Abstract: Scarcity of Fossil Fuels which leads to increase in cost of fuel, this is affecting the automotive industries very badly. This is the major concern, because of which major automotive companies are shifting towards new emerging technology. The new emerging technology is of Vehicles which are not using fossil fuels rather they are making use of electricity. Electricity is available in many different forms. In this paper, comparisons between various vehicles are carried out which are not using any kind of fossil fuels for their operation. Electrically operated vehicles such as Electric Vehicles (EVs), Electric Hybrid Vehicles (EHVs) and Fuel Cell Hybrid Vehicles (FCHVs) are discussed. The operation or performance of electricity operated vehicles vastly depends on it Energy Storage System (ESS) This paper also represents various energy storage techniques. After the detailed study of every electrically operated vehicle it is found that every vehicle is having some merits and demerits depending on the performances requirement and applications.

Keywords: Electric Vehicles (EVs), Electric Hybrid Vehicles (EHVs), Fuel Cell Hybrid Vehicles (FCHVs) and Plug-in Hybrid Vehicles (PHVs), Ultra-Capacitors (UCs) and Energy Storage System (ESS).

I. INTRODUCTION:

The fossil fuels are on the verge of extension. In near future of about 100 years, near about 90% of the fossil fuels will get extinct. As per the World Oil and Gas Review 2015; BP Statistical Review of World Energy 2015, report the three major sources viz, coal, Natural and Gas are going to extinct in near future [1]-[4]. The following fig. 1. represents the amount of fossil fuel reserves around the world.

![Fossil Fuel Reserves](http://www.eniscuola.net/en/mediateca/fossil-fuels-world-reserves/)

Fig: 1. Fossil Fuel Reserves

The major consumptions of fossil fuels are in automotive sectors and within next 50 years the number of automotive vehicles will reach a count of 3 billion which is the major sector responsible for emission of Green house gases and are responsible for hazardous environmental conditions.

To overcome all the unnecessary conditions, the major automotive vehicle manufacturers are coming up with new emerging technology related with electricity operated vehicles. As the invention of electricity operated vehicles are not new. The first electricity operated vehicle was invented way back in 1800 century. But due to lack to technology and resources, it was unable to compete with the IC Engine Vehicles [2]-[6].

The major issue with the electrically operated vehicles was the performance. The issues with these vehicles were speed, power and long distance journeys. As the time passes, the new technologies were developed in the field of electrically operated vehicles and the above issues are now minimized. The various types of electrically operated vehicles such as Electric Vehicles (EVs), Electric Hybrid Vehicles (EHVs), Fuel Cell Hybrid Vehicles (FCHVs) and Plug-in Hybrid Vehicles (PHVs) are developed. The performance of each vehicle depends on the energy storage capacity. The major
characteristics of energy storage systems (ESS) include power density, energy density, cost, maintenance and life. Currently, the combination of batteries and ultra-capacitors (UCs) are the most common options for electrically operated vehicles which achieve major characteristics required for any electrically operated vehicle.

In case of Plug-in Hybrid vehicles, there is a need of reinforcement of low-voltage grids and till now for which infrastructure is not ready to give power to a large number of Plug-in Hybrid vehicles. The system is still not that much matured to apply this system throughout. Also, intelligent system is needed to make the communication happen between the grid and the vehicle. The success of Vehicles-to-Gird (V2G) largely depends on the consumer’s approval. All with difficulties, there are few working models in some of the countries where they are using Plug-in Hybrid vehicles and they are quiet successful in running it [39].

II. Electric Vehicles & Electric Hybrid Vehicles

Electric Vehicles (EVs) are those vehicles which are using some kind of electric motor or traction motor for Propulsion. The operation of these electric motors is carried out with Batteries, which are important component and majorly responsible for the performance of the electric vehicle. In Electric Vehicles (EVs), operation of Electric motor propulsion purely fully depends on battery. Electric vehicles (EVs) run only on electricity. Most of them can run from 80 to 100 miles, while a few advanced models can run upto 250 miles. Now, due to advancement in the battery technology, it takes few minutes (upto 30 minutes) to charge a battery earlier it took up to nearly a full day (with Level 1 charging) to recharge it, depending on the type of charger and battery [4]-[10]. The fig.2 shows the block diagram of electric vehicle.

![Fig.2. Block Diagram of Electric Vehicle](https://www.omicsonline.org/open-access/electric-vehicles-and-driving-range-extension--a-literature-review-2167-7670-1000154.pdf)

Electric hybrid vehicles (EHVs) are the combination of IC (Internal Combustion) engines and electric motors. These kinds of vehicles are configured in such a way to achieve the objectives like improved fuel efficiency, increase in power and additional power for the necessary electronic components. In EHV, Gasoline is the main source of energy and IC engine is the main power driver for the vehicle. As mentioned, electric motor will improve the system efficiency and reduces fuel consumption by using kinetic energy during course of regenerative braking and also it optimizes the IC engine operation by regulating the engine torque and speed. These provide the better advantage over the pure electric vehicles (EVs).

