CAMBRIDGE
INSTITUTE OF TECHNOLOGY

MODULE – 3

- IC Engines
- Insight into Future Mobility

Department of
Mechanical Engineering

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Internal Combustion Engines - Contents

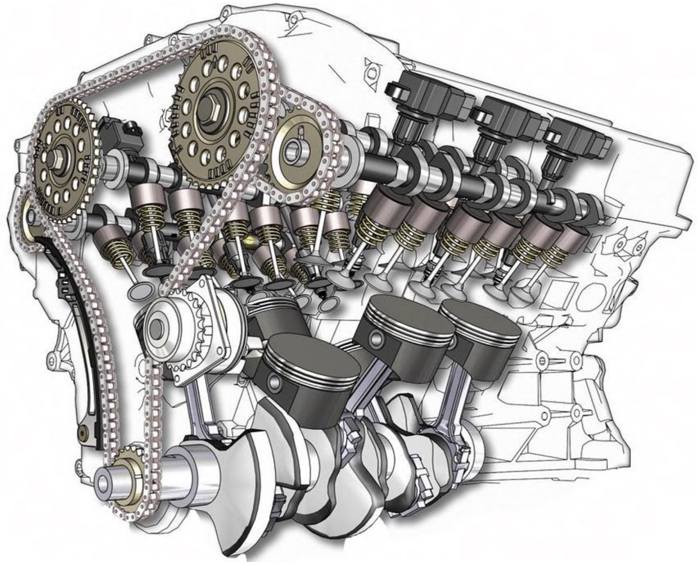
- Definition
- Classifications.
- I.C. Engines Parts.
- I C Engine Terminologies
- 4 Stroke Petrol and Diesel Engine.
- P-V diagrams of Otto and Diesel Cycles.

Heat Engine: In thermodynamics, **a heat engine** is a system that converts heat or thermal energy into mechanical energy

There are two main types of heat engines:

1. External combustion engine:
The fuel burns outside the cylinder and away from the main body of the engine.
Ex: Steam engines, steam turbines,

2. Internal combustion engine: the fuel burns inside the cylinder.
Ex: Petrol engine, diesel engine,

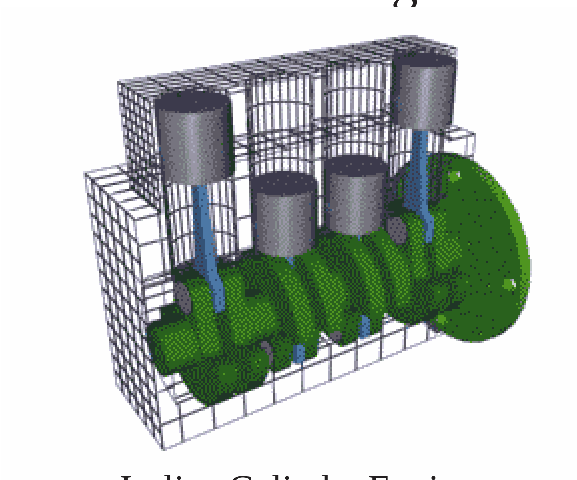


Internal Combustion(IC) Engines - Classification

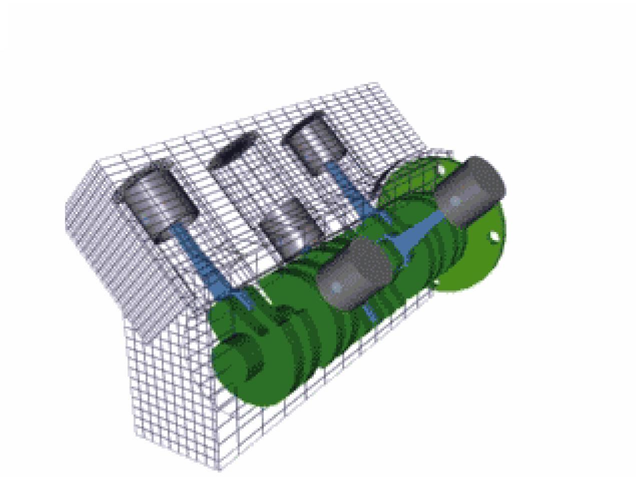
1. Type of Fuel Used
   a. **Petrol Engine**
   b. **Diesel Engine**
   c. **Gas Fuel Engine**
2. Type of Thermodynamic Cycle
   a. **Otto Cycle**
   b. **Diesel Cycle**
3. Number of strokes
   a. **Two stroke**
   b. **Four Stroke**
4. Method of Ignition
   a. **Spark Ignition Engine**
   b. **Compression Ignition Engine**
5. Number of Cylinders
   a. **Single-cylinder**
   b. **Multi-cylinder**
6. Orientation of Engine
   a. **Horizontal Engine**
   b. **Vertical Engine**

7. Cylinder Arrangement

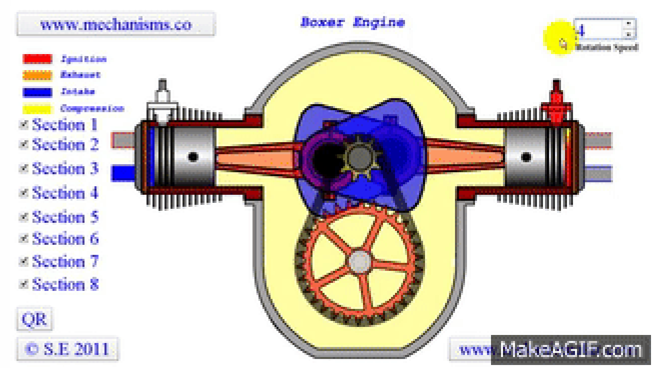
a. In-line Cylinder Engine
b. V Cylinder Engine
c. Radial Engine
d. Boxer Engine



