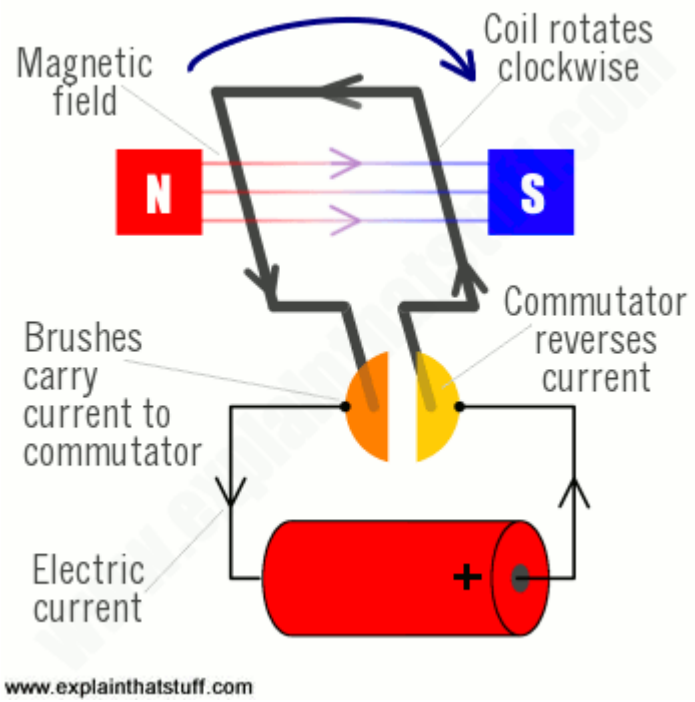
Who would win?

A complex machine optimized over 100 years to precisely mix combustible fuel and air at an exact ratio to transfer the linear motion of pistons to rotational motion through a series of small explosions



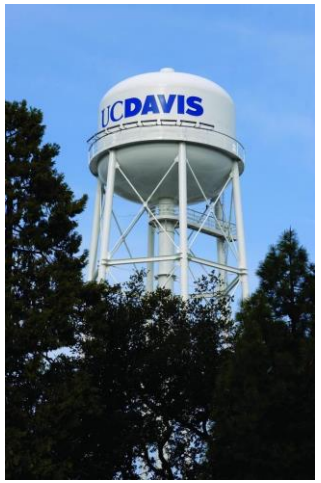
Some spinny magnets

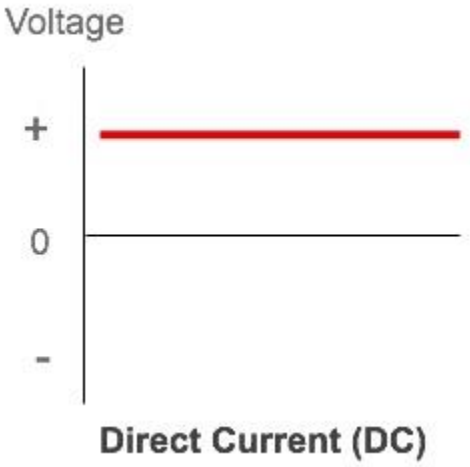
How motors work



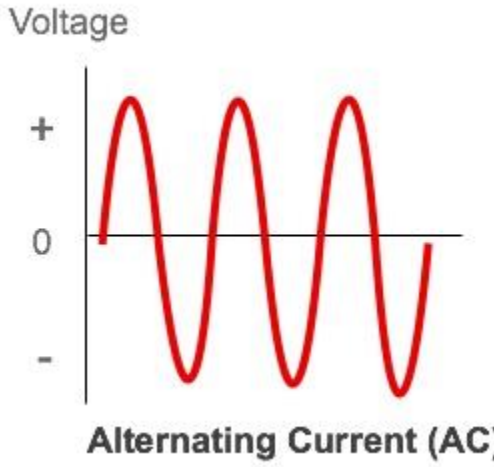
- Faraday's law of induction (Faraday's Law):
  - An electric current produces a magnetic field
  - *And conversely*: a magnetic field can produce an electric current
- Sending a current through a coil can produce magnetic fields that cause the coil to rotate in the presence of an external magnetic field (motor)
- The exact opposite can also occur: if you spin the coil, an electric current will be induced (generator)

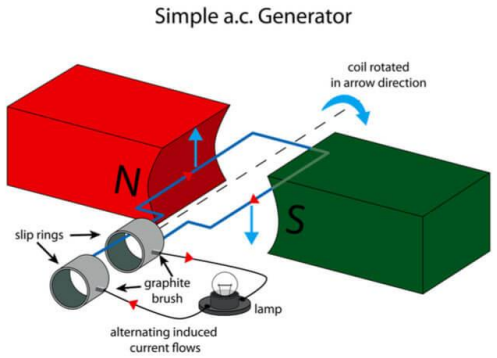
AC versus DC power





- Direct Current does not fluctuate and can be produced from sources such as batteries
- Imagine the current like water coming continuously from a water tower

