Developments in Electric Automotive Technologies

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Abstract - *The transportation has a significant impact on Global Warming every year and the biggest contributor are tailpipe emissions observed from vehicles. In order to limit Climate Change, we need to work on limiting Global Warming. Over the last 2 decades, researchers have been focusing their efforts on the development of propulsion technologies for vehicles which do not release Greenhouse gases. Advancements in IC Engine technologies as well as new technologies such as Hybrid Electric Vehicles and Battery Electric Vehicles have been developed. This paper provides an overview of these developments and the impact that they have had on Global Warming.*

***Key Words*: Battery electric vehicle, Hybrid Electric vehicle, Global Warming, IC Engines, Series and Parallel Hybrids**

1.INTRODUCTION

The annual temperature of the Earth has been steadily rising as a result of global warming. This growth was first noted in 1880, and it has continued every year since. This increase occurred at a rate of 0.07 degree Celsius every ten years between 1880 and 1980. However, between 1981 and now, the pace of change in the earth's temperature has accelerated dramatically. Since 1981, the annual global temperature increase has averaged 0.18 degrees Celsius every ten years. Limiting this increase in temperature to its lowest level has become a critical issue in the current circumstances. [1]

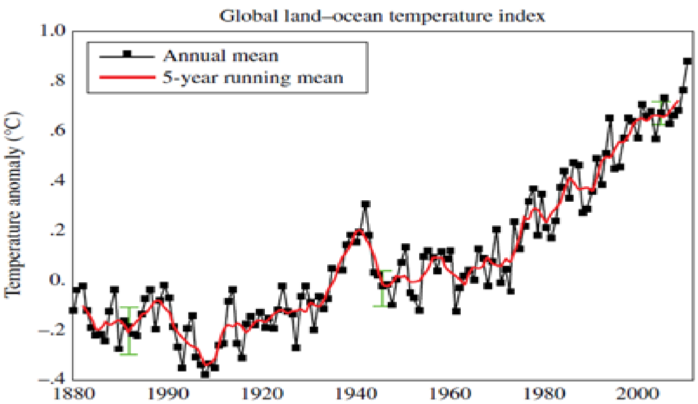

Fig.1- Global annual mean surface air temperature change [8]

The Industrial Revolution was a key contributor to this rise in temperature. In the late 18th century, the United States of America and Europe experienced the industrial revolution. Simply described, the industrial revolution was a move from an economy focused on agriculture and handmade crafts to one based on industry and machine manufacturing. This resulted in the development of machinery, which eventually led to the development of a mass-production systems. These machines were powered by fossil fuels, which resulted in the production of greenhouse gases. The creation of these GHG emissions grew as industrialization spread throughout civilization. This was a major factor in the rise in the temperature of the Earth.[2]

The transportation sector is a key contributor to Global Warming in the current context. Internal combustion engines used in transportation emit a range of greenhouse gases from their tailpipes, including carbon dioxide (CO2), methane (CH4), and nitrous oxide (NO2). The air conditioners also release hydrofluorocarbons. Carbon dioxide is the most significant contributor to greenhouse gas emissions since it is the gas emitted in the greatest quantity by automobiles. Various options, such as Hybrid-Electric Vehicles (HEVs), Electric Vehicles (EVs), and Hydrogen Fuels, have been investigated to reduce these emissions. Hybrid-Electric Vehicles are powered by a mix of electric motors and an internal combustion engine (IC Engine). Electric vehicles, on the other hand, are powered entirely by electricity. [3][4]

In this paper, the various hybrid and electric vehicle technologies and their future have been discussed.

2 INTERNAL COMBUSTION ENGINES

In the current age, the fossil fuel powered internal combustion engines remain the highest used power source for vehicles in the world. While significant efforts have been made to transition from the IC Engines to non-polluting vehicles, combustion powered vehicles still remain popular because of their low cost and high range. [5]

Reciprocating Engines are the most commonly used engines in the automotive sector. They can be classified based on a number of factors.

Classification of Reciprocating Engines based on the number of strokes in one operating cycle-

- 4-Stroke Engine

- 2-Stroke Engine

The 4 – Stroke engine is the most commonly used engine in automobiles, and it has been discussed in this paper.

Based on the method of ignition used in these engines, they can be classified into 2 main types-

2.1 Spark Ignition Engines

Spark Ignition engines, also known as Petrol Engines or Gasoline Engines, operate based on the principle of the Otto cycle. The P-V diagram of the Otto cycle is given below-

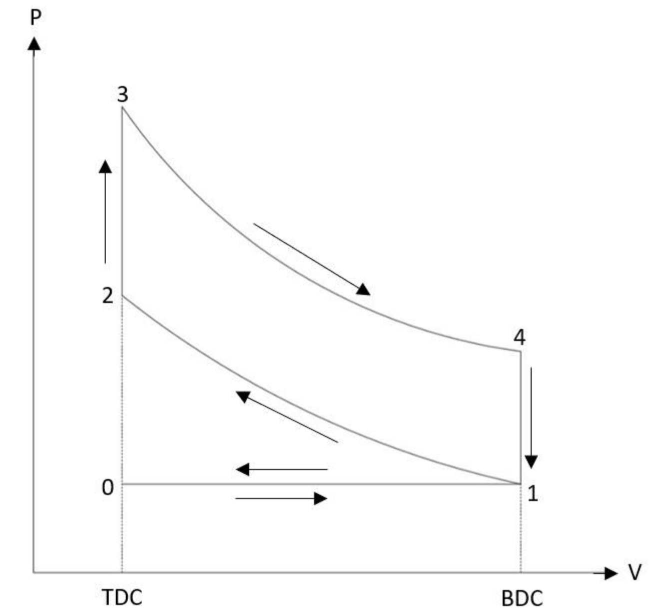

Fig.2- Otto Cycle

The Otto Cycle explains the working of the SI Engine by explaining the compression and expansion of the fuel in the combustion chamber i.e., the piston. The above diagram explains the working of a 4 stroke SI Engine as follows-

Process 0 – 1:- The first process of the otto cycle is the intake of air and fuel into the combustion chamber. This intake is known as the fuel-air mixture or the charge. As the piston starts to move from the Top Dead Centre (TDC) to the Bottom Dead Centre (BDC), the intake valve is opened, and the combustion chamber is filled with the charge by the time the piston reaches the BDC. This is known as the Suction or charging stroke and is the first stroke of the cycle.