Mainly there are two types of Electric hybrid vehicles (EHVs) available, one is Series EHV and the second is Parallel EHV. The basic difference between the two is the connection of engine and motor. If the IC engine and electric motor are parallel then it is Parallel EHV and if IC engine and electric motor are in series then it is Series EHV as shown in the below diagram [21]. The fig.3 shows the block diagram of Series and Parallel electric hybrid vehicle.

![Fig.3. Block Diagram of Series and Parallel Electric Hybrid Vehicle](a)
The performance of these vehicles largely depends on the selection of battery for suitable applications. There are various types of batteries that can be used for these vehicles. Before selecting a proper type of batteries, characteristics like energy density, power density, compact size and reliability should be checked [3]. Following are major types of batteries that are used in Electric Vehicles & Electric hybrid vehicles:

1. **Lead Acid Batteries:**
   This type of batteries is most commonly used in earlier electric vehicles in late 1800 century. The lead acid battery technology is known to all and quiet matured technology. In this battery, lead acts negative electrode (Cathode) and lead oxide acts as positive electrode (Anode) and the diluted sulfuric acid as electrolyte. The automobile industries started the experimentation with the lead acid batteries intensively in early 1900 century. Lead acid batteries were used as a starter for the IC engines through electric motor starter. It was a simple experiment of using 12V lead acid battery for providing some of the functions to vehicles like to key start the cold engine and providing power supply to the parking lights. Further, the 48V lead acid battery power supply came into existence and used for supplying power from electric machines to the vehicle transmission system. The advantage of 48V battery was that, the power rating has gone up from 2-3.5kW to 7-11kW. This helps in reducing the CO\(_2\) emission and improved fuel efficiency of the vehicle [12].

   Currently, lead acid batteries are extensively used for ignition, starting and lightning (ISL) purpose and sometimes also called as ISL batteries or starting, ignition and lightning (SIL) batteries. The anticipated annual world market for these batteries in 2010 was nearly about 38 billion. The following fig.4 shows the market capital for lead acid batteries upto 2020.


   The application of lead acid battery is widely used in E-bikes. China is the main user of these lead acid batteries. It is estimated by that in china 95% of the E-bikes are powered by the lead acid batteries [13].

   The basic problems with the lead acid batteries are their bulkiness and low power and energy densities due bulk lead collectors. These batteries have poor specific energy (upto 34 Wh/kg) [14]. Though, this problem can be solved by using noncorrosive light weight collectors. Also, these batteries are not suitable to discharge below 20% of their rated capacity [3]. Above this, most of these batteries are not suitable for fast charging (it takes 14-16 hours time for charging). Low charging state causes sulfation that causes poor performance [6]. Due to the some of the above major demerits, the inventions of more efficient batteries took place.
2. **Nickel-Metal Hydride (Ni-MH) Batteries**

It consists of Nickel Hydro-oxide as positive electrode (Anode) and the negative electrode (Cathode) consists of an alloy of vanadium, titanium, nickel, and other metals. The main advantage of these batteries is that its energy density is twice to that of Lead acid batteries. This reduces the weight which leads to reduced energy cost. Also the size required size of the battery is less compare to lead acid battery [14]. The fig.5 shows the constructional features of Nickel-Metal Hydride (Ni-MH) Battery.

Ni-MH batteries are highly robust, can handle high temperature (from -50°C to 70°C) and they are fast charging batteries. In China, all the E-vehicles are manufactured with Nickel-Metal Hydride batteries. Apart from this, Nickel-Metal Hydride batteries are replacing lead acid batteries in many applications like in case of Telecommunications (as Power Backup), in many Bus Transportation and in many smart integrated energy solutions. The intense research and development work is currently carried out in the field of improving the gravimetric energy, higher power delivery at low temperature; extended life cycle at high temperature, safe operation at high voltage and lower manufacturing and material costs [15]. They are used mostly because they are well fabricated as per the engineering concepts and also they are safer as compared to the Li-ion batteries. Due to the above qualities, they are used extensively in Toyota Hybrid vehicles with 1.3kWh and 40kW ratings. With this system, Toyota has sold nearly about 3 million hybrid cars [39].