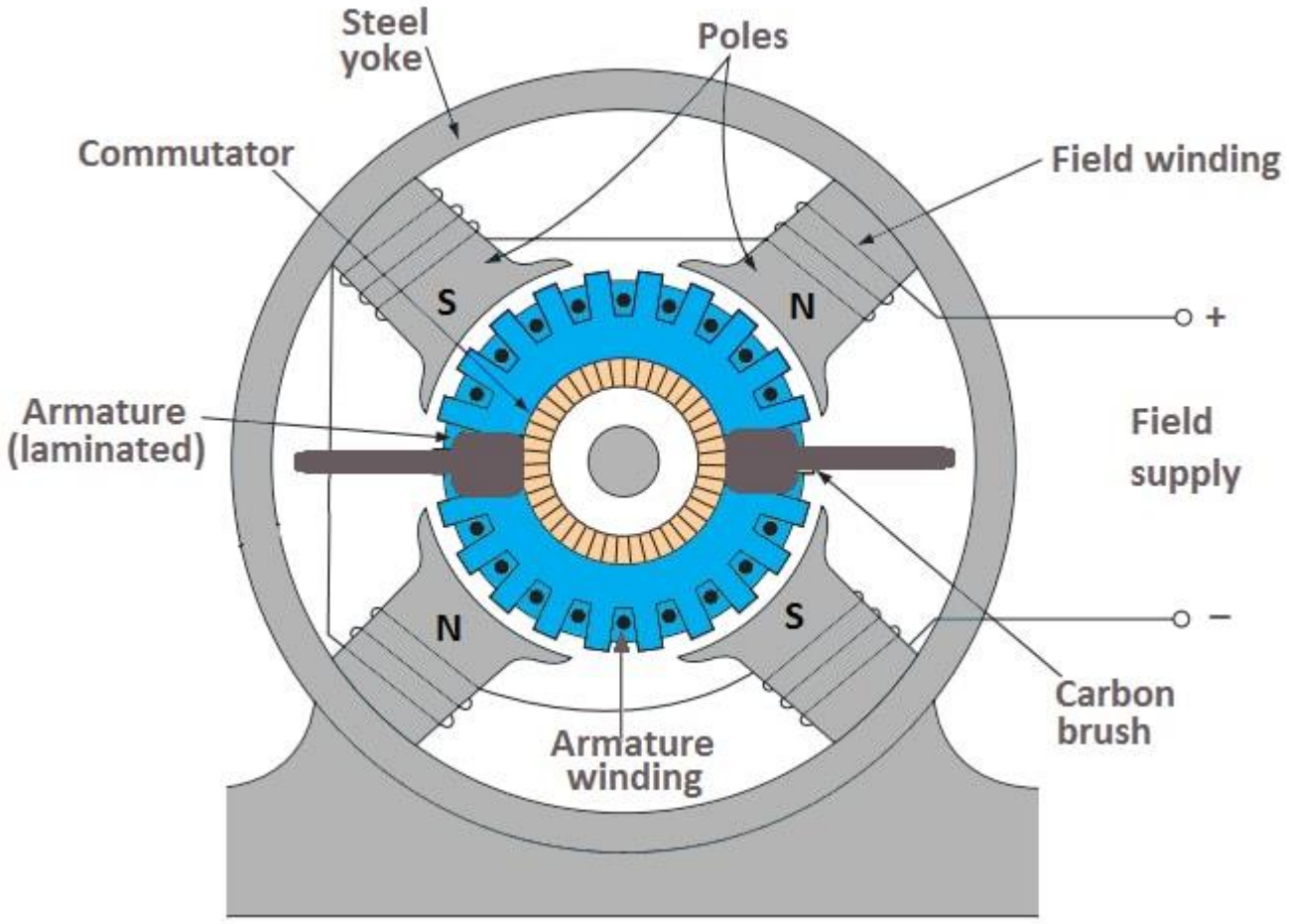




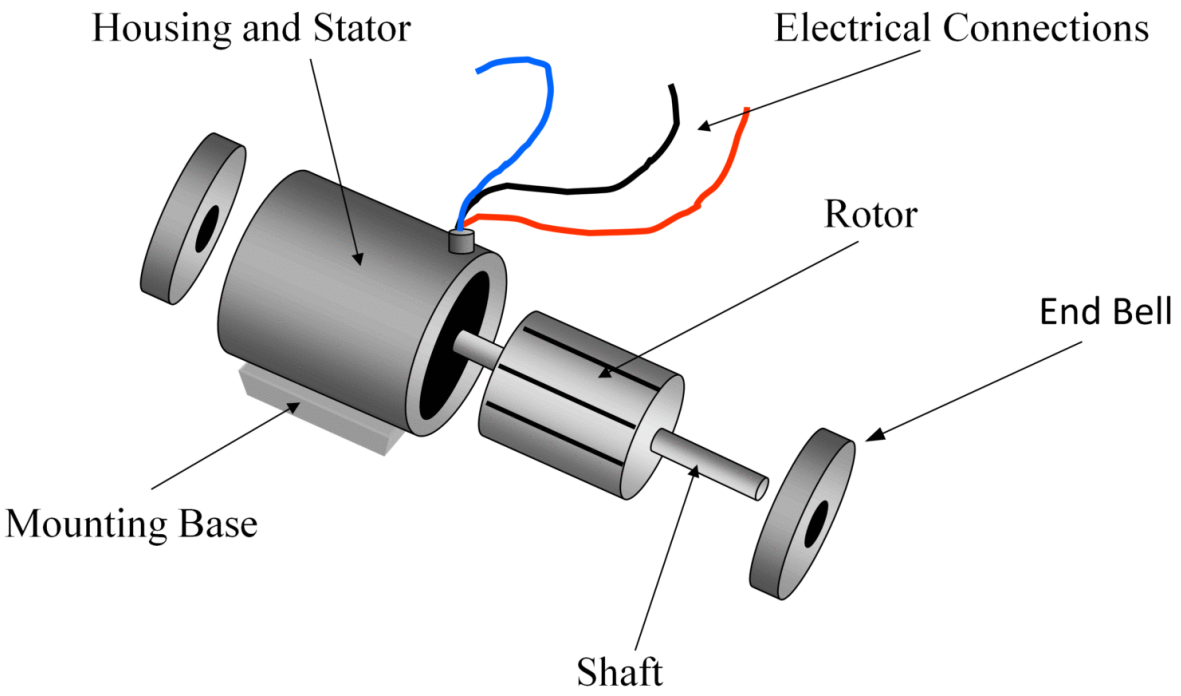
- Alternating current fluctuates due to the spinning operation of generators
- Imagine the current like water coming in phases as from a hand pump

DC Motors

- Two types of DC motors:
  - Brushed: internally commutated motors powered by direct current. Charge and polarity of brushes control direction and speed
  - Brushless (BLDC): higher efficiency, similar in construction without the brushes. Magnets mounted around the rotor
- DC motors typically have better speed control and output range.
- Employed by EVs such as the Nissan Leaf and Chevrolet Bolt.



