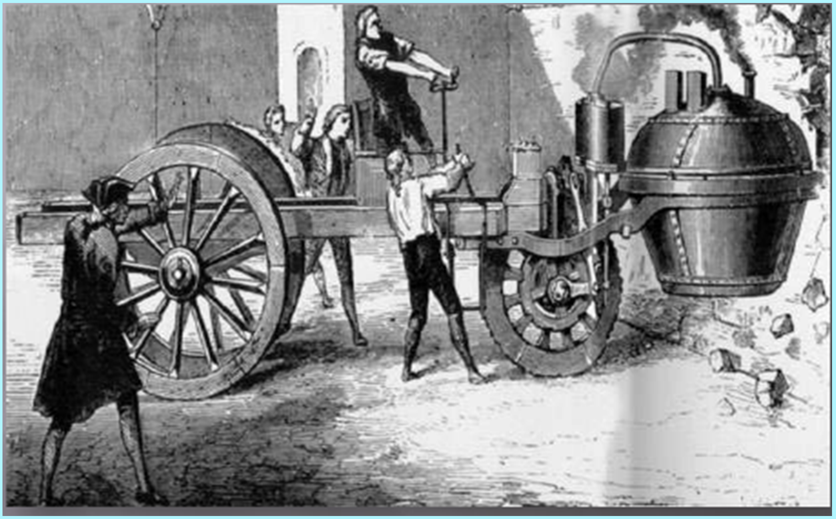
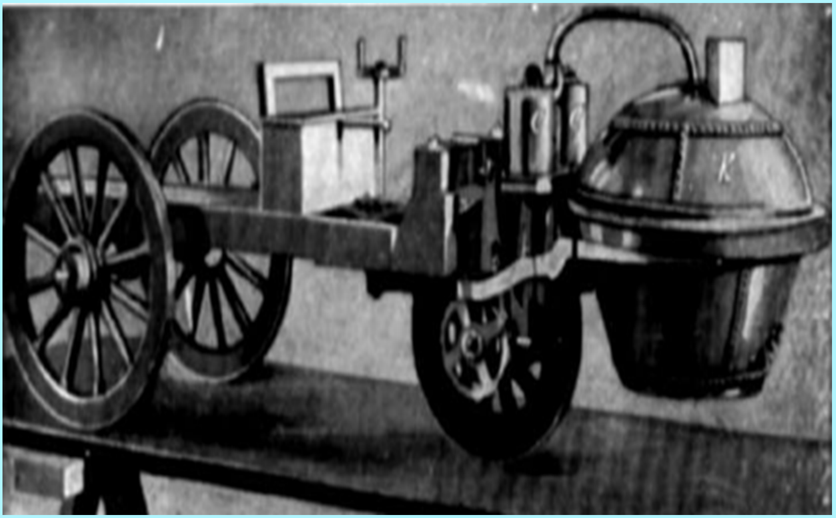
Unit 1:- Electric and Hybrid Powertrain Technologies

By:- Dr. Chetan Khadse

History of Wheels….



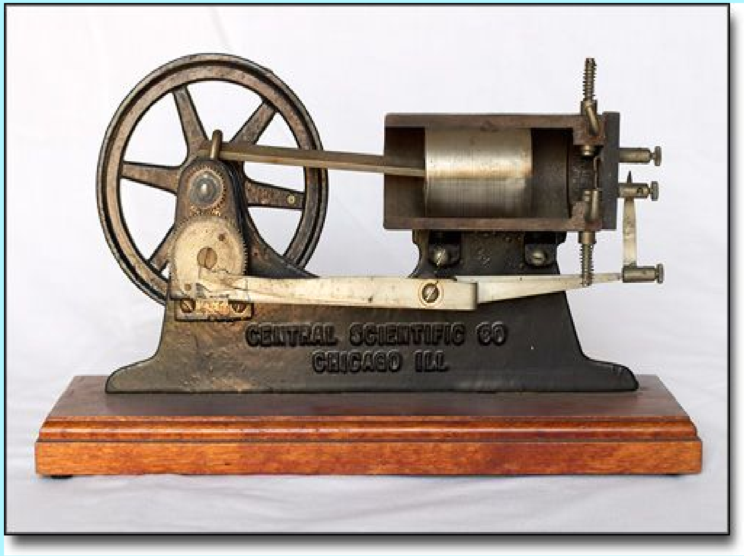


- In the early 15th century, the Portuguese arrived in China combination of two culture provides the creation of a wheel that turned under its own power.
- By the 1600s, small steam-powered engine models were developed,
- France invented first self propelled mechanical vehicle in 1769. Built the first True Automobile Tricycle, Steam Engine, 4 passengers and 2.25 miles per hour
- Then the journey begins with

History of Wheels….

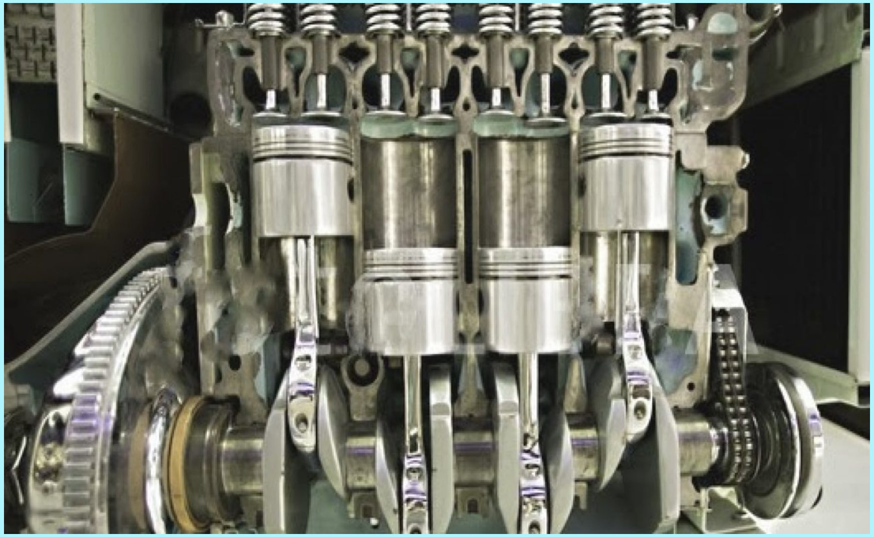
Henry Ford
- 1908 - Invented the Model T
- Inexpensive
- Versatile
- Easy to maintain
- Enabled middle class people to own an automobile

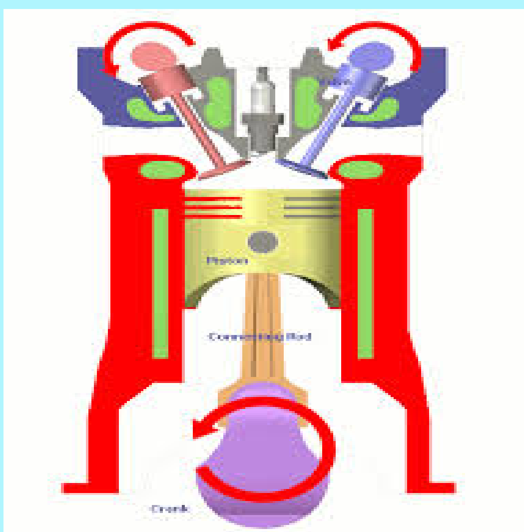
History of IC Engine….



- In 1806, Swiss engineer François Isaac de Rivaz built an engine powered by internal combustion of a hydrogen and oxygen mixture.
- In 1864, Nicolaus Otto patented the first atmospheric gas engine.
- In 1872, American George Brayton invented the first commercial liquid-fueled internal combustion engine.
- In 1876, Nicolaus Otto, working with Gottlieb Daimler and Wilhelm Maybach, patented the compressed charge, four-stroke cycle engine.

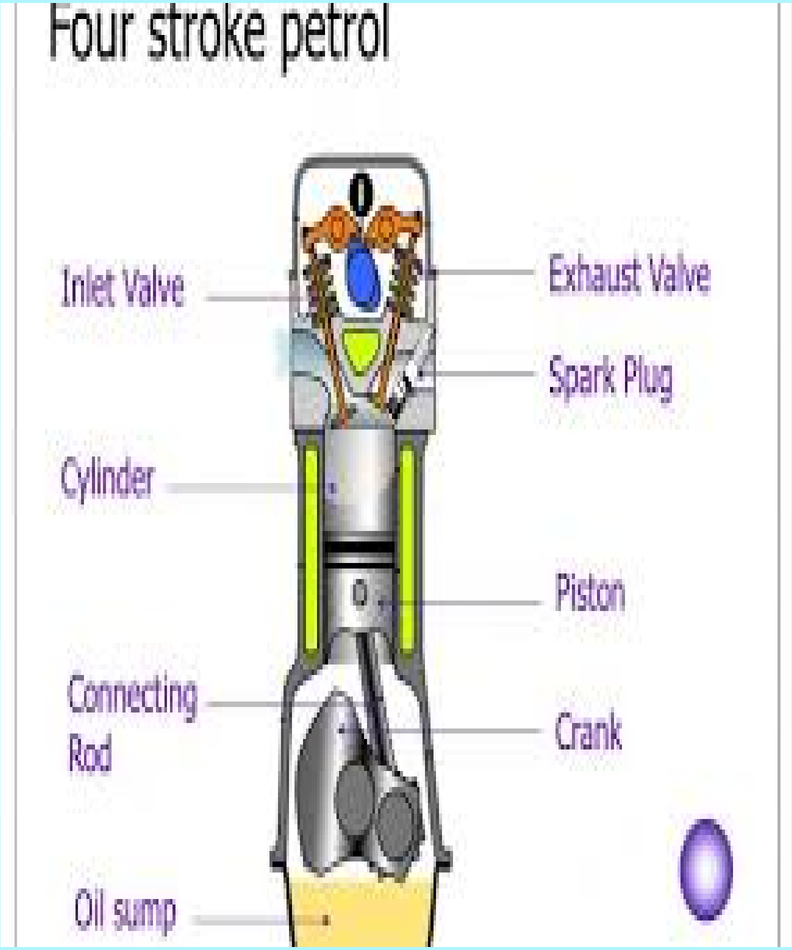
IC Engine….





- In Internal Combustion Engines (IC Engines), combustion of fuel takes place inside the engine cylinder.
- Examples: Diesel Engines, Petrol Engines, Gas engines.
- IC Engines are classified into
  - ü Cycle of operation (No of Strokes per cycle)
    - Two Stroke Cycle Engines
    - Four Stroke Cycle Engines
  - Ignition Method :
    - Spark Ignition (SI)
    - Compression Ignition

Four Stroke Cycle Petrol Engines….



Construction :

•A piston reciprocates inside the cylinder

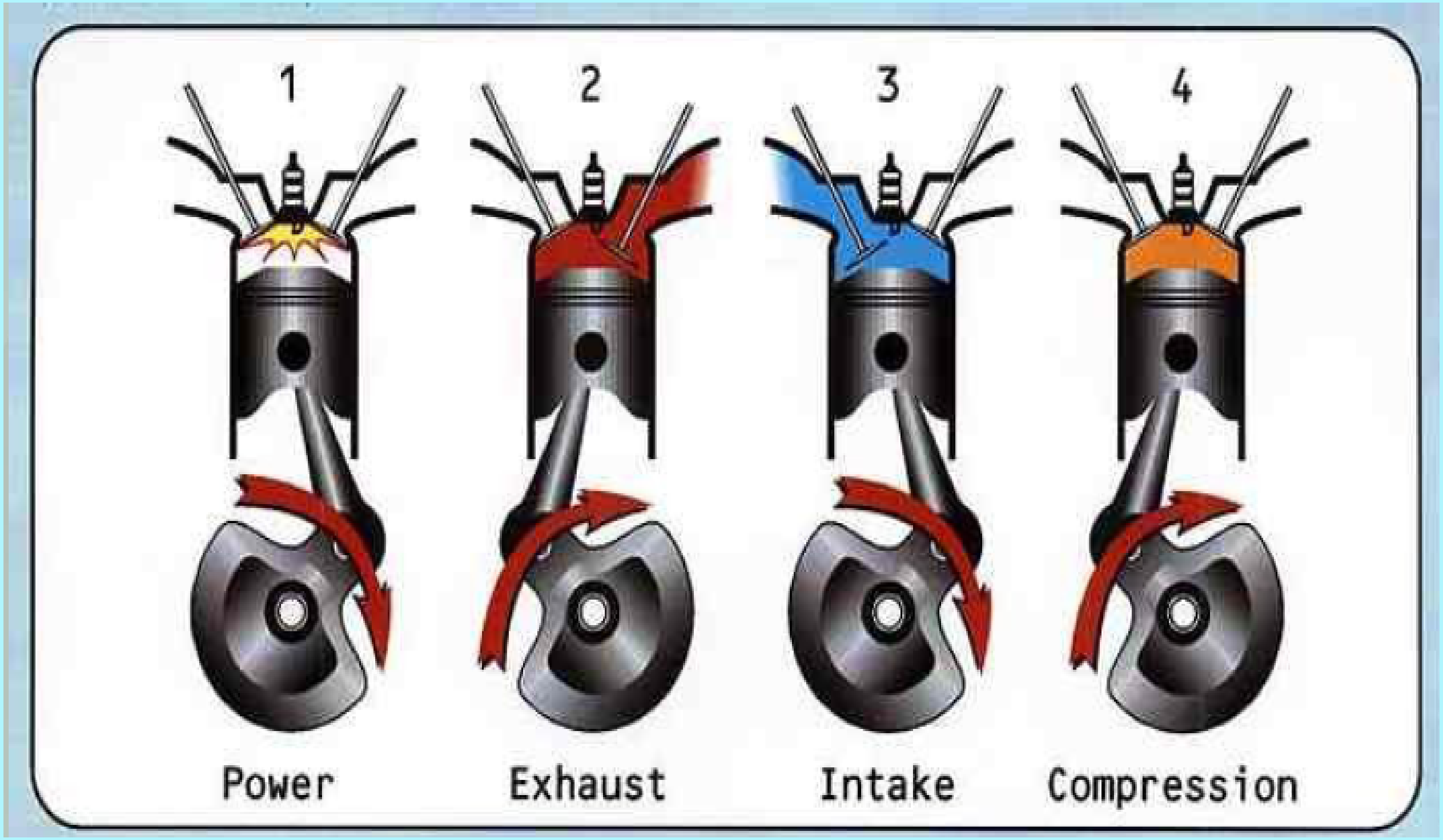
•The piston is connected to the crank shaft by means of a connecting rod and crank.

• The inlet and exhaust valves are
Mounted on the cylinder head.

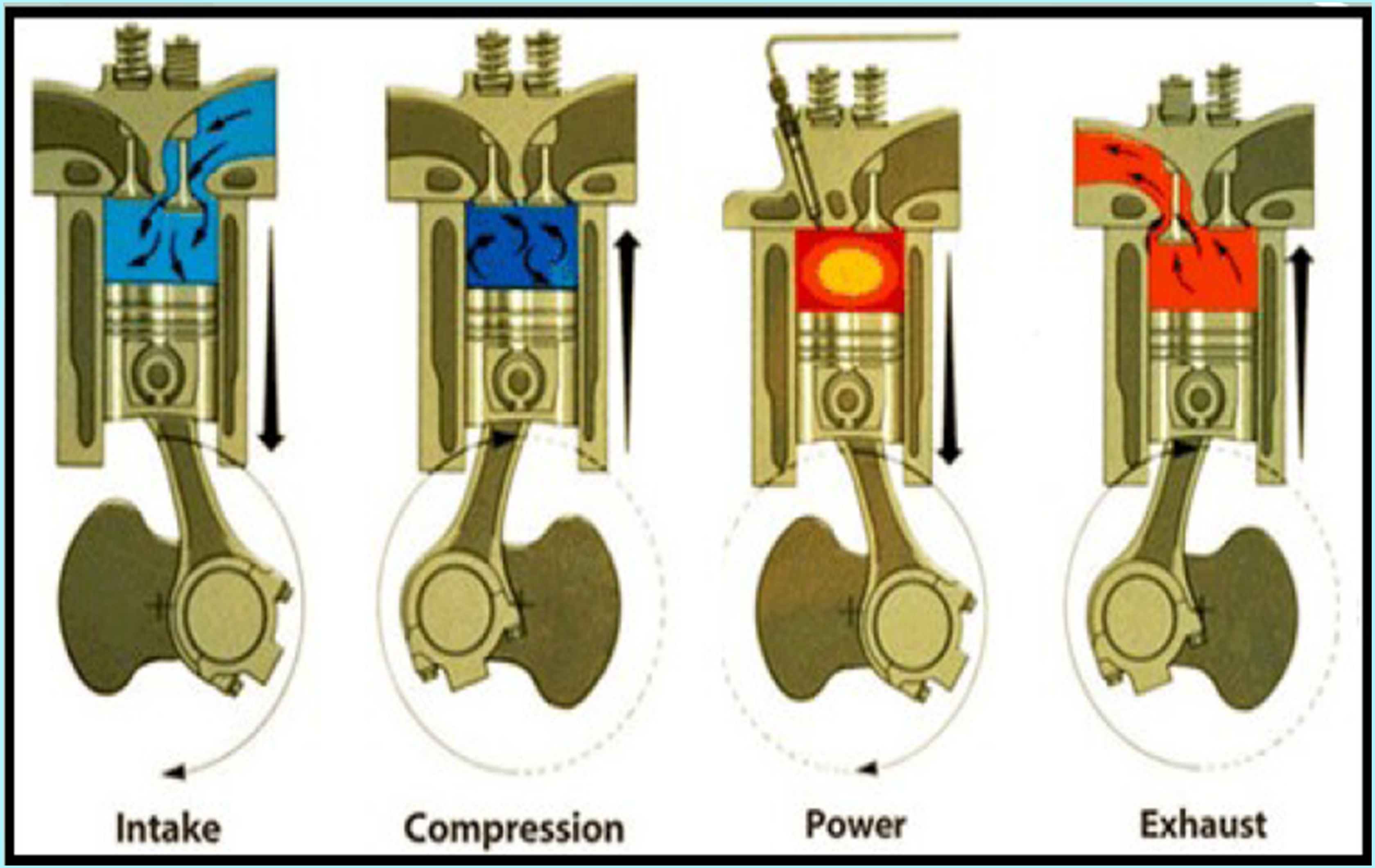
•A spark is provided on the cylinder
Head.

• The fuel used is petrol

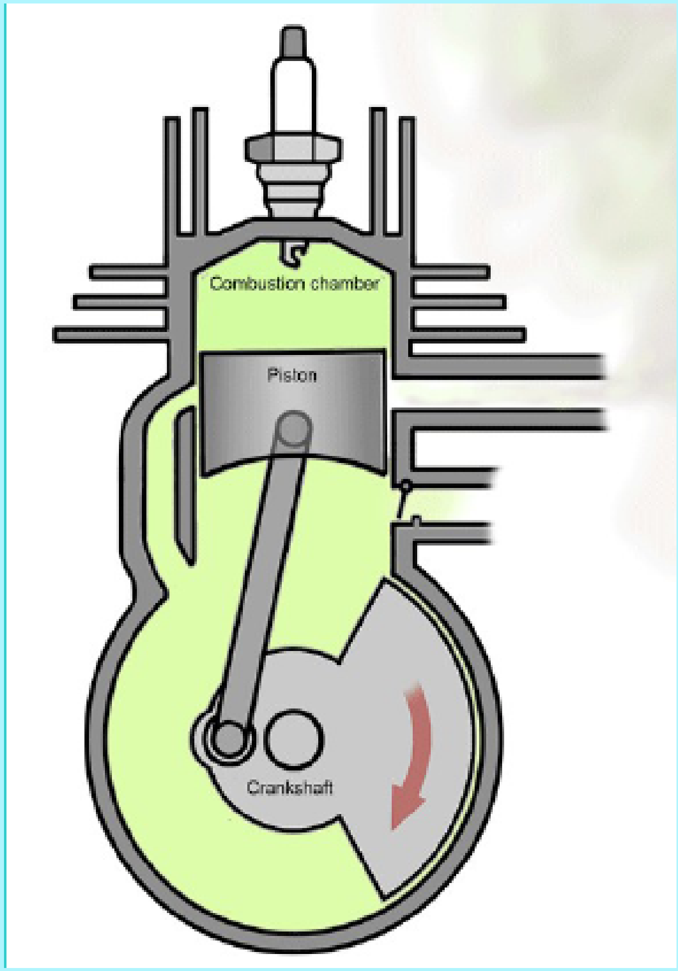
Four Stroke Cycle Petrol Engines….



Four Stroke Cycle Diesel Engines….

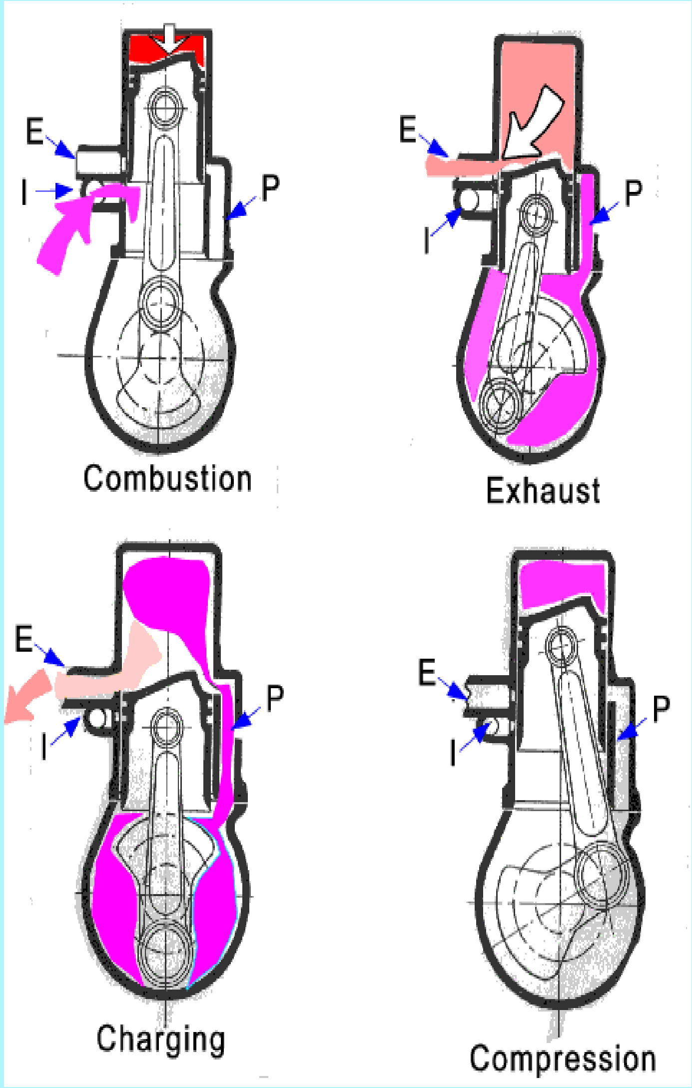


Two Stroke Cycle Petrol Engines….



- Piston is connected to the crankshaft by means of connecting rod and crank.
- There are no valves in two stroke engines, instead of valves ports are cut on the cylinder walls.
- There are three ports, namely inlet, exhaust and transfer ports.
- The closing and opening of the ports are obtained by the movement of piston. The crown of piston is made in to a shape to perform this.
- A spark plug is also provided.

Two Stroke Cycle Petrol Engines….

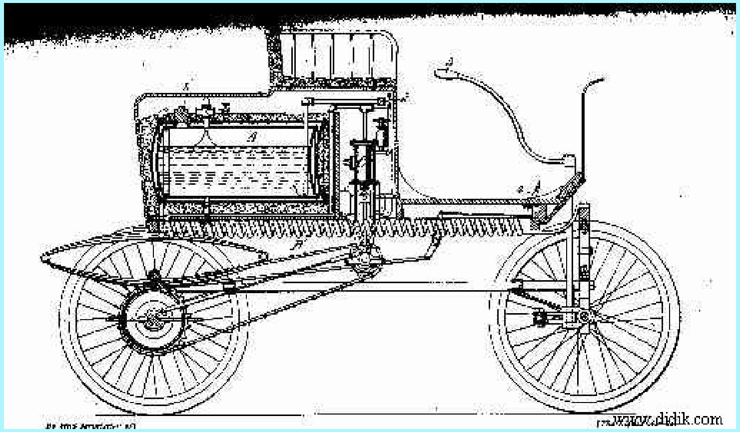


- All the processes in the two stroke cycle engine are completed in two strokes.
- These engine have 1power stroke per revolution of the crankshaft.
- In the two stroke engine there is a two opening called ports are provided in place of valve of four stroke engines
- Here suction and exhaust strokes are eliminated . The exhaust gases are driven out of the cylinder by the fresh fuel entering the cylinder.

Spark Ignition vs Compression Ignition

S.No.	Spark Ignition Engines (SI)	Compression Ignition Engines (CI)
1	It draws air fuel mixture into the cylinder during suction stroke	It draws only air into the cylinder during suction stroke.
2	Petrol engines operate with low pressure and temperature	Diesel engines operate with high pressure and temperature
3.	Pressure ranges from 6 to 12 bar Temperature ranges from 250° to 300° C	Pressure ranges from 35 to 40 bar Temperature ranges from 600° to 700° C

History of Electric Vehicle (EV)….



- The first EV (tricycle) was built in 1834, which was built on a non-rechargeable battery built by Thomas Davenport
- After the invention of lead acid battery, rechargeable battery based EV was possible and was built in 1874, by, David Salomons.
- The first commercial product was developed by 1886.
- In 1900, among 4200 automobiles that were sold in USA, 38% were EVs.

History of Electric Vehicle (EV)….

- Electric Carriage and Wagon Company, which came up with its model called, ‘Electrobat’, in 1894.
- There was a model called, ‘Victoria’, in 1897, which, has become a household name
- There is a company called, ‘BGS’, in France, which has developed, many types of EVs, in all scales. Right from cars’, buses’ and limousines’ of all varieties.
- One of the BGS car had a world record of, 290 kilometeres per charge.

History of Electric Vehicle (EV)….

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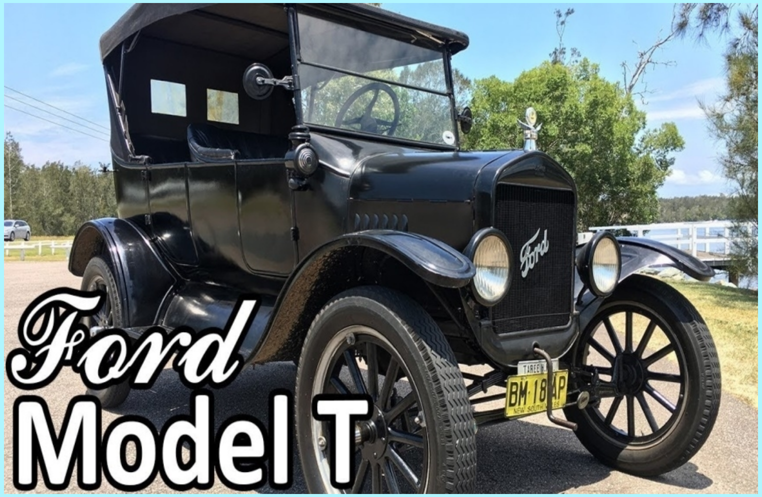
- One of the BGS car had a world record of, 290 kilometers per charge.
- By 1912, around 34,000 EVs, were

History EV Disappearing in 1930….



But unfortunately, EVs started disappearing due to two developments in1930…

1. Henry Ford, has gone for mass production of, 'Ford, Model T', in 1925. was able to reduce the price of it, by over one third of its, conventional price, at 1909.
2. Incidentally, the IC engines that time were unable to start on its own and need manual cranking. Another development, which supported the first development, was the invention of Automobile Starter motor by Charles Keetering.

History EV appearing again in 1970….

- First was, there was oil shortage in Arabian countries and Global countries were looking at possibility of alternate, energy resources.
- Secondly, by 1950s onwards, lot of cities like, London and California, have seen worst kind of smog.

In 1976 congress enacted public law for Electric & Hybrid Vehicle Research. Which helps in development of EV technologies and making it feasible for commercially.

Famous regulation ‘CARB’(California Air Resources Board) rules says that, 2% of all vehicles by 1998, should be of Zero Emission Type and 10% by 2003.

History Phase II Push for EV….

There was also a great push, in academic circles

- One of them was the organisation of, ‘Great Electrical Car Race’, in 1968.
- This race is between, Boston near MIT, to Pasadena, near California Institute of Technology, (Caltech)
- MIT to Pasadena and Pasadena to MIT, covering a distance of, around 3500 miles and they were able to recharge their EVs, by 53 intermediate recharging stations.
- Which led to development of EVs, in many universities & Industries in US

History Phase II EV Cars….

Many auto makers in US, Japan and Europe, started development of EVs.

Many companies like

- General Motors, Ford and Chrysler in US.
- In Japan, almost all the companies like, Toyota, Nissan, Honda, Mitsubishi, Suzuki
- In Europe, Peugeot, Renault, BMW, Mercedes, Audi, Volvo, Volkswagen led the way for the development of EVs.
- General Motors first launched Electrovair in 1966, Electrovan in 1968, Electrovette in 1979.

Phase III EV Cars….

By late 1990s, many companies were able to launch a very good vehicles, in terms of performance and efficiency in their Ev's.

Popular Evs:

ü GM EV1 : 100 KW, I.M., lead acid,100 kms/hr, 9 s, 144 Km

ü Nissan Altera EV: 62 KW, PMSM, 120 kms/hr, 192 Km range.

ü NIES Luciole: 72 KW, in wheel PMSM, VRLA, 130 kms/hr, Solar

ü HKU-U2001: 45 KW, PMSM, Ni-Cd,110 kms/hr, 176 Km

ü Reva : 13 KW, SEDC, VRLA ,65 kms/hr, 80 Km

Popular HEVs 1990

ü Toyota Prius: 52 KW, ICE, 32KW PMSM, Ni-mh, 160 kms/hr

ü Honda Insight: 50 KW, ICE, 10KW PMSM, Ni-mh, 26-30kms/litr

Phase III EV Cars….

Current Popular EVs

ü Tesla Roadstar 2007 Model-S(2012), Model-X(2015), Model-3(2017)

ü Nissan Leaf

ü Chevy Bolt

ü BMW 13

Current popular HEVs are PHEV (Plug-in hybrid electric vehicles).

ü Honda Accord hybrid

ü Toyota Camry, Toyota Prius hybrid

ü Ford Fusion hybrid

luxury versions ('Luxury Sedans')

Lexus RX,

Volvo T8

BMW xDrive

Thank You

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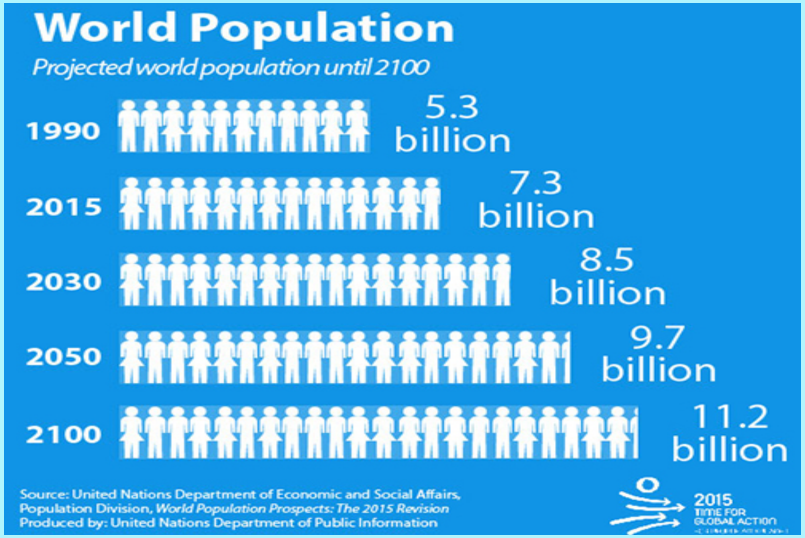
Syllabus…Unit 1 Focus On….

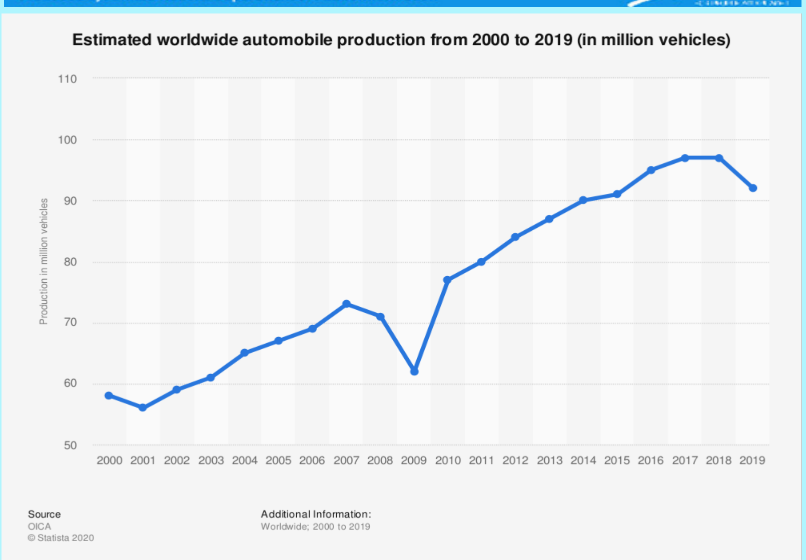
Lecture	Topics to be covered
L1	Introduction to vehicles, IC engine & Battery Electric Vehicles (BEV’s) , history and social importance
L2	Benefits of E vehicles, Types of E-vehicles on the basis of propulsion devices, Energy sources and energy carriers.
L3	PEV’s & HEV’s , BEV, HEV, FCEV, UCEV and UFEV
L4	Classification of HEV, Micro hybrid, mild hybrid, full hybrid, plug-in hybrid and range extended hybrid electric vehicle.
L5	Parallel hybrid, Series Hybrid, Power split and compound Hybrid Configuration Plug-in Hybrid Electric Vehicles (PHEV’s),
L6	Hybrid Hydraulic vehicles (HHV),Pneumatic Hybrid Vehicles, (PHVs)
L7	Power/Energy Management System

Lecture 2

- Why E- Vehicle?
- Global Energy Consumption
- Sustainable Transport
- Benefits of EV’s
- Comparison on Energy Sources
- New Trends in Energy Sources
- Energy Densities
- Pollutants and Greenhouse Gases
- Energy Diversification
- Fuel Tank to Wheel Efficiency
- Well to Wheel Efficiency
- Benefits & Limitations of EV
- Major Trends That Impact The Future

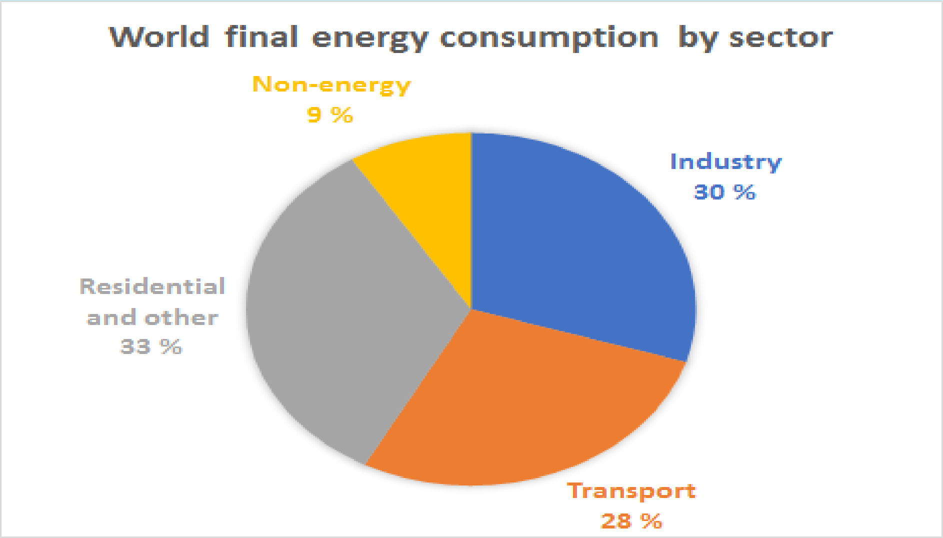
Why E-Vehicles….





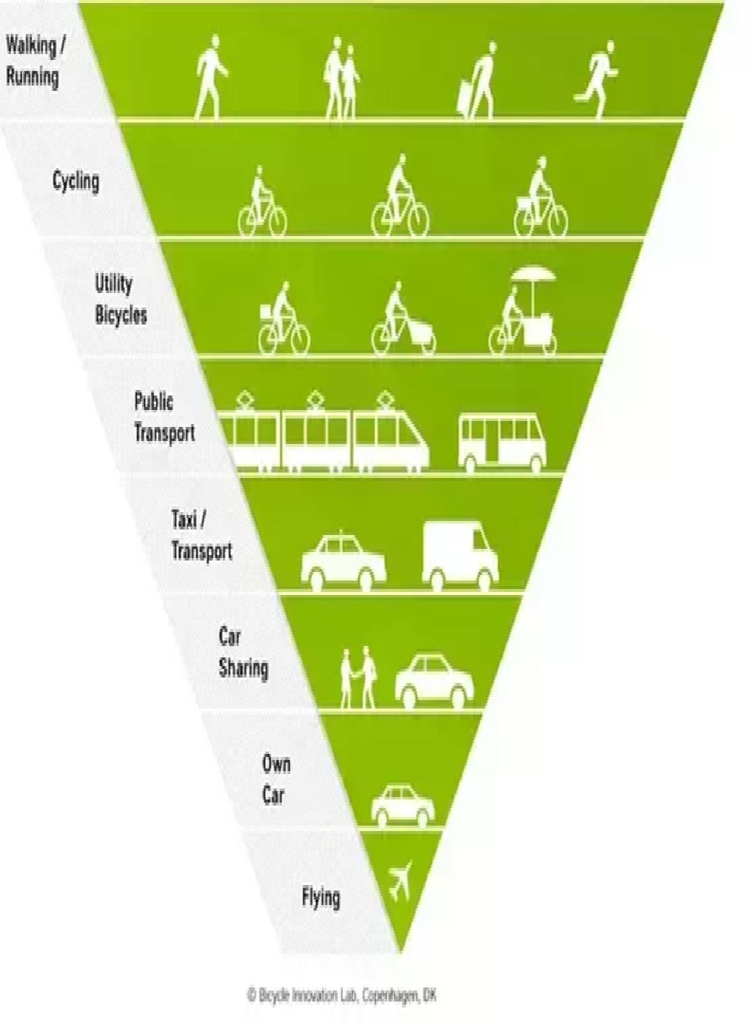
- Global Population: The global population which is 7.8 billion in March 2020, if it increases with the current trend, may become 10 billion by 2050.
- Global Vehicle Rate: It means the vehicles in use may increase from 700 million which was there in 2000 to 2.5 billion by 2050.
- If vehicles are IC engine based then mostly all the cities will be covered with permanent smog with extreme air pollution. The health will be in danger.

Global Energy Consumption….



- Global Energy consumption: The second largest usage of energy globally is transportation about 28%.
- According to Air Research Board (ARB) which came in 2011, around 9000 people die every year in California due to fine particle matter.
- It is quite alarming.
- One of the promising solutions is *Sustainable Transport*

Sustainable Transport….