Though, of these many advantages NiMH batteries are having some of the demerits like lower charging efficiency, issues with the self discharge, cannot be used for high temperature conditions. Also, as compared to the Li-ion (Lithium-Ion) Batteries, these batteries have lower energy efficiency under charge – discharge cycle. But these, batteries are more suitable for higher current rate discharge than Li-ion Batteries. The state of charge (SOC) effect on energy efficiency is not that much but surely the battery value is not 100%. [16]. Also, the main problem with this technology is the limited amount of potential to expansion of technology and economic enhancements.

3. **Nickel–Cadmium (Ni–Cd) Batteries**

The above fig.6 shows the Structure of Nickel–Cadmium (Ni–Cd) Battery. In this battery, for the positive electrode Nickel Hydroxide (NiOH₂) is used and Cadmium (Cd) is used as negative electrode. The Alkaline Potassium Hydroxide (KOH) is used as Electrolyte. They can used for longer period with higher discharge rate capacity (of about 50-55Wh/Kg).
The reaction within the battery is as given in form the following equations:

\[
\text{Cd} + 2OH^- \rightarrow \text{Cd(OH)}_2 + 2e^- \quad \text{Eq. 1.1}
\]
\[
\text{NiO}_2 + 2H_2O + 2e^- \rightarrow \text{Ni(OH)}_2 + 2OH^- \quad \text{Eq. 1.2}
\]
\[
\text{Cd} + \text{NiO}_2 + 2H_2O \rightarrow \text{Cd(OH)}_2 + \text{Ni(OH)}_2 \quad \text{Eq. 1.3}
\]

This reaction helps in having wide temperature range, low internal resistance, high discharge rate without affecting the capacity of the battery and above all its practically maintenance free. The only factor affecting the usage of this battery is its high cost (3-4 times the cost of lead acid battery). This is mainly due to recycling cost of the material used. The one problem is with the Cadmium, it is highly toxic and hazardous to environment and it needs to be disposed in a very specific manner [17]. Despite of all these demerits, it is used in vehicles like Electric version of Peugeot106, Citroen AX, Renault Clio, and Toyota Prius and in Ford Think Car [18]. The specification of typical Ni-Cd battery is shown in the following table no.1.

Table No. 1. Specification of Ni-Cd Battery used for Electric Vehicles

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific energy</td>
<td>40–55 Wh kg(^{-1}) depending on current</td>
</tr>
<tr>
<td>Energy density</td>
<td>70–90 Wh l(^{-1}) depending on current</td>
</tr>
<tr>
<td>Specific power</td>
<td>(~125) W kg(^{-1}) before becoming very inefficient</td>
</tr>
<tr>
<td>Nominal cell voltage</td>
<td>1.2 V</td>
</tr>
<tr>
<td>Amphotre efficiency</td>
<td>Good</td>
</tr>
<tr>
<td>Internal resistance</td>
<td>Very low, (~0.06) (\Omega) per cell for a 1 Ah cell</td>
</tr>
<tr>
<td>Commercially available</td>
<td>Good in smaller sizes, difficult for larger batteries</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>(-40) to (+80) (^{\circ}) C</td>
</tr>
<tr>
<td>Self-discharge</td>
<td>0.5% per day, very low</td>
</tr>
<tr>
<td>Number of life cycles</td>
<td>1200 to 80% capacity</td>
</tr>
<tr>
<td>Recharge time</td>
<td>1 h, rapid charge to 60% capacity 20 min</td>
</tr>
</tbody>
</table>

The most significant advantage of Ni-Cd battery is the way in which it deals with the problem of overcharging. This is due to the chemical reaction of that is produces same amount of cadmium hydroxide which exactly required to convert backs to Cadmium [18].

4. Lithium-Ion (Li-Ion) Batteries:

The above fig. 7 shows the Charging / Discharging Process of Lithium-Ion Battery. The Li-ion Batteries are the most widely used batteries in many electronic and small household components. It is type of rechargeable battery is which lithium ions move from negative electrode to positive electrode. The negative electrode of this battery is made up of Carbon and the positive electrode is of Metal oxide (in general Cobalt Oxide). The electrolyte is normally any salts but should contain lithium ions. It has very high energy density with fine high temperature performance (twice that of Ni-MH Battery) and it is recyclable. It has high power capacity of about 300W/kg, long life operations up to 1000 cycles and also
it is light in weight. Due to all these advantages, immense research is going on in the field of Li-Ion Batteries and sooner or later it is going to replace all other batteries which are used in Electric vehicles [3].

Apart from these types of batteries, there is one more battery type which is more often used in electric vehicles, i.e. high temperature sodium-nickel-chloride (NaNiCl) battery (Zebra Battery). These batteries are having very high self discharge rate of about 10% in 24hours in stand-by condition if not maintained at high temperature. Due to this reason, this battery is used in Fleet vehicles like buses, where there is constant operation and no additional battery heating is required [39].

