Electric and Hybrid Vehicles: Current trends and future strategies

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Outline

- Brief History of Electric Vehicles
- Electric vehicles
- Hybrid Vehicles
- Electric Vehicle Charging
- Challenges
- Next Steps

2

History of Electric Vehicles

3

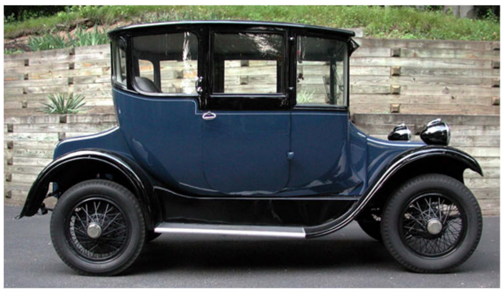
EV History

- 1834 - Non-rechargeable battery powered electric car- invented by Thomas Davenport
- 1851 - Non-rechargeable 19-mi/h electric car.
- 1859 - Development of lead acid storage battery.
- 1874 - Battery powered carriage.
- Early 1870's - Electricity produced by dynamo-generators.
- 1881 First electric vehicle (Gustave Trouve), Int'l Exhibit of Electricity, Paris, FR.
- 1890's : EV's outsold gas cars 10 to 1, Oldsmobile and Studebaker started as EV companies
- 1900 - 4,200 automobiles sold:
    - 40% steam-powered
    - 38% electric powered
    - 22% gasoline powered
- 1920's - EVs disappear and ICEVs become predominant.

4

Early Electric Vehicles

Thomas Davenport and the First Electric Car



1914 Detroit Electric car

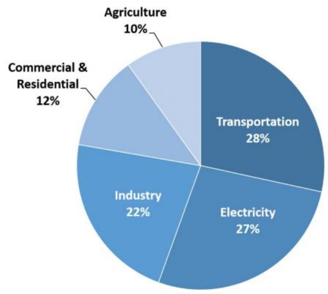
5

Disappearance and Resurgence of EVs

- Factors that Led to the Disappearance of EV
  - Invention of starter motor in 1911 made gas vehicles easier to start.
  - Improvements in mass production of Ford model T (gas-powered car) vehicles which sold for $260 in 1925 compared to $850 in 1909. EVs were more expensive.
  - Rural areas had very limited access to electricity to charge batteries, whereas, gasoline could be sold in those areas.
- Resurgence of EVs in 1960's
  - Resurgence of EV research and development in 1960's due to increased awareness of air quality.
  - Congress introduces bills recommending the use of EVs as a means of reducing air pollution

6

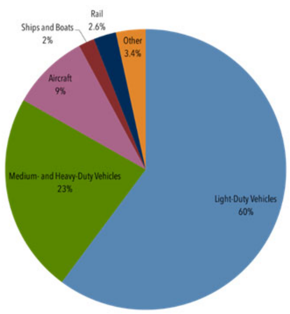
U.S. Greenhouse Gas Emissions by Economic Sector



US Transportation sector accounted for:

- About 1/3rd of total energy use and greenhouse gas emissions
- More than 70% of petroleum consumption

- In 2018, greenhouse gas emissions from transportation accounted for about 28% percent of total U.S. greenhouse gas emissions, making it the largest contributor of U.S. greenhouse gas emissions.
- In terms of the overall trend, from 1990 to 2018, total transportation emissions have increased because the number of vehicle miles traveled increased by 46% percent from 1990 to 2018.



Total 2019 CO_2 emissions: 34GT (Global)

– USA: 4.9GT; China: 9.8GT: India: 2.5GT

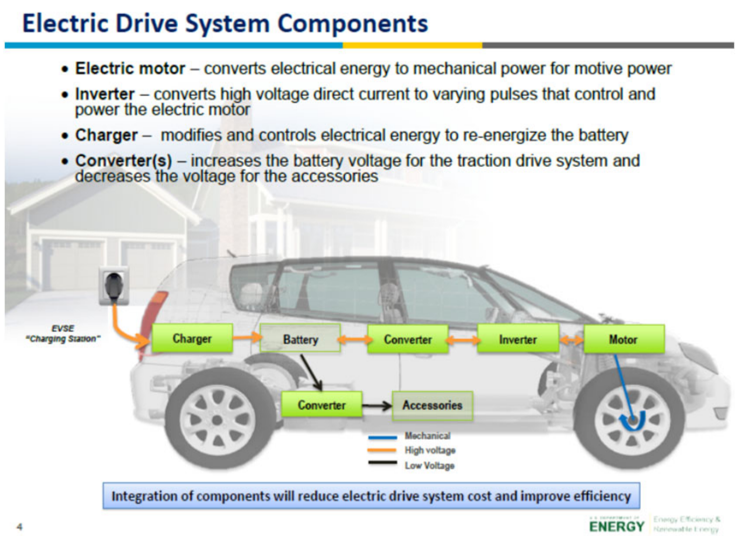
https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

