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A Comparative Assessment of Electric Vehicle Life-cycle focusing on key Performance issues of Lithium-ion batteries

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~ Never give up, no matter how hard life gets no matter how much pain you feel. Pain will eventually subside, nothing remains forever, so keep going and don't give up.

~ Imran Khan

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Abstract

The Life Cycle Assessment (LCA) method has been developed for the quantitative ecological assessment and ultimately provides a decision support technique in the field of vehicle engineering. LCA is used for acquiring an estimate for energy consumption and impact of vehicles on the environment. The basic problem in the objective definition is that the vehicles have become the primary cause of greenhouse gas emission. LCA comprises of two main parts: vehicle life cycle and fuel life cycle. This research work made a compared the life cycle CO_2 emissions of Electric Vehicles (EVs) and the Internal Combustion Engine (ICE) vehicles. In addition, most of the researches are focused on the use phase in comparing various transportation options and vehicle production when conventional and EVs are compared. Although EVs do not have any tailpipe emissions yet their batteries production results in the environmental burdens. To elude the problem shifting, LCA perspective can be used for the traction batteries' environmental assessment. The greenhouse gases discharged by the conventional ICE raise an environmental concern. This concern is mitigated by the acceleration in rapid growth of electric vehicle usage. Incorporation of solar photovoltaic (PV) into the electric vehicle charging system has numerous advantageous factors such as low cost of PV modules and renewable energy need for solving the greenhouse gases effects. Various challenges faced by this technology are highlighted in this research work.

Keyword: Electric Vehicle, Photovoltaic, Lithium Ion Battery, Charging Systems, Renewable Energy, Life Cycle Assessment method

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1 Electric vehicle

1.1 Introduction

Currently majority of transport systems completely depends on the fossil fuels. And these fossil fuels are the main reason for greenhouse emission. The passenger cars are the main consumers of these fossil fuels and they are emitting large Carbon dioxide gasses. In this modern world low carbon emission, energy conservation and environment protection are the main concern of the researchers.

The concept of having zero emission vehicles make the researchers to work on the development of new transportation tools. So one of the predominant future technologies to combat these greenhouse gas emissions is the battery powered electric car and plug in Hybrid electric car. Different varieties of electric cars are being developed by different industries. The ranges of these EVs are below 40 miles and their power ranges from few tens of kilowatts for small size cars to few hundred of kilowatts of the performance cars.

1.2 Background of Electric vehicles

Electric vehicles are not from now but we saw first electric vehicle on the roads in the middle of 19 century. But at that time due to high cost of EV, very low speed and due absence of well-developed batteries they become disappearing from the roads and due low prize of the fossil fuels ICE took their place in the market. But electric vehicles have used since in the form of electric trains and other such type of uses.

The first model of EV is related to many peoples in the history but in 1828 a Hungarian scientist Anyos Jedik invented early type of electric motor and he also created a small model of car which he powered by his own motor. Vermont blacksmith and Thomas Davenport in 1834 worked on the same type of motor which was operated on short circular electrified track. 1n 1834 the first small size electrical car which was powered by non-rechargeable primary cells was invented by Sibrandus Stratingh and his assistant. But when we stepped into 21st century due concern over the problems which are related to ICE including the damages caused by these vehicles to our environment and depletion of the fossil fuels very rapidly and good research in the electric vehicle and improvement in these EVs interest in electric and other fuel vehicles are very increased. And now since 2010 we can see the combine sale of both type vehicles and as we are moving to the future there is much increase in the sale and use of EVs.

1.3 Impact of Transport’s Systems on Our Environment

1.3.1 Major Cause of Emission of Greenhouse Gases

In the recent years allot of work is done to decrease the greenhouse gasses emission. If we see the industrial sectors we can note that greenhouse gasses emission are decreased in a very good manner but on the other hand in the recent years the emission of these gasses are increased from our transport systems. If we discuss only EU we can say that emissions of these gasses are increased about 17 % as compared to 1990. In 1990 emission of these gasses was 13 % but in 2014 it was 20 %. And now EU is working on reduction of these types of transport vehicles on the roads to reduce emission of these gasses and also to improve the energy security.

1.3.2 Air Pollution

We use vehicles in the areas where allot of people live and do work for their living like towns and cities and these vehicles are the main source of harmful gasses and air pollutants. They release gasses like nitrogen oxides and also particulate matter. And these types of pollutants are harmful for human life and they are affecting lives on very large scale. If we compare vehicle emission with the emission of other sectors like big industries or power plants we can say that these sources of emissions are not affecting the human life on that scale as emissions from vehicles are effecting because we build these sectors in a less populated areas where not that much people live.

1.3.3 Noise

In vehicles noise can come from two sources. The noise from the vehicle’s engine and noise from the tires and the road contact. This noise increases from the engine noise when we increase the speed of vehicle. These types of noise are affecting all the EU cities (both inside and outside the urban areas). These types of noise are affecting human health and wellbeing. 90 million people were affected by these noises in 2012 that were living in the cities.

1.3.4 Waste and Resource Use

Large amount of raw material and energy is needed in manufacturing of vehicles both EVS and ICEs. And large amount of raw material is not available in the EU or they are not in required quantity so we get these raw products from other countries and we import them for our use. In EU many millions of tons of waste are produced by the vehicles at the end of their life.

1.4 Why electric vehicles?

1.4.1 Clean Alternative

As compared to the gasoline-powered vehicle the EV has very fewer moving parts. For Electric vehicles we do not use any type of liquid and we also do not need to change the oil so we can say that most of the maintenance cost which we need for ICE are removed.

Electric vehicles move on the electrical energy and we do not need fossil fuels so our greenhouse emission in EVs is zero. Gasoline-powered vehicle use fossil fuels and they are the cause of greenhouse emission during the peak hours in the middle of the city. Electric vehicles moving on the motor and they give 100% torque at zero rpm without the emission of harmful gasses.

1.4.2 Savings

Electric vehicles can save us good amount of money because we can fuel them for cheap price. We can also get money from grids by giving the energy back to the grids in the peak hours. We can charge EVs in off peak hours when power is cheap and we can sell power back to the grids in on peak hours.

1.4.3 Safe to Drive

These cars are tested by the same procedures like the other fuel cars. When accidents take place we can expect to open the air bags and electricity supply to cut from battery. This can prevent us from injuries.

1.4.4 Reduced Noise Pollution

Electric vehicles use electric motor to move so they are much quieter as compared to the other vehicles. Because these electric motors are capable of providing very soft drive with good acceleration so we reduced the noise pollution.

1.4.5 Domestic Energy Independence

Nowadays we are using many renewable sources to produce electricity. The electricity used in common household may come from any RES like wind, solar and other low emission sources like natural gas, hydro, which enable the EVs to reduce the greenhouse emissions.

1.4.6 Cost Effective

At the initial phase of development of EVs it would cost very good amount. But with more research and development of new technologies now both cost and maintenance are in affordable range. The large improvement and production of batteries and incentives from governments have reduced the cost and now they are very cost effectives as compared to the past.

1.5 Various Types and Specifications of Electric Vehicles

We can choose from various types of EVs that are now available in the markets which are pure battery electric vehicle, various kinds of hybrids vehicles and also the vehicles which are powered by fuel cells. But here we need to understand the basic difference between them and advantages and disadvantages of their uses.

1.5.1 Conventional Vehicles

These are the ICE vehicles and for running they will use only fossil fuels to power the engine. They also produce allot of noise and pollute our environment due to emission of greenhouse gasses. From last century conventional vehicles have been produced in much larger quantity the reasons for that mass production of these vehicles are not that much advancement in the pure electric vehicles. Accordingly large refueling facilities and repairing centers has been developed.

Advantages

- Different models are available in the markets we can choose between various models and designs accordingly our wish.
- We are using these types of vehicles from last century so their infrastructure is very well developed. We can find refueling stations everywhere we can refill them any time anywhere.

Disadvantages

- Greenhouse gasses emission.
- Depend on the fossil fuels so these natural resources are decreasing sharply.
- They have low energy efficiency.
- They are the reason for noise pollution.

1.6 Electric Vehicle vs. Internal Combustion Engine

Electric vehicles do not use fossil fuels so they will not produce any tailpipe carbon emission. From economic point of view EVs have some very good advantages. The cost of electricity which we use in charging of our EVs over a distance of one mile is much lower than the gasoline cost which is required to run ICE over the same distance. Also the maintenance cost of EVs is much less compared to ICE due to the simplicity of a battery electric motor system but for ICE frequent maintenance is required. We can also mention that the technology of automotive battery is evolving rapidly since the current generation of EVs came on the roads with the price per kilowatt hour of lithium ion battery.

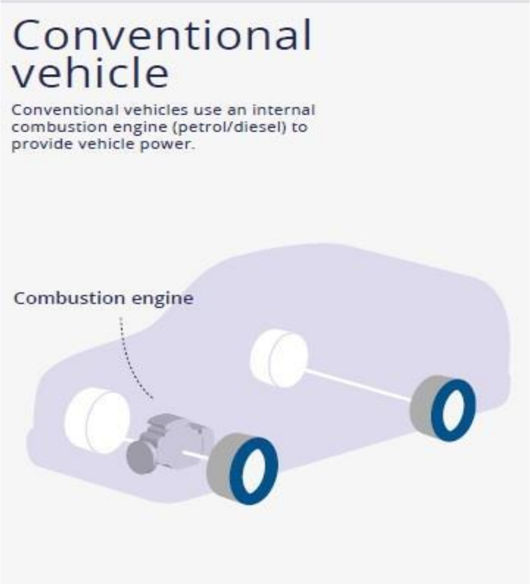


Figure 1.1 Conventional Vehicle with an Internal combustion engine

But total cost of ownership of EVs is very much greater than the total cost of ownership for an equivalent ICE. EVs are expensive due to high rates of the battery because till now battery manufacturing is very expensive and they are imposing much cost burden on the EV owner. But a lot of researchers are working to minimize the high costs of these batteries and we are very hopeful that these batteries will soon not that much expensive as now they are.

We must also consider the other impacts on the environment that rise from operation and producing of EVs and ICE. There are direct impacts on aquatic life, human terrestrial as well depletion of fossil fuels. These are the other vital issues which we must consider against the reduction in global warming related to EVs.

1.6.1 Battery Electric Vehicle (BEVs)

They run entirely by an electric motor. We use on board battery for storing electricity. In BEVs battery must be charged regularly. We can charge the battery of these vehicles by plugging in the vehicle to charging points which is connected to the local power grid. According to the latest research these types of vehicle has the good efficiency as they can convert 80 % of the stored power into the electric motion. The concept of regenerative braking can also be used here. Regenerative braking provides further energy to the battery. Regenerative braking system keep the battery of the vehicle charged by converting the heat energy due to breaking into the electricity normally this heat energy are lost through braking.

In BEVs there are no tail greenhouse gasses emissions so it will keep the air quality good and clean. They are environmentally friendly because we can charge the battery of vehicle well also from renewable energy sources since these RES are emission less from harmful gasses.

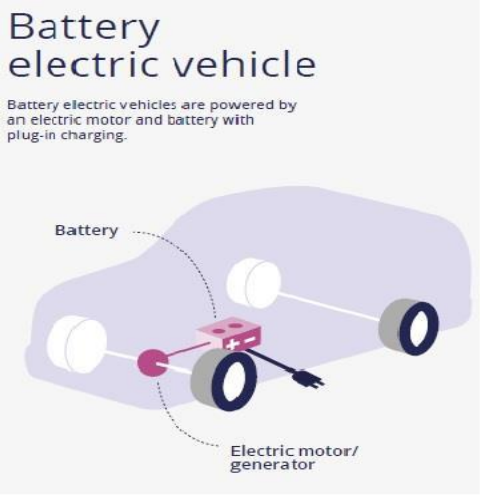


Figure 1.2 Battery Electric Vehicle (BEV) using battery with plug-in charging

If we compare BEVs with ICE we will find that these vehicles have very limited driving range and they also need very long time for charging the battery. But if we use large batteries which can store large amount of energy we can extant the driving range. But these large batteries will cost large.

Advantages

- They have higher efficiencies.
- We can recharge them by installing recharging unit in our home or office.
- Low engine noise.
- Zero emission vehicles.

Disadvantages

- Take long time to recharge the battery.
- Limited driving range.
- Very few charging units.

1.6.2 Hybrid Electric Vehicle (HEVs)

These types of vehicles are available for commercial use in the markets for more than 15 years. These vehicles also have combustion engine. Their working technique is different from BEVs because they are the combination of both electric motor and combustion engine. In these types electric motor only help the combustion engine like to accelerate the vehicle. They battery cannot be charged from the electric grid but they are charged when vehicle is moving on the road and can also be charged by regenerative breaking.

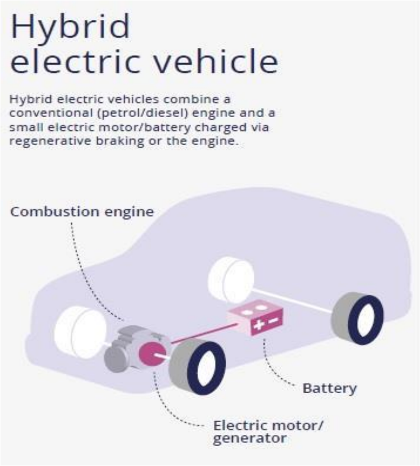


Figure 1.3 Hybrid Electric Vehicles (HEV) using battery charged with regenerative braking

HEVs have good fuel efficiency and greenhouse gasses emissions are also very less compared to the conventional vehicles. As we are advancing in HEVs we are reducing the greenhouse emission more and more with latest technologies. In markets we have different types of HEVs.

Micro HEVs

Electric engine of this type cannot power the engine of vehicle but they are limited to regenerative braking and by this they only charge the battery of vehicle.

Full HEVs

In this type we can use the vehicle to drive foe small distances by using electric power motor. We can connect the electric motor and the combustion engine in various ways.

Parallel hybrids

When we want to power the vehicle together (power with electric motor and combustion engine) we connect them parallel.

Power split hybrids

We can drive power split hybrids alone from the battery also. But we can use them only for short distance and in very slow speed. We can drive HEVs 100 % from electric power batteries in this configuration.

Advantages

- They have higher efficiencies.
- Large number of fueling stations.

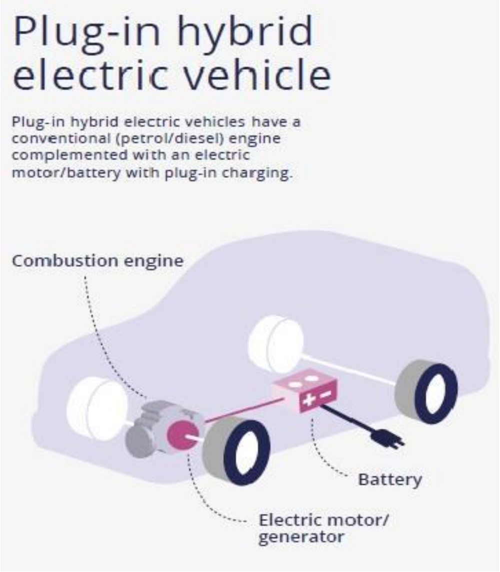
Disadvantages

- Dependency on fossil fuels.
- Reasons for greenhouse gasses emission.
- Noisy engines.

Their manufacturing technology is much complex.

1.6.3 Plug-in Hybrid Vehicles (PHEVs)

They are designed in such a way that we can power the engine by electric motor and ICE either using them together or separately. We can charge the battery which is on board by connecting it to the local power grid. Combustion engine in this configuration is use when we need higher power for wheels and when our battery charge is lower than the required level.



Plug-in hybrid electric vehicle

Plug-in hybrid electric vehicles have a conventional (petrol/diesel) engine complemented with an electric motor/battery with plug-in charging.

Figure 1.4 Plug-in hybrid Electric Vehicle comprising of conventional engine with an electric motor

The batteries we use in PHEVs have less capacity as compared to BEVs so their driving range is also small. The have less capacity batteries because they rely alone on electric power very less so we use these vehicles only for our short trips like moving in our city. PHEVs batteries are very expensive compared to BEHs in terms of price per KWh.

PEHVs impact on the environment depends on its mode of operation. When used in only electric mode so it will have zero emission and it is in environment friendly mode but when it is moving by combustion engine so it will be using fossils fuels and again it will have greenhouse emission and will be polluting our air. And in this mode its greenhouse emission will be greater compared to conventional vehicle of similar size the reason is the additional batteries which increased the mass of vehicle.

Advantages

- They have higher efficiencies.
- Large number of fueling stations.
- We can have the charging units install in our homes and offices.

Disadvantages

- They have very complicity in the technology.

1.6.3.1 Range-Extended Electric Vehicles (REEVs)

In this type of electric vehicle the combustion engine is not directly connected to the wheels but instead the combustion engines are used as an electricity generator source to power the electric motor and to charge the battery when it is lower than the

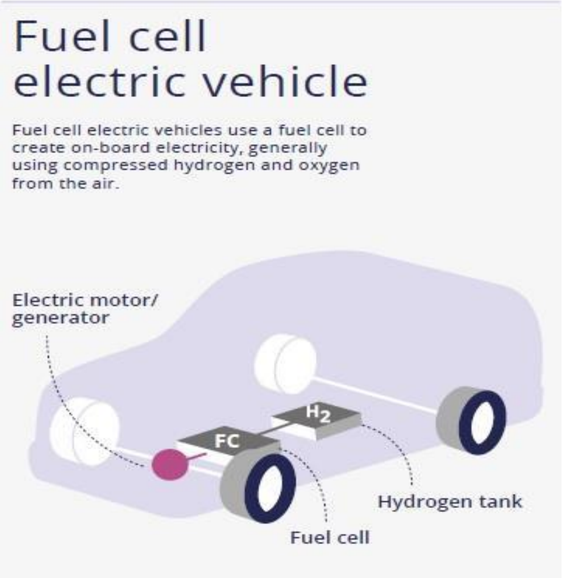


Figure 1.5 Fuel Cell Electric Vehicle with compressed hydrogen and oxygen

required level. We can also charge the on-board from the local power grids. In this type of electric vehicle the motor and the wheels are directly run by the electric motor only.

REEVs have engine which is smaller in size compared to conventional engine because in this case this engine is only use for to charge the battery when it is low and the vehicle mass is now also reduced.

Advantages

- They have higher efficiencies.
- Large number of fueling stations.
- We can have the charging units install in our homes and offices.

Disadvantages

- They have very complicity in the technology.

1.6.3.2 Fuel cell electric vehicle (FCEVs)

They are entirely run by electricity. In this type of vehicle we do not store the electric power in the batteries but instead we use fuel cell 'stack' and on-board hydrogen tank. Fuel cells combine the hydrogen from the on-board tank with the oxygen from around the air and run the wheels. Compared to BEVs the FCEVs are better because we can use them for longer driving ranges and they can be refueling very fast. They are better to use for heavy size vehicles and for larger distances.

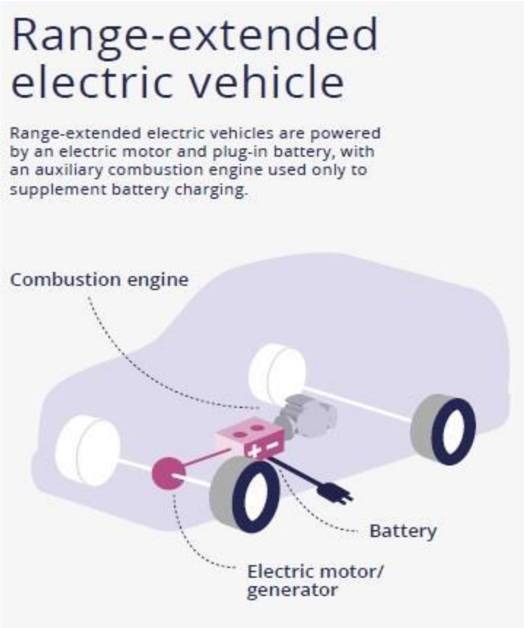


Figure 1.6 Range-extended Electric Vehicle having an auxiliary combustion engine

This technology is in development and allot of researchers are currently working on it so they are not commercially available.