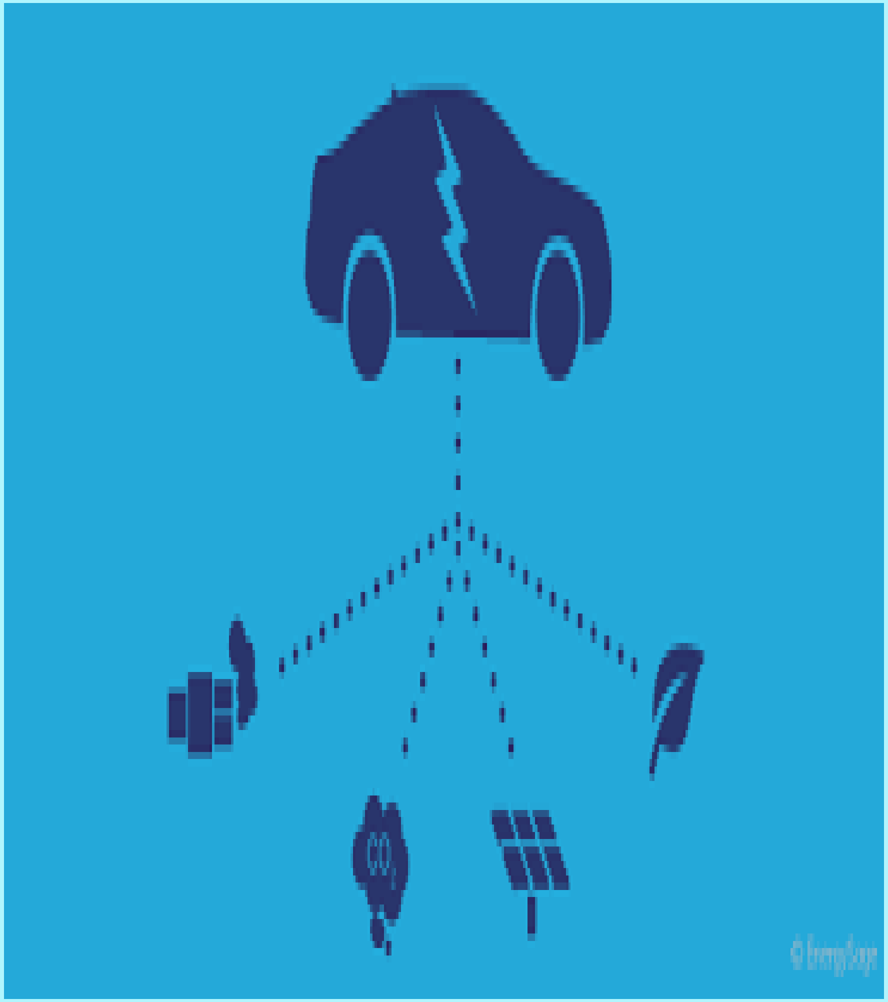
Sustainable Transport

- Low or zero Emission Vehicles
- Promotion of public transport
- Maximum use of renewable energy sources.

It also means we will be less dependent on fossil fuels which is the large source of air pollution.

One of the ways is use of EV's

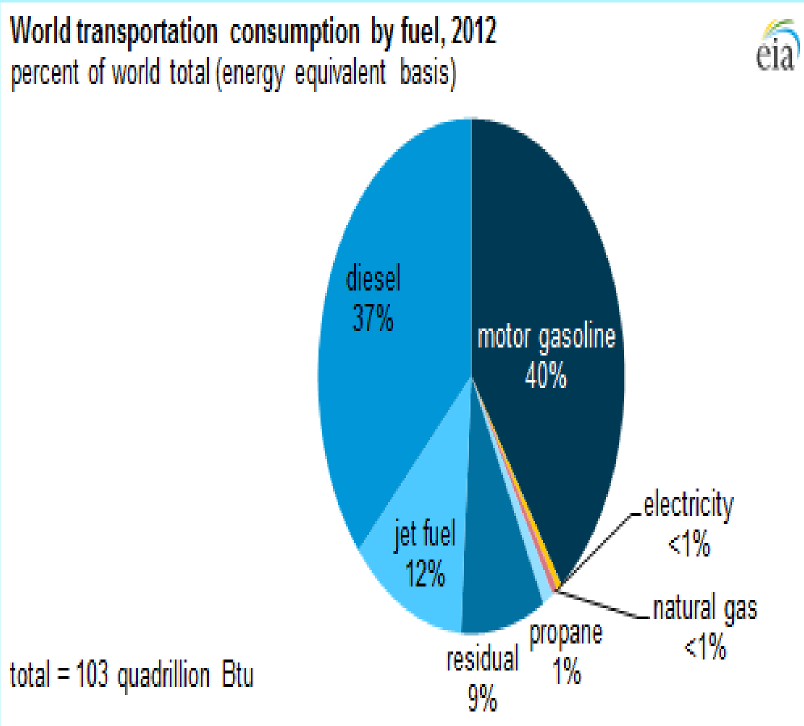
Benefits of EV’s…



EV’s benefits can be compared on the following terms

- Energy Sources
- Pollution
- Energy diversification
- Efficiencies
- Capital and operating cost and performance

Comparison on Energy Sources….

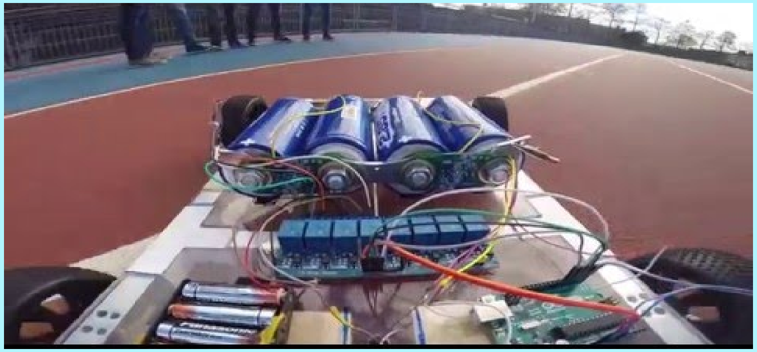


Various Energy Sources Used For Transportation are…

- Liquid Petroleum
  - Petrol
  - Diesel
- Gaseous fuels
  - Compressed Natural Gas (CNG)
  - Hydrogen

Both petrol and diesel have similar energy content per unit mass which means they have same specific energy.

New Trends in Energy Sources….



New trends are…

- Batteries
- Ultra-capacitors
- Ultra-flywheels

- Battery stores the energy in chemical form and provides energy in electrical form.
- Ultra-capacitors stores the energy in electrostatic form
- Ultra-flywheel stores the energy in mechanical form.

Energy Densities….

- Since diesel is more denser compared to petrol, it has higher energy content per unit volume. The energy per unit volume is also known as *Energy Density*.
- By having higher energy density the diesel is more fuel economical compared to petrol.
- The CNG has higher specific energy compared to liquid fuels but it has very low energy density.
- Hydrogen requires storage at a very high compressed state by using high pressure and therefore it requires lot of ancillaries around its fuel tank but on the positive side it has very high energy density compared to petrol, diesel and CNG. There is a serious effort to make hydrogen based fuel cell electric vehicles a commercial viability.

Energy Densities….

- Batteries: Lithium ion battery has specific energy 75 times low and energy density 25 times low compared to petrol which means that for the same energy content, the mass of lithium ion battery will be 75 times more compared to a petrol and it requires 25 times more volume compared to petrol.
- Ultra capacitors provides very high specific power. But it can store very limited energy.
- Ultra-flywheel stores energy in mechanical form at very high speeds but it has drawbacks such as it is less reliable and there is a safety concern around it when it is used inside the electric vehicle.

Pollutants and Greenhouse Gases….

- Particulate Matter
  - ü PM 10
  - ü PM 2.5
- CO,Co2
- CH4
- Nox
  - ü N2O
  - ü NO2
  - ü NO
- VOCs
- Hydrocarbons
- SOx
  - ü SO2

• Nitrogen oxides (NO_2)	• Volatile organic compounds(VOCs)	• Aldehydes
• Sulfur dioxide (SO_2)	• Peroxides	• Organic acids
• Ground level ozone (O_3)	• Particulate matter (PM)	• Hydrocarbons

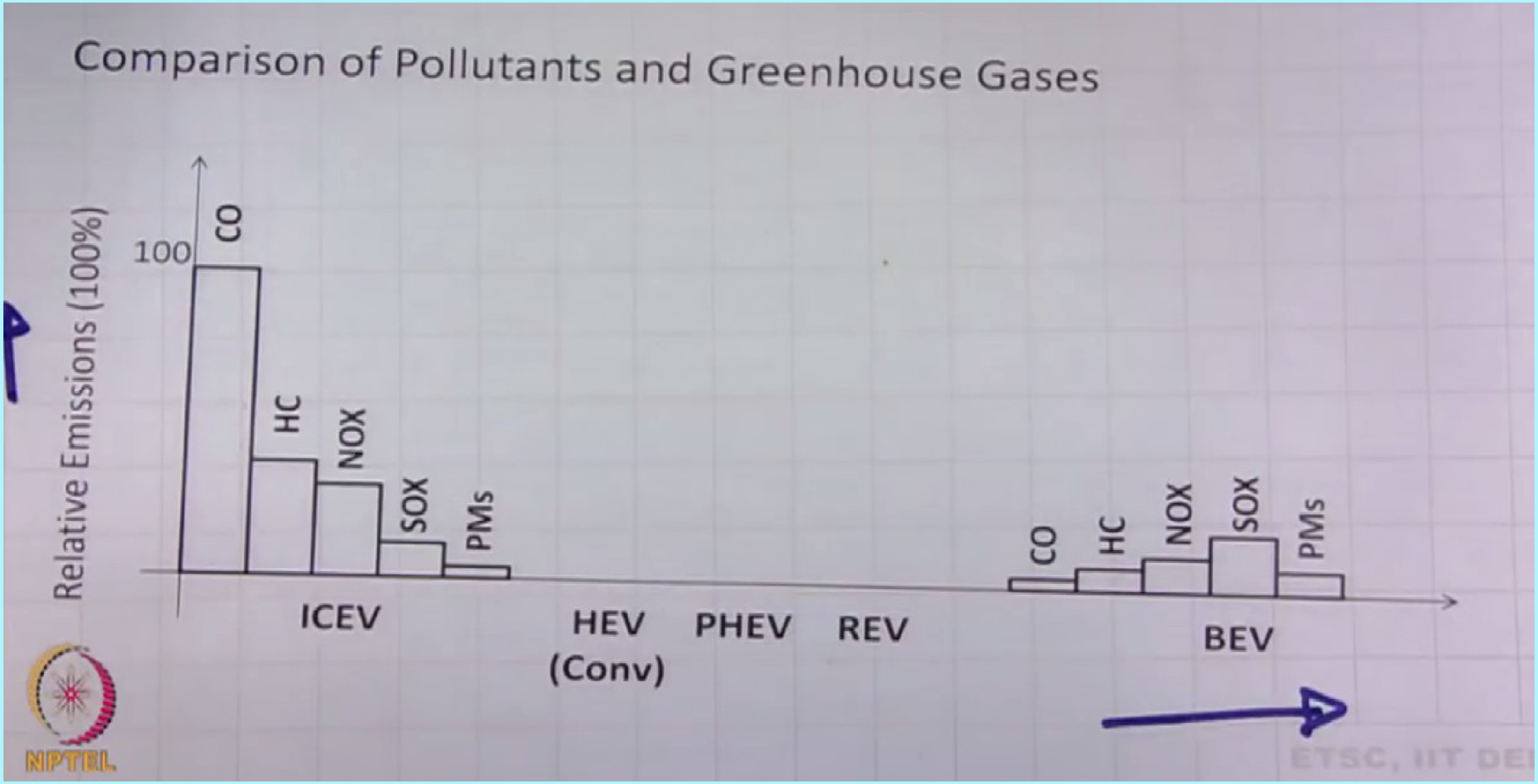
Pollutants and Greenhouse Gases….

- Particulate matter are particles released as a part of combustion cycle. These particles are extremely small in the range of micrometers. There fore, they enters the body and affect heart, lungs and brain and cancerous in nature
- PM particles less than 10 micrometer which is PM10 are very dangerous and if inhaled can cause severe damage. So these are clubbed and referred as PM2.5
- CO,Co2, CH4 and Nox gases are known as greenhouse gases. Due to the presence of these gases, the infrared radiations are trapped in the atmosphere and cause greenhouse effect such as climate change and global warming.
- Carbon Monoxide is a colorless, odorless gas which is very dangerous for human health. It is highly poisonous.

Pollutants and Greenhouse Gases….

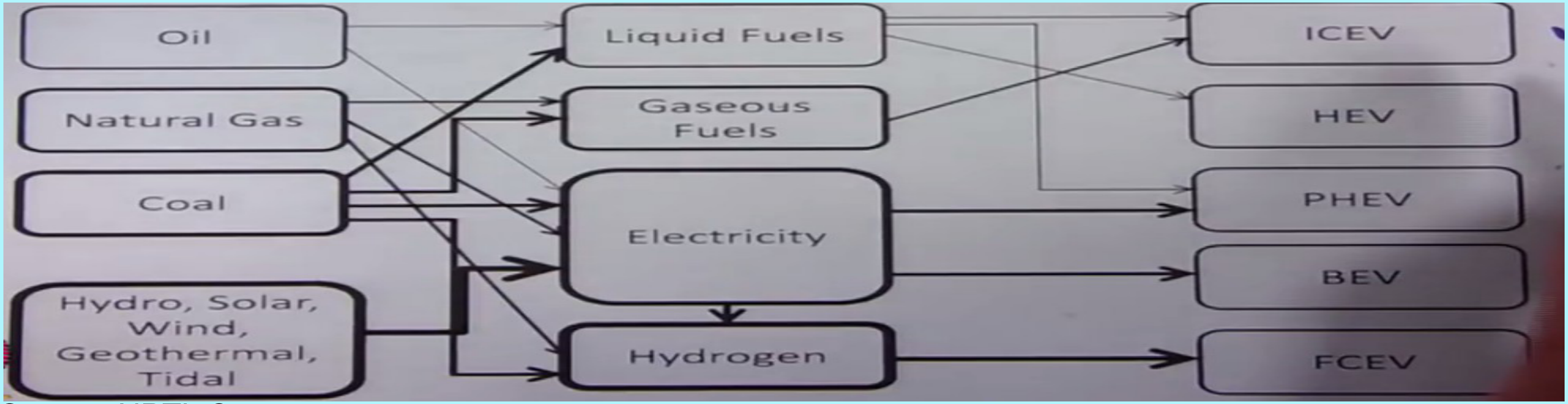
- NOx gases, VOC and total hydrocarbons are responsible for building ground level ozone layer and is very dangerous for humans. It causes lining in the lungs and major respiratory illnesses such as asthma and lung inflammation.
- Diesel engine are the main source of NOx gases, can be filtered using catalytic converter but these devices are costly. NOx gases can be minimized by use of urea filters.
- Sulphur dioxide gas is released by coal based thermal power plants. Electricity is used in EVs, they are creating more SOx gases in the atmosphere. Sox reacts with oxygen and water present in atmosphere and creates sulphuric acid, major reasons for acidic rains.
- The solution is low Sulphur coal should be used for power generation which is costly of course.

Pollutants and Greenhouse Gases….



Source: NPTL Course

Energy Diversification….



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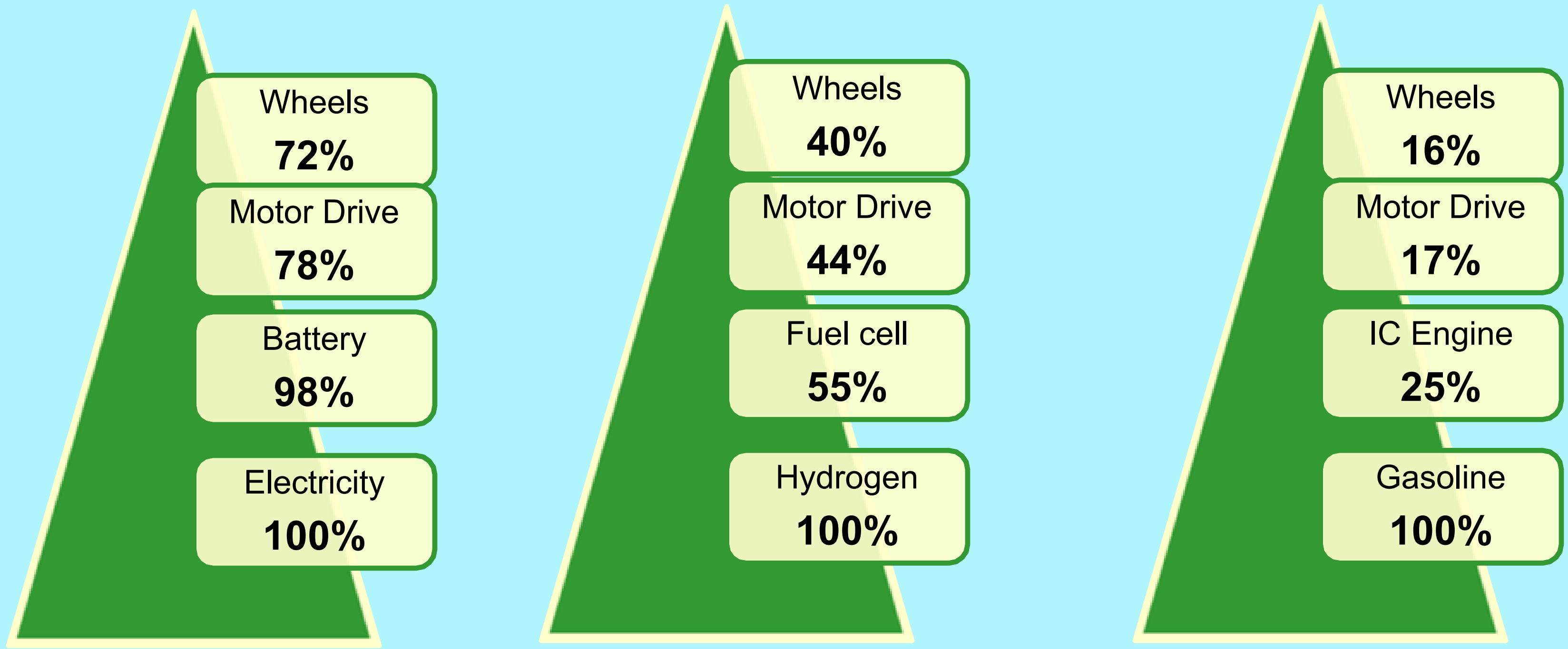
- IC engine vehicles typically use liquid fuels and gaseous fuels which are coming from either oil or natural gas.
- Pure electric vehicle such as battery electric vehicle and fuel cell electric vehicle use either electricity or hydrogen as energy carriers.
- Electricity can be generated by almost all the energy sources. EVs have a definite advantage compared to IC engine which requires oil and natural gas as its fuel. PHEV you can say is most energy diversified because it can run on both liquid fuels, and electricity

Fuel Tank to Wheel Efficiency….

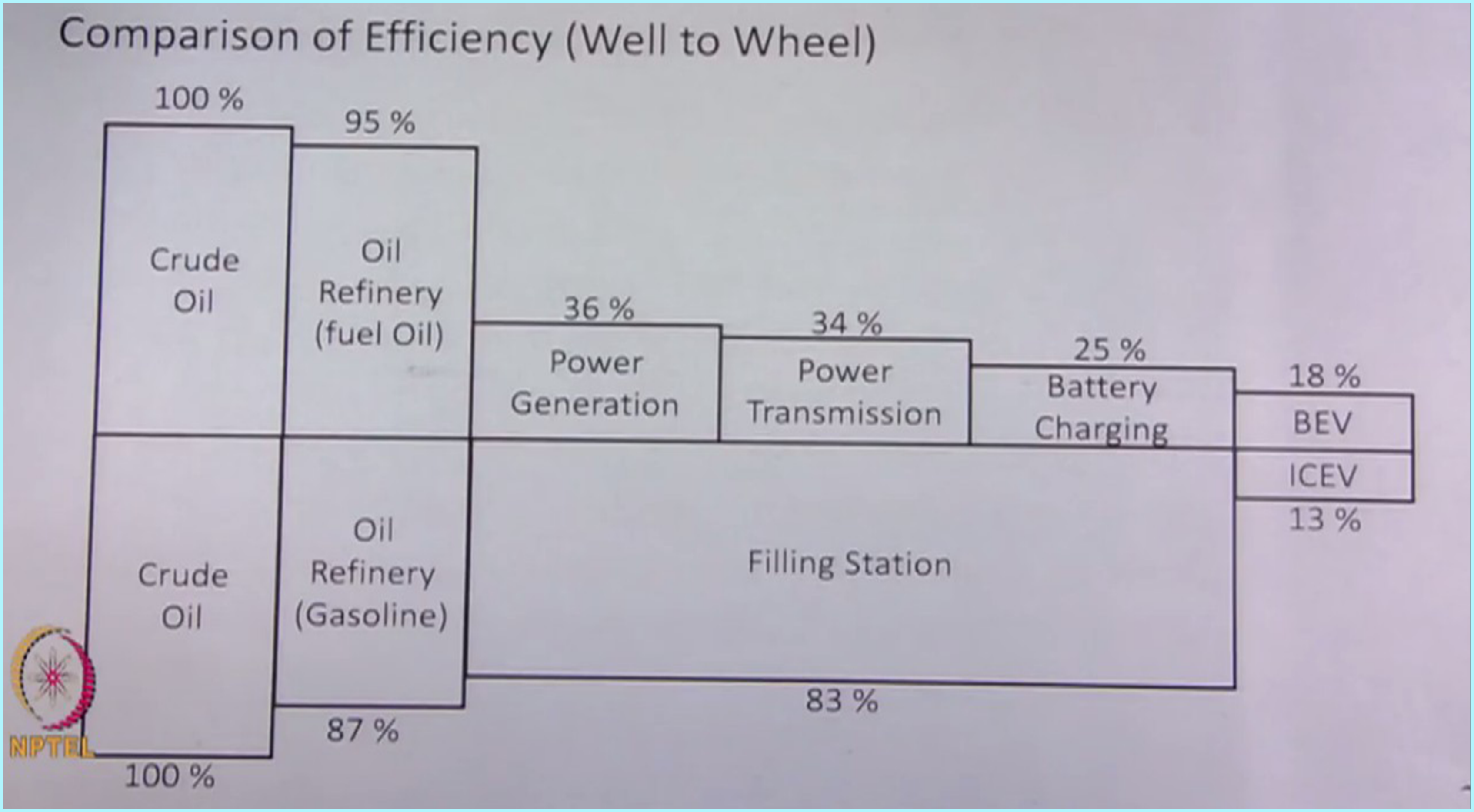


Battery Electric Vehicles (BEV)

Fuel Cell Electric Vehicles (FEV)

Internal Combustion Vehicles (ICV)

Well to Wheel Efficiency….



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Benefits & Limitations of EV….

- Battery electric vehicle have higher fuel economy compared to IC engine based vehicles

But, they are more expensive because of higher initial battery cost, and the requirement of battery replacement after few years.

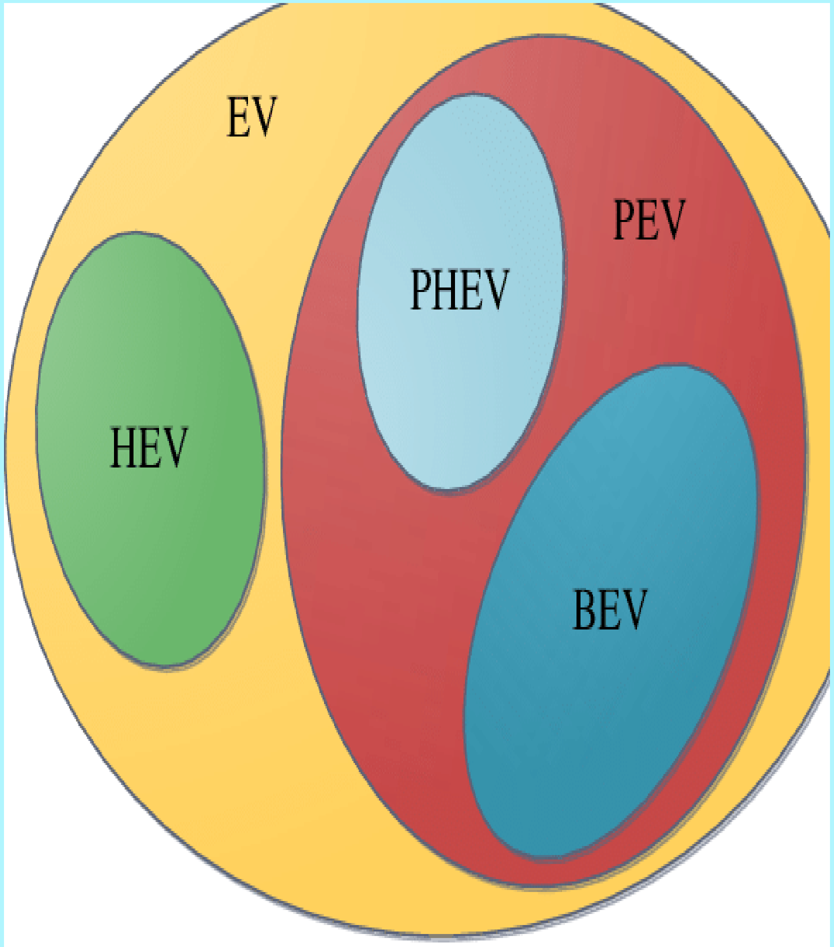
- The BEV requires less maintenance and more reliable.
- The BEV can recover energy during braking. It is also less noisy.
- The BEV have high performance and smooth control.

But, On the negative side, BEV requires continuous charging and they have a limited range per charge.

- The BEV can be charged using renewable energy sources such as solar.

But for the same energy requirement, BEV requires more space and is more heavy.

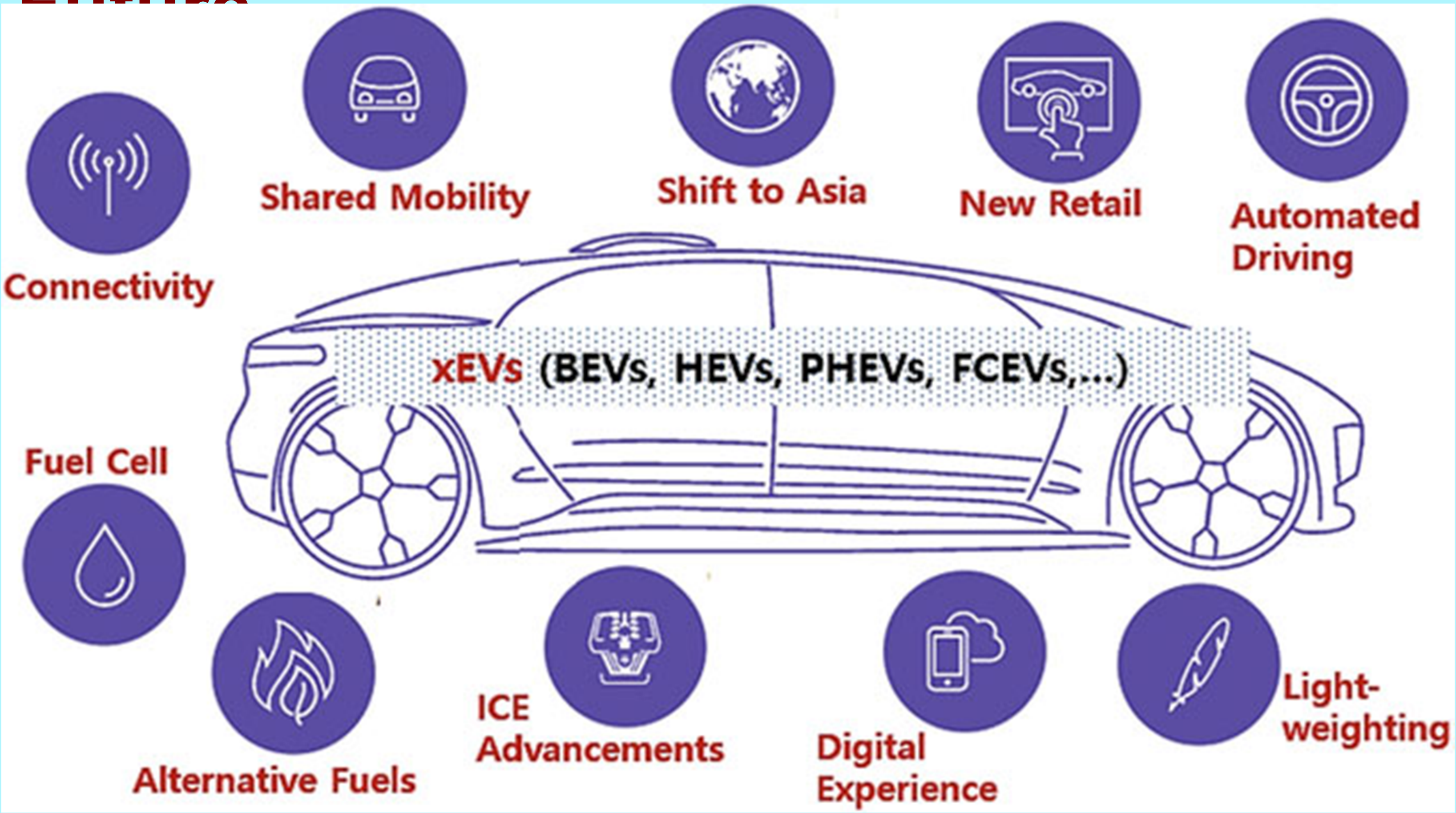
Overview of Types of EVs ...



EVs can be classified in various ways

- Propulsion Devices
  - ü Pure Electric Vehicle (PEV)
  - ü Hybrid Electric Vehicle (HEV)
- Energy Sources
  - ü Battery Electric Vehicle (BEV)
  - ü Hybrid Electric Vehicle (HEV)
  - ü Fuel Cell Electric Vehicle (FCEV)
- Energy Carriers

Major Trends That Impact The Future



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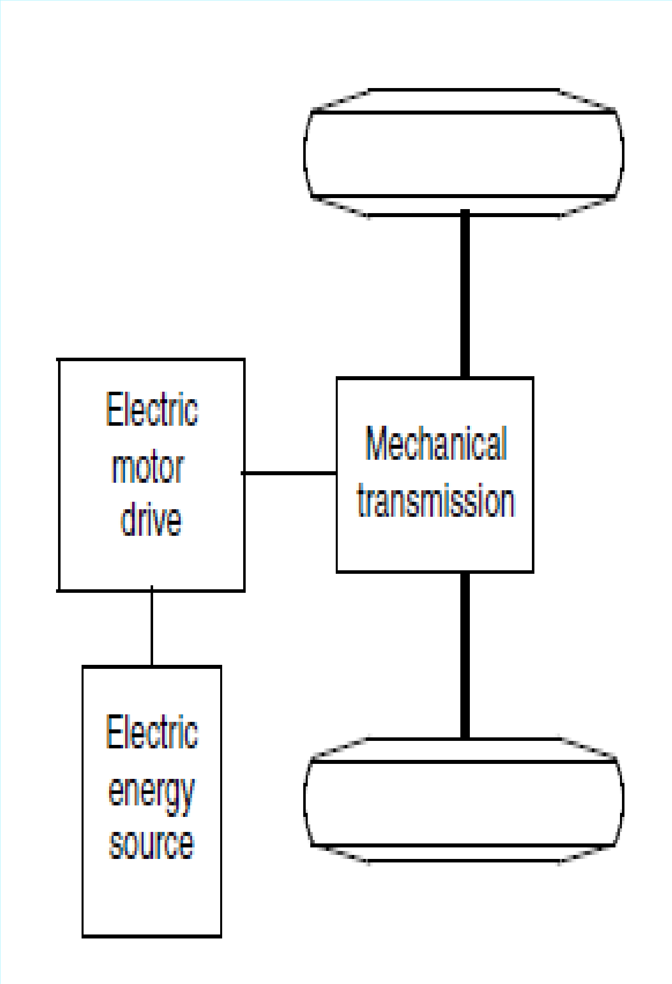
L7	Power/Energy Management System

Lecture 3

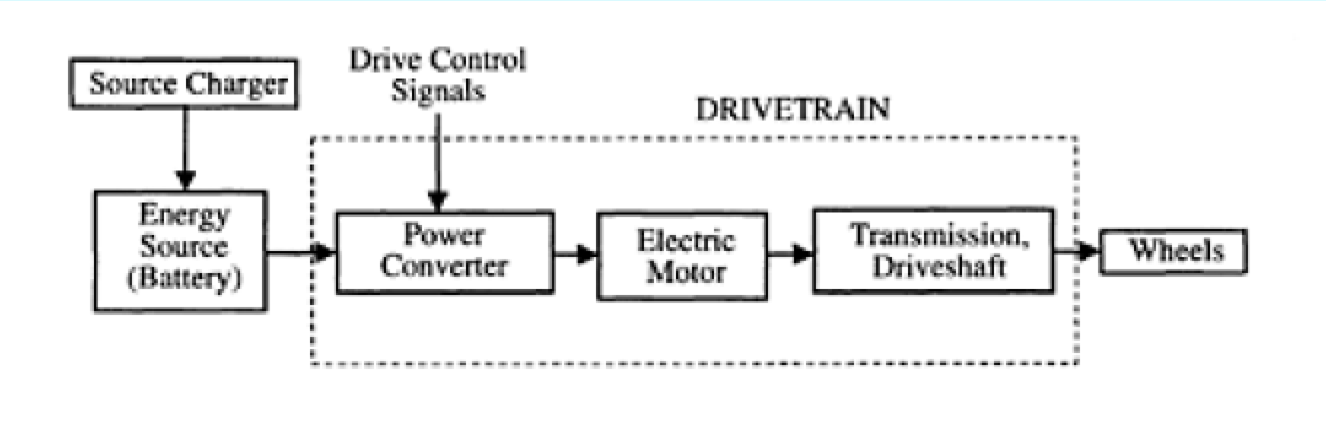
- EV Basic system
- E-Vehicle Basic Block Diagram
- Components of an EV….
- Types of E- Vehicle?
- EV’s Classification: Propulsion Devices
- EV’s Classification: Energy Carrier
- EV’s Classification: Energy Sources
- Fuel Cells
- Ultra Capacitors
- Ultra Fly Wheel
- HEV’s Basics
- HEV’s Classification
- HEV’s Conventional Hybrid & Grid-able HEV
- Overall Classification of HEV

E-Vehicle Basic System ….



- The EV was mainly converted from the existing ICEV.
- It is done by replacing the internal combustion engine and fuel tank with an electric motor drive and battery pack while retaining all the other components
- Drawbacks such as its heavy weight, lower flexibility, and performance degradation have caused the use of this type of EV to fade out

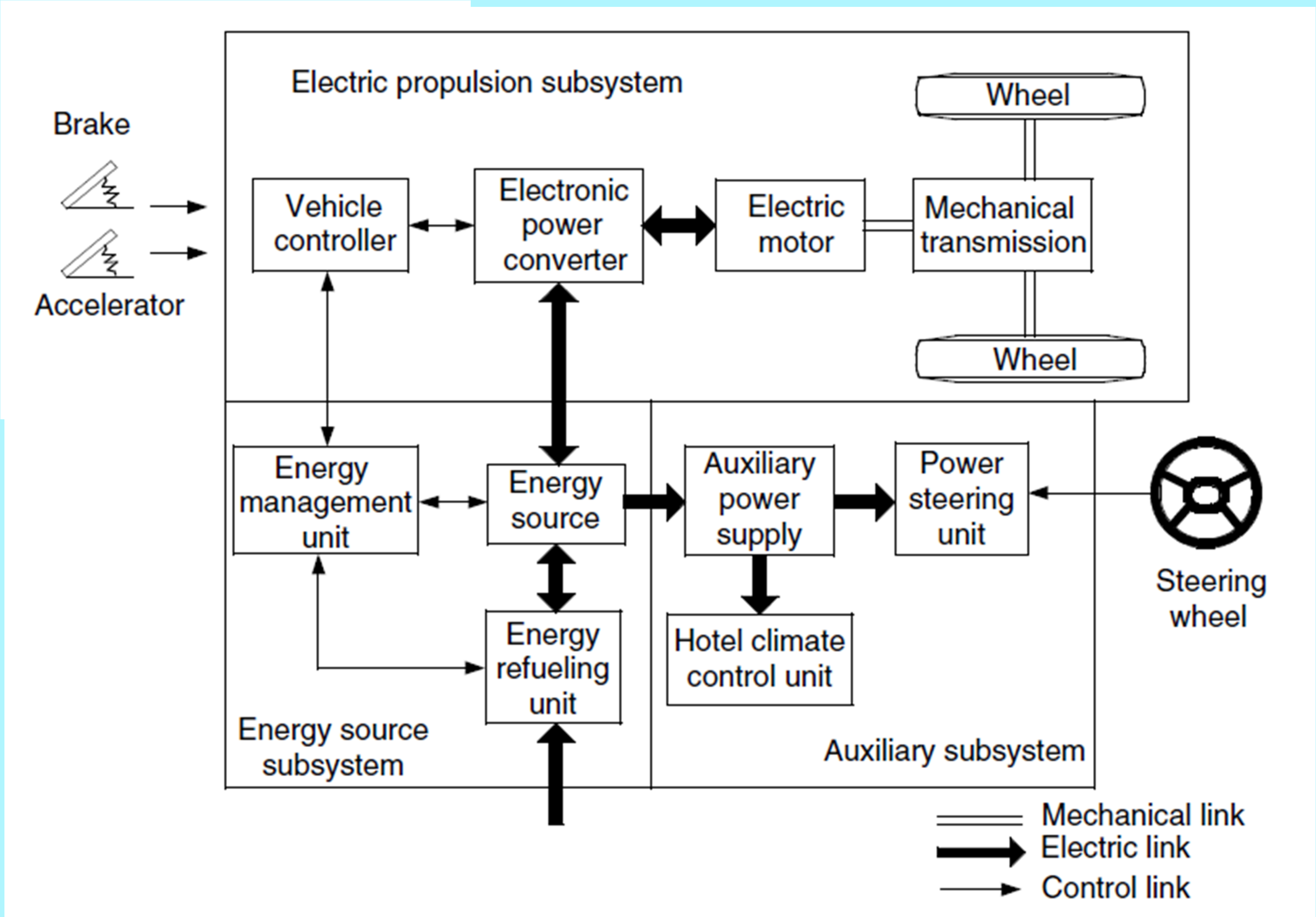
E-Vehicle Basic System ….



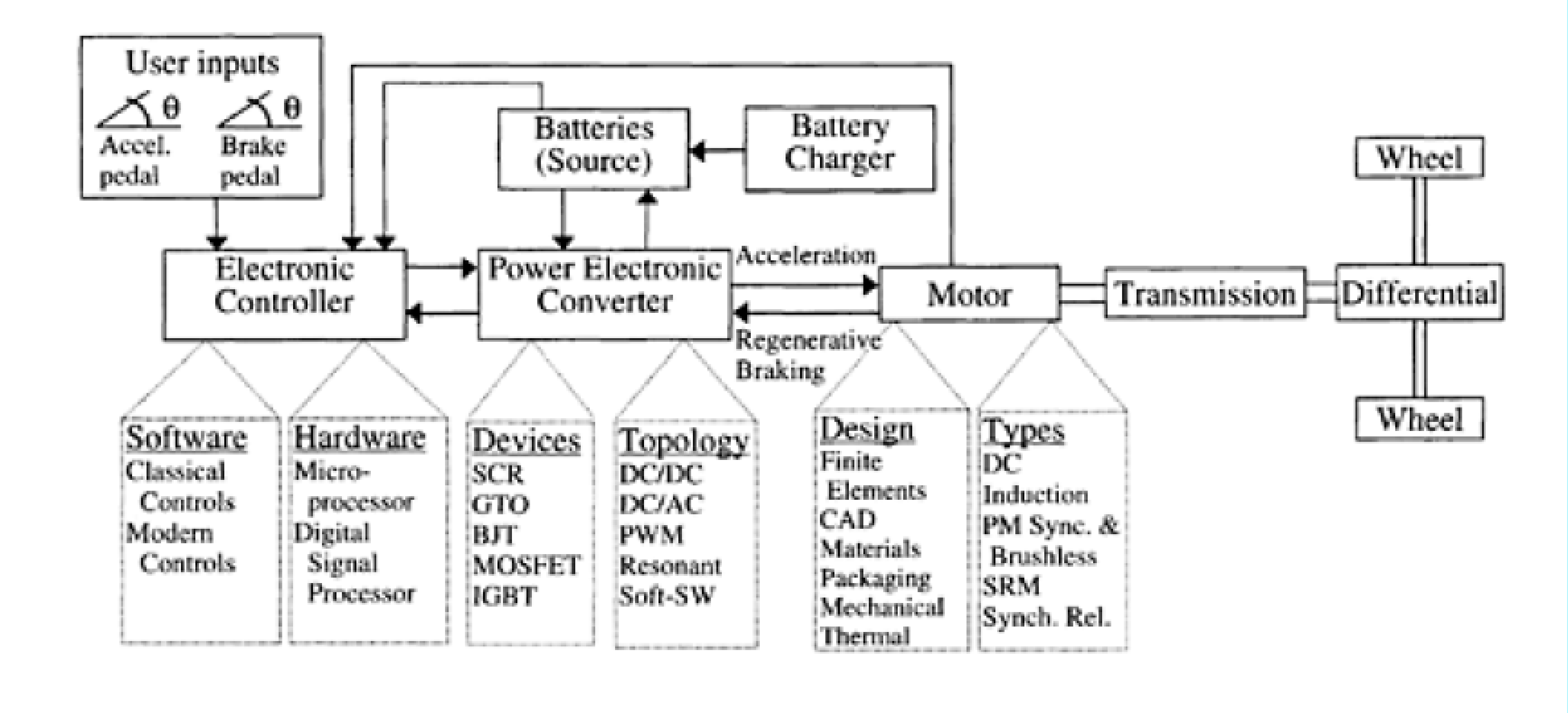
An EV has the following two features:

- The energy source is portable and chemical or electromechanical in nature.
- Traction effort is supplied only by an electric motor
- The electromechanical energy conversion linkage system between the vehicle energy source and the wheels is the drivetrain of the vehicle. The drivetrain has electrical as well as mechanical components.