7

Electric Vehicles

8

Electric Drive System Components



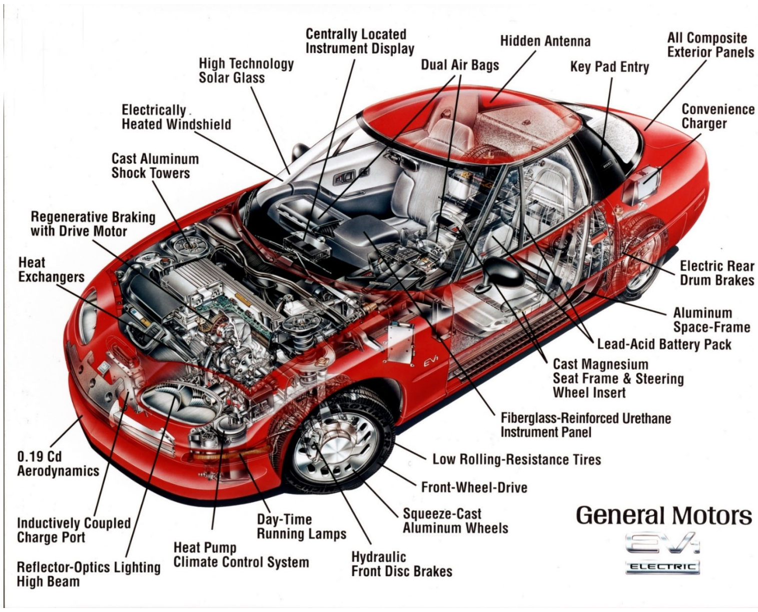
9

GM Impact 1990/EV1

- The Impact prototype was powered by two induction motors, one driving each front wheel. The battery pack consists of 32 compact 10-volt Delco Remy lead-acid batteries, connected in series. The inverter for converting the battery voltage to ac has 288 MOSFETs, each leg consisting of 24 parallel connected devices, switching at about 20 KHz. The slip frequency of the AC current was varied to maintain the highest possible efficiency throughout the RPM range. Each motor's output is transmitted to the tires via a 10.5:1 planetary gear unit.
  - Motor Type — Three phase induction motor
  - Max. motor output — 57 bhp @ 0 to 6600 rpm (per motor)
  - Motor speed at 60 mph — 9500 rpm
  - Top speed — 100 mph (rev.limited to 75 mph)
  - Torque — 47 lb-ft @ 0 to 6600 rpm (per motor)
  - Inverter type — Dual MOSFET inverter
  - Frequency range — 0-500 Hz
  - Battery type — Lead acid, 32, ten volt batteries in series.
  - Capacity — 42.5 amp. hour,13.6 KWh
  - Battery weight — 395 Kg
  - Battery charger — Integral with dual inverter package
  - Recharge Time — 2 hrs (80%)
  - Range — 120 miles @ 55 mph
  - Acceleration(0 to 60 mph) — 8 seconds
  - Vehicle weight — 1000 Kg
- GM's Impact was the first production intent EV announced by a major car manufacturer. Impact technology led to the production of EV1 electric vehicles.

10

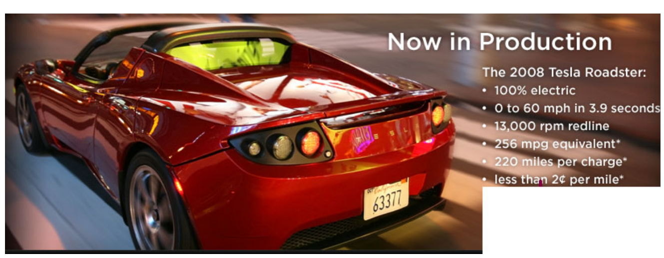
GM EV1 1996-1999



11

Tesla Roadster - 2008

- Top Speed – 125 mph
- 2 Speed Transmission
- Range – 220 miles
- Full charge in 3.5 hrs (with 70 amp home charging station)
- Shaft Drive
- Weight – 2690 lbs
- 6,831 Lithium Ion batteries (laptop)
- Each cell is independent
- 100,000 mile life expectancy
- 3-phase, 4-pole electric induction motor, 215 kW
- Propels car 0 – 60 mph in under 4 seconds
- 85% – 95% efficient



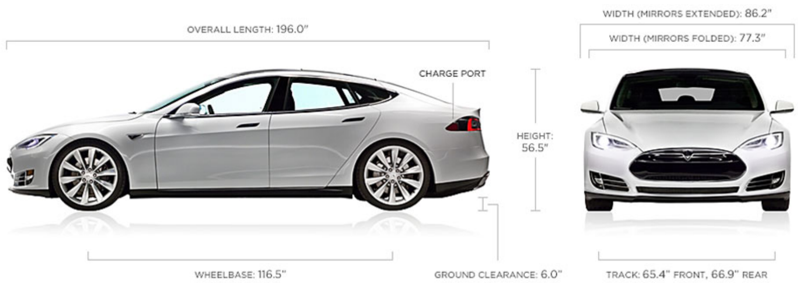
Discontinued

12

Tesla Model S - 2012

Powertrain:

Model S is a rear wheel drive electric vehicle. The liquid-cooled powertrain includes the battery, motor, drive inverter, and gear box. Microprocessor controlled, 60 kWh lithium-ion battery (230 miles range, It is 300 miles with 85 kWh), Three phase four pole induction motor with copper rotor (310 kW, 600 N·m), Inverter with variable frequency drive and regenerative braking system , and Single speed fixed gear with 9.73:1 reduction ratio.



Charging:

- 10 kW capable on-board charger with the following input compatibility: 85-265 V, 45-65 Hz, 1-40 A (Optional 20 kW capable Twin Chargers increase input compatibility to 80 A)
- Peak charger efficiency of 92%
- 10 kW capable Universal Mobile Connector with 110 V, 240 V, and J1772 adapters

13

Electric Vehicles (EV)