Process 1 – 2:- The second process of the Otto cycle consists of the isentropic compression of the charge present in the combustion chamber. At the end of the first process, when the piston reaches the BDC, the inlet valve is closed. With the inlet and exhaust valves being closed, the piston starts to move from the BDC to the TDC. This leads to the compression of the charge which causes a decrease in its volume and an increase in its pressure as shown in the above diagram. This is known as the compression stroke and is the second stroke of the Otto cycle.

Process 2 – 3:- The third process of the otto cycle is the ignition of the charge with the help of a spark generated from the spark plug. At the end of the second process, the piston is located at the TDC, and the charge is in a compressed state at high pressure. The spark generated by the spark plug ignites the air-fuel mixture and this leads to the combustion of the fuel. As the volume remains constant, this process is an isochoric process and the pressure in the combustion chamber further increases.

Process 3 – 4:- The fourth process consists of the isentropic expansion of the charge in the combustion chamber. The high pressure at point 3 exerts a force on the piston which causes the piston to start moving from TDC to BDC. As the volume of the combustion chamber increases, the pressure in the combustion chamber is also relieved. The work is being done by the system on the piston. This process is known as the Expansion or the working stroke of the Otto cycle.

Process 4 – 1:- The fifth process deals with the rejection of heat generated in the combustion chamber to the surrounding media. This may be air or coolant depending on the power and the size of the engine being used. As the volume remains constant and the heat is rejected to the surroundings, this process is an isochoric process which leads to a decrease in the pressure in the combustion chamber.

Process 1 – 0:- The last process of the Otto cycle consists of removing the waste gases produced in the combustion chamber during combustion. During this process, the piston moves from the BDC to the TDC, and the exhaust valve is opened to facilitate the removal of waste gases from the combustion chamber. This process is known as the exhaust stroke and is the last stroke of the Otto cycle. [5]

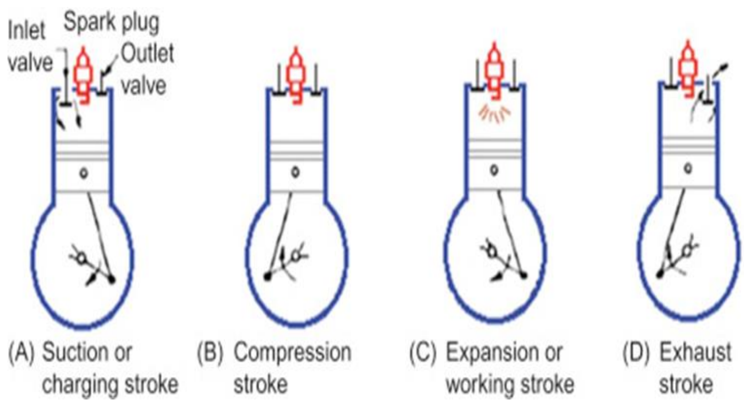

Fig.3- Working of a Spark-Ignition Engine [6]

2.2 Compression Ignition Engines

Compression Ignition Engines, also known as Diesel Engines, operate on the principle of the Diesel cycle explained below-

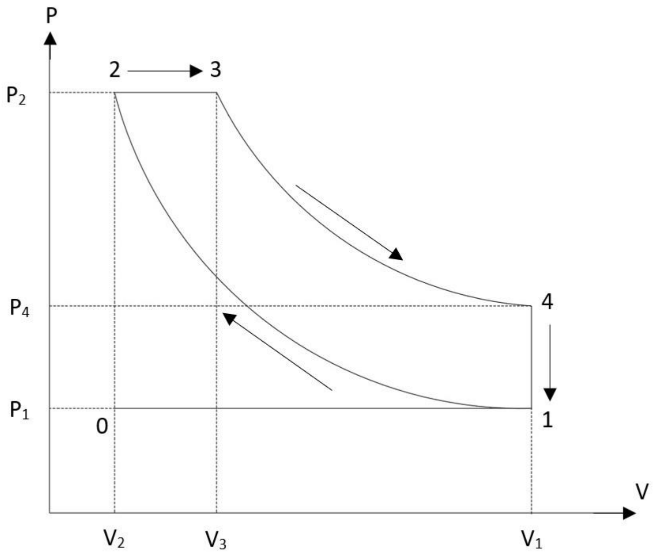

Fig.4- Diesel Cycle

Process 0 – 1:- The first is the intake of fresh air from the atmosphere into the combustion chamber. Unlike the Otto cycle, the intake in the diesel cycle consists of only air as compared to the air-fuel mixture of the Otto cycle. Similar to the Otto cycle, as the piston starts to move from the TDC to the BDC, the intake valve is opened, and the combustion chamber is filled with the air by the time the piston reaches the BDC. This is known as the Suction stroke and is the first stroke of the cycle.

Process 1 – 2:- The second process of the Diesel cycle consists of the isentropic compression of the air present in the combustion chamber. At the end of the first process, when the piston reaches the BDC, the inlet valve is closed. With the inlet and exhaust valves being closed, the piston starts to move from the BDC to the TDC. This leads to the compression of the charge which causes a decrease in its volume and an increase in its pressure as shown in the below diagram. At 2 or just before reaching 2, fuel is injected into the chamber from a fuel injector. This is known as the compression stroke and is the second stroke of the cycle.

Process 2 – 3:- As the fuel was injected into the combustion chamber, the hot and compressed air present causes the fuel to burn and combustion takes place. This leads to the transfer of thermal energy from the chemical process into the compressed gas in the chamber. Because of the energy released during combustion, the piston starts moving downwards. Thus, the volume of the chamber starts increasing and the pressure remains constant. This process is an isobaric process as the pressure remains constant during this process.

Process 3 – 4:- The fourth process consists of the isentropic expansion of the hot and compressed air in the combustion chamber. The high pressure at point 3 exerts a force on the piston which causes the piston to start moving from TDC to BDC. As the volume of the combustion chamber increases, the pressure in the combustion chamber is also relieved. The work is being done by the system on the piston. This process is known as the Expansion stroke of the Diesel cycle.

Process 4 – 1:- The fifth process consists of the decrease in the pressure of the combustion chamber. This abrupt decrease in pressure occurs as a result of the exhaust valve being opened at the end of the previous process. As the volume remains constant during the process, it is an isochoric process which leads to a decrease in the pressure in the combustion chamber.