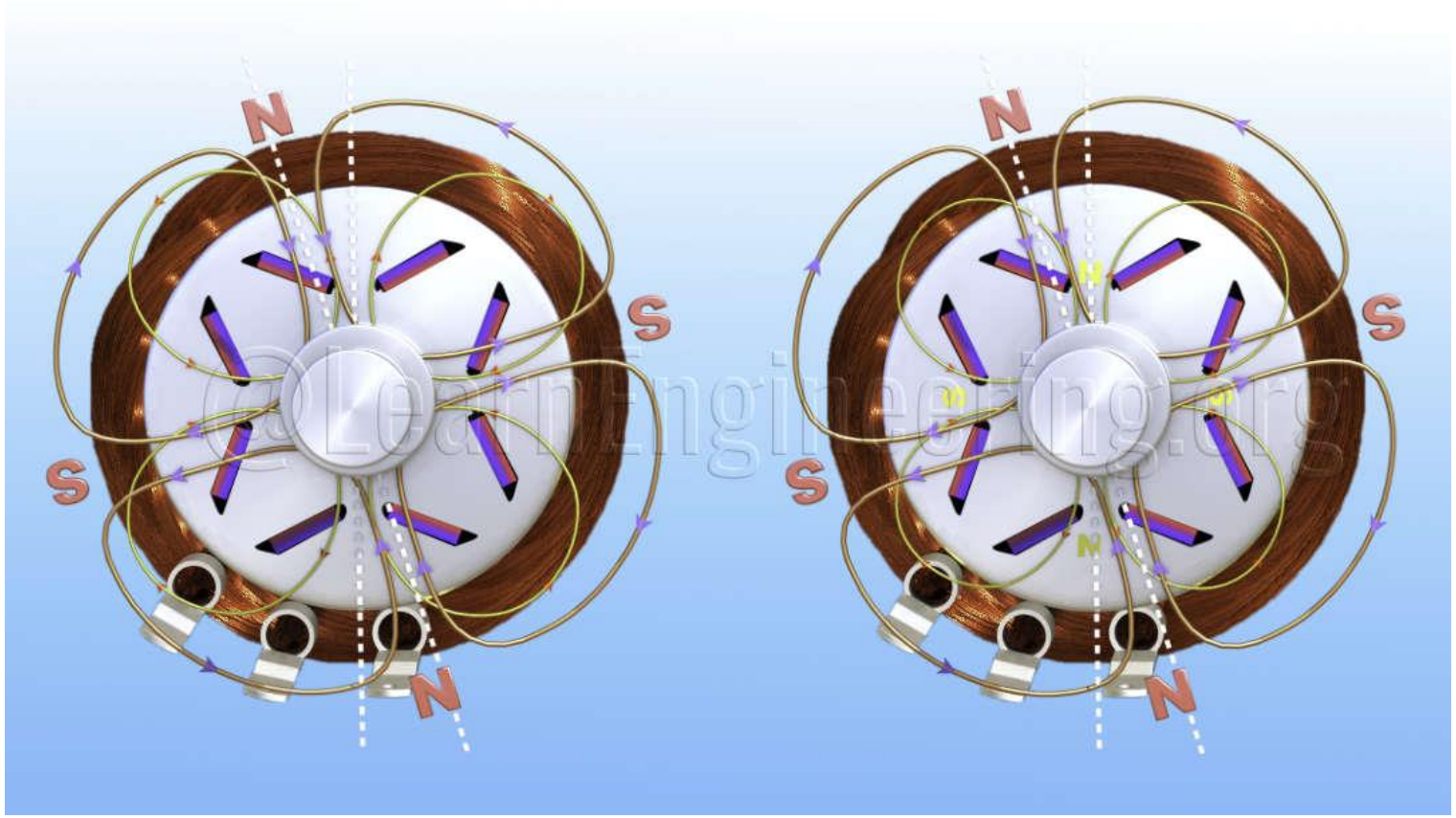
AC Motors



- Two types of AC motors:
  - Synchronous: rotate at same frequency as supply current
  - Induction: current to turn rotor created by EM-induction from stator
- Typically have higher power output and efficiency
- Tesla uses advanced form of induction motors

IPM-SynRM electric motor (Tesla)

- Motor technology has vastly improved over the last decade
- Permanent magnet motors are more efficient and have higher torque
- Tesla's configuration has slots cut into the rotor to reduce eddy currents and back EMF

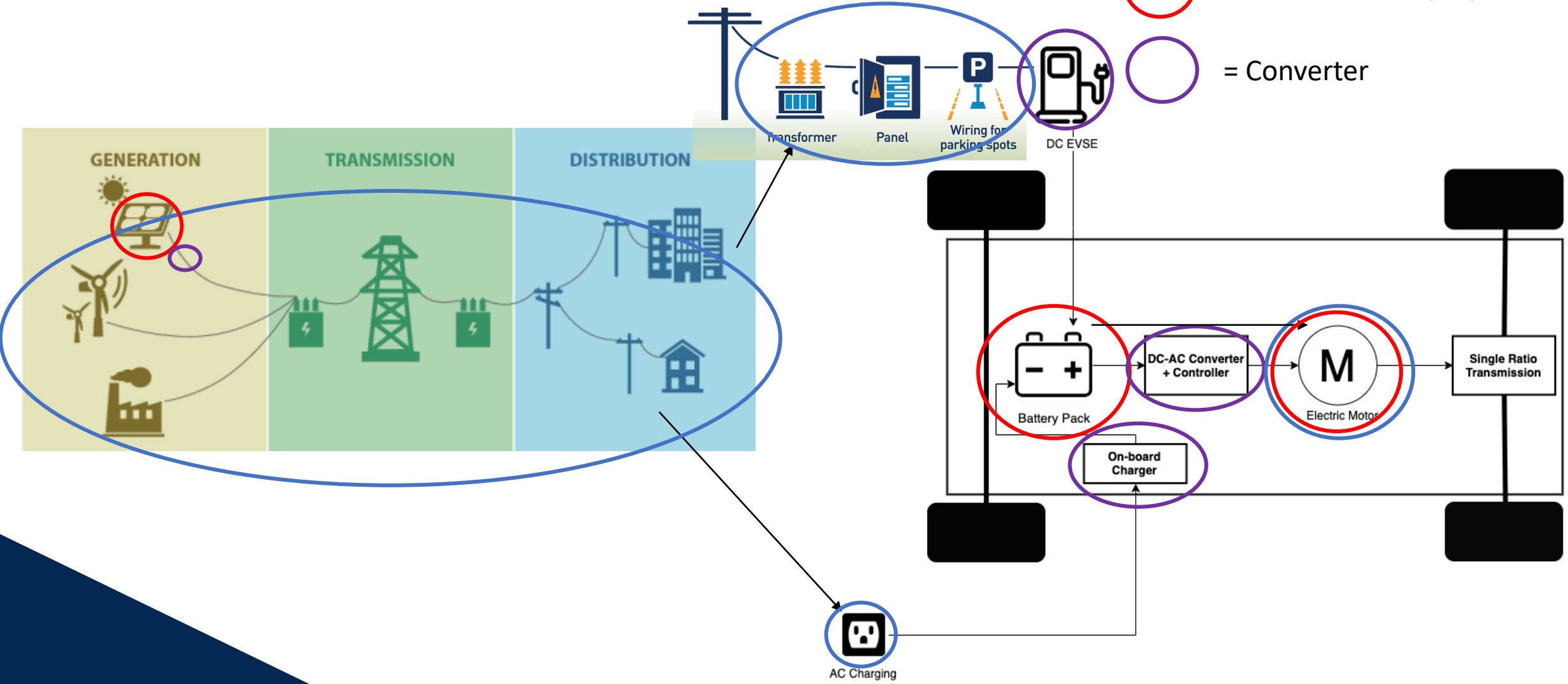


AC versus DC for EVs

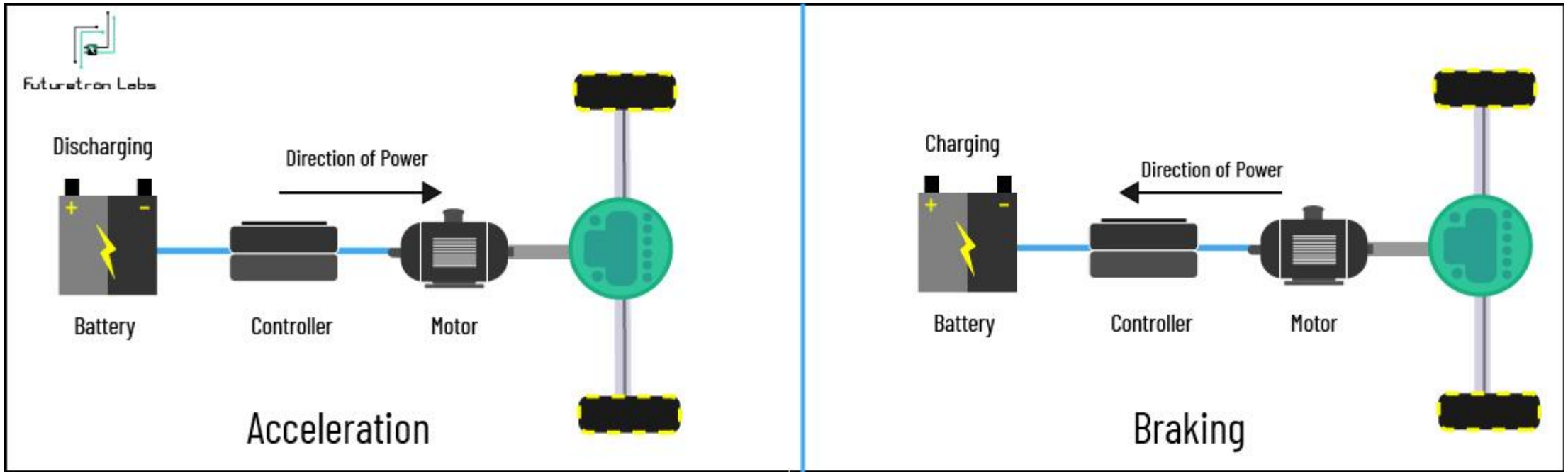
= Alternating Current (AC)

= Direct Current (DC)

= Converter



Regenerative braking



- A generator is simply a motor in reverse. Kinetic energy goes from the wheels to power the generator which translate motion into electricity to charge the battery.