The available energy get reduces and internal impedance will be increased due to low temperature performance of this battery, this is one of the most effective limitations of this battery. It also degrades the overall cell life. These issues are more predominant in cold countries. Due to this reason, an efficient thermal management system is necessary to address above problems. There are various thermal methods like gaseous cooling & liquid cooling with their respective merits and demerits. Major research work is going on the fields of detecting lithium plating which is to be applied to overcome the poor low temperature performance effects [19].

More often, these batteries are used in electric vehicles and the only major problem is the cost. Cost increases exponentially with the increase in the power requirement particularly in case of Electric Vehicle operated with the Battery and the Plug-in Electric Vehicles. In recent years the production cost of the lithium ion cells is about INR 9500/- per kWh and the market price is about INR12300/- per kWh. It is been targeted to bring down the market price as low as INR 8100/- per kWh. The applications of these batteries is found in various recent automobiles like Tesla Model 3 & Model S, Chevrolet Bolt etc. which uses batteries in the range from 6kWh to 100kWh and has a range from 20km to 320km. In last few years the consumers are more interested in Electric Vehicles (EVs) than in the Plug-in Electric Vehicles (PHVs) due to this fact, the burden on the production of Lithium Ion batteries increases and manufacturers are pressurized to bring down the price and increase the specific energy of these batteries [20]. The below table no.2 shows the Deficits of Present Lithium Ion Batteries and Probable Cure.

Table No.2 Deficits of Present Lithium Ion Batteries and Probable Cure

<table>
<thead>
<tr>
<th>Location within Battery</th>
<th>Deficits</th>
<th>Probable Cure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative Electrode</td>
<td>Low Capacity Density</td>
<td>Replace Carbon with improved Alloy which has high columbic efficiency, good power Capability</td>
</tr>
<tr>
<td>Negative Electrode and Electrolyte Interface</td>
<td>Deposition of solid electrolyte inter-phase growth on first cycle and increasing</td>
<td>Coating to electrode and additives in the electrolyte to protect the inter-phase during the large changes</td>
</tr>
<tr>
<td>Positive Electrode</td>
<td>Low specific capacity and low charging voltage</td>
<td>Replacement of electrode material with the material having good power capability and high columbic efficiency</td>
</tr>
<tr>
<td>Positive Electrode and Electrolyte Interface</td>
<td>Low Columbic Efficiency at higher voltage which reduces specific capacity, cell life and increased impedance</td>
<td>Coating to electrode and additives in the electrolyte prevents the increased impedance at high voltage.</td>
</tr>
<tr>
<td>Separators</td>
<td>Presence of conducting Particles of lithium dendrites</td>
<td>Coating used for separators to be improved or combine chemically with lithium dendrites</td>
</tr>
<tr>
<td>Metal collectors</td>
<td>Solid metal foils increase the cost, they are use to provide electrical and thermal conductivity</td>
<td>Perforated or expanded metal foils to be used</td>
</tr>
</tbody>
</table>

The basic technology that is needed for the EVs and EHV's are there and available since many years, now the research is going on in refinement of these technologies that how to improve it further in terms of fuel consumptions, Long Run with least charging, Cost reduction etc. The manufacturers of various EVs and EHV's are having it all and are ready for this new evolution, but the question is whether the Government is ready for this massive change.

Government, no doubt is supportive for Green revolution and for low emission vehicles. They need to address the financial aspects to bring down the market shares in favor of people who are ready for this change. The Government needs to modify financial elements in lowering down the initial vehicle cost and should provide subsidies in fuel prices for these types of vehicles.
Due to the illustrative effects of Air Pollution on people’s health, UK government is providing incentives for replacing diesel vehicles with the EVs / EHV. The reason behind this is the lopsided diesel market share. In London, Petrol-EHV (Toyota Prius) is the most popular hire vehicle due the fact of lower total cost of ownership (TOC). This is small but very effective step taken by the UK government in minimizing the air pollution [22].

In view towards the increasing pollution through-out, the new finding shows that this is going to happen in near future across all major places on the globe. In regard to this, as per the Indian scenario some of the statistics shows that EV- 2 Wheelers will have major share by 2050, the policies will be pushed by the government regarding more utilization of EV-2 Wheelers by 2030. This enables the drastic reduction in the Co2 emissions. The EV 4-Wheelers will be flourished by 2050 [23]. The Indian governments with the help of some prominent EVs and EHV manufacturers are on a mission of CO2 emission free country and sooner or later they are going to achieve it. The below table no. 3 shows the List of Major Companies manufacturing EVs and EHV in India.