Process 1 – 0:- The last process of the Diesel cycle is similar to that of the Otto cycle, and it consists of removing the waste gases produced in the combustion chamber during combustion. During this process, the piston moves from the BDC to the TDC to facilitate the removal of waste gases from the combustion chamber. This process is known as the exhaust stroke and is the last stroke of the Diesel cycle.

Internal Combustion engines can also be classified based on their 'method of charging', i.e., the means of providing the intake to the combustion chamber. They are of 2 types-

- Naturally Aspirated (NA) Engines
- Supercharged Engines

Naturally Aspirated engines are engines that are provided with air, in case of CI Engines, or air-fuel mixture, in case of SI engines, at or near the atmospheric pressure. A Supercharged Engine on the other hand is provided with intake at a higher pressure than the atmospheric pressure through the means of Turbochargers or Superchargers.

In order to meet the emission targets, set by the governing agencies, car manufacturers needed to reduce the CO2 emissions produced by their vehicles while also maintaining a similar level of power to drive the vehicle. The solution to this obstacle came in the form of 'Engine Downsizing'.

Downsizing is defined as the method of using a smaller engine in a vehicle which delivers a similar level of power to that of a larger sized engine, while providing better fuel efficiency and lesser emissions. The power output of an engine depends on the power generated through the combustion of the air or air-fuel mixture in the combustion chamber of the engine. This combustion is dependent on the amount of oxygen being pumped into the combustion chamber during the intake stroke. The higher the amount of oxygen, the higher the power that will be generated through combustion. By using technologies such as a turbocharger, air at higher pressure, and thus at higher densities can be pushed into the combustion chamber. Thus, even though the size of the engine would have been reduced, the use of these technologies helps in providing the required power output while also reducing the Greenhouse Gas emissions considerably.

In addition to using superchargers and turbochargers, technologies such as the Variable Valve Timing (VVT), Variable Valve Lift (VVL), Direct Injection (DI) and Exhaust Gas Recirculation (EGR) have been researched which have helped in facilitating even better gains from using a downsized engine as compared to a naturally aspirated one.
Research conducted by Aaron Isenstadt et al.[6] has shown the benefits in fuel consumption by using the downsizing techniques listed above. They are summarized in the table given below-

Table 1:- Study conducted by Aaron Isenstadt[7]

	NAS 2002	NHTSA 2008-2011	EPA/NHTSA 2017-2025
GDI	4-6%, n/a	1-3%, $200-250	1-3%, $164-296
Turbo	5-7%, $350-560	3-6%, $116-262	0-6.5%, $118-133
VVT	2-3%, $35-140	2-3%, $36-146	1-5.5%, $31-124
VVL	1-2%, $70-210	1-2% $73-218	2.8-4.9%, $99-296
CVA	5-10%, $280-560	5-10%, $291-582	-
Higher volt.*	1-2%, $70-280	1-2%, $73-291	12.1-24.6%†, $310-1307

Notes: GDI = Gasoline Direct Injection. VVT = Variable Valve Timing. VVL = Variable Valve Lift. CVA = Continuous Valve Actuation. *NAS/NHTSA 2008-2011 considered 42V systems, EPA/NHTSA 2017-2025 considered >42V systems. † Higher pressure turbos generate the highest fuel consumption reductions, but with cooled EGR.

3. HYBRID POWERTRAINS

The advancements that have been made in the Internal combustion engine technologies to limit emissions and improve fuel efficiency have been significant. However, in order to further limit emissions, manufacturers have been looking at electric energy as a source to power our vehicles since 1990's and the early 2000's. Instead of completely replacing the Internal combustion engine with an electric motor, however, they have found a way to combine both the IC Engine as well as the electric motor into one package. These vehicles equipped with both an internal combustion engine and an electric motor are known as the Hybrid Vehicles.[9]

Thus, a Hybrid Electric Vehicle (HEV) can be defined as a combination of the traditional Internal combustion engines and the electric motors. In HEV's, both the IC Engine and the electric motor are used to power the vehicle. Based on the ratio of the power provided by the electric motor to the sum of the power provided by the IC Engine and the electric motor, HEV's are classified into different types. This Ratio is known as Hybridisation Ratio or Degree of Hybridisation.

Classification according to the Hybridisation ratio

3.1 Micro Hybrids

Micro hybrids can be defined as vehicles that consist of a small electric motor which only serves the purpose of providing some functionalities to the vehicle such as the start stop system. The micro hybrid is not a hybrid in the actual sense of the word. It is only classified as a hybrid owing to the electric motor present in the vehicle.

3.2 Mild Hybrid

Mild Hybrid vehicles are vehicles with an electric motor that provides such as start-stop and also utilizes regenerative braking to recharge the batteries. The start-stop function allows the vehicle to shut down the IC Engine when the vehicle is coasting or when the vehicle is stopped at a traffic light. While the coasting, the engine would be shut off and the speed would be maintained by using the electric motor mounted in the vehicle. When the driver would want to increase or decrease the speed, the IC Engine would start again, and the electric motor would be shut off. During braking, the electric motor will have the capability to convert the kinetic energy from the wheels into electric energy to recharge the battery.[9]

Sometimes the motor might also be used for directly powering the wheels of the vehicle when extra power or extra traction is required. This was the case for the Mazda Demio. The front wheel drive vehicle has the front wheels powered by the IC while the rear wheels are powered by the motor.[10]

3.3 Full Hybrid

A vehicle is classified as a full hybrid when the vehicle has the capability to run solely on the IC Engine, solely on the Electric Motor, or run as a combination of both the IC Engine and the Electric motor. As compared to the mild hybrid, a full hybrid consists of a larger electric motor and a much larger battery pack. A full hybrid provides all the advantages of the mild hybrid, while also being able to be run on electric only power for a specified distance and within a specific speed limit. This system helps in the increasing the range of the vehicle as the power is being provided by a combination of the IC Engine and the Electric motor. This also helps in reducing the wear and tear of the IC Engine as the load on the engine is significantly reduced.[9]

3.4 Plug-In Hybrid

Plug-in Hybrids can essentially be described as a Full Hybrid with the capability to be plugged in and its battery to be charged from an external source. As the battery can be charged externally, the battery in PHEV's is generally larger than that in a Full hybrid. This helps in further increasing the range of the vehicle as the battery is not restricted to only being charged while driving the car or through regenerative braking. The size of the battery pack does not necessarily have to be larger than that in the full hybrid. It depends on the space available in the vehicle. A very small battery would only provide incremental gains while a very large battery would not only cost a lot, but also increase the weight of the vehicle substantially.[9]

Hybrid vehicles can further be classified based on the design of the powertrain, i.e., the arrangement of the IC Engine and the Electric Motor/Generator in the vehicle.