ICV vs EV torque

2022 Ford Mustang / Torque

350 to 420 lb-ft

2022 Ford Mustang

Sports car

MSRP: From $27,205

Horsepower: 310 to 470 hp

MPG: Up to 21 city / 32 highway

Curb weight: 3,532 to 3,868 lbs

Dimensions: 188″ L x 75″ W x 54-55″ H

Engine: 2.3 L 4-cylinder, 5.0 L V8

2022 Ford Mustang Mach-E / Torque

317 to 612 lb-ft

2022 Ford Mustang Mach-E

Sport utility vehicle

MSRP: From $42,895

Horsepower: 266 to 459 hp

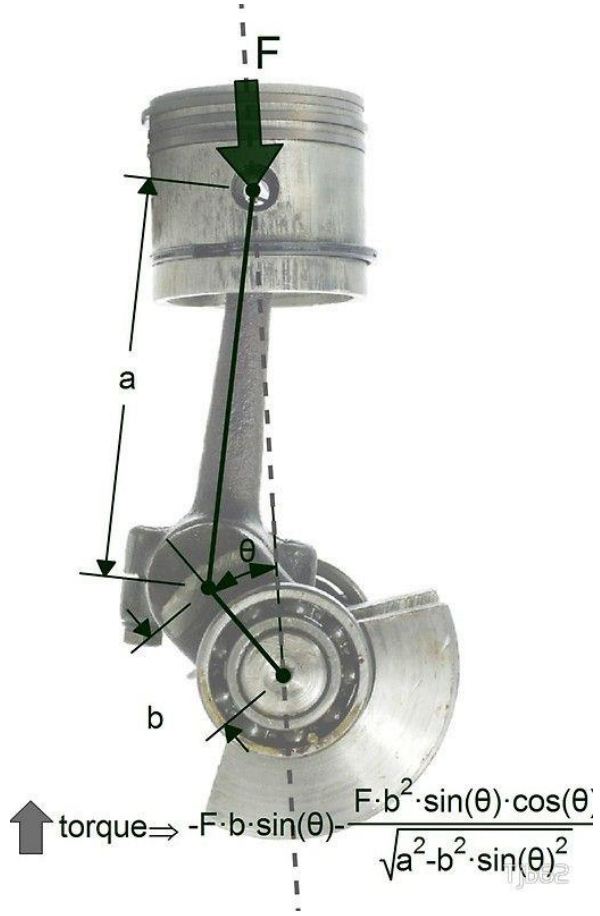
Range: 270 to 300 mi battery-only

MPGe: Up to 108 city / 94 highway

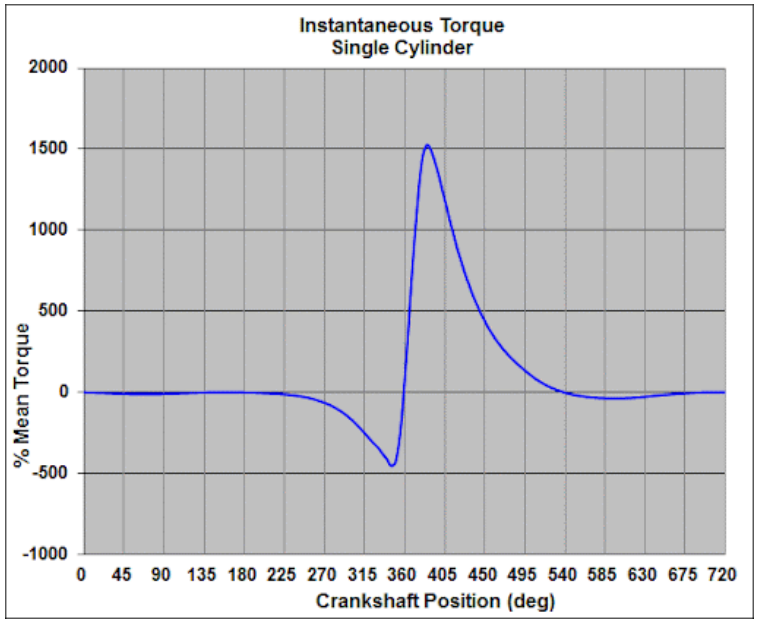
Engine: Electric

Curb weight: 4,394 to 4,920 lbs

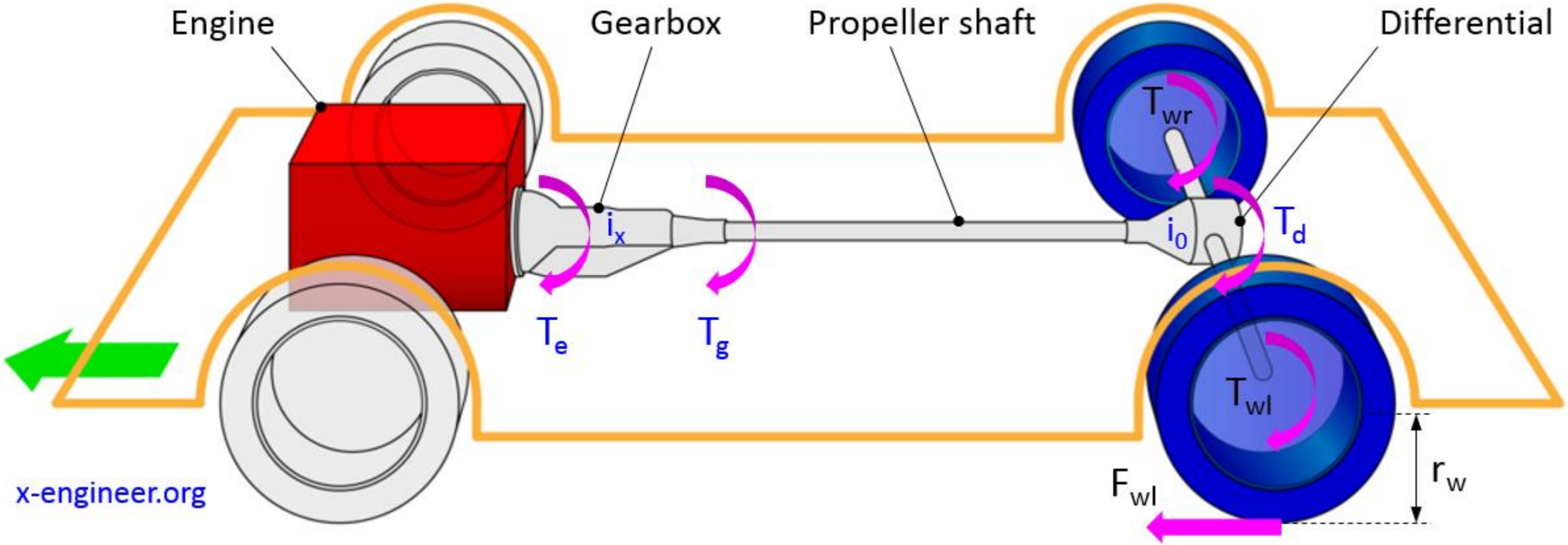
What is torque?