Advantages

- They have higher efficiencies.
- Low engine noise.
- Zero greenhouse gases emission.

Disadvantages

- They are very limited commercially.
- Lacking refueling
- Technology complexity.

2 Batteries for EVs

Since the beginning of electric vehicles different battery technologies have been used. Lead acid and nickel metal hybrids were the batteries which were used in early stages but with advancement in the research now they are obsolete, and no one uses these batteries as the main source of storage in EVs. We have seen the use of lead acid batteries in the ICE vehicles because they are the cheap source of power storage but lead acid batteries has poor specific energy. Compare to the lead acid batteries NiMH batteries have good specific energy actually they have double specific energy to that of lead acid batteries. Due to double specific energy they were considered good choice for EVs. NiMH batteries also reduced the energy cost for EVs and they also have very well energy density compared to the lead acid. But they also have some drawbacks like low charging efficiencies and the self-discharging issue (at room temperature it discharges approximately 12.5 % per day) but this value increases when the temperature increases so they were also bad choice for EVs in high temperature.

2.1 Lithium Ion Batteries

Electric vehicles we are using today they have lithium ion batteries as the main source for power storage. Compared to the lead acid and NiMH, Lithium ion batteries have very good specific energy. These batteries have high output energy and power per unit of battery mass. So they are smaller in size and also light in mass. Due to these reasons Lithium ion batteries are now widely used in cell phones, digital cameras, laptops and other electronic appliances which are for every day of use.

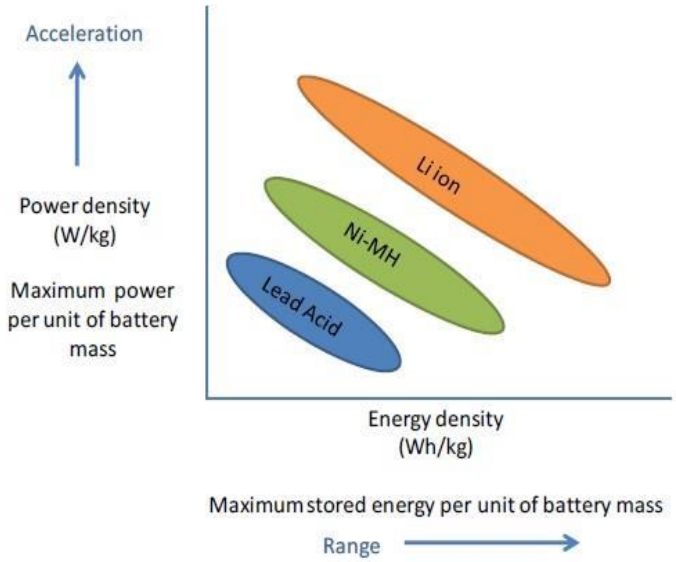


Figure 2.1 Comparison of different type of batteries used for Electric Vehicles

Compared to lead acid and NiMH, these batteries have no memory effect and they have very good and long life cycle. Lithium ion batteries also have some drawbacks. There are safety concerns which are related to the overcharging and overheating of lithium ion batteries. They may catch fires due to fluctuating charging or if there is any damage to the lithium ion battery. But researchers are working on these issues and in future there are allot of chances that this technology and safety of EVs will be improved.

2.1.1 Advancement in EVs battery technology

EVs available for commercial use they all are running by lithium ion batteries. There are also variations present in the lithium ion batteries and we can study the variation with respect type of cathode we use and the size of cell which we are using.

Small-format cells

Small-format cells has been produced for more than 20 years and primarily it was used in consumer electronics. And Tesla has signed four years deal with Panasonic to deliver 2 billion cells and for now they are they only one who are using the small-format cells in EVs. It is believed that cathode of this cells are the combination of the materials such as NMC, LCO, etc. These cells have the risk if they are overheated so for small-format cells we need advance cooling and very well battery management system.

Large-format cells

Small-format cells are only used by Tesla and all others manufacturer of the EVs they use the other cells format which is large-format cells. Material use for making of the cathode is LiMn204 and they have less energy density so they are not as much exposed to the heating issue compared to the small-format cells. Large-format cells are not that much economical they are expensive and small-format cells are cheap. Research are going on using the alternative cathodes like NCA and LFP so to find the cheap source with good safety and high energy density.

2.2 Italian market for EVs

According to the survey in EU 91 % of the vehicle owners travel the distance less than 100 km every day, and 75 % are even less than 50 km per day. And in Italy the average distance covered by everyday travel is nearly 45 km and that is a distance which can be easily travel by EV. Italy is the most promising country with respect to renewable technologies and allot of work is done for environment friendly technologies like wind turbines and Photovoltaic technologies. And these RES are the main sources for charging the EV batteries but instead of all these EVs are very much lower than other EU countries in Italy. Strange thing is that environmental issues like greenhouse gas emissions and pollutant emission are very well discussed by everyone in the Italian public but there is no special concentration toward the use of EVs which can overcome the issues regarding greenhouse emission [40].

Italy is in the middle of economic crisis from last few years and due to these crises allot of vehicles are sold which increases the total number of registered vehicles. Approximately 243000 new vehicles are added to the total of 37080753 vehicles. In these total sold vehicles number of Hybrid vehicle have been increased compared to the last few years. In 2015 total number of sold hybrid vehicles were 26117 that was a little increase compared to 2014 when only 21504 hybrid vehicles were sold. If we see the statistic of sold EV it was 1460 EVs in 2015 and in 2014 total 1110 units of EVs were sold in Italian market. So its impact in Italy on total automotive industry is negligible [40].

2.3 Electric Vehicle connection with Photovoltaic

The application of EVs for the green environment can as be used a part of energy storage system with PV can be another motivation for research on EV.

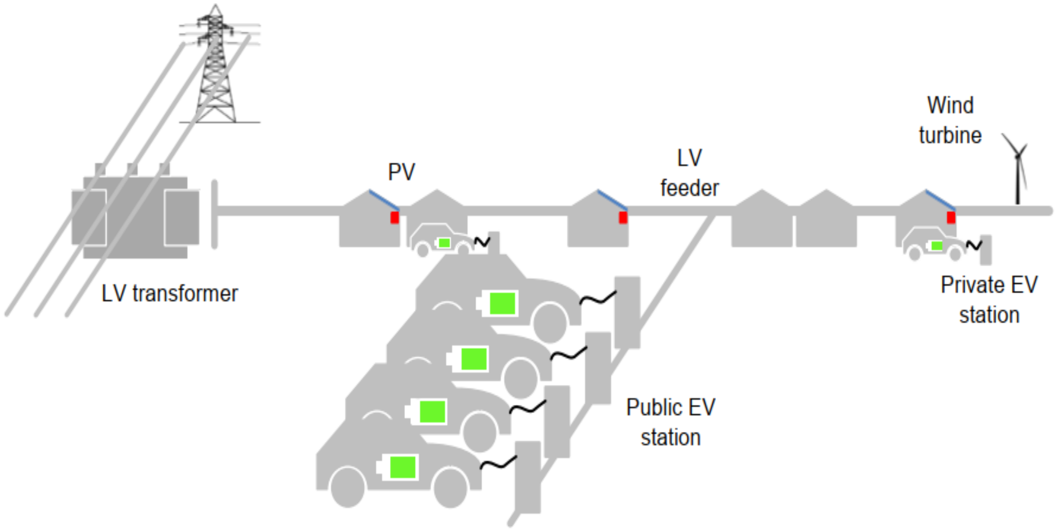


Figure 2.2 Application of EVs with PV for the green environment

The possible solution to enable the integration of an active EV with the power grid is defined when we have bidirectional battery system operating. The requirements to enable an active EV participation with the power system are defined. The interaction between the EVs and the grid should involve a safe bidirectional EV battery operation [3].

We have three types of EVs now a days PHEV (plug-in Hybrid EV), HEV (Hybrid EV), BEV (Battery EV). BEVs are totally electrical vehicle which run only by electricity. PHEVs are hybrid vehicle their battery can be charged by power station as well as internal motor can charge them. HEV on the other hand are only charge their battery by motor then don't get energy from power grid. The motor runs by onboard combustion engine in the hybrid vehicle [2]. The electric motor has mechanical link with the wheels which get its power form the battery. Whereas when combustion engine is working battery is charged by the motor which is run which act as a generator [2]. Recharging this vehicle has a great impact on the electric grid. Because they need great power therefore undesired effect can on due to high demand. PHEVs are also of great interest in their potential to work as a backup power system from homes or public station in the scenario of vehicle to grid power transfer.

These EVS are considered non-linear loads on power grid whose impacts on supply stability has been already well studied. The penetration rate of EVs into transportation increase the idea that one should not use them as load but also use energy storage devices. It is a very promising technology in for future a large no of light vehicle spends a lot of time for not being operate. There are many possibilities to work them to support power grid as an energy storage device.

The concept of V2G (vehicle to grid) and (G2V) is an exploring idea for the future. This concept has two impact on EVs. EV can act in discharge mode, as a source for grid, and as a charging mode (load) to get energy from the grid. This concept has attracted the attention of grid operators and owners, because EVS has essential and sustainable effect in future. In V2G idea EVs as ESSs cut off peak load and can work as aback for emergency conditions [4].

The Idea of green environment is increasing the size of EVs in the market which is also supporting the idea of back up energy devices for the market. This increasing no of EVs are diverting the idea of power operators to do some flexible action. The benefit of EVs can be as storage device support the idea to update the power station for V2G compatibility. The PVs system can be designed to supply bulk amount of energy to EVs for charging with the minor support from the power grid. PVs are considered as leading impact to plays an important role in energy efficient and zero polluted environments.

2.4 EVs as Storage

In order to support the solution of technical issues faced by PVs it is recommend having energy storage capability in the system. The interconnection of EVs and PVs looks very promising due to many similarities among one of the most important matches is that EVs can be connected to the grid in the same way, at same voltage levels in the same amount of ranges as in the PV system. i.e. EVs in residential area are like that residential PVs in parameter values [5-6]. PV is integrated to the power grid with same electronic interface as EV. The main difference is that EV has ESS and bidirectional it can act has load and as well as source to supply energy to the grid while on the other hand PV act as a source only, EVs have power and energy limitation, capacity limitation while PVs does not have these typical types of energy limitation. Because of these common features PV and V2G from the grid perspective the support function need for PV will be similar of EVs. It is also possible that the standard implied by IEEE-1547 and IEC-62116 will apply same to EVs with small modification [5].

ESSs accessibility can be the other issue for the power sector. Resources depend on the primary source of energy the battery which is directly dependent on the location of the vehicle. This implies method of another part of study which complicated things. Most commonly people look for the location where there is a large part of population with EVs. which must be easy for the people [4].

As well as the when the energy is needed on urgent conditions. i.e. emergency conditions the distance of vehicle from the charging station can be the important factor to restrict the process. Lastly in the condition when needed to be transfer power to the grip V2G the driver or operator should be there to set an electrical connection between vehicle and the charging point [7].

2.4.1 EV Integration in Distribution Systems

Renewable Energy Sources (RES) are difficult to predict since RES require dedicated techniques for both the planning phase as well as the exploitation phase. Household load and the capacity of Grid are constant thus RES generation is possible only in the case of Electric Vehicle (EV) charging. The effectiveness of the Power Grid system's planning phase and operating phase depends on the prediction of load and energy generation [2].

Recent advancements in the RES have made the effectiveness of the Power system more complex as it needs to ability to forecast the power system dynamics and provide optimal managing plan. The use of advanced prediction methods in combination with the optimization techniques have enhanced the existing methods to formulate improved predictive model of power system and to create efficient information as well as resources management. Different methodologies for the coordination of EVs Load, has been proposed during periods of high PV generation and low demand or vice versa [2]. The only problem in operating and dispatching of power supplies for PV penetration in the power grid is the uncertainty factor. This problem is mitigated by solving the difference among the intermittent power supply and the power system hard operation to provide accurate output power prediction particularly for the power supplies like PV station which rely on the weather conditions. For instance, if the solar radiations are predicted, high penetration of solar power can be ensured. For efficient system operation and effective load management, solar power forecast is crucial [2].

A neuro-fuzzy system Glow-worm Swarm Optimization (GSO) algorithm used in yield promising predictive results in operating phase conditions in various weather conditions [2]. Vehicle-to-Grid (V2G) which is the capability of EV to charge or discharge bi-directionally in order to produce power grid peak shaving and ancillary services. V2G can decrease power generation costs, enhance the grid reliability, reduce emission by providing better integration of solar and wind power and lastly give more revenue to the EV owners. Although there are numerous advantages of V2G yet there are some concerns such as lack of communications infrastructure between EV charging locations and grid operators, lack of expertise with distributed power generation and its effect on the power distribution systems and the minimal number of engineering staff who can handle these new methodologies and face the challenges related to them.

Another problem is the fact that in many regions the low voltage and medium voltage distribution infrastructure are not capable of handling huge bi-directional power flow. With the exponential increase in the number of vehicles if a certain number of vehicles are converted to Plug-in Hybrid Electric Vehicle (PHEV) with V2G system and have them online, then there will always be enough vehicles as spinning reserve [2].

Certain factors also contribute such as economic condition of the driver, EVs charging profile, electricity availability and charging rates [2]. The EVs charging profile can be controlled as at a certain point most efficient resource use can simultaneously enable prevention of congestion and control of voltage.

- The most economical choice would be selecting 3kW charger for conducting different possible solutions. At Night when demand is low as well the power is coming from the generators.

- In case, there is a need for faster charging approximately 15kW then higher voltage level connection can be installed in the parking areas (charging stations). In daytime when limited time for charging. When demand is high as well as the PV supply is high.

Another mitigation method for system integration between connected EV and power grid availability is to exploit the EV availability, charging power modulation, and stabilisation of energy flux from power grid to the electric vehicle [2].

2.5 Wireless Charging of EVs.

Another method to charge the electrical vehicle is providing wireless charging stations. Inductive power transfer (IPT) Technology. The type of charging without any physical contact. By means of no electrical visible electrical connection. This energy transfers the energy coming from the grid to the Vehicle and as well as in the reverse direction using magnetic circuits working at resonance [4]. The charging can put into working when the vehicle is planned to park for a long time or somewhere there are some small stops (quasi dynamics) or moving with uniform speed by taking the advantage of this technology.

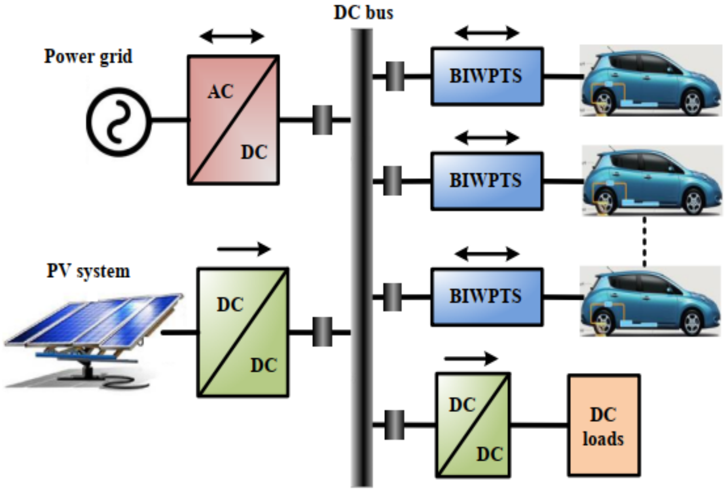


Figure 2.3Wireless Charging for Electric Vehicles using PV

The energy stored in batteries of EVs as a source can be transferred to the power grid. For this a purpose a significant control scheme needs to be design and implement to convert these moving sources of energy individual energy in order to provide a complete source of energy storage for the power [4].

Research has been done to see the comparative analysis for the efficiency of EVs connection in the form of conductive and inductive form conduction, the studies shows that EVs provide comparative 10% of success interaction while inductive connection provide 65 % of success. So, we need to consider a bidirectional inductive wireless power transfer system (BIWPTS) technology in order to achieve the integration between the PV generation and power grid to achieve G2V and V2G services [4].

2.6 eMobility Infrastructure:

In this section, the eMobility infra-structure as well as the stakeholders involved are discussed in detail. It will also provide details of communication protocols relevant to eMobility infra-structure. Various components of eMobility infrastructure are the charging stations, electric vehicles (EVs) as well as the power grid. Some of the components are not directly essential in the charging process, like the automotive manufacturers, which are sometimes considered to be part of the eMobility infra-structure and other times excluded.

Power grid station and the additional part are mostly referred to as the backend of the eMobility infra-structure. This backend is mandatory to handle the billing, energy exchange and other additional services. The power grid can only communicate with the vehicles the charging station. Vehicle-to-Grid also commonly called V2G interface indicates the connection between the charging spot and the EV. eMobility infrastructure permits bi-directional flow of both energy and data. Different mediums such as the internet, power-line-communication (PLC), or the cellular network are used to transmit the communication. Special purpose protocols and some open standards are required for the communication of data using these mediums. Figure 2.4 shows the overview of a high-level eMobility Infrastructure and its components.

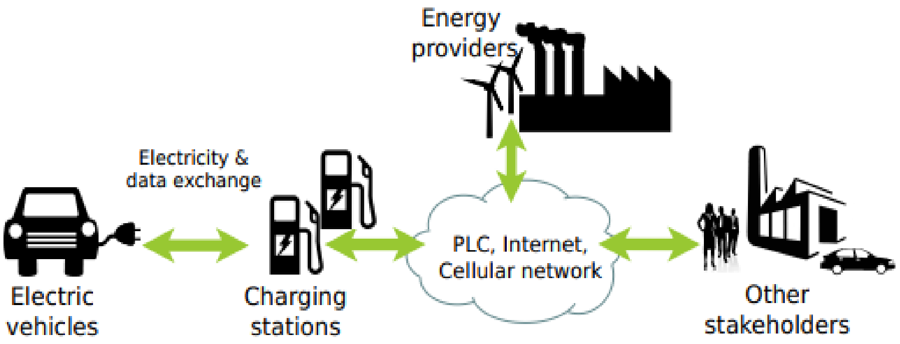


Figure 2.4 High-level overview of e-Mobility Infrastructure comprising of Stakeholders, Energy providers, Charging Stations and EVs

According to the eMobility infra-structure the EVs are plugged into the charging station, afterward the communication is carried out using the power-line. This charging spot which is connected with the power grid for the delivery of electricity as well as for carrying out the communication, with the help of power-line-communication, with the power grid until a nearby aggregator charging station is accessed and then the internet of the cellular network. Several energy providers simultaneously stay connected to the power grid.

2.6.1 Electric Vehicles (EVs)

The eMobility in not only limited to vehicles, but also includes other transports like buses, vans, motorcycles, trucks, and scooters. Basic two types of EVs are Battery Electric Vehicles (BEV) or Fully Electric Vehicles (FEV), having no auxiliary on-board power. The second type of EVs includes Extended-Range Electric Vehicles (E-REV) and plug-in hybrid electric vehicles (PHEV), having an internal combustion engine (ICE) that recharges the battery and/or drives the wheels whenever the internal battery is consumed. The EVs can get charged by any charging station for recharging the EV battery that is all of the charging stations are technically compatible with all types EVs [42-43].