Nissan Leaf

Tesla Model S

KIA Soul

BMW i3

Mahindra E20 Plus

Ford Focus

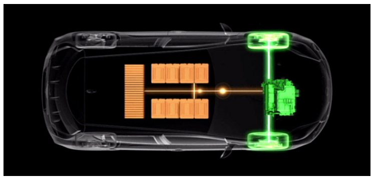
Chevrolet Volt

Mitsubishi i-MIEV

BYD e6

14

2017 Nissan Leaf



Battery Housing

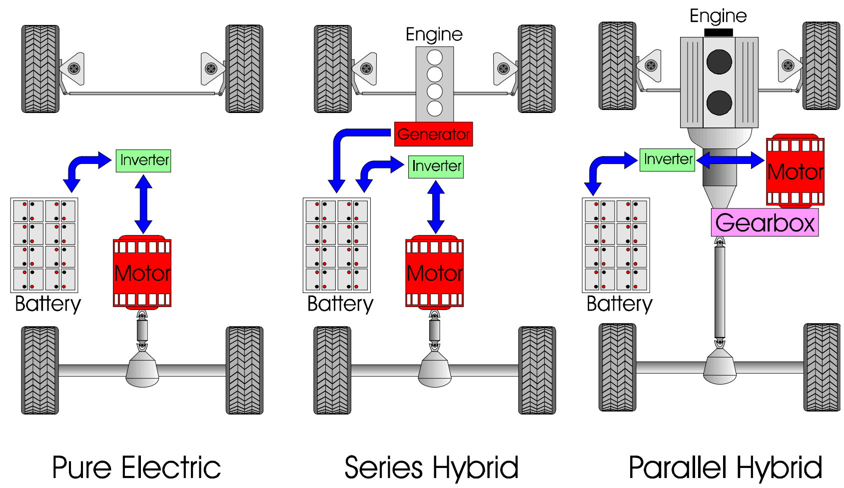
Horsepower	**107 HP**
MPGe(City/Highway)	120/101
Torque	187 lb-ft
Range	107miles
Battery Type	Li ion
Battery Energy	30kWh
Battery charger	6.6kW
Charging time	6hours

15

Hybrid Vehicles

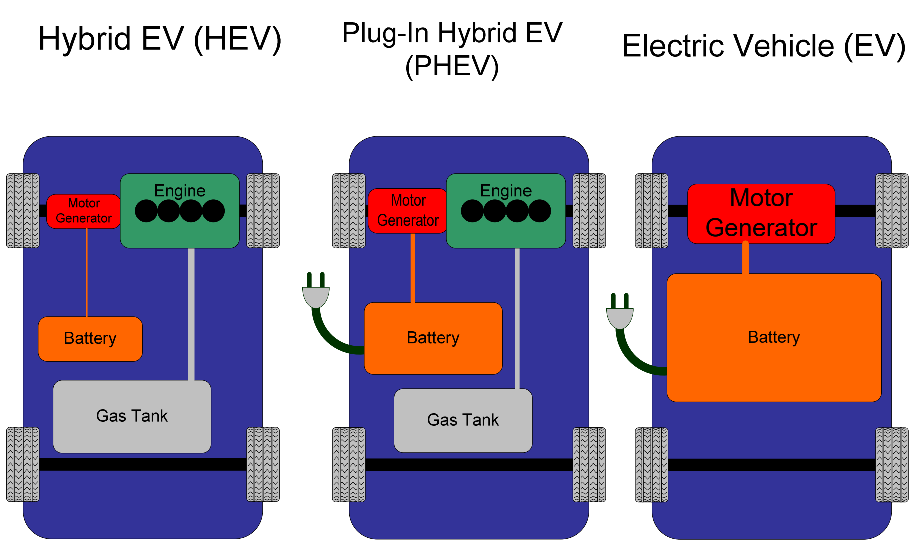
16

Electric and Hybrid Vehicle Configurations



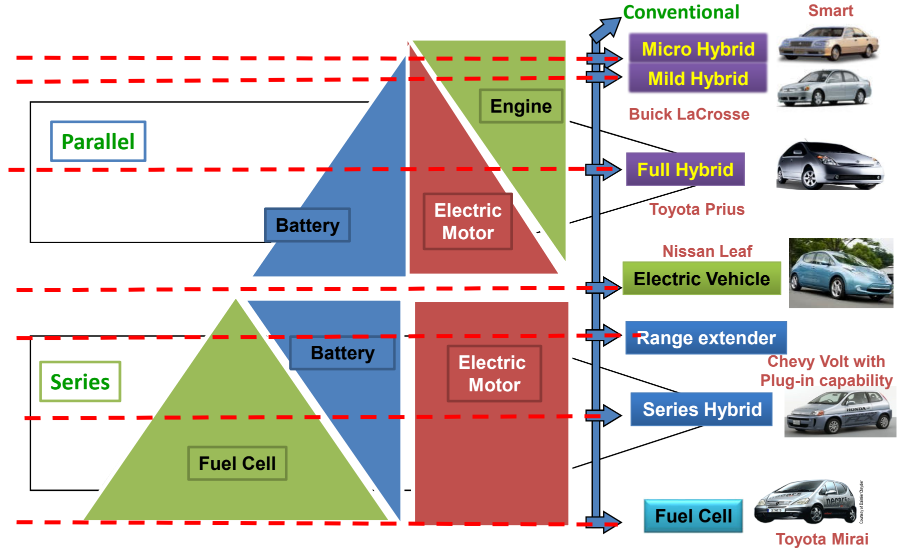
17

EV, HEV, and PHEV



18

Hybrid Power train Topology



Degrees of Hybridization

The vehicle is a….

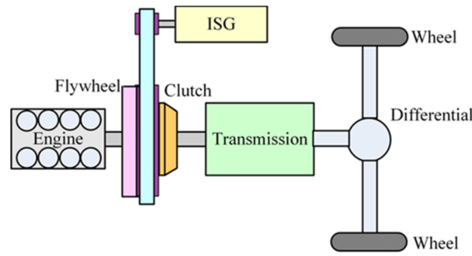
If it…	Micro Hybrid	Mild Hybrid	Full Hybrid	Plug-in Hybrid
Automatically stops/starts the engine in stop-and-go traffic				
Uses regenerative braking and operates above 60 volts				
Uses an electric motor to assist a combustion engine				
Can drive at times using only the electric motor				
Recharges batteries from a wall outlet for extended all-electric range				

Function	Micro Hybrid	Mild Hybrid	Full Hybrid	Plug-in Hybrid
Fuel economy	5% to 10%	7% to 15%	>30%	>50%
Power levels	3kW to 5kW	10kW to 15kW	>20kW	>20kW

Source: http://www.hybridcenter.org/hybrid-center-how-hybrid-cars-work-under-the-hood.html

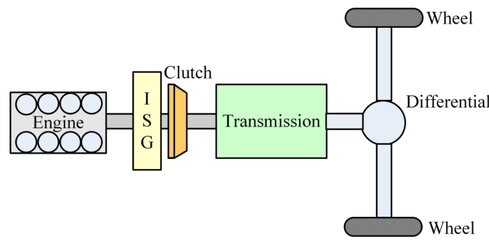
48/12 Volt Architectures (Micro and Mild Hybrids)

- There are 2 basic Architectures for 48/12 Volt Systems, which can be functionally identical within the power range of an accessory belt drive
  - Belt Driven Alternator-Starter
    - Advantageous when other powertrains are used on the same vehicle since the basic engine & transmission configuration is common.