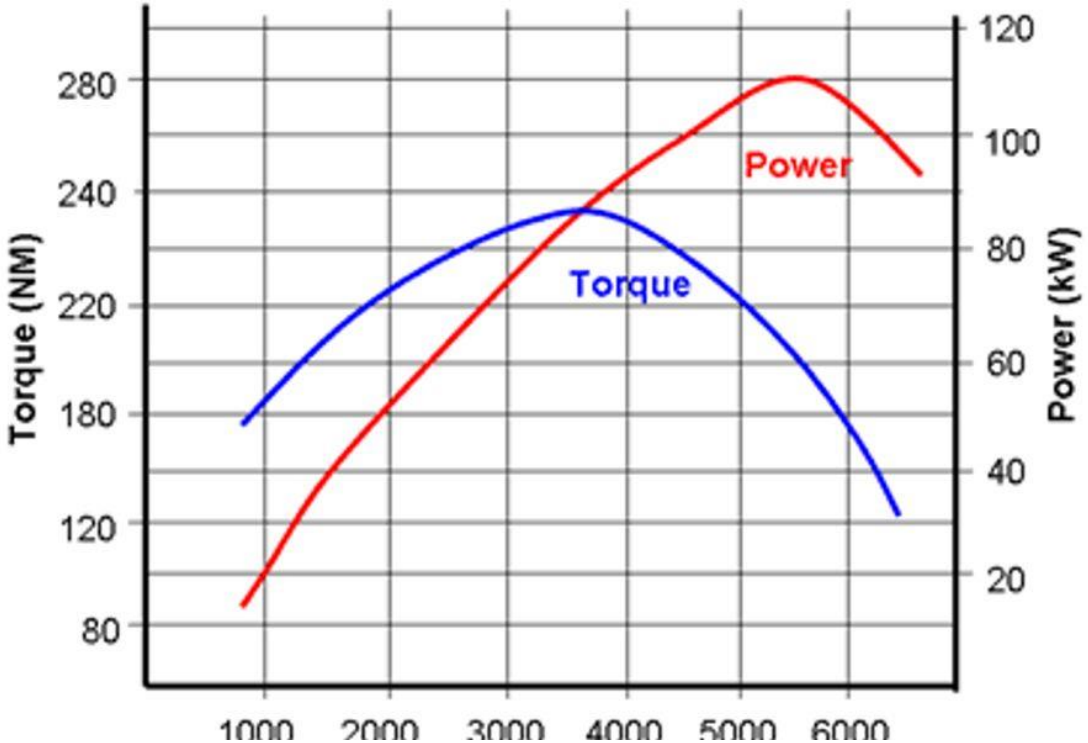
- Torque describes the force subjected to the drive shaft (expressed as Force x Distance)
- Oftentimes described as the “jerkiness” of the vehicle (think of the sensation of being pushed into your seat)