Table No 3. List of Major Companies manufacturing EVs and EHV in India

<table>
<thead>
<tr>
<th>Fully Electric Cars</th>
<th>Hybrid Cars</th>
<th>Motorcycles and Scooters</th>
<th>Bicycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mahindra e2oPlus</td>
<td>1. Toyota Prius</td>
<td>1. Twenty Two Motors</td>
<td>1. Hulikkal Electro India Pvt Ltd</td>
</tr>
<tr>
<td>4. Mahindra e-KUV 100</td>
<td>4. Honda Accord Hybrid</td>
<td>4. Okinawa Autotech Pvt. Ltd.</td>
<td>4. EBike India</td>
</tr>
<tr>
<td>5. Tata Tiago Electric</td>
<td></td>
<td>5. Ather Energy Pvt Ltd (to be launched)</td>
<td>5. Electrotherm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Buses</th>
<th>Mini pickup trucks</th>
<th>Rickshaws</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. India's first electric bus was launched in Bangalore in 2014.</td>
<td>1. Mahindra</td>
<td>1. Volta Motors</td>
</tr>
<tr>
<td>2. Ashok Leyland launched its electric bus in October 2016.</td>
<td>2. Tata Motors, Ace Electric in 2016</td>
<td>2. Kinetic Green</td>
</tr>
<tr>
<td>3. Tata Motors launched its pure electric bus ‘Starbus Electric 9m’ and hybrid ‘StarBus Electric 12m’ in January 2017.</td>
<td>3. Ashok Leyland, Dost Electric pickup truck</td>
<td>3. Gayam Motor Works</td>
</tr>
<tr>
<td>4. Goldstone Infratech Supplied Himachal Pradesh Transport Corporation with 25 electric buses in September 2017.</td>
<td></td>
<td>4. REEP Industries - REEP Motors</td>
</tr>
<tr>
<td>5. 25 ‘Made in India’ Tata Starbus Hybrid electric buses delivered in Maharashtra on March, 2018</td>
<td></td>
<td>5. Mahindra electric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Ampere Vehicles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7. Go Green BOV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8. OK play</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9. Atul Auto Ltd.</td>
</tr>
</tbody>
</table>
Ultracapacitors:

Though the various types of batteries are discussed, still that is not the only energy storage device available in the market. There are certain applications of EVs and EHV where there are some requirements like higher specific energy and higher specific power long operating life with higher temperature sustainability. These can be achieved by using Ultra-capacitors [24]. In some cases it is found that ultra-capacitor much more efficient performance as compared to traditional battery systems. Also the life of the ultra-capacitor is much more superior to batteries (ultra-capacitor life is equal to vehicle life) [25]. The energy stored (E) in the ultracapacitor is given by

\[ E = \frac{1}{2} CV^2 \]  

*Where, E = Energy Stored in Capacitor*  
*C = Capacitance in Farad*  
*V = Applied voltage in volts*

The voltage is directly proportional to the Energy stored. Therefore it is desirable to have higher rated applied voltage.

But to absorb the advantages of both Battery and Ultracapctor, the combination of both are used in practical applications (Hybrid Energy Storage System). The reason behind this that, due the dependency of voltage on the State of Charging (SOC), it is thorny to use ultra-capacitors individually as an ESS (Energy Storage System) for EVs and EHV [26]. There are various types of ultracapcitors used in conjunction with the batteries to achieve the best performance as per the applications. In common, there are five maturity technologies in ultracapacitors like carbon-metal fiber composite, binder carbon, doping of carbon films with conducting polymer films, mixed metal oxide coating on metal films and foamed carbon. Out of these five technologies, carbon composites electrodes are having higher densities as compared to the other technologies [28]. Commercially developed ultracapacitors are available from in different size and shapes depending upon the applications (single cells to cell modules). The companies like Maxwell, Ness, EPOCS, Nippon Chem-Con & Power systems are some of the manufacturers of ultracapcitors for EVs and EHV [22]-[24].

The capacitance value for these ultracapacitors varies from 1000-5000Farad. These are specially designed for high power applications. The following table no. 4 shows the Specification of Ultracapacitors.