Belt Driven Integrated Starter/Generator System

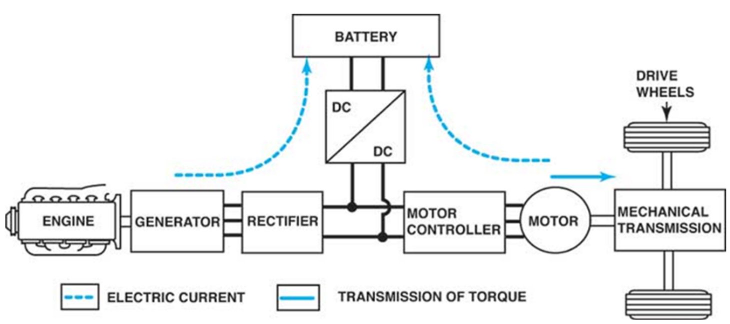
- Integrated Starter-Alternator
    - Does not have large starter-alternator external to the powertrain
    - Can transmit more power since it is not limited by belt drive.
    - Packaging tradeoff at the expense of serviceability



Integrated Starter Generator (ISG) Architecture

22

Series Hybrid Vehicles



The electric motor provides all the propulsion power

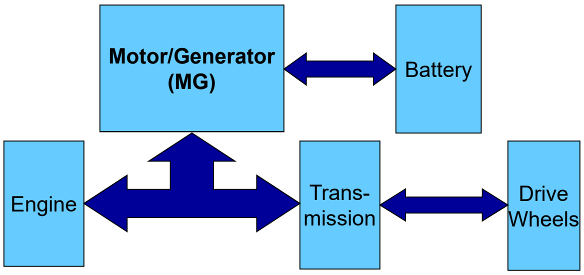
- Uses two Machines: generator and motor
- Generator sized for continuous power of vehicle
- Motor sized for peak power of vehicle
- All power must flow from engine through generator and motor to drive wheels

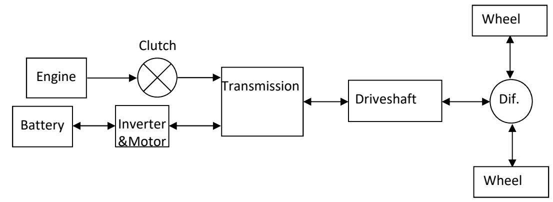
Advantages:
- Flexibility of location of engine-generator (e-g) set
- Simplicity of drivetrain
- Suitable for short trips

Disadvantages
- Needs 3 propulsion components (ICE, Generator and Motor)
- Motors must be designed for maximum sustained power, *P*
- All 3 drivetrain components need to be sized for long distance-sustained, high-speed driving

22

Parallel HEV



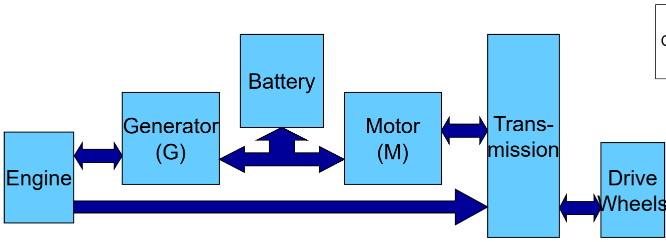


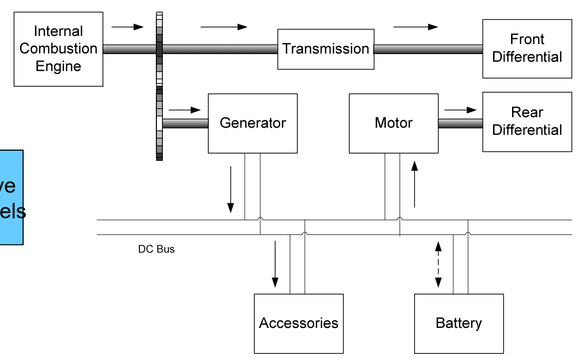
- A parallel hybrid is an HEV in which more than one energy converter can provide propulsion power
- Uses one machine for motor and one for generator functions
- Motor sized for a fraction of peak vehicle power
- Power flows from engine directly through transmission to drive wheels

Both the ICE and the electric motor are connected to the driveshaft

- Advantages
  - Smaller engine or motor can produce the same performance
- Disadvantages
  - Control complexity
  - Power blending from the ICE and motor necessitates a complex mechanical device

Series-Parallel Combination HEV



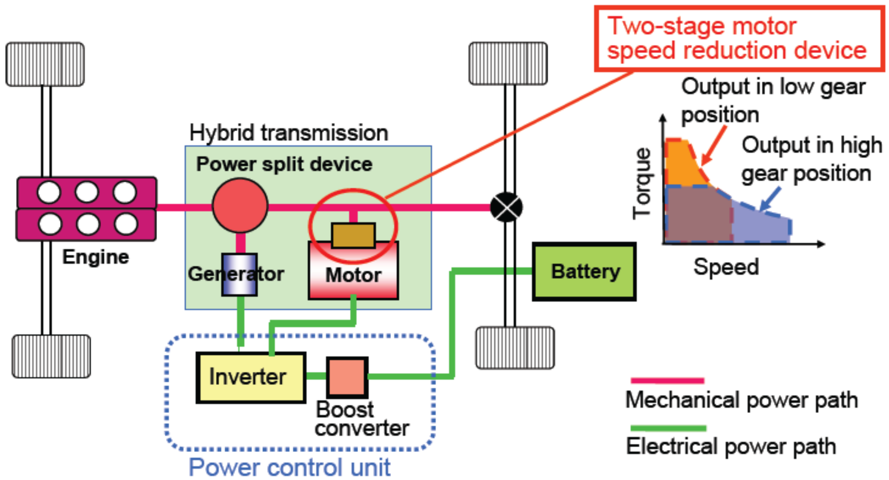


- Uses two Machines: generator and motor
- Motor and generator are sized for fraction of peak vehicle power
- Provides both series and parallel path from engine to drive wheels