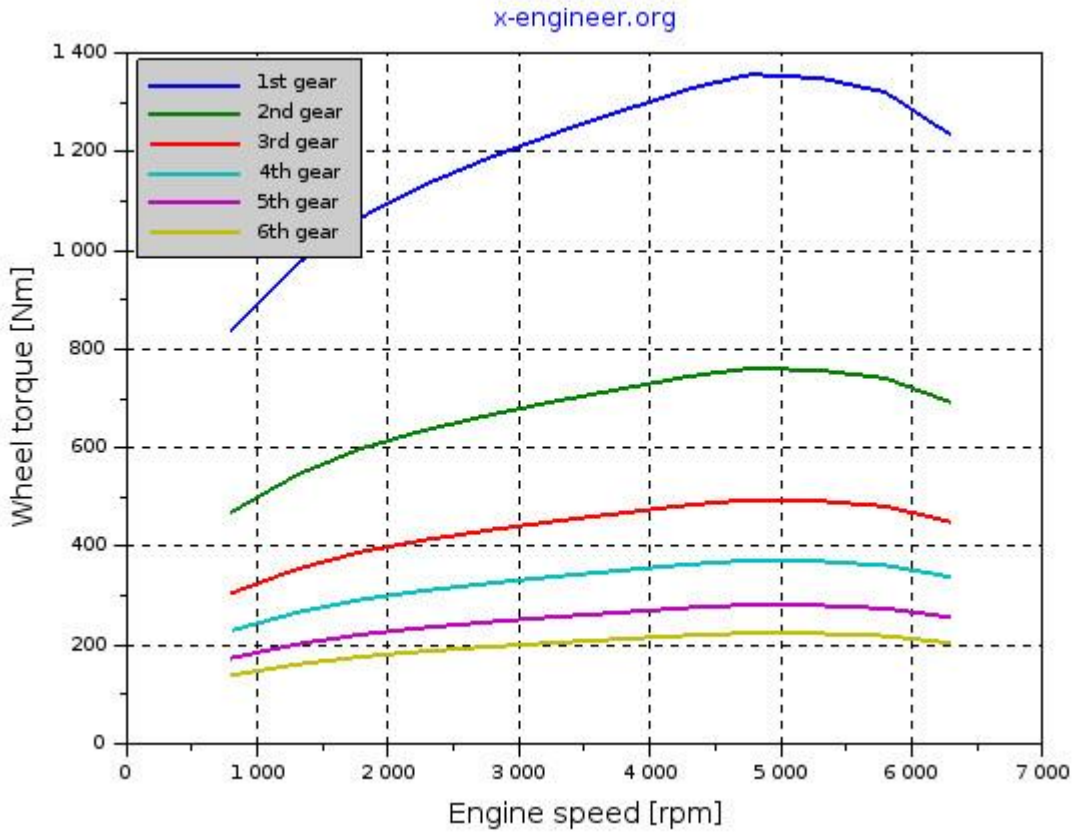


Engine torque versus torque at the wheels

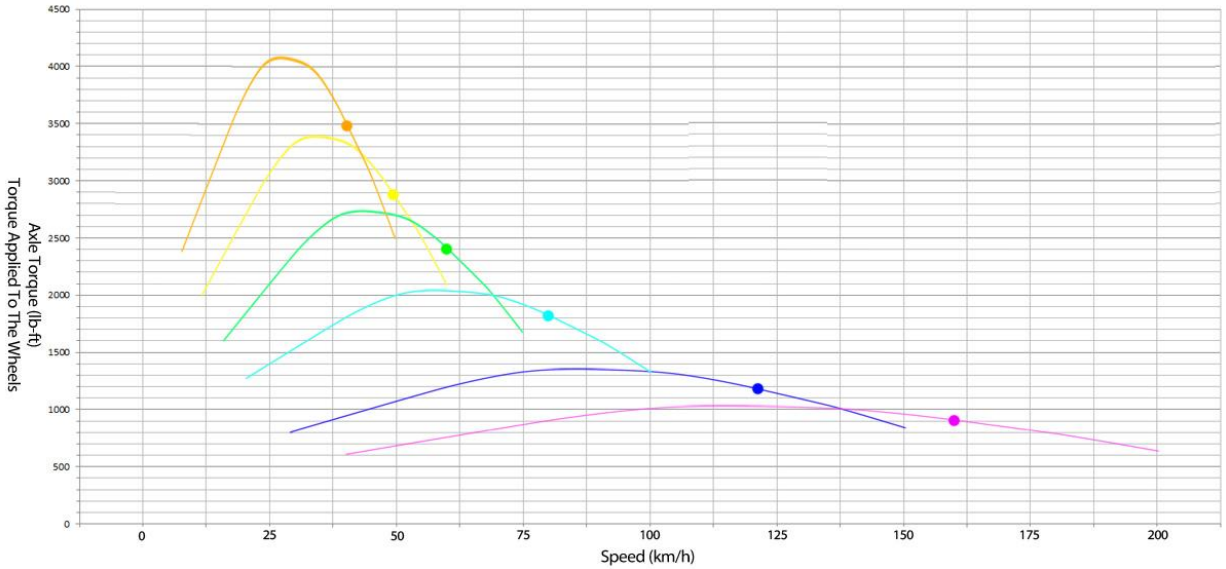


Torque, horsepower, and RPM

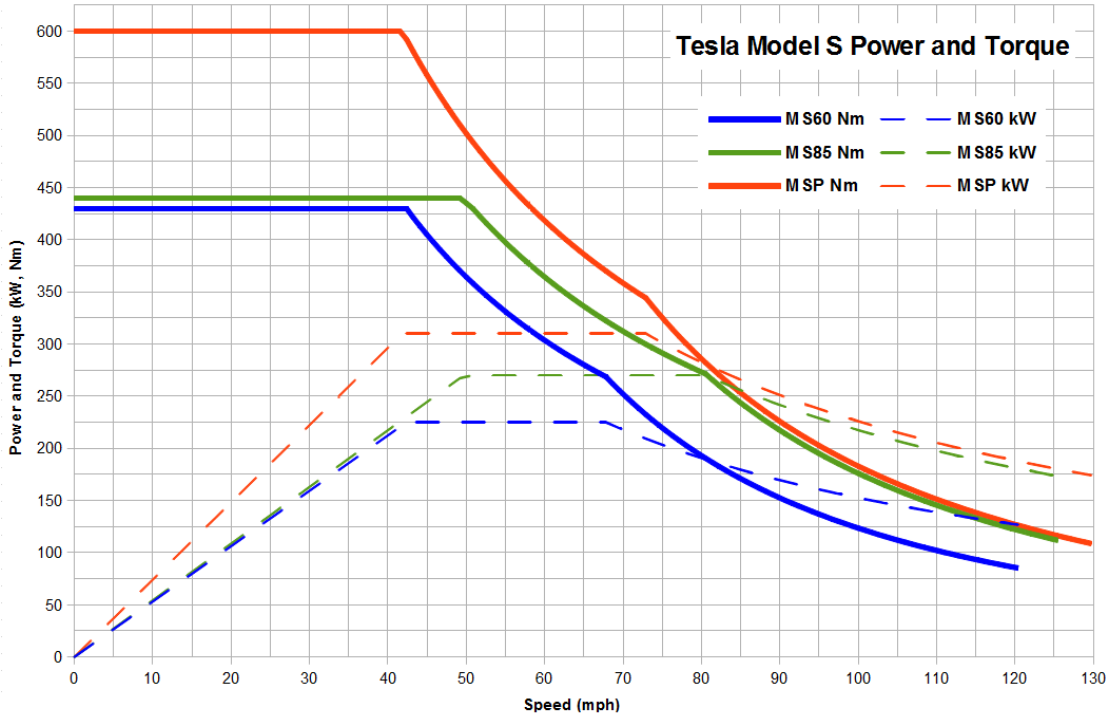




Torque comparison between gas and electric cars



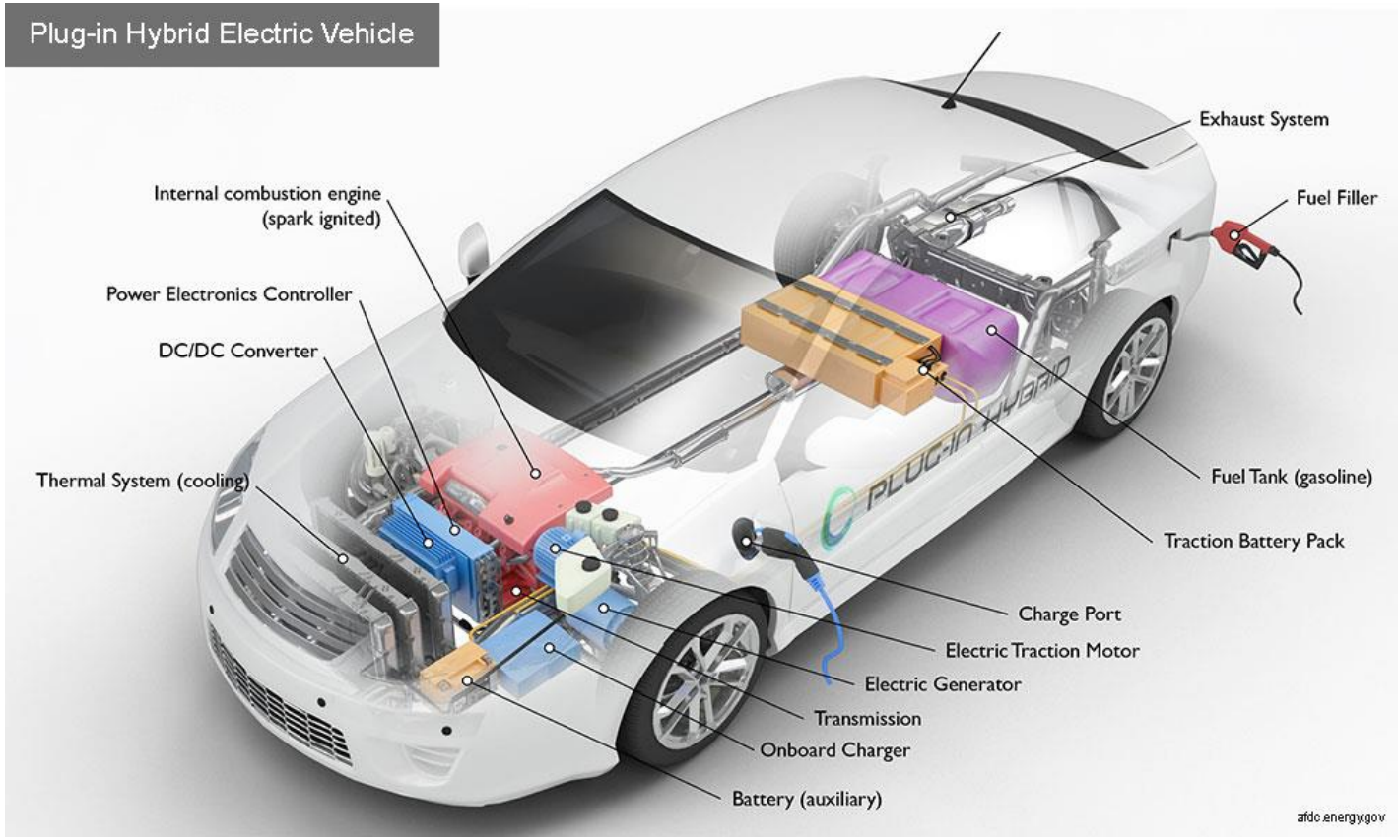
- Gasoline engines need some time to increase their torque due to the time it takes for pistons to go through their thermodynamic cycle and due to inherent losses such as friction