<table>
<thead>
<tr>
<th>Device</th>
<th>V rated (V)</th>
<th>C (F)</th>
<th>R (mOhm)</th>
<th>RC (sec)</th>
<th>Wh/kg (1)</th>
<th>W/kg (95%) (2)</th>
<th>W/kg Match. Imped.</th>
<th>Wgt. (kg)</th>
<th>Vol. lit.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxwell**</td>
<td>2.7</td>
<td>2800</td>
<td>.48</td>
<td>1.4</td>
<td>4.45</td>
<td>900</td>
<td>8000</td>
<td>.475</td>
<td>.320</td>
</tr>
<tr>
<td>Ness</td>
<td>2.7</td>
<td>10</td>
<td>25.0</td>
<td>.25</td>
<td>2.5</td>
<td>3040</td>
<td>27000</td>
<td>.0025</td>
<td>.0015</td>
</tr>
<tr>
<td>Ness</td>
<td>2.7</td>
<td>1800</td>
<td>.55</td>
<td>1.00</td>
<td>3.6</td>
<td>975</td>
<td>8674</td>
<td>.38</td>
<td>.277</td>
</tr>
<tr>
<td>Ness</td>
<td>2.7</td>
<td>3640</td>
<td>.30</td>
<td>1.10</td>
<td>4.2</td>
<td>928</td>
<td>8010</td>
<td>.65</td>
<td>.514</td>
</tr>
<tr>
<td>Ness</td>
<td>2.7</td>
<td>5085</td>
<td>.24</td>
<td>1.22</td>
<td>4.3</td>
<td>958</td>
<td>8532</td>
<td>.89</td>
<td>.712</td>
</tr>
<tr>
<td>Asahi Glass</td>
<td>2.7</td>
<td>1375</td>
<td>2.5</td>
<td>3.4</td>
<td>4.9</td>
<td>390</td>
<td>3471</td>
<td>.210</td>
<td>.151</td>
</tr>
<tr>
<td>Panasonic</td>
<td>2.5</td>
<td>1200</td>
<td>1.0</td>
<td>1.2</td>
<td>2.3</td>
<td>514</td>
<td>4596</td>
<td>.34</td>
<td>.245</td>
</tr>
<tr>
<td>Panasonic</td>
<td>2.5</td>
<td>2500</td>
<td>.43</td>
<td>1.1</td>
<td>3.70</td>
<td>1035</td>
<td>9260</td>
<td>.395</td>
<td>.328</td>
</tr>
<tr>
<td>EPCOS</td>
<td>2.7</td>
<td>3400</td>
<td>.45</td>
<td>1.5</td>
<td>4.3</td>
<td>760</td>
<td>6750</td>
<td>.60</td>
<td>.48</td>
</tr>
<tr>
<td>Okamura Power Sys.</td>
<td>2.7</td>
<td>1350</td>
<td>1.5</td>
<td>2.0</td>
<td>4.9</td>
<td>650</td>
<td>5785</td>
<td>.21</td>
<td>.151</td>
</tr>
<tr>
<td>ESMA</td>
<td>1.3</td>
<td>10000</td>
<td>.275</td>
<td>2.75</td>
<td>1.1</td>
<td>156</td>
<td>1400</td>
<td>1.1</td>
<td>.547</td>
</tr>
</tbody>
</table>

(1) Energy density at 400 W/kg constant power, Vrated / 1/2 Vrated  
(2) Power based on P=9/16*(1-EF)*V2/R, EF=efficiency of discharge  
** Except where noted, all the devices use acetonitrile as the electrolyte

In case of hefty applications, the energy density is in-between 3.5-4.5Wh/kg and power density is about 95%. (800-1200W/kg) [28].

III. AUTOMOTIVE FUEL CELL HYBRID VEHICLE
Fuel Cell, as name suggests it is closely related with a battery, which generates electrical energy from converting chemical energy. The major difference between these is that batter forms a closed energy storage device and once it exhausted, it needs to be discarded or recharged. But in case of fuel cell, can run for indefinite period of time as long as fuel source is provided to it (same like IC engines as long as fuel is supplied energy will be delivered by the engine). Generally, Electrolyzer is the man part of hydrogen fuel cell, which is an electrochemical converter which separate out the water into oxygen and hydrogen with the help of electricity. It is basically, an endothermic process where the heat is required during the reaction process. In this, hydrogen is stored at high pressure in tanks or in bottles. To produce electrical energy from this fuel cell, both the gases flow into the fuel cell and due to cell reaction, water cracking takes place into hydrogen and oxygen which reacts and produce water as by-product, heat is also produced with this electrical energy is produced [39]. The following fig.8 shows the Structure of Hydrogen Fuel Cell.

![Fig. 8 Structure of Hydrogen Fuel Cell](https://en.wikipedia.org/wiki/Fuel_cell)

Basically, it generates electrical energy from fuel feed to anode and oxidant to the cathode which reacts with the electrolyte. In the process of generation, the reactant flows into the cell and the product reaction flows out of the cell. There are various amalgamations of fuel and oxidants are possible and based on this there are various types of fuel cell available in the market. The most common of all is the Hydrogen fuel cell, as it is nonpolluting (as the byproduct is water) and has the maximum energy density. The following table shows the various characteristics of fuel cell. The following table no. 5 represents the different Types of Fuel Cell.