Classification based on design of powertrain

3.5 Series Arrangement

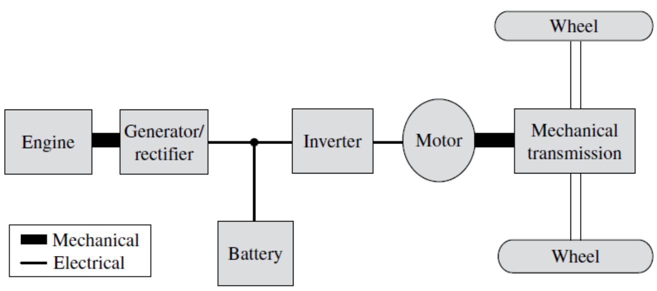

Fig.5- Series Architecture of Hybrid Vehicles[9]

In the series arrangement of hybrid vehicles, the wheels are powered by the electric motor instead of the engine. The role of the engine is to convert the chemical energy generated by the combustion of the fuel in the combustion chamber into mechanical energy. However, instead of being coupled to the wheels as is the case in traditional vehicles, in the series arrangement, the output from the engine is provided into a generator to convert the mechanical energy into electrical energy. This electrical energy is the used to drive the electric motor, which in turn drives the transmission and hence drives the wheels of the vehicle. Electrical energy may also be provided to the motor through the means of a battery.[9]

An advantage of the series architecture lies in the fact that the engine is not directly powering the wheels of the vehicle. Thus, the engine speed does not affect the speed of the vehicle directly. This allows the engine to be run at an optimum speed independent of the speed of the vehicle which allows for better fuel efficiency and hence may help in increasing the range of the vehicle.[9]

The power modes that the series architecture can operate in are as follows-

Engine Only Mode- At Moderately high-power demand of the vehicle, for example while cruising, the inverter and generator of the vehicle would be turned on and the energy generated by the engine would be directly used to power the vehicle. The battery of the vehicle would not be utilized, and it would neither discharge nor recharge as the State of Charge (SOC) of the battery is very high.

Battery Only Mode- During periods of low power demand, the battery would be the one powering the wheels of the vehicle and the engine would be shut off. Th battery would provide electrical energy to the motor which would in turn power the wheels of the vehicle.

Combined Mode- When the power demanded by the vehicle is very high, both the engine and the battery would be activated and power from both sources would be utilized to power the wheels of the vehicle.

Split Mode- When the power demanded by the vehicle is so low that the power generated by the engine would be more than the required amount of power, and the SOC of the battery pack is also low, then some amount of electrical energy generated by the engine would be used to recharge the battery and the rest of the power would be used to power the vehicle.

Stationary Charging- When the engine of the vehicle is turned on and the vehicle is not moving or is standing idle, then the energy generated by the engine would be used to charge the battery of the vehicle while the vehicle is in the idle state. Thus, it is known as Stationary Charging mode.

Regenerative Braking- When the vehicle is braking, the electric motor that was previously providing electricity to the wheels would be used as a generator to convert the kinetic energy of the wheels into electrical energy which would be used to charge the battery of the vehicle.

3.6 Parallel Arrangement

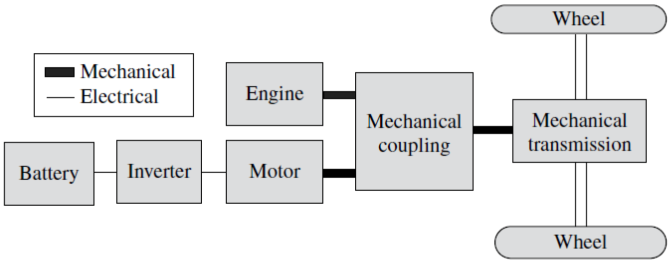

Fig.6- Parallel Architecture of Hybrid Vehicles[9]

In contrast to the Series arrangement, both the engine and the electric motor can be used to provide energy to the wheels of the vehicle. This can be done either in the combined power mode or both, the engine, and the electric motor, can supply energy to the final drive independent of each other.

The engine and the electric motor are connected using connecting mechanisms such as gears or belts in the mechanical coupling to combine the power obtained from each source. As compared to the series architecture, the parallel arrangement needs only two propulsion devices namely, the Internal Combustion Engine and the Electric Motor. The generator to convert the mechanical energy obtained from the engine into electrical energy is not required in case of the parallel architecture. The power modes of the parallel architecture can be explained as follows-[9]

Engine Only Mode- Similar to the series architecture, at moderately high-power demand, the engine of the vehicle would be turned on and it would directly provide the mechanical energy generated through combustion in the engine to the wheels for propulsion. The battery of the vehicle would not be utilized, and it would neither discharge nor recharge as the State of Charge (SOC) of the battery is very high.

Battery Only Mode- During periods of low power demand and high battery SOC, the battery would be the one powering the wheels of the vehicle and the engine would be shut off. Th battery would provide electrical energy to the motor which would in turn power the wheels of the vehicle.

Combined Mode- When the power demanded by the vehicle is very high, both the engine and the battery would be activated and power from both sources would be utilized to power the wheels of the vehicle similar to that in the series architecture.

Split Mode- When the power demanded by the vehicle is so low that the power generated by the engine would be more than the required amount of power, and the SOC of the battery pack is also low, then some amount of mechanical energy generated by the engine would be converted by the electric motor, acting as a generator, into electrical energy which would be used to recharge the battery and the rest of the power would be used to power the vehicle.

Stationary Charging- When the engine of the vehicle is turned on and the vehicle is not moving or is standing idle, then the energy generated by the engine would be used to charge the battery of the vehicle while the vehicle is in the idle state. The mechanical energy would be converted into electrical energy through the electric motor acting as a generator. Thus, it is known as Stationary Charging mode.

Regenerative Braking- When the vehicle is braking, the electric motor that was previously providing electricity to the wheels would be used as a generator to convert the kinetic energy of the wheels into electrical energy which would be used to charge the battery of the vehicle.