2.6.2 Charging Stations

There are different types of charging stations. Using a standard socket (16 Ampere with 230 Volts, equals 3.7 kW) it takes about ten hours to charge a fully depleted battery having a range of approximately 150km [17]. Numerous vehicle owners need to charge their vehicle which it is parked somewhere for a longer period of time. This could take time while it is parked at home, during the day on the offices or mall's parking area and any other parking services. To quickly charge the e-vehicle exceptionally fast charging stations are essential. Such charging stations are similar to the gas stations for the vehicles powered by fossil fuel [18]. Fast-charging at 200 kW might take approximately 11 minutes for an empty 150 km range battery [17]. Presently, the highest power levels considered by the focus group on EU eMobility are at the 86 kW [18]. At this point of power level charging a 150 km range battery would take approximately 70min.

Charging Location	***Charging Speed***	***Ownership***	***Energy Supply***
Home	Slow	Private	Domestic energy supplier, distinct charging connection/meter
Office	Slow	Private	Employer's energy supplier, distinct charging connection/meter
Parking Area	Slow	Municipality	Newly deployed connection
Fast Charging Station	Fast	Private	Newly deployed connection

Table 2.1 Comparison of the different charging locations

2.6.3 Power Grid

Power grid contains the electricity distributors as well as the electricity producers. The power grid has a hierarchical structure, which depends on the transmitted voltage of the power grid is distributed into low, medium and high voltage power grids. The power plants are associated to the high voltage power grid.

The Advanced Metering Infrastructure (AMI) monitors as well as manages the power grid. Smart-meters are used to monitor the electricity usage and further report the consumed energy amount to the energy supplier in an hour or less [22]. This makes it possible to closely monitor the energy consumption and allows energy distributors to manage the electricity supply to smaller grids based on the real-time demand. In order to significantly reduce the dependency on fossil fuels and nuclear power plants, more and more renewable energy sources are used.

The low voltage grid supplies electricity to residential areas and businesses [19]. Often the low voltage grid is divided into small sections called micro grids. For energy providers renewable energy sources often pose challenges. Since the amount of electricity obtained from renewable sources can fluctuate a lot, the electricity amount is hard to predict and cannot be controlled. For example, solar power highly depends on the cloud coverage and can only be utilized during daytime. Similarly wind energy is weather dependent and exponentially increases until it reaches a certain wind speed. Once this ceiling value is reached any further increase in wind speed will not create more electricity.

2.6.4 Charging Infrastructure

The charging infrastructure includes the various types of charging stations and the power grid they are connected to. To offer fast charging new connections need to be installed. For slow charging the current infrastructure is enough [18,17]. Beside the electricity exchange the charging infrastructure is also responsible to securely transmit any required data, such as billing information. Furthermore, all charging systems (i.e. plug, communication protocol) should be compatible with each other and any type of electric vehicle, so that vehicles can charge at any charging station. The charging stations are operated by an electricity supplier, similarly how gas stations are affiliated with an oil company.

Electricity Companies

Electricity companies include the energy suppliers and distributors. The increasingly interconnected energy grid allows more detailed and near real-time energy demand monitoring. The variable supply of renewable energy can be matched with the demand. Energy providers hope to store excess energy in electrical vehicles and retrieve the energy when energy supply is low and the vehicles do not need the energy [20]. This is called smoothing out the energy demand. For example, on a bright, sunny day the energy provider may want to pass on all the energy to plug in vehicles. The energy exchange needs to be closely monitored and the vehicle's bill is debited or credited accordingly.

Governments/municipalities (EU)

Due to the environmental benefits, many governments are exploring the possibilities of electric driving. Studies are conducted how to increase the number of electric vehicles, what impact eMobility can have and how to support the trend [21].

Further, governments and the European Union are aiming to align the eMobility efforts to produce an international, compatible infrastructure.

Mobility/Billing Operator

Several billing methods have been proposed. The main approaches are prepaid, subscriptions and billing via the domestic energy bill [21-22]. Mobility operators may offer contracts similar to mobile phone subscriptions with which the vehicle driver can charge at any associated charging stations. Also, roaming at other charging stations may be supported [23-24].

2.6.5 Standardization Organizations

The international standardization organizations, and the working bodies made by them and other parties are working on the different sanerios of eMobility infrastructure [21][24][26]. The International Standards Organization (ISO), Society for Automobile Engineers (SAE) and International Electro-mechanical Commission (IEC) have issued many standards with respect to battery management system, communication protocols and charging plugs [24]. Likewise, national associations, for example, the Deutsches Institute hide Normung e. V. (Clamor) and the Japan Electric Vehicle Association Standards (JEVS) are also working on standards. The ISO/IEC 15118 standard (at the season of composing still being worked on) addresses the e-vehicle to grid communication V2G, including cases, system and application protocols compatibility, physical and data link connect layer prerequisites [24].

3 Life Cycle Assessment of Conventional and Electric Vehicles:

Internal combustion engines (ICE) are the main source of transportation in this modern world but they are also the main source of greenhouse gasses emissions and producing CO2 which are damaging our environment. On other hand Electric vehicles (EVs) may be the solution to control CO2 emission and greenhouse gasses. Positive points of EVs mainly include high tank-to-wheel efficiency, zero or low local greenhouse gasses emissions and a quiet way of operation. Now many countries those are facing environmental and energy problems are focusing on development of EVs and trying to replace the ICE.

The transportation sector is one of the major contributors for global climate warming and greenhouse gas emissions. In the last 10 years, the global CO2 emission increased by 13%, with 25% of the increase coming from transportation sector. Furthermore, by 2050, the global CO2 emission is still expected to increase by 30%-50% (Lin et al. 2011). The proportion of the total CO2 emissions by transportation sector is highest in China (30.98%) followed by Germany (19.9%) and United State (7.86%) (International Energy Agency, 2013) and this proportion varies across different countries [41].

In order to compare EV and ICE vehicles we will use approach for this, and this approach is known as life cycle assessment (LCA). All steps which are required to produce a fuel, to manufacture a vehicle and to operate and maintain the vehicle throughout its life time including disposal and recycling at the end of its life cycle. Life cycle of a vehicle is divided into two categories:

1) *Fuel life cycle:* This includes the feedstock production, fuel consumption, feedstock transportation and fuel distribution.

2) *Vehicle life cycle:* This includes vehicle material production, assembly, distribution, operation, maintenance, and disposal.

3.1 Fuel Life Cycle Emissions

This part is also known as Well-to-Wheel cycle, which includes feedstock production, feedstock transportation, fuel production, fuel distribution, and fuel combustion. Studies done for calculation of emission of fuel is the focus of this part. In this study we will use a model known as GREET (greenhouse gases regulated emissions and energy consumption in transportation) by Wang 1999 and this model was used for calculating the emissions of the fuel life cycle[39][45]. This model work first by estimating the energy use and then the emissions of fuel throughput for all the stages.

In fuel cycle, emissions of pollutant for a stage of the life cycle is calculated by the following formula summing over all fuel types j and technologies. k:

$$EM_i = \sum_j \sum_k EF_{fuel,tech,k,j} \times EC_{ik} \times Share_{fuel,j} \times Share_{tech,k,j}$$

Where,

EM_i = Combustion emissions of pollutant i $[g/\,J]$

EF_{ijk} =Emission factor of pollutant i for fuel j with combustion technology k $[g/J]$

EC= Inverse efficiency ratio for consumption of fuel j with combustion technology k

$Share_{fuel}$= Share of fuel j out of different fuels consumed during the stage $[\Sigma_j fuel_j \ = \ 1]$

$Share_{tech}$ = Share of combustion technology k out of different combustion technologies for fuel j $[\Sigma_k tech_{k,j} \ = \ 1]$

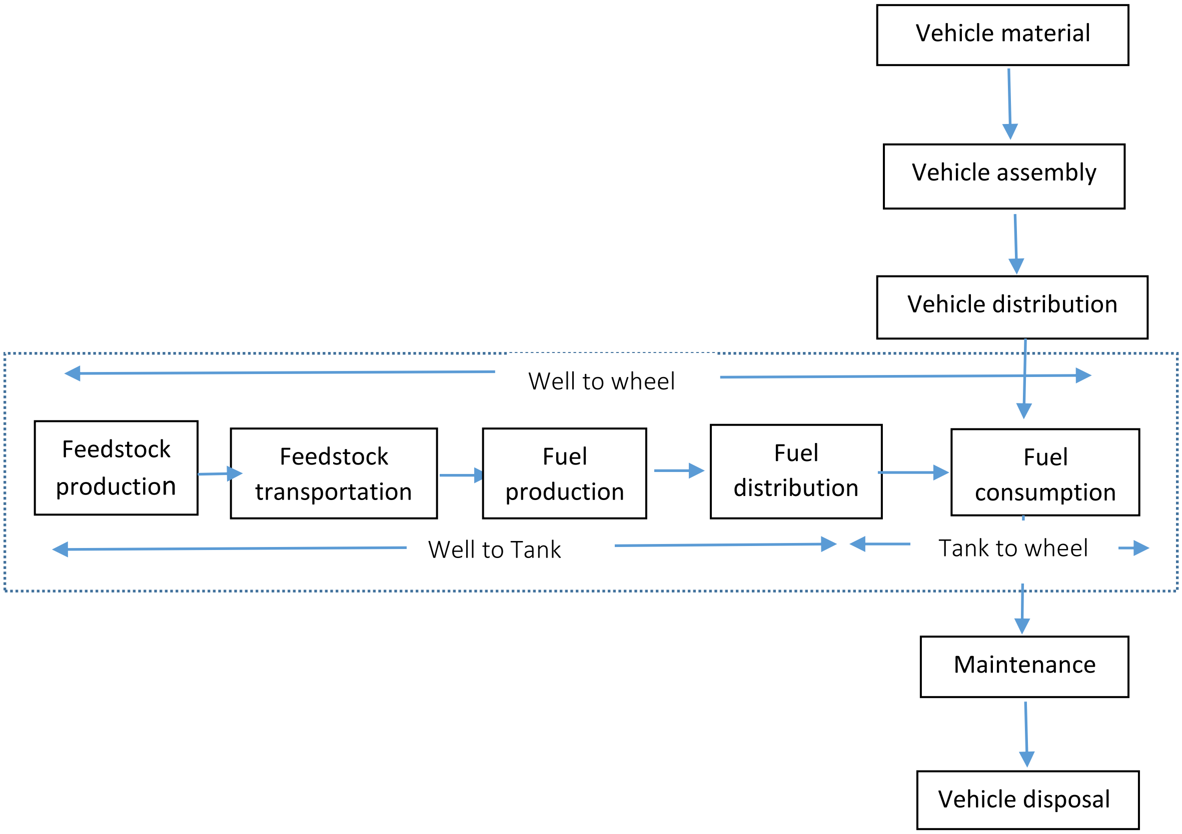


Figure 3.1 Well-To-Wheel Cycle[43]

In this model CO_2 emission factors of fuel are calculated by using a carbon balance formula. Which is the carbon contained in a process fuel burned minus the carbon contained in combustion emissions for volatile organic compounds (VOCs), carbon monoxide, and methane are assumed that they are converted to CO_2. The formula is given as under

$$EFCO_{2\,jk} = \left[\frac{\rho_j}{LHV_j} \times C{:}J - \left(VOC_{jk} \times 0.85 + CO_{jk} \times 0.43 + \ CH_{4\,jk} \times 0.75\right)\right] \times \left(\frac{44}{12}\right)$$

Where,

$EFCO_{2\,jk}$ = Emission factor for CO2 for fuel j and combustion technology k [g/J]

ρ_j = Density of fuel j [g/l]

LHV_j = Low heating value of fuel j [J/l]

$C{:}J$ = Carbon ratio of fuel j

VOC_{jk} = VOC emission factor for combustion technology k, burning fuel j [g/J]

CO_{jk}= CO emission factor for combustion technology k, burning fuel j [g/J]

$CH_{4\,jk}$ = CH_4 emission factor for combustion technology k, burning fuel j [g/J]

0.85 = Carbon ratio of VOC

0.43 = Carbon ratio of CO

0.75 = Carbon ratio of CH_4

44 = Molecular weight of CO_2

12 = Molecular weight of elemental carbon.

3.2 Vehicle Life Cycle Emissions

In this section, we will describe the emission of carbon which occurs during each phase of vehicle life stage.

3.2.1 Material Production

The process takes into the consideration of the materials from which the vehicle is made up of like body and doors, brakes, chassis, interior and exterior, tires, and wheels and must consider the extraction and processing phases also. If we are considering the EVs, we will consider the materials which are used for production of batteries like lithium iron phosphate, lithium nickel cobalt manganese, lithium manganese oxide. Studies show that the emission of carbon dioxide for material production is based on the following two things (mass of the material and energy consumption). The formula we use for calculating the emission of CO_2 during material production are given as under (Wang et al 2013) [45]:

$$C_m = \propto_m M_m \beta_M$$

Where,

$\propto_m$= energy required for processing per mass $[J/kg]$

M_m = material mass $[kg]$

β_M = Energy consumption factors for CO_2 $[g/J]$

The energy consumption factors are calculated based on the following equation:

$$\beta_m = (P_t\beta_t + P_e\beta_e)$$

Where,

P_t= Thermal energy needed in material production given in percentage.

P_e= electrical energy needed in material production given in percentage.

The steel and aluminum production have very high carbon emissions (values of P_t and P_e are 85% and 15% for steel, and 25% and 75% for aluminum).

Vehicle Assembly and Distribution

This is calculated by the same formula discussed above

$$C_m = \propto_m M_m \beta_M$$

Where,

M_m= vehicle mass

$\propto_m$=energy required per mass for assembling a vehicle

Carbon dioxide emissions during assembly process is approximately in order of one ton. And the distribution depends on the distance and transportation mode of shipping the vehicle to the customer. At this stage the CO_2 emission is lower compared to other stages[39].

3.2.2 Vehicle Operation

During this stage the emission of CO_2 is known as “tank-to-wheel”. And this is the stage where all vehicles have most carbon emission and energy intensive phase in their life cycle. During this stage the emission of CO_2 totally depends on the life time of the vehicle. Study done by Wang et al. (2013), the vehicle life time is considered as 300,000 km. In another study by Aguirre et al. (2012), they considered vehicle lifetime as 180, 000 miles. Both studies show that during vehicle operation ICE vehicle produce 96% carbon dioxide, and EV produce 69%.

EVs emission is dependent only on the production of electricity. If electricity is obtained from renewable energy sources such as wind turbines, nuclear, solar power, and hydropower, electric vehicles have significantly lower emissions. But on the other hand if electricity is produced from non-renewable energy sources such as coal or natural gas produces more carbon dioxide emissions.

The impacts of EVs are highly dependent on vehicle operation energy consumption and the electricity mix used for charging. As examples, we compare some real-life cases considering a vehicle life time of 250,000 km, an ICE fuel consumption of 6 l / 100 km, and a typical EV energy consumption of 20 kW/100 km. The following five cases are estimated based on CO2 emission factor and energy mix for different countries.

Case 1: ICE (CO_2 emission factor for gasoline: 2.38 kg/l): 250,000 ×6/100×2.38 = 35,700 kg

Case 2: EV (China CO_2 intensity 1100 g/kWh): 250,000×20/100×1.10=55,000 kg

Case 3: EV (USA CO_2 intensity 650 g/kWh): 250,000×20/100×0.65=32,500 kg

Case 4: EV (Germany CO_2 intensity 550 g/kWh): 250,000×20/100×0.55 =27,500 kg

Case 5: EV (Japan CO_2 intensity 400 g/kWh): 250,000×20/100×0.4 =20,000 kg

3.2.3 Vehicle Maintenance and Disposal

In this stage we consider the maintained and repairing of the vehicle during its life cycle. But this phase does not make any noticeable contribution they contribute very less to the emission (less than 10%) during operation both in terms of material and fuel. Onat et al. (2015) reported that vehicle maintenance phase for ICE vehicle produces 12.19 g CO_2 equivalents/km and for EV it is 8.53 g CO_2 equivalents/km. Vehicle disposal is the final stage of a vehicle's life cycle. Generally, recycling is already being taken care of in production stage. Otherwise it will give a negative footprint.

3.3 LCA Analysis of Different Scenarios

To analyze the LCA of EVs and to further investigate the different scenarios of electricity production we have proposed a meta-model by integrating multiple key performance evaluation parameters as well as the literature data.

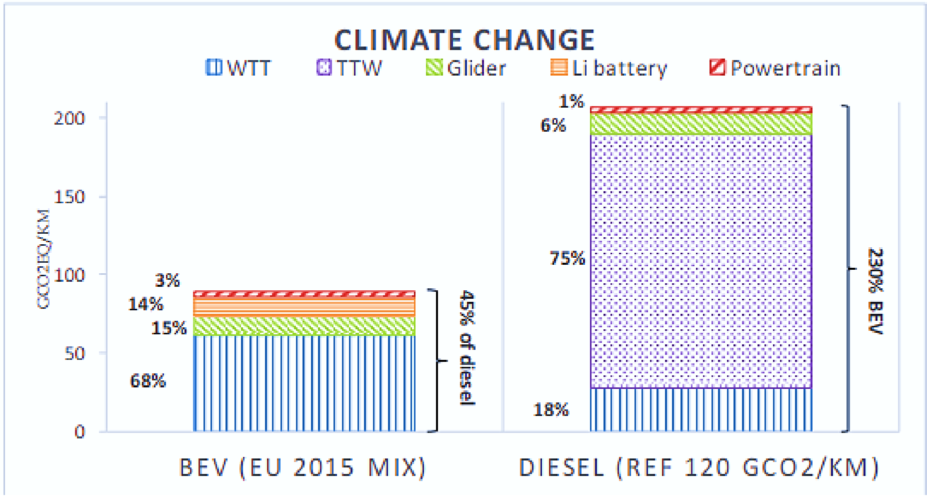


Figure 3.2 Climatic Change with respect to BEV and Diesel Usage

Complete vehicle life-cycle can be categorized into sections namely; Well-to-Tank (WTT) stage which refers to the fuel supply chain, Tank-to-Wheel (TTW) which is related to the energy conversion in the vehicle, Glider which describes the maintenance, manufacturing, as well as the recycling of any vehicle, and lastly the powertrain which discusses the manufacturing of the battery, electronic and the motor. The selected battery for EV discharges throughout its whole functional lifetime, half of carbon dioxide CO_2 amount in comparison to a benchmark conventional vehicle. Approximately 70 percent of the EV impact initiates from the electricity production of the electricity i.e. E28 mix 2015: 300 g CO_2/km, while the remaining 30 percent of the EV impact is distributed evenly among the glider production (15%) and the li-ion battery (approximately 15 percent). The battery production impact is substantial which can further be reduced by the help of a cleaner source of electricity. In case of using renewable electricity (wind energy) for the electricity production, the impact is reduced to 65 percent of its original impact. Recycling has vital role in reducing the battery manufacturing impact, in case of using the crediting system, since it decreases the primary materials usage.

Primary materials' production is an energy intensive as well as a toxic process which can be eluded in the future if the new batteries use secondary materials, instead of primary materials, which are acquired from obsolete **batteries** during the recycling process combined with the renewable energy usage of the GHG emissions in the manufacturing process which can further be lowered to 35 percent of the original impact.