- A small series element + parallel HEV (Ex: Toyota Prius)
- IC engine is also used to charge the battery
- Electric motor delivers power to the front wheel in parallel with the ICE
- Inverter is bi-directional: Charging batteries and providing power to motor
- Central control unit regulates the power flow

Toyota Hybrid System II

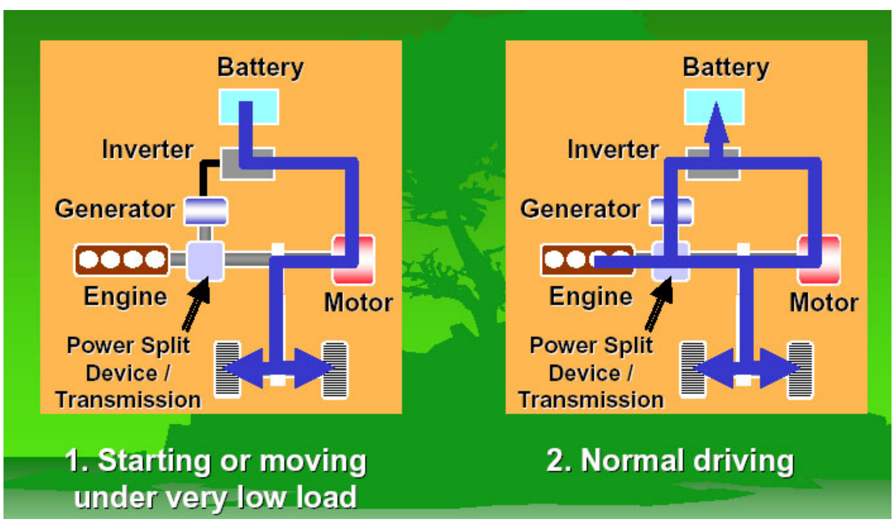
With two-stage motor speed reduction device



TOYOTA

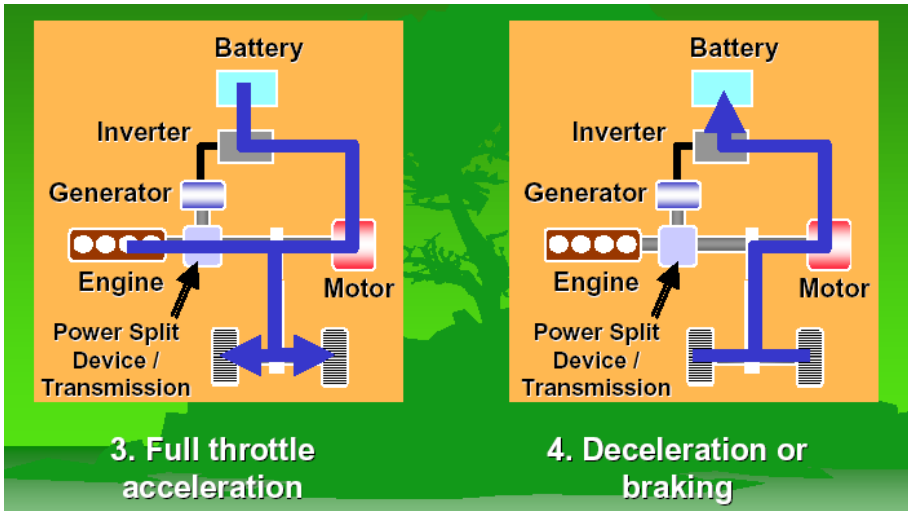
25

PRIUS OPERATION



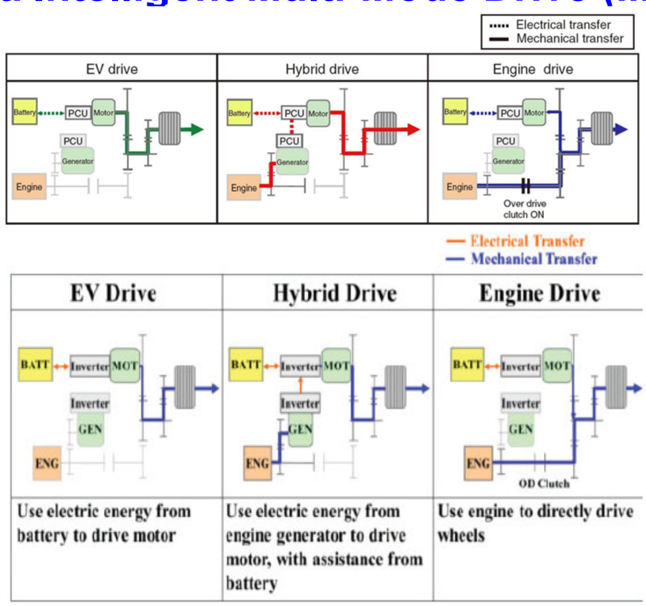
26

PRIUS OPERATION



27

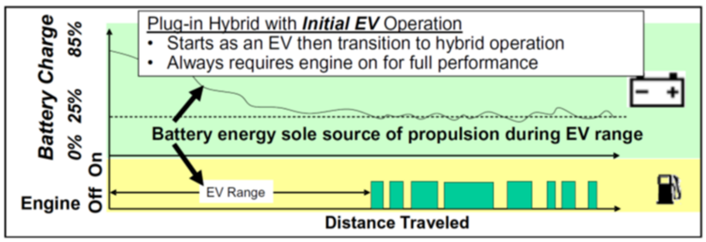
Honda Intelligent Multi-Mode Drive (iMMD)