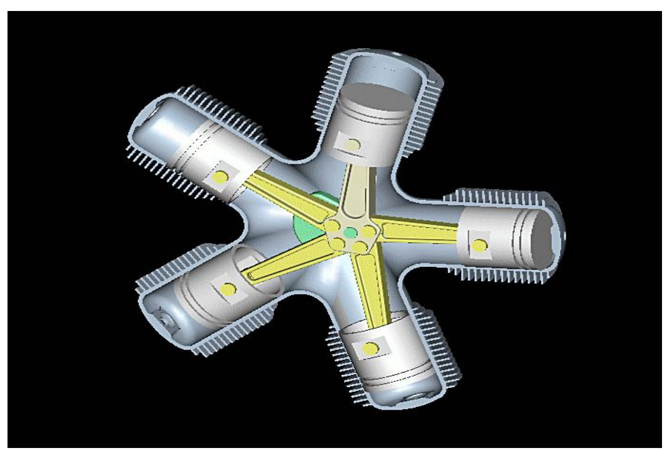
In-line Cylinder Engine



V Cylinder Engine

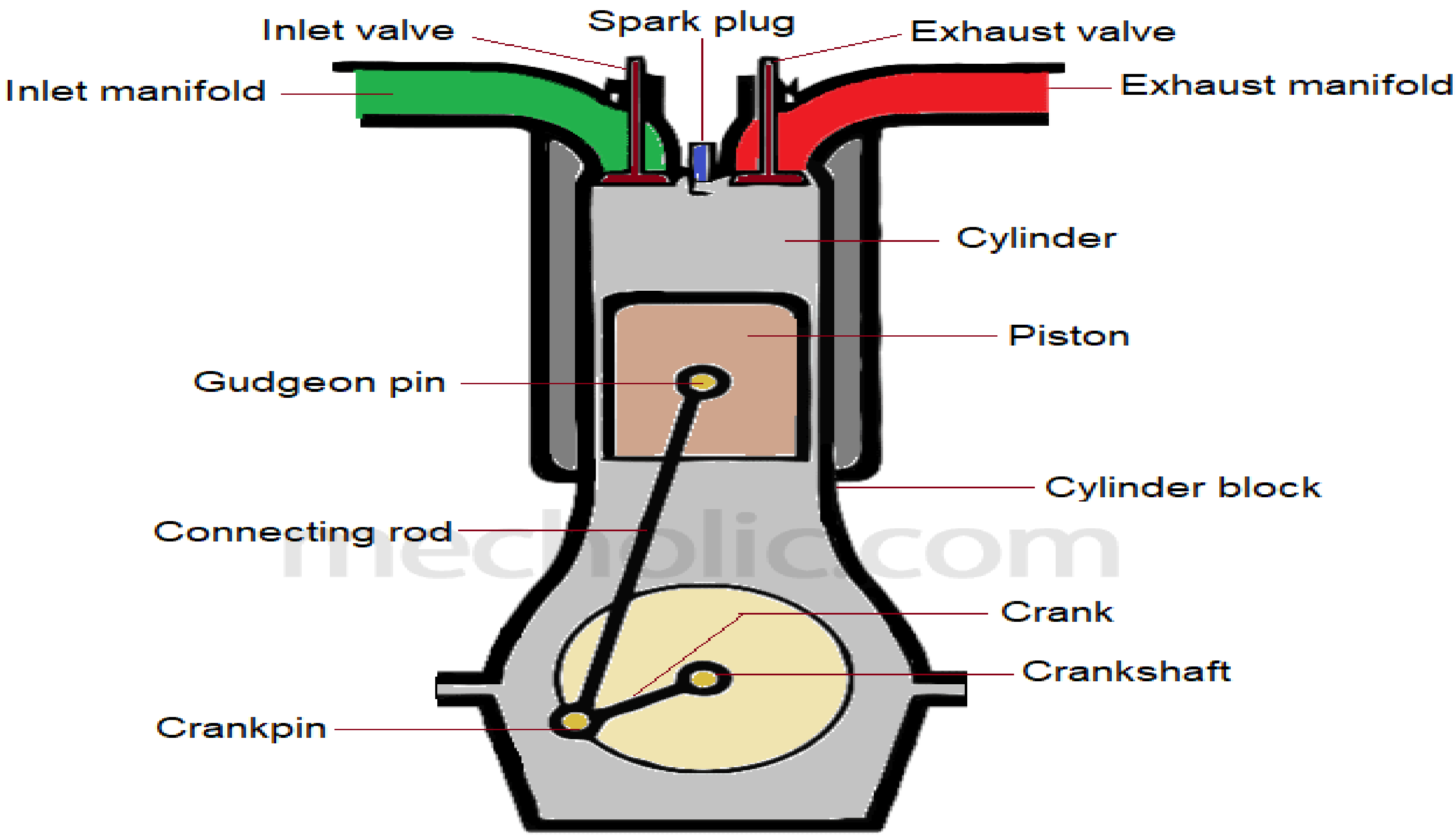


Boxer Engine

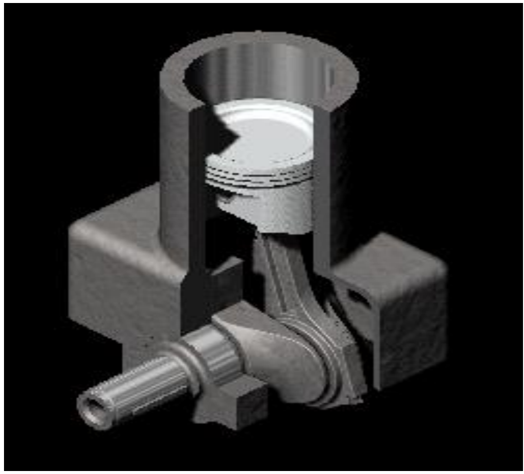


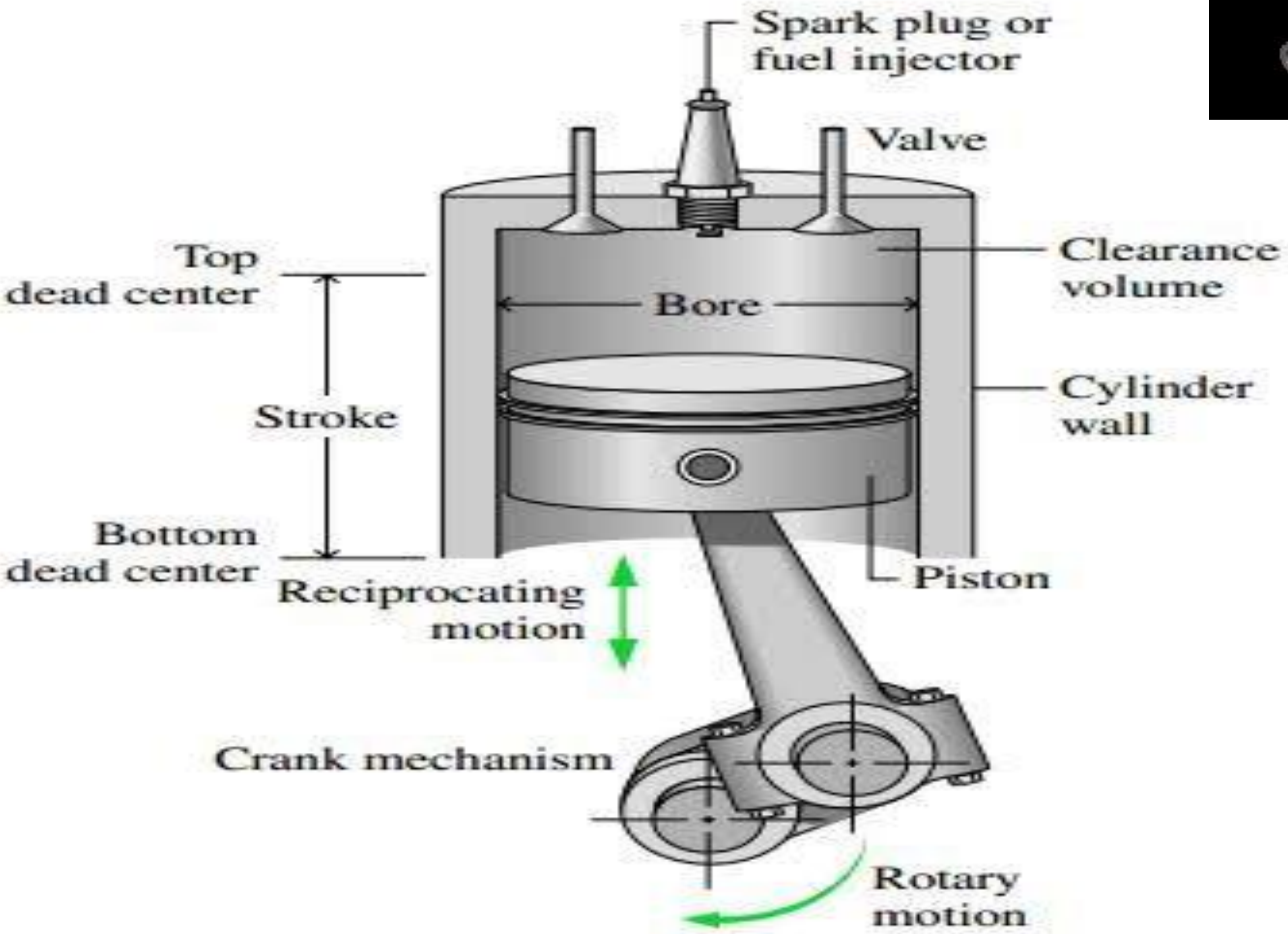
Radial Engine

I C Engine Parts



I C Engine Terminology:





I C Engine Terminology: (Continued….)

1. **Bore:** The inside diameter of the cylinder is called 'bore'.
2. **Top dead center (TDC):** The extreme position of the piston farther to the crankshaft is called 'top dead center' or 'TDC'.
3. **Bottom dead center (BDC):** The extreme position of the piston nearer to the crankshaft is called 'bottom dead center' or 'BDC'.
4. **Stroke:** It is the linear distance travelled by the piston from the TDC to BDC or from BDC to TDC.
5. **Clearance volume (Vc):** It is the volume of cylinder above the top of the piston, when the piston is at the TDC.

I C Engine Terminology: (Continued….)

6. **Swept volume or Stroke volume (Vs):** It is the volume swept by the piston as it moves from BDC to TDC or TDC to BDC.

7. **Compression Ratio (CR):** It is the ratio volume above the piston at BDC to the that of when piston at TDC.

$$Compression\ Ratio\ CR = \frac{Volume\ above\ piston\ at\ BDC}{Volume\ above\ piston\ at\ TDC} = \frac{V_s + Vc}{Vc}$$

6. **Piston Speed:** The average speed of the piston is called 'piston speed'.

Piston speed = 2.L.N

Where, L = Stroke length in m

N = Speed of engine in RPM.

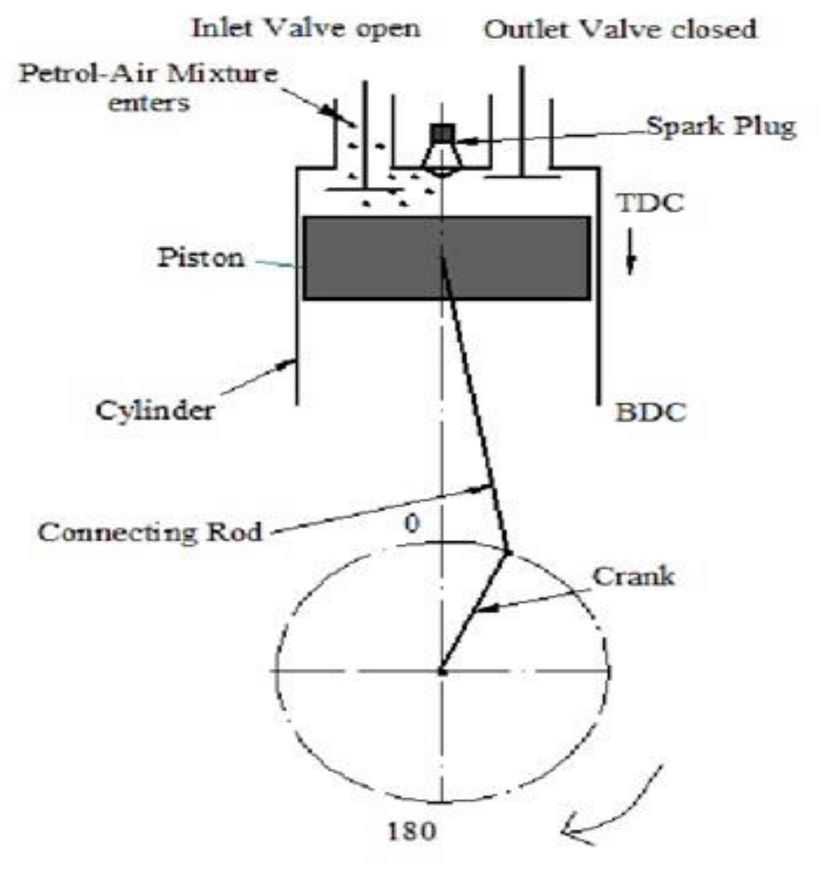
FOUR-STROKE PETROL or SPARK IGNITION (SI) or OTTO ENGINE:

1. Suction Stroke

Position of piston	: At TDC
Piston Movement	: Moves from TDC to BDC
Crank Shaft Rotation	: 0 to 180
Valve position	: Inlet valve Open

Process: At the start of suction stroke, inlet valve opens and piston is at TDC. Piston moves from TDC to BDC.

During downward movement of piston permits the air and fuel to enter inside the combustion chamber due suction. Stroke ends at when piston reaches to BDC.



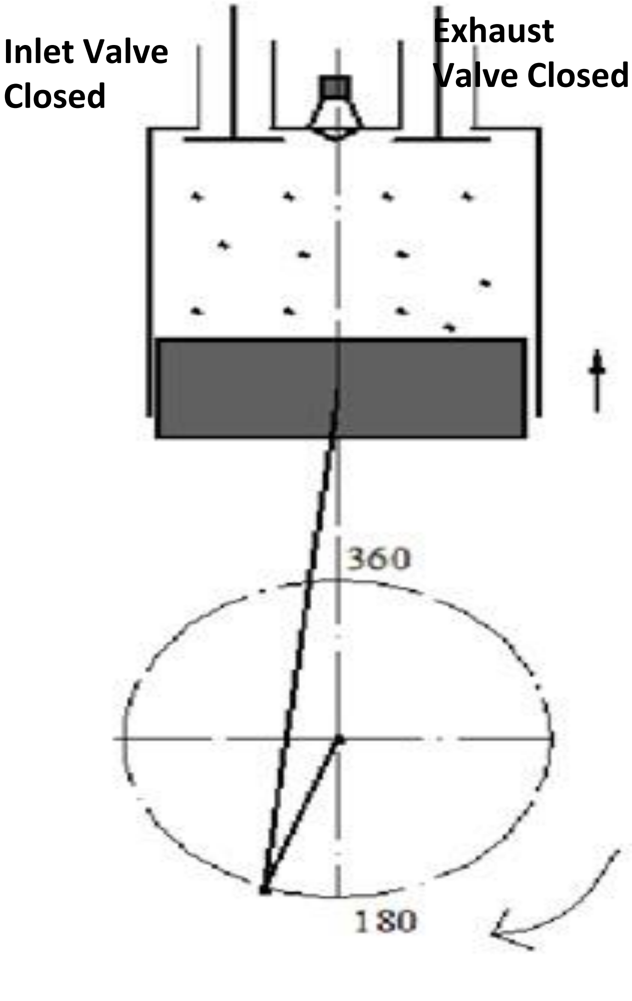
(a) Suction Stroke

2. Compression Stroke

Position of piston	: At BDC
Piston Movement	: Moves from BDC to TDC
Crank Shaft Rotation	: 180 to 360
Valve position	: Both Valve Closed

Process: At the start of compression stroke, inlet valve closes and piston is at BDC. Piston moves from BDC to TDC.

During upward movement of piston compresses the air fuel mixture above the piston. Compression of air fuel is done to increase the temperature of the mixture to bu. Compression Stroke ends at when piston reaches to TDC.



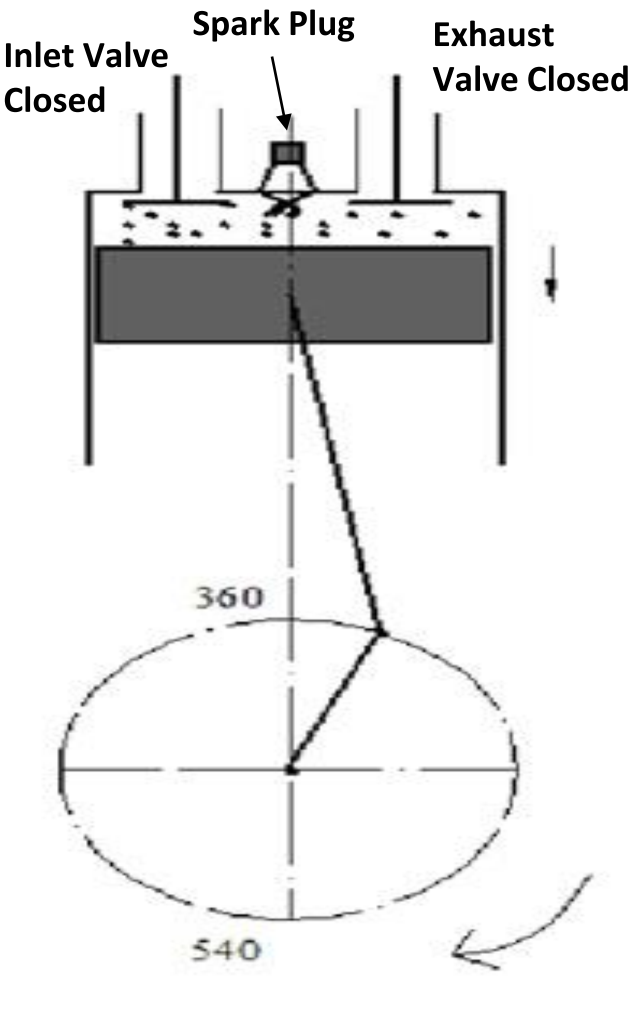
(b) Compression Stroke

3. Power Stroke

Position of piston	: At TDC
Piston Movement	: Moves from TDC to BDC
Crank Shaft Rotation	: 360 to 540
Valve position	: Both Valve Closed

Process: At the start of power stroke, piston is at TDC. Spark is ignited with spark plug. Spark will ignite the air fuel mixture and starts burning. The burnt air fuel mixture will produce high pressure burnt gases with will push the piston downward with enormous force. Hence piston moves from TDC to BDC.