EVs could be fuelled by the help of a wide range of primary sources of energy including coal, gas, wind, coal, solar, biomass, nuclear and oil; overall decreasing the dependency on the oil reservoirs and in result increasing the energy providence security. The allocated electricity's carbon footprint for the EVs is of ultimate significance for the inclusive environmental performance. Various scenarios have been calculated for investigation of the effect of any change in the electricity mix using same vehicles as reference can be described as follows:

a) Different EU countries' Grid Electricity intensity

b) Power-plants' Carbon intensity

c) Overall effect of anticipated enhancements in the electricity carbon intensity

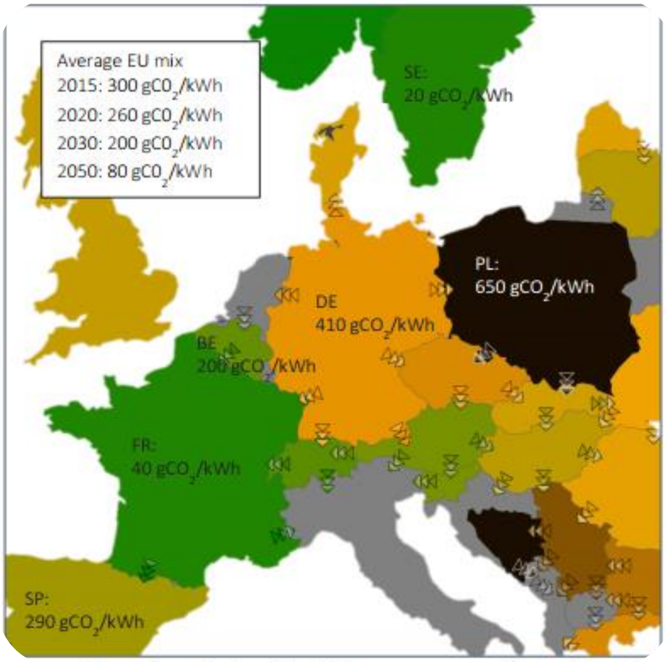


Figure 3.3 Assumptions for the carbon footprint of the different European countries

Various assumptions for the carbon footprint in case of various EU countries are based on the literature review [20] and illustrated in Figure 3.3. Both France and Sweden have the lowest electricity mix with a carbon footprint, because of the renewables and nuclear sources inclusion, respectively. Spain as well as Belgium has

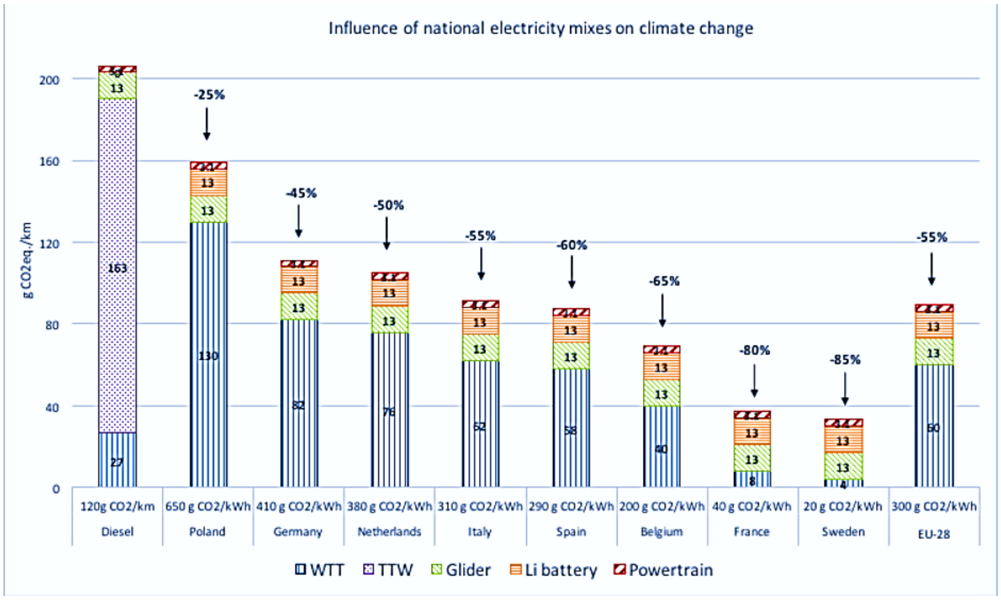


Figure 3.4 Influence of the carbon footprint of national electricity grids on the comparison of life cycle GHG emissions of BEV, according to the electricity mixes in [29]

carbon intensive of the electricity mix of 200-290 g CO_2/kWh, whereas in Germany approximately 410 g CO_2 are released per produced electricity. The highest GHG emissions are seen to be in Poland which produces electricity mix of 650 g CO_2/kWh because of the inclusion of hard-coal power plants. According to the statistics shown in the form of geographical presentation in Figure 3.3, the average EU country (28 member countries) has electricity carbon footprint of 300 g CO_2/kWh in year 2015 and by 2030 it is expected to be reduced ominously to about 200 g CO_2/kWh and in 2050 it is expected to be as low as 80 gCO2/kWh. Carbon C footprint of EU member countries in year 2015, as well as the prognosis of European countries mix in years 2015, 2020, 2030 and 2050 are discussed in detail in [29].

Figure 3.4 illustrates the impact of the carbon intensity of the national electricity grid on the impact of EVs compared with reference conventional vehicles. It is clear from Figure 3.4 that the carbon intensity of the electricity grid plays vital role. In Poland, the EVs using electricity from the power grid have the highest GHG emissions compared to the rest of the BEVs, but still the related GHG emissions are calculated to be 25 percent lower in comparison to the benchmark conventional diesel vehicle. The electricity grids having the lowest carbon footprint provide GHG emissions up to 85 percent in comparison to the conventional benchmark vehicle.

Figure 3.5 depicts the carbon (C) intensity of different production units including the solar, gas, hard coal, wind, nuclear and also the anticipated enhancements of the EU carbon intensity of electricity grid during the time period ranging from 2015 to 2050. As the carbon intensity of the EU average grid is expected to drastically lessen, the GHG emissions distributed to EVs will significantly reduce by each decade.

Following are the conclusions drawn from the investigation of different aspects of LCA.

1. The foremost important prospect for improving the BEV's impact depends on the electricity source mix. Guaranteeing the relatively high usage of renewable energy will radically decrease the impact of a BEV. The de-carbonization of the electricity power grid will decrease several impacts of the BEV, especially reducing the climate change impact. Replacing the coal based power plants and switching to the natural gas or renewable energy source will considerably enhance the performance in East of Europe.
2. BEVs have substantial lower impact on the climatic change as well as the urban air quality, in comparison to the conventional vehicles.
3. Novel chemistries for lithium-ion batteries which can avoid energy intensive as well as toxic materials' usage can drastically lessen the impact. The fine-tuning i.e. the minimization of usage of material in anode and cathode along with the optimization of the production process (by larger volumes) of the already existing battery technologies will enhance the general impact of a BEV.

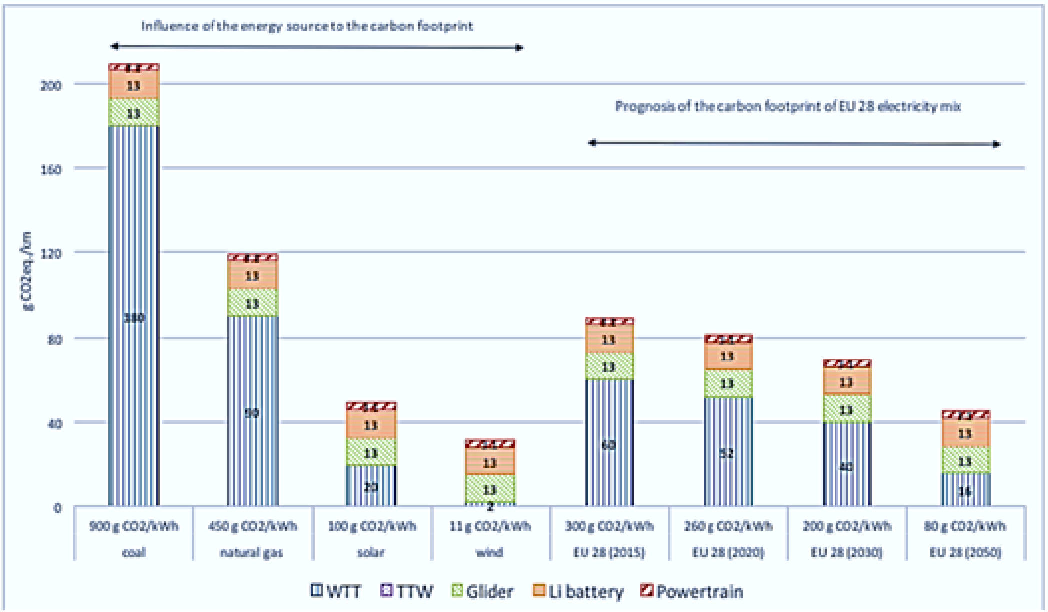


Figure 3.5 GHG emissions of EVs depending on the energy sources and the prognosis of the reduction in carbon intensity

4. Any decrease in the weight of a BEV or its related electricity consumption aspects will significantly decrease the impacts associated with the electricity generation. BEV weight drop has to come from the replacement of the steel chassis with any other material having less weight and in the meantime enhance the battery's energy density.
5. The recycling process of a li-ion battery for a BEV has a positive impact since it assists in saving materials and at the same time helps in avoiding the carbon intensive procedure of primary material manufacturing in near future. It is suggested that EU policy makers have combined both the end-of-life of the vehicle end-of-life edict along with the end-of-life of the battery edict for increasing the required recycling efficiency of the vehicule battery.
6. To decrease the environmental impact caused by the manufacturing phase of all BEV components, usage of renewable energy for both electricity and heat generation plays a vital role for further reduction of the environment impact.

3.4 Recycling

Demand for Li-ion battery is increasing rapidly due to advancement in EVs and other applications like mobile phones and laptops. But it is impacting our environment negatively as we have discussed in the above section. We should find the best recycling techniques by which we can decrease the environmental pollution by reducing CO2 and GHGs emission. Through the recycling process we can get lithium, nickel and other materials back and we can use them again. We can use three basic recycling techniques:

- Hydrometallurgical recovery.
- Pyro metallurgical recovery. This process works only at high temperature.
- Direct recycling. Direct recycling allows for a higher percentage of the battery materials to be recovered.

4 Lithium Ion Batteries:

As far as we know till the end of 1900s the only source of power which we have was the battery. At that time we were not that much developed in power generation and grid supplies. But with time and continuously improvements and development in power generation and grid supplies many different types of batteries are also developed. Wet cells were very common, and it was used in open container containing liquid electrolyte and metallic electrodes. This type of battery was able for reuse just by substituting the materials.

In the early age of battery development the current was produced as the assembled battery however there was a problem this type of battery could not be recharged electrically the reason was the depletion of active elements. Then there was a very good breakthrough when the lead acid batteries were invented and that batteries were rechargeable and can store the electric energy. It can store energy repeatedly again and again and its life time was increased. And Li-ion batteries become more popular in the market of rechargeable batteries. The reasons for popularity were high energy density and long life but the price per unit was high.

4.1 Li-Ion Battery Structure

Like other types of available batteries, the li-ion rechargeable battery is made of one or more power-generating sections which are known as cells. Each cell has three main working components which are as follows:

1. A positive electrode (which is connected to the battery's positive terminal) which is also known as cathode. It is typically made from a chemical compound called lithium-cobalt oxide ($LiCoO2$) but in newer batteries, from lithium iron phosphate ($LiFePO4$).
2. A negative electrode (which is connected to the negative terminal) which is known as anode. It is generally made from carbon (graphite) and the electrolyte varies from one type of battery to another
3. An electrolyte in between them which is a chemical. The type of electrolyte varies from one type of battery to the other type of battery.

4.1.1 Working of Li-Ion Battery

Nearly all types of Li-ion batteries work in the same manner. When we are in the charging phase of the battery, the positive electrode (lithium-cobalt oxide) always gives up some of its lithium ions, which then move through the electrolyte to the negative electrode (graphite electrode) and remain on the electrode. During this process the battery takes in the energy and stores it. Ions move from cathode toward the anode through electrolyte.

When the battery is discharging phase, the li-ions move back through the electrolyte toward the positive electrode, which produce the energy and that energy powers the battery. Now in both cases (charging and discharging of the battery) electrons flows in the opposite direction to the ions around the outer circuit. The electrons do not flow through the electrolyte. The ions move through the electrolyte, but the electron moves through the external circuit and they flow in the opposite direction [55].

Here we need to understand this that the movement of ions (through the electrolyte) and electrons (around the external circuit) they both are interconnected processes, and if one of them stops the other process will stop automatically. If ions stop moving through the electrolyte in the case when the battery is completely discharged, the electrons will not be able to move through the outer circuit either.so in this case we will lose our power. Similarly, if we switch off whatever our battery is powering, the flow of electrons stops and so also the flow of ions. The battery essentially stops discharging at a high rate (but it does keep on discharging, at a very slow rate, even in the case when it is not connected to anything).

Unlike the other batteries, li-ion have the built-in electronic controllers that regulate how they charge and discharge. These electronic controllers prevent the overcharging and overheating of the Li-ion batteries that can cause it to explode in some conditions.

4.1.2 How Lithium-Ion Battery Charges and Discharges

As the name suggests, this battery is all about the movement of lithium ions. The ions move one way when the battery charges and they move in the opposite way when the battery discharges [55].

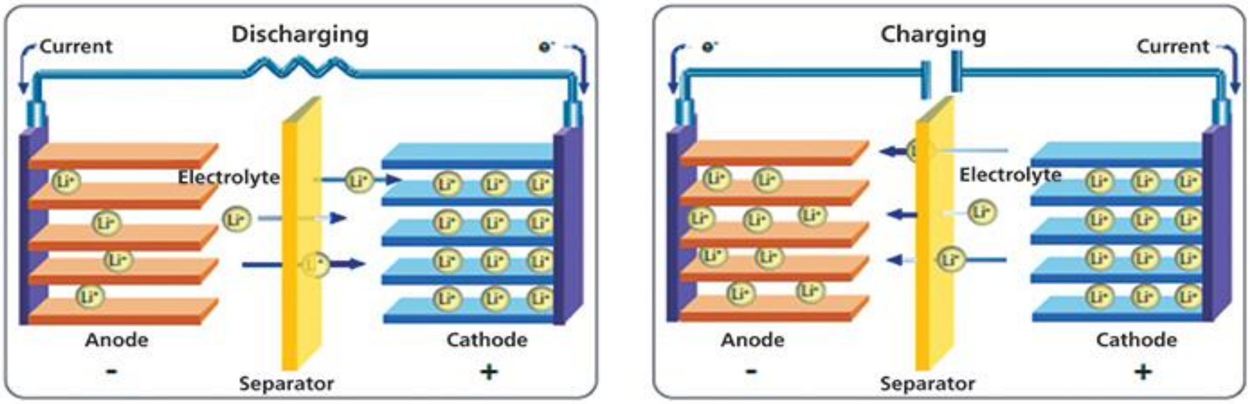


Figure 4.1 Lithium-Ion battery charges and discharges

When the battery is in the charging phase, lithium ions moves from the positive electrode (cathode) towards the negative electrode (anode) through the electrolyte. At the same time electrons also moves from cathode to anode, but this process take the longer path around the outer circuit. The electrons and ions now combine at the negative electrode and deposit lithium there.

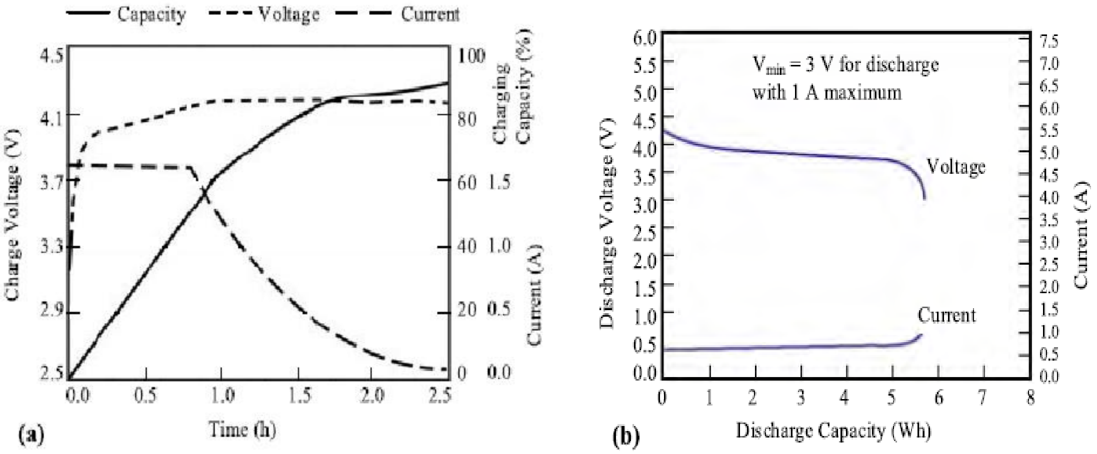


Figure 4.2 Relation between Capacity, Voltage and Current with respect to Charging and Discharging of Lithium-Ion Battery

When no more ions will move, it means that the battery is fully charged, and we can use it. When the battery is in the discharging phase, the ions move back through the electrolyte from the negative electrode to the positive electrode. Electrons will also move from the anode towards the cathode through the outer circuit. When the ions and electrons combine at the positive electrode, lithium is deposited there [47].

When all the ions have moved back (from anode to cathode), the battery is fully discharged and needs the charging.

4.1.3 Characteristics of Lithium-Ion Batteries

The important characteristics of Li-ion batteries are as follows:

- The size of the Li-ion batteries (physical and energy density).
- Capacity and life cycles.
- Charging and discharging characteristics.
- Cost.
- Battery performance in a wider temperature range.
- Self-discharge profile and leakage and the toxicity impact.

So we can say that lithium ion batteries have both positive and negative points. The positive point can include the high specific energy which is 230Wh/kg and it has very good power density which is also very high which is 12kW/kg. It also has good energy density and long and very good life cycle as compared to the other batteries. The electronic protection system is always needed during charging and discharging due to which it has high costs and li-ion batteries emit the GHGs during the manufacturing process and disposal of it are the negative point [48][55].

We can see from the above figures the Li-ion battery has very good charging and discharging characteristics. While charging the battery it's charging capacity increases gradually with the charge voltage while maintaining the constant current. And when the voltage reaches to the maximum level the current start decreasing exponentially. While on the other hand the discharge capacity maintains an almost constant voltage and current to the load although there is a small increase and decrease in the values of current and voltage respectively until the cell capacity reaches the minimum level [48].

4.1.4 Lithium-Ion Components

The Li-ion battery is consisting of four primary components including

- The cathode
- The anode
- The electrolyte
- The separator

The cathode is made up of lithium-metal-oxide powder. The lithium ions enter the cathode when the battery is in discharging phase and leave it when the battery is in charging phase. The reactions below show the chemistry functions in moles. The chemical reaction that occur at cathode is given as follows.

$$LiMO_{2_{Li_1}} \times MO_2\,C \;\times LiC\,C \;\times e$$

The anode is made up of from graphitic carbon powder. The lithium ions leave the anode when the battery is in discharging phase and enter the anode when the battery is in the charging phase. The chemical reaction is given as follows:

$$C\;C\;LiC\;C \times e_{Li} \times C$$

Both the cathode and anode are made of lithium metal oxide and lithiated graphite in Li-ion batteries where both structures are organized in layer on aluminum and copper current collectors respectively.