28

Plug-in Hybrid Vehicle

- All-electric range
  - Get home with exactly no battery charge left
- Charge-sustaining mode

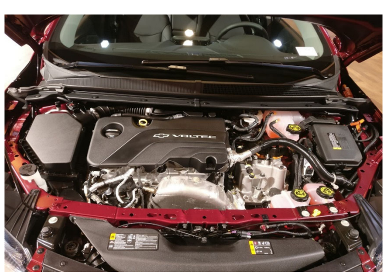


[Tate, Harpster, and Savagian 2008]

Electric Vehicle Team

Massachusetts Institute of Technology

2017 Chevrolet Volt Plug-in Hybrid



Power	87 kW PM Motor 48kW ferrite motor
Torque	294 lb-ft
EPA MPG (City/Highway/Combined)	43/42/42
MPGe	106 miles
Range Electric/Overall	53miles/420miles
Battery Type	Li ion
Battery Pack	18.4kWh, 300V
Charging time @ 120V	13hrs
Charging time @ 240V	4.5hrs
Curb weight	3543 lbs

In EV driving, the 2 motors can be linked together so the total power is actually higher than the original Volt which allows the 2016 Volt to accelerate from 0-30 mph in a very aggressive 2.6 seconds.

2017 Toyota Prius Plug-In Hybrid

Horsepower, 1.8L engine (EV/ECO/Power)	95 HP @5200rpm	System net power	121 HP
Torque	105 lb-ft	Motor type	PMSM
Curb weight	3365lb	Voltage	600V(max)
Acceleration 0-62mph	10.7secs	Battery voltage	351.5V
Top speed electric/combined	62mph / 112mph	Battery capacity	8.8kWh
Range (electric/total)	25miles / 640miles	EPA MPG (city/high/combined)	55/53/54
Battery charging time 240V	2hrs 10min	Battery charging time standard	5hrs 30mins
Battery Type	Li ion		

31

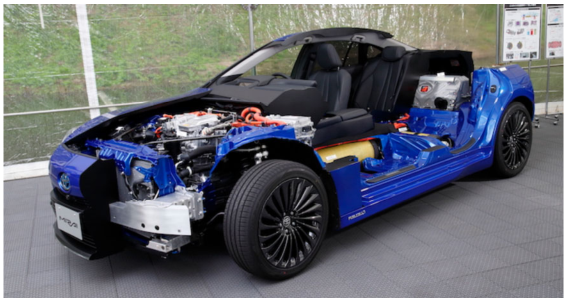
2020 Mitsubishi Outlander PHEV-2020

Motor: Twin AC Synchronous permanent magnet motor:141.7 kW

Motor Torque output	195Nm
Battery	12kWhr Li-ion - 300 V
Engine	117HP @4,500rpm, 2 L
Pure EV range	22 miles
Total range	310 miles

32

2021 Toyota Mirai Fuel Cell Vehicle



Toyota hydrogen fuel cell car Mirai .
Base Price: $49,500
Range: 650 km
Trunk can hold 5.6 kilograms of hydrogen
when compressed at 10,000 psi
Lithium ion battery : 310.8V and 4.0 Ah,
Motor: 182-hp/221 lb-ft Permanent-magnet motor
Range: 404 miles

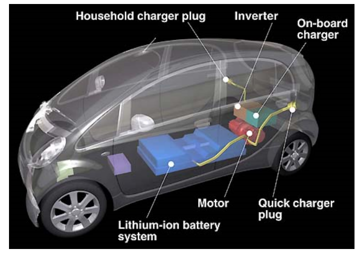
33

https://fuelcellsworks.com/news/new-mirai-hydrogen-fuel-cell-electric-vehicle-under-the-skin/

Electric Vehicle Charging

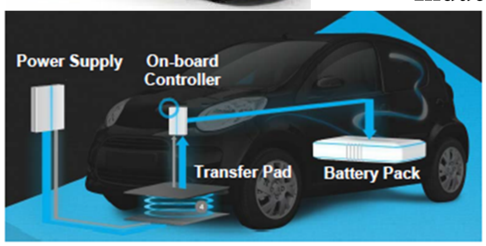
34

Electric Vehicle Charging



Conductive Charging

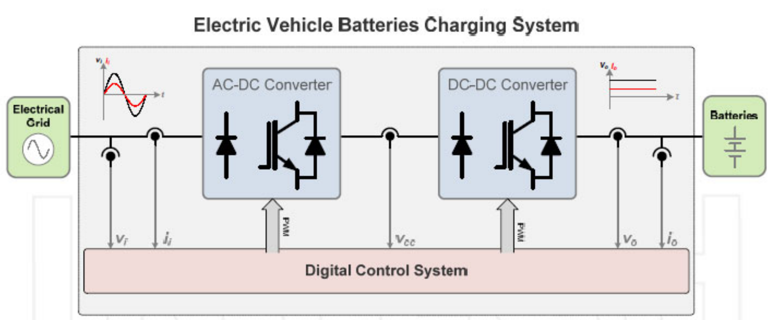
Inductive charging

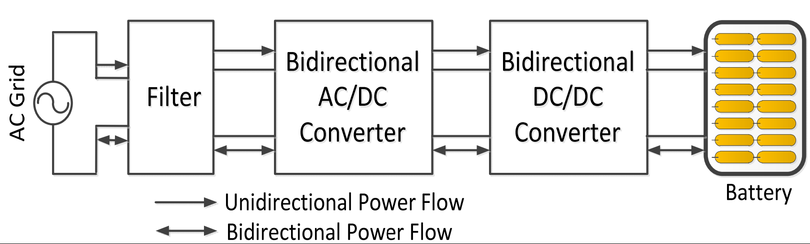


To charge, an EV has to be simply parked or driven over a pad

35

Structure of electric vehicle battery charging system





36

DC Fast Charging

- DC-fast charging (DCFC) enables a direct connection to the DC leads to the vehicle battery for the very fastest rate charging.
- DCFC is most often associated with the fastest charging rates possible in an attempt to approach the rapid energy transfer rate of gasoline refueling.
- DCFC charge rates of 100kW+ require grid connections that are only typically available in commercial or industrial sites (and not homes).
- For an intercity trip, a rough estimate is that a large battery BEV (such as an 85kWh Tesla Model S) can acquire enough charge for about 2.5 hours of highway driving in 30 minutes at the fastest Tesla Supercharger DCFC station.
- Siemens has developed a 150kW charger with up to 920V capability.
- Automobile manufacturers are launching long-distance battery-powered vehicles worldwide, which can recharge a range of 500 km in 10 to 15 minutes (Charging like refueling)