The power stroke completes at when piston reaches to BDC. The some power produced in this stroke is conserved to move piston in remaining stroke with the help of flywheel



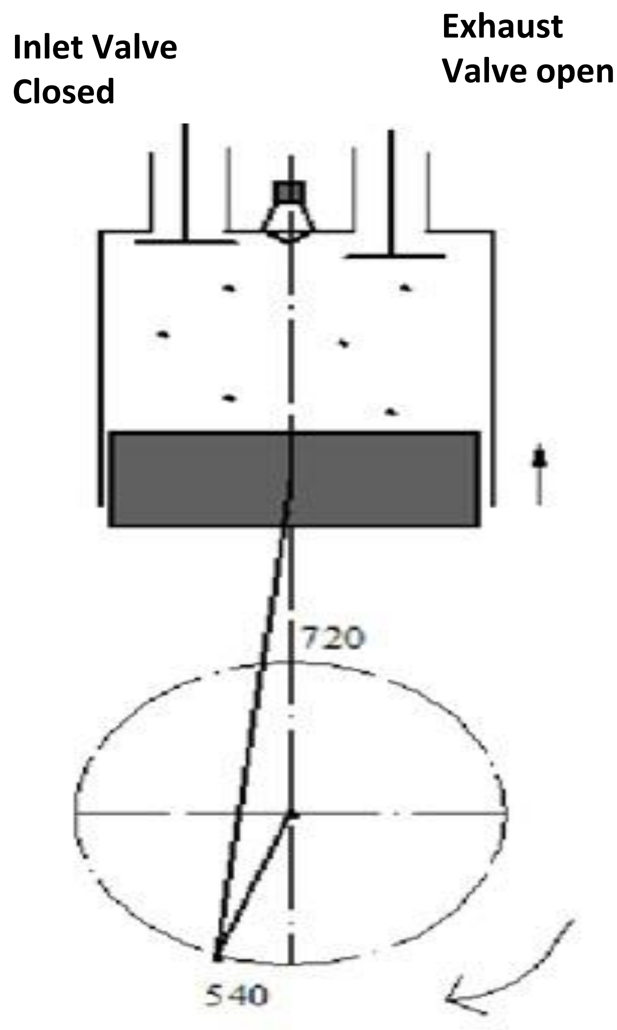
(c) Power Stroke

4. Exhaust Stroke

Position of piston	: At BDC
Piston Movement	: Moves from BDC to TDC
Crank Shaft Rotation	: 540 to 720
Valve position	: Exhaust Valve Open

Process: At the start of exhaust stroke, exhaust valve opens and piston is at BDC. Piston moves from BDC to TDC.

During upward movement of piston take away the burnt gas outside the combustion chamber. Stroke ends at when piston reaches to TDC.



(d) Exhaust Stroke

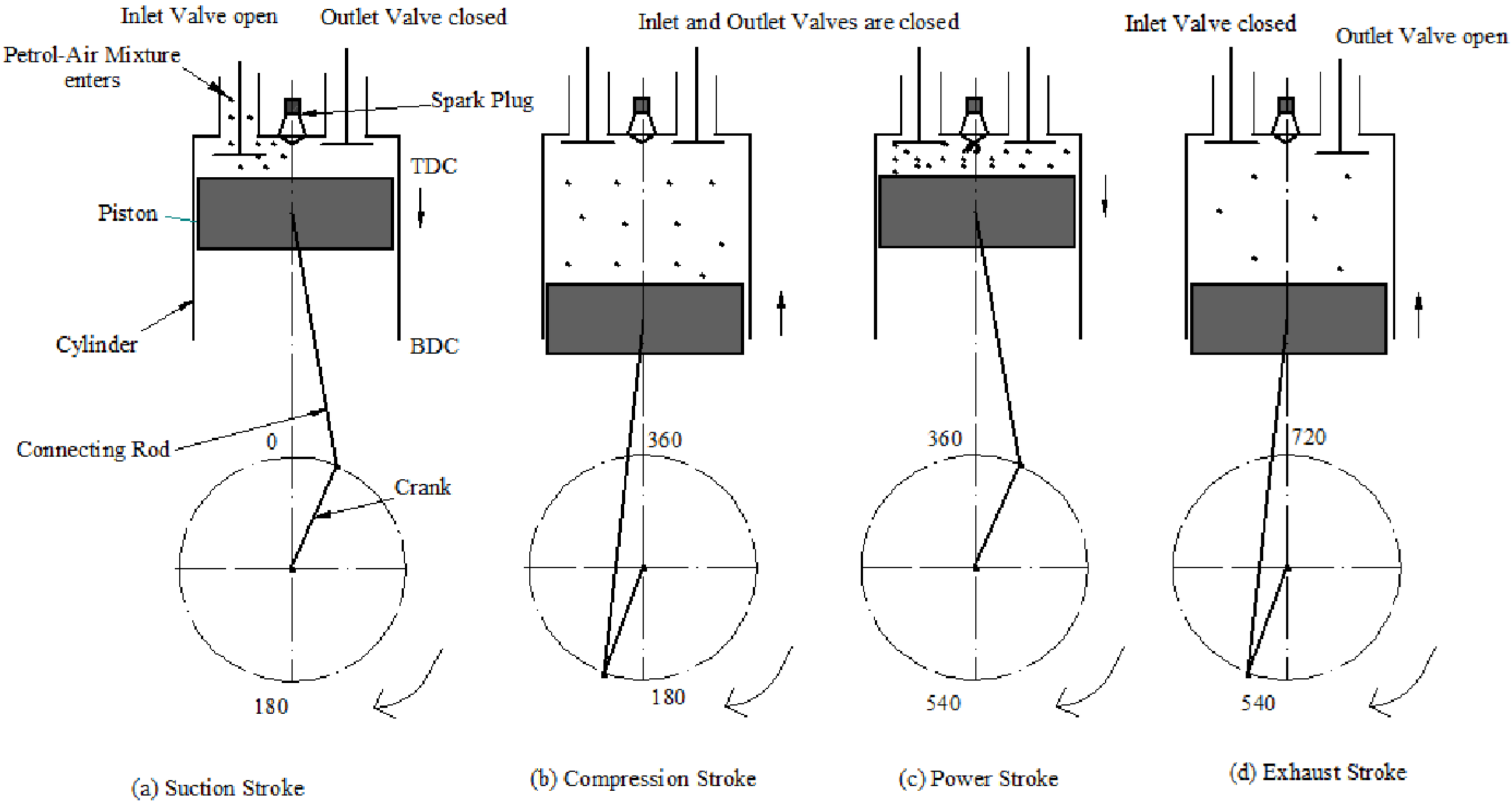
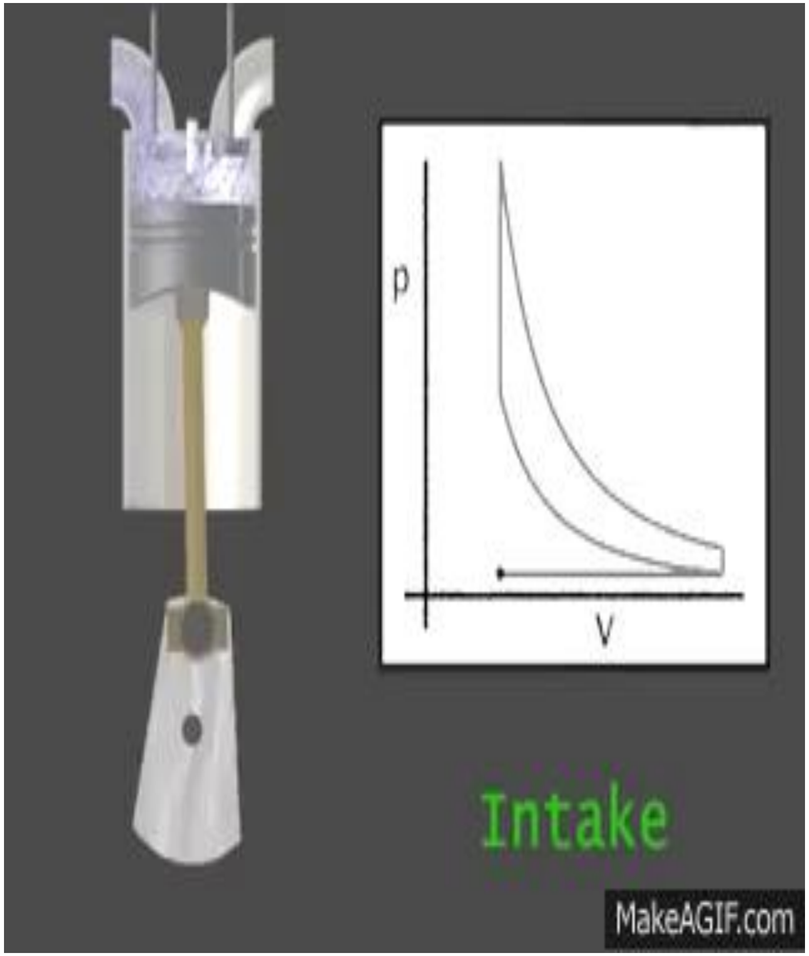


Fig.:- Working of a 4-Stroke Petrol Engine

P-V Diagram of 4-Stroke Otto Engine



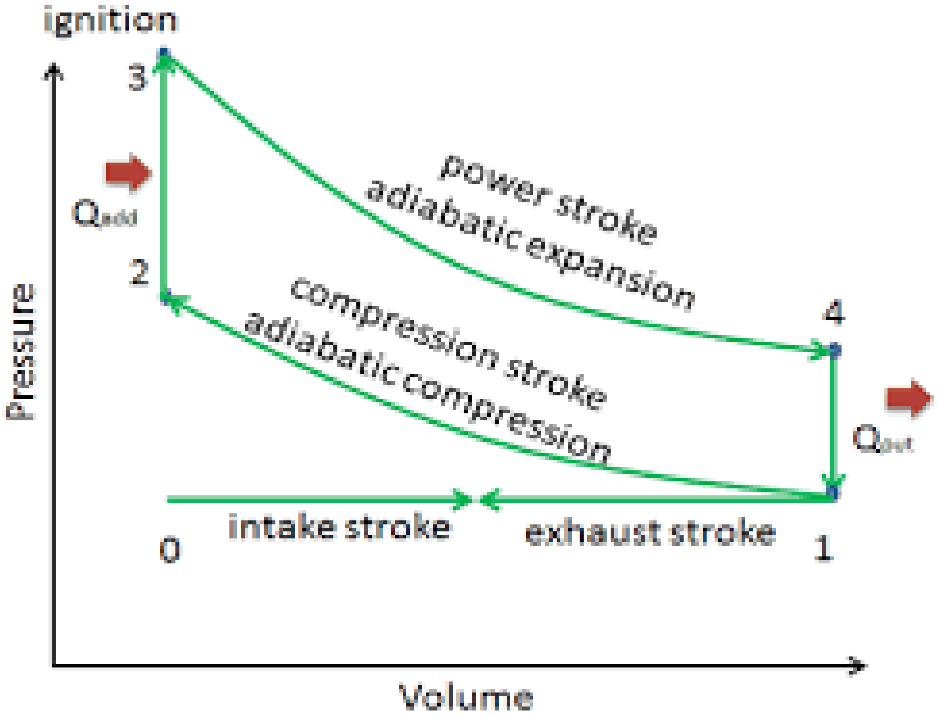


Fig.:- P-V Diagram of Petrol/Otto Engine

At a glance………

Position of Piston at the beginning of stroke	At TDC	At BDC	At TDC	At BDC
Inlet Valve Position	Open	Closed	Closed	Closed
Exhaust Valve Position	Closed	Closed	Closed	Open
Crank angle rotated	0 - 180	180 – 360	360 – 540	540 – 720
Need of the stroke	To intake the air - fuel mixture inside the combustion chamber	To increase the pressure through which the temperature of air – fuel mixture (charge) is increased for easy burning.	To push the piston with enormous pressure from the force generated from burnt gases.	To remove the burnt gases from the combustion chamber.