The electrolyte is composed of lithium salts and organic solvents. The electrolyte is use for the transportation of the lithium ions between the cathode and anode rather than electrons. The separator is a micro-porous membrane that is used to rule out the short circuit between the cathode and anode and that only allows lithium ions to pass through the pores. The overall reaction of the lithium battery is given as follows.

$$LiMO_2C\ C_{Li} \times C\ C\ Li\ I\!:\ \times\ MO_2$$

4.1.5 Lithium-Ion Batteries Formations

These batteries can be constructed and packed in two major formations. Which are either in cylindrical or prismatic shapes which are known as Li-ion polymer batteries. It can be shaped as the cylindrical structure of rolled and plastered layers in metal cans with electrolytes. But in the stacked form the three layers are confined in laminate film and where their edges are heat sealed aluminized plastic. A gel or polymer is often used to prevent the electrolyte from leaking in this package. For the energy source in EVs Li-ion cells must be assembled into modules and then further composed into battery packs of series-parallel connected cells to achieve the precise energy demands [49].

4.1.6 Types of Lithium-Ion Batteries

In Lithium-ion batteries the main sources of the active lithium ions are the positive electrode material (cathode). And if we want to achieve high capacity a good amount of lithium is also included in this material. Additionally positive electrode material follows a reversible process to exchange the lithium which is done with slight structural modifications to its basic properties. In the electrolyte the materials are prepared from high lithium ions that have diffusivity, good conductivity and high efficiency. Those types of positive electrode materials involve lithium cobalt oxide ($\boldsymbol{LiCoO_2}$)**,** lithium manganese oxide **(**$\boldsymbol{LiMn_2O_4}$**)**, lithium iron phosphate **(**$\boldsymbol{LiFePO_4}$**)**, lithium nickel-manganese-cobalt oxide **(**$\boldsymbol{LiNiMnCoO_2}$**)**, lithium nickel cobalt aluminum oxide **(**$\boldsymbol{LiNiCoAlO_2}$ **)** and lithium titanate ($\boldsymbol{Li_4Ti_5O_{12}}$) [49].

4.1.6.1 Lithium Cobalt Oxide ($LiCoO_2$)

Lithium cobalt oxide first invented by Sony in 1991 and improvement in the materials was done by Mizushima.

It has very high specific energy and this high specific energy makes this type of battery the common choice for mobiles, tablets, laptops and cameras.

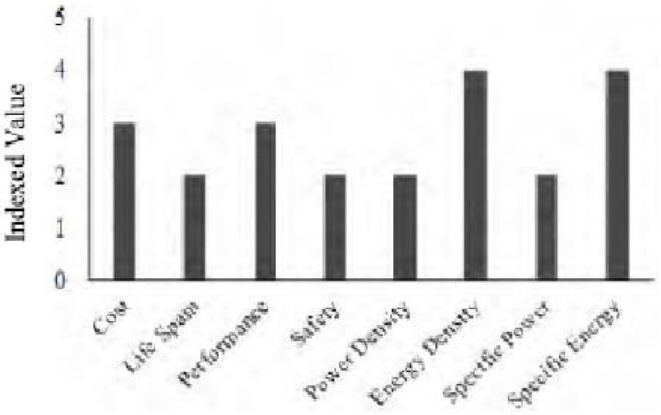


Figure 4.3 Lithium Cobalt Battery Performance

The cost of this type battery is high due to the constrained accessibility of cobalt and due to the high cost, the replacement of the cathode materials would be required to increase its applications which is done in the case of EVs [47]. The battery is comprised of a cobalt oxide positive electrode and a graphite carbon negative electrode in a layered structure that release lithium particles to travel between cathode and anode during charging and discharging. This type of batteries has a short life period and very restricted load capacities and it is not able to be charged and discharged at currents which are out of its range. Also this type of batteries requires special protection against overheating and excessive stress while charging quickly. The charge and discharge rate need to be limited to a secure level of approximately 1C.

4.1.6.2 Lithium Manganese Oxide ($LiMn_2O_4$)

This type of battery was first introduced in 1994 and it was built by Bellcore lab. It has 3D spinal architecture and it was organized as a diamond structure and this

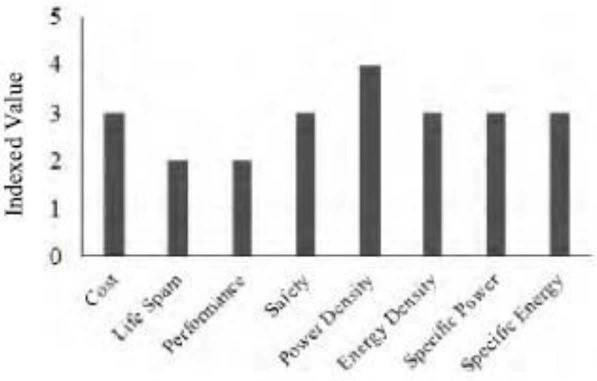


Figure 4.4 Lithium Manganese Battery Performance

diamond structure allows the particle to steam on the electrode so that it enhances current dealing and reduces internal resistance to charge quickly and discharges with a high current. Due to its special structure it has high thermal stability and safety, but its life period is also limited by this structure. Lithium manganese oxide has much more specific energy compared to cobalt, but cobalt life period is greater than manganese oxide.

The capacity of this type battery is approximately 33% lower compared with Li-cobalt but on other hand this type of battery provides approximately 50% more energy than nickel-based batteries. If we want to study the general performance except for power density the current outlines of Li-manganese offer enhancement in specific power, energy density, well-being and life span [47].

4.1.6.3 Lithium Iron Phosphate ($LiFePO_4$)

In 1996 it was found by the University of Texas that phosphate could be used as a cathode material for lithium batteries. In this type of batteries the cathode is steady in the overcharged condition and it can tolerate high temperatures without any damage. The cathode material in this type of battery is more secure than other cathode materials like $LiCoO_2$ or $LiMn_2O_4$ batteries. Operating temperature of this battery range from -30◦C to +60◦C. The cell packing temperature range from -50◦C to +60◦C.

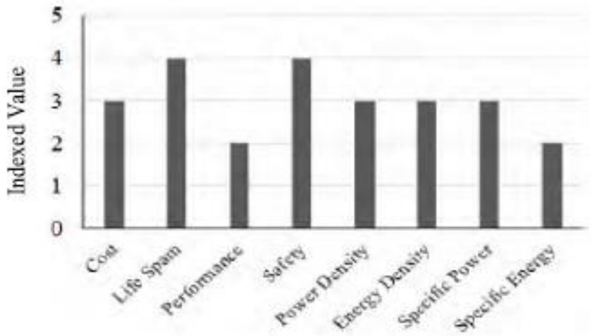


Figure 4.5 Lithium Phosphate Battery Performance

It is made up of Nano scale phosphate materials and has a very low resistance, long life span, high-load handling capability, improved security and thermic consistency. It also do not have any toxic effects and they are also less expensive. Due to temperature it has some negative performance and service life properties. These batteries can provide a specific energy and nominal voltage of approximately 160 mAh/g and 3.40 V, respectively [47].

4.1.6.4 Lithium Nickel Manganese Cobalt Oxide ($LiNiMnCoO_2$)

Nowadays the battery manufacturing companies are more interested in a cathode which is made up of from the mixture nickel-manganese-cobalt (NMC). We use this type of cathode to get either high specific energy or high-power density. The combination of nickel and manganese exhibits good overall performance drawing out the high specific energy of nickel and the low internal resistance effect of manganese, although nickel is low stable, and manganese provides low specific energy.

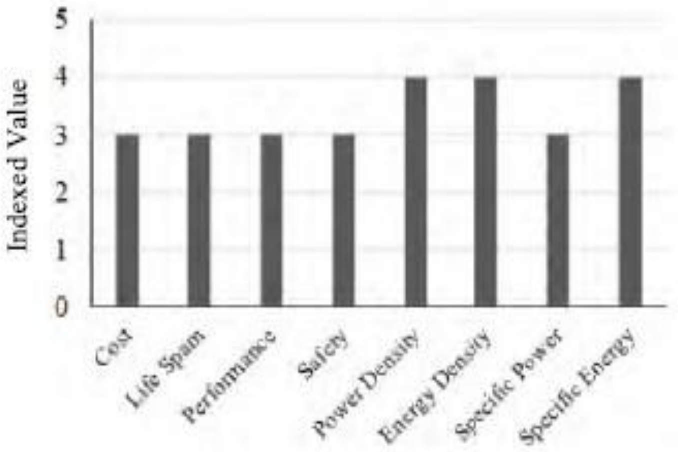


Figure 4.6 NMC Battery Performance

The mixture of cathode consists of 33% nickel, 33% manganese and 34% of cobalt. It also brings the costs of raw material very low because of the very less amount use of cobalt content. Nowadays due to their high specific energy and minimum self-heating rate they have very high demand in the EVs.

4.1.6.5 Lithium Nickel Cobalt Aluminum Oxide ($LiNiCoAlO_2$)

This type of batteries has a small amount of the worldwide market share and automobile industries are focusing on use of NCA battery production because of its high

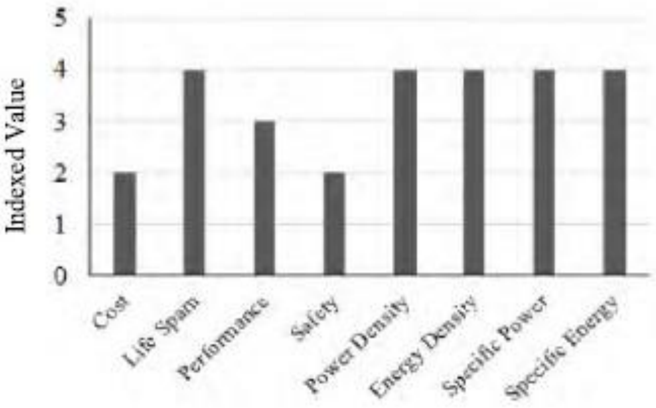


Figure 4.7 NCA Battery Performance

profile i.e., high specific energy and power densities and long-life span considering cost and safety.

4.1.6.6 Lithium Titanate ($Li_4Ti_5O_{12}$)

Lithium-titanate anodes have been commonly used for batteries since the 1980s. It has special type of spinel architecture and it is also the substitution for the graphite anode of the Li-ion battery.

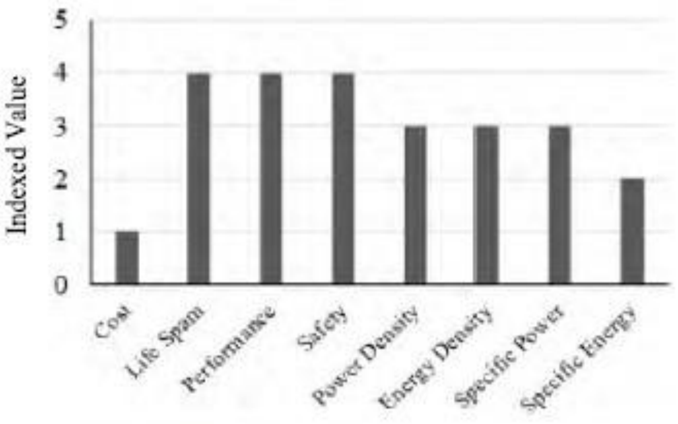


Figure 4.8 Lithium Titanate Battery Performance

It is normally 2.40 V and shows a high capacity, a high charge and discharge rate and a high life span compared to that of a typical Li-ion battery. Moreover this type of batteries can be operated safely and have phenomenal features at cold temperatures. Because its specific energy is not high, unlike other Li-ions, the developments and

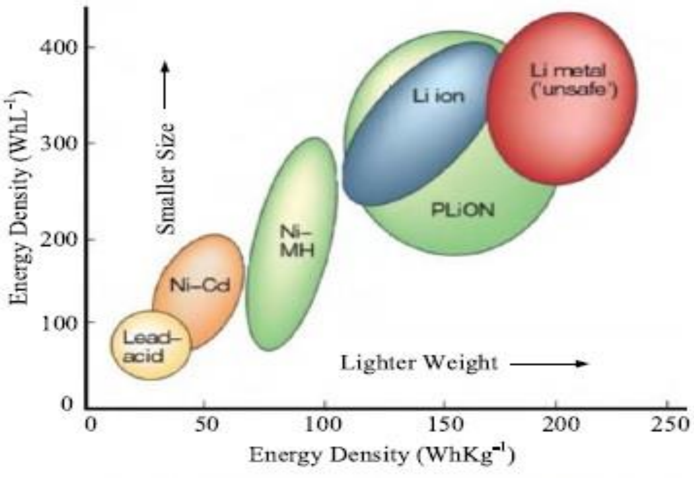


Figure 4.9 Gravimetric & Volumetric Energy Density of Various Battery Types

research are working on improving the specific energy and reducing the price.

4.1.7 Performance Comparison of Lithium-Ion Battery with other Batteries

Today in the market different types conventional batteries are available such as lead-acid batteries, nickel-cadmium (Ni-Cd) batteries and nickel-metal hydride (Ni-MH) batteries. But the Li-ion batteries have better high energy efficiency and power density as compared to the other available batteries, due to which these batteries are lighter in weight and smaller in size. If we want to see the other advantages of Li-ion batteries compared to the other batteries that will include a broad temperature range of operation, they have rapid charge capability, they have long life span, low self-discharge rate, energy, and voltage efficiency. And we can say that these are the specific reasons for domination of Li-ion batteries commercially the battery markets for powering bio-implanted devices, medical instrumentations and portable devices. Li-ion batteries has slightly linear discharge characteristics as compared to other type of batteries. All other types of batteries have smooth and flat discharge characteristics with their own specific energy and power level [46].

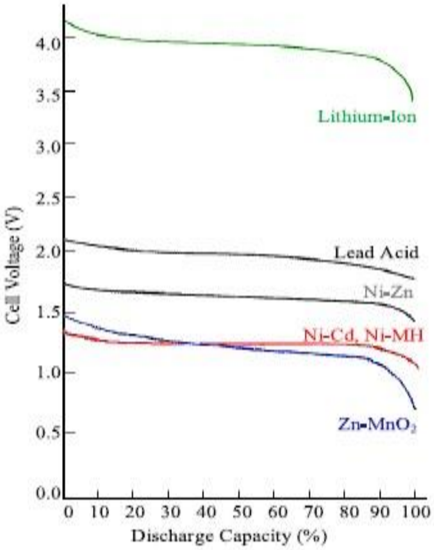


Figure 4.10 Discharge Characteristics of Lithium-Ion, Lead Acid, Ni-Zn, NiCd, NiMH and Zn-MnO2 cells

4.1.8 Performance Comparison between Lithium-Ion Battery Types

4.1.8.1 Lithium Cobalt Oxide

The specific energy is high as compared to the other Li-ion batteries and this is the reason they are good choice for use in laptops and mobile phones. It has a moderate performance with low cost. But it also has some drawbacks which are low specific power, low safety, and a low lifespan [47][56].

4.1.8.2 Lithium Manganese Oxide

The specific power is moderate and if we want to talk about specific energy and level of safety so they both are also moderate when compared to the other types of lithium-ion batteries. But the one advantage it has on other types is the low cost of this battery. The drawback is it in not good in performance and it has short life [56].

4.1.8.3 Lithium Nickel Manganese Cobalt Oxide

The two noticeable positive points of this type of battery is

- First is its high specific energy which makes it feasible for use in electric powertrains, EVs and electric bikes.
- Second is the cost. It has low cost compared to other Li-ion batteries.

In terms of specific power, safety, lifespan and performance it is moderate as compared to the other lithium-ion batteries [56].

4.1.8.4 Lithium Iron Phosphate

In terms of use this type of battery has only one major disadvantage and that is low specific energy. If we forget about the specific energy for a while and see other characteristics they range from moderate to high. It has high specific power, level of safety is also high, high lifespan and all of these characteristics comes at a low cost. The performance of this battery is also moderate.

4.1.8.5 Lithium Nickel Cobalt Aluminum Oxide

It has only one advantage as compared to the other types and the only positive point is the high specific energy. Except high specific energy it does not offer much when compared to other types of Li-ion batteries. But for use in the electric power trains it is a good battery [56].

4.1.8.6 Lithium Titanite.

This battery has high safety, high performance and a high lifespan. It has low specific energy, but it can be compensated for a moderate specific power. And the cost of this battery is very high, so this is the only drawback of this battery.it has very good and fast charging time. Table 4.1 provides the performance comparison of different type of lithium-Ion batteries [56].

Li-ion Battery Type	Specific power	Specific energy	Safety	Lifespan	Cost	Perform-ance
Lithium Cobalt Oxide	Low	High	Low	Low	Low	Medium
Lithium Manganese Oxide	Medium	Medium	Medium	Low	Low	Low
Lithium Nickel Manganese Cobalt Oxide	Medium	High	Medium	Medium	Low	Medium
Lithium Iron Phosphate	High	low	High	High	Low	Medium
Lithium Nickel Cobalt Aluminum Oxide	Medium	High	Low	Medium	Medium	Medium
Lithium Titanate	Medium	Low	High	High	High	High

Table 4.1 Performance Comparison of Different Type of Lithium-Ion Batteries

4.1.9 Issues with Lithium-Ion Batteries

4.1.9.1 Temperature

In Li-ion batteries the temperature generates due to the chemical reactions that take place inside the battery. And we can say that this temperature production inside the batteries is the main and common problem of all batteries. And eventually this temperature kills the battery. Temperature control mechanism is necessary for the lithium ion batteries to keep it safe from any type of damage. Battery will operate both in low and high temperature. At low temperature the rate of chemical reaction is decreased and due to this decreased rate of chemical reaction the charging and discharging of the battery is also reduced. And if the temperature of the battery is increased it will cause the abnormal behavior of the chemicals and will finally result in the explosion of the battery [47].

4.1.9.2 Safety

Engineers and scientists are working on the safety of Lithium ion batteries and they are very much concerned about the safe operation of the battery. Whenever we want to use the Li-ion batteries we will use them in packs due to safety concerns and single cell of the battery will never be used because of its explosive characteristics. Lithium ion batteries will always requires some circuits to keep an eye on the battery conditions and to protect them from any fault when we are using the battery. So due to this specific reason, the development of Li-ion battery packs is more difficult than building and arranging batteries [54][52].

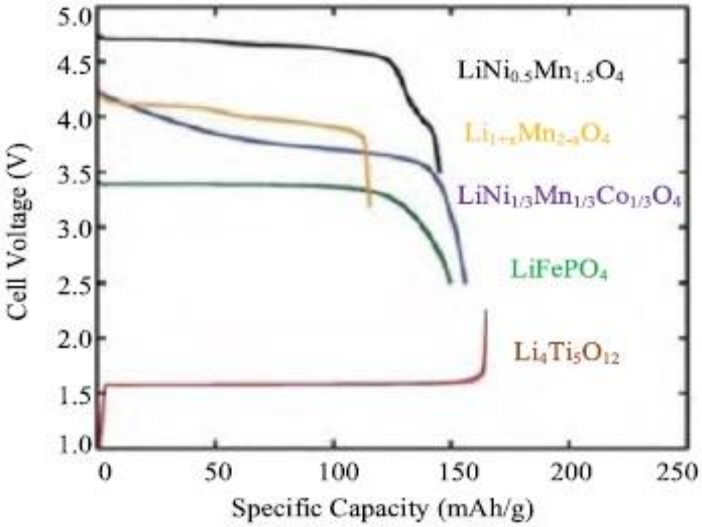


Figure 4.11 Operating Voltage Profile of all Lithium Electrode Materials

4.1.9.3 Life-Cycle

The loss of a cell function has a negative effect on the life cycle of the battery. It is necessary here to mention that if a cell of battery work outside of its operating range the capacity loss will occur. This will affect the battery life and will decrease the life cycle of the battery and even it is possible that will cause the permanent loss of use. The life cycle of the battery depends on the cell chemistry and the amount of time battery spent at the upper and lower temperature limits. Due to anode plating the lifecycle of battery falls slowly at a low temperature. But decreases sharply at a high temperature due to the chemical breakdown.