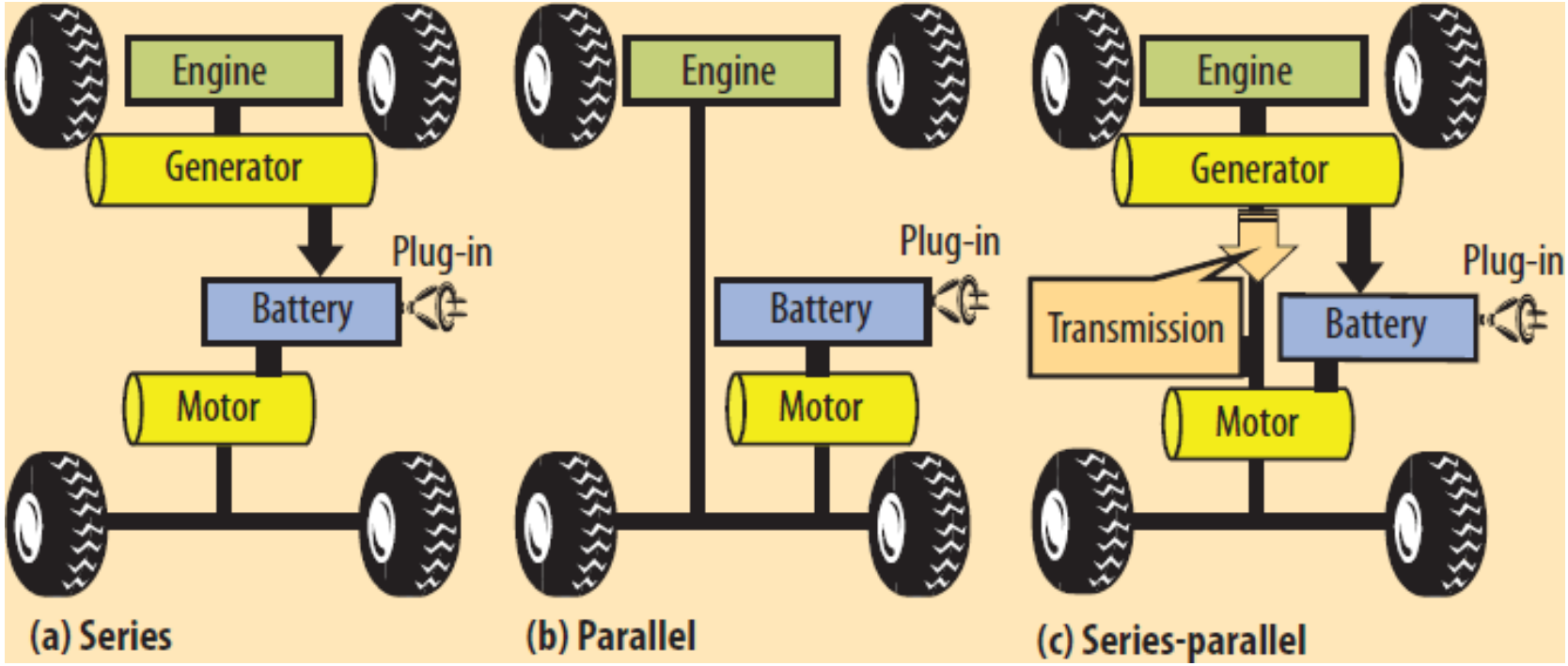
- Electric vehicles have full access to their motor torque at 0 speed, typically leading to faster initial acceleration

PHEV diagram

- Plug-in hybrids must contain the technologies of both ICVs and BEVs
- Due to size limitations, PHEVs are generally much shorter in electric range (<50 miles)