3.7 Series-Parallel Arrangement

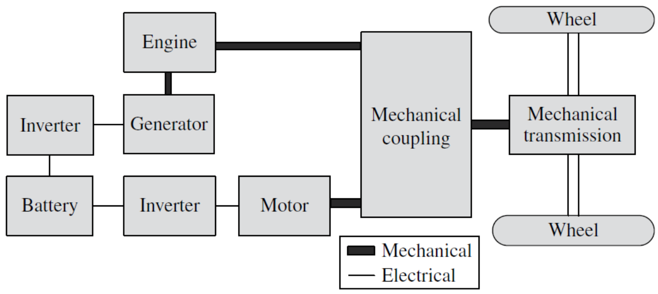

Fig.7- Series – Parallel Architecture of Hybrid Vehicles[9]

In the Series – Parallel arrangement of the powertrain in hybrid vehicles, the features of both, the series arrangement and the parallel arrangement are provided to the vehicle. In this arrangement, the engine and the motor are linked together using a mechanical coupling consisting of either gear or pulleys, which provides energy to the wheels to drive the vehicle. However, the engine is also attached to a generator which can be used to convert the mechanical energy generated from the engine into electrical energy and provide this electrical energy to the motor through an inverter. This is similar to the setup of the series arrangement. Thus, the features of both the series arrangement and the parallel arrangement can be observed here.

Thus, this arrangement can be utilized as a series or a parallel arrangement depending on the power requirement of the vehicle at any given instant. However, the increased complexity and components add to the manufacturing cost and thus, a series - parallel architecture hybrid vehicle is generally costlier than a sole series or parallel hybrid vehicle. An advantage of this setup is the increased fuel efficiency and drivability of the vehicle.[9]

The Hybrid vehicles that are or have been in production utilize planetary gears and multiple motors to facilitate their hybrid setups. Some of these production vehicles and their setups are being discussed below.

Hybrid Powertrain Technologies in Production

3.8 Toyota Prius and Ford Escape Powertrain

The Toyota Prius is one of the best-selling hybrid vehicles. Its success was based on the powertrain developed by Toyota to power the Prius and it is based on the series – parallel architecture discussed above. The Ford Escape Hybrid Vehicle also uses a similar powertrain and it can be seen in the image provided below.

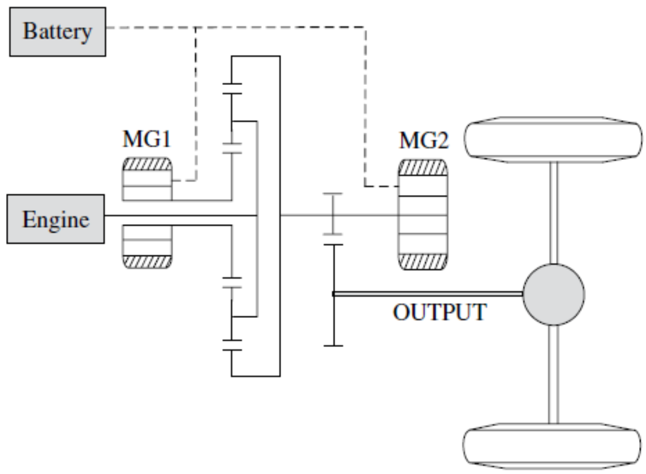

Fig.8- Toyota Prius and Ford Escape Powertrain[9]

In the above diagram, it can be observed that a planetary gear is present in the powertrain. The engine is connected to the carrier of the planetary gear. The electric motor (MG2) is connected to the ring gear of the planetary gear setup as well as directly connected to the final drive of the vehicle enabling it to provide energy directly to the wheels of the vehicle. A generator (MG1) is connected to the sun gear of the planetary setup and a battery is connected to the generator as well as the electric motor to facilitate the charging and discharging of the battery as and when required. Note that there is no clutch present in this setup and thus the planetary gear is always rotating whenever the vehicle is in motion.[9]

This powertrain consists of 4 driving modes as follows-

Launch and Reverse Mode- During the launch of the vehicle and reversing the vehicle, the power to the wheels will be provided only through the electrical energy stored in the battery. The engine will be shut down and the battery and electric motor will handle the power demand as the power demanded during launch and during reversing is very low.

Cruising or Normal Acceleration Mode- When the vehicle is cruising or is accelerating at a constant rate, the powertrain will run in the power split mode as discusses above. The mechanical energy generated by the engine is split where the energy is used to drive the wheels as well as being converted by the generator to electrical energy to power the electric motor. The amount of energy to be provided by the motor is determined by the difference between the total torque that has been demanded by the vehicle and the total torque being provided by the engine in the high efficiency setup.

Sudden Acceleration Mode- When there is a sudden or high demand of power from the vehicle, the powertrain operates in the same manner as that in the normal acceleration mode. However, instead of the electrical energy provided to the electric motor being only from the generator, the battery also provides energy to the motor to meet the high-power demand of the vehicle.

Regenerative Braking- During braking, the electric motor acts as a generator and converts the kinetic energy of the wheels into electric energy to charge the battery, while also slowing down the vehicle.

The Toyota Prius provides high mileage and fuel efficiency figures while also emitting less Greenhouse Gases as compared to a similarly priced Gasoline vehicle. For example, the 2016 Toyota Corolla provides a mileage of 31 mpg compared to the 52-mpg provided by the Toyota Prius. That is 67.5% higher than the mileage of the Corolla. The tailpipe emission figures also favour the Prius with the Prius emitting 170 grams of CO2 per mile whereas the Corolla emits 282 grams of CO2 per mile. Thus, the Prius emits 39.7% less CO2 than the Corolla. [11]

3.9 GM Two-Mode Hybrid Transmission

The GM Two-Mode Hybrid Transmission was developed jointly by GM, BMW, Chrysler, and Mercedes-Benz in 2005. The setup is given below-

The setup consists of 2 planetary gears denoted by P1 and P2, and 3 clutches denoted by C1,C2,C3 respectively. The engine is connected to the ring gear of P1. The Electric Motor MG1 is connected to the sun gear of P1 and the carrier of P1 is connected to the wheels of the vehicle. The electric motor MG2 is connected to the sun gear of P2 and the carrier of P2 is also connected to the wheels of the vehicle. Using 2 clutches C2 and C3, the ring gear of P2 can either be connected to the ground or to the shaft of the Electric motor MG1. The battery is connected to the electric motors MG1 and MG2.[9]