4.1.9.4 Memory Effect

This issue arises when we recharge the battery repeatedly after being discharged partially in irregular manner and arise due to many charge and discharge cycle at normal operation. Especially in EVs when we use the breaks during this the engine will start working as a generator and it will partially charge the battery but when we want to accelerate the engine then the battery is partially discharged. This process of partially charging and discharging of the battery will lead it to the memory effect in Li-ion batteries which are used in EVs. We can overcome this problem by subjecting individual cell to deep charge-discharge cycle process by using optimal charge and discharge control technique [54].

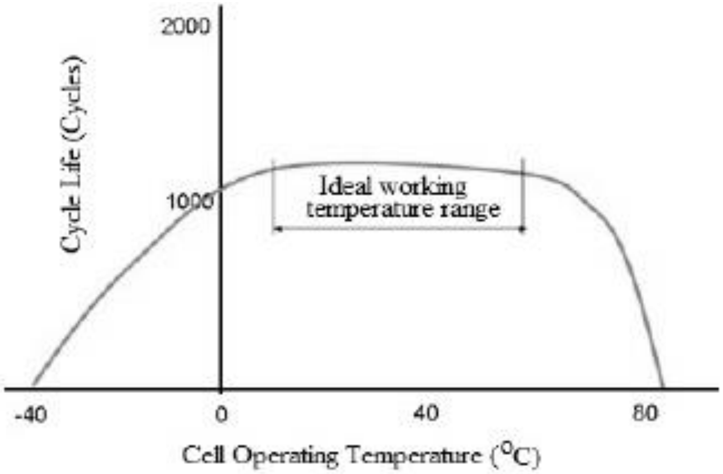


Figure 4.12 Life-Cycle and Temperature Graph (Cycle Life vs. Cell Operating Temperature)

4.1.9.5 Cost

Lithium is the best chose for batteries and a lot of work is going on to deal with the prize issue. If we see lithium price one decade ago it was very high but a lot of work in this field open ways for it to use it in a numerous application, so demand is increased greatly and now the price is more negotiable. Over last five years the market price of Li-ion batteries has been greatly decreased and in last three years the price has been dropped 15% nearly each year and it may fall more than 255 by 2020. And in the coming future the cost and the availability will mainly depend on the market demand and in the advancement in EVs technology and the number of this vehicle in use. But a lot of research is also under way on the effect of lithium on our environment and there are chances it will change the mind set of researchers about use of that much lithium in the future and that will also affect the cost [50].

4.1.9.6 Environmental Impact

Increasing the air pollution in recent decades and also the oil prices and the demand of enormous energy for sustainable transportation have caused a trend towards automobile as EVs, HEVs, and PHEVs. It is claimed by *Toyota* that more than 7% of the world transportation will be by electric vehicle by 2020. Although use of these EVs has a great positive impact on the environment but on other side the Li-ion battery emits CO2 and GHGs during production and disposal. The US EPA examined Li-ion batteries for its use of nickel- and cobalt-based cathodes and solvent-based electrode processing in a study and found high environmental impacts, such as resource reduction, global warming, ecological toxicity and human health impacts and so on. According to this study, the people involved in the production, processing, and use of cobalt and nickel metal compounds may be affected with adverse respiratory, pulmonary and neurological diseases [50][54].

4.1.9.6.1 Exhausting our natural resources

It is believed that one of the largest deposits of lithium is stored under the Salar de Uyuni in northern Chile and southern Bolivia. And the Bolivian Andes Mountain contain over two-thirds of the world’s total lithium supplies, according to some experts. Due to presence of that large amount of lithium intense drilling operations are going on over the last few years to extract the large amount of lithium.

That much increase in demand for lithium is due to the announcement that made by the Chinese government in 2015, when it prioritized electric vehicles (EVs) as part of its 13th Five-Year Plan. Over the period from 2016-2018. Now the price of lithium has more than doubled and is expected to keep on rising as global demand continues to increase [50][52].

The problem is that extraction of lithium will need 500,000 gallons of water just to produce single ton of lithium. So that much water use for extraction will take the water away from the farmers of that area that water which is necessary for cultivation of their crops and livestock.

4.1.9.6.2 A polluting after-effect

To extract lithium we use the toxic cocktails of chemicals. And these toxic chemicals are infiltrating the nearby rivers, stream and other water supplies. During the mining operation in 2016 in liqi River in Tibet this catastrophe occurred where mining operations contaminated the water and resulted in thousands of dead fish and many poisoned cattle and yak. In the last seven years this occur three times [50][52].

Also in the areas where lithium is mined from rock rather than under the ground, chemicals are still use in the process. A recent report into the effects of a lithium mine in Nevada found fish had been affected by the operation up to 150 miles away.

5 Recycling of Li -ion Batteries

The drive to replace polluting petrol and diesel cars with a new breed of electric vehicles has gathered momentum in recent years. The benefits of driving an electric vehicle (EV) are numerous. EVs pump less CO2 into the atmosphere and reduce noise pollution in cities. They are also becoming increasingly affordable for middle- and low-income consumers as demand drives down battery prices and governments implement national and local policies aimed at incentivizing EV growth [29].

But although EVs are often touted for their sustainability, they nonetheless carry with them environmental concerns. This is especially true when it comes to their batteries, which typically must be replaced every seven to 10 years for smaller vehicles and three to four for larger ones, such as buses and vans; contain toxic chemicals that cannot simply be tossed into a landfill, and involve an intensive manufacturing process.

Given the relative newness of the global electric vehicle market (10 years ago, consumer electric vehicles were nearly non-existent), the question of battery recycling is just coming to the forefront now. As of this year, pioneering first-generation electric vehicle models such as the 2010 Nissan Leaf are being retired and replaced with newer models. This also means that for those early models, owners must soon replace their batteries, as well.

After a battery is smelted, the lithium ends up as a mixed byproduct and extracting it is costly. The price of fully recycling a lithium-ion battery is falling towards €1 per kg. The problem is, the value of the raw minerals reclaimed from the process is only a third of that [30].

The spiraling environmental cost of our lithium battery addiction As the world scrambles to replace fossil fuels with clean energy, the environmental impact of finding all the lithium required could become a major issue in its own right [29].

It’s especially risky when lithium-ion batteries end up in the back of a dry recycling truck surrounded by paper and cardboard. lithium-ion batteries are one of the most common fire starters in recycling trucks!

If countries meet the Paris climate change targets, the resulting electric vehicle boom would lead to more spent lithium-ion batteries than ever**.** By 2030, electric vehicles alone could leave up to 11 million tons of lithium-ion batteries which need to be recycled**.** Without action, we risk releasing dangerous toxins from the damaged lithium-ion batteries [30].

Currently, however, it’s estimated that only about 5% of lithium-ion batteries that power various home electronics and other goods are recycled. This build-up will only increase as electric vehicles continue to gain popularity. It has been estimated that as many as 11 million tons of used lithium-ion batteries could accumulate worldwide between now and 2030.

Electric vehicle batteries are simply too big to be kept at home and can’t be left in a landfill**.** A smelting process is used to recover many minerals, but it alone can’t recover the precious lithium[29].

Figure 5.1 Tesla Battery Pack

Companies such as Aceleron and Nissan, think the solution is reusing the spent batteries, rather than recycling. Many EV batteries which are ‘spent’ still have up to 70% capacity left – more than enough for other uses. After used EV batteries have been broken down, tested, and re-packaged, they can be used for things like home energy storage**.** Either way, we need a solution for a problem which is getting worse by the month[30].

British and French governments last month committed to outlaw the sale of petrol- and diesel-powered cars by 2040, and carmaker Volvo pledged to only sell electric or hybrid vehicles from 2019[31].

Umicore of Belgium has been one of the few companies recycling lithium-ion batteries, through a process of smelting and leaching with chemicals to recover metals. It is now operating a pilot process for recycling electric car batteries, it says, in preparation for the “sizeable” numbers that are likely to come to the market in 2025. One problem is that lithium ion batteries in electric cars use a variety of chemical processes, making it difficult to develop standardized recycling [33].

This has an environmental cost. Not only do the batteries carry a risk of giving off toxic gases if damaged, but core ingredients such as lithium and cobalt are finite and extraction can lead to water pollution and depletion among other environmental consequences [31].

In the case of the older-technology lead-acid batteries, 96 percent of the materials in the battery -- including the nasty lead -- is recovered. To compare, only 38 percent of the material in glass bottles is recovered in the recycling process. They can also be recharged and reused before being recycled. Hybrid cars currently on the road, like the Toyota Prius, use nickel metal hydride batteries, which can be dismantled and recycled in much the same way [32].

Since lithium-ion battery-powered cars are just now coming to the mass market, the recycling centers that can reclaim their components are still in their infancy, too. Toxco, a big lead-acid battery recycler, is set to open the first lithium-ion battery recycling plant in the U.S. Companies like Tesla Motors, which has had lithium-powered electric sports cars on the road for a couple of years now, already sends its spent batteries to Toxco's current facilities for recycling [32].

When lithium-ion batteries reach a recycling plant, there are two ways to pulverize them. If they are completely without a charge, they're simply shredded so that the metal components, like copper and steel, can be easily sorted out. If the batteries could still possibly have a charge, though, they're frozen in liquid nitrogen and smashed to frozen bits (cool!). The liquid nitrogen is so cold, the batteries can't react, so the smashing is safe. And probably fun. Then the metals are separated out for reuse [32].

Carbon, which is the most expensive battery component, is almost always used as the anode material. Cobalt and lithium are quite limited materials and they are interesting due to their scarcity. Nickel is highly toxic for the environment, but manganese is not as worrisome as the others mentioned [34].

Most EVs run on lithium-ion batteries. As car batteries are spent and replaced, finding ways to recycle and reuse them can reduce the need for additional resource extraction, which is good for the environment and for human rights. Although electric car batteries are no longer fit to power an electric vehicle after seven to 10 years (or four for a larger vehicle) of use, they still contain about 70% of their capacity when they're retired, according to The Guardian. When this is the case, they can be repurposed in a number of creative ways. Additionally, they can be recycled through smelting, direct recovery, and other, newer processes. lithium is a highly reactive element. These batteries have a flammable electrolyte and pressurized contents that could lead them bursting into flames [29].

Several battery recycling methods are already in use, such as pyrolysis, hydrothermal recycling, and direct physical recycling. These have their advantages and disadvantages. Direct and hydrothermal methods use the chemistry-specific process and require sorting the batteries by content. Direct physical recycling requires improving and adaptations, such as unpacking the cell interior and enabling efficient removal of materials for processing.

The number of electric cars in the world passed the 2m mark last year and the International Energy Agency estimates there will be 140m electric cars globally by 2030 if countries meet Paris climate agreement targets. This electric vehicle boom could leave 11m tones of spent lithium-ion batteries in need of recycling between now and 2030, according to Ajay Kochhar, CEO of Canadian battery recycling startup Li-Cycle [31]

Lithium-ion batteries are a crucial component of efforts to clean up the planet. The battery of a Tesla Model S has about 12 kilograms of lithium in it, while grid storage solutions that will help balance renewable energy would need much more [33].

Like any mining process, it is invasive, it scars the landscape, it destroys the water table and it pollutes the earth and the local wells

Paradoxically, "the green EV" could generate more carbon emissions than fossil fuels cars due to its procurement of raw materials, manufacturing, use and recycling process. Manufacturing a battery requires a lot of energy, from the mining of raw materials to the energy consumed in production. Although EVs are presented as super clean energy, consumers need to also consider the following [34]:

Environmental impacts in the Democratic Republic of the Congo such as the dust, fumes, and the wastewater caused by cobalt mining;

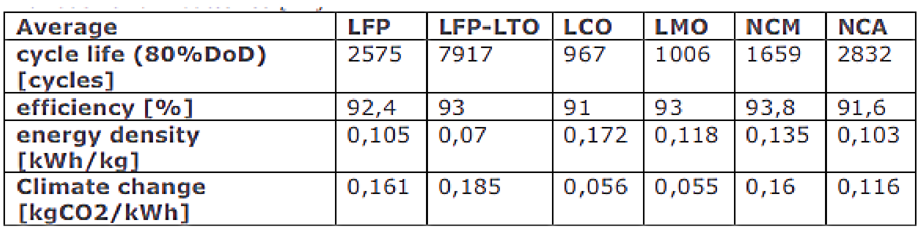
a) problems in Latin America such as water shortages and toxic spills from lithium mining;
b) a polluted river caused by nickel mining in Russia;
c) air pollution in north-eastern China

The battery is an expendable item and has its lifetime. The logical question here is what will be done with the tons and tons of dead batteries after they have served their purposes. According to the Financial Times' estimation, 11 million tons of spent Li-Ion batteries will be in the market by 2025. To protect our environment from pollution and toxic waste, the battery resources need to be used in the best possible way [34].

As mentioned above, a battery is composed of different items: the electrolyte, separator, foils, and casing which are all made from different materials. They need to be disassembled and then recycled, which makes this process quite complicated. Bolts are preferred over glue, and electronic modules and copper connectors should be simple to separate. The figure below shows the battery components and building materials.

The first solution would be the batteries re-use principle, where the EV batteries in "bad condition" could be used in other applications such as in households or energy backups. When the capacity of a car battery drops below 70-80 percent, they are no longer suitable for an EV but still strong enough for many other applications. The EV batteries have quite a long lifecycle, estimated up to 10 years, and by re-purposing them, this lifecycle can be prolonged even up to about 20 years [34].

Battery recycling is a second solution which could be combined with the first solution. The battery is made by combining different materials inside, thus its recycling is a complex and expensive process. Lithium is a valuable material. To reclaim one ton of lithium, about 30 tons of batteries need to be recycled. However, for extracting one ton of raw lithium from a mine, about 1375 tons of soil must be excavated as well[34].



Average	LFP	LFP-LTO	LCO	LMO	NCM	NCA
cycle life (80%DoD) [cycles]	2575	7917	967	1006	1659	2832
efficiency [%]	92,4	93	91	93	93,8	91,6
energy density [kWh/kg]	0,105	0,07	0,172	0,118	0,135	0,103
Climate change [kgCO2/kWh]	0,161	0,185	0,056	0,055	0,16	0,116

Table 5.1 Comparison of various Lithium-Ion Batteries on different parameters leading to Climate Change (kgCO_2/kWh)

Generally, it is expected that no issues will occur with recycling the cobalt or nickel, but recycling lithium requires introducing new processes. Using the pyrolysis method is unlikely to be cost effective. Hydrothermal and direct physical methods could help solve this issue, however, upgrading the methods is required[34].

The main issue with battery recycling is that it is currently expensive. Basically, it is cheaper to buy new material then recycle the used one. The environmental issues are definitely an important aspect in the case of battery materials. The recycling methods need to be improved upon in order to be more cost-effective, but government regulations must be also adapt to enforce battery recycling[34].

The simple method Chen and his colleagues developed preserves that microstructure. The researchers first cycled commercial lithium cells until they had lost half their energy storage capacity. They removed the cathode material from their aluminum foil substrate and soaked it in a hot lithium salt bath. Then they dried the solution to get powder, which they quickly heated to 800 degrees C and then cooled down very slowly[34].

Most battery-LCA studies focus on climate change, but other impact categories (mainly toxicity) are also relevant. Toxicity levels are primarily a function of the mining activities of the raw materials and the primary processes. The LFP battery is expected to score best on toxicity, compared to other chemistries, due to the absence of nickel and cobalt, whose mining creates a large environmental burden. Table 5.1 summarizes literature findings on the toxicity potential of manufacturing lithium batteries. It is expected that soon, the usage of materials will be fine-tuned, production processes will be optimized when traction batteries are mass produced, a projection of production optimization and its effects on cost erosion are discussed in and could be seen as exemplary for other impacts. Sales prices of batteries packs are expected to go down to 100$/kWh between 2025 and 2030 [34].

5.1 Llithium-Ion Batteries Recycling Process

Recycling process of Li-ion batteries can be divided in two processes commercially. Firstly, physical processes in which we deal with the separation of the battery components and dismantling of the battery. Secondly, chemical processes which includes leaching, precipitation and refining.

No.	Company	Country	Recycling material
1	Umicore	Belgium	Li-ion only
2	Batrec AG	Switzerland	Li-ion only
3	Recupyl	France	All Lithium Batteries

4	SNAM	France	Li-ion only
5	Xstrata	Canada	All Lithium Batteries
6	Inmetco	USA	All Lithium Batteries
7	Chemetall	Germany	Unknown
8	Accurec	Germany	Unknown
9	Stiftung Gemeinsames	Germany	Unknown
10	G&P Batteries	UK	Li-ion only
11	SARP	France	Li-ion only
12	Revatech	Belgium	Li-ion only
13	TES-AMM	Singapore	Li-ion only
14	BDT	USA	All Lithium Batteries
15	Akkuser Ltd	Finland	All Lithium Batteries

Table 5.2 Commercial processes for recycling of lithium batteries

5.1.1 Recupyl

This process was developed by Recupyl SA. France was the country from where this process was started and this process was implemented in Singapore. By using this process we are able to treat 320 tpa of lithium-ion batteries. In this process we use both physical and chemical treatments to produce lithium carbonate. In this process firstly we produce fine powder by crushing and then magnetic separation of battery scrap. Then we introduce this produced fine powder to hydrometallurgical process. In hydrometallurgical process we perform hydrolysis, leaching and precipitation. As the output we get Lithium as Li_2CO_3 and cobalt as cobalt hydroxide. The steps involved in the Recupyl process are shown in Figure 5.2.

5.1.2 Crushing of the Batteries

This process includes two steps. These steps takes place in a rotary shredder. This crusher works in the presence of CO_2 and also 10-35% of argon. During the process CO_2 will start reaction with any element of lithium to produce Li_2CO_3 and this product is less reactive element as compared to the pure lithium. Once the batteries are crushed then we start the physical separation process. During the crushing of batteries some gasses are produce. And these produced gasses are used to create an inert atmosphere above the hydrolysis reaction. And the remaining produced gas during the process is fed to lithium precipitation step now as the batteries are crushed and the scrap are produced we will start separating the battery scrap. We will separate the scrap by screening, magnetic separation and dens metric separation.

For the screening step we will use the vibrating screens. Dimensions of the screen will be 3 mm and 500 µm. The -3 mm fraction will contain metal oxides and carbons. And then it is further screened on the 500 µm screen. The -500 µm fraction is rich in cobalt and we will have Lithium in this fraction. The +500 µm fraction is rich in copper. We will send the cobalt-rich fraction to the hydrometallurgical treatment process and on other hand the copper rich fraction is combined with the steel and sold. We will treat the +3 mm fraction by magnetic separation.

In the magnetic fraction we will have steel (from battery casings). On the other hand we will separate the non-magnetic fraction further by a dens metric table. Paper and plastics are present in the low density non-magnetic fraction. And in high density, non-magnetic fraction we will have non-ferrous metals. Both of these fractions are in solid form.

The material that we got during the physical separation process is then treated by hydrolysis. We put the material in stirred water. And then the solution of lithium hydroxide is added to the stirred water to achieve a pH of 12-13. And now the Lithium from the electrodes will dissolve in the solution to produce lithium salts. Hydrogen gas is produce during the hydrolysis reaction. Inert gas which was produced during the crushing step in now used vent off the hydrogen. The metal oxides and carbon are suspended in solution and after they are separated out by filtration. And the solution which contain the lithium is sent to a lithium precipitation step.

Lithium is precipitated from the alkaline leach solution as Li_2CO_3, using CO_2 gas. The CO_2 that we use during this process is that which we get during the crushing stage. The Precipitation process will take place at a pH level of 9. And we get this pH level by the addition of acid. Finally the precipitate is cleaned with a CO_2-saturated solution and then it is dried at 105°C.