E-Vehicle Basic Block Diagram ….

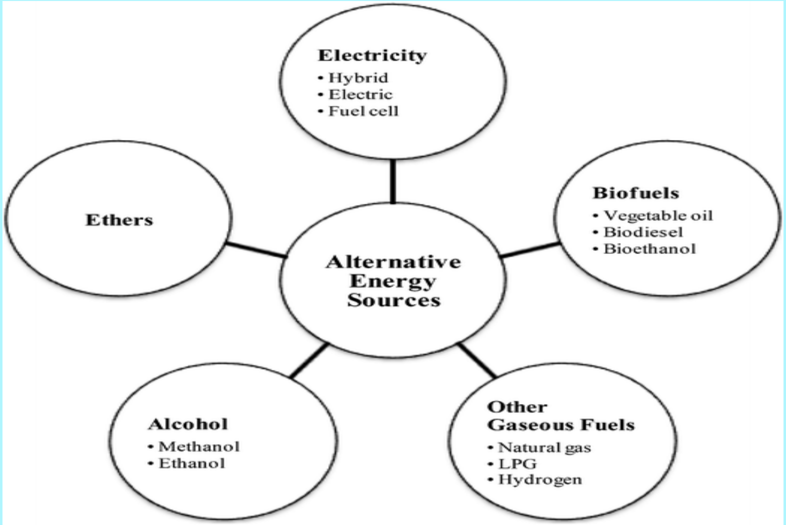


Components of an EV….



- The primary components of an EV system are the motor, controller, power source, and transmission. The detailed structure of an EV system and the interaction among its various components are as shown in figure

Types of E-Vehicles….



- E- vehicles can be classified on the basis of
  - ü Propulsion Devices

The propulsion system transfers the power to the wheels by a mechanical mechanism, IC Engine Or Electric Motor, or by a combination of both.

- ü Energy Sources

A vehicle that has two or more energy sources and energy converters is called a hybrid vehicle. EVs use chemical batteries, fuel cells, ultra capacitors, and/or flywheels for their corresponding energy

EV’s Classification: Propulsion Devices…

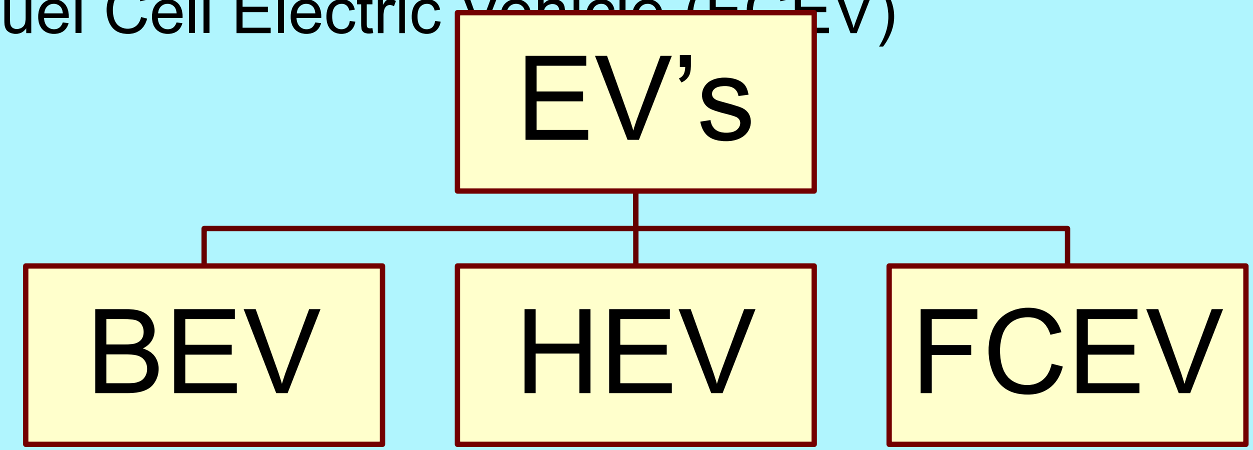
Based on Propulsion Devices, EV’s can be classified as

ü Pure Electric Vehicle (PEV)

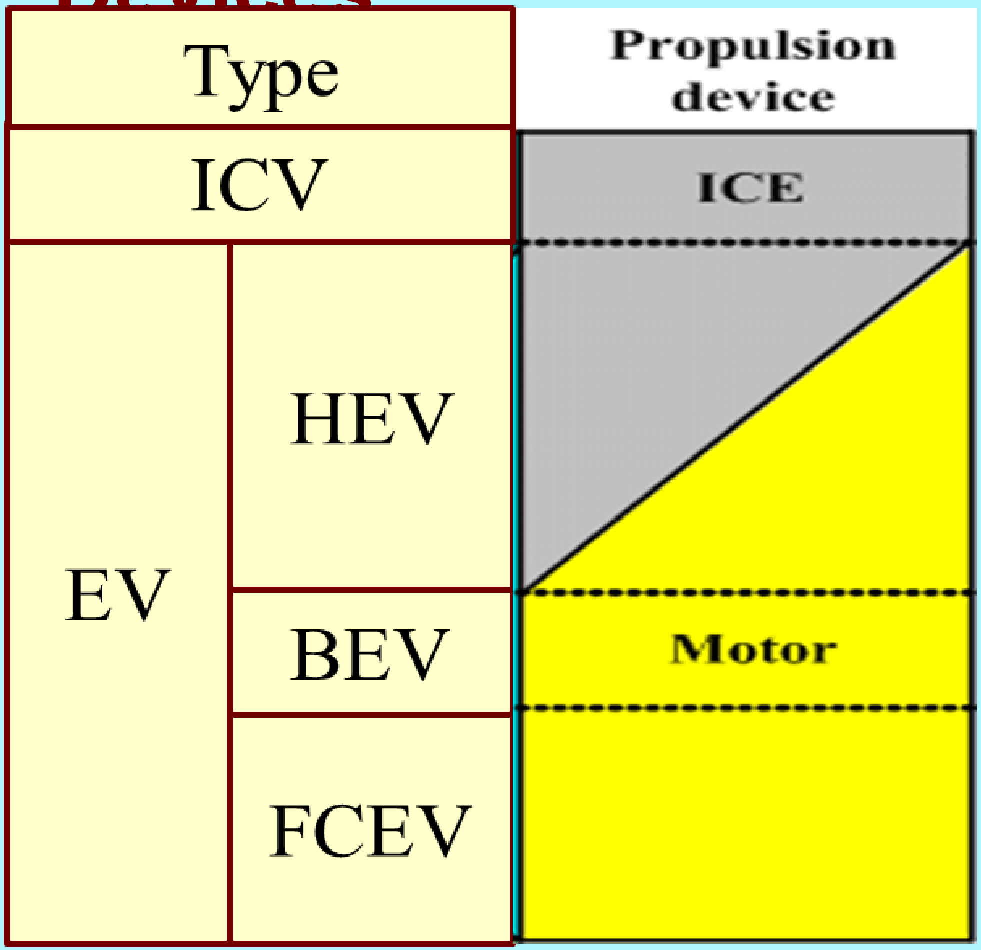
As per energy source used also called Battery Electric Vehicle (BEV)

ü Hybrid Electric Vehicle (HEV)

ü Fuel Cell Electric Vehicle (FCEV)



EV's Classification: Propulsion Devices



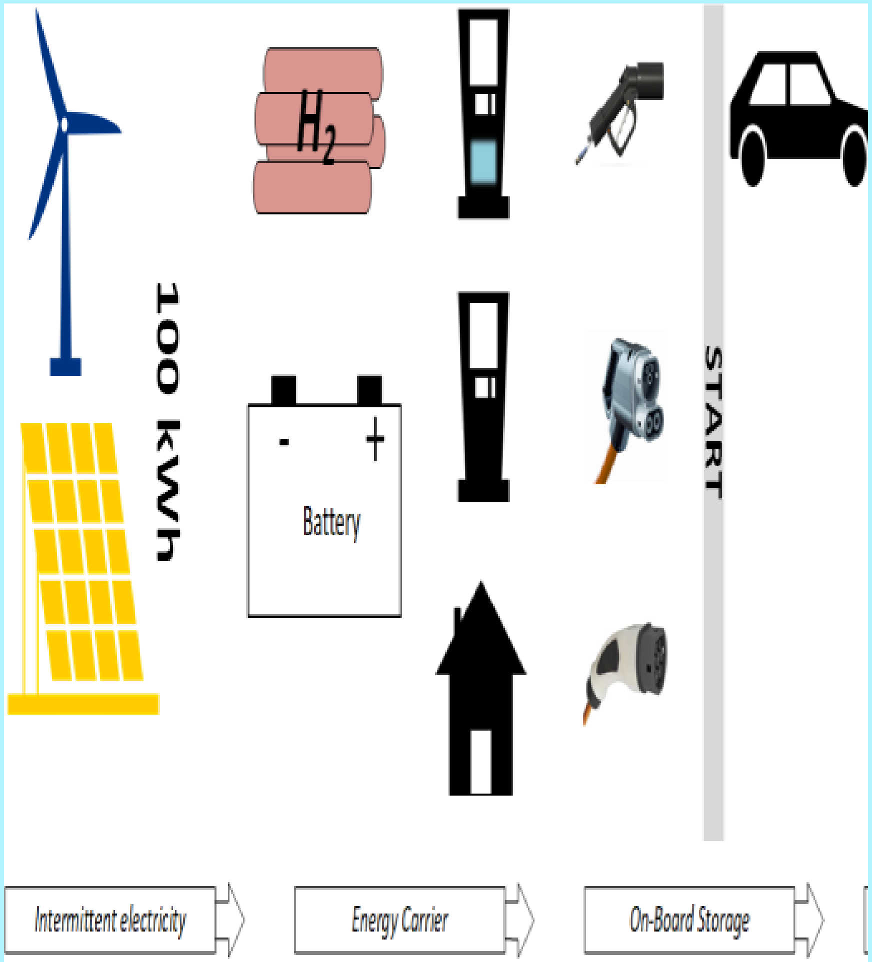
Based on Propulsion Devices, EV's can be classified as

- ü Pure Electric Vehicle (PEV)

As per energy source used also called Battery Electric Vehicle (BEV)

- ü Hybrid Electric Vehicle (HEV)
- ü Fuel Cell Electric Vehicle (FCEV)

EV's Classification: Energy Carrier….

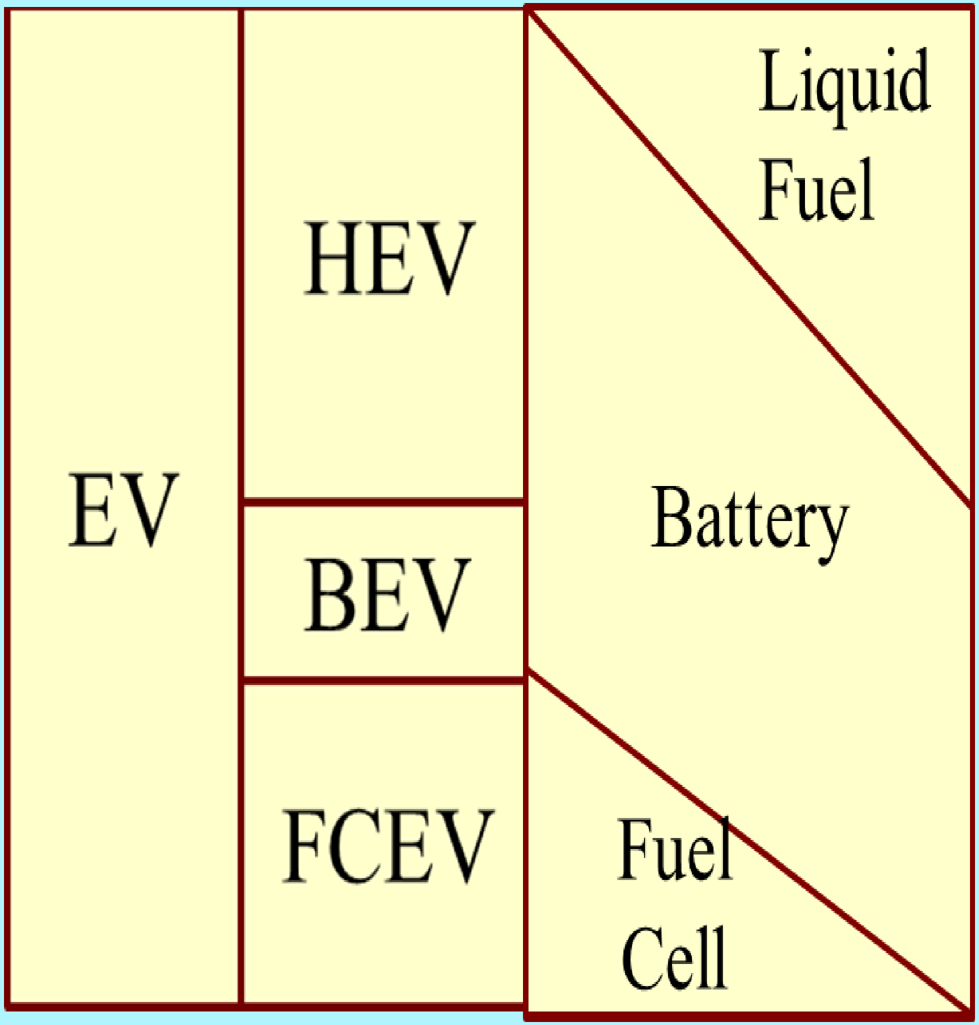


E- vehicles can be classified on the basis of

- ü Energy Carriers

If we classify The EVs on the basis of energy carriers, hybrid vehicle uses either **Liquid Fuel** or **Electricity** as energy carriers while a pure electric vehicle uses either **Battery or Hydrogen** as energy carriers.

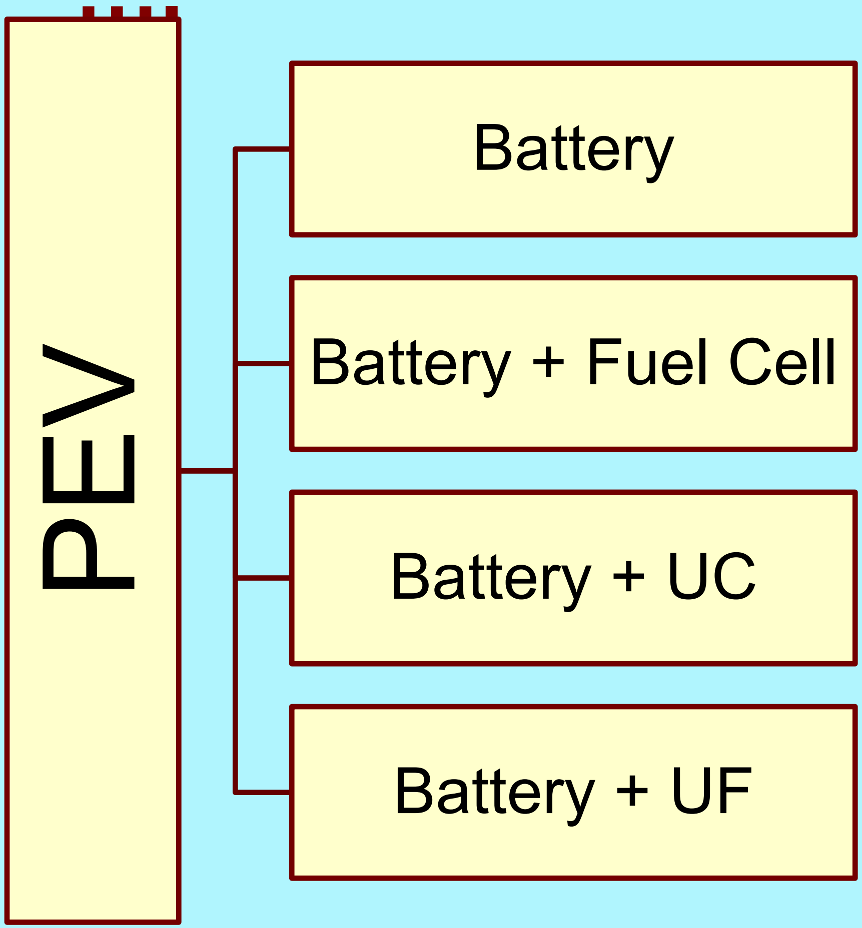
EV's Classification: Energy Sources



Based on Energy Sources, EV's can be classified as

- Hybrid Electric Vehicle (HEV), Battery Electric Vehicle (BEV) and Fuel Cell Electric Vehicle (FCEV)
- Hybrid Electric Vehicle (HEV) uses both liquid fuel and battery as energy source
- BEV uses only battery
- FCV vehicle uses both battery and fuel cell

EV’s Classification: Energy Sources



A similar classification can be done on the basis of energy carriers

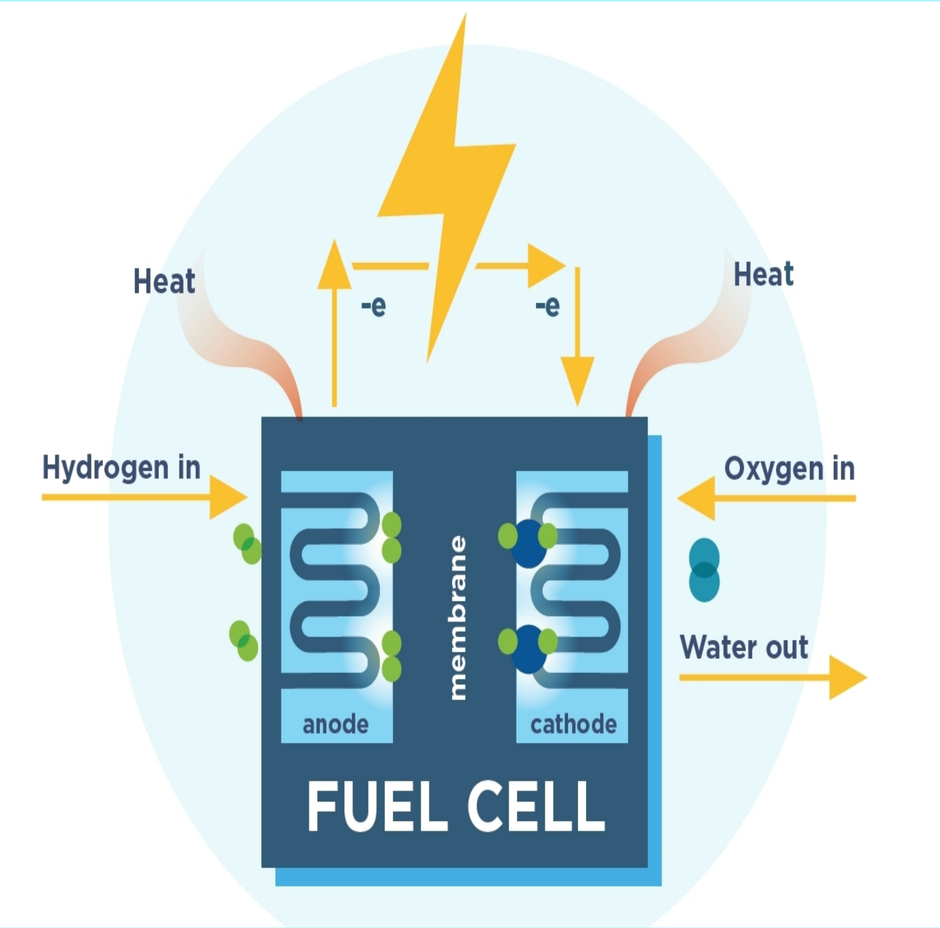
- Energy carrier for battery is electricity
- Energy carrier for a fuel cell is Hydrogen.
- Energy carrier for Ultra-capacitors is stored Electric energy
- Energy carrier for Ultra-flywheel is stored Mechanical energy
- The battery is a common energy source

EV's Classification: Energy Sources

- BEV uses battery as sole energy source,
- FCEV, UCEV and UFEV uses battery as a hybrid energy source.
- In a fuel cell electric vehicle, battery is primarily used for absorbing the regenerative power since fuel cell is incapable of storing the renewable energy.
- In ultra-capacitor and ultra-flywheel based EVs, batteries are required for storing energy since ultra-capacitor and ultra-flywheel have very low specific energy.

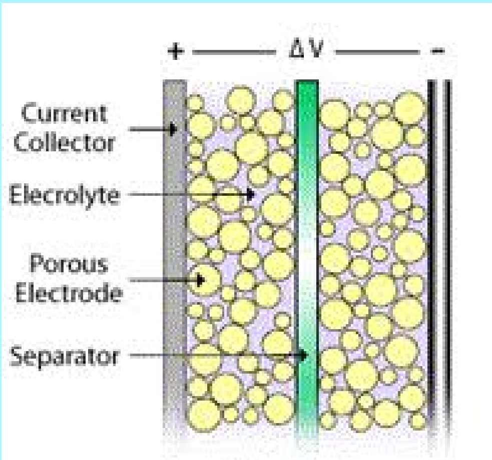
As we Know Hybrid Electric Vehicle (HEV) uses both motor and IC engine for propulsion. On the basis of ratio of hybridization between electric motor and IC engine, it is classified in to further types.

Fuel cell….



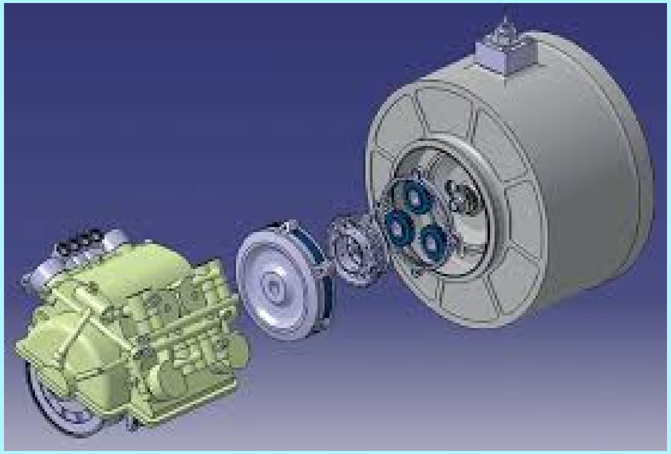
- A fuel cell is a galvanic cell in which the chemical energy of a fuel is converted directly into electrical energy by means of electrochemical processes.
- The fuel and oxidizing agents are continuously and separately supplied to the two electrodes of the cell, where they undergo a reaction.
- Energy carrier for a fuel cell is Hydrogen.

Ultra Capacitor….



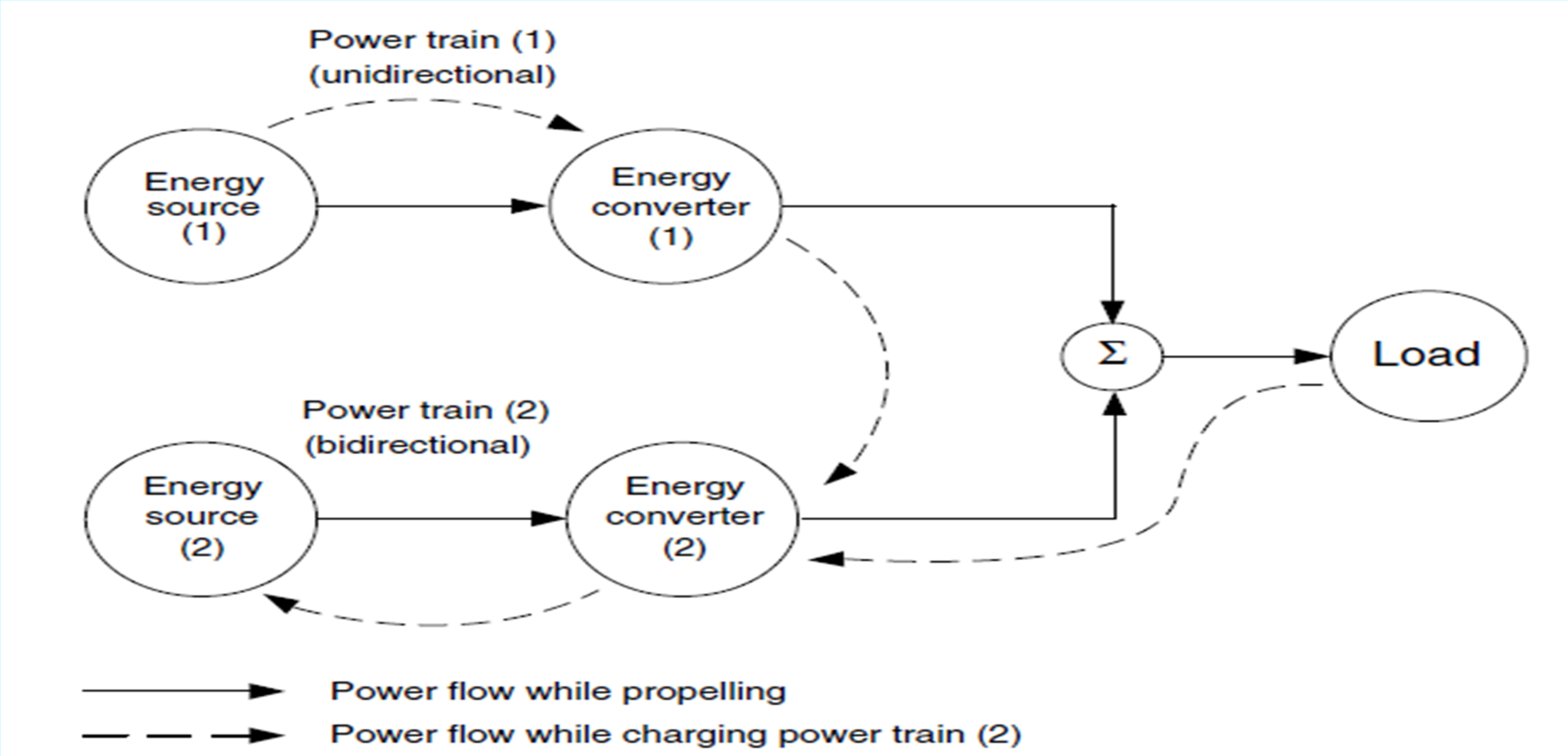
- The frequent start/stop operation of BEVs adversely affects the life cycle of batteries due to the high variation of the battery discharge profile.
- They have significant difficulty providing sudden bursts of power for rapid acceleration and hill-climbing, due to their relatively low specific power density.
- Ultra-capacitors are an energy (storage) source device with a high specific power density, high efficiency, and long cycle life, with the disadvantage of having low specific energy density.

Ultra Flywheel….



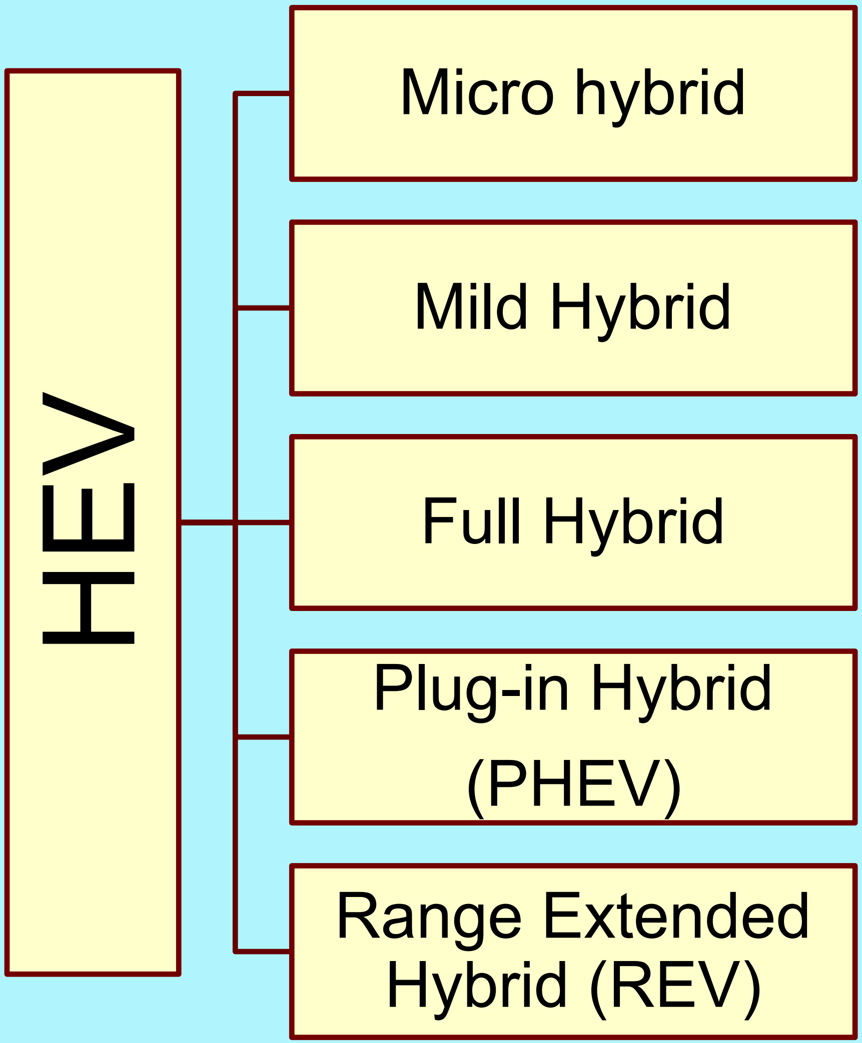
- Flywheels can achieve the potential energy storage requirements for EV applications. It can feasibly satisfy the requirements regarding high specific energy, high specific power, long cycle life, high energy efficiency, quick recharging, limited maintenance, and cost effectiveness.
- Flywheels are used in a hybrid configuration (with the primary source in a BEV) as an auxiliary energy source, they function to store energy in a mechanical form.

HEV's Basics….



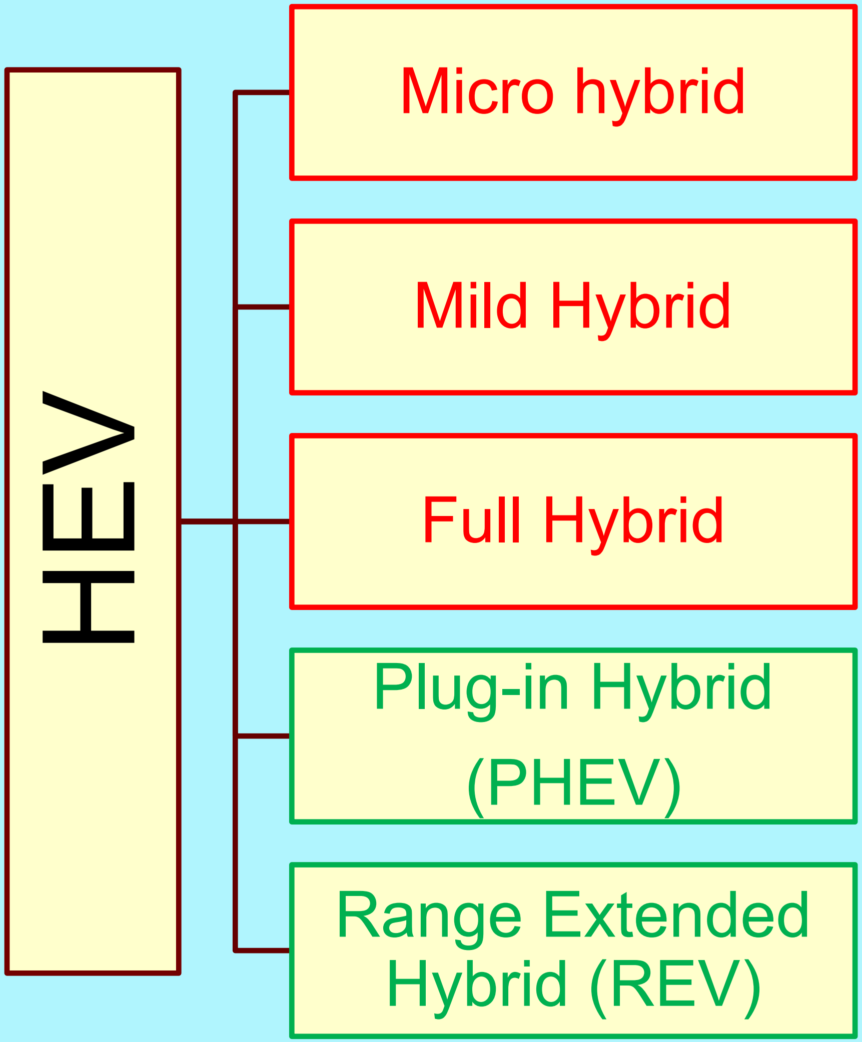
A vehicle that has two or more energy sources and energy converters is called a hybrid vehicle. A hybrid vehicle with an electrical power train (energy source energy converters) is called an HEV.

HEV's Classification….



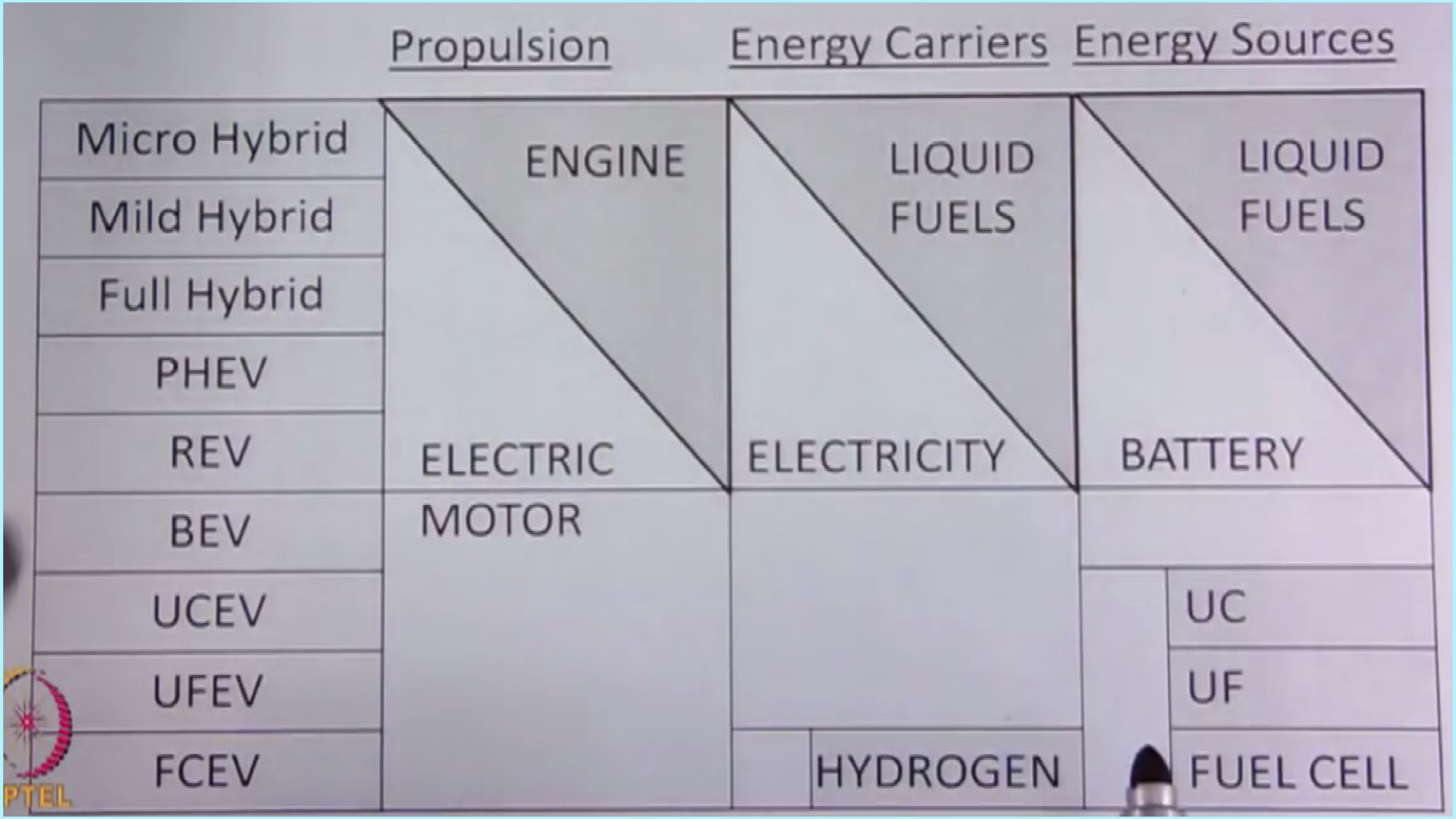
- The rating of electric motor is very low in micro hybrid vehicle and is high in REVs.
- On the other hand, the rating of IC engine is high in a micro hybrid while it is low in a REV
- Micro hybrid, Mild hybrid and Full hybrid are clubbed and known as **Conventional Hybrid** electric vehicle.
- Plug-in hybrid or PHEVs and range extended hybrid which is known as REV are clubbed under **Grid-able HEVs**

HEV's Conventional Hybrid & Grid-able HEV….



- **Conventional Hybrid** electric vehicle can be refueled only at the filling stations or petrol pumps.
- **Grid-able HEVs** can be refueled both electrically and at the filling stations
- **Grid-able HEV** enables direct charging of battery using charging ports in addition to refueling by liquid fuels at a filling station.

Overall Classification of HEV….



Source: NPTL Course

Unit 1:- Electric and Hybrid Powertrain Technologies

By:- Dr. Chetan Khadse

Syllabus…Unit 1 Focus On….