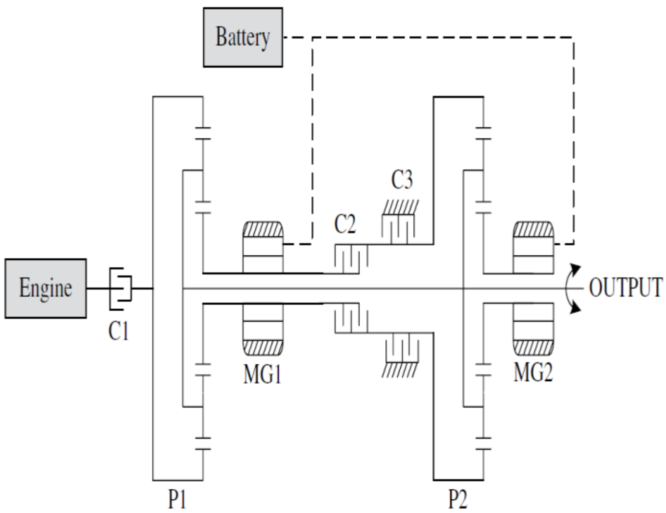

Fig.9- GM Two-Mode Hybrid Transmission[9]

The operating modes of this transmission are explained as below-

Launch and Reverse Mode- Similar to the Toyota Prius powertrain, during vehicle launch and reverse, only the electric motor are utilised to provide energy to the wheels of the vehicle. The clutch C2 is kept in an open position and the clutch C3 is utilised to ground the ring gear of the planetary gear P2. The battery provides electrical energy to the electric motors MG1 and MG2. The electric motor MG1 does not rotate the output shaft and instead provides the electrical energy in the form of mechanical energy to the engine. The electric motor MG2 is responsible for driving the wheels of the vehicle during launch and reverse.

Low range Mode- In this mode, the Engine clutch C1 is engaged and the clutch C3 is engaged. This mode consists of various setups as follows-

- **Engine Alone (CVT 1)-** In this mode, the electric motor MG2 is turned off. The electric motor MG1 can work either as an electric motor or as a generator in this mode. When MG1 is acting as a motor, P1 helps to combine the speed of the engine and the electric motor MG1. When MG1 is acting as a generator, the power output of the engine is split and some of it is utilised to drive the wheels while the rest of it is used to charge the battery.

- **Combined Mode (CVT 2)-** In this mode, MG2 is turned on and it helps in combining the power from the engine and MG2. The Electric motor MG1 might also work as an electric motor which would help provide maximum output from the powertrain.

- **Power Split Mode (CVT 3)-** In this mode, MG2 acts as a generator to charge the battery and MG1 can be utilised either as a motor or as a generator depending on the power requirement.

High Range Mode- In the High range mode, in order to maximise range, C1 and C2 are engaged and C3 is open. As C2 is engaged, the sun gear of P1 is connected to the ring gear of P2 and they rotate at the same speed as the electric motor MG1. The engine is rotating at a constant speed and MG1 and MG2 are controlled to work either as electric motors or as generators depending on the power required by the vehicle. This mode ensures the highest range possible based on the power demand of the vehicle.

Regenerative Braking- During Braking, the clutches C1 and C2 are kept open while the clutch C3 is engaged. This results in the engine and MG1 not being connected to the shaft and the ring gear of P2 to be grounded. MG2 acts as a generator and converts the kinetic energy of the wheels into electrical energy, which is then used to charge the battery, while producing the braking torque for the vehicle.[9]

4. ELECTRIC POWERTRAINS

An electric vehicle, also known as a Battery Electric Vehicle (BEV), may be defined as a vehicle that is powered by electricity provided by a rechargeable battery on-board the vehicle. As compared to the Hybrid Electric Vehicles, BEV's do not have an engine mounted in the car. All of the energy required for propulsion of the vehicle is provided in the form of electrical energy from batteries.

With the recent attention towards the climate change in the past decade, manufacturers have started shifting their focus towards the development of Electric Vehicles, as they seem to solve the huge negative impact that conventional IC Engine Vehicles pose to the efforts being made to control Global Warming. Thus, Electric vehicles have been gaining traction over the past few years and the impact can be seen in the report titled 'Global EV Outlook 2021' published by the International Energy Agency (IEA).

As can be observed from the above diagram, there has been a steady increase in the electric car registrations around the world in 2020. The study shows an increase of 41% in 2020 under the circumstances of the Covid-19 Pandemic, which has shown a 16% decrease in global car sales in 2020. This suggests that people are leaning towards purchasing electric cars over conventional IC engine vehicles. The report also stated that in the first-quarter of 2021, global electric car sales rose by around 140% compared to the same period in 2020. This shows the ever-increasing demand of electric cars in today's automobile market.[13]