Observation: In one thermodynamic cycle, crank shaft completes two revolutions.(0 to 720). Therefore, **for one power stroke there are two revolutions of crankshaft.**

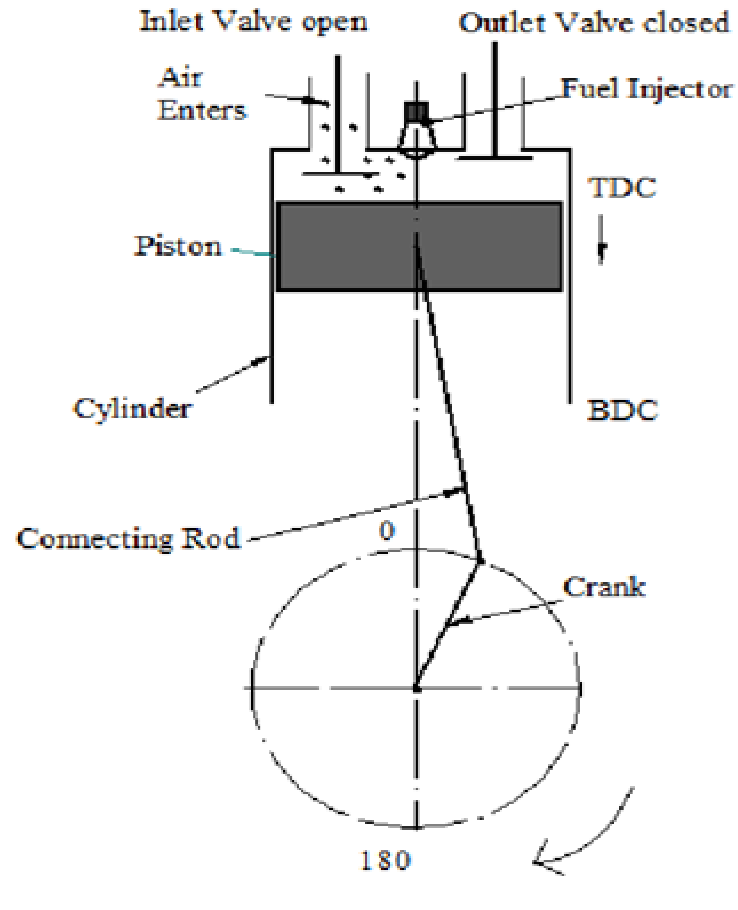
FOUR-STROKE DIESEL ENGINE or COMPRESSION IGNITION (CI) ENGINE

Position of piston	: At TDC
Piston Movement	: Moves from TDC to BDC
Crank Shaft Rotation	: 0 to 180
Valve position	: Inlet valve Open

Process: At the start of suction stroke, inlet valve opens and piston is at TDC. Piston moves from TDC to BDC.

During downward movement of piston permits the **air** to enter inside the combustion chamber due suction. Stroke ends at when piston reaches to BDC.

1. Suction Stroke



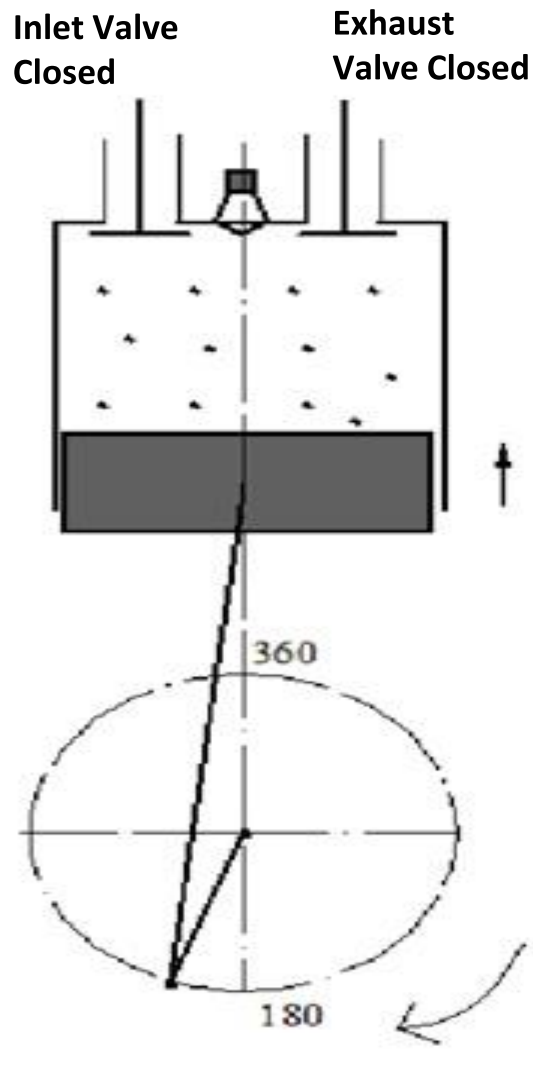
(a) Suction Stroke

2. Compression Stroke

Position of piston	: At BDC
Piston Movement	: Moves from BDC to TDC
Crank Shaft Rotation	: 180 to 360
Valve position	: Both Valve Closed

Process: At the start of compression stroke, inlet valve closes and piston is at BDC. Piston moves from BDC to TDC.

During upward movement of piston air above the it is compressed to increase air temperature more than the self ignition temperature of the fuel. By the time piston reaches to TDC air achieves the self ignition temperature. Compression Stroke ends at when piston reaches to TDC.



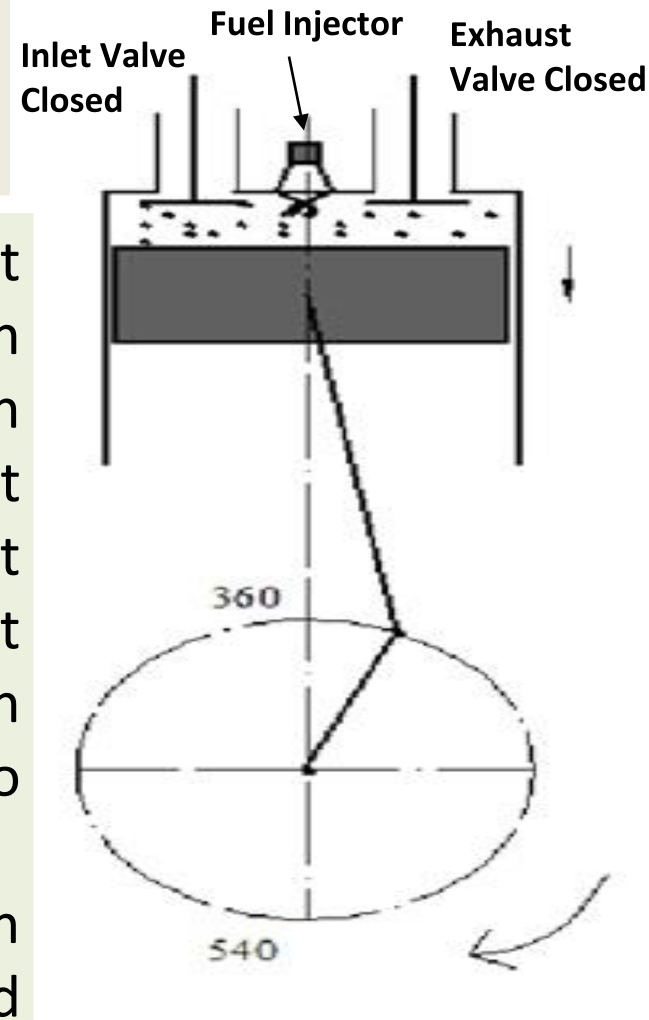
(b) Compression Stroke

3. Power Stroke

Position of piston	: At TDC
Piston Movement	: Moves from TDC to BDC
Crank Shaft Rotation	: 360 to 540
Valve position	: Both Valve Closed

Process: At the start of power stroke, piston is at TDC. A measured quantity of fuel is injected with high pressure. Soon fuel enters the combustion chamber it start burning since already air is at more than burning temperature of fuel. The burnt air fuel mixture will produce high pressure burnt gases with will push the piston downward with enormous force. Hence piston moves from TDC to BDC.

The power stroke completes at when piston reaches to BDC. The some power produced in this stroke is conserved to move piston in remaining stroke with the help of flywheel



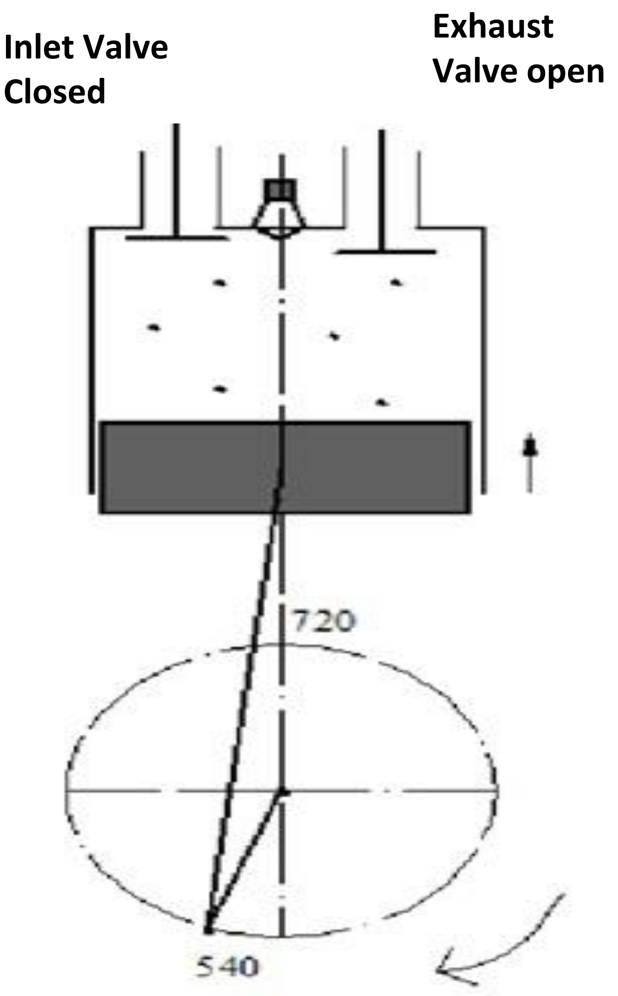
(c) Power Stroke

4. Exhaust Stroke

Position of piston	: At BDC
Piston Movement	: Moves from BDC to TDC
Crank Shaft Rotation	: 540 to 720
Valve position	: Exhaust Valve Open

Process: At the start of exhaust stroke, exhaust valve opens and piston is at BDC. Piston moves from BDC to TDC.

During upward movement of piston take away the burnt gas outside the combustion chamber. Stroke ends at when piston reaches to TDC.