Lecture	Topics to be covered
L1	Introduction to vehicles, IC engine & Battery Electric Vehicles (BEV’s) , history and social importance
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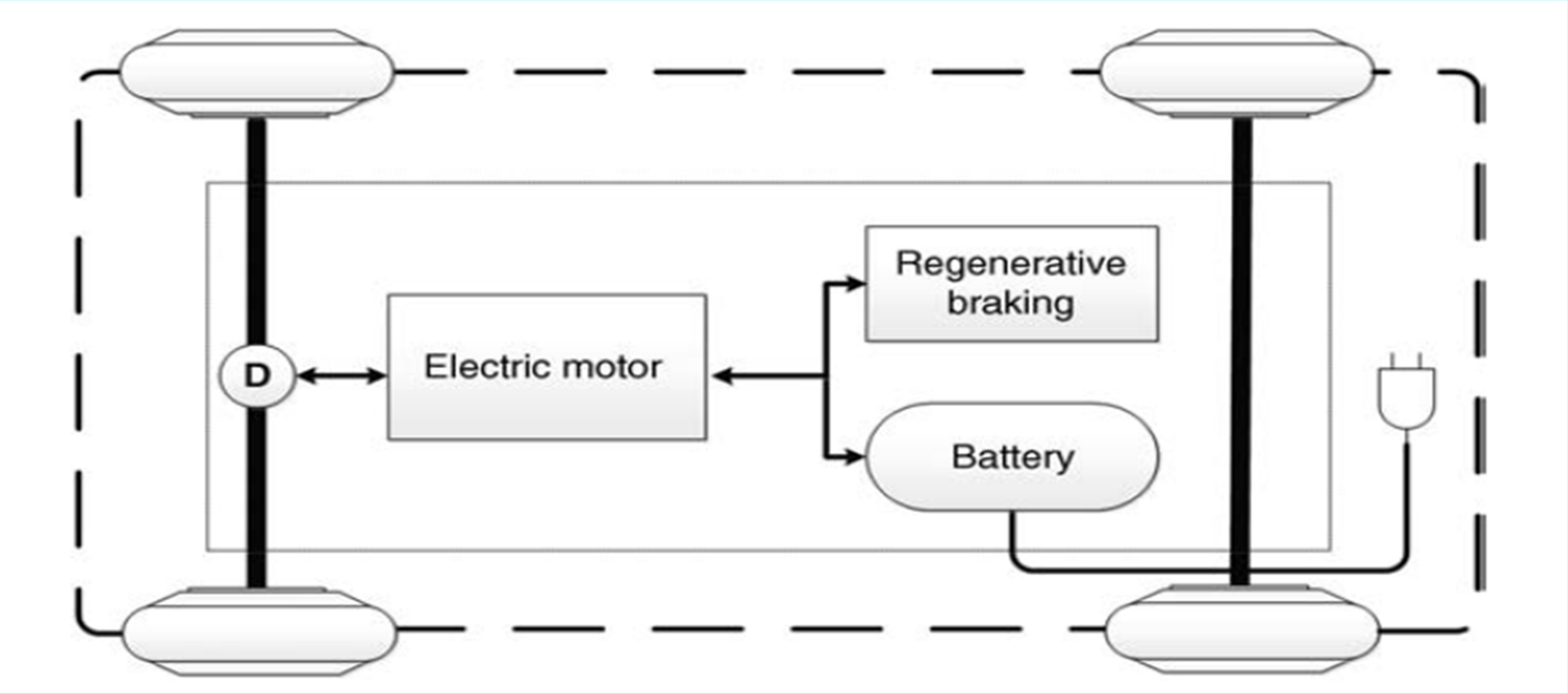
L6	Hybrid Hydraulic vehicles (HHV),Pneumatic Hybrid Vehicles, (PHVs)
L7	Power/Energy Management System

Lecture 4

- BEV (Battery Electric Vehicle)
- BEV Internal Blocks
- Fuel Cell Electric Vehicle
- Integrated Starter Generator (ISG)
- Micro, Mild and Full Hybrid
- Micro Hybrid Schematic
- Micro Hybrid
- Mild Hybrid Schematic
- Mild Hybrid
- Micro, Mild and Full Comparison
- OOL in Full Hybrid
- Grid-able HEV
- Types of Full Hybrid

BEV (Battery Electric Vehicle)….

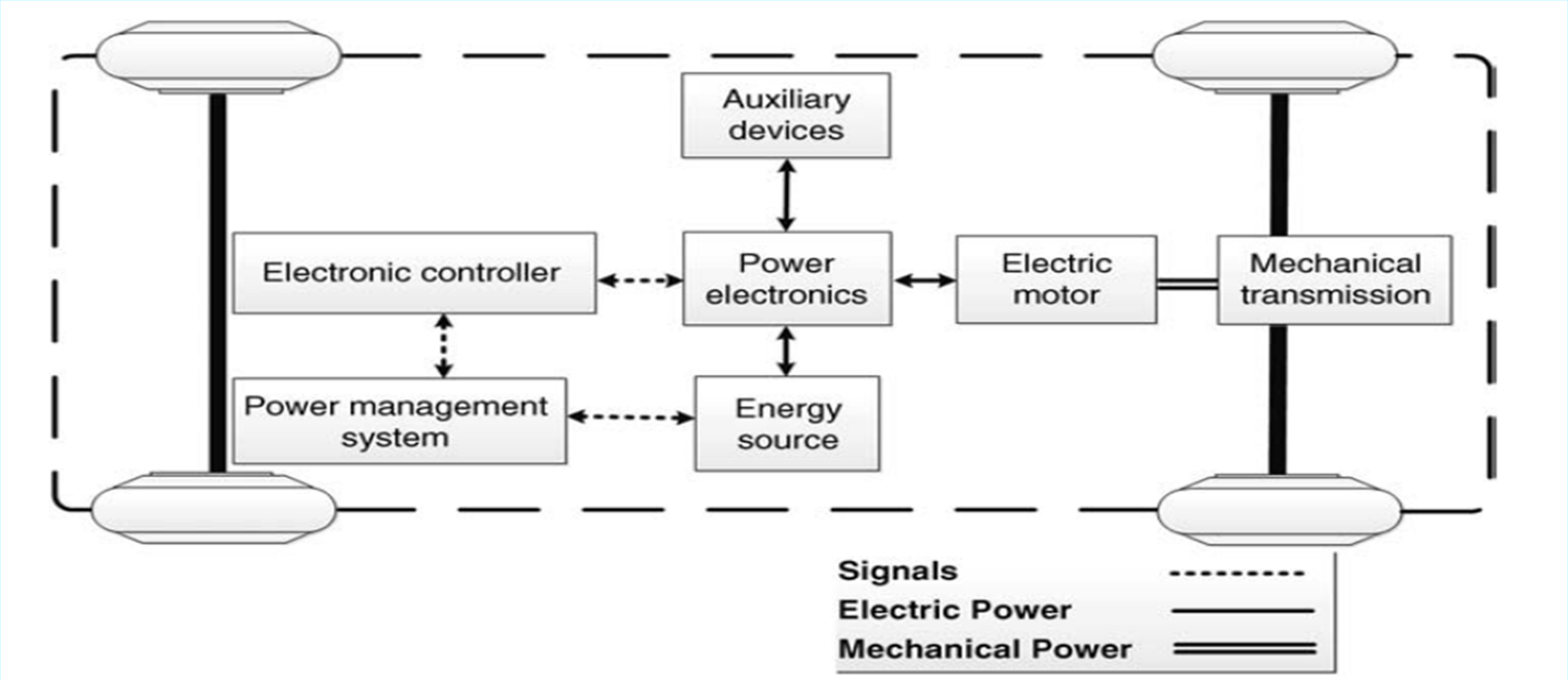


The figure depicts a schematic of a battery-powered electric vehicle (BEV).

BEV (Battery Electric Vehicle)….

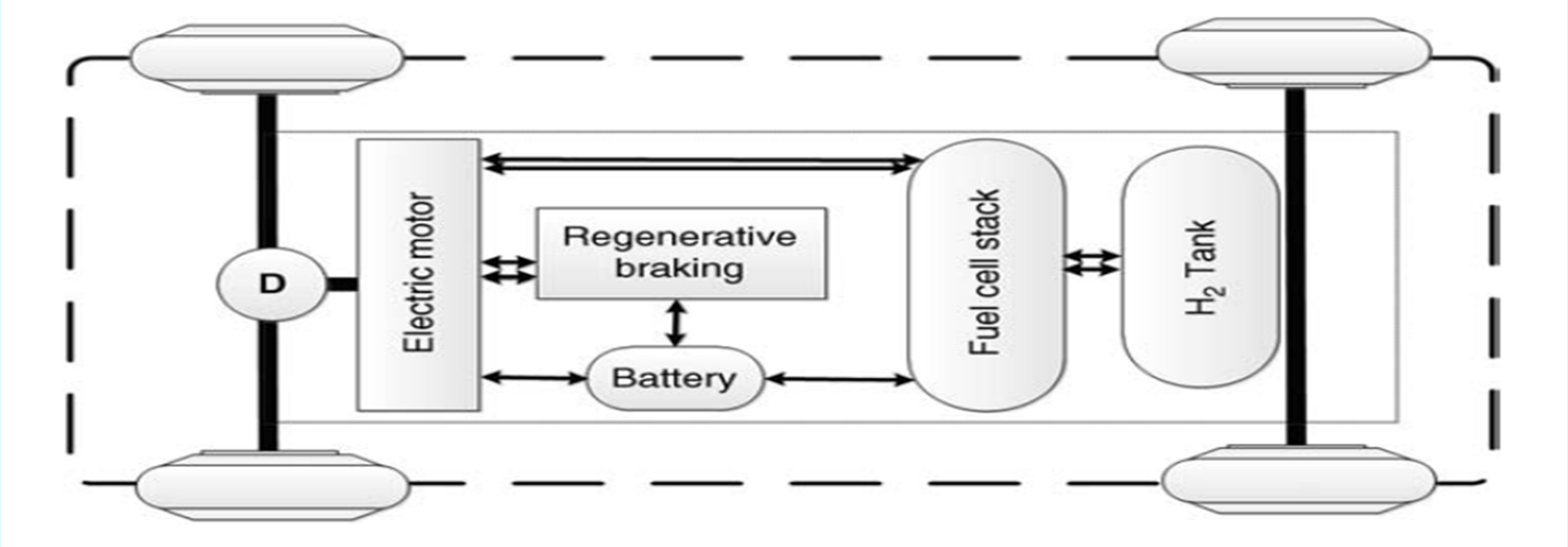
- BEVs use one or more electric motors for propulsion and batteries to store electricity.
- The battery bank in a BEV is normally charged directly from the grid using a battery charger
- The electrical energy stored in the battery is transferred to the wheels using an electric drive consisting of a power converter and electrical machine via transmission gears and differential.
- This power converter has to be designed to carry bidirectional power flow since it can also be used to regenerate the power coming from the wheels during braking.
- Clutch is normally not required in a battery electric vehicle as in conventional IC engine based vehicle.

BEV Internal Blocks….



- Due to the limited capacity of EV battery packs, the driving range currently possible on a single battery charge is shorter than that of a conventional vehicle running on a full tank of gasoline.

Fuel Cell Electric Vehicle….

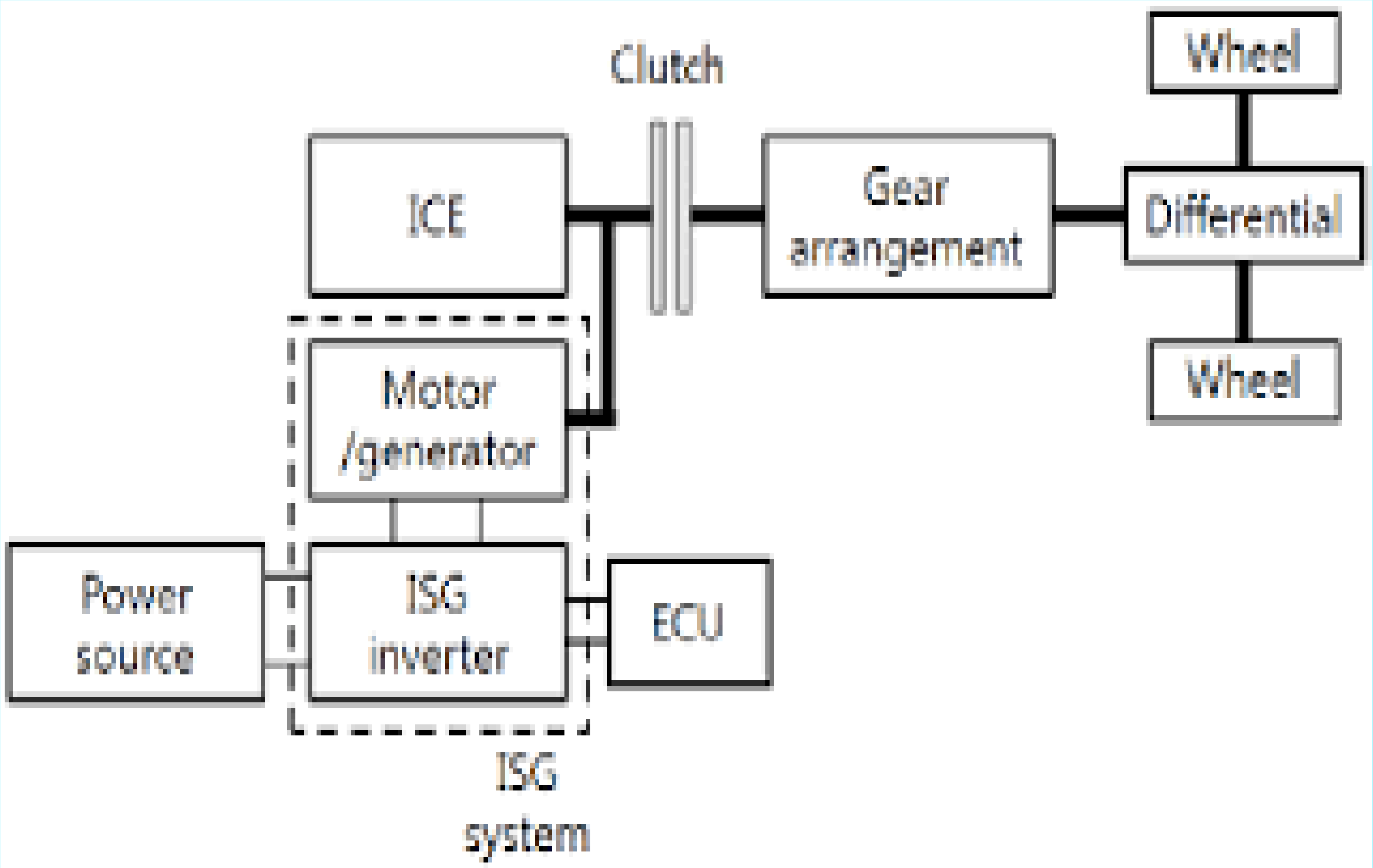


- It uses fuel cell as a source of energy which is connected to hydrogen tank.
- A boost converter is required to step up the voltage of the fuel cell to charge the battery and store the energy.
- Battery bank enables two purposes. First, it allows fuel cell to operate at optimum efficiency. Secondly, it can support the transient mechanical energy requirements at the wheels.

Fuel Cell Electric Vehicle….

- It can also help to store the regenerative energy coming during braking since fuel cell is incapable of storing the regenerative energy.
- The most prominent advantage of FCEVs is their driving range, which is similar to that of a vehicle operating with an ICE.
- What determines the FCEV range is the amount of hydrogen fuel available in the fuel tank, independent of the fuel-cell size.
- In fact, the relevance of fuel-cell sizes is contingent on the required power level of the FCEVs.
- A fuel-cell is not a storage device. It is an energy source unit where generated electricity either provides direct power to the traction motors or remains stored in the on-board energy storage for future use.

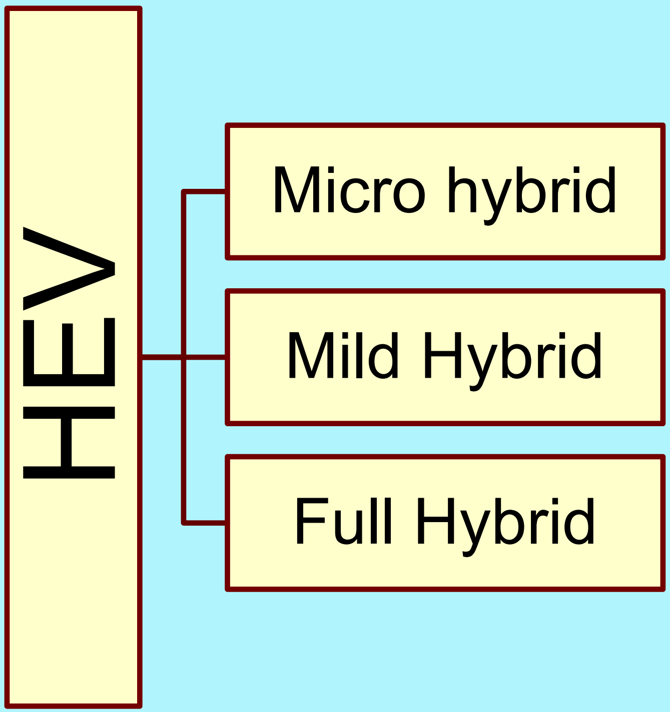
Integrated Starter Generator ….



Integrated Starter Generator (ISG)….

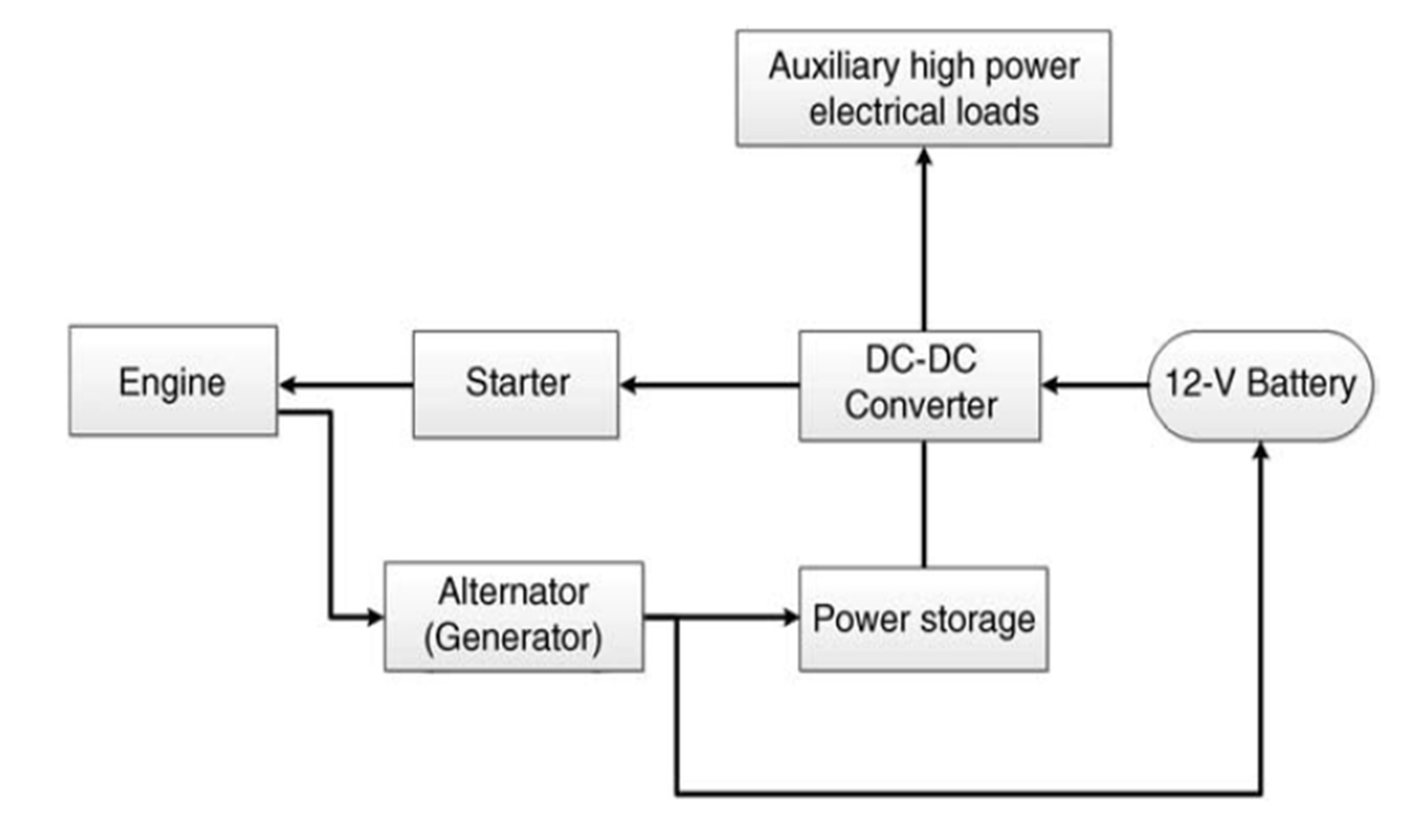
- IC engine requires a starter motor for starting IC engine and an alternator to recharge the battery once the IC engine has started functioning.
- These two functions can be clubbed together in a device called integrated starter generator or ISG in short form.
- An ISG in an electrical machine which can be connected to the IC engine either using a belt driven system or it can be directly mounted to the crankshaft.
- It can assist IC engine in various ways
  - ü Start /Stop & Instant Restart
  - ü Regenerative Braking
  - ü Torque Augmentation
    - Boost / Launch

Micro, Mild and Full Hybrid ….



- Micro hybrid:
  - ü ISG, 3 to 5 KW, 14 to 42 volts
  - ü Start/stop, Regenerative Braking.
- Mild hybrid
  - ü ISG, 7 to 15 KW, 100 to 150 volts
  - ü Start/stop, Regenerative Braking
  - ü Power Assist
- Full hybrid
  - ü Electronic Variable Transmission,
  - ü 50 to 60 KW, 500 to 600 volts
  - ü Start/stop, Regenerative Braking
  - ü Power Assist, Electric Launch
  - ü High efficiency mode in Optimal Operation Line (OOL) mode in ICE

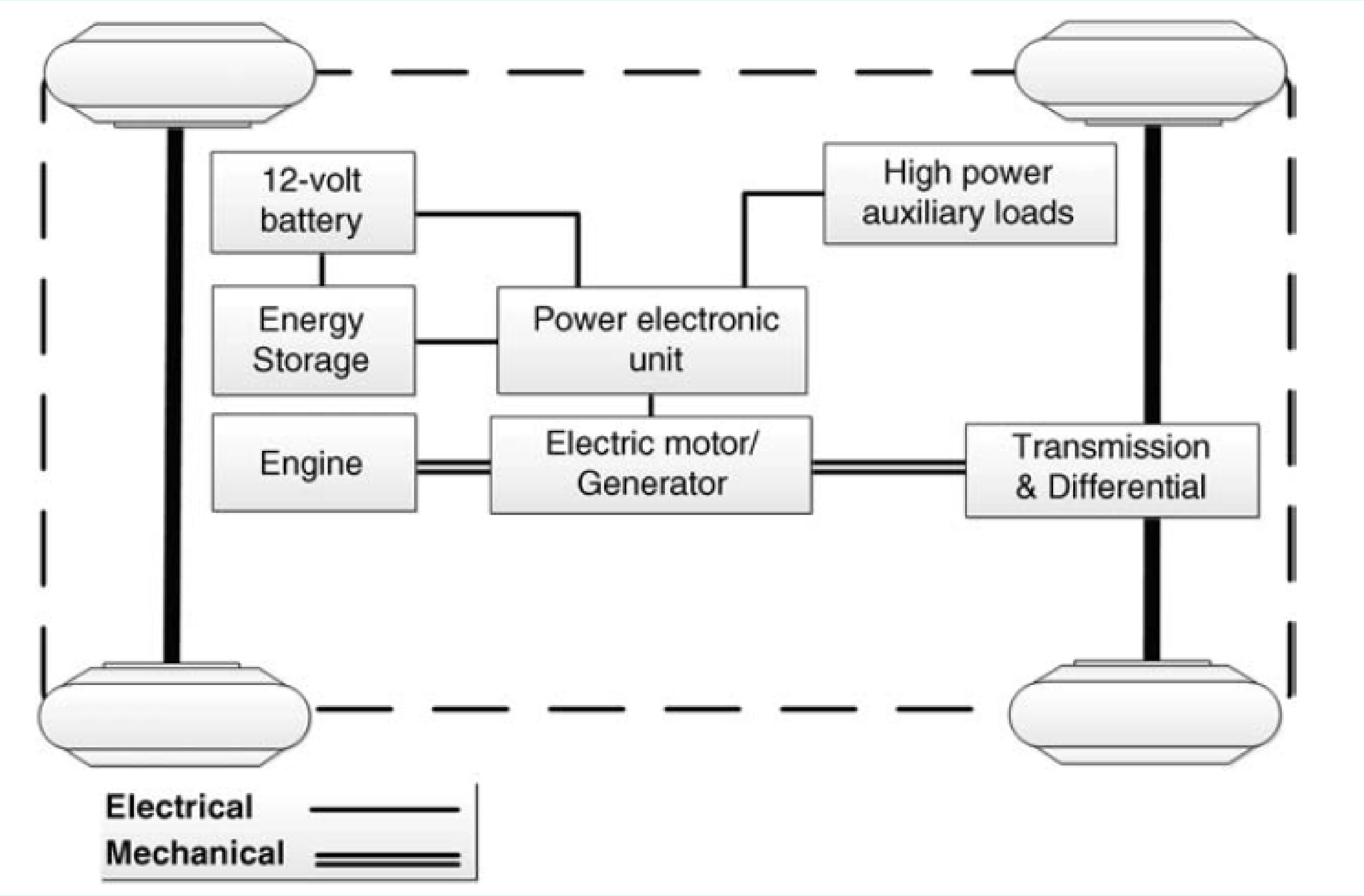
Micro Hybrid Schematic ….



Micro Hybrid ….

- A micro-hybrid is a vehicle in which an electric machine functions in applications such as stop/start and regenerative braking, but not to supply additional torque when the engine is running.
- Most micro-hybrid applications have been focused on small gasoline engines, but the achievement of stop/start in a diesel engine is a considerably greater challenge due to the much higher starting torque requirement.
- The BMW 1 series and the Smart For two, manufactured by Mercedes, are examples of commercialized micro-hybrid vehicles

Mild Hybrid Schematic ….



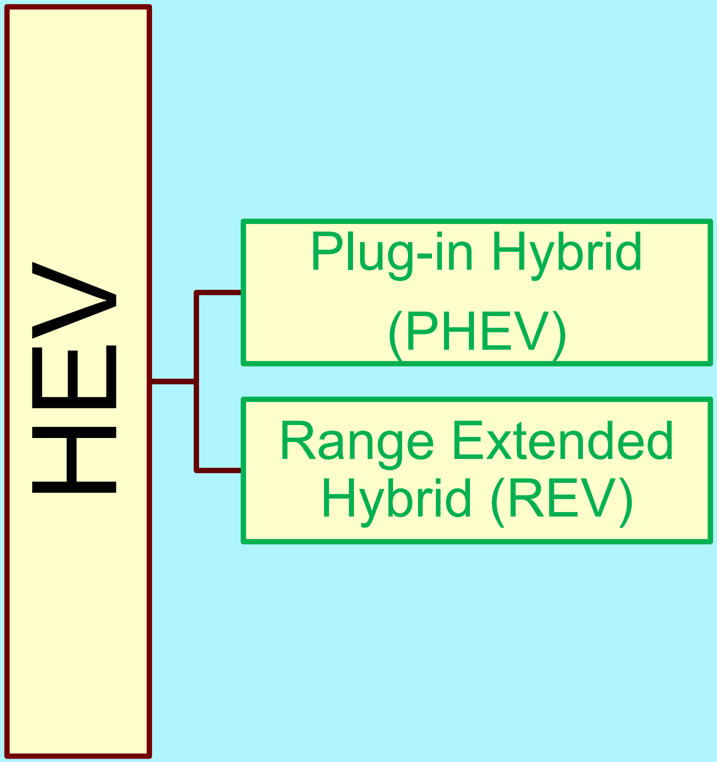
Mild Hybrid ….

- A mild-hybrid has an electric motor-generator integrated to provide up to approximately 10% of the maximum engine power in the form of additional torque.
- Mild HEVs improve the drawbacks of fossil-fuel vehicles, where engine efficiency is not at its maximum levels.
- The ICE consumes more fuel and emits more emissions when coasting, braking, or idling. Mild HEVs can provide some level of power assistance to the engine whenever the engine is not efficient, and are able to provide engine start–stop functionality.
- Moreover, during idling, they can turn off the engine and use electric power instead.

Micro, Mild and Full Comparison….

	Engine Start/Stop	Regenerative Braking	Motor Assist	Electric Drive
Micro-hybrid	Yes	Slight	Slight	No
Mild-hybrid	Yes	Yes	Yes	No
Full-hybrid	Yes	Yes	Yes	Yes

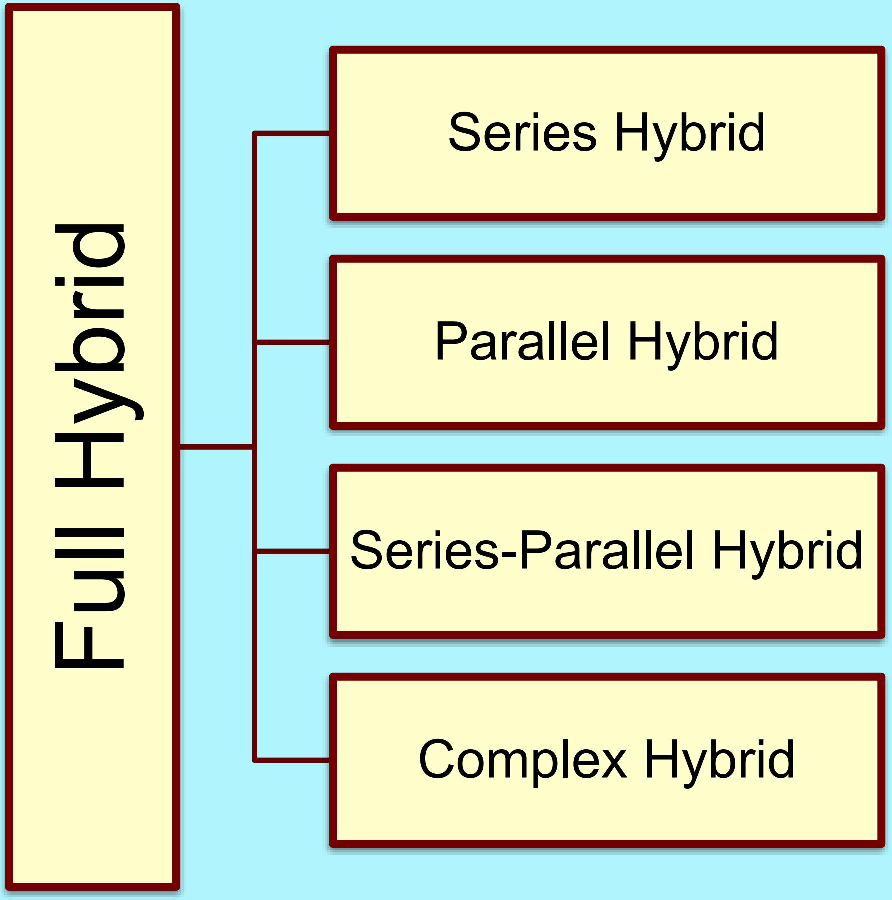
Grid-able HEV….



- **Plug in Hybrid**
  - ü Derived from Full Hybrid.
  - ü Mostly operates in the blended mode. The electric motor and IC engine complements each other, in such a way that the fuel economy is maximum
  - ü Requires a higher battery bank compared to a full hybrid
- **Range Extended Vehicle**
  - ü Derived from a battery electric vehicle. Operates in pure electric mode

ü Works till a threshold of battery pack voltage is reached where it starts the smaller rated IC engine to charge the battery.

Types of Full Hybrid ….



A full hybrid HEVs can be further classified into four types. Will study it in details latter.

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Lecture 5

- Challenges of BEV
- Challenges of Conventional HEV’s
- Challenges of Grid able HEV’s
- Challenges of Fuel Cell EV’s
- Challenges of UCV & UFV
- Components of an EV
- Transmission Configurations EV
- Front & Rear Wheel Drivetrain
- Dual & Four Wheel Drivetrain
- Architecture of EV
- Hybrid Drive train
- Classification as per Drive Train
- Series Hybrid
- Series Hybrid Operation Modes

Challenges of BEV ….

- Limited Driving Range
  - ü The energy storage capacity of a battery electric vehicle is lower compared to a IC engine based vehicle because of low specific energy and low energy density of battery compared to a liquid fuel. Therefore, it offers a limited
  - ü For similar conditions, BEV gives 120 kilometers per charge ICE gives 500 kilometers per charge
- High Initial cost
  - ü More battery banks are used to match the operation of IC engine
  - ü It is not only oversized, it is very costly
  - ü The battery have a limited cycle life of around 1500 which means four to five years, it requires replacement of battery bank

Challenges of BEV ….

- Lack of charging infrastructure

ü Normal charging: 5 to 8 hrs., 110-120V, 13 to 40 Amp, 2 to 4 KW

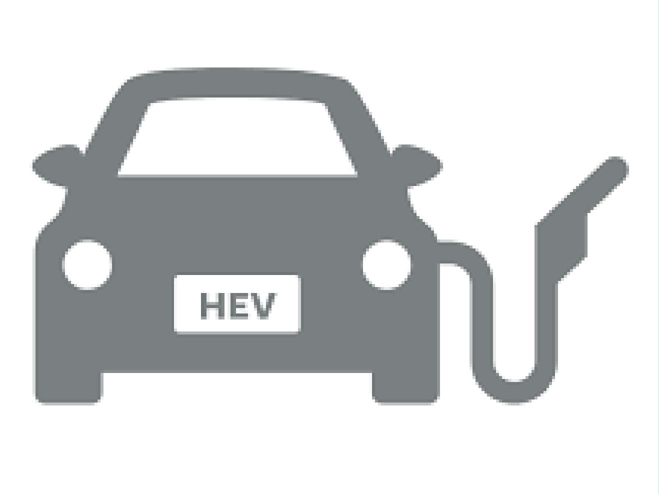
ü Fast charging: 30 min to 1 hour, 200 to 400 Volt, 100-200 Amps and 50 kilowatt

ü Battery swapping station

- Cost Charging infrastructure
- Effect on the power grid

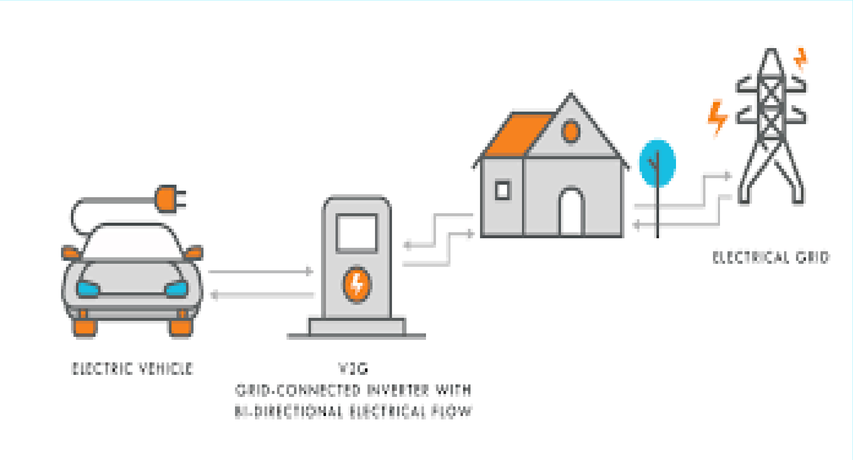
ü These systems put a lot of pressure on the power grid since it is drawing very high currents from the utility grid and it requires a costly charging infrastructure.

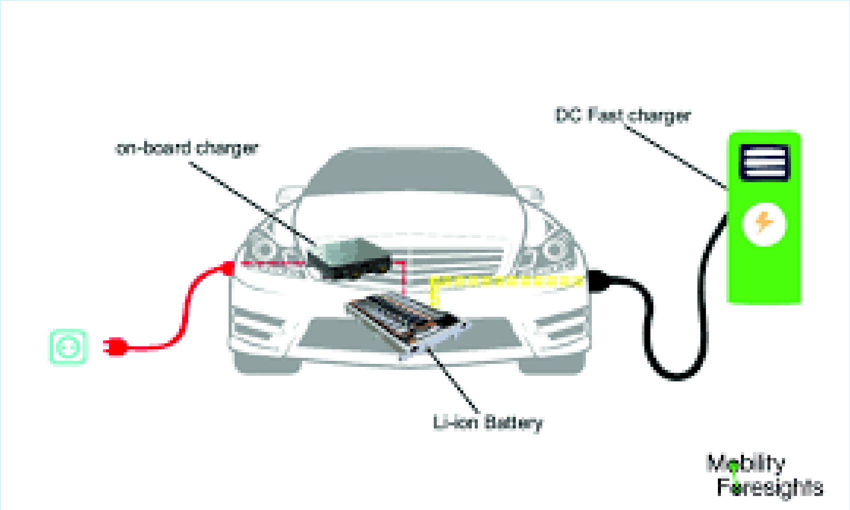
Challenges of Conventional HEV's….



- Non-zero emissions
- Low energy diversification that it can be only refueled using oil and natural gas.
- Complex Systems and lot of coordination
- Variable Transmission system
  - ü Has its own losses
  - ü It creates a lot of noise
  - ü It requires regular lubrication
- System is quite heavy and also bulky

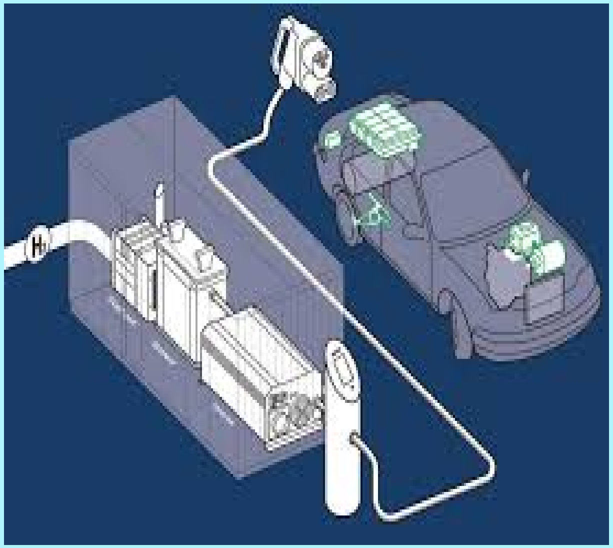
Challenges of Grid able HEV's….





- All challenges of conventional HEV
  - ü Non-zero emissions
  - ü Low energy diversification
  - ü Variable Transmission system
  - ü Heavy and Bulky
- Installation of Onboard charges
- More Initial cost
  - ü It is more costly since it requires more battery capacity

Challenges of Fuel Cell EV's….



- More Initial cost
  - ü Cost of Fuel cell
- Lack Of Hydrogen Refueling Infrastructure
- The Storage Of Hydrogen
  - ü Compressed Hydrogen Gas

Similar to CNG, hydrogen gas can be compressed

ü Liquid Hydrogen : It requires technology similar to cryogenic storage technology which is also costly.

ü Metal Hydrides: It can also be stored in a solid form as metal hydrides, very similar to battery swapping.

ü It has high safety concerns of explosion and lots of safety factors to be in place before it can be commercially viable

Challenges of UCV & UFV ….

- More Initial cost
  - ü Cost of UCV & UFV is high.
- Low Specific Energy

It cannot be used as a sole energy source
and it requires battery as a hybrid energy source along with it.

- UFV has a extra safety concern

Ultra-flywheel which stores mechanical energy at high speed of flywheels often have safety concerns and is less reliable.

Components of an EV ….

- **Battery**

It powers the electric motor. Its capacity is defined in Ah. The design of battery includes complex calculations which determines various battery parameters

- **Power convertor**

The electrical energy stored in battery is fixed DC which should be converted to either variable DC or Variable AC which depends on the type of electric motor used for power the wheels

- **Electric Motor**

DC series, Induction motors were used at the earlier stage. Now the scope has shifted towards special electrical machines

Components of an EV ….

- **Clutch**

The engine must be decoupled from the wheels to shift from low speed to high speed gears or vice versa, this is done by the clutch.