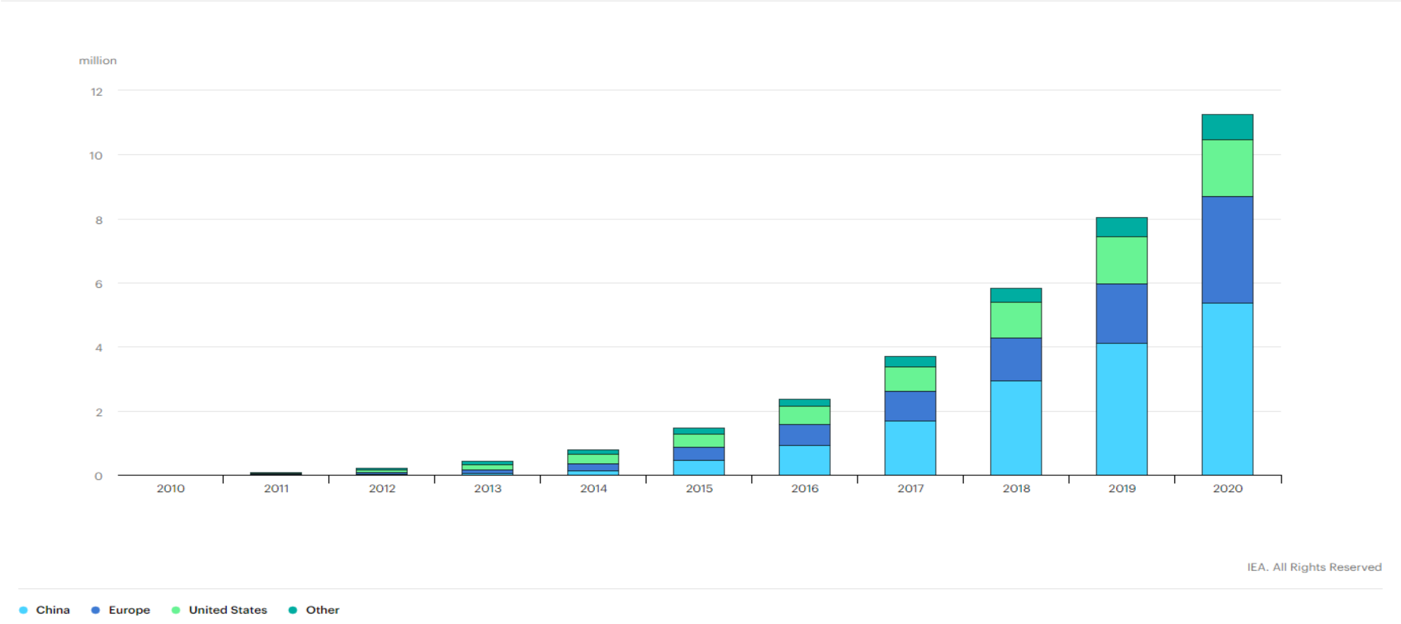

Fig.10- Global electric vehicle stock by region, 2010-2020 [12]

At the forefront of the electric car development for the past few years has been Tesla, who are currently the world leader in electric car manufacturing. [14] Tesla have surpassed the milestone of selling 1 million Electric Vehicles in March 2020, with their Tesla Model 3 being the highest selling electric car in the world with more than 1 million units sold worldwide.[15]

4.1 Key Components and Working of an Electric Vehicle

The most important components of an electric vehicle are as follows-

Battery- The battery Is the main energy storage system of the vehicle. The main purpose of the battery is to provide electrical energy to the electric motor which drives the wheels of the vehicle.

Charging Port and Charger- The charging port is location on the vehicle where an external power supply is connected in order to charge the vehicle. The onboard charger helps in converting the incoming electricity from AC to DC in order to charge the batteries of the vehicle.

Transmission- The transmission is responsible for transferring the mechanical energy received from the electric motor into the wheels and thus converting it into kinetic energy.

Electric motor- The electric motor, along with the battery pack, is the most important component of an electric vehicle. The electric motor is responsible for driving the wheels of the vehicle. The motor receives electrical energy from the battery and converts it into mechanical energy which it then provides to the wheels. These electric motors can also be used in the form of generators to facilitate the principle of regenerative braking which has been discussed earlier in this paper.

Battery (Auxiliary)- The auxiliary battery is responsible for powering the accessories of the vehicle such as the infotainment system, the air conditioning, etc.

DC-DC Converter- The DC-DC Converter converts the high voltage electricity of the battery pack into low voltage electricity which is then used to power the vehicle electronics and also recharge the auxiliary battery.

The working of an electric vehicle can be explained based on the working of the above-mentioned components. First, the battery pack is charged from electricity obtained from an external power source. This electricity obtained from the external power source is first converted from AC to DC by the charger and is then utilized to charge the battery. The battery then provides electrical energy to the electrical motor in order to power the wheels. The electric motor converts the incoming electrical energy into mechanical energy and feeds it into the transmission. The transmission facilitates the distribution of the mechanical energy obtained from the motor to the wheels of the vehicle.[16][17]

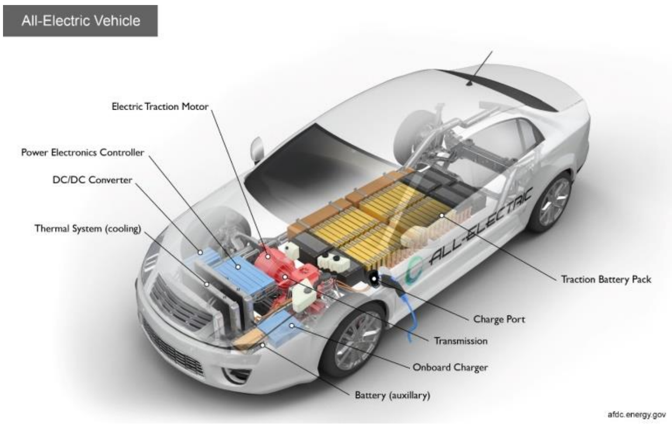

Fig.11- Components of an Electric Car[16]

4.2 Battery Technology in Electric cars

4.2.1 Lithium-ion Batteries

The most commonly used batteries for electric vehicles is the lithium ion (Li-ion) battery. Lithium ions travel from the negative electrode to the positive electrode and vice-versa during the charging and recharging phases of the battery. Generally, Li-ion batteries have cathodes made of Lithium Cobalt Oxide and Anodes made of Carbon in the form of Graphite.[19] Other materials for the cathode are also being researched such as Lithium Magnesium Oxide, which is the typical substance used in batteries for electric and hybrid electric vehicle applications, and Lithium Iron Phosphate, which has recently seen an increase in research being done due to the shortage of rare metals such as cobalt.[18]

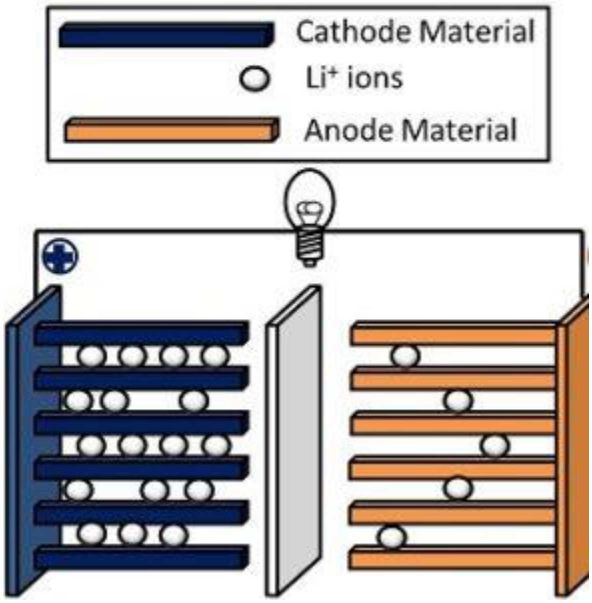

Fig.12- Schematic of a Li-ion Battery[18]

During the discharge cycle, the lithium atoms present at the anode are ionized and they are converted to Li+ ions. These Li+ ions then travel through the electrolyte in the battery to the cathode. When they reach the cathode, they once again from Lithium atoms. During the charging cycle, these Lithium atoms present at the cathode move through the electrolyte and back to the anode. The electrolyte used on these cells is generally of the organic type known as ether.[18] In order to form the large battery packs that are used in vehicles, smaller cells are combined such that they function as a large battery pack instead of making a larger cell.