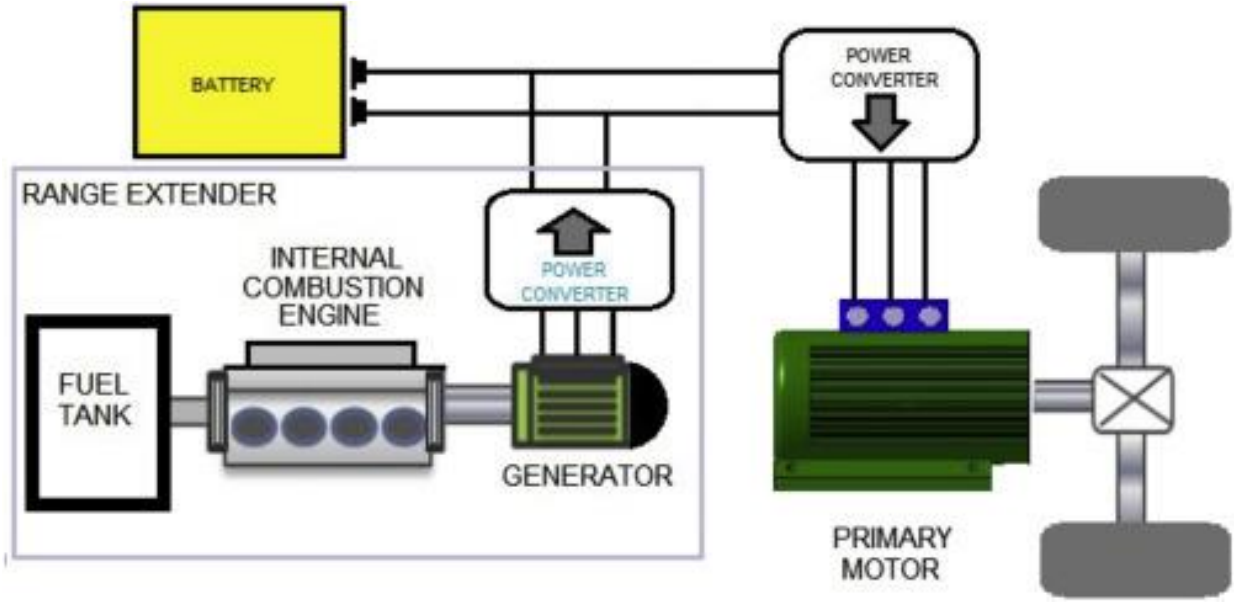


PHEV configurations



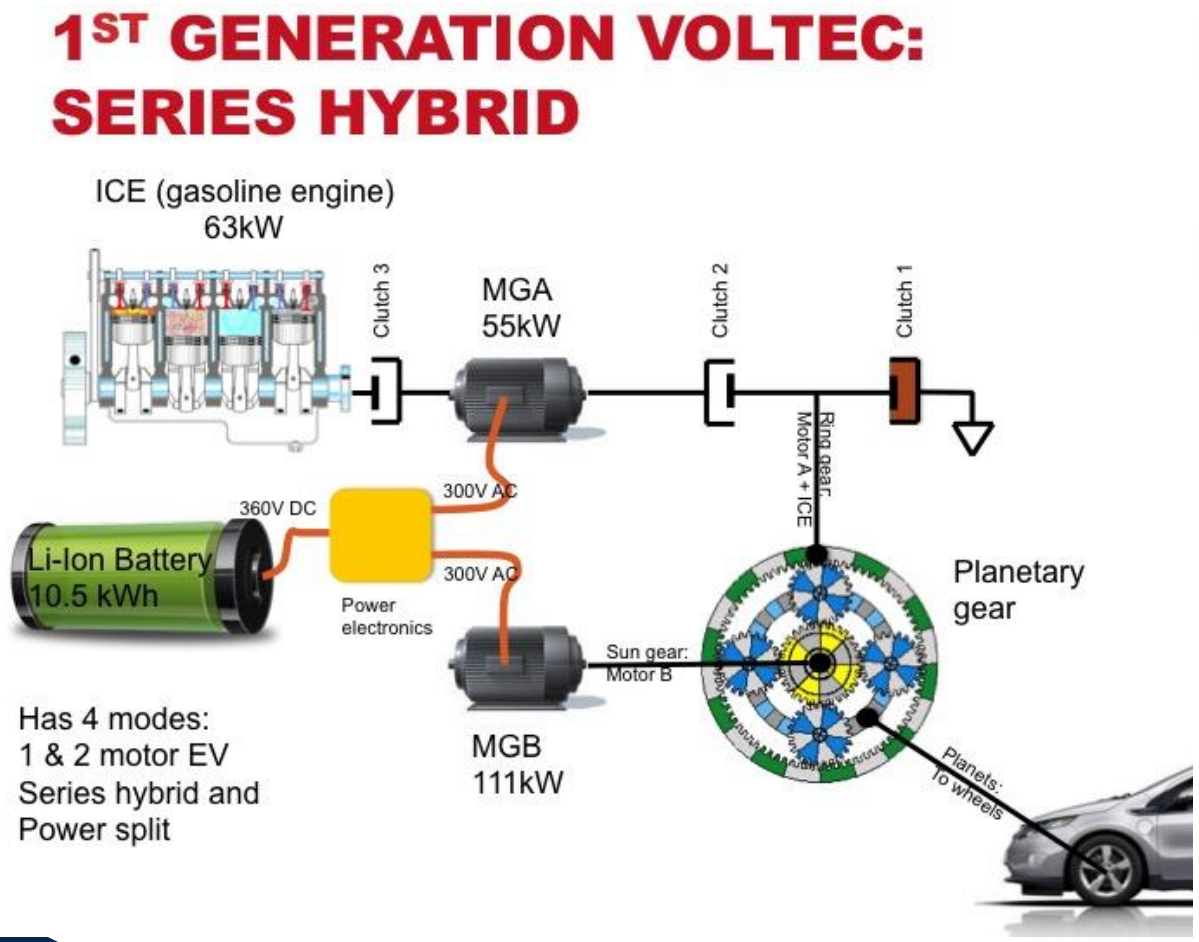
- Series – engine can only power the battery, not the drivetrain
- Parallel – engine can only power the drivetrain, not the battery
- Series-parallel – engine can power both the battery *and* drivetrain

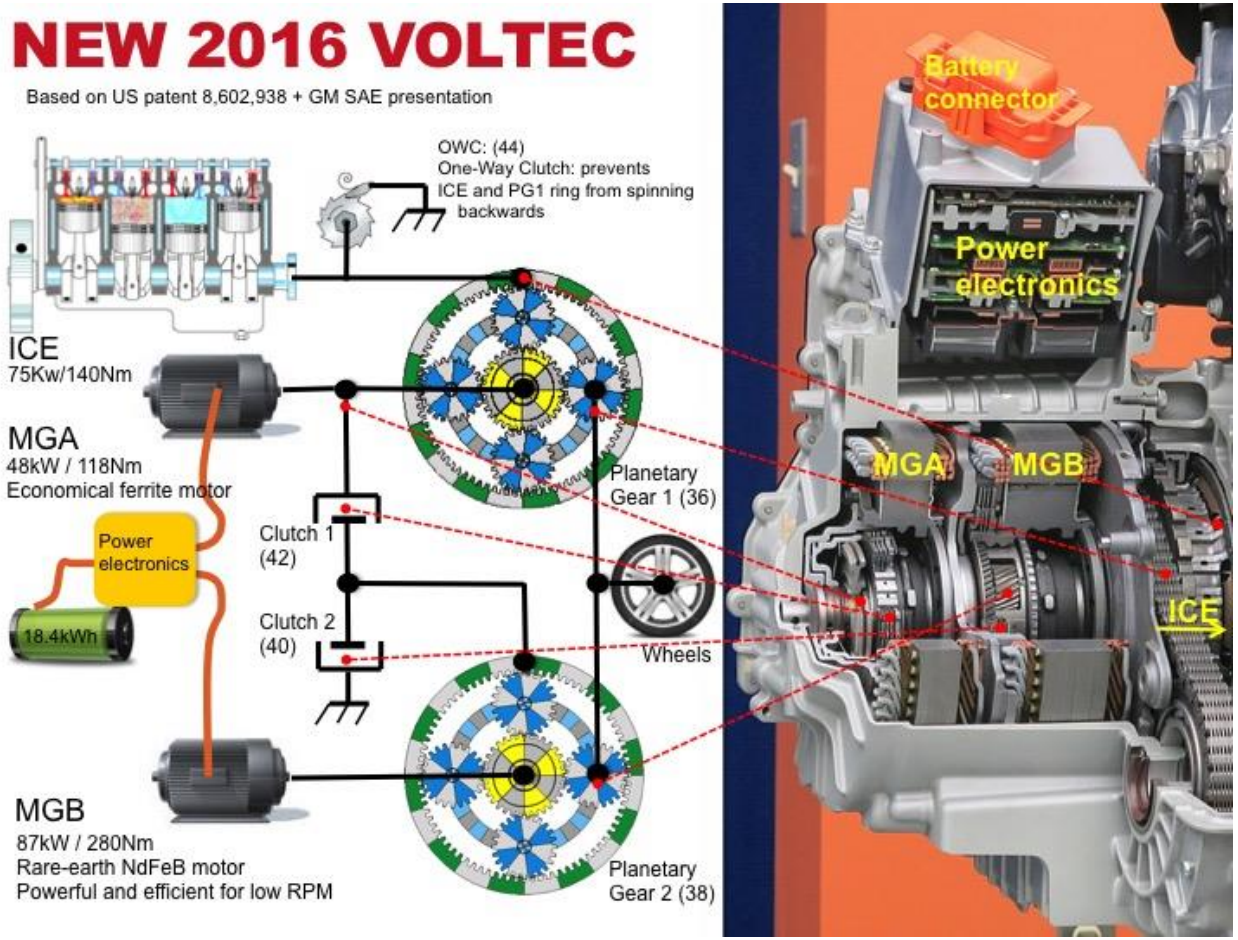
Range Extender (series example)



- Some versions of the BMW i3 (Rex, for range extender) contained an engine that powered a generator to charge the battery

Chevrolet Volt Planetary Gear





Powertrain technology will continue to improve!

- Tons of room for improvements across the drivetrain:
  - Innovations in the motor—more power and higher efficiency
  - Control systems to improve efficiency
  - Battery attributes that may decrease weight, increase in energy and power density
- The last decade has already led to many innovations, this will continue as more automakers increase their EV portfolios