<table>
<thead>
<tr>
<th>Table No. 5 Types of Fuel Cell</th>
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<tbody>
<tr>
<td>PAFC</td>
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<tr>
<td>Temp(°C)</td>
</tr>
<tr>
<td>Density (W/cm²)</td>
</tr>
<tr>
<td>Life (kh)</td>
</tr>
<tr>
<td>Cost ($/kW)</td>
</tr>
</tbody>
</table>

PAFC-phosphoric acid fuel cell.
MCFC-molten carbonate fuel cell.
AFC-alkaline fuel cell.
SOFC-solid oxide fuel cell.
DMFC-direct methanol fuel cell.
SPFC-solid polymer fuel cell also known as proton exchange membrane fuel cell.

In case of fuel cell hybrid vehicles (FCHVs), the fuel cell is used instead of batteries or in many major applications; fuel cell is used in combination of batteries / ultracapacitors to power the motor drive mechanism. In general, hydrogen fuel cell is commonly used in FCHVs. In this, oxygen from the air and the hydrogen from the compressed hydrogen tanks are utilized for generating necessary electrical energy from the fuel cell. These vehicles are nonpolluting (emits vaporized water and waste heat). Polymer Electrolyte Membrane Fuel Cell (PEMFC) is used in FCHVs, which uses hydrogen and as and requires oxygen to produce electrical energy.

The main component of any FCHV is the fuel cell stack. Individual fuel cell can produce voltage up to 1.1 volts which is not even close to the FCHV requirement. Fuel cell stack is nothing but the combination of fuel cell arranged in such a way to produce the necessary electrical output required for the FCHV. The power developed by the fuel cell stack depends upon the size and the number of individual fuel cell in the stack. Using of FCEVs are having number of merits like its pollution
free (zero CO2 emission) and also reducing the dependability on oil (fossil fuel). Apart from these, there are some more abilities of using fuel cell like it can be utilized as a back power source for remote locations, in distributed power generation and sometimes in co-generation, it can also be used to provide auxiliary power source to the conventional shipping vehicles etc [32].

1. Polymer Electrolyte Membrane Fuel Cell (PEMFC) Hybrid Vehicles:

The PEMFC technology is widely used in FCEVs. The construction of PEMFC consists of an electrolyte which is water based and polymer acidic membrane and electrodes are made of platinum alloys. They operate at low temperature (below 100ºC). For the operation of this cell, it requires pure hydrogen. The hydrogen is processed at the anode where the electrons are separated from the protons at the platinum surface. The proton passes along the membrane towards the cathode while the electron travels outwards outer circuit giving out the electrical energy. The by-product of this cell is only pure water. They extensively used in light vehicle applications. The reactions at the anode and at the cathode are given by the following expressions.

At Anode
\[ H_2 \rightarrow 2H^+ + 2e^- \quad E^o = 0 \text{ V} \quad \frac{dE^o}{dT} = 0 \text{ mV K}^{-1} \]

At Cathode
\[ \frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O \quad E^o = 1.2291 \text{ V} \quad \frac{dE^o}{dT} = -0.8456 \text{ mV K}^{-1} \]

Total Reaction
\[ H_2 + \frac{1}{2}O_2 \rightarrow H_2O \quad E^o = 1.2291 \text{ V} \quad \frac{dE^o}{dT} = -0.8456 \text{ mV K}^{-1} \]

In most of the Hybrid vehicle cases, the PEMFC is use in conjunction with the battery or with the ultracapacitors for the better performance of the FCEVs. In which, PEMFC is the main energy source and the ultracapacitor or battery acts as a secondary energy source or vice versa.

2. Direct Methanol fuel Cell (DMFC):

The operation is of this cell is quiet similar to the PEMFC, the only difference is the fuel used. Methanol is used as a fuel in this type of cell. The main advantage of this fuel cell is the transportation of methanol, due to this it is normally used in the portable devices. It is hardly used in and FCEVs. The one demerit of this type of fuel cell is that its efficiency is less than that of PEMFC. There are two type of methanol fuel cell viz; Indirect and Direct. In case of Indirect Methanol fuel cell, the fuel methanol is first reacted with hydrogen and then fed to the cell, whereas in case of direct fuel cell the methanol solution is used to carry the reactant to the cell. The operating temperature range is from 50ºC to 120ºC. The reactions at the anode and at the cathode are given by the following expressions.