Lithium-ion batteries are so abundantly in use as they offer a variety of advantages. Firstly, they have very high energy densities as compared to other battery technologies. They also require low maintenance and have only around 1.5-2% self-discharge rate per month. They also do not suffer from memory effect. These factors have made Li-ion batteries the most abundantly used batteries in the world.[18]

However, these advantages also come with disadvantages. Li-ion batteries are known to tend to overheat, which may lead to fires. The fumes emitted by such fires are flammable as well as toxic and can cause serious damage.[20] The extraction of lithium from the earth has also been known to be a cause of water contamination and leads to the production of by products such as large amounts of magnesium and lime waste.[21] The rare metals required for the manufacturing of Li-ion batteries such as nickel and cobalt have also been running low and this could lead to an increase in price of Li-ion batteries in the coming years.

4.2.2 Sodium-ion Batteries

In order to overcome these disadvantages of Li-ion cells, there has been a lot of development being made in the technology of Sodium-ion (Na-ion) cells. Sodium-ion cells work on a similar principle as that of the Lithium-ion cells. The difference between the 2 technologies is that Na-ion cells use a sodium-based cathode as compared to a lithium based one. Also, the anode cannot be made of graphite as graphite would be unable to store the sodium ions in appreciable quantities. To combat this, a carbon bases element known as hard carbon is being researched.[22]

As compared to the Lithium-ion cells, the sodium-ion cells are a little bit expensive and are not as energy efficient. However, with the ongoing research in hard carbon anodes and the potential of li-ion battery costs to increase over time as a result of shortage of raw materials, sodium-ion batteries may very well be able to replace the li-ion batteries in all commercial applications. One of the biggest advantages of Na-ion cells stems from the fact that Na-ion cells can be stored at 0 Volts as compared to the Lithium-ion cells. This helps in alleviating the safety problems of the lithium-ion cells as Na-ion cells would be able to be transported in large quantities while being stored at 0 volts which would help prevent the chance of fire.[22][23]

5. CONCLUSION

Automotive Technology has come a long way since researchers started looking for ways to reduce the impact of the transportation sector to Global Warming. Hybrid electric vehicles were introduced with technology that helped in increasing the mileage and efficiency of vehicles, while also reducing the Greenhouse Gas emission from these vehicles. Building on the foundation laid by Hybrid vehicles, Electric vehicles were developed which run solely on electric power and hence do not emit any gases at all. These electric cars have been rising in popularity and this can be observed with most of the car manufacturers planning to introduce electric cars as part of their fleet as soon as possible. Research is also being done to develop alternative solutions for the battery to be used in electric vehicles as lithium and other rare metals are getting scarce which may lead to an increase in price of battery packs, and thus an increase in price of electric vehicles, in the near future.

REFERENCES

[1] https://www.nrdc.org/stories/global-warming-101#causes
[2] Industrial Revolution | Definition, History, Dates, Summary, & Facts | Britannica
[3] Global Warming: Causes, Effects and Solutions by Umair Shahzad, University of Nebraska at Lincoln
[4] Greenhouse Gas Emissions from a Typical Passenger Vehicle | US EPA
[5] Heywood, J. (2018). Internal Combustion Engine Fundamentals 2E
[6] Krzysztof Jan Siczek, in Tribological Processes in the Valve Train Systems with Lightweight Valves, 2016
[7] Downsized, boosted gasoline engines; Aaron Isenstadt and John German (ICCT); Mihai Dorobantu (Eaton); David Boggs (Ricardo); Tom Watson (JCI)
[8] http://data.giss.nasa.gov/gistemp/graphs/
[9] Hybrid Electric Vehicles- Principles and Applications with Practical Perspectives; Chris Mi and M. Abul Masrur
[10] https://newsroom.mazda.com/en/publicity/release/2003/200311/1127e.html
[11] https://www.fueleconomy.gov/
[12] IEA, Global electric vehicle stock by region, 2010-2020, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-electric-vehicle-stock-by-region-2010-2020
[13] IEA (2021), Global EV Outlook 2021, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2021
[14] Newest CAM study shows Tesla as EV sales leader - electrive.com
[15] https://cleantechnica.com/2020/03/10/tesla-passes-1-million-ev-milestone-and-model-3-becomes-all-time-best-seller/
[16] https://afdc.energy.gov/vehicles/how-do-all-electric-cars-work
[17] Cheng, K.W.E. (2009). Recent development on electric vehicles. 2009 3rd International Conference on Power Electronics Systems and Applications, PESA 2009. 1 - 5.
[18] Lithium-Ion Battery - Clean Energy Institute (washington.edu)
[19] Science and Applications of Mixed Conductors for Lithium Batteries - Michael M. Thackeray, John O. Thomas, and M. Stanley Whittingham
[20] Willstrand, O., Bisschop, R., Blomqvist, P., Temple, A., & Anderson, J. (2020). Toxic Gases from Fire in Electric Vehicles.Retrievedfrom http://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-52000
[21] Amui, Rachid (February 2020). "Commodities At a Glance: Special issue on strategic battery raw materials". United Nations Conference on Trade and Development.
[22] Peters JF, Peña Cruz A, Weil M. Exploring the Economic Potential of Sodium-Ion Batteries. Batteries. 2019; 5(1):10. https://doi.org/10.3390/batteries5010010
[23] The Scale-up and Commercialization of Nonaqueous Na-Ion Battery Technologies - Bauer, A., Song, J., Vail, S., Pan, W., Barker, J., Lu, Y., Adv. Energy Mater. 2018, 8, 1702869. https://doi.org/10.1002/aenm.201702869