(d) Exhaust Stroke

FOUR STROKE DIESEL ENGINE OR COMPRESSION IGNITION ENGINE:

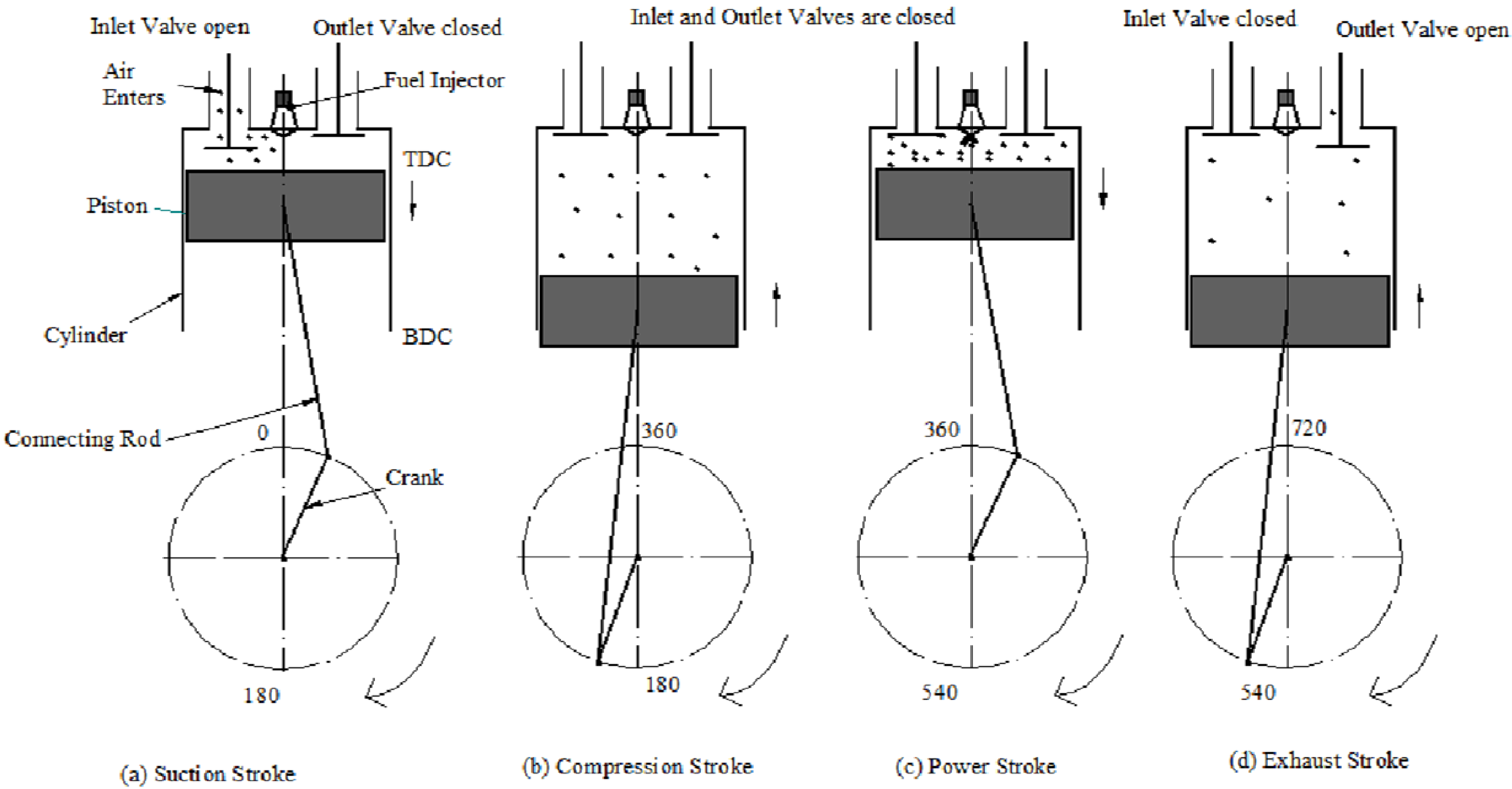


Fig.:- Working of a 4-Stroke Diesel Engine

P-V Diagram of 4-Stroke Otto Engine

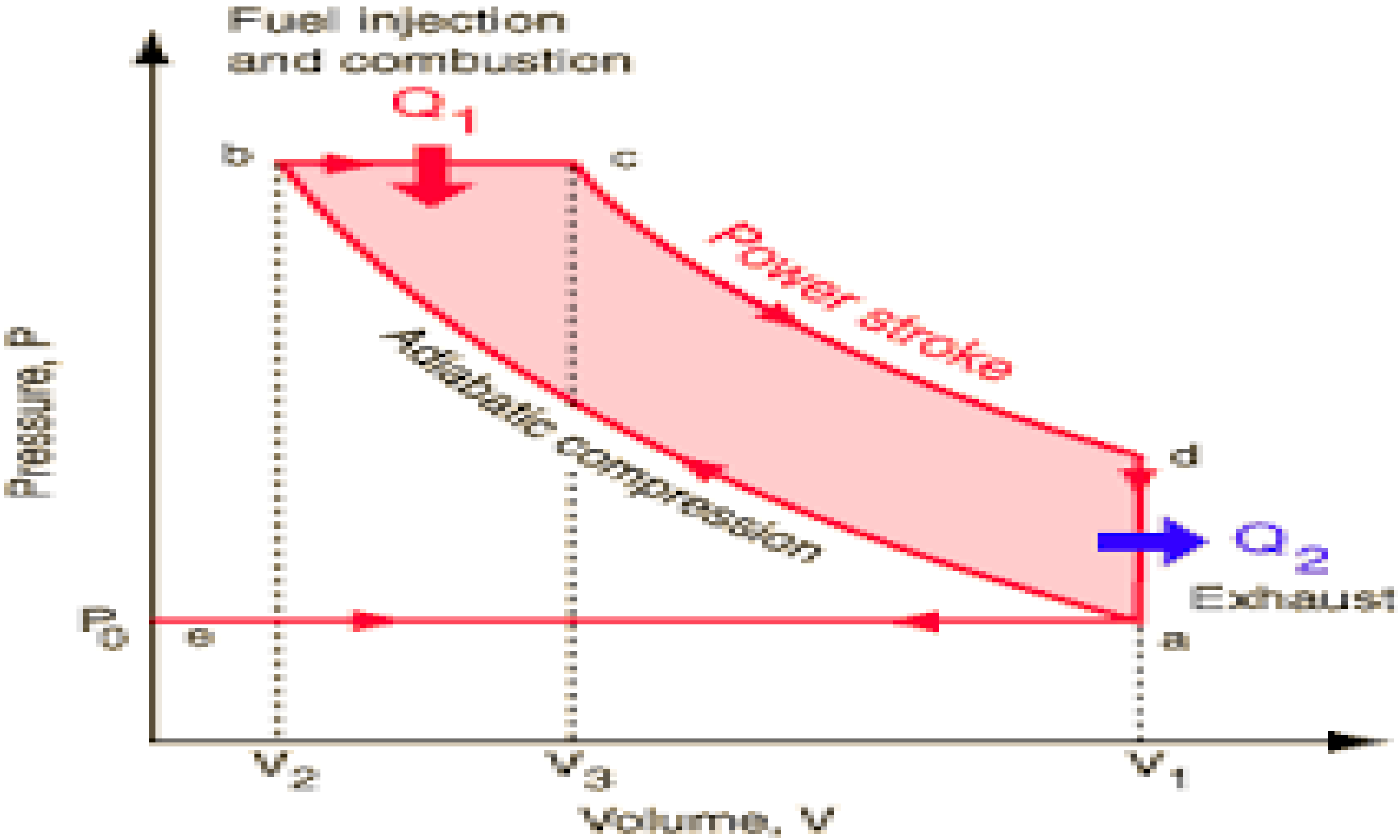


Fig.:- P-V Diagram of Diesel Engine

At a glance………

Position of Piston at the beginning of stroke	At TDC	At BDC	At TDC	At BDC
Inlet Valve Position	Open	Closed	Closed	Closed
Exhaust Valve Position	Closed	Closed	Closed	Open
Crank angle rotated	0 - 180	180 – 360	360 – 540	540 – 720
Need of the stroke	To intake the air inside the combustion chamber	To increase the pressure through which the temperature of air above the **self ignition** temperature of fuel.	To push the piston with enormous pressure from the force generated from burnt gases.	To remove the burnt gases from the combustion chamber.

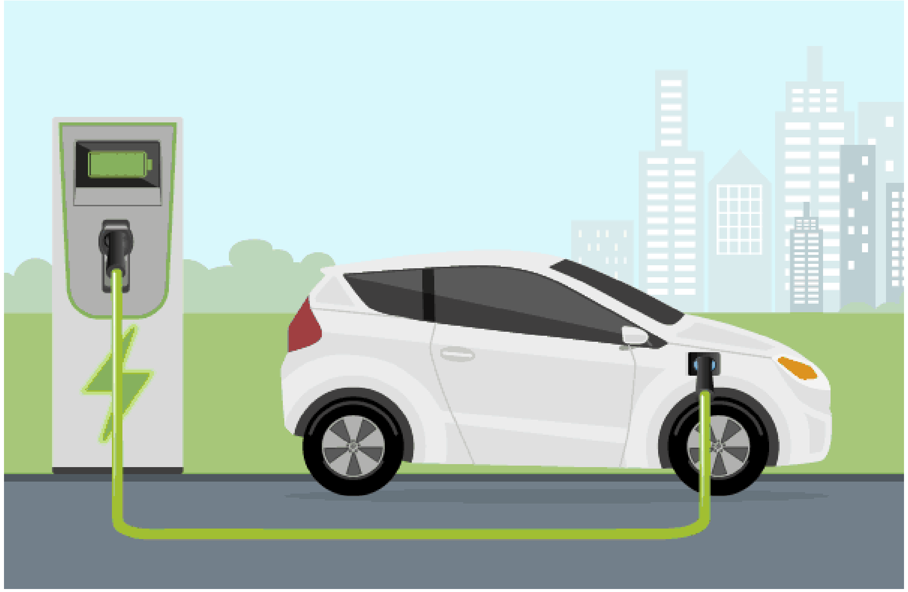
Observation: In one thermodynamic cycle, crank shaft completes two revolutions. (0 to 720). Therefore, **for one power stroke there are two revolutions of crankshaft.**

Comparison between Petrol and diesel engine

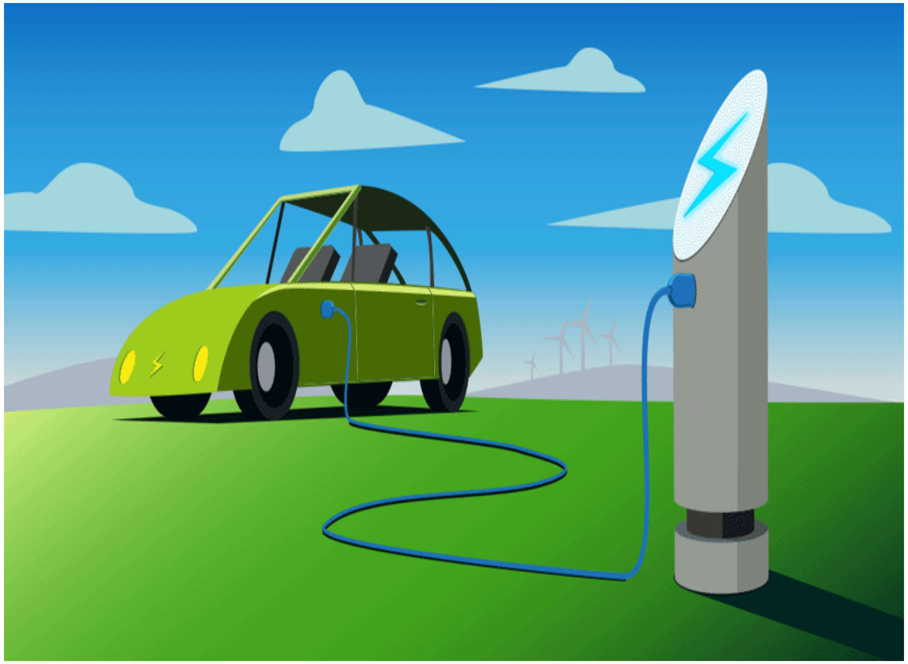
Sl No	Parameter	Petrol Engine	Diesel Engine
1	Theoretical Cycle	Otto Cycle	Diesel Cycle
2	Fuel Used	Petrol, CNG,LPG etc	Diesel and Biodiesel
3	Charge drawn during suction stroke	Air and petrol (Fuel) mixture	Only fuel(Diesel) is injected
4	Ignition of fuel	Spark Ignition	Compression Ignition
5	Compression ratio	Low (7:1 to 12:1)	High (16:1 to 22:1)
6	Engine Speed	High Speed	Low Speed
7	Power output	Low due to low CR	High due to high CR
8	Noise and vibration	Low due to low CR	High due to high CR
9	Thermal Efficiency	Low due to low CR	High due to High CR
10	Initial cost	Low due to light in construction	High due to bulky construction
11	Maintenance cost	Low	High

Insight into Future Mobility

Electric vehicles: An automobile that is powered entirely or partially by electric motors, using energy stored in rechargeable batteries.



The electric vehicle has many advantages over the conventional internal combustion engine vehicle (ICEV), such as an absence of emissions, high efficiency, independence from petroleum, and quiet and smooth operation.