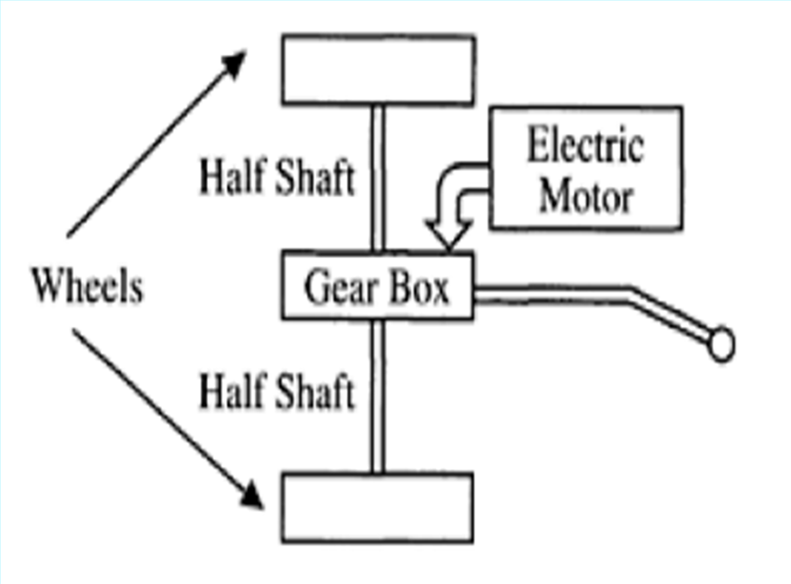
- **Transmission**

The gearbox is also called as transmission
which allows transfer of power from engine to wheels.

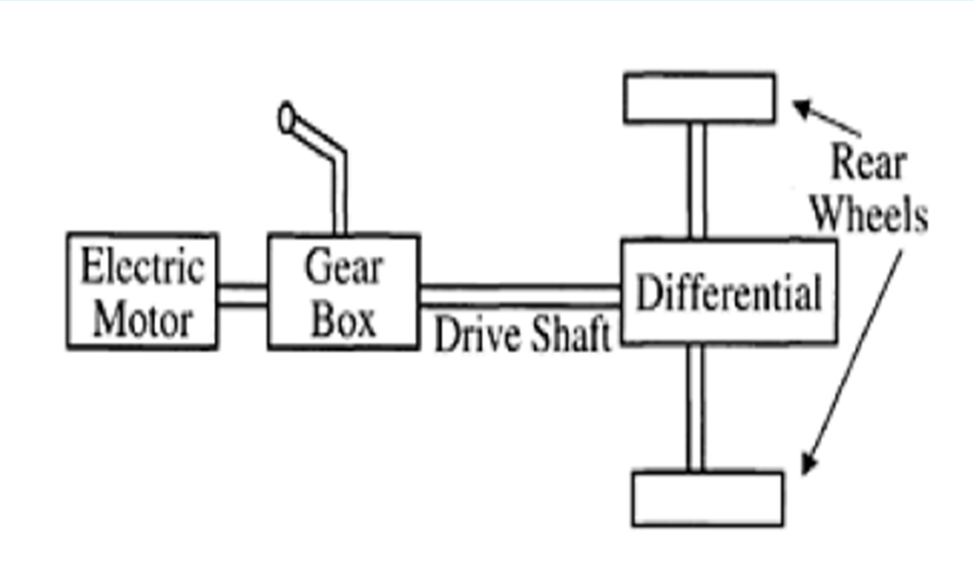
- **Drivetrain**

The combination of Electric motor, Clutch, Gearbox is referred to as drivetrain

Transmission Configurations EV….



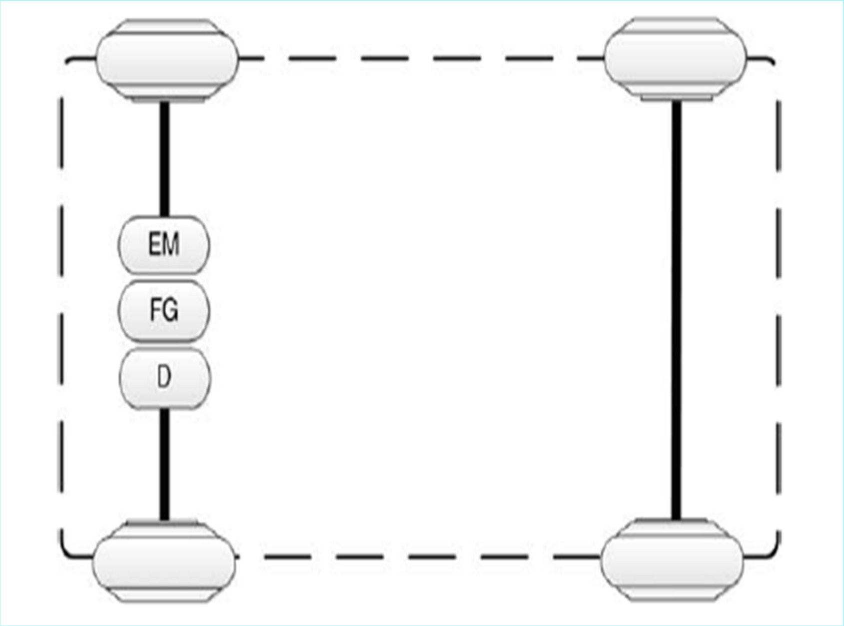
Front-wheel Drive



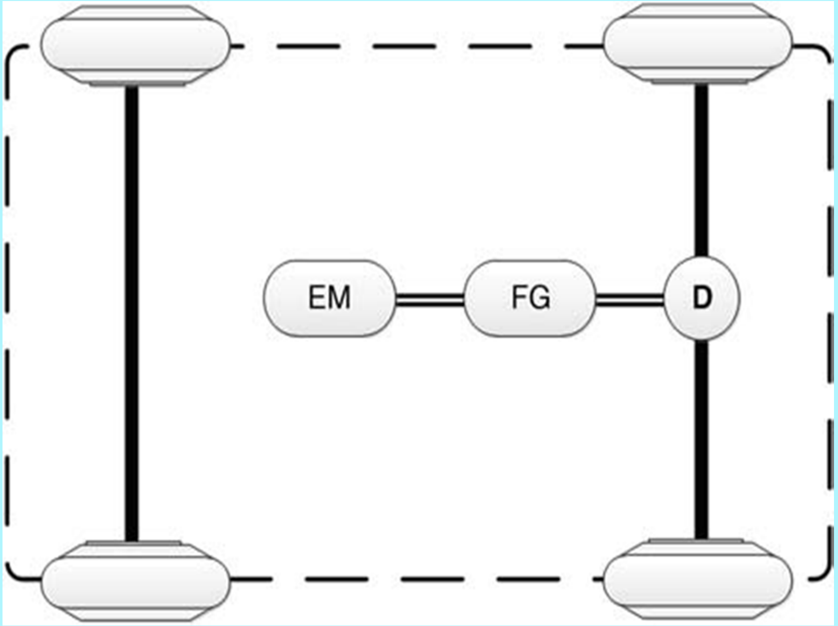
Rear-wheel Drive

Single Propulsion Motor: The single motor drives the transaxle on a common axis, delivering power to the two wheels differentially through a hollow motor shaft

Front & Rear Wheel Drivetrain….



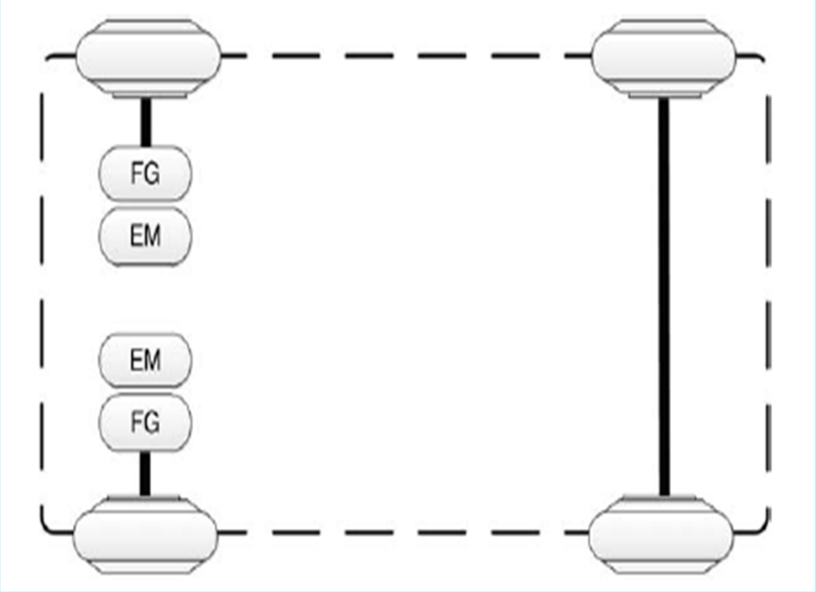
Front- out wheel Drive



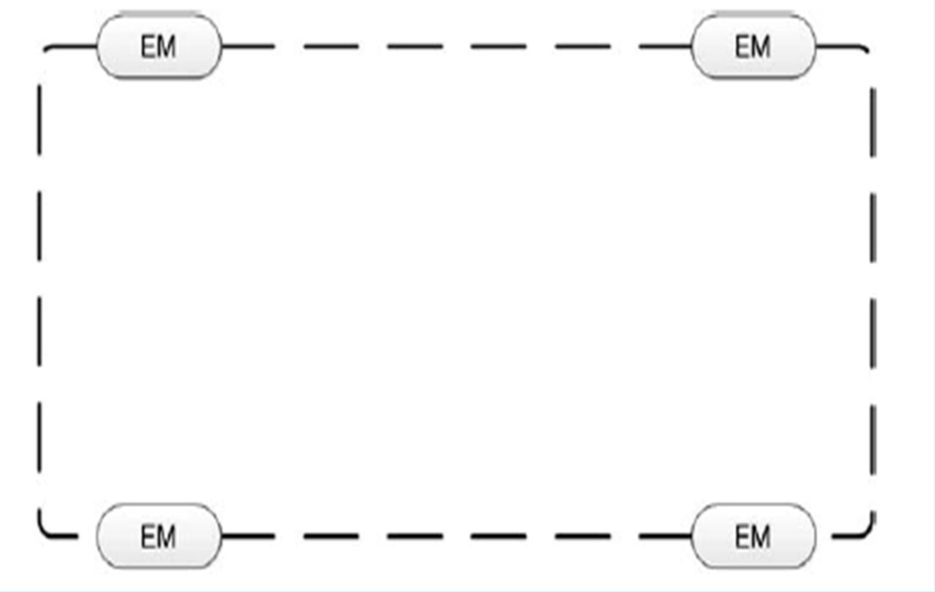
Rear- out wheel Drive

EM Electric Motor
FG: Fixed Gear
D: Differential Gear

Dual & Four Wheel Drivetrain ….



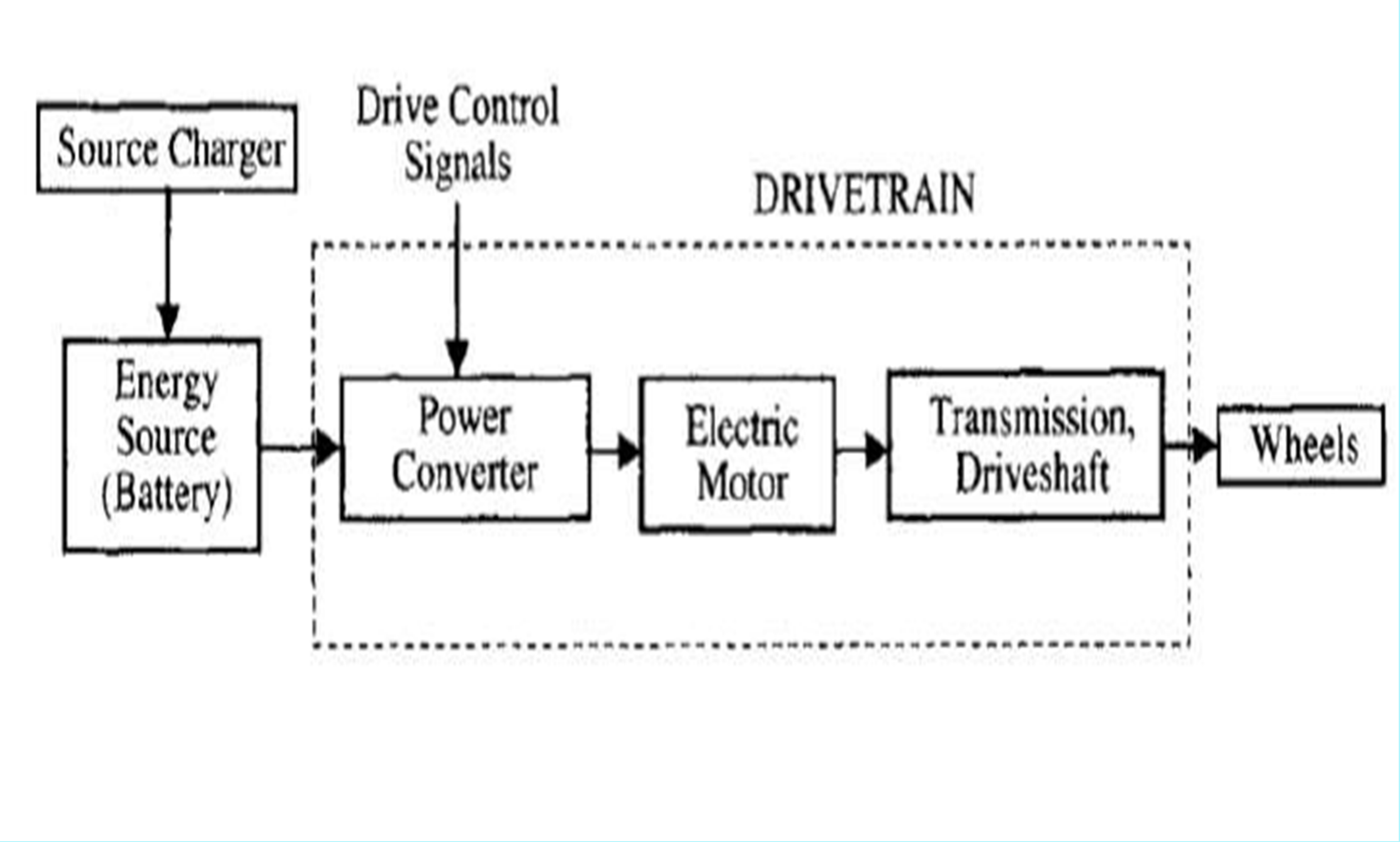
Front- out wheel Dual Drive



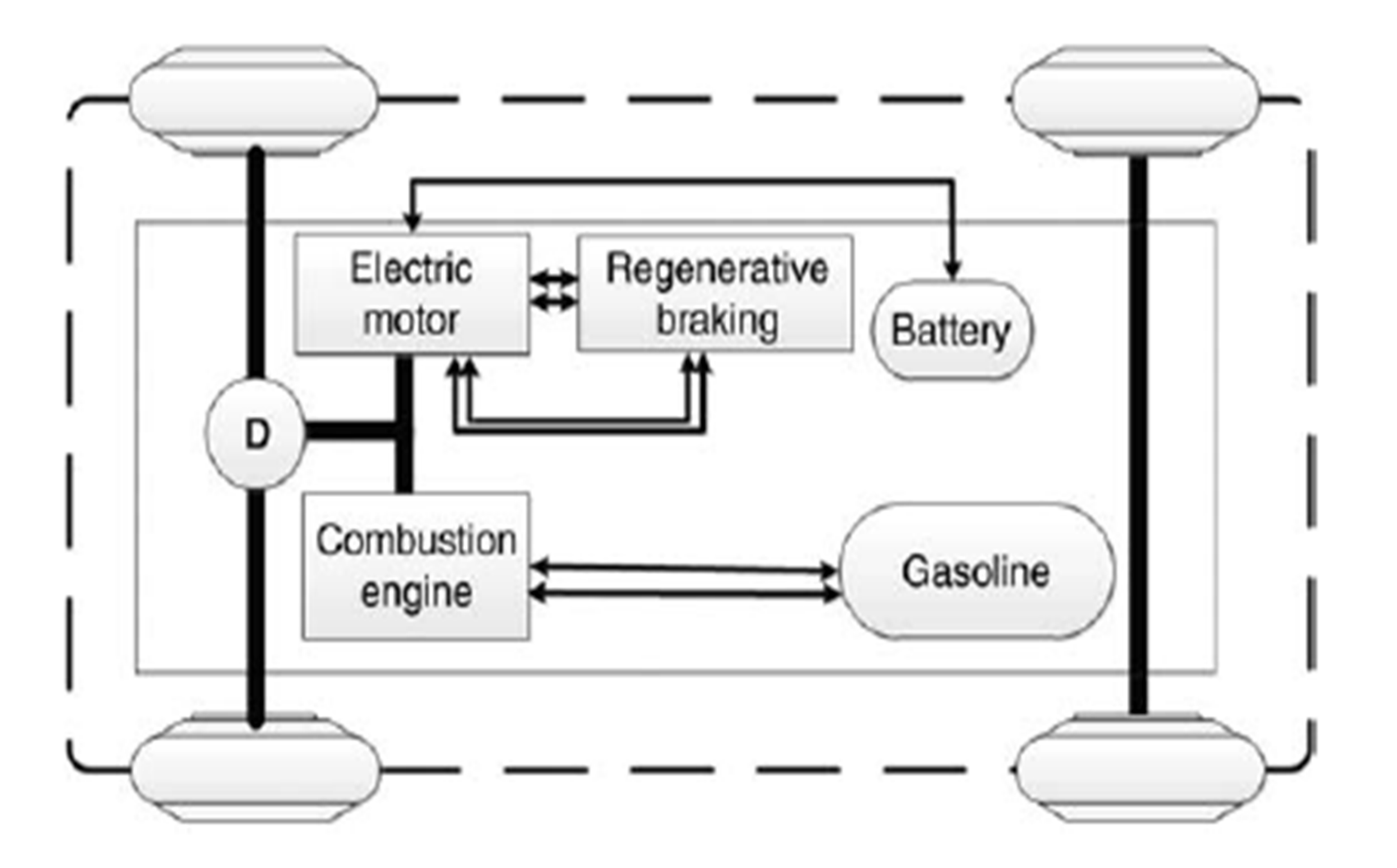
In wheel / Four Wheel Drive

EM Electric Motor
FG: Fixed Gear
D: Differential Gear

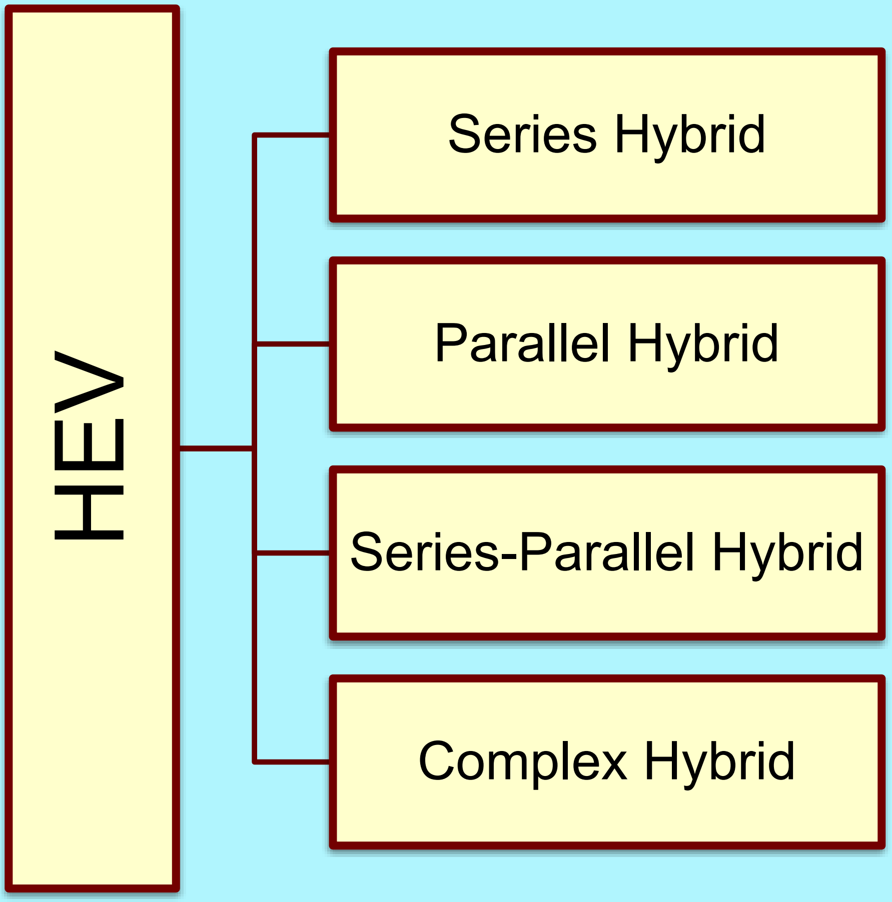
Architecture of EV….



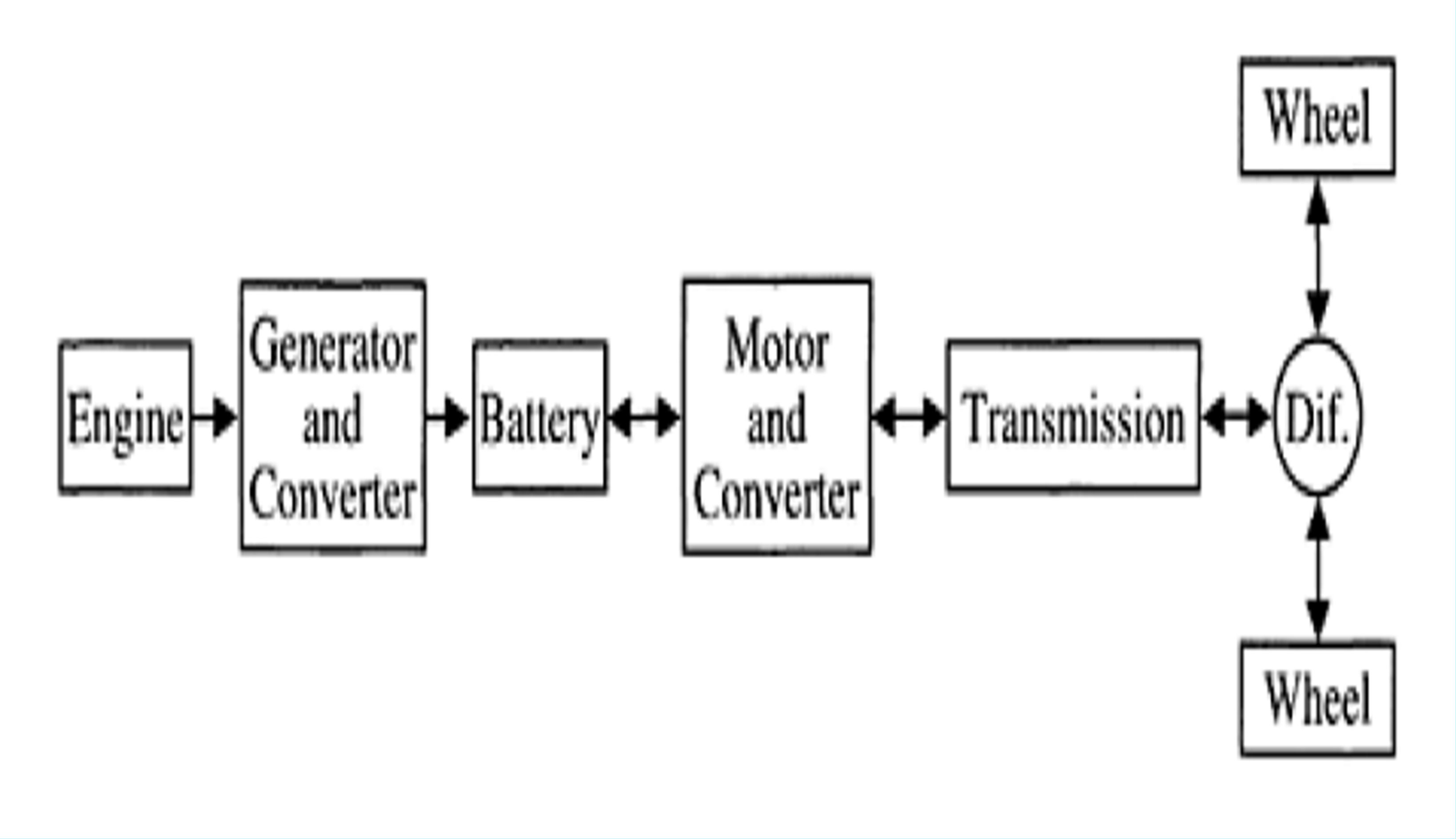
Hybrid Drivetrain of EV….



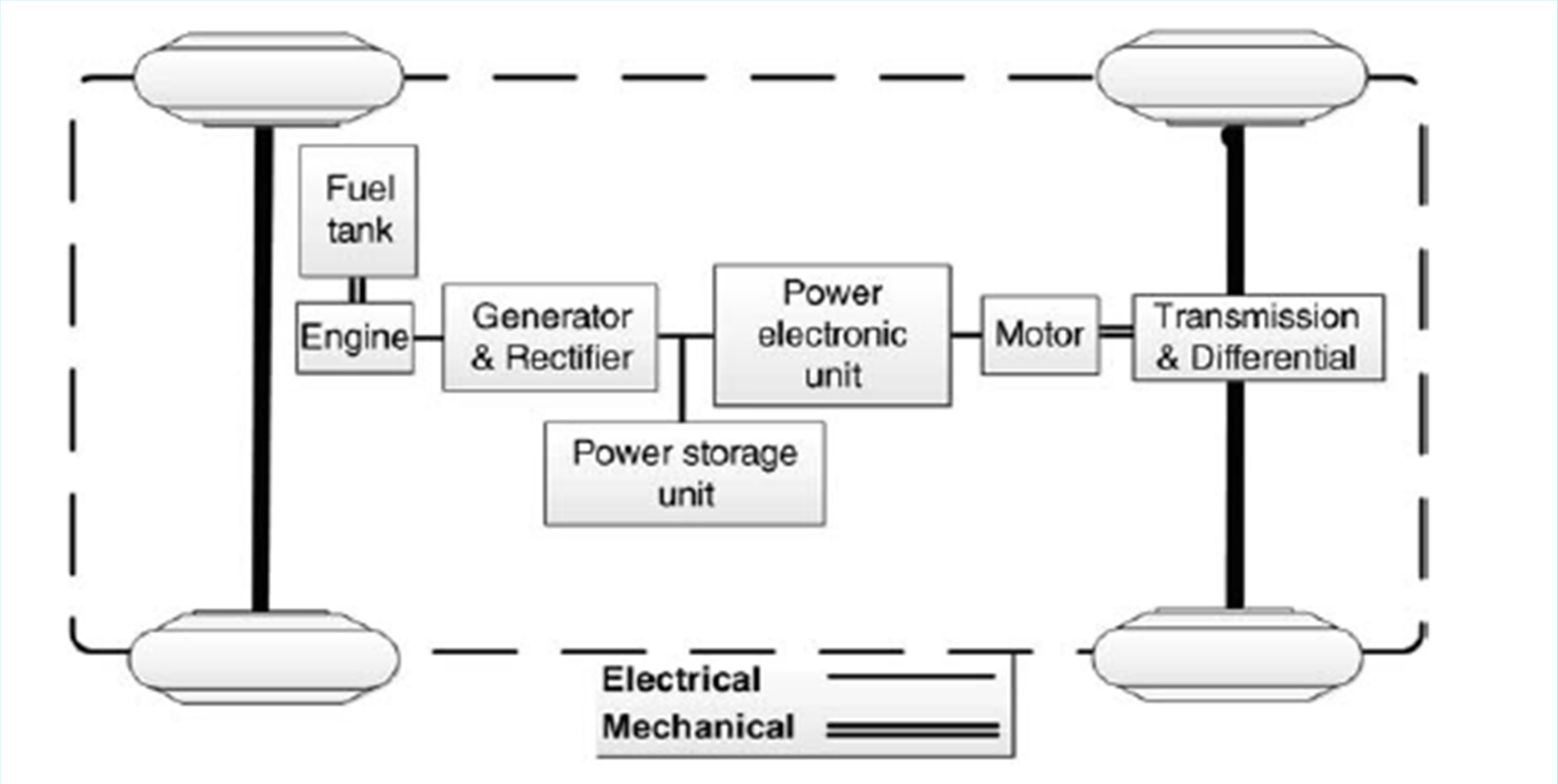
Classification as per Drive Train ….



Series Hybrid ….



Series Hybrid ….



Series Hybrid Operation Modes….

1. *Engine-alone traction mode:* In this mode, the combustion engine only provides the total required power for vehicle motion through the generator while the electric motor acts as an electric transmission between the engine and the driving wheels. The batteries neither provide nor receive any power from the drivetrain.
2. *Electric-alone traction mode:* In this mode, the engine is off and the electric source supplies the total required power for vehicle motion.
3. *Hybrid mode:* In this mode, the engine–generator and batteries simultaneously deliver traction power to the wheels.

Series Hybrid Operation Modes….

4. *Engine traction and battery charging mode:* In this mode of operation, the engine–generator provides the traction power while charging the batteries.
5. *Regeneration mode:* The regenerative braking system charges the batteries during braking, decelerating, and downhill travel. In this mode, the traction motor operates as a generator and the engine-generator is not active.
6. *Battery-charging mode:* In this mode, the traction motor stops while the batteries are charged by the engine–generator.
7. *Hybrid battery-charging mode:* Both the engine–generator and traction motor operate as a generator and charge the batteries simultaneously.

Unit 1:- Electric and Hybrid Powertrain Technologies

By:- Prof. Dr. Saket Yeolekar

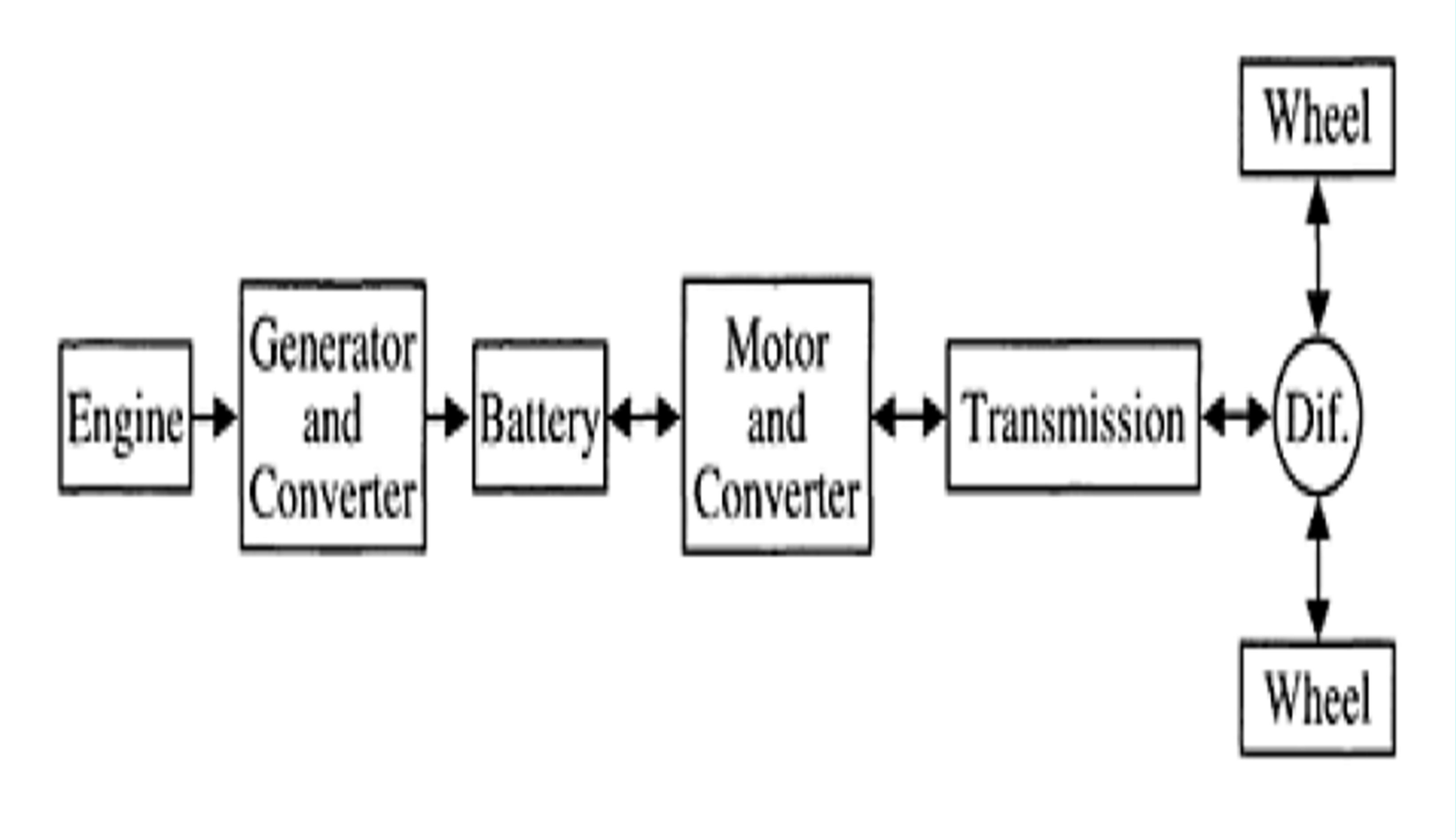
Syllabus…Unit 1 Focus On….

Lecture	Topics to be covered
L1	Introduction to vehicles, IC engine & Battery Electric Vehicles (BEV's) , history and social importance
L2	Benefits of E vehicles, Types of E-vehicles on the basis of propulsion devices, Energy sources and energy carriers.
L3	PEV's & HEV's , BEV, HEV, FCEV, UCEV and UFEV
L4	Classification of HEV, Micro hybrid, mild hybrid, full hybrid, plug-in hybrid and range extended hybrid electric vehicle.
L5	Parallel hybrid, Series Hybrid, Power split and compound Hybrid Configuration Plug-in Hybrid Electric Vehicles (PHEV's),
L6	Hybrid Hydraulic vehicles (HHV),Pneumatic Hybrid Vehicles, (PHVs)
L7	Power/Energy Management System

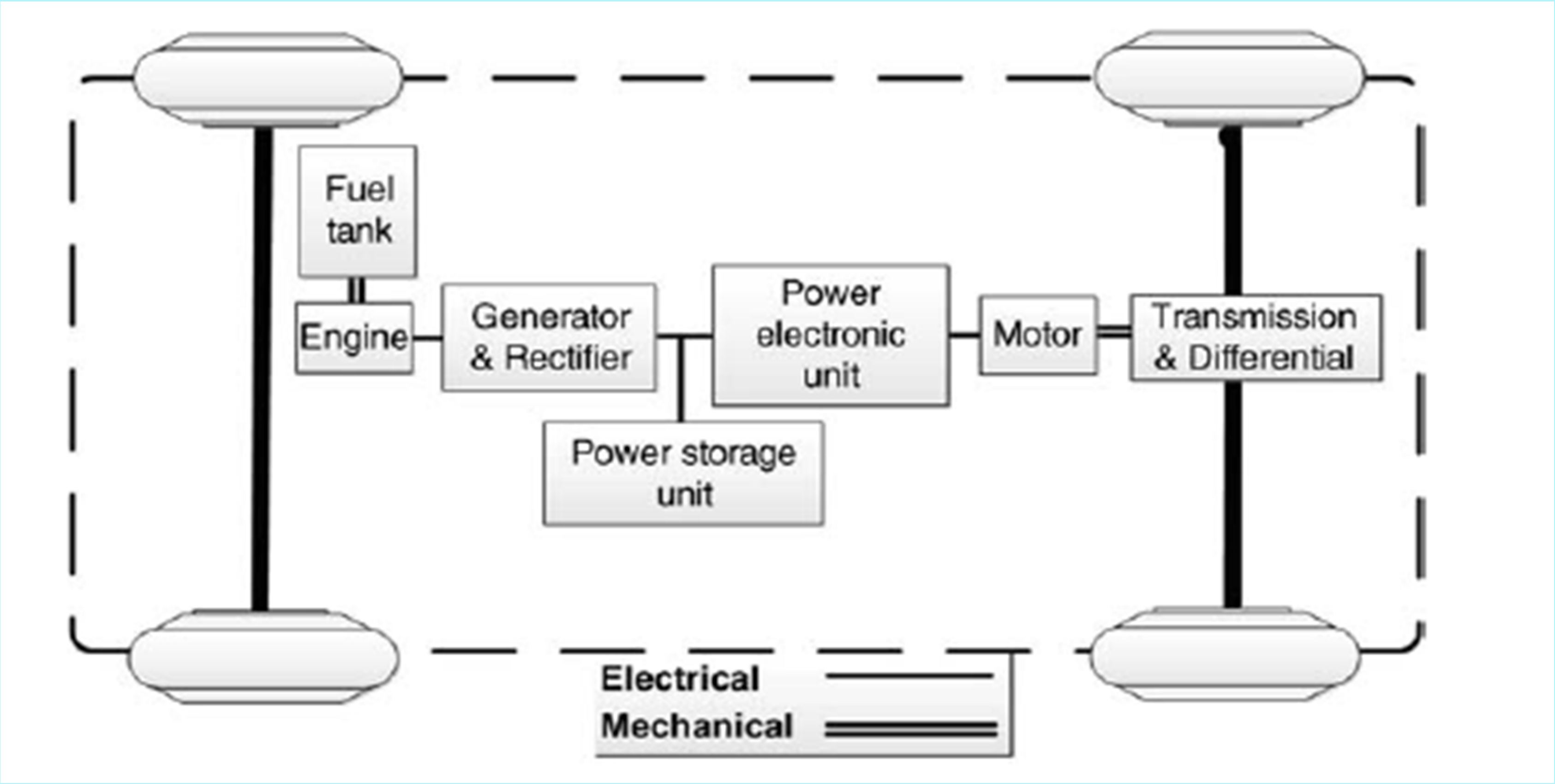
Lecture 6

- Series Hybrid
- Series Hybrid Advantages
- Series Hybrid Disadvantages
- Parallel Hybrid Drivetrain
- Parallel Hybrid
- Parallel Hybrid Single-Shaft
- Parallel Hybrid Double-shaft
- Operating Modes Parallel Hybrid
- Advantages of Parallel Hybrid
- Disadvantages of Parallel Hybrid
- Series-Parallel Hybrid
- Operating Mode : Series-parallel Hybrid

Series Hybrid ….



Series Hybrid ….



Series Hybrid Advantages….

A series hybrid is one in which only one energy converter can provide propulsion power. The heat engine or ICE acts as a prime mover in this configuration to drive an electric generator that delivers power to the battery or energy storage link and the propulsion motor.