At Anode
\[ CH_3OH + H_2O \rightarrow 6 H^+ + 6 e^- + CO_2 \]

At Cathode
\[ \frac{3}{2}O_2 + 6 H^+ + 6 e^- \rightarrow 3 H_2O \]

The Overall Reaction
\[ CH_3OH + \frac{3}{2}O_2 \rightarrow 2 H_2O + CO_2 \]

The applications of these cells are restricted only upto portable devices like laptops, mobiles, digital cameras etc; and not even near to any kind of electric vehicle. The application of DMFC depends on the stack construction and also depends on its available modules that can be rearranged as per the power requirement of certain applications [36].

3. Solid Oxide Fuel Cell (SOFC):

SOFC consists of solid ceramic electrolyte (Zirconium Oxide). It employs solid oxide (ceramic) electrolyte to conduct from cathode to anode. They are having the highest operating temperature range of about 1000ºC. The recent research is going on in the field of reducing the operating temperature of the SOFCs so that the overall cost required for the high
temperature will get reduced. By using the CO as fuel will bring down the temperature to about 350°C and also the efficiency is around 65-81%. Also the overall efficiency is around 80%. Now a day’s Proton conducting SOFCs are used which employs transport of proton instead of oxygen ions for low temperature applications. Constructional-wise, there are 3 different types of SOFCs: Planer, Co-Planer and Micro-Tubular. In case of Planer type SOFC, hydrogen and air flows through the channels formed by anode and cathode. In case of tubular SOFCs, the tube itself forms the cathode and components of cell are constructed around the tube. These types of fuel cell are extensively used for small power generation up to 100kW off-grid type [37]. The recent development if going on in the field of generation of power in MW by using SOFC, Roll-Royce is developing the SOFC with integrated planar to achieve the above power requirement in MW.

As in case of electric vehicles, Nissan Motor Company, Japan is extensively doing research in the field of SOFC and have developed electric vehicle which uses SOFC and operates on bio-ethanol with e-Bio SOFC Power generator [38].

Market Survey of FCEVs:

By the various surveys and reports it is quite clear that fuel cell is going to be the future driving mechanism for all the major vehicle manufacturing companies. As per the Global fuel cell electric vehicle market report, the fuel cell market is to be estimated near around $138 billion till 2022. In this report, all the factors like applications, types, customers, top companies and places. It also considered the latest trends in the FCEVs from customer’s point of view to prepare a competent plan of action to grow at more rapidly rate [33].

Large scale research is going on in developing the raw material technology in increasing the efficiency at minimum cost and maximum vehicle life. By 2024, top vehicle manufacturing companies will be producing FCEVs which will a big competition for the ICs engines. The FCEV cars will have a growth of about 25% and FCEV bikes will increase by 23% till 2024. This change will be majorly seen in the US and in China. To name few, General Motors, Honda, Hyundai, Toyota, Nissan and Daimler will be some of the high-flying market players in FCEVs market contributors [34].

In terms of fuel cell technology, hydrogen fuel cell will be more competent as compared to others fuel cell technologies. The market share of hydrogen fuel cell will reach by 82% as compared to the other types of fuel cell by the end of 2021. The infrastructure development in terms of hydrogen production will be sufficiently organized till the end of 2021 and this will be major reason behind the development of FCEVs with hydrogen fuel cell technology. As to give the scenario, only the state of California there will be near about 100 hydrogen refueling stations to satisfy of about 1.5 million FCEVs [35]. There are few major fuel cell technologies discussed that will be reason behind the success of FCEVs.

IV. CONCLUDING REMARK:

To reduce CO2 emission and to protect the environment electric vehicles (EVs), electric hybrid Vehicles (EHVs) and fuel cell hybrid vehicles (FCHVs) are the emerging technologies that can surpass the conventional combustion engines in near futures (by 2030). These technologies were available almost from the beginning of 20th century but it will be more utilized in the upcoming years due to the development in energy storage systems in contributions with the various power electronics devices.

This paper presents the prime components that are used in electric vehicles (EVs), electric hybrid Vehicles (EHVs) and fuel cell hybrid vehicles (FCHVs) along with their working and suitability as per their respective applications. Also in addition to this, latest market trends and future scope for these vehicles are discussed. From this, it is clear that by these components like batteries, ultracapacitors and fuel cell as homogenous technologies required in electric vehicles (EVs), electric hybrid Vehicles (EHVs) and fuel cell hybrid vehicles (FCHVs) cannot be used alone as to get the required results. These devices are to be used in conjunction with each other (in Hybrid form) to provide the efficient and economical solutions as per the respective applications. The extensive research is going on this field to improve the electric vehicles and to reduce the fossil fuel dependency with economical solutions so that the CO2 emission will become zero as per the vehicles are concerns.

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“The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.”