Hybrid Electric Vehicles

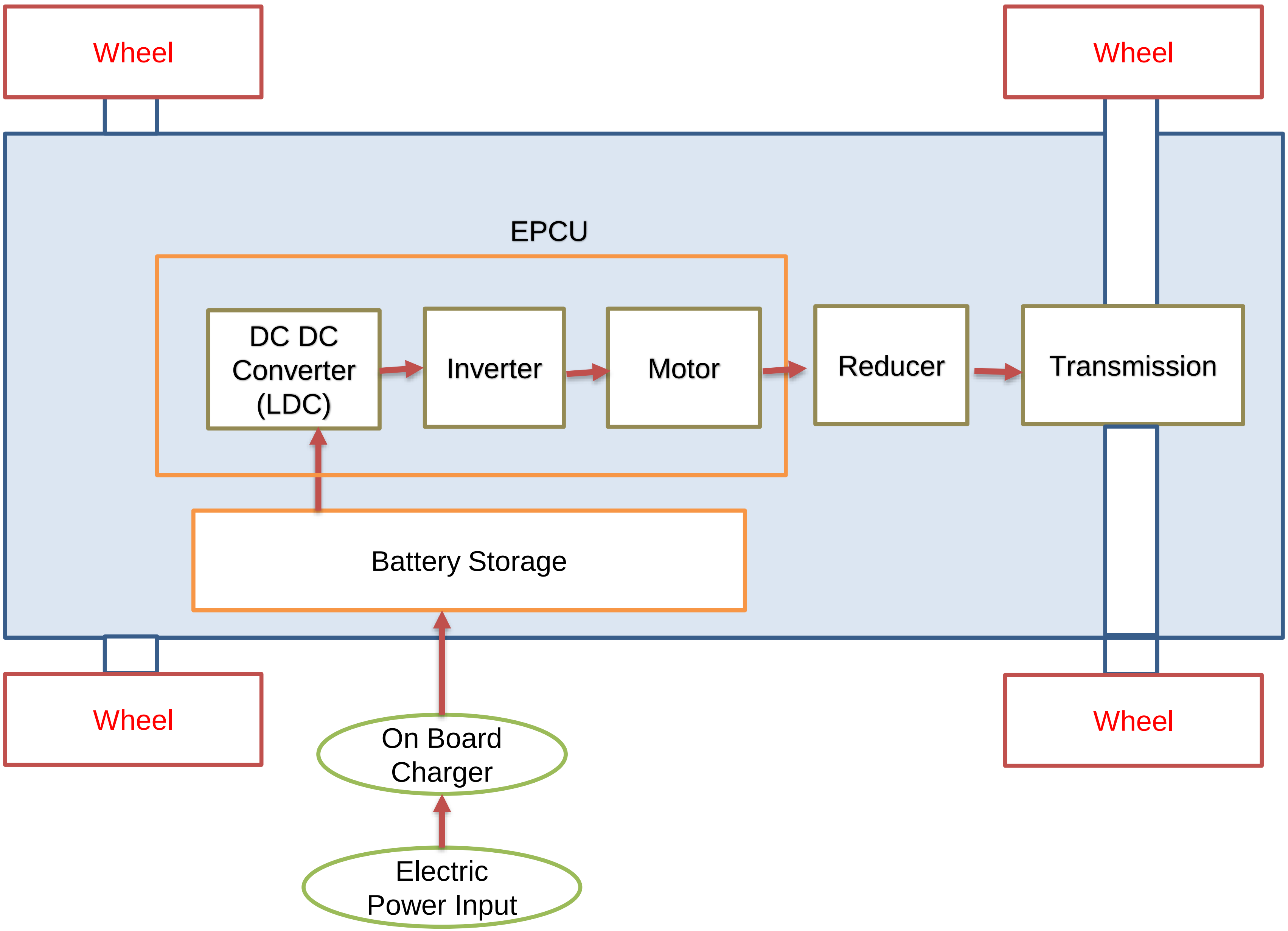
Hybrid electric vehicles (HEV), which use two power sources — a primary power source and a secondary power source — have the advantages of both ICE vehicles and EV and overcome their disadvantages.

Internal combustion engines (ICE) provide good performance and long operating range by utilizing the high energy-density advantages of petroleum fuels. Battery-powered electric vehicles (EV), on the other hand, possess some advantages over conventional ICE vehicles, such as high energy efficiency and zero environmental pollution.

Components of Electric Vehicles

1. Motor
2. Reducer
3. Traction Battery
4. On Board Charger [OBC]
5. Electric Power Control Unit [EPCU]

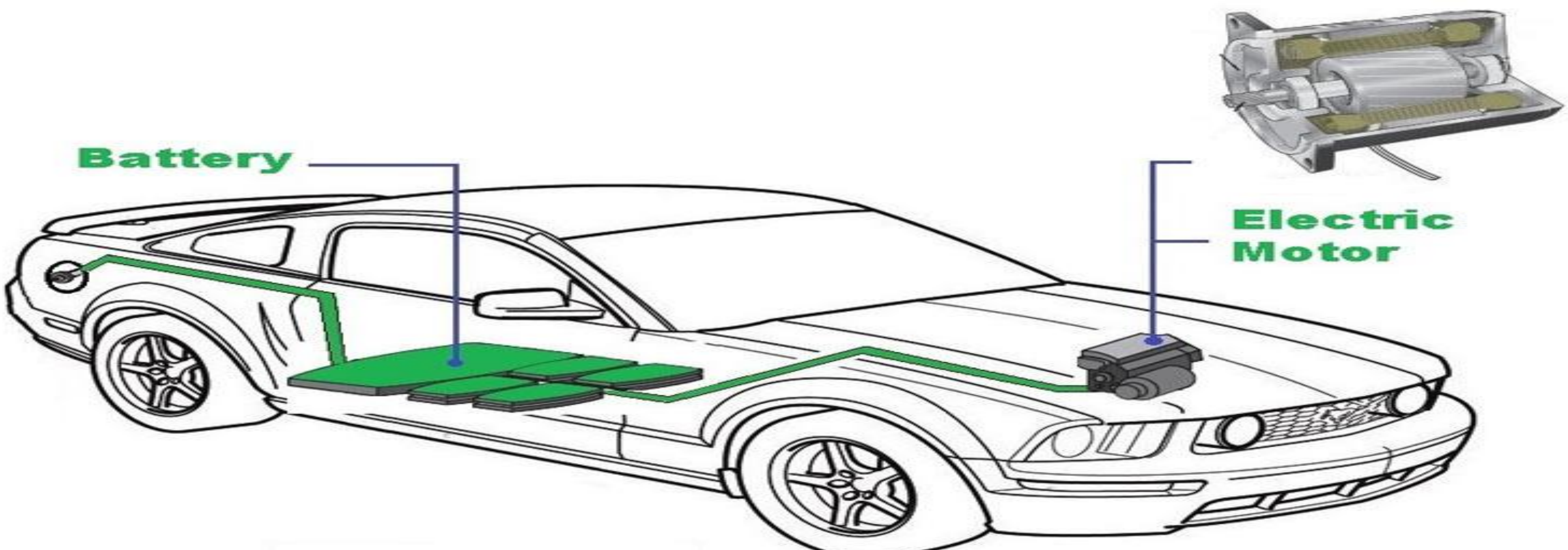
Layout of Electric Vehicles



1. Motor: The motor **converts electric energy into kinetic energy** that moves the wheels.

The power control unit converts DC from battery packs to AC to the motor using Inverters. The motor converts AC supply to the mechanical work. Generally, an Induction motor is used as driving motor for EV due its simple design and low cost. Earlier, BLDC(Brushless DC motors) and PMSM(Permanent Magnet Synchronous Motors) were also used as motors in EV's.

In some vehicles, The motor is also coupled with an **electric generator**. It converts the kinetic energy generated while in neutral gear(e.g. while the car is going downhill) into electric energy saved to the battery. This kind of attachment will ensure the **regenerative breaking systems**.



2. Reducer: The reducer **modifies the number of revolutions the EV motor** generates and transfers this to the drive shaft.

The reason why this piece of machinery is called a reducer is due to the fact that the EV motor has a far higher RPM than that of an internal combustion engine. So, in an internal combustion engine vehicle, the transmission changes the engine RPM to match the driving situation. In an electric vehicle, the reducer also must always lower the RPM of the electric engine to the right level.

With the lowered RPM provided by an EV reducer, the powertrain can utilize the resulting higher torque.

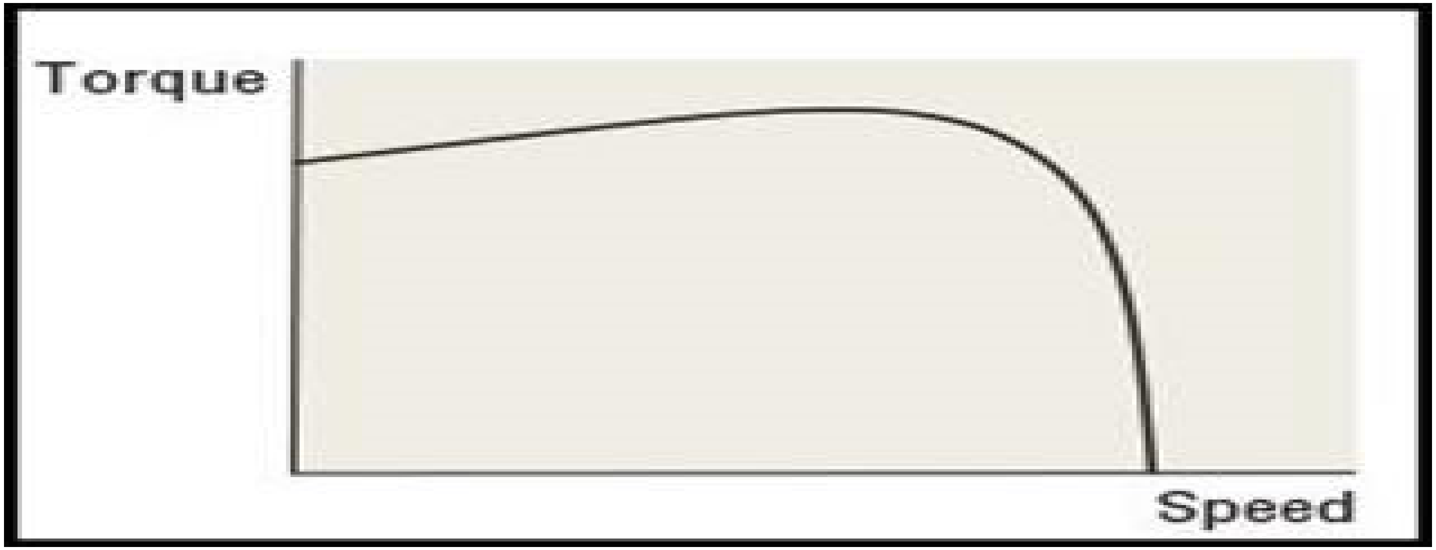


Fig: At very high speed the torque on the driving shaft reduces drastically. Hence, we need a reducer to maintain proper torque on shaft.

3. Traction Battery: The battery stores electrical energy and is the equivalent of a fuel tank in an internal combustion engine. The maximum driving distance of an EV is often determined by the battery capacity, the higher the capacity, the higher the driving distance. Carrying large battery packs adds payload on the vehicle performance. Hence we desire high density with light weight battery packs.

Battery stores electric energy. When, electric power control unit, gives signal to battery, it will release the DC current to inverter and then used to rotate the shaft. The most widely used is the type of lithium-ion batteries.

4. On Board Charger [OBC]: It is a device that convert AC power into the practical DC form. It is usually mounted inside the vehicle and it's main function is power conversion. The main function of an on-board charger:

- To manage the flow of current from the grid to the traction battery.
- To controls the level of current and voltage at which the battery is charged.