The suspended solids in the solution that we get during the hydrolysis step is leached in sulfuric acid at a pH level of 3 and a temperature of 80°C. The metal oxides will dissolve and we will get carbon as the residue. Now we will filter the leach product and will purify the solution prior to cobalt precipitation.

We will remove the copper and iron from the solution during the purification process. Copper is removed by adding shots of steel. We will add some soda to in order to increase the pH level to 3.85 to precipitate the iron. Now our solution is free from iron and copper and it is ready to feed it to cobalt precipitation.

We can recover the cobalt from the solution either by process of electrolysis, or by precipitation as $Co(OH)_3$ through the addition of sodium hypochlorite. The final solution which remains will contain some lithium and this solution is sent to the lithium precipitation step.

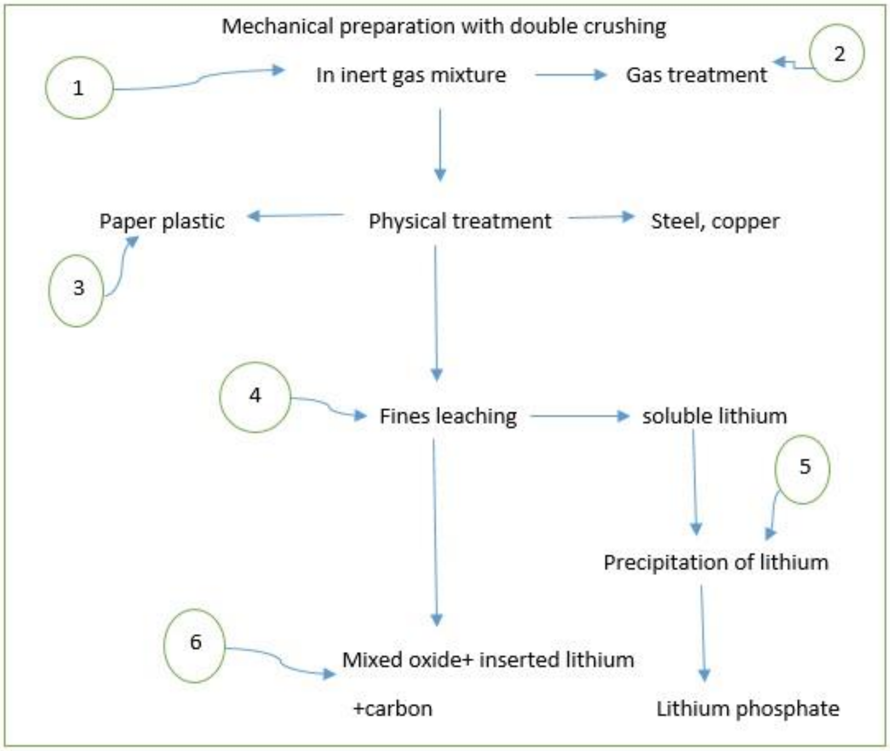


Figure 5.2 Basic steps involved in the Recupyl process

5.1.3 Umicore

This process is a pyro metallurgical process. In this process we use the patented IsaSmelt furnace technology. This process is use for the treatment of lithium-ion and Nickel Metal Hydride batteries. We do not perform any pre-treatment of the above mention batteries prior to smelting. We get the Cobalt and the nickel from the alloy phase and the lithium remains in the slag.

The IsaSmelt furnace is a furnace with a top submerged lance. We combine the batteries with limestone, sand, coke and slag formers and then we fed them to the furnace through the lance. There must be present 30-50% of battery scrap the reason is to produce a product with an economically viable content of cobalt and nickel. We also need the air for the process and this required air is fed from the bottom of the furnace and this air is pre-heated to 500°C. we divide this furnace into three different temperature zones. And those zones are

- Pre-heating zone.
- The plastic pyrolysing zinc
- The smelting zone (as shown in Figure 5.3)

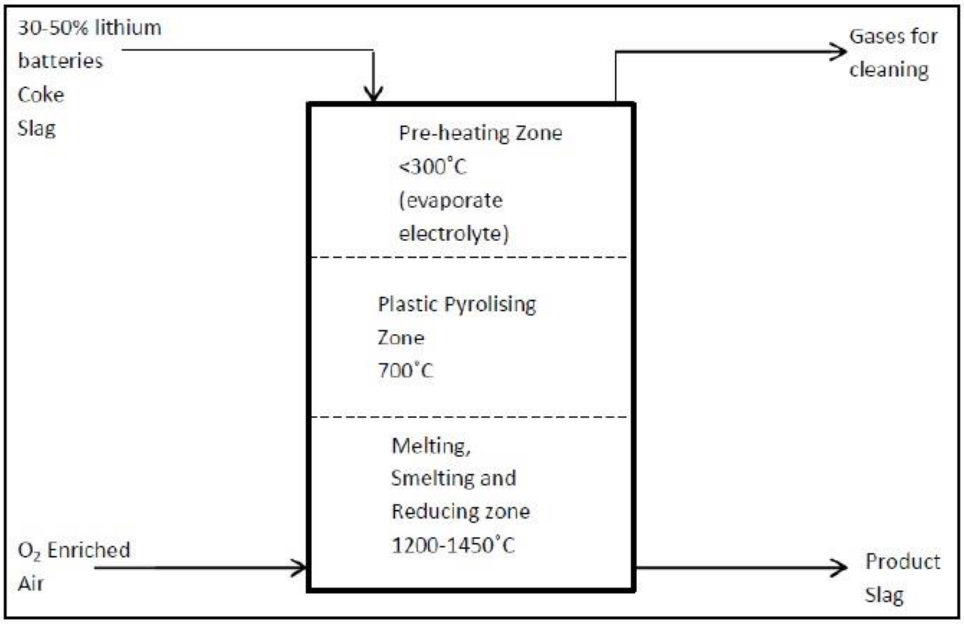


Figure 5.3 Temperature zones in IsaSmelt furnance used in Umicore Process

At the top of the furnace we have the pre-heating zone and in this zone we keep the temperature below 300°C. In this zone the furnace is heated by using the gas which is flowing from the hotter zones below. In this zone evaporation of electrolyte takes place. Slow heating reduce the risk of explosions [51].

The second zone which is the middle zone of the furnace is the plastic pyrolysing zone. We keep the temperature in this zone around 700˚C. In this zone removal of the plastic from the batteries occurs and this is done by pyrolysis. This is an exothermic process, so in this process energy is released and this energy is then used to heat the gases which move upward to the pre-heating zone. Finally the remaining material is smelted in the last zone which is the smelting zone. Smelting zone is at the bottom of the furnace. This zone need very high temperature as compared to the other zones. We will keep the temperature in the range of 1200-1450°C. Flow of pre-heated, oxygen-enriched air is injected via tuyeres into the bottom of the furnace in the smelting zone. Copper, cobalt, nickel and some iron report to the alloy phase. In the slag phase we will have lithium oxide and also the oxides of other metals which includes aluminum, silicon, calcium and the remaining iron.

Concrete blocks are made from the slag and then they are sold to the construction industry. And finally the alloy phase is treated in a hydrometallurgical process.

We use the post combustion chamber for heating the off-gas from the furnace and it is heated to above 1150˚C by using a plasma torch. We inject the combustion chamber with calcium, zinc oxide or sodium products to capture halogens evolved from electrolyte and binder evaporation. Then we inject the Water vapors into the gases to cool it down to 300˚C.

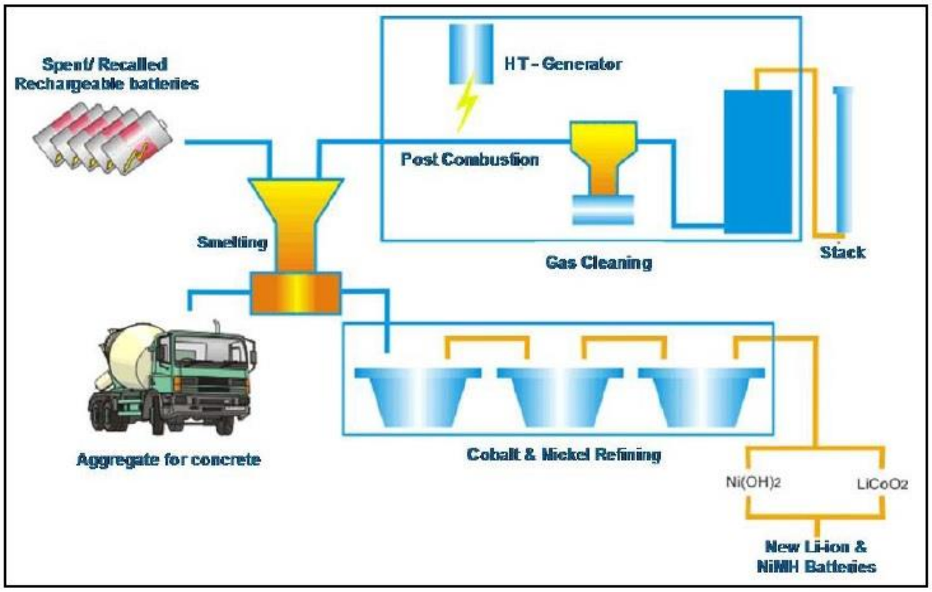


Figure 5.4 Flow Chart of Umicore Process

By dissolution and precipitation we can recover copper, cobalt, nickel, zinc and iron by using the alloy phase. The cobalt and nickel products are $CoCl_2$ and $Ni(OH)_2$, respectively. Then we use $CoCl_2$ to produce $LiCoO_2$ [53].

5.1.4 Toxco

This process is a hydrometallurgical process. In this process we perform the following steps

- Pre-treatment of the batteries.
- Separation of battery components.
- Leaching.
- Solution purification.
- Lithium precipitation.

During recycling of Lithium batteries it is necessary to perform the pre-treatment step because the lithium metal and as well the by product which we may get during the cycling process are toxic, corrosive and highly reactive. So pre-treatment process will render the lithium. In this process the cryogenic cooling technique is use to rendered the batteries.

In cryogenic cooling process we cool the batteries between -175°C and -195°C and we use liquid nitrogen for cooling. The reactivity of battery materials become very low at these temperatures and the risk of explosion is avoided. At the low temperatures the plastic casing of the batteries becomes brittle and they can be broken very easily. This step is not necessary for the batteries which are completely discharged.

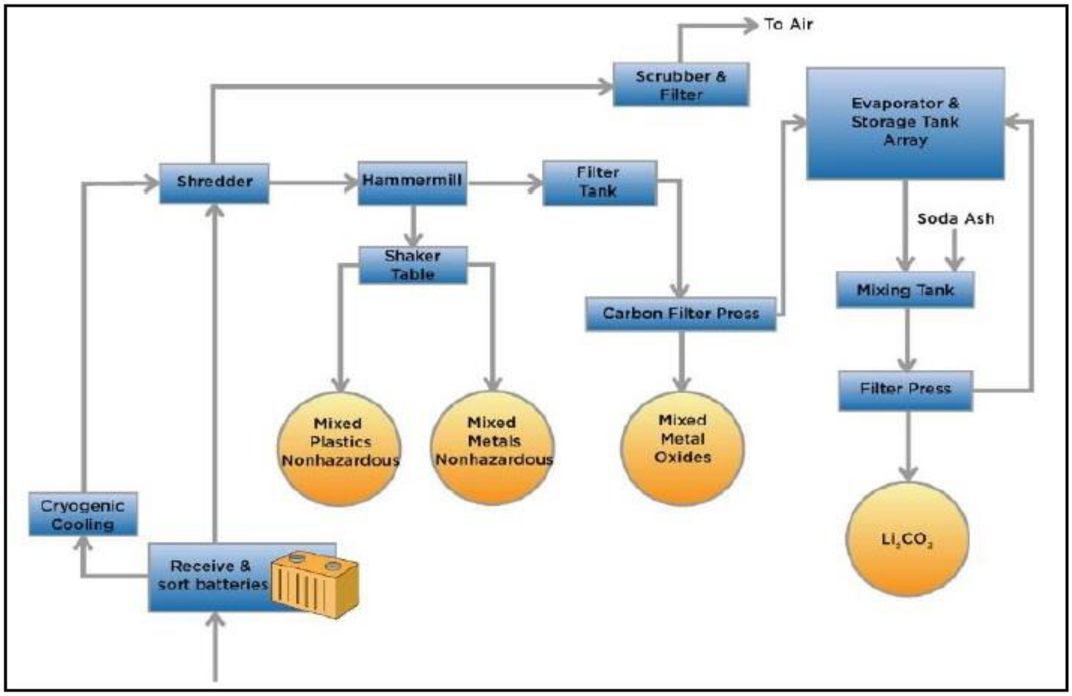


Figure 5.5 Flow Diagram for the Toxco Process

Once the batteries are cooled then they are shredded and sent to a hammer mill, where the batteries are milled in a lithium brine. Hammer mill is the place where the Lithium is dissolved. LiCl, $LiCO_3$ and $LiSO_3$ are the salts which are formed in the solution. The hammer mill is fitted with a screw press. The screw press is use to separate the lithium-containing solution from the undissolved product which is known as “fluff”. This solution will have some undissolved fine material, consisting of metal oxides and carbon.

We use the shaking table to separate the fluff. The separation process will produce low density stream (consisting of plastics and stainless steel) and a high density (copper-cobalt) product. We packed both of these products and then they are sold.

Now we send the lithium-containing solution to a holding tank before applying the filtration. In case it is necessary we set the pH level of the solution at 10 by the adding some amount of LiOH. LiOH is used instead of NaOH in order to prevent contamination of the lithium product with Na.

We filter the material from the holding tank using the filter press. The cake contains metal oxides. We need to evaporate the water from the solution so the solution is send to the dewatering tanks and here the water is evaporated from the lithium-containing solution. The concentration of the lithium salts start increasing and finally the salts precipitate out.

Now we will filter the product from the dewatering tanks and then purified with an electrolytic membrane. It contain 28% of the moisture (filter cake). Then purification step is started. A solution of mild sulfuric acid is added to the filter cake it results in the dissolution of the metal salts. Li^+ ions pass through the membrane and precipitate as LiOH. The LiOH is converted to Li_2CO_3 by the addition of CO_2. Then it is filtered, washed, dried and packaged. The remaining solution is disposed.

5.1.5 Inmetco

The International Metals Reclamation Company (INMETCO) works on a pyrometallurgical facility. And it is used for treating metal waste, including spent batteries. This process was designed for treatment of furnace dust, mill scale and swarf. Used batteries form a secondary feed to the furnace. The waste contains nickel and cadmium and dolomitic, carbon and chromium refractories. The steps that are included in the process are feed preparation, reduction, melting and casting. In alloy we get copper, nickel, iron and cobalt. The Lithium is lost to the slag phase and in the process the organic electrolyte and the plastic casing are volatilized [53].

We prepare the battery feed for the process and we do this by opening up the batteries, remove the plastic from the batteries and drain the electrolyte. We then shred the batteries. We blend the other solid feeds and add carbon based reductant. The whole mixture is then pelletised. At the pelletising stage we add the liquid waste and this liquid waste contains the nickel and cadmium. The shredded batteries and the pellets are combined and then they are fed to the reduction step [51].

The reduction process will take place in a rotary hearth furnace and this furnace operates at 1260°C. The time for reduction process is 20 minutes. During reduction process the metal oxides are reduced to metals. Off-gas from the rotary hearth furnace is scrubbed and the scrub solution is sent to a wastewater treatment facility, from which treated water is recycled to the process. During waste water treatment we recover cadmium, zinc and these products are then sent to another facility for metal recovery [53].

From the rotary hearth furnace we get the reduced products and these reduced products are then fed to a submerged electric arc furnace (SEAF) for smelting. From SEAF we get the products in alloy form which contain iron, nickel, chromium and manganese. The alloy is fed to a casting step. The slag is sold as an aggregate for building.

In the final step which is the casting step we cast the alloy into stainless steel (pigs). We pour the molten metal into molds, which are then cooled with water. And we sold the pigs to the stainless steel industry. The typical composition of pig alloy is 10% nickel, 14% chromium and 68% iron. The INMETCO Process is illustrated in Figure 5.6.

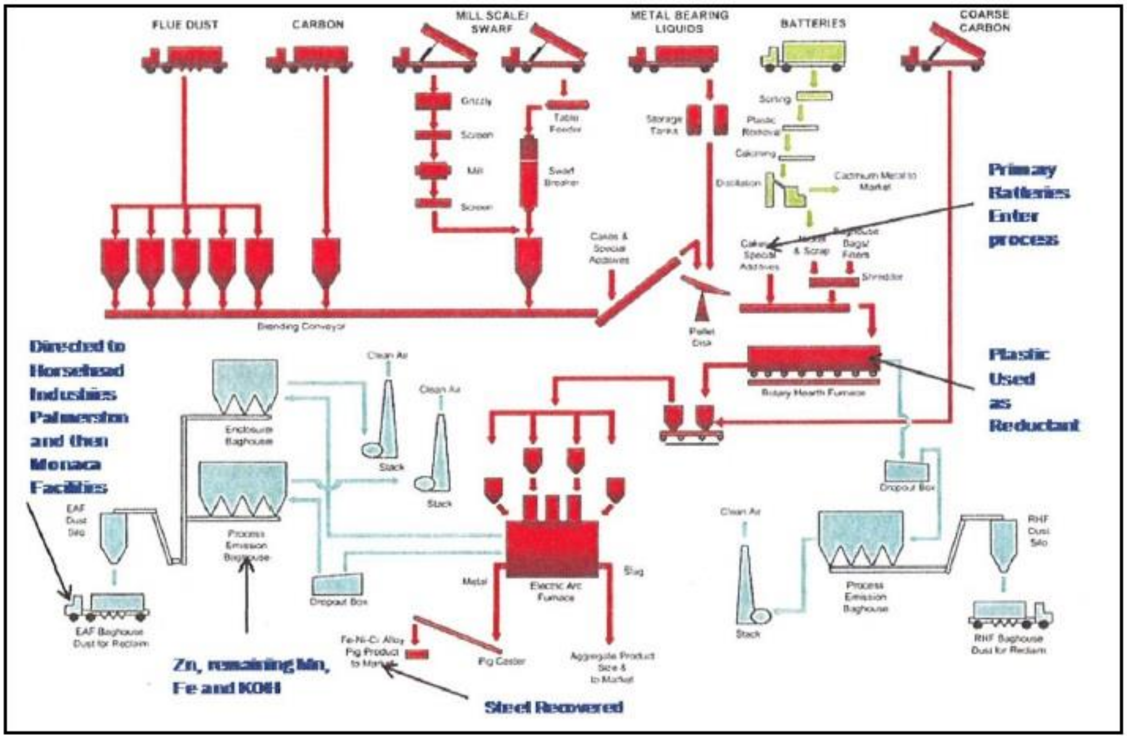


Figure 5.6 Flow Diagram for INMETCO Process

5.2 Proposed Options for Recycling of Lithium Batteries

Typically the recycling process of Lithium batteries starts from the pre-treatment step. In pre-treatment step we separate electrodes of the battery from the other battery components then it is followed by a metal recovery step and finally the step of separation of the individual metals. Skinning, removal of crust, crushing and sieving these are the steps that are performed during the pre-treatment step. Hydrometallurgical or pyro metallurgical are the methods which are used for the recovery of metals from the electrodes [53].

We select the recycling process of lithium on the basis of various craterous. Some of these criteria are given as below.

The criteria which are necessary:

- The recycling process must recover lithium and cobalt from the batteries.
- The process must be able to treat lithium ion car batteries.
- Any waste which is produced during the recycling process and is sent to a landfill must be non-toxic and non-flammable.