BYD's new 150 kW DC fast charger earns UL certification

https://chargedevs.com/newswire/byds-new-150-kw-dc-fast-charger-earns-ul-certification/

http://tec.ieee.org/newsletter/january-february-2015/plug-in-hybrid-electric-vehicle-dc-fast-charging-the-future-just-got-more-interesting

37

Bi-directional on-board charger (V2G and G2V)

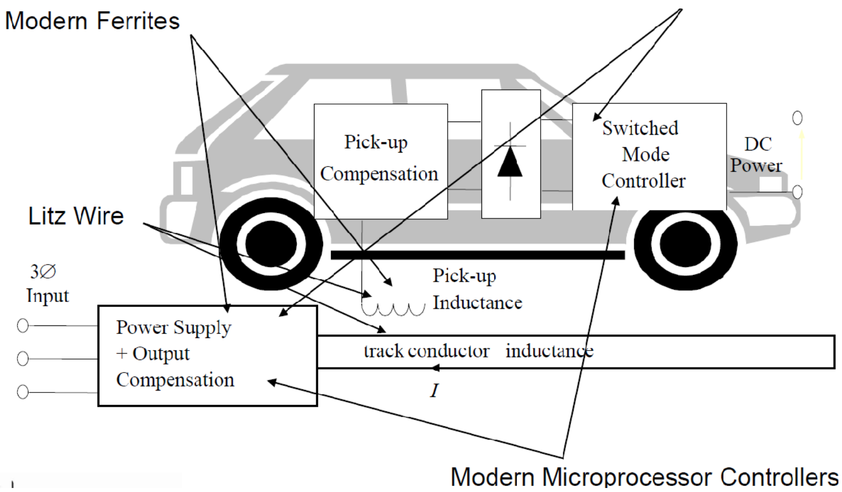
Bel Power Solutions has introduced the a 22/25 kW bi-directional liquid-cooled on-board inverter battery charger with export functionality. Up to 4 of these charging units can be connected in parallel, with efficiency near 94%.

It is possible to connect this charger to a charging station or directly to the grid (190-264 VAC single-phase or 330-528 VAC three-phase) to charge EV batteries. The output voltage covers a wide variety of batteries from 240 VDC to 800 VDC, with a constant 60-amp output current. When running on battery power, the system can export up to 25 kW (400 VAC @ 50 Hz or 480 VAC @ 60 Hz) to power three-phase AC equipment.

https://chargedevs.com/newswire/bel-power-solutions-announces-bi-directional-on-board-charger/

38

Wireless EV battery charging

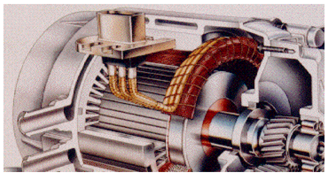


An inductive power wireless (IPT) transfer uses strongly coupled magnetic resonance to transfer power from a transmitting on the ground to the receiving pad in the EV

Challenges

Electric Motors for EV/HEVs

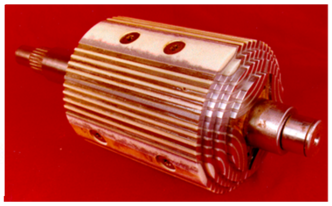
- Motor determines the characteristics of the drive system and the controller, and also it determines the ratings of the power devices of the inverter. Types of motors considered for EV/HEVs are:
  - Three phase induction motor
  - Permanent magnet synchronous motor
    - Surface mount motor
    - Interior PM motor
    - Concentrated winding motor
  - Switched Reluctance Motor
  - Synchronous Reluctance Motors



Induction motor

PM motor

Switched Reluctance Motor



Synchronous Reluctance

Power Electronics

- **Power electronics and high power density electric machines are the enabling technologies for the successful development of MEAs. Further work is needed in the following areas:**
  - Power device packaging required to withstand the large temperature variations, and high thermal cycle capability
  - Effects of EMI, and EMI mitigation at high altitudes
  - Fault tolerant power conversion topologies
  - High temperature operation of power electronics and electric machines (For embedded generation, up to 250ºC)
  - Passive components with reduced weight, volume, and high temperature capability
- **Wide band gap devices (SiC and GaN) can meet some of the challenges:**
  1. Reduced heat-sinking / thermal management
  2. Closer integration into the hostile engine environment
  3. Reduced passives with increased switching frequency
  4. Alternative circuit topologies with inherently reduced passives
- **Several companies have developed inverter prototypes based on SiC switches that show significant size reduction up to 1/6 of the size with silicon devices**

42

Integrated Motor and Inverter

The Integral e-Drive division of Integral Powertrain has collaborated with McLaren Applied Technologies and Hewland Engineering to design a new electric axle system. The e-axle features integrated inverter technology from McLaren, two 200 kW permanent magnet motors from Integral e-Drive, and two reduction gear sets for torque vectoring from Hewland. Overall power density is 4.4 kW/kg