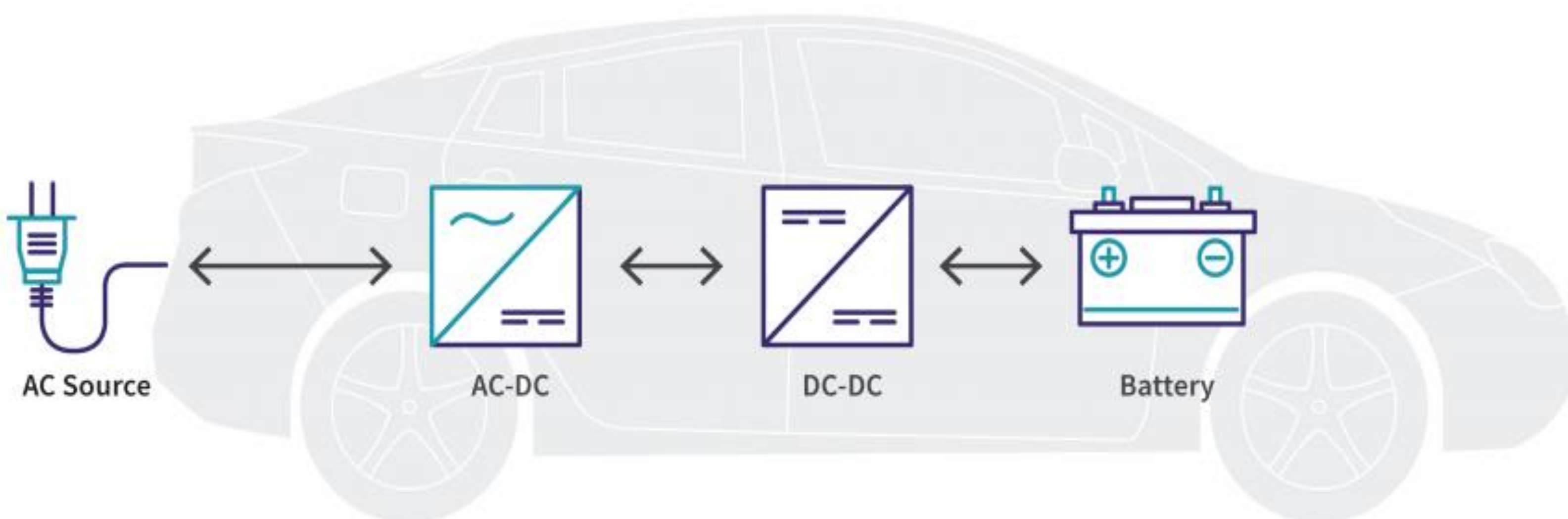


Fig: Working principle of On Board Charger.

5. Electric Power Control Unit(EPCU) The Electric Power Control Unit(EPCU) controls devices that control the flow of the electric power in the vehicle. It consists of the inverter, the Low voltage DC-DC Converter(LDC), and the Vehicle Control Unit(VCU).

- **Inverter:** The inverter converts the battery's DC into AC, which then is used to control the motor speed. The device is responsible for executing acceleration and deceleration, so it serves a crucial part in maximizing the EV's drivability.
- **Low voltage DC-DC Converter(LDC):** The LDC converts the high voltage electricity from the EV's high-voltage battery into low-voltage(12V) and supplies it to the vehicle's various electronic systems. All electronic systems in the EV use electricity in low voltage, so the high voltage in the battery must be converted first to be useful for these systems.
- **Vehicle Control** Unit It controls nearly all the vehicle's power control mechanisms, including the motor control, regenerative braking control, A/C load management

Different Configurations of Electrical Vehicles

There are four types of electric vehicles configurations are available:

1. Battery Electric Vehicle (BEV): Fully powered by electricity. These are more efficient compared to hybrid and plug-in hybrids.

2. Hybrid Electric Vehicle:

a). Hybrid Electric Vehicle (HEV): The vehicle uses both the internal combustion (usually petrol) engine and the battery-powered motor powertrain. The petrol engine is used both to drive and charge when the battery is empty. These vehicles are not as efficient as fully electric or plug-in hybrid vehicles.

b). Plug-in Hybrid Electric Vehicle (PHEV): Uses both an internal combustion engine and a battery charged from an external socket (they have a plug). This means the vehicle's battery can be charged with electricity rather than the engine. PHEVs are more efficient than HEVs but less efficient than BEVs.

3. Fuel Cell Electric Vehicle (FCEV): Electric energy is produced from chemical energy. For example, a hydrogen FCEV.

Battery Electrical Vehicles(BEV)

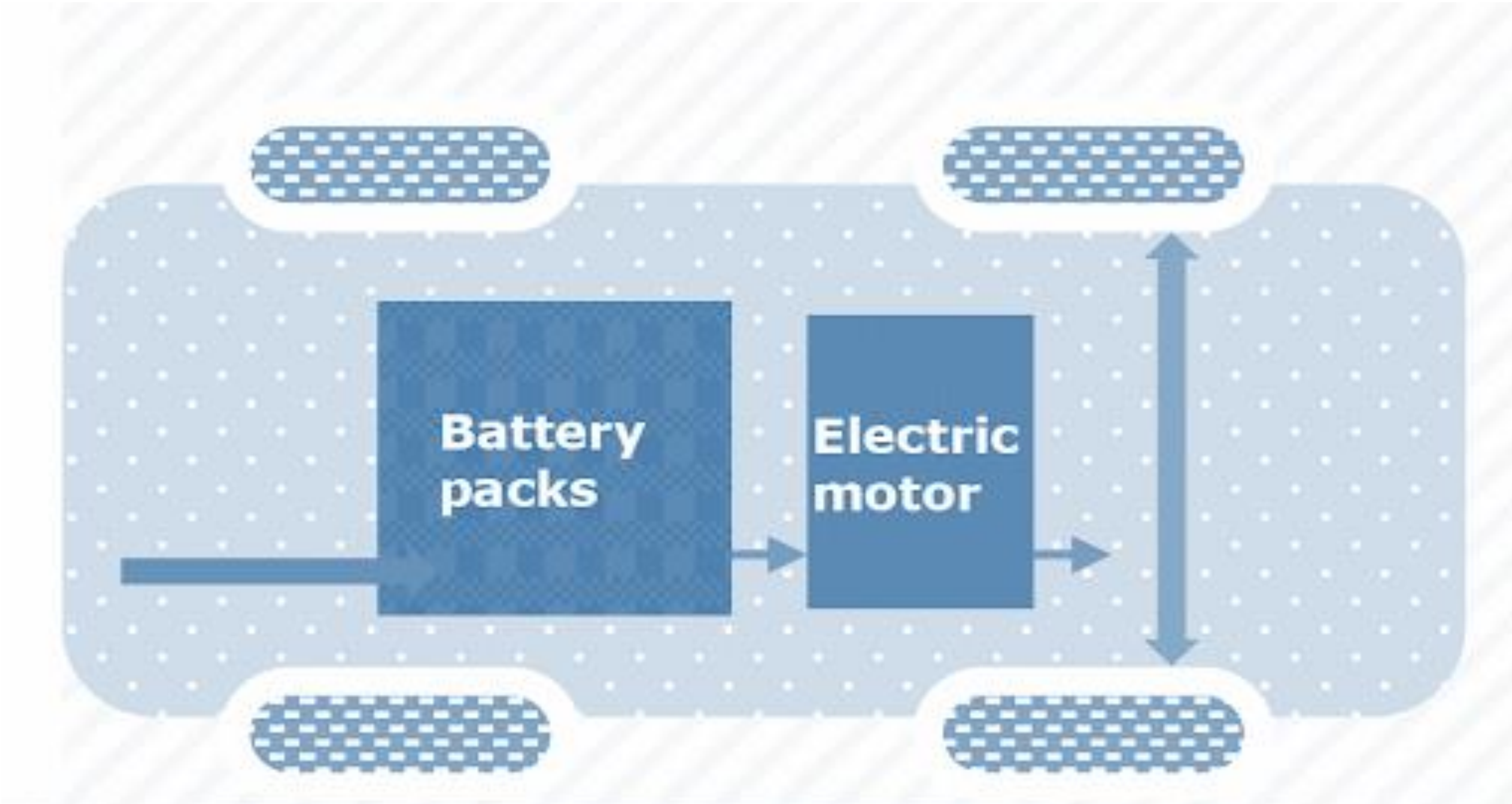


Fig: Battery Electrical Vehicle Basic Configuration.

BEVs are also known as All-Electric Vehicles (AEV). Electric Vehicles using BEV technology run entirely on a battery-powered electric drivetrain. The electricity used to drive the vehicle is stored in a large battery pack which can be charged by plugging into the electricity grid. The charged battery pack then provides power to one or more electric motors to run the electric car.

Working Principles of BEV:

The power for the electric motor is converted from the DC Battery to AC. As the accelerator is pressed, a signal is sent to the controller. The controller adjusts the speed of the vehicle by changing the frequency of the AC power from the inverter to the motor. The motor then connects and leads to the turning of wheels through a cog. If the brakes are pressed, or the electric car is decelerating, the motor becomes an alternator and produces power, which is sent back to the battery

Examples of BEV:

MG ZS, TATA Nexon, TATA Tigor, Mahindra E20 plus, Hyundai Kona, Mahindra Verito

Hybrid Electrical Vehicles(HEV)

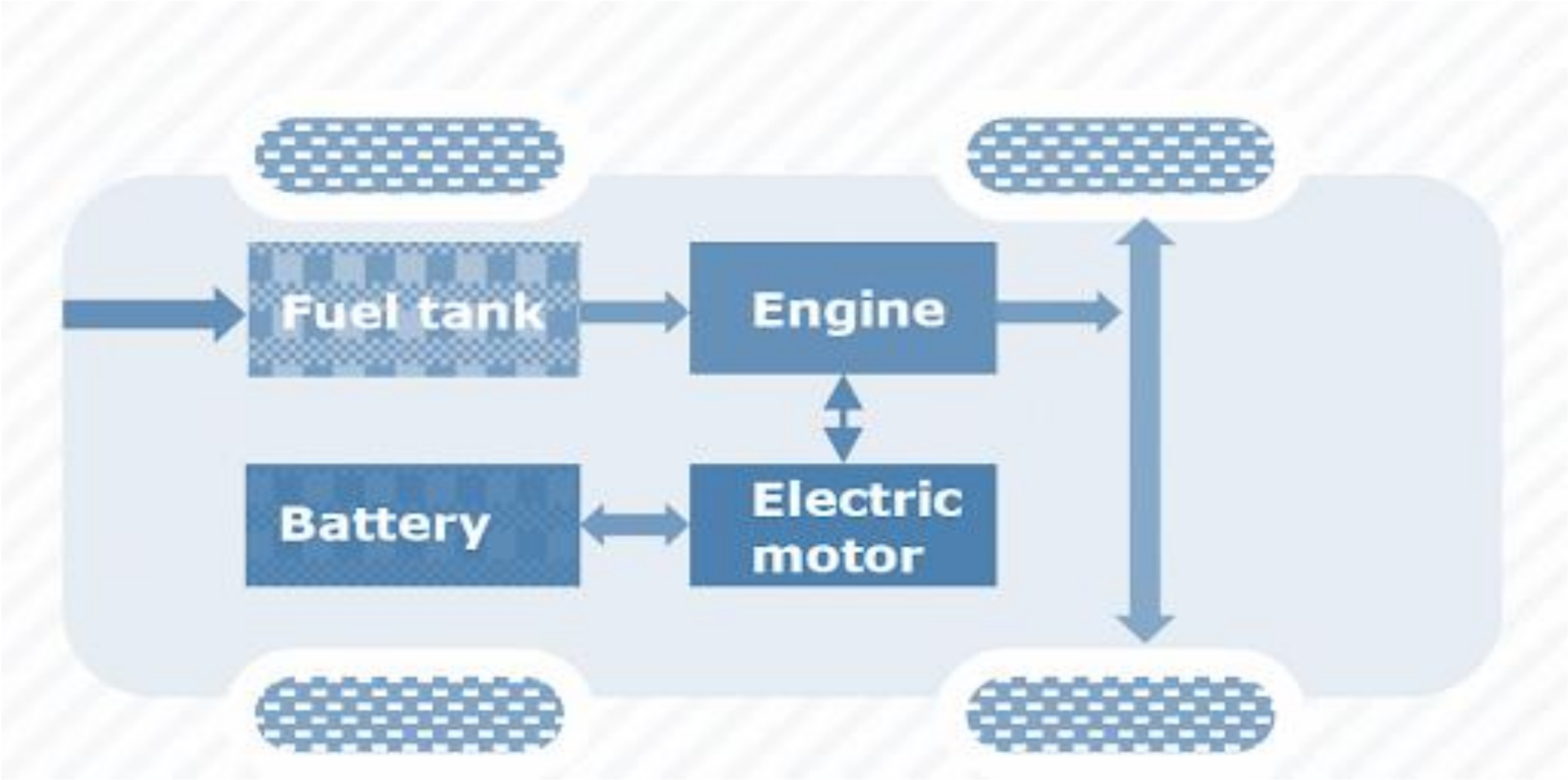


Fig: Hybrid Electrical Vehicle Basic Configuration.