Advantages

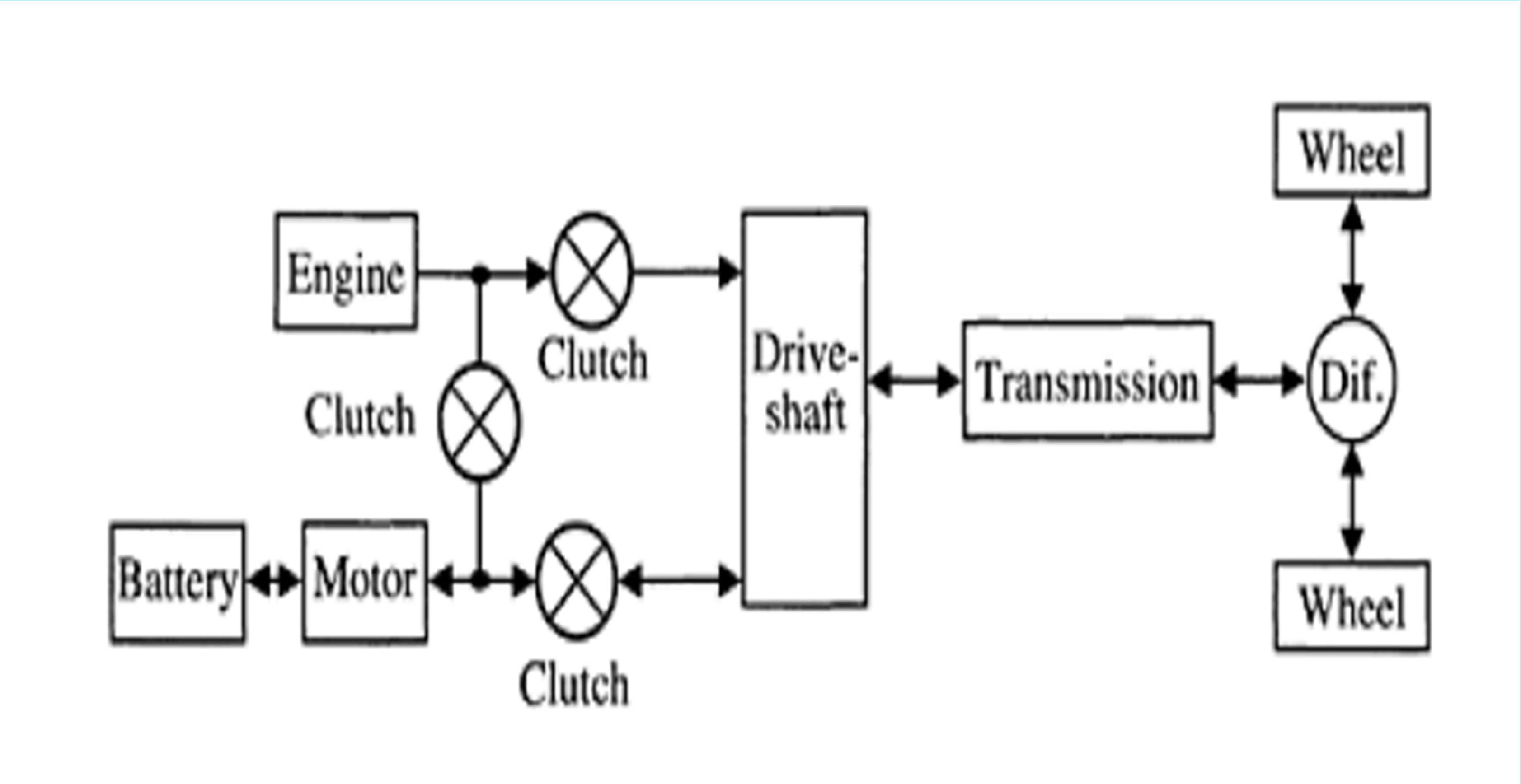
1. Flexibility of location of engine-generator set
2. Simplicity of drivetrain
3. Suitability for short trips
4. Simplicity of control algorithms used to control the power converters, hence achieving smooth speed control of electric motors

Series Hybrid Disadvantages….

1. It needs three propulsion components: ICE, generator, and motor.
2. The motor must be designed for the maximum sustained power that the vehicle may require, such as when climbing a high grade. However, the vehicle operates below the maximum power most of the time.
3. All three drivetrain components need to be sized for maximum power for long-distance, sustained, high-speed driving.

This is required, because the batteries will exhaust fairly quickly, leaving ICE to supply all the power through the generator.

Parallel Hybrid Drivetrain ….



Parallel Hybrid Drivetrain

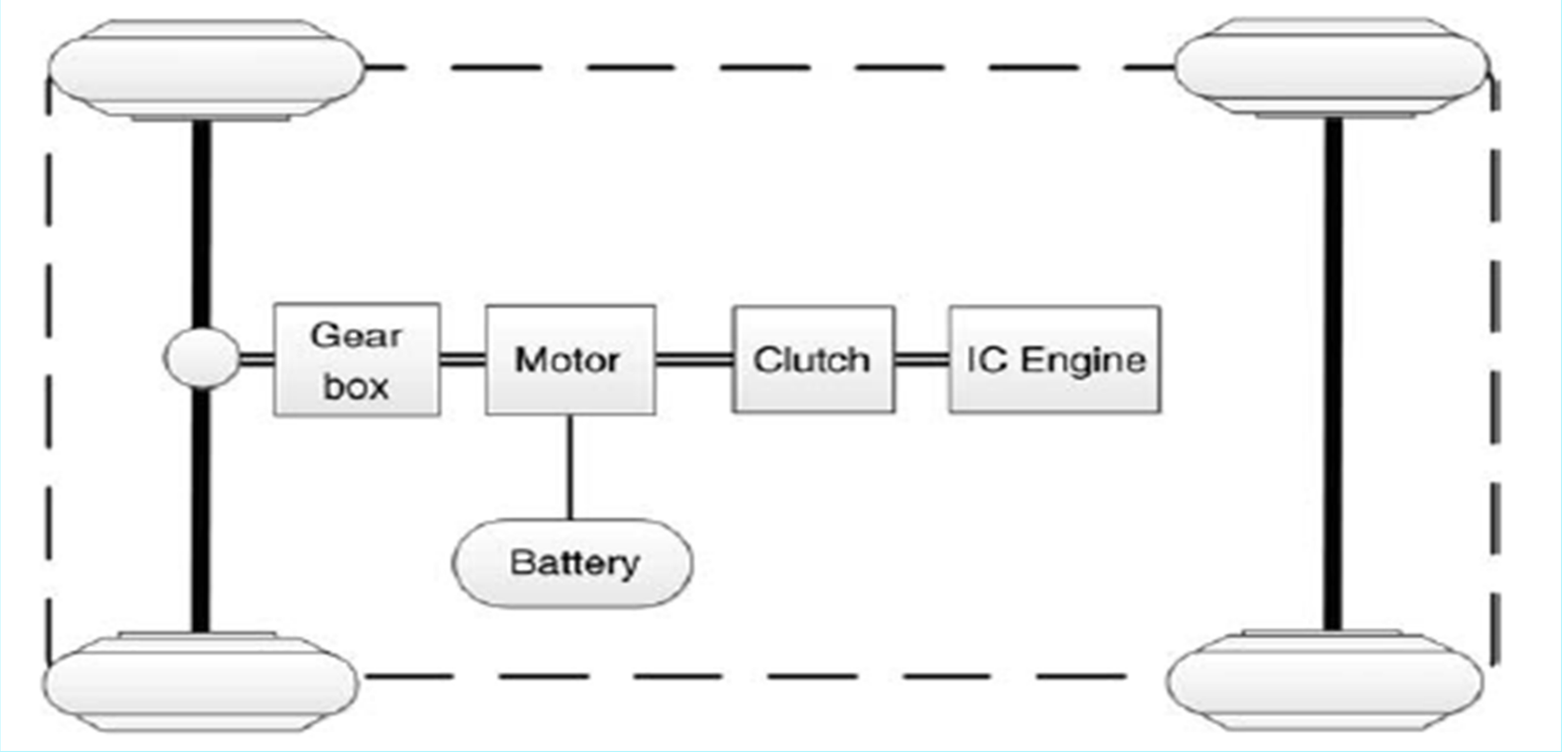
Parallel Hybrid….

- Parallel hybrid configuration is the most popular configuration in HEVs. This configuration mechanically couples the mechanical and electrical powers, allowing their use either simultaneously or independently.
- Usually, in parallel hybrid powertrains, the mechanical and electrical power outputs are combined by using mechanical devices such as torque-couplers and speed couplers.
- A mechanical torque-coupler adds the torques of the combustion engine and the electric motor using a gearbox unit or a pulley/chain assembly.
- In contrast, speed-couplers can be in the form of a planetary gear unit, they combine the combustion engine and electric motor powers. An electric motor with a floating stator can work as a speed-coupler as well.

Parallel Hybrid….

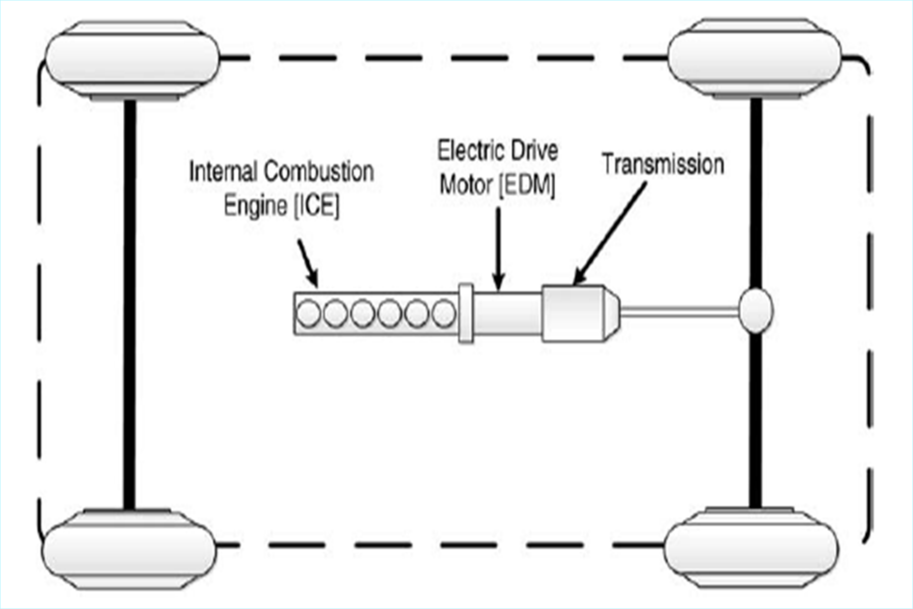
- The main benefit of hybrid powertrains with speed-couplers over those with torque couplers is the decoupled speeds of the two power plants, granting the opportunity to choose the speed of both the power plants independently.
- In a parallel hybrid arrangement, it is possible to shut off the ICE and only run the electric motor from the battery pack (as in a full electric vehicle).
- The ICE has the ability to recharge the battery during less intense power driving cycles, thereby making it more efficient for highway driving than the stop–start conditions of city driving.

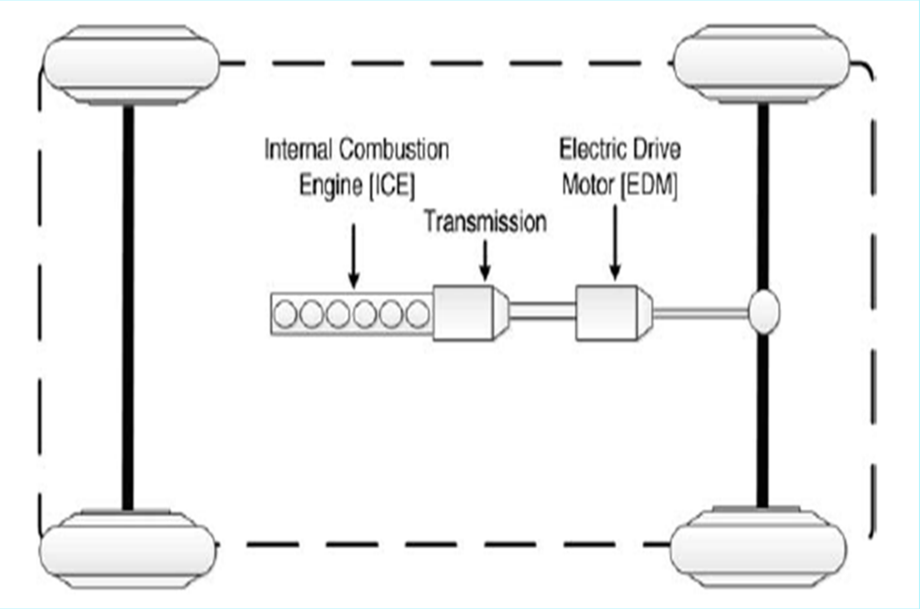
Parallel Hybrid Single-Shaft….



Parallel Single-Shaft Hybrid Powertrain

Parallel Hybrid Single-Shaft….

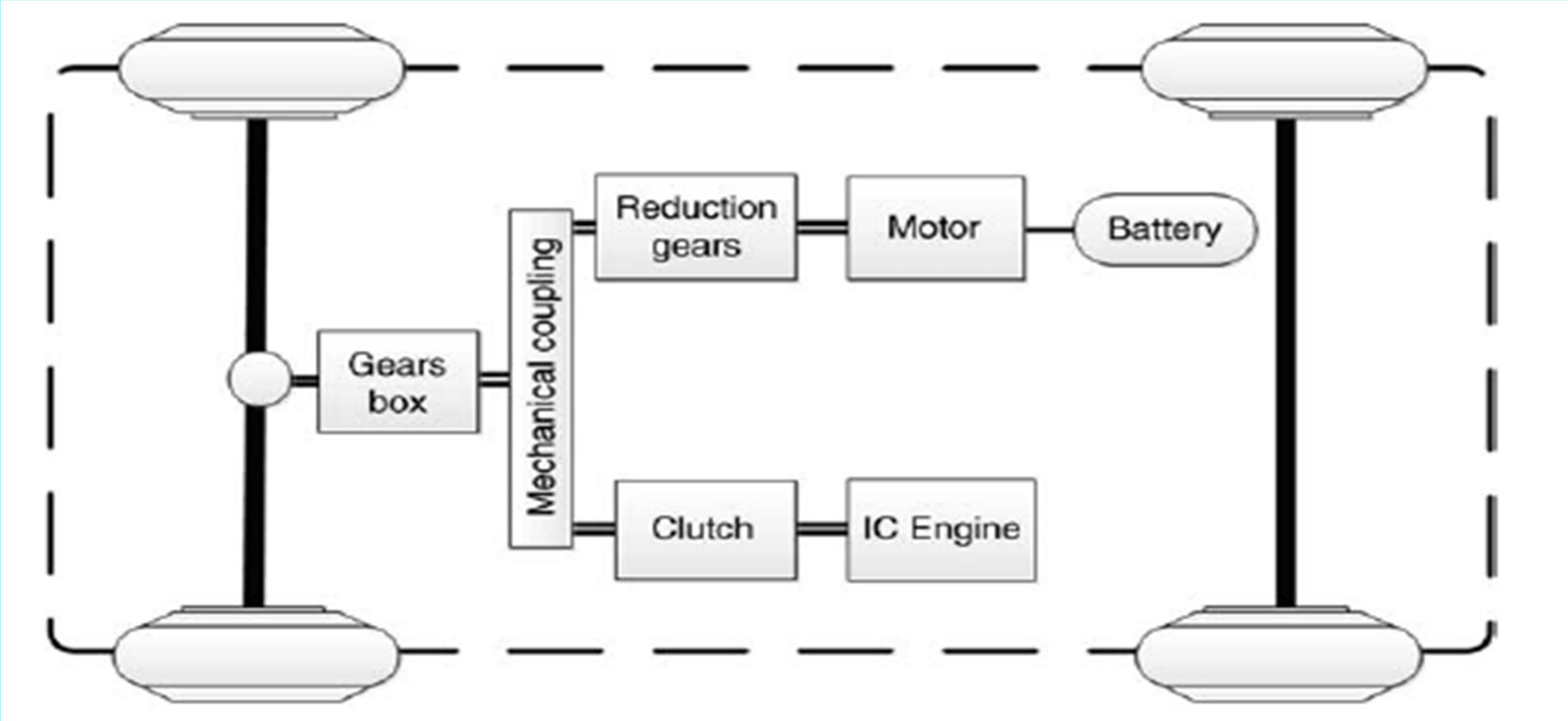




Pre-transmission parallel hybrid Powertrain

Post-transmission parallel hybrid Powertrain

Parallel Hybrid Double-shaft ….



Double-shaft parallel hybrid powertrain

Operating Modes Parallel Hybrid ….

1. *Engine-alone traction mode:* In this mode, the combustion engine generates the total required power for vehicle motion while the motor is off. This mode is used when the engine is running at or near its optimal operating conditions, such as when cruising.
2. *Electric-alone traction mode:* In this mode, the engine is off and the electric source supplies the total required power for vehicle motion. This mode is on when the ICE efficiency is low, such as when starting the vehicle, or when the vehicle speed is low (e.g., during reverse gear).
3. *Hybrid mode:* In this mode, the wheels receive power from both power sources. This mode is activated in conditions requiring more power such as when accelerating or during high speed driving

Operating Modes Parallel Hybrid ….

4. *Engine traction and battery charging mode:* In this mode the power generated by the ICE is more than the power required for vehicle motion. In this case, the additional power recharges the battery by switching the electric motor to operate as a generator.
5. *Regeneration mode:* In this mode, the kinetic energy the vehicle wastes while braking, or during downhill motion recuperates through the regenerative system of the powertrain.

Some of the parallel hybrid vehicles in the market are the Chevy Malibu Hybrid, the Honda Insight, the Ford Escape Hybrid, and the Honda Civic Hybrid.

Advantages of Parallel Hybrid ….

1. It needs only two propulsion components: ICE and motor/generator. In parallel HEV, the motor can be used as the generator and vice versa.

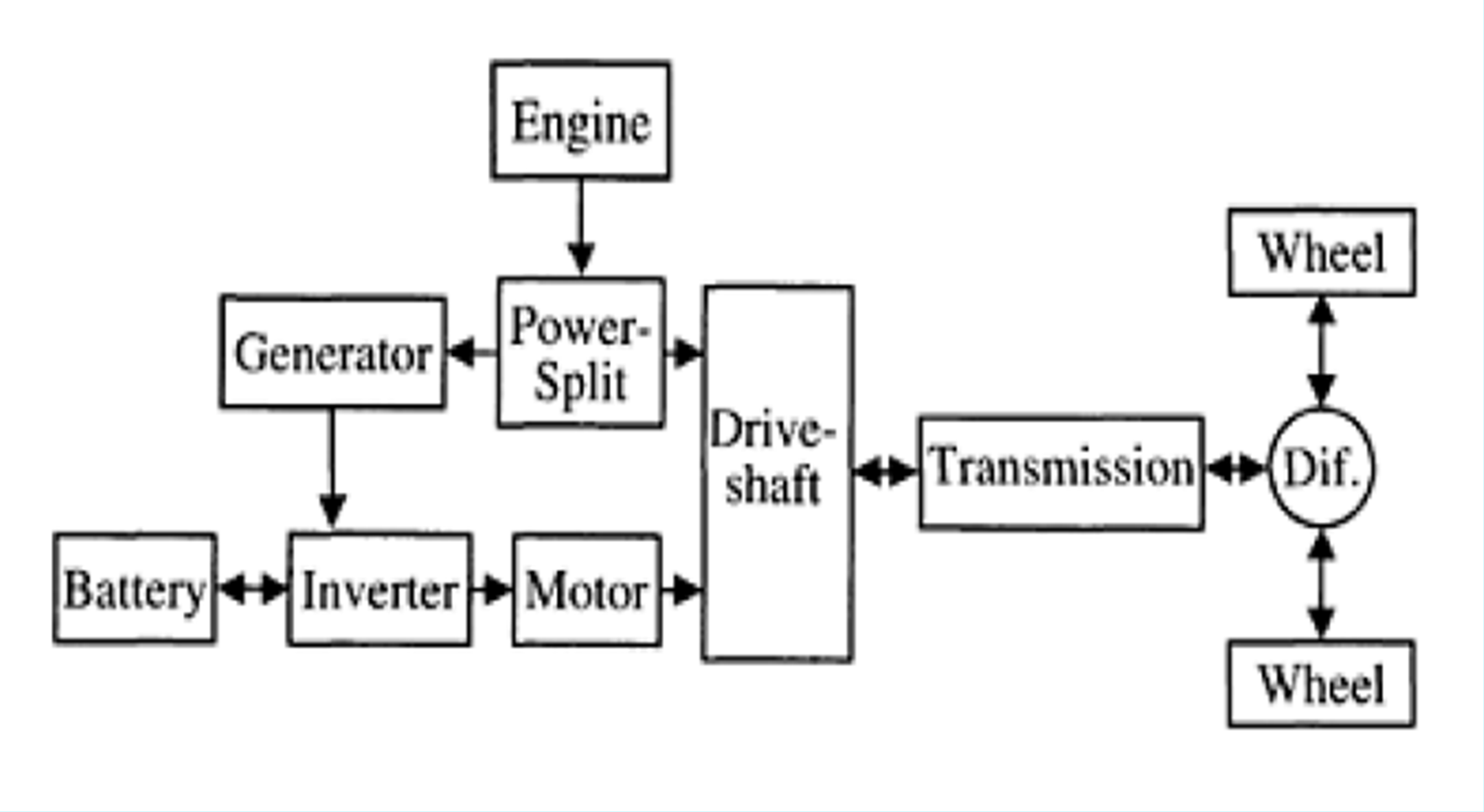
2. A smaller engine and a smaller motor can be used to get the same performance, until batteries are depleted.

- For short-trip missions, both can be rated at half the maximum power to provide the total power, assuming that the batteries are never depleted.
- For long-distance trips, the engine may be rated for the maximum power, while the motor/generator may still be rated to half the maximum power or even smaller.

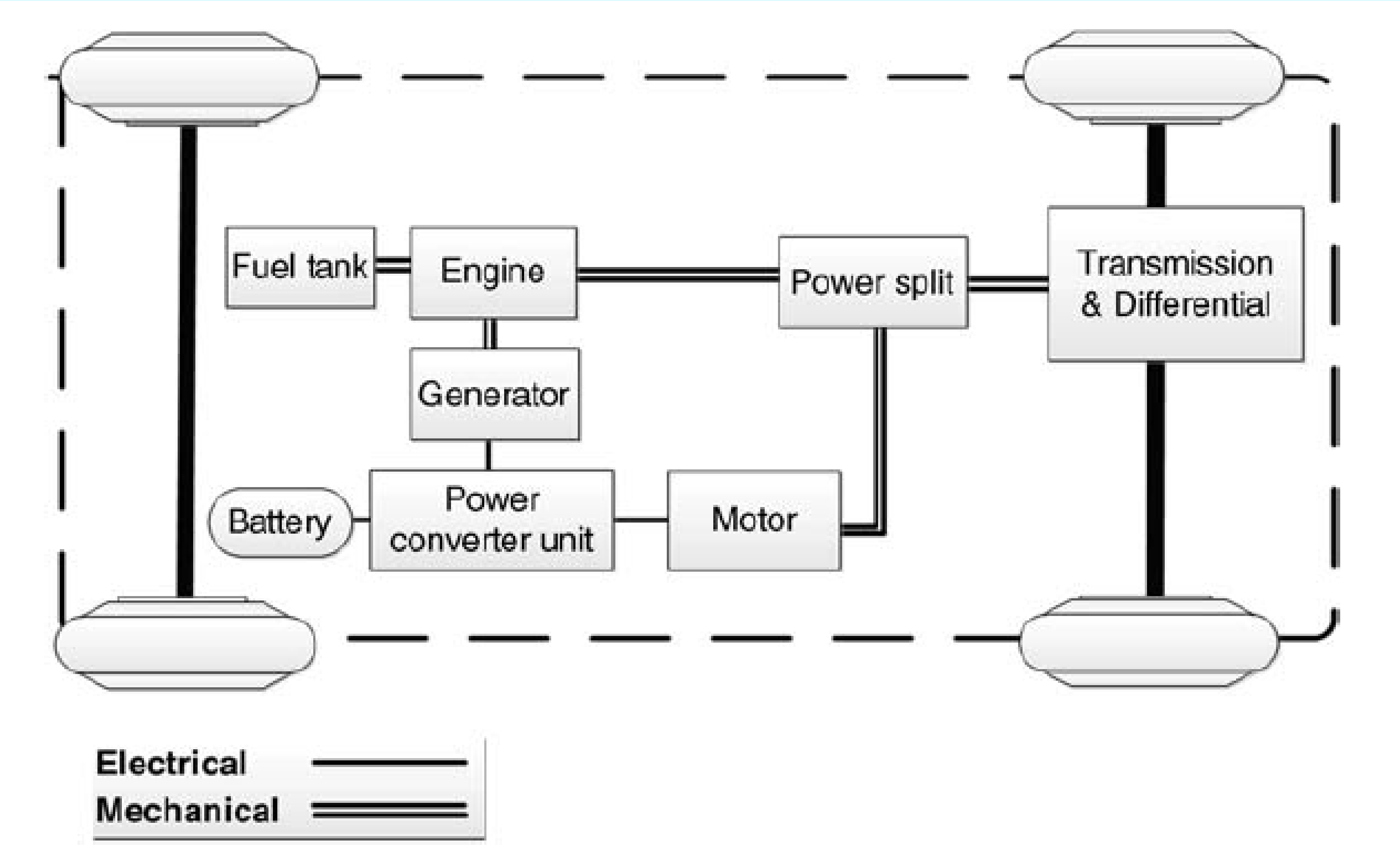
Disadvantages of Parallel Hybrid ….

1. The control complexity increases significantly, because power flow has to be regulated and blended from two parallel sources.
2. The power blending from the ICE and the motor necessitates a complex mechanical device.

Series-Parallel Hybrid ….



Series-Parallel Hybrid ….



Series-Parallel Hybrid ….

- Series-parallel hybrid systems takes advantage of the best features of both series and parallel hybrids
- In comparison with a parallel hybrid powertrain, a series-parallel uses an additional electric motor that primarily functions as a generator
- On the other hand, when compared to a series hybrid powertrain, the series-parallel connects the engine to the final drives through a mechanical link, thus allowing the engine to drive the wheels directly
- Systems split the power from the engine between two paths: one transfers the power to the wheels through a mechanical gear system, and the other transfers the power to the wheels through a generator and an electric motor.
- The example is of the *Toyota Prius hybrid* design.

Operating Mode : Series-parallel Hybrid ….

- There are two groups of a series-parallel hybrid powertrain in operating mode of a series-parallel hybrid powertrain: ICE-heavy and electric-heavy.
- The operation mode of ICE-heavy is similar to that of a parallel hybrid, in which the engine is more active than the electric motor.
- The operation mode of electric-heavy is similar to that of a series hybrid powertrain, in which the electric traction motor is more active than the engine.
- It uses a power split device to effectively combine the engine driving power and the motor driving power.
- A planetary-geared, electrically controlled, continuous variable transmission (E-CVT), and magnetic continuous variable transmission (M-CVT) are the main devices used to combine the powers.

Unit 1:- Electric and Hybrid Powertrain Technologies

By:- Prof. Dr. Saket Yeolekar

Lecture 7

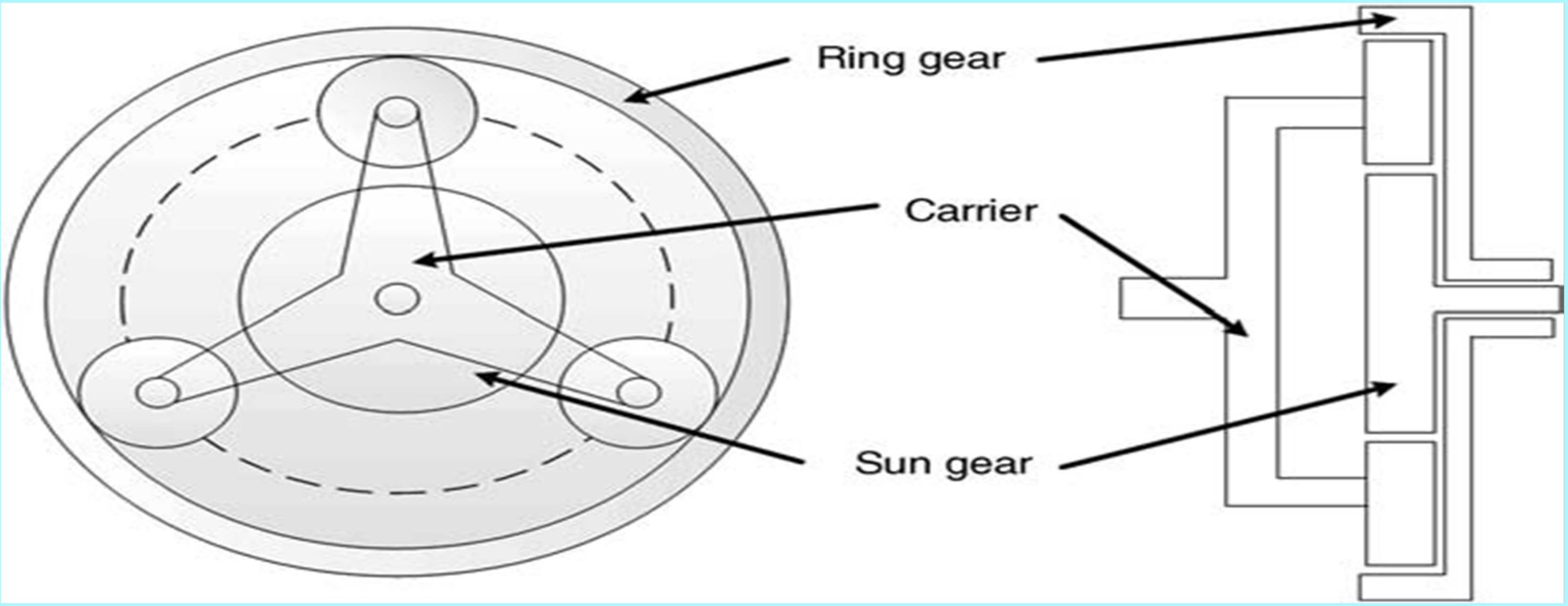
- Operating Mode : Series-parallel Hybrid
- E-CVTs Electric Continuous Variable Transmission)
- M-CVTs (Magnetic Continuous Variable Transmission)
- Compound Hybrid Configuration
- Compound Hybrid Modes of Operations
- Plug-in Hybrid Electric Vehicles (PHEVs)
- PHEVs Operations
- Comparisons
- Hybrid Hydraulic Vehicles (HHVs)
- HHVs Operations
- Series Hydraulic Hybrid Powertrain
- Series HHV Operations

Operating Mode : Series-parallel Hybrid ….

- There are two groups in operating mode of a series parallel hybrid powertrain: ICE-heavy, Electric-heavy.
- The operation mode of ICE-heavy is similar to that of a parallel hybrid powertrain, in which the engine is more active than the electric motor.
- The operation mode of Electric-heavy is similar to that of a series hybrid powertrain, in which the electric traction motor is more active than the engine
- A series-parallel hybrid powertrain uses a power split device to effectively combine the engine driving power and the motor driving power. A planetary-geared, electrically controlled, continuous variable transmission (E-CVT), and magnetic continuous variable transmission (M-CVT) are the main devices used to combine the powers.

E-CVT….

- E-CVTs typically function as a power split device in hybrid powertrains to combine the engine power and the electric motor/generator through a planetary gear set.
- A planetary gear set makes it possible to achieve a combination of either two input shafts and one output shaft, or a combination of one input shaft and two output shafts.

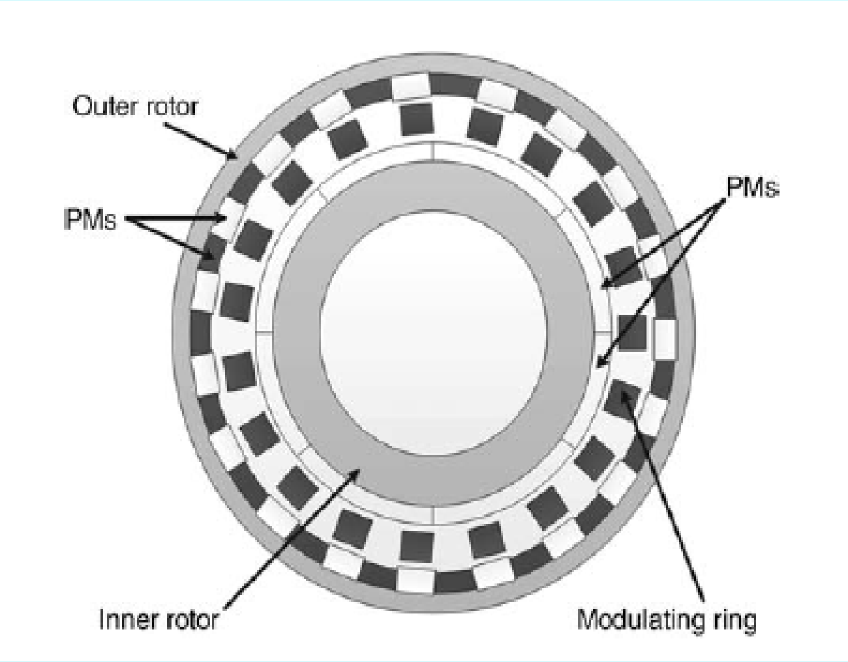


E-CVT….

- The ring carrier transfers the traction motor power to the final drive only during “electric mode,” while it can provide additional traction power to the wheels during “hybrid mode.”
- The sun carrier is used during regenerative mode or for starting the engine.
- In addition to the ability to continuously vary the speed of the engine, the E-CVT has a smooth and continuous performance during the regenerative braking process.
- However, it suffers from low power density, low efficiency, and noise problems. High speed or high load conditions can magnify these issues

M-CVT….

- A magnetic continuous variable transmission (M-CVT) achieves torque transmission and variable gear ratios by magnetic materials and without mechanical contact.
- It includes: three coaxial magnetic rotors, namely, the outer rotor, the inner rotor, and the modulating rotor, as well as a stator and electronic control unit

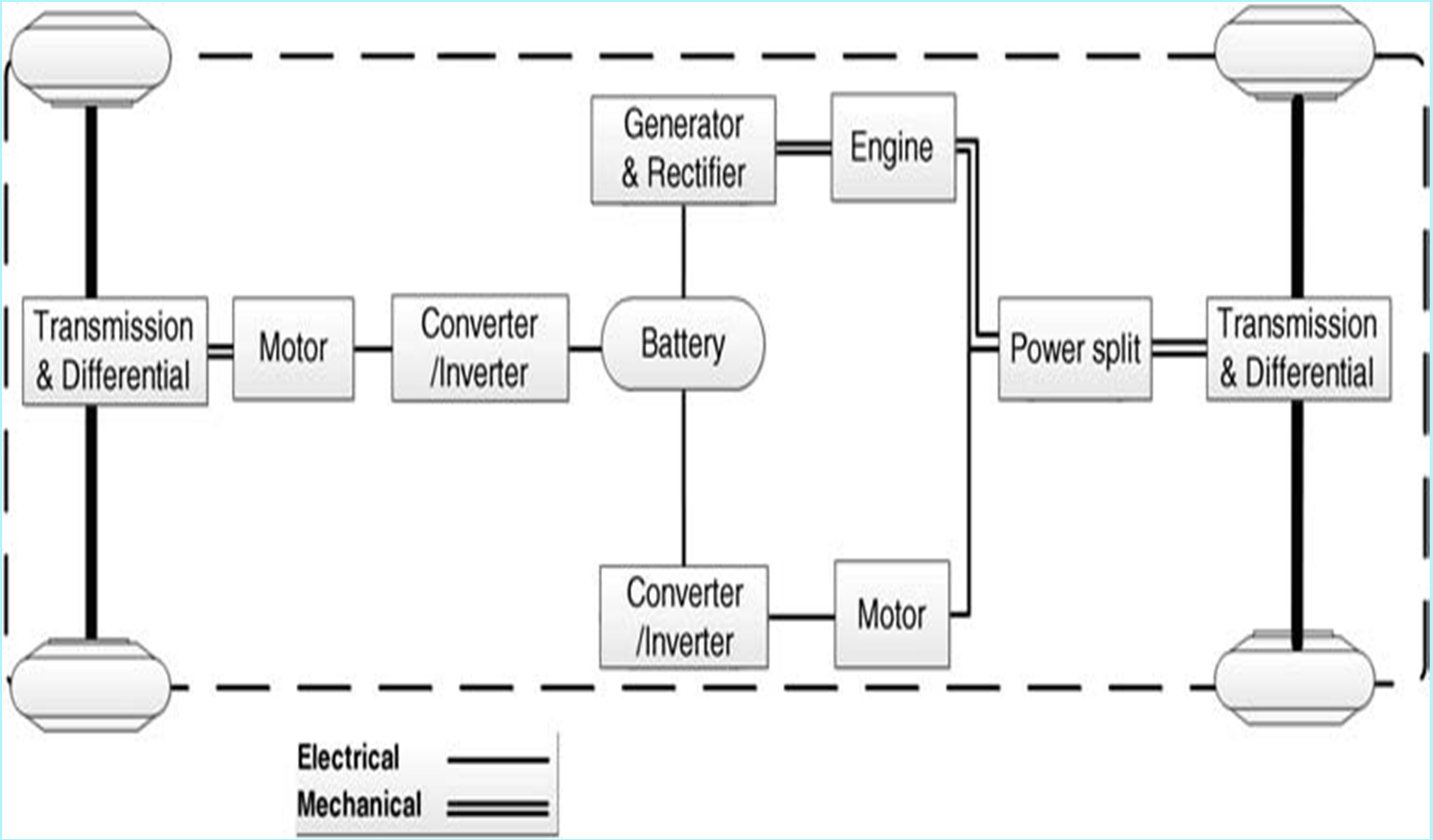


- This device splits the power flow from the engine into two paths.
- First Path generates power by sharing the outer rotor (magnetic gear) with the rotor of the traction motor
- Second forms by sharing the inner rotor of the magnetic gear with the rotor of the motor-generator

M-CVT….

- Two consecutive converters, which are separately coupled to the stators of the motor and the generator, control the generated power flow.
- The proper locking of the rotors, which activate and deactivate the magnetic field according to the engine load and driving conditions, provide a continuous gear ratio change and a proper power split.
- The outer rotor transfers the traction motor power to the final drive only during “electric mode,” while it can provide additional traction power to the wheels during “hybrid mode.” The inner rotor works during regenerative mode, or for starting the engine.

Compound Hybrid Configuration….



Compound Hybrid Modes of Operations….

The structure of a compound hybrid configuration, also known as a complex hybrid, is similar to that of a series-parallel hybrid

The difference relies on the bidirectional functionality of the electric motor in a compound powertrain and the unidirectional functionality of the generator in a series-hybrid powertrain

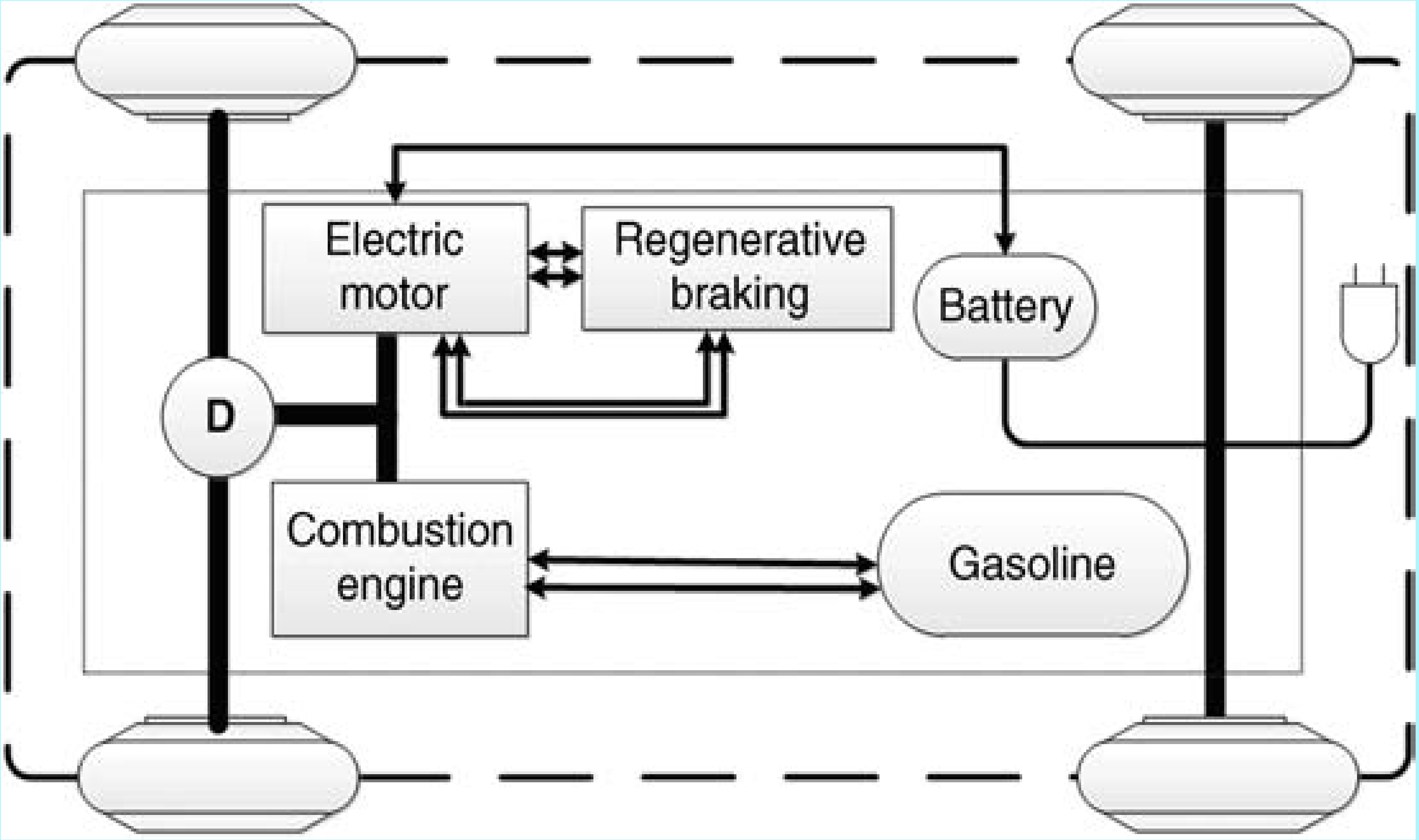
Modes:

- *Start-up mode:* In this mode, the engine is off, while the battery provides electrical power to both the front and rear electric motors to individually drive the front and rear axles.
- *Electric mode:* In this mode, the battery provides the power to only the front electric motor to propel the front axle, while the engine and rear electric motor are off. This

Compound Hybrid Modes of Operations ….