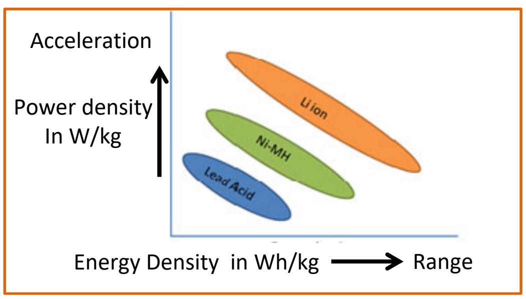
BorgWarner to build integrated drive module for Ford Mustang Mach-E

https://chargedevs.com/newswire/integral-edrive-partners-with-mclaren-and-hewland-on-new-electric-axle-system/

43

Battery characteristics

- The main considerations in the selection of EV/HEV batteries are
  - ∗ Power density
  - ∗ Energy density
  - ∗ Weight
  - ∗ Volume
  - ∗ Cycle life
  - ∗ Temperature range
  - ∗ Environmental conditions
  - ∗ Cost



Battery type	Lead acid	NiMH	Lithium-ion
Energy Density (Wh/kg)	30-40	50-80	100-160
Power density (W/kg)	120-200	250-1000	1000-1500
Cycle life	200-300	300-500	500-1000

44

Lithium ion batteries

Li-ion systems get their name from their unique cathode materials. The lithium-ion family is divided into three major battery types, so named by their cathode oxides, which are cobalt, manganese and phosphate. The characteristics of these Li-ion systems are as follows.

- **Lithium-ion-cobalt** or *lithium-cobalt* (LiCoO2): Has high specific energy with moderate load capabilities and modest service life. Applications include cell phones, laptops, digital cameras and wearable products.
- **Lithium-ion-manganese** or *lithium-manganese* (LiMn2O4): Is capable of high charge and discharge currents but has low specific energy and modest service life; used for power tools, medical instruments and electric powertrains.
- **Lithium-ion-phosphate** or *lithium-phosphate* (LiFePO4): Is similar to lithium-manganese; nominal voltage is 3.3V/cell; offers long cycle life, has a good safe record but exhibits higher self-discharge than other Li-ion systems.

45

Solid state batteries

- Solid-state batteries replace the liquid or polymer electrolyte found in current lithium-ion batteries with a solid
- The key difference between the commonly used lithium-ion battery and a solid-state battery is that the former uses a liquid electrolytic solution to regulate the flow of current, while solid-state batteries opt for a solid electrolyte. A battery's electrolyte is a conductive chemical mixture that allows the flow of current between the anode and cathode.
- Solid state batteries still work in the same way as current batteries do, but the change in materials alters some of the battery's attributes, including maximum storage capacity, charging times, size, and safety.
- The main benefits are batteries that are lightweight, smaller, higher-capacity and cheaper than current liquid-based lithium-ion batteries
- Solid state Batteries are becoming increasingly relevant with the adoption of electric vehicles. Toyota and Dyson both believe solid-state batteries could be in final products in the very near future.

46

EETT Roadmap

Electrical and Electronics Technical Team Roadmap Roadmap October 2017

Table 2. Technical Targets for Electric Traction Drive System

ETDS Targets			
Year	2020	2025	Change
Cost ($/kW)	8	6	25% cost reduction
Power Density (kW/L)	4.0	33	88% volume reduction

Table 3. Technical Targets for High Voltage Power Electronics

Power Electronics Targets			
Year	2020	2025	Change
Cost ($/kW)	3.3	2.7	18% cost reduction
Power Density (kW/L)	13.4	100	87% volume reduction

Table 4. Technical Targets for Electric Traction Motor

Electric Motor Targets			
Year	2020	2025	Change
Cost ($/kW)	4.7	3.3	30% cost reduction
Power Density (kW/L)[1]	5.7	50	89% volume reduction

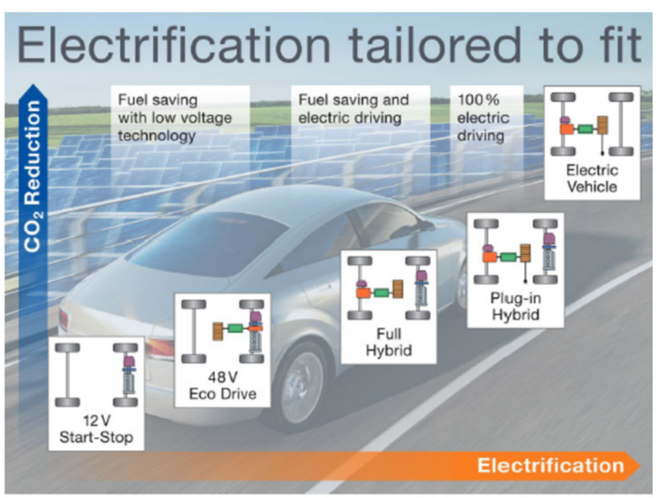
Table 5. Technical Targets for DC/DC Converter

DC/DC Converter Targets	2020	2025
Cost, $/kW	<50	30
Specific power, kW/kg	>1.2	4
Power density, kW/L	>3.0	4.6
Efficiency	>94%	98%

Table 6. Technical Targets for On-Board Charger

On-Board Charger Targets	2020	2025
Cost, $/kW	50	35
Specific power, kW/kg	3	4
Power density, kW/L	3.5	4.6
Efficiency	97%	98%

https://www.energy.gov/sites/prod/files/2017/11/f39/EETT%20Roadmap%2010-27-17.pdf



Connected Electric Vehicle

Vehicle to grid
Smart energy system

Future Vehicles

- MOSFET-**IGBT**-Silicon carbide based vehicles
- Advanced high density packaging and operating at junction 250^{0}C temperature and up to 100kHz
- Induction- **PM**--Synchronous Reluctance?
- Presently, no standards for nominal battery voltage. In future, there will be standards based on the classification of the vehicles
- Lead acid- NIMH-**Lithium ion-** Solid state- Lithium Air (Long term ?)
- Wireless Charging
- Renewable energy for charging
- Grid integration: Most new electric vehicles come with grid power connection as standard
- Driverless-Autonomous-connected
- 3D printing, packaging, and miniaturization
- New materials and processes
- Flying cars and VTOL vehicle

Questions?