HEVs have both engine and electric motor. The engine gets energy from fuel, and the motor gets electricity from batteries. The transmission is rotated simultaneously by both engine and electric motor. This then drives the wheels.

Working Principles of HEV:

The fuel tank supplies energy to the engine like a regular car. The batteries run on an electric motor. Both the engine and electric motor can turn the transmission at the same time.

These vehicles are not as efficient as fully electric or plug-in hybrid vehicles.

HEVs are also known as series hybrid or **parallel hybrid**.

Plugin Hybrid Electrical Vehicles(PHEV)

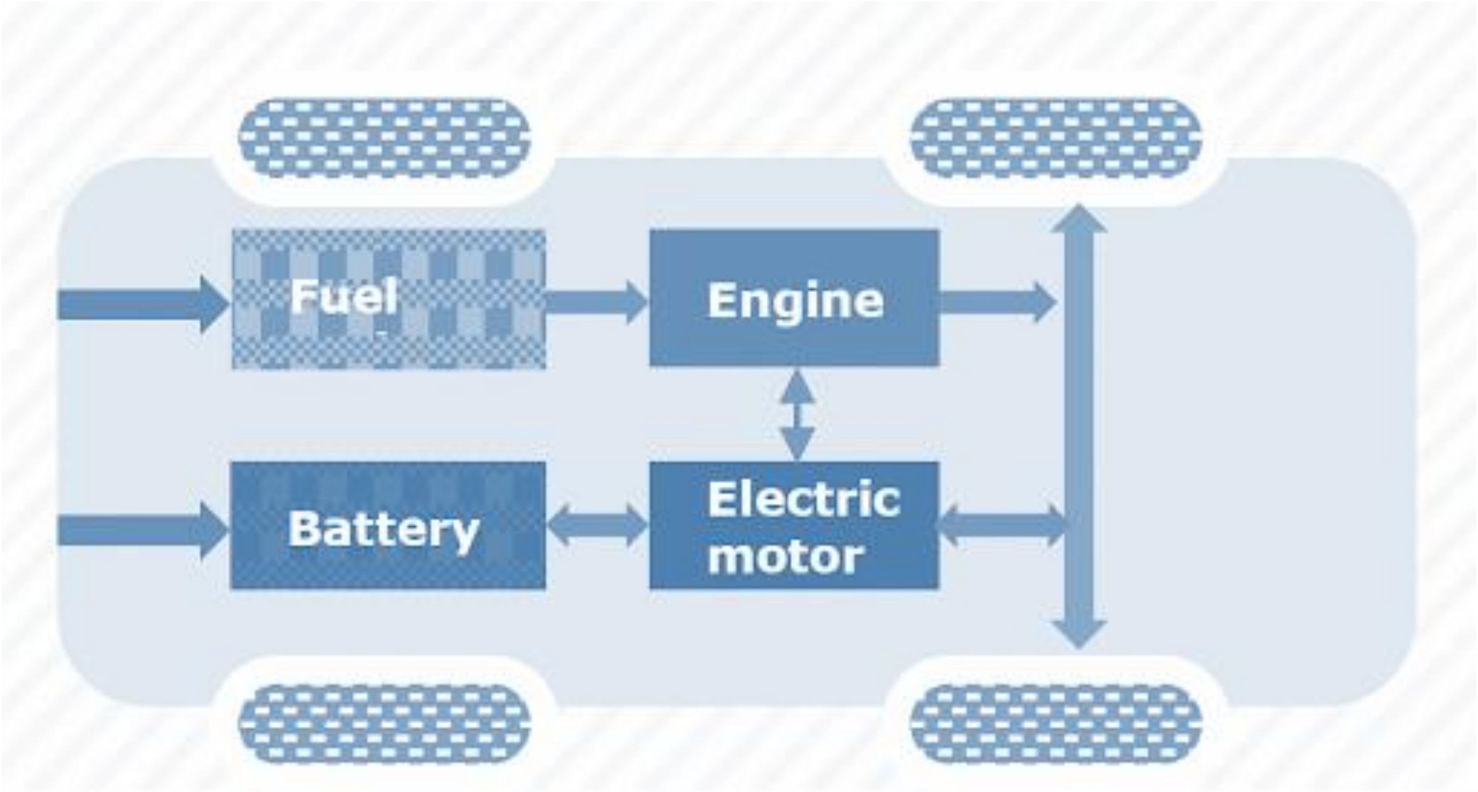


Fig: Plugin Hybrid Electrical Vehicle Basic Configuration.

They have both engine and a motor. You can choose among the fuels, conventional fuel (such as petrol) or alternative fuel (such as bio-diesel). It can also be powered by a rechargeable battery pack. The battery can be charged externally.

Working Principles of PHEV:

PHEVs start-up in all-electric mode and make use of electricity until their battery pack is depleted. Once the battery gets drained, the engine takes over, and the vehicle operates as a conventional, non-plug-in hybrid. PHEVs can be charged by plugging into an outside electric power source, engine, or regenerative braking. When brakes are applied, the electric motor acts as a generator, using the energy to charge the battery. The engine's power is supplemented by the electric motor; as a result, smaller engines can be used, increasing the car's fuel efficiency without compromising performance.

Examples of PHEV:

Porsche Cayenne S E-Hybrid, BMW 330e, Porsche Panamera S E-hybrid, Chevy Volt, Chrysler Pacifica, Ford C-Max Energi, Mercedes C350e, Mercedes S550e, Mercedes GLE550e, Mini Cooper SE Countryman, Ford Fusion Energi, Audi A3 E-Tron, BMW i8, BMW X5 xdrive40e, Fiat 500e, Hyundai Sonata, Kia Optima, Volvo XC90 T8.

Fuel Cell Hybrid Electrical Vehicles(FCEV)

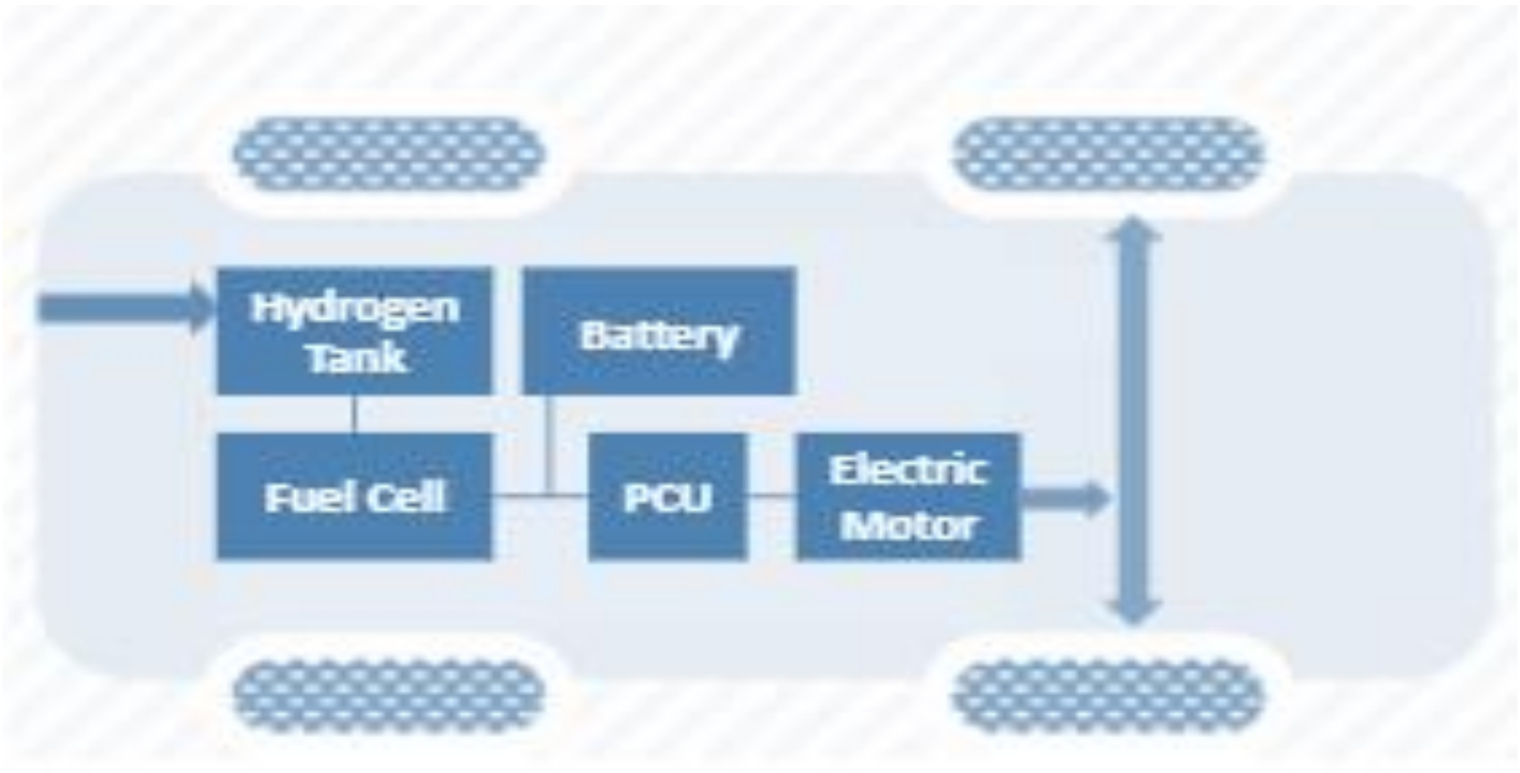


Fig: Fuel Cell Hybrid Electrical Vehicle Basic Configuration.

They have both engine and a motor. You can choose among the fuels, conventional fuel (such as petrol) or alternative fuel (such as bio-diesel). It can also be powered by a rechargeable battery pack. The battery can be charged externally.

FCEVs are also known as Zero-Emission Vehicles. They employ 'fuel cell technology' to generate the electricity required to run the vehicle. The chemical energy of the fuel is converted directly into electric energy.

Working Principles of FCEV:

The FCEV generates the electricity required to run this vehicle on the vehicle itself. This energy is used to store in batteries in a vehicle. These batteries will release the energy to the motor and this energy need is controlled by the MCU. The motor is further connected to wheels.

Since this type of vehicles are not assisted by the I C Engines or any other auxiliary source of energy (like HEV, PHEV) is called as Zero Emission Vehicles.

Examples of FCEV:

Toyota Mirai, Riversimple Rasa, Hyundai Tucson FCEV, Honda Clarity Fuel Cell, Hyundai Nexo.

Advantages of Electric and Hybrid Vehicles

- Electricity is readily available.
- Since there is no IC engine, the vehicle runs without noise.
- There are no emissions from EVs, hence they are environmental friendly.
- Manufacturing the EV is very easy; you have to merely assemble various components of the vehicle. This is especially true for small motorcycles or mopeds.
- Less maintenance: This is due to the fact that electric cars have fewer moving parts and therefore, fewer parts can brake or worn down.
- Perfect for short distances: electric cars are a suitable alternative when it comes to driving short distances like urban mobility.

Limitations of Electrical and Hybrid Vehicles

- The battery has to be charged regularly and it takes about 6-8 hours to recharge completely.
- Low range: While the average electric car may have a range of around 150 miles, the average range of conventional cars would be around 300 miles.
- Charging may be an issue: As such there are less battery charging stations available on roads and highways. Home must be outfitted with a charging station to recharge the electric vehicle battery.
- Charging takes much longer: Will have to spend longer at electric charging stations compared to the fueling of conventional cars.