- *Hybrid mode:* In this mode, the engine and two electric motors are on. The engine and front electric motor work together to propel the front axle, while the rear electric motor simultaneously drives the rear axle. This mode is on during heavy load conditions, such as full-throttle acceleration.
- *Engine traction and battery charging mode:* In this mode of operation, the engine power is divided to provide the traction power to the front-wheel axle and to charge the battery through the electric motor, which is switched to its generator mode. This mode is suitable for normal driving conditions.
- *Regeneration mode:* The regenerative braking system charges the batteries during braking, decelerating, and downhill travel. In this mode, the two electric motors operate as generators to simultaneously recharge the

Plug-in Hybrid Electric Vehicles (PHEVs)….



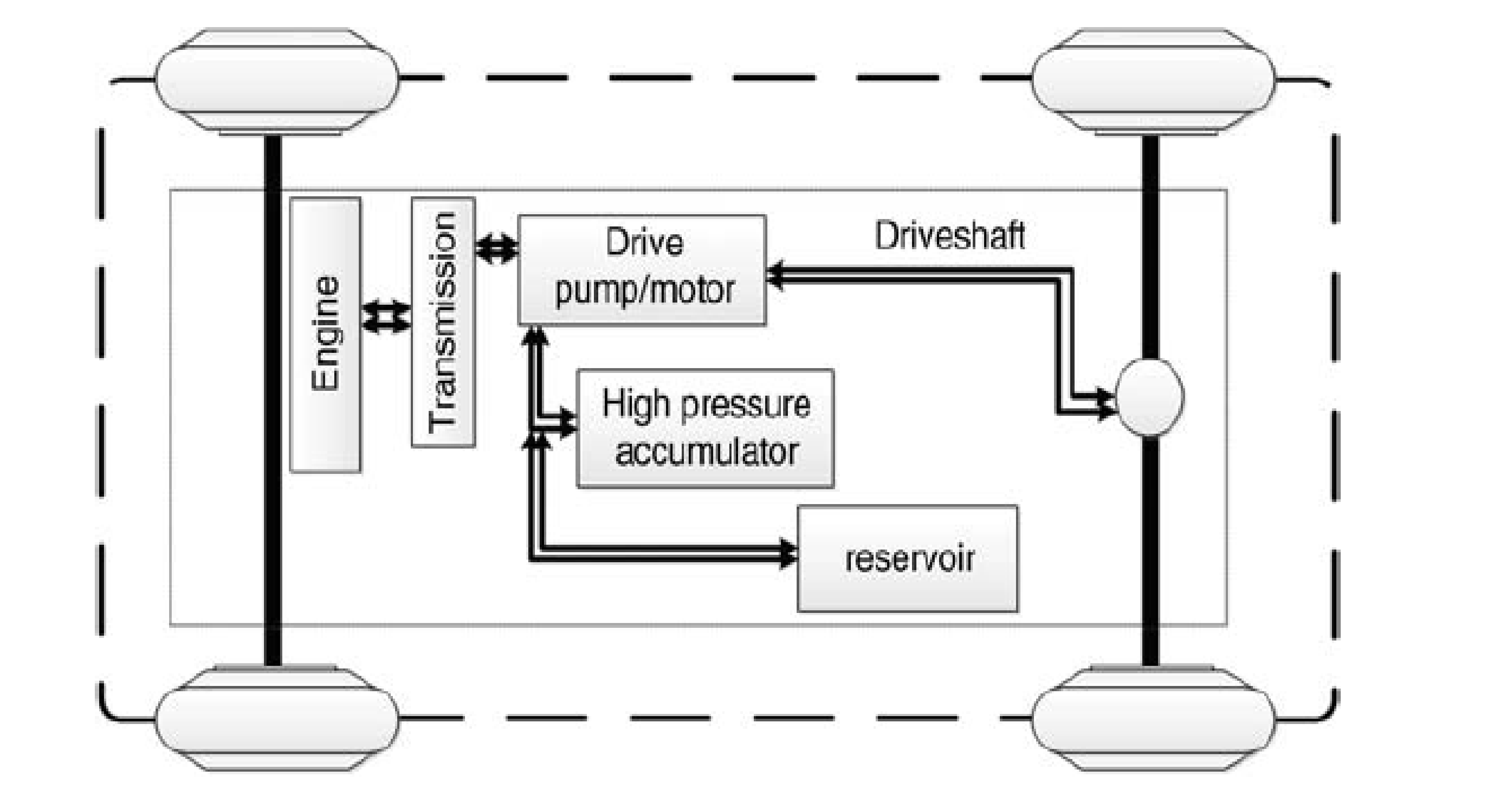
PHEVs Operations ….

- Plug-in hybrid electric vehicles combine the advantages of hybridization with the chance to travel using only electricity provided by the grid for a certain time, rather than just through internal recharging systems.
- The primary power source of PHEVs is electricity, while the ICE may be used as the secondary power source.
- Advantages of PHEVs over BEVs include its reduced dependence on recharging infrastructure which lowered costs
- PHEVs can be emission-free if they run on electricity mode
- a PHEV labeled PHEV‘X’ indicates the distance the vehicle can travel when in electricity mode. For example, “PHEV20” stands for a plug-in hybrid vehicle capable of running on electricity for 20 km

Comparisons….

	Advantages	Disadvantages	Major Issues
BEV	• Zero local emission • High energy efficiency • Independent of fossil fuels • Commercially available	• Relatively short range • High initial cost	• Battery size and management • Charging facilities • Cost • Battery life time
FCEV	• Zero/low local emission • High energy efficiency • Independent of fossil fuels (if not using fossil fuel to produce hydrogen)	• Relatively short range • High initial cost • Under development	• Fuel-cell cost • Fuel-cell life cycle and reliability • Hydrogen production • Hydrogen distribution and infrastructure • Cost
HEV	• Low local emissions • High fuel economy • Long driving range • Commercially available	• Dependence on fossil fuels • Higher cost than ICEVs	• Battery sizing and management • Control, optimization, and management of multiple energy sources
PHEV	• Minimum local emissions • Higher fuel economy than ICEVs • Longer driving range than BEVs • Commercially available	• Slightly dependence on fossil fuels • Higher cost than ICEVs	• Battery sizing and management • Control, optimization, and management of multiple energy sources

Hybrid Hydraulic Vehicles (HHVs)….

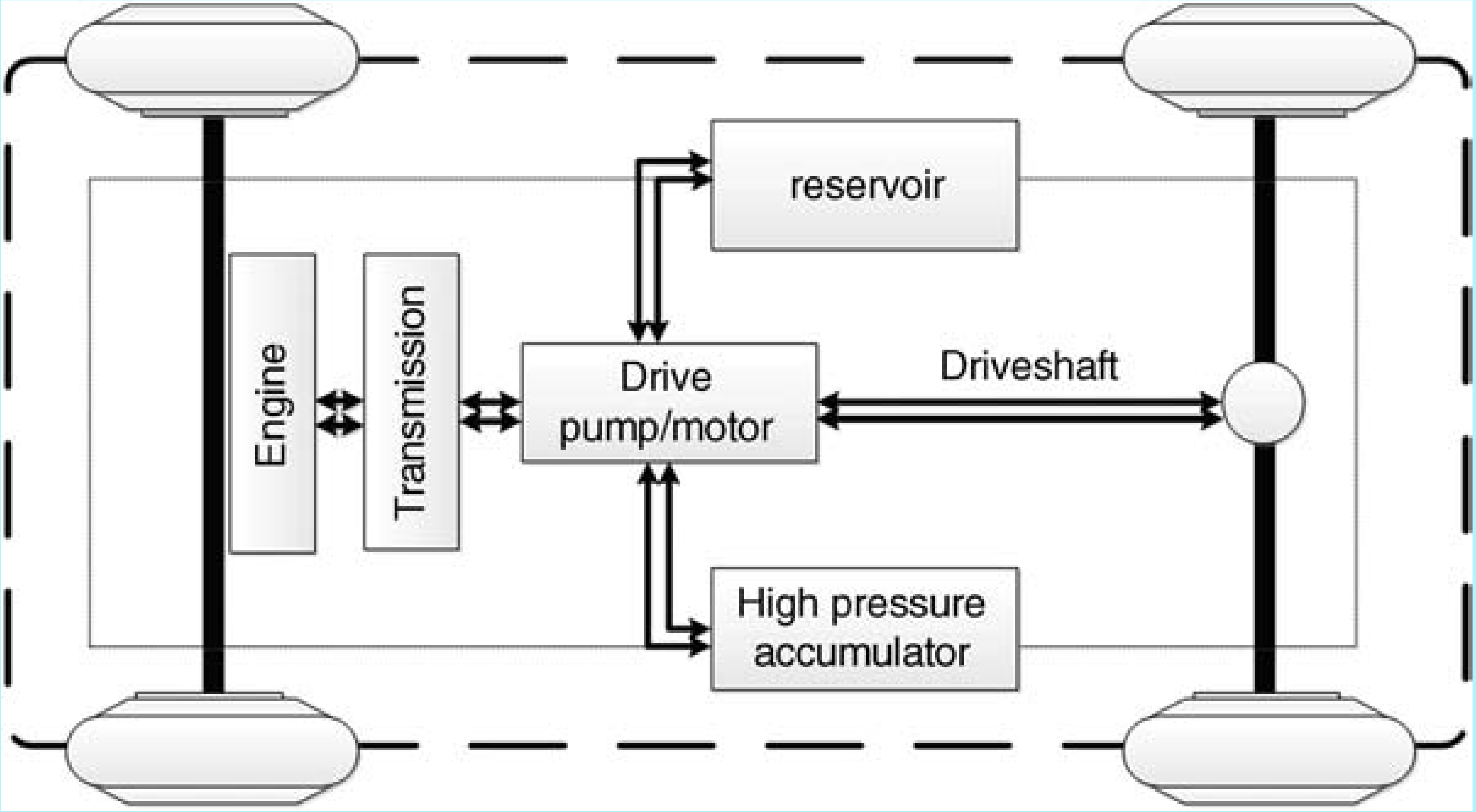


A Parallel Hydraulic Hybrid Powertrain Structure

HHVs Operations….

- With a principal operation similar to that of electric hybrids, hybrid hydraulic vehicles (HHVs) use two propulsion power sources: an IC engine and a hydraulic motor.
- Hydraulic hybrid systems transfer energy from the engine to the wheels using fluid power.
- An accumulator, a reservoir, and a hydraulic drive (pump/motor) are the main components that establish the drivetrain of HHVs
- The accumulator is a high pressure hydraulic fluid vessel that stores energy and compresses nitrogen gas using hydraulic fluid
- The hydraulic drive pressurizes and transfers hydraulic fluid from the reservoir to an accumulator when it operates as a pump or vice versa when it operates as a hydraulic motor.
- With current technologies, it is possible to recuperate up to

Series Hydraulic Hybrid Powertrain….



A Series Hydraulic Hybrid Powertrain Structure

Series HHV Operations….

- Hydraulic power stored in the accumulator is directly transmitted to the wheels while decoupling the ICE from the wheel loads
- This configuration does not have the conventional powertrain, and the vehicle is propelled by the transfer of high-pressure fluid from the accumulator to the reservoir through the drive acting as a motor.
- The series configuration involves fewer mechanical components than a parallel configuration, thus resulting in better efficiency
- In addition, this configuration switches the ICE off when it is not at optimum working operations, such as during light acceleration or short cruising. the engine will turn on when the pressure level drops below a certain threshold, and assist the hydraulic system to complete its circuit.

Unit 1:- Electric and Hybrid Powertrain Technologies

By:- Prof. Dr. Saket Yeolekar

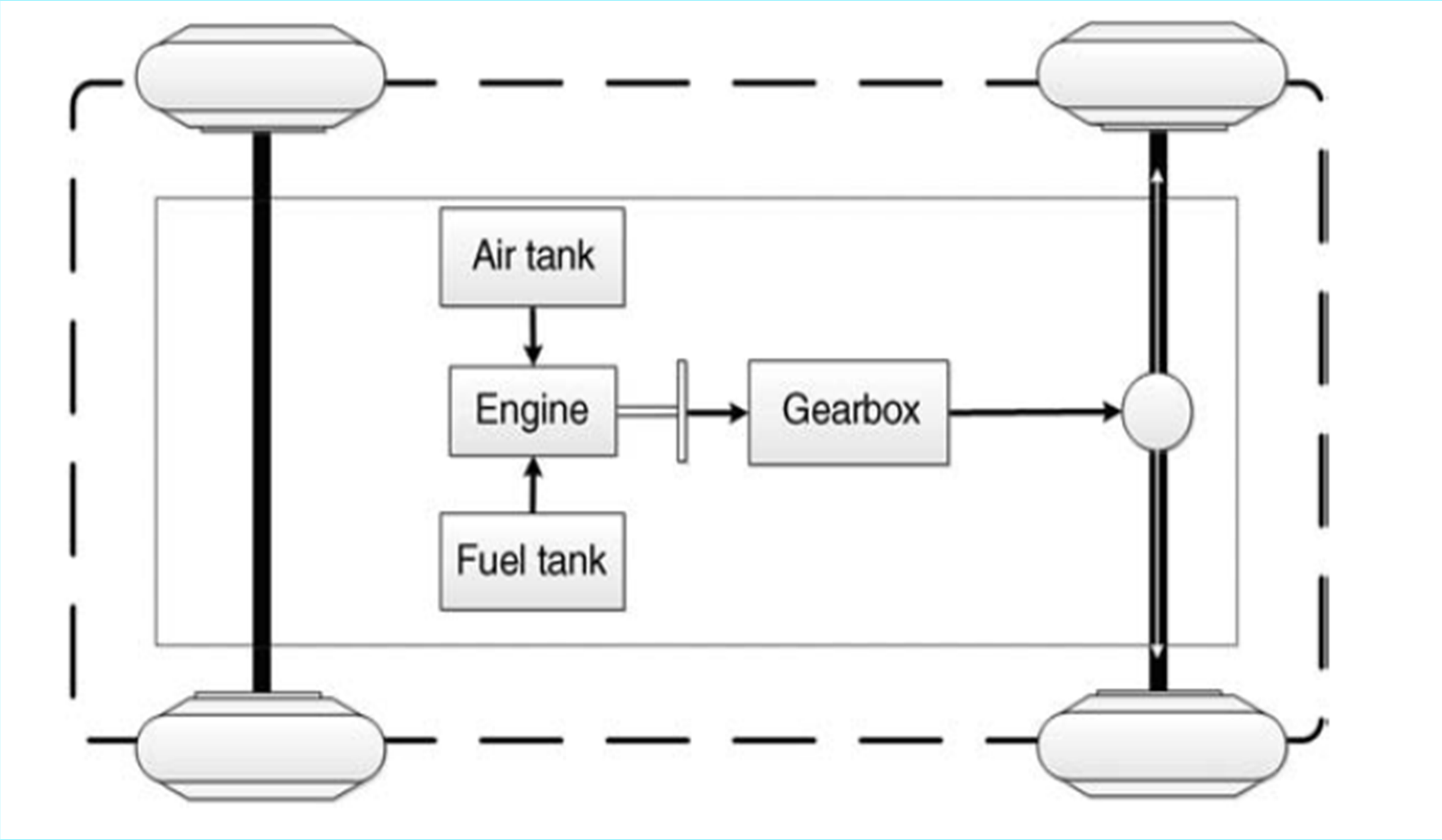
Lecture 8

- Pneumatic Hybrid Vehicles (PHVs)
- Energy flow in supercharged mode in PHVs
- Pressurized air Uses in PHVs
- Series PHVs
- Parallel PHVs
- Challenges in PHVs
- Vehicle Dynamics: Description of Vehicle Movement
- Vehicle Dynamics: Vehicle Resistance
- Rolling Resistance
- Aerodynamic Drag: Shape drag
- Aerodynamic Drag: Skin Friction
- Grading Resistance
- Dynamic Equation
- Tire–Ground Adhesion and Maximum Tractive Effort

Pneumatic Hybrid Vehicles (PHVs)….

- Pneumatic hybrid vehicles are based on the same principles as hybrid electric vehicles. They employ two energy sources, fuel and pressurized air, to propel the vehicle.
- During braking, the kinetic energy of an air hybrid vehicle is converted to pressurized air by running the same ICE in the compressor mode.
- Pneumatic hybrid engines can have four modes of operation:
    - ü Compression Braking (CB)
    - ü Air Motor (AM)
    - ü Supercharged
    - ü Conventional internal combustion
- When the driver applies the brake pedal, fuel is shut off, and the engine operates as a two-stroke air compressor, storing the vehicle's kinetic energy in the form of

Energy flow in supercharged mode in PHVs….

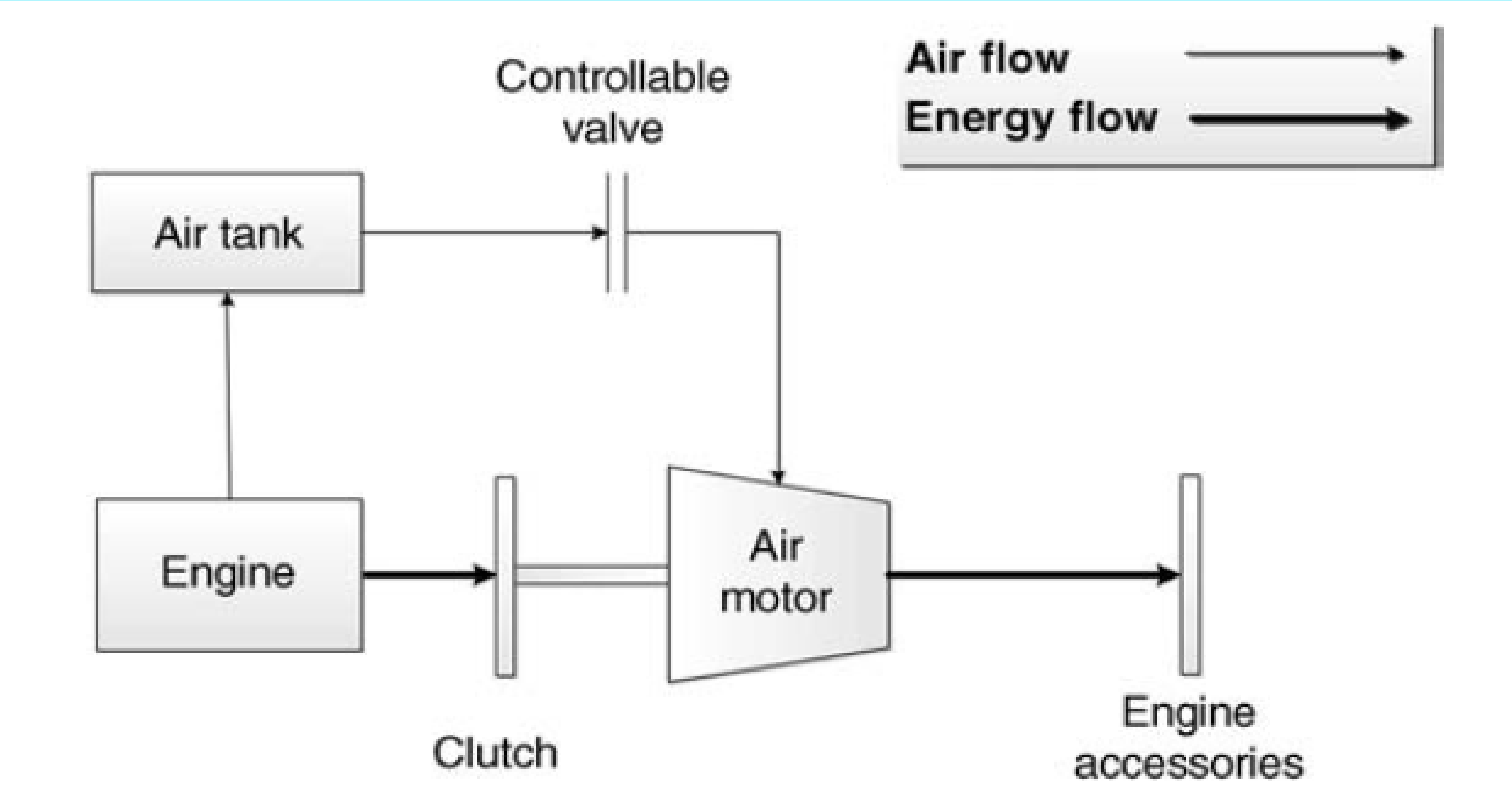


Pressurized air Uses in PHVs….

There are various uses for the energy stored in the tank.

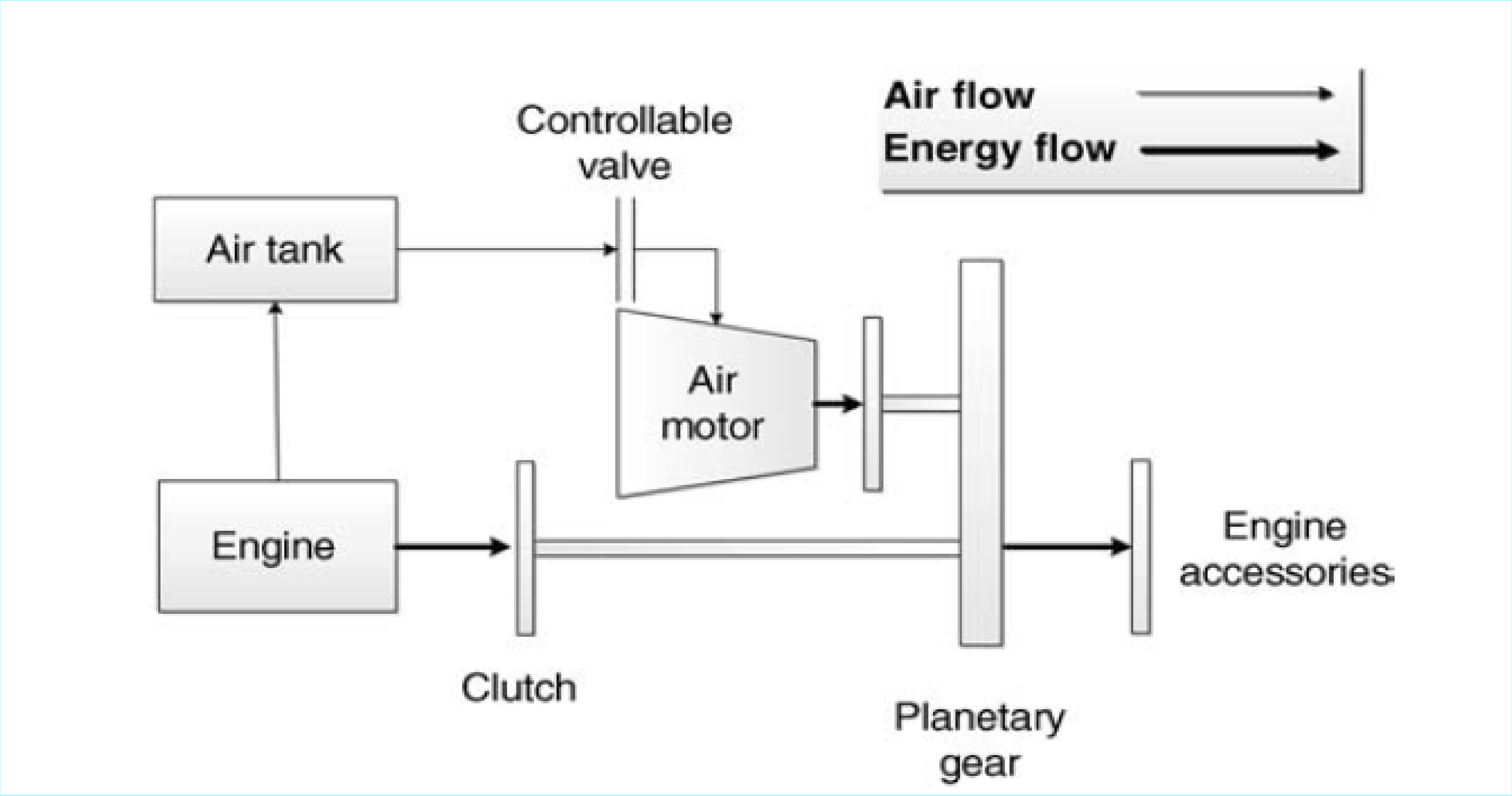
- Run the internal combustion engine as an air motor. The charging valve between the air tank and engine opens and the pressurized air runs the engine as a two-stroke air motor. This mode operates during low load engine conditions to avoid high fuel consumption.
- The second option of using the stored braking energy is to run the engine in air motor mode to start it up. It is possible to activate start-up mode after a long stop to avoid a cold start, or after a short stop to avoid engine idling, resulting in a lower engine fuel consumption and emission.
- Stored energy can run the engine accessories. Some attempt has been made to remove all or some of the engine accessories from the engine to avoid excessive power losses.

Series PHVs….



Series configuration for running engine accessories in PHVs

Parallel PHVs….



A parallel configuration for running engine accessories in PHVs

Challenges in PHVs….

- Although the air hybrid concept seems to be simple, there are some practical issues to resolve before accepting the concept as a hybrid powertrain solution. One of the most important challenges of air hybrid engines is the poor energy-storing capacity of the system due to the low air pressure when the engine is used as a compressor.
- The maximum storing pressure is a function of the engine compression ratio that limits the energy density of the stored pressurized air.
- Another challenge in the implementation of air hybrid engines is the inevitability of using flexible valvetrains. Due to different operational modes, it requires a flexible valvetrain to implement the concept. This could increase the engine complexity and costs.

Challenges in PHVs….

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Vehicle Dynamics: Description of Vehicle Movement

- The tractive effort, *Ft*, in the contact area between tires of the driven wheels and the road surface propels the vehicle forward. It is produced by the power plant torque and is transferred through transmission and final drive to the drive wheels.
- While the vehicle is moving, there is resistance that tries to stop its movement. The resistance usually includes tire rolling resistance, aerodynamic drag, and uphill resistance.
- According to Ne law, vehicle acceleration can be written as

$$\frac{dV}{dt} = \frac{\Sigma F_t - \Sigma F_{tr}}{\delta M_v}$$

where V is vehicle speed, ΣFt is the total tractive effort of the vehicle, ΣFtr is the total resistance, Mv is the total mass of the vehicle, and δ is the mass factor, which is an effect of rotating components in the power train.

Vehicle Dynamics: Description of Vehicle Movement

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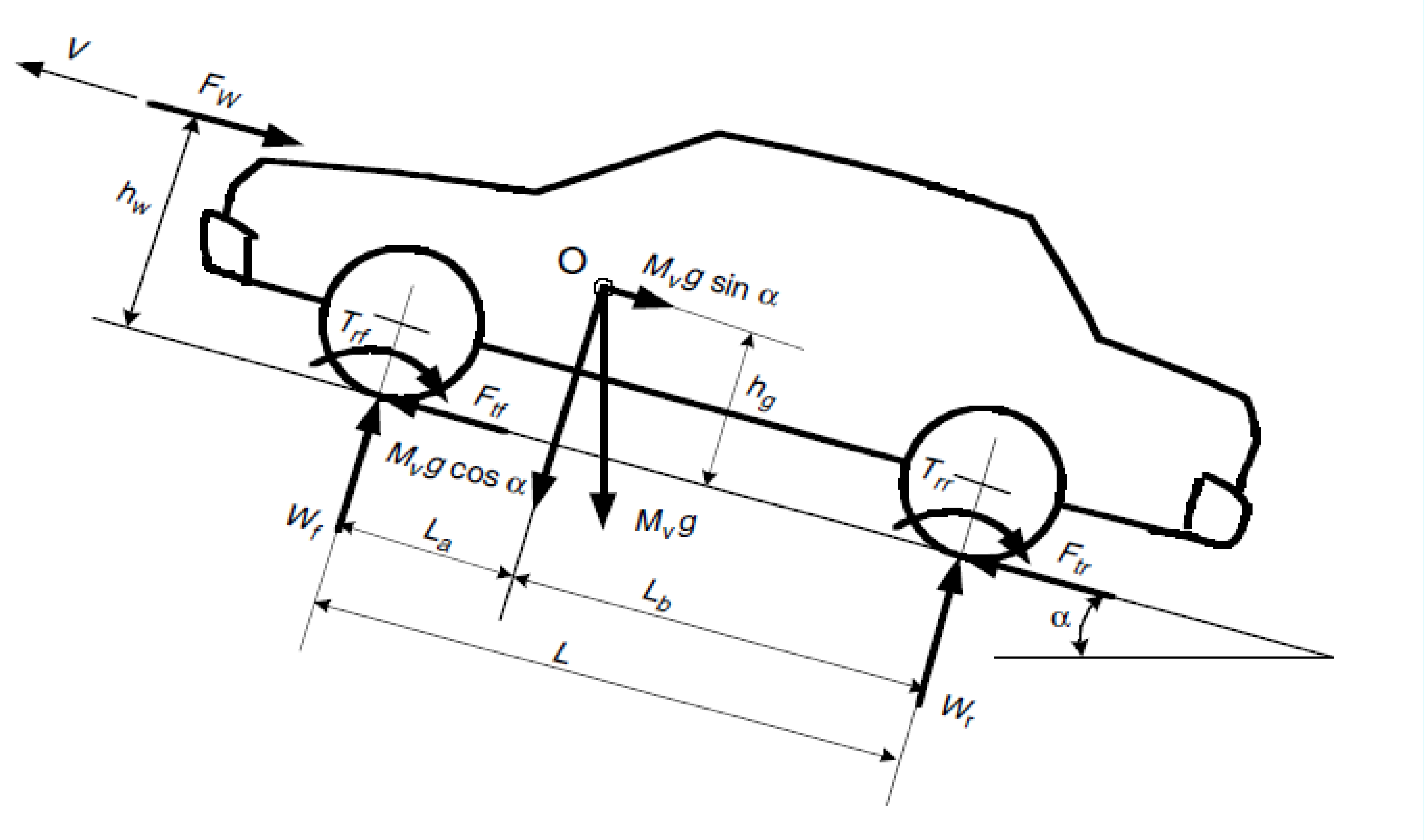
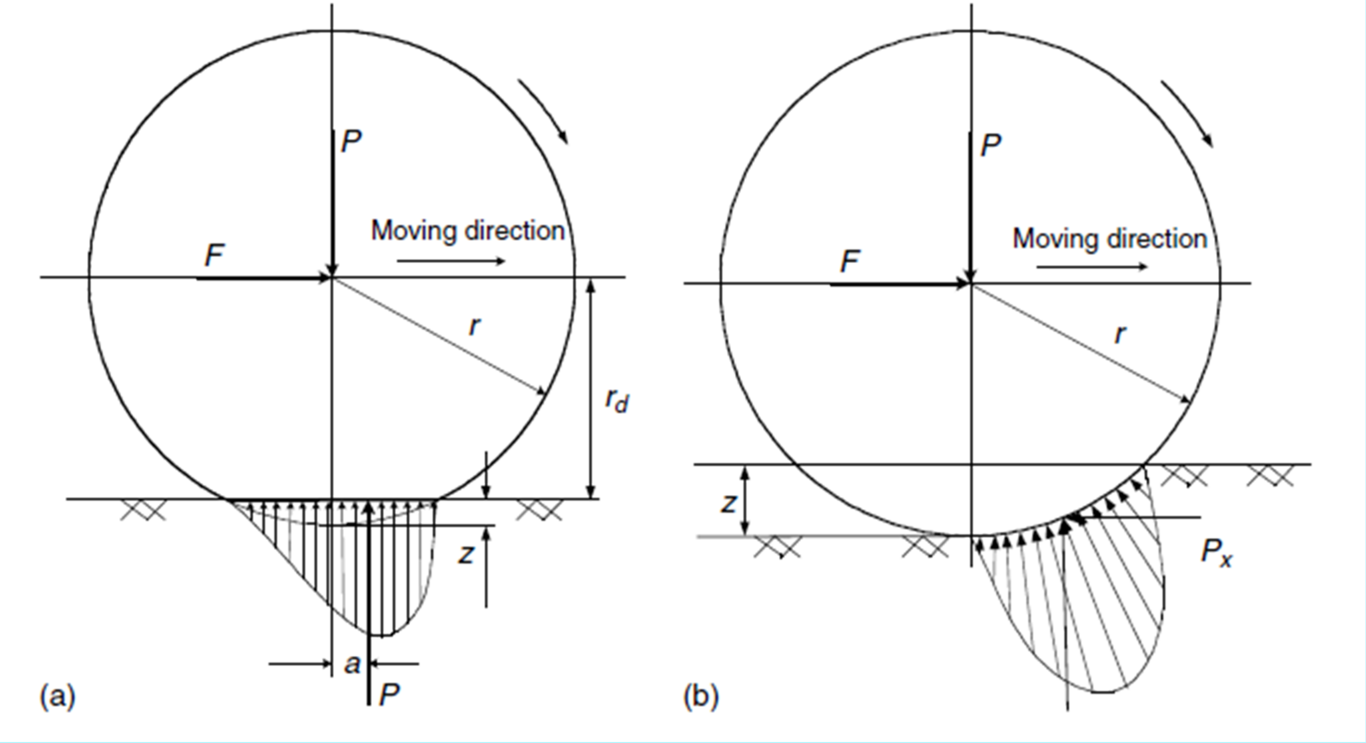


Forces acting on a vehicle

Vehicle Dynamics: Vehicle Resistance….

- vehicle resistance opposing its movement includes:
  - ü Rolling resistance of the tires (torque *Trf* and *Trr*)
  - ü Aerodynamic drag, *Fw*
  - ü Grading resistance, *Mv g* sin α



Tire deflection and rolling resistance on a (a) hard and (b) soft road surface

Rolling resistance ….

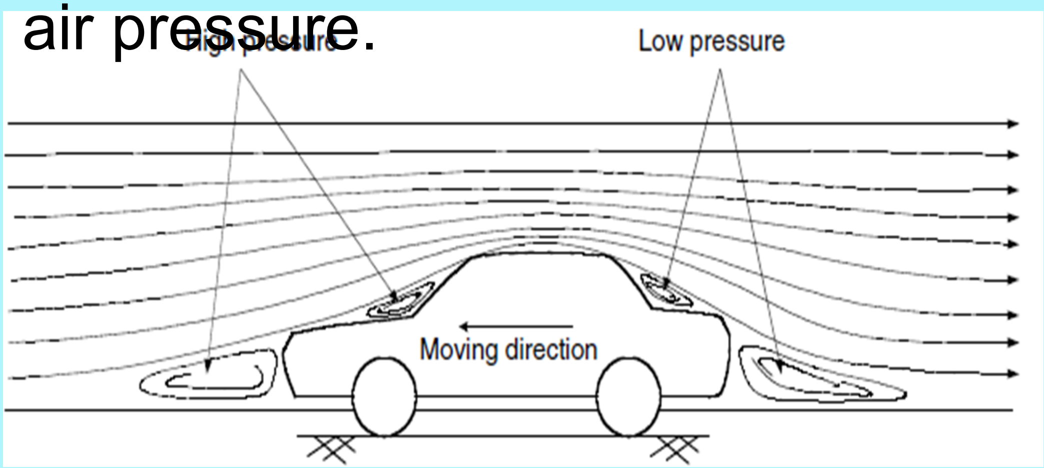
Rolling resistance of the tires (torque *Trf* and *Trr*):

- The rolling resistance of tires on hard surfaces is primarily caused by hysteresis in the tire materials.This is due to the deflection of the carcass while the tire is rolling.
- The hysteresis causes an asymmetric distribution of ground reaction forces. The pressure in the leading half of the contact area is larger than that in the trailing half
- On soft surfaces, the rolling resistance is primarily caused by deformation of the ground surface ground reaction force almost completely shifts to the leading half.
- The rolling resistance coefficient, *fr*, is a function of the tire material, tire structure, tire temperature, tire inflation pressure, tread geometry, road roughness, road material, and the presence or absence of liquids on the

Aerodynamic Drag: Shape drag….

Avehicle traveling at a particular speed in air encounters a force resisting its motion. This force is referred to as aerodynamic drag. It mainly results from two components: *Shape drag and Skin friction.*

Shape drag: The forward motion of the vehicle pushes the air in front of it. However, the air cannot instantaneously move out of the way and its pressure is thus increased, resulting in high air pressure.

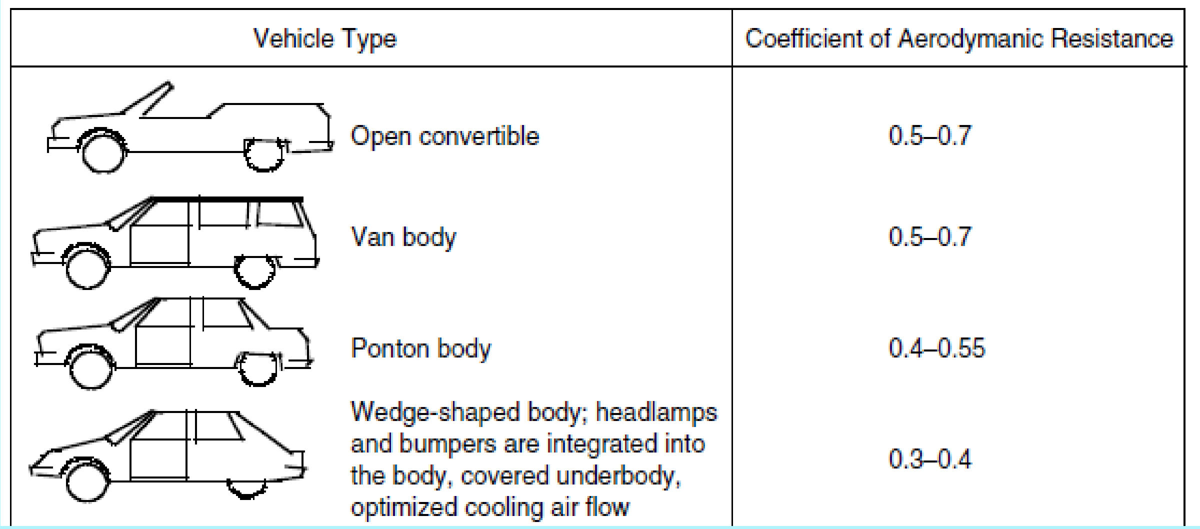


In addition, the air behind the vehicle cannot instantaneously fill the space left by the forward motion of the vehicle. This creates a zone of low air pressure.

Aerodynamic Drag : Skin friction :....

Skin friction : Air close to the skin of the vehicle moves almost at the speed of the vehicle while air far from the vehicle remains still. In between, air molecules move at a wide range of speeds. The difference in speed between two air molecules produces a friction that results in the second component of aerodynamic drag.

Aerodynamic drag is a function of vehicle speed *V*, vehicle … air density ρ.



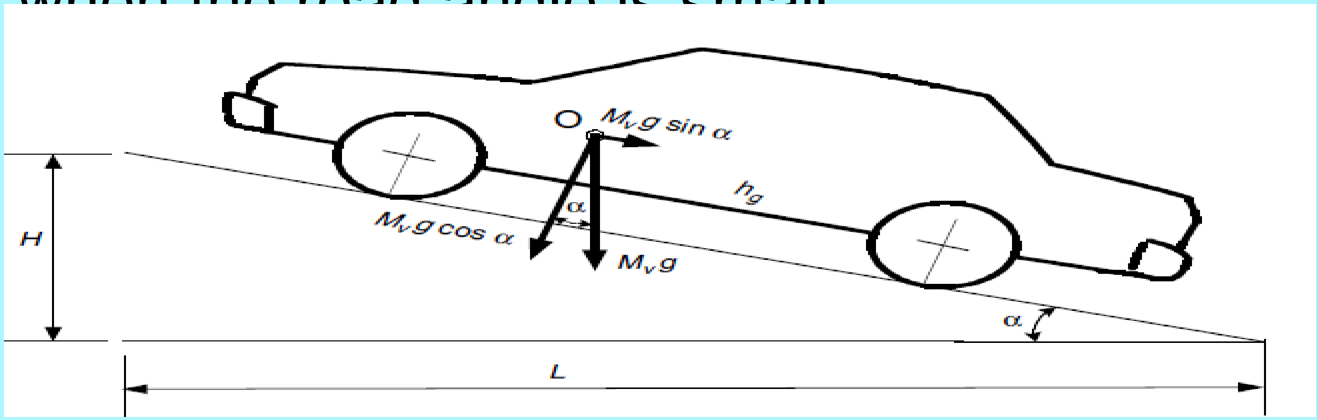
Vehicle Type	Coefficient of Aerodymanic Resistance
Open convertible	0.5–0.7
Van body	0.5–0.7
Ponton body	0.4–0.55
Wedge-shaped body; headlamps and bumpers are integrated into the body, covered underbody, optimized cooling air flow	0.3–0.4

Indicative drag coefficients for different body shapes

Grading Resistance ....

- When a vehicle goes up or down a slope, its weight produces a component, which is always directed to the downward direction.

This component either opposes the forward motion (grade climbing) orhelps the forward motion (grade descending). In vehicle performance analysis, only uphill operation is considered. This grading force is usually called grading resistance. The road angle, α, is usually replaced by grade value when the road angle is small.



Dynamic Equation....

In the longitudinal direction, the major external forces acting on a two-axle vehicle include the rolling resistance of front and rear tires *Frf* and *Frr*, which are represented by rolling resistance moment *Trf*
and *Trr*, aerodynamic drag *Fw*, grading resistance *Fg* (*Mv g* sinα), and tractive effort of the front and rear tires, *Ftf* and *Ftr*. *Ftf* is zero for a rear-wheel-driven vehicle, whereas *Ftr* is zero for a front-wheel-driven vehicle.
The dynamic equation of vehicle motion along the longitudinal direction is expressed by

$$M_v \frac{dV}{dt} = (F_{tf} + F_{tr}) - (F_{rf} + F_{rr} + F_w + F_g),$$

Tire–Ground Adhesion and Maximum Tractive Effort...

- When the tractive effort of a vehicle exceeds the due to the adhesive capability between the tire and the ground, the drive wheels will spin on the ground.
- Actually, the adhesive capability between the tire and the ground is sometimes the main limitation of vehicle performance.
- This is especially true when the vehicle drives on wet, icy, snow-covered, or soft soil roads. In this case, a tractive torque on the drive wheel would cause the slipping on the ground.
- The maximum tractive effort on the driven wheel depends on the longitudinal force that the adhesive capability between the tire and ground can supply, rather than the maximum torque that the engine can supply.
- Experiments shows that, the maximum tractive effort of the drive wheel closely relates to the slipping of the running

Unit 1:- Electric and Hybrid Powertrain Technologies

By:- Prof. Dr. Saket Yeolekar

Lecture 9

- Power Train Tractive Effort
- Vehicle Speed
- Power Plant Characteristics
- Gasoline engine Characteristics
- Electric Motor Characteristics
- Transmission Characteristics
- Manual Gear Transmission Characteristics
- Hydrodynamic Gear Transmission Characteristics
- Vehicle Performance (Gasoline)
- Vehicle Performance (Electric Motor)
- Operating Fuel Economy
- Fuel Economy of Internal Combustion Engines
- Braking Performance

Power Train Tractive Effort ….

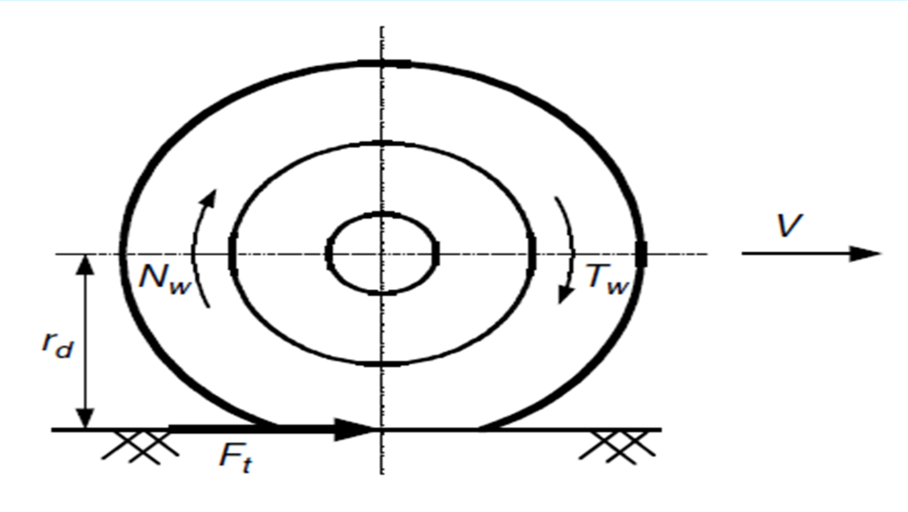
- Power train, consists of a power plant (engine or electric motor), a clutch in manual transmission or a torque converter in automatic transmission, a gearbox (transmission), final drive, differential, drive shaft, and driven wheels.
- The gearbox supplies a few gear ratios from its input shaft to its output shaft for the power plant torque–speed profile to match the requirements of the load.
- The torque on the driven wheels, transmitted from the power plant, i

$$T_w = i_g \, i_0 \, \eta_t T_p$$

where *ig* is the gear ratio *ig=Nin/Nout,* η*t* is the efficiency of the driveline, *Tp* is the torque output from the power plant

Power Train Tractive Effort and Vehicle Speed…

- The tractive effort on the driven wheels



$$F_t = \frac{T_w}{r_d} = \frac{T_p\, i_g\, i_0\, \eta_t}{r_d}.$$

Mechanical efficiency of various components:
Clutch: 99%
Each pair of gears: 95–97%
Bearing and joint: 98–99%

Manual gear Efficiency :
Direct gear: 90%
Other gear: 85%
Transmission with a very high reduction ratio: 75–80%

Vehicle Speed….

The rotating speed (rpm) of the driven wheel can be expressed as

$$N_w = \frac{N_p}{i_g i_0}$$

where *Np* is the output rotating speed (rpm). The translational speed of the wheel center (vehicle speed) can be expressed

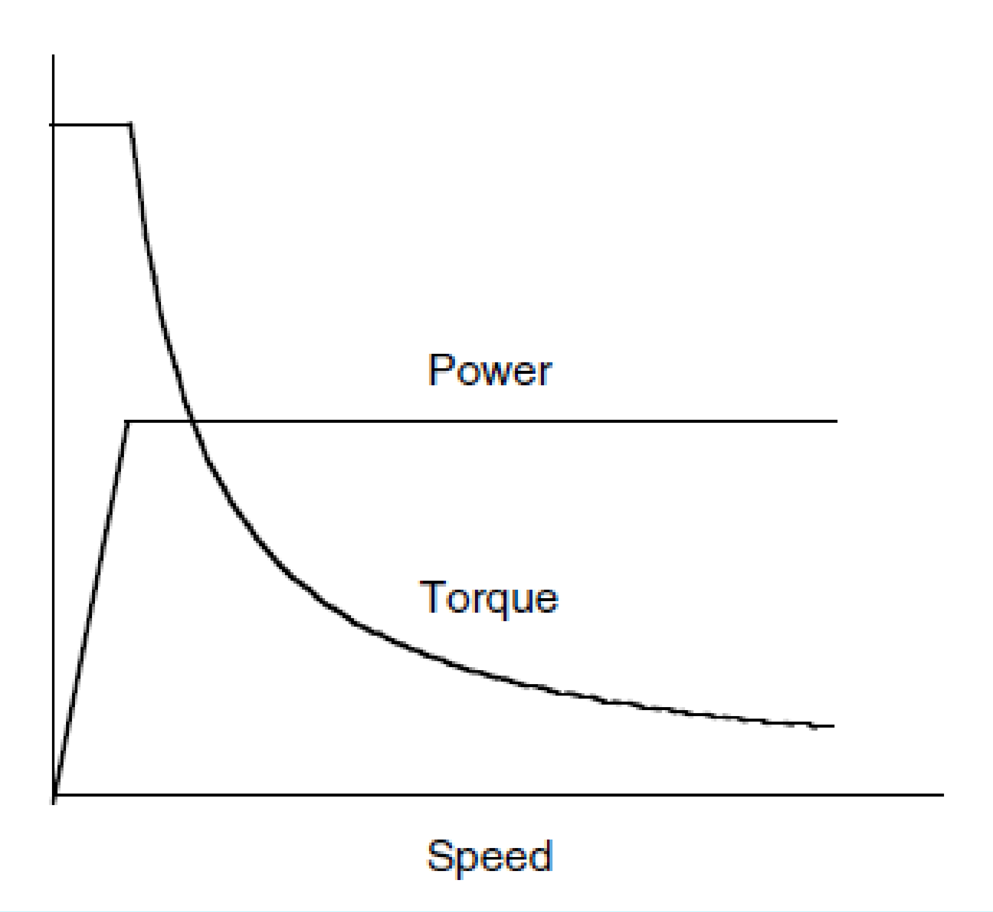
$$V = \frac{\pi N_w r_d}{30} \text{(m/s)}.$$

From above expressions vehicle speed can be expressed as

$$V = \frac{\pi N_p r_d}{30 i_g i_0} \text{(m/s)}.$$

*ig i*0 are the gear ratio of transsmition to final drive, *Np* is the output rotating speed, rd is wheel radius.

Power Plant Characteristics….



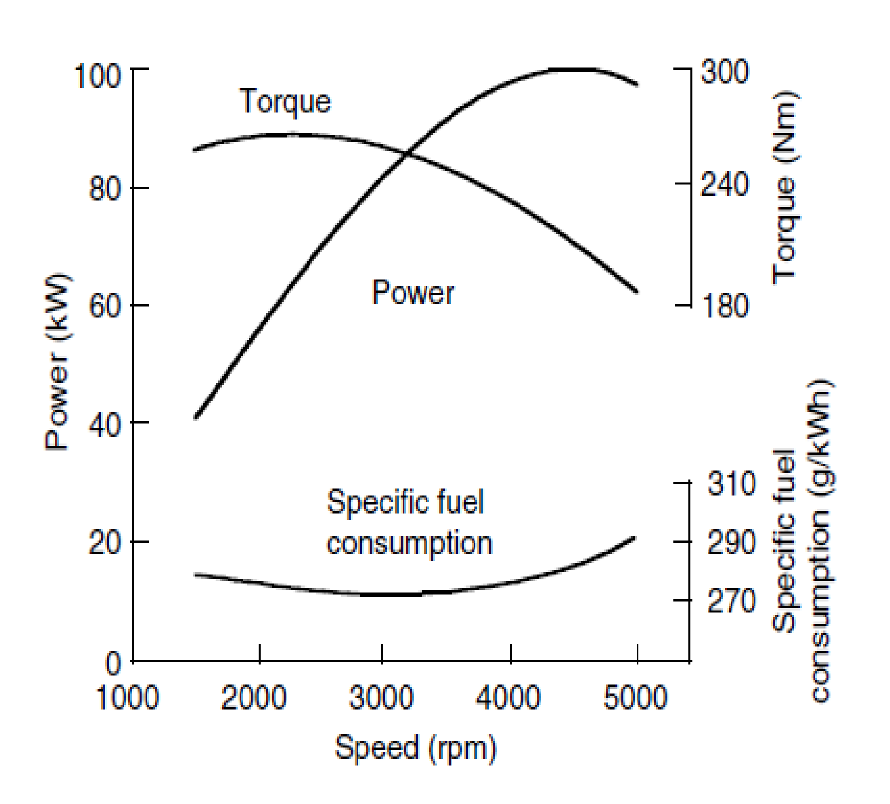
Ideal performance characteristics for a vehicle traction power plant

- The ideal performance characteristic of a power plant is the constant power output over the full speed range.
- Consequently, the torque varies with speed hyperbolically
- At low speeds, the torque is constrained to be constant so as not to be over the maxima limited by the adhesion between the tire–ground contact area.

Gasoline engine Characteristics….

- Since the internal combustion engine and electric motor are the most commonly used power plants for automotive vehicles to date, it is appropriate to review the basic features of the characteristics that are essential to predicating vehicle performance and driveline design
- The internal combustion engine usually has torque–speed characteristics far from the ideal performance characteristic required by traction.
- It starts operating smoothly at idle speed. Good combustion quality and maximum engine torque are reached at an intermediate engine speed. As the speed increases further, the mean effective pressure decreases because of the growing losses in the air-induction manifold and a decline in engine torque.

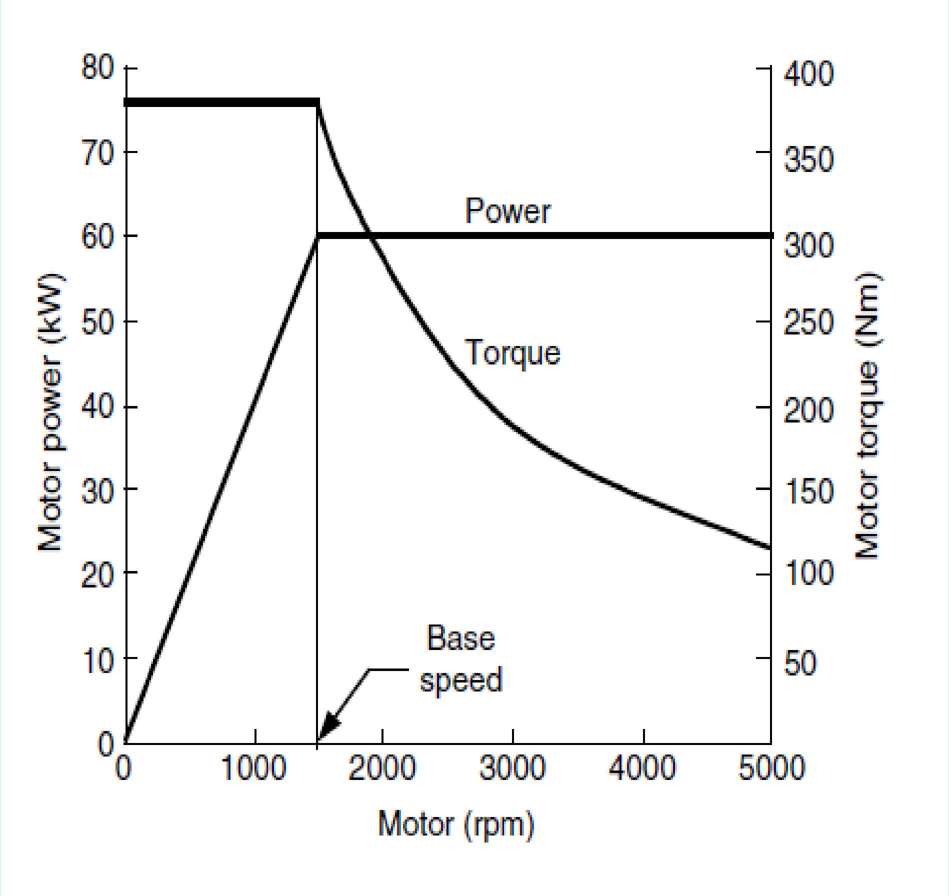
Gasoline Engine Characteristics….



Gasoline engine in full throttle

- Power output, however, increases to its maximum at a certain high speed. Beyond this point, the engine torque decreases more rapidly with increasing speed. This results in the decline of engine power output.
- In vehicular applications, the maximum permissible speed of the engine is usually set just a little above the speed of the maximum power output.
- The internal combustion engine has a relatively flat torque–speed profile (compared with an ideal one),

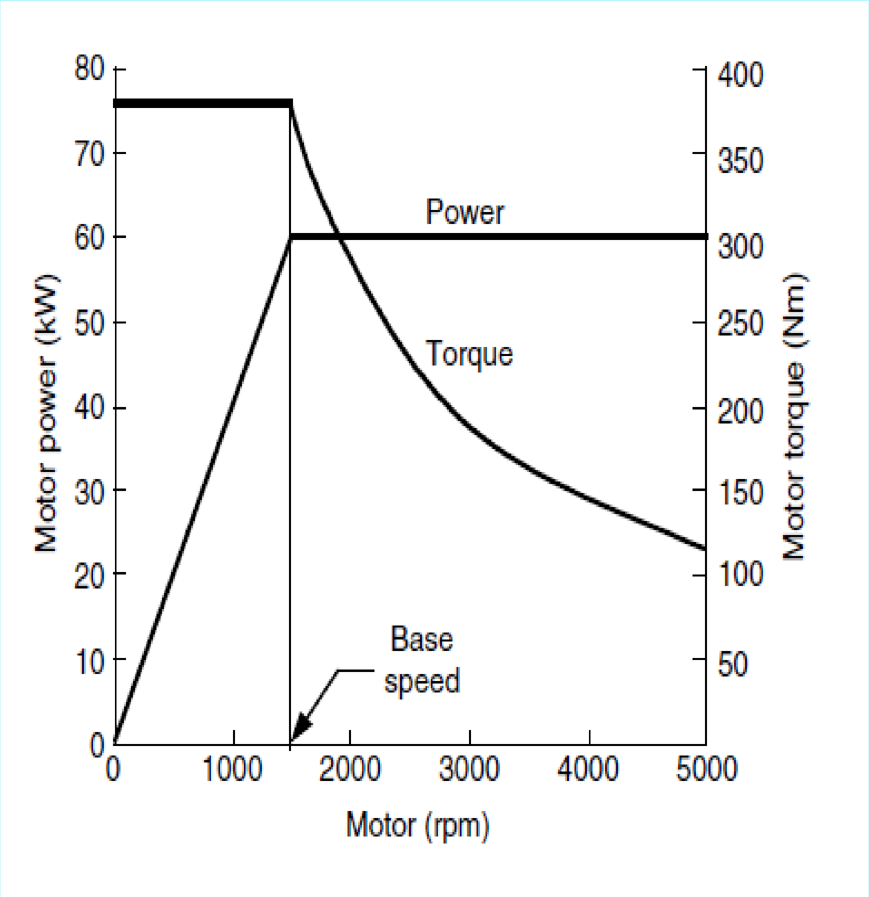
Electric motors Characteristics….



Electric traction motors (full load)

- Electric motors, usually have a speed–torque characteristic that is much closer to the ideal characteristics
- Generally, the electric motor starts from zero speed. As it increases to its base speed, the voltage increases to its rated value while the flux remains constant.

Electric motors Characteristics….



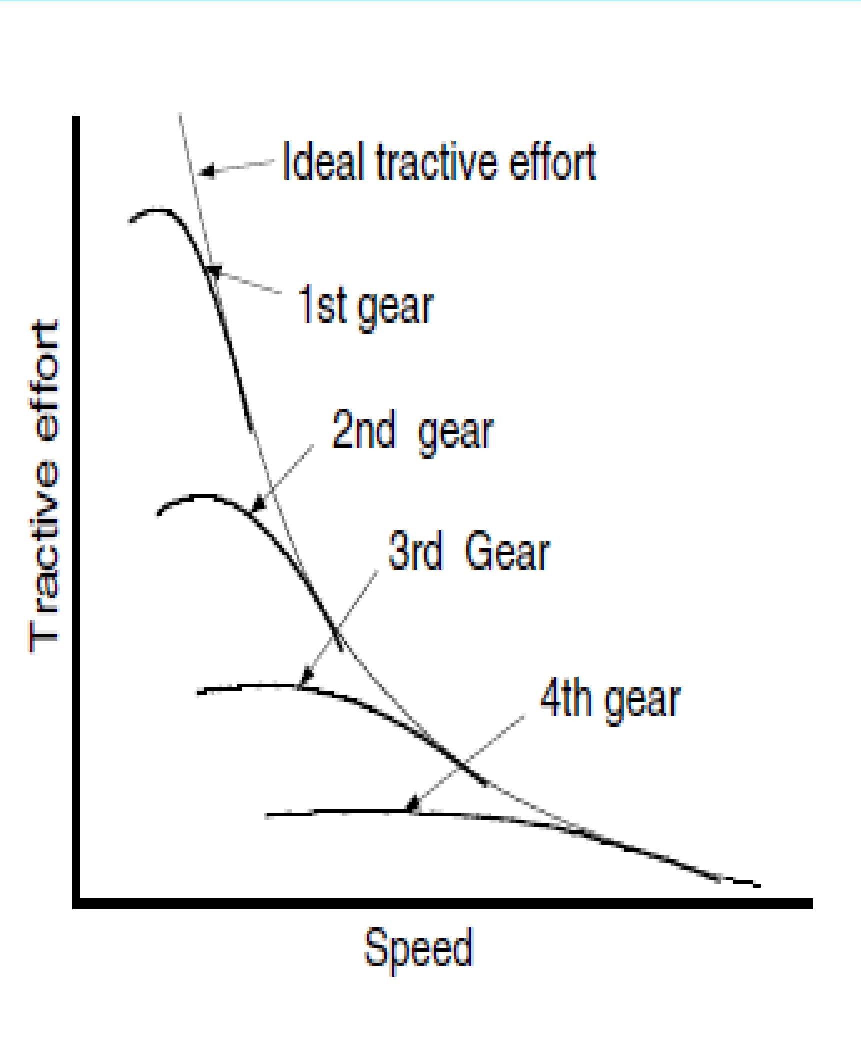
Electric traction motors (full load)

- Beyond the base speed, the voltage remains constant and the flux is weakened. This results in constant output power while the torque declines hyperbolically with speed.
- Since the speed–torque profile of an electric motor is close to the ideal, a single-gear or double-gear transmission is usually employed

Transmission Characteristics….

- The transmission requirements of a vehicle depend on the characteristics of the power plant and the performance requirements of the vehicle.
- Well-controlled electric machine such as the power plant of an electric vehicle will not need a multi-gear transmission
- However, an internal combustion engine must have a multi-gear or continuously varying transmission to multiply its torque at low speed.
- There are usually two basic types of transmission:
  - ü Manual gear transmission
  - ü Hydrodynamic transmission

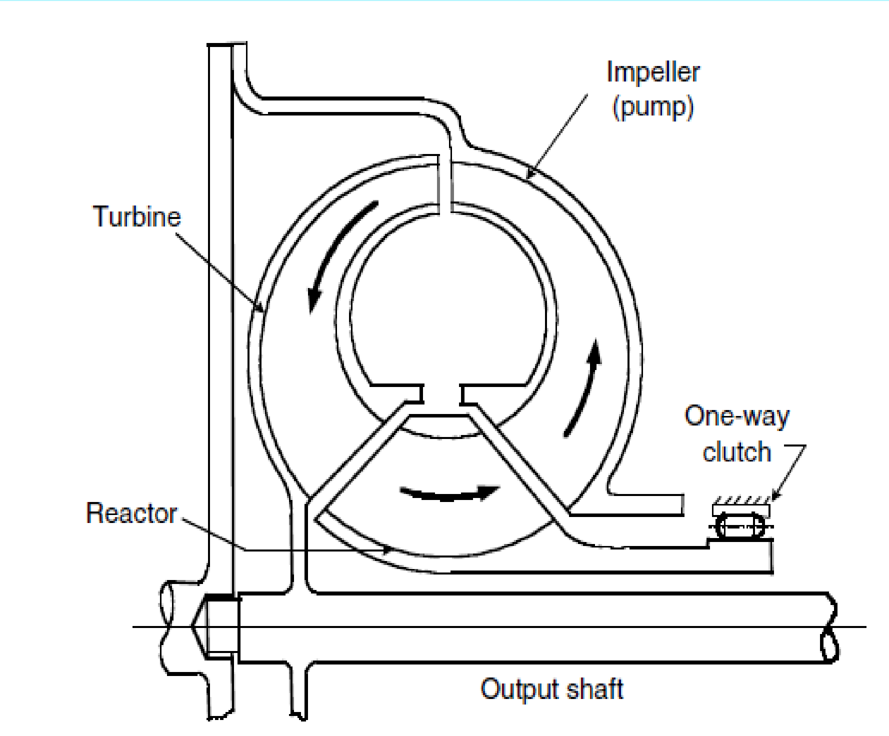
Manual Gear Transmission Characteristics….



- The maximum speed requirement of the vehicle determines the gear ratio of the highest gear (i.e., the smallest ratio)
- The gear ratio of the lowest gear (i.e., the maximum ratio) is determined by the requirement of the maximum tractive effort
- hip can ratios

$$\frac{i_{g1}}{i_{g2}} = \frac{i_{g2}}{i_{g3}} = \frac{i_{g3}}{i_{g4}} = K_g$$

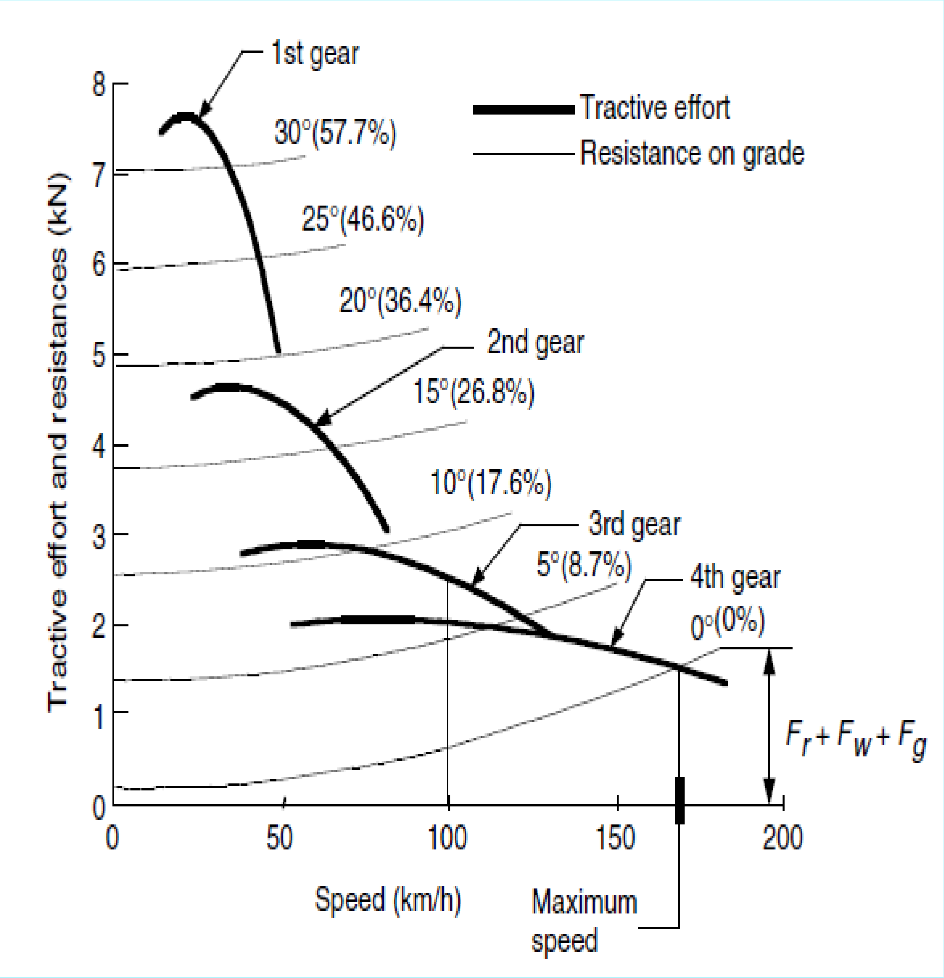
Hydrodynamic Gear Transmission Characteristics….



Schematic view of a torque converter

- Hydrodynamic transmissions use fluid to transmit power in the form of torque and speed and are widely used in passenger cars
- They consist of a torque converter and an automatic gearbox. The torque converter consists of at least three rotary elements known as the impeller (pump), the turbine, and the reactor
- The impeller is connected to the engine shaft and the turbine is connected to the output shaft of the converter, which in turn is coupled to the input shaft of the multispeed gearbox.

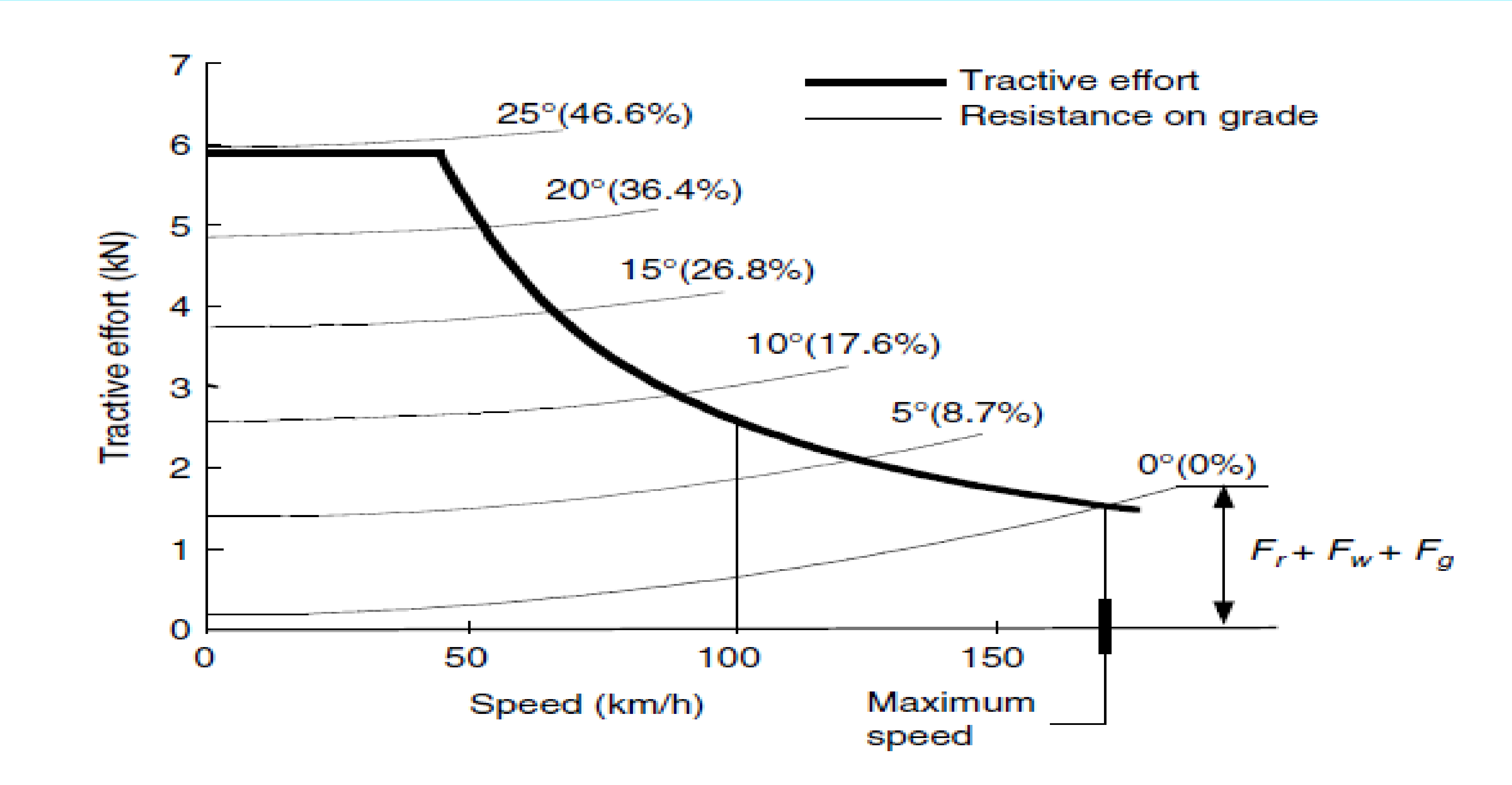
Vehicle Performance (Gasoline) ….



Gasoline engine-powered vehicle with multispeed transmission and its resistance

- The performance of a vehicle is usually described by its maximum cruising speed, gradeability, and acceleration.
- The predication of vehicle performance is based on the relationship between tractive effort and vehicle speed
- It is assumed that the maximum tractive effort is limited by the maximum torque of the power plant rather than the road adhesion capability

Vehicle Performance….

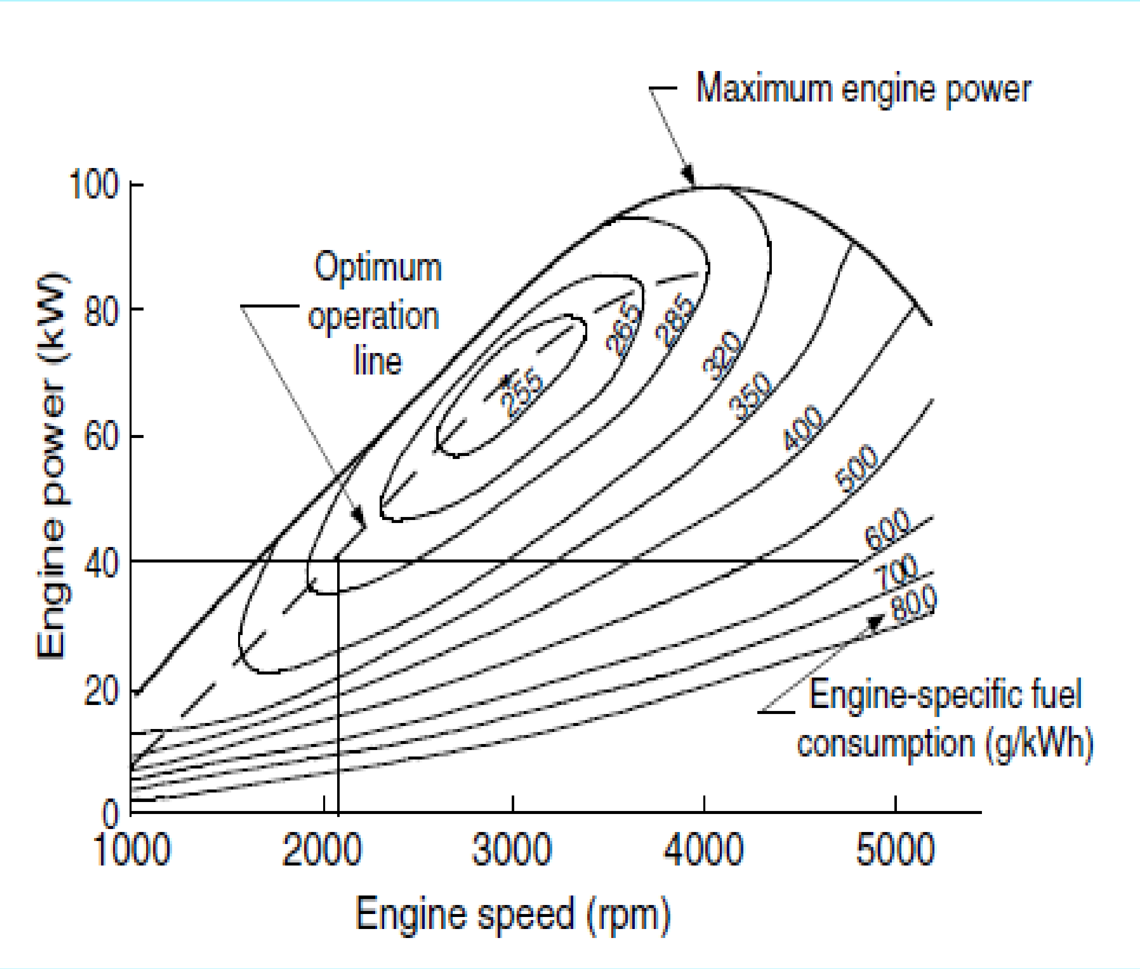


Electric motor-powered vehicle with single-speed transmission and its resistance

Operating Fuel Economy….

- The fuel economy of a vehicle is evaluated by the amount of fuel consumption per 100 km traveling distance (liters/100 km)
- or mileage per gallon fuel consumption (miles/gallon), which is currently used in the U.S.
- The operating fuel economy of a vehicle depends on a number of factors, including fuel consumption characteristics of the engine, gear number and ratios, vehicle resistance, vehicle speed, and operating conditions

Fuel Economy of Internal Combustion Engines….

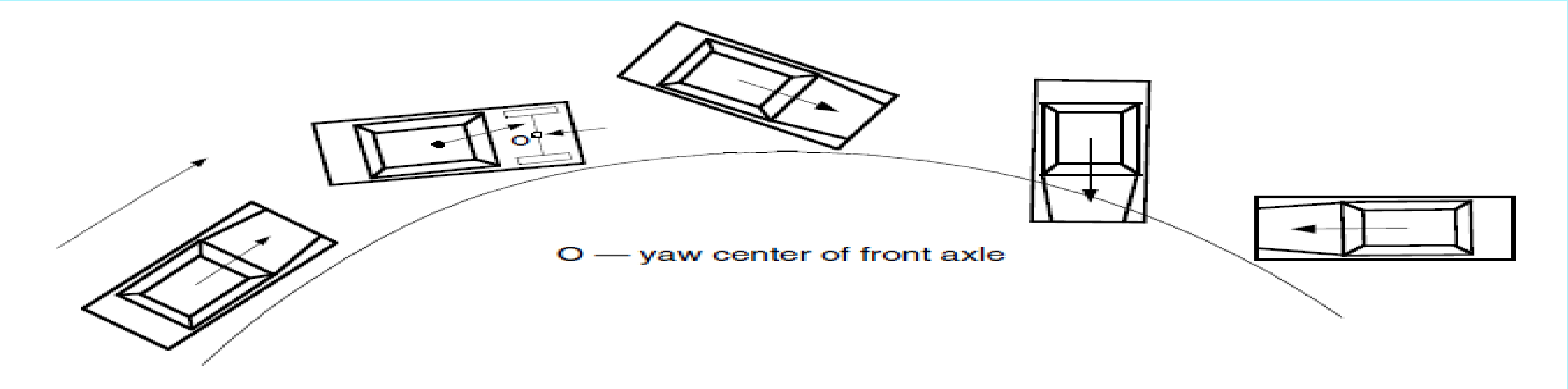


power output of 40 kW, its minimum specific fuel consumption would be 270 g/kWh at a speed of 2080 rpm

- The fuel consumption is quite different from one operating point to another. The optimum operating points are close to the points of full load (wide-opened throttle)
- The speed of the engine also has a significant influence on fuel economy.

Braking Performance….

- The braking performance of a vehicle is undoubtedly one of the most important characteristics that affect vehicle safety
- A well-designed regenerative braking system not only improves vehicle efficiency but also potentially improves braking performance. It can be Braking Force can be improved by Braking Distribution on Front and Rear Axles



Loss of directional stability due to the lockup of rear wheels