- It must be possible to test the process steps at a lab scale within the budget of this project
- The recycling process must contain various steps which have been demonstrated at a commercial scale

Advantageous criteria:

- The recycling techniques which we use must be able to treat different battery types (NiMH, primary lithium batteries).
- The product that we get in the final step must be of a battery grade so that it can be used in production of new batteries.
- All products can be fed into another industry.
- The recycling process should be simple to design and operate.
- The process should be scalable.

Now we will further discuss two options for the recycling of lithium ion batteries that were selected for further test work.

5.2.1.1 1st Option

We have selected hydrometallurgical process as the first option. And this process is capable of recovering both lithium and cobalt from the used Lithium batteries. The Recupyl and the Toxco processes which we have discussed above they both are the hydrometallurgical processes. Both of these processes contain pre-treatment of the batteries and physical separation of the battery components and finally dissolution of lithium in alkaline solutions [51].

In the Toxco process we will get the solids remaining when the lithium dissolution process is completed. These solid remaining will contain cobalt and other metal oxides. We select the Recupyl process because in this process the steps for the cobalt recovery are known. In this process we separate the cobalt from other metals by dissolving it in the acidic solution and selective precipitation [53].

We start the Recupyl process from the crushing stage. We crush the used batteries in an inert atmosphere but on the other hand in Toxco we use a cryogenic crushing method. And we use this method for the pre-treatment of the ore. For the Recupyl process we can say that cryogenic crushing may be suitable for pre-treatment and should not be excluded at this stage. Both steps are relatively simple and also cost effective.

In Recupyl process we can recover the cobalt using two options namely electrolysis and cobalt hydroxide precipitation.

The steps for option 1 are:

- Inert or cryogenic crushing.

- Screening.
- Magnetic separation.
- Density separation.
- Hydrolysis.
- Lithium precipitation.
- Metal dissolution in acid.
- Iron precipitation.
- Copper precipitation and cobalt precipitation.

5.2.1.2 2nd Option

For second option we have considered both pyrometallurgical and hydrometallurgical process. Pyrometallurgical are capable of treatment of more than one type of feed but lithium in these processes report to the slag. In a hydrometallurgical process we treat the slag to recover lithium from the slag [51].

So for pyrometallurgical purpose we have selected the Umicore process. The reason for selecting the Umicore process is that this process has been demonstrated on a commercial scale, and the equipment use for this process is a single piece [53]. Lithium can be found in the slag in Umicore process and in the alloy phase cobalt, copper and nickel can be found. It may be possible to run the furnace with a more reductive atmosphere with the result that all metals including lithium are reduced and no slag phase forms [51].

In hydrometallurgical process we dissolve the lithium from the slag and for this process the first step is grinding of the slag. The first process is then followed by lithium dissolution and precipitation. For dissolution step we use the following agents HCl, H_2SO_4, NaOH, $Ca(OH)_2$ and LiOH [55].
From the alloy phase the cobalt must be recovered. And this can be done by acid dissolution and selective precipitation of the metals.

The steps for option 2 are:

- Smelting.
- Slag grinding.
- Slag dissolution.
- Filtration.
- Possible solution purification.
- Lithium precipitation.
- Alloy dissolution.
- Iron precipitation.
- Copper precipitation and cobalt precipitation.

6 Lithium ion BEV

6.1 Electric Vehicle-Supply Equipment (EVSE)

Battery Electric Vehicles (BEVs) can escalate their stored energy by plugging into the grid. On the basis of the battery type, vehicle type, and the capacity of the EVSE, there are variations in the charging durations of BEVs. Government and industry entities in the EU, U.S. and China have defined, and have repeatedly refined, EVSE standards set that govern connector design and charging capacity. Battery charging time is determined by the current and voltage provided by the connection. Business electric distribution infrastructure as well as common household delivers 220V in the EU and China whereas 120V in North America. As compare to low capacity charging, the higher capacity charging mostly needs extra electrical work to upgrade the service. Although the recent advancements in high capacity DC charging and battery technologies are leading to reduce the charging duration, but high capacity EVSE increases charging cost. Because of this reason, high capacity charging stations are always installed for usage by multiple vehicles. A more elaborated discussion of EVSE and their charging scenarios is provided in this report [35].

Irrespective of the charger type or the type of car, the most important concept is to understand that charging speed varies; it is different at 1% in comparison to that at 99% of charge. Mainly, when your battery near to empty point, electricity flows in at a fast pace but as it gradually gets charged, this charging rate slows down. This concept is known as “tapering,” and it is evident in the beginning till it is about 50% charged, but as it gets filled up above 80% the charging rate must be slow. Therefore it is recommended to charge only up to 80% unless there is a need for full charging i.e. up to 99% or 100%, and some of the charging stations actually stop charging off when the charging reached 80%[36].

Apart from the above discussion, there are different types of chargers which are faster than the other types. Most frequently used are the “level 2” chargers which charge car with the same rate as the home EVSE. Another type is “level 3” chargers (also known as DC fast chargers) which charge with much more speed as compare to the level 2 chargers. Technically they are not commonly refer to as “level 3” chargers as the level 1 and level 2 chargers deliver AC electricity to the vehicle using onboard charging where as these fast chargers detour the onboard charger and deliver DC electricity to the battery by the help of special charging port. In order to simplify this for consumers, the term “level 3 charging” is used. Furthermore, in the following section, we have discussed the

Tesla Supercharging also commonly refer to as “level 4 charging” since it is comparatively faster than the level 3 charging[35].

6.2 Types of EV Chargers

- A “Level 1” charging station uses a standard AC 120V household outlet and is the least expensive. Charging time varies from vehicle to vehicle, but usually takes around 10 to 20 hours for an empty battery to be filled at full capacity [38].

- A “Level 2” charging station is an AC 240V station supplied with at least 30 amperes which is a good choice for places far from the city, where customers might spend few hours or more. Such locations are well suited to Level 2 charging, which typically can add 20 to 25 miles of range in a single hour.

- A “Level 3” charging station – also called Direct Current Quick Charger (DCQC) – is known to be the most powerful as well as the fastest type of charging station available. These are ideal charging stations for places along the highways, where vehicles are to be charged as fast as possible, are optimal solution for DC charging which adds 50 to 75 miles of range in approximately 20 to 30 minutes. DCQCs are capable of supplying approximately 50 to 135 kilowatts of electricity and are hence the most expensive among the three types of charging stations [35-36].

There are three main categories of EV charging – **rapid**, **fast**, and **slow**. These characterize the power outputs, and thus the charging speeds available to charge an electric vehicle.

Rapid chargers are one of the two types; either AC (Alternating Current) or DC (Direct Current). Present-day Rapid AC chargers are rated at 43 kW, whereas the most Rapid DC units are at least 50 kW. Both of these will charge the majority of electric vehicle types up to 80% in about 30 to 60 minutes (depending on the capacity of the battery). One of the most commonly known Rapid DC is the Tesla Superchargers which charge at about 120 kW. These Rapid AC devices use a tethered Type-2 connector, and their Rapid DC chargers are installed with a CHAdeMO, CCS or Tesla Type-2.

Fast chargers include chargers which provide power from 7 kW to 22 kW, which usually fully charge an electric vehicle in 3 to 4 hours. Common fast connectors are a tethered Type-1 or a Type-2 socket (using a connector cable supplied with the vehicle).

Slow units (up to 3 kW) are recommended for overnight charging and typically take around 6 to 12 hours for an electric vehicle, or 2 to 4 hours for a PHEV. Electric Vehicles charge on slow devices via a cable connecting the vehicle to a 3-pin or Type-2 socket [38].

6.3 Car using lithium-Ion batteries

6.3.1 Charging with an Audi e-tron

The charging speed is approximately 150 kW for 175 kW fast chargers and about 50 kW for the other chargers. In Figure 6.1, the charge curve shows the charge speed for both chargers. On average the e-tron charges 100 km in 10 minutes (175 kW charger) or in 30 minutes (50 kW charger). In case of 175 kW charger, the charge speed will slowly drops to 80 percent whereas at the 50 kW charger charging slows down only at 98 percent [37].

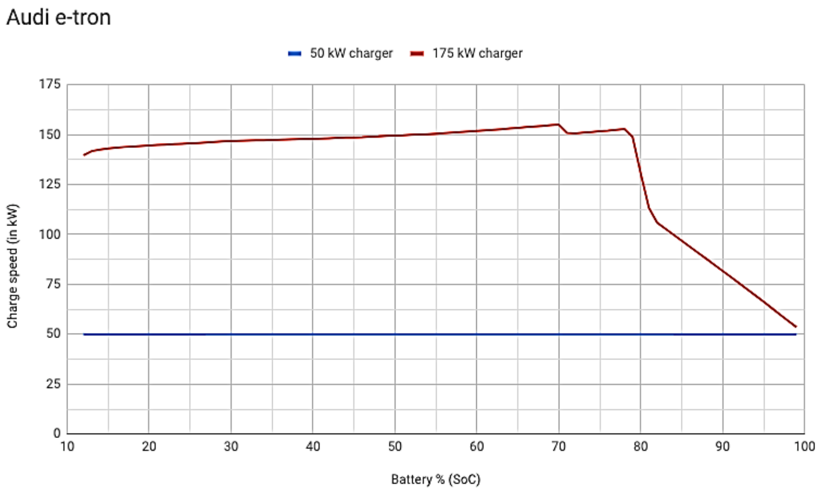


Figure 6.1 Charge Curve depicting the charge speed for 50 kW and 175 kW charger in Audi e-tron

The e-tron is capable of charging at up to 11kW AC and at 150kW DC; at 11kW the e-tron can be fully charges in 8.9 hours and if using 150kW DC charging stations, at such charging stations, customer will able to charge the e-tron to 80 percent in under 30 minutes and to 100 percent within 50 minutes.

6.3.2 Charging with a BMW i3

The charging speed of the BMW-i3 accessible to 50-kilowatt DC Quick charge stations which is capable of refilling the car's battery pack to 80% full in approximately 20 to 35 minutes. Quick charging is preferable with 90% or more of EV charging, it shouldn't be make-or-break for most EV buyers.

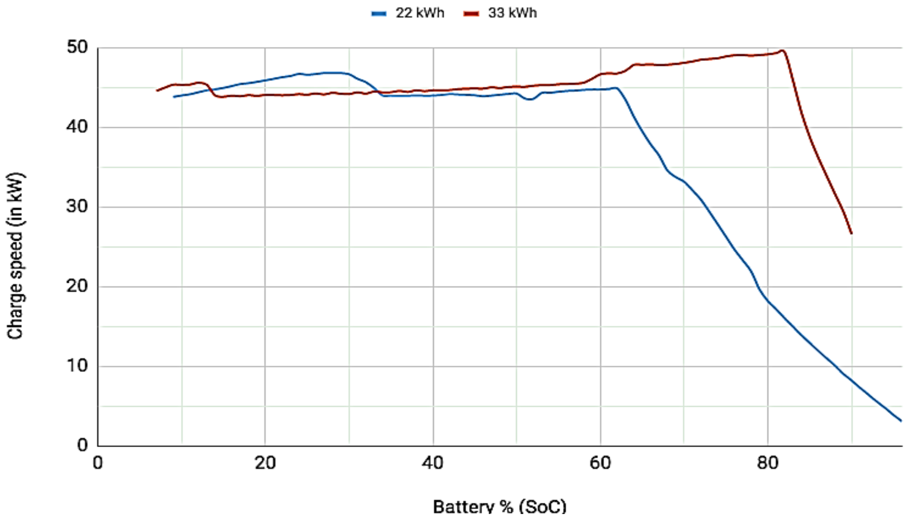


Figure 6.2 Charge Curve illustrating the charge speed for 22kW and 33kW charger in BMW i3

The BMW engineers equipped the i3 having an onboard charging system that technically can handle 7.7 kW. The high "Level 2" rate can be difficult to supply with the household power, yet around 6.6 kW, it means an additional hour charging which adds approximately 20 to 25 miles of driving.

It doubles the added range in an hour from electric vehicle equipped with weak charging of 3.3kW charger. The 22 kWh Charger does fast charging until 65 percent and then charging gets slower above this whereas the 33 kWh edition Charger does fast charging up to 85 percent, afterward the charging will go slower above this level as shown in Figure 6.2.

All of the BMW i3 variants are have an 11 kW on-board charger for AC charging in addition to their Rapid 50 kW DC charger. This implies that even when BMW i3 is connected to a fast charger with a rated output above 11 kW, the BMW i3 will only charge at 11 kW.

6.3.3 Charging with a Tesla Model 3

Battery Capacity of Tesla model 3 is 75 kWh. The time needed to charge tesla 3 long Range at 11kW is 8 hours and at 125 kW at it take s 35 mints to reach from 10% to 80 %.

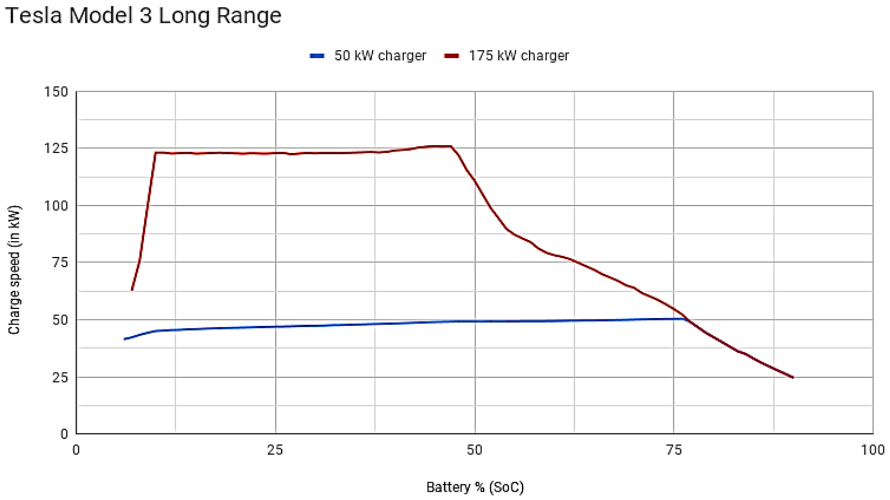


Figure 6.3 Charge Curve illustrating the charge speed for 50kW and 175kW charger in Tesla Model 3 Long Range

Rapid charging ensures more driving miles by adding as much range as possible in the shortest time duration. The charging power will decrease considerably after 80 percent state-of-charge has been reached. A typical rapid charge thus rarely exceeds 80 percent SoC (as presented in Figure 6.3). The rapid charge rate of an electric vehicle depends on the charger in use and the maximum charging power the electric vehicle can handle.

6.3.4 Charging with a Jaguar I-PACE

In case of Jaguar I-PACE, the charge speed is up to 100 kW for the 175 kW fast chargers and approximately 50 kW for other chargers. In the charge curve given in Figure 6.4, it is evident that the charge speed of the I-PACE at both chargers declines after attaining a certain level. On average the I-PACE charges 100 km within 15 to 30 minutes. At a 175 kW charger the charge speed will slowly drop to 40 percent. In case of 50 kW chargers this decline happens after 80 percent.

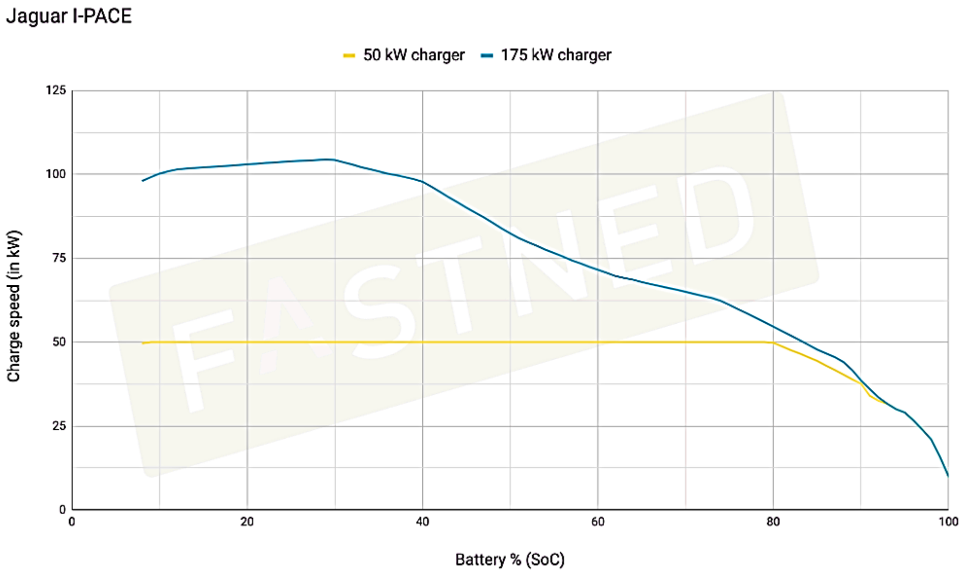


Figure 6.4 Charge Curve showing the charge speed for 50kW and 175kW charger in Jaguar I-PACE

6.3.5 Charging with a Kia e-Niro

For the Kia e-Niro electric vehicle, the charge speed is noted to be 77 kW for 175 kW fast chargers for the 64 kWh edition. The charge speed for other chargers is merely 50 kW for both the 39 as well as the 64 kWh edition. In the charge curve shown in Figure 6.5, it can be seen that the charge speed of the 64 kWh e-Niro, at both chargers, starts to decline slowly from after charging onwards.

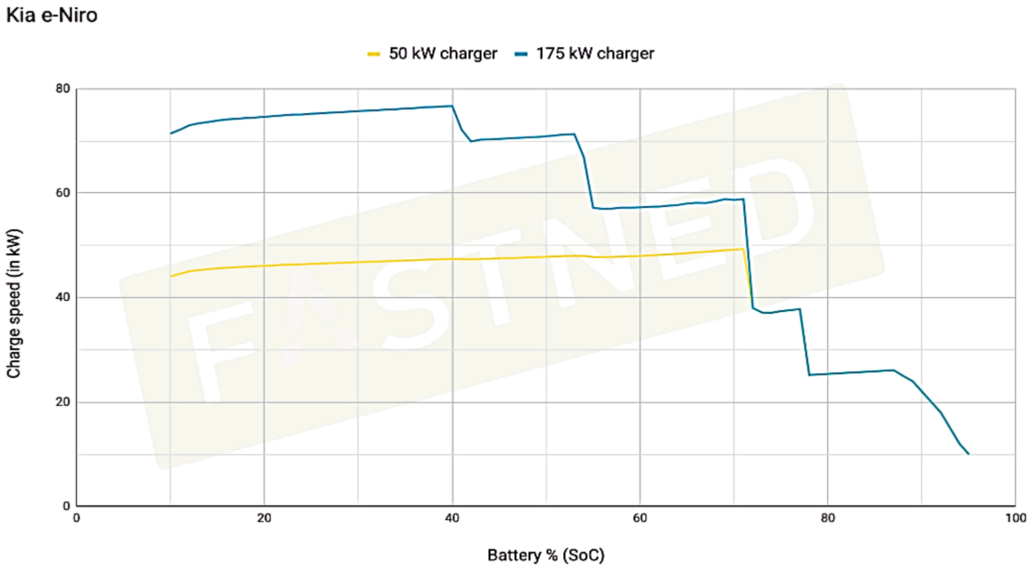


Figure 6.5 Charge Curve illustrating the charge speed for 50kW and 175kW charger in Kia e-Niro

On average the Kia e-Niro is capable of charging 100 km in 15 to 25 minutes. The charge speed drops in steps after 73 percent.

6.3.6 Charging with Hyundai Ioniq

For Hyundai Ioniq the charge speed is approximately 70 kW for the 175 kW fast chargers and 50 kW for other chargers. The charge curve shown in Figure 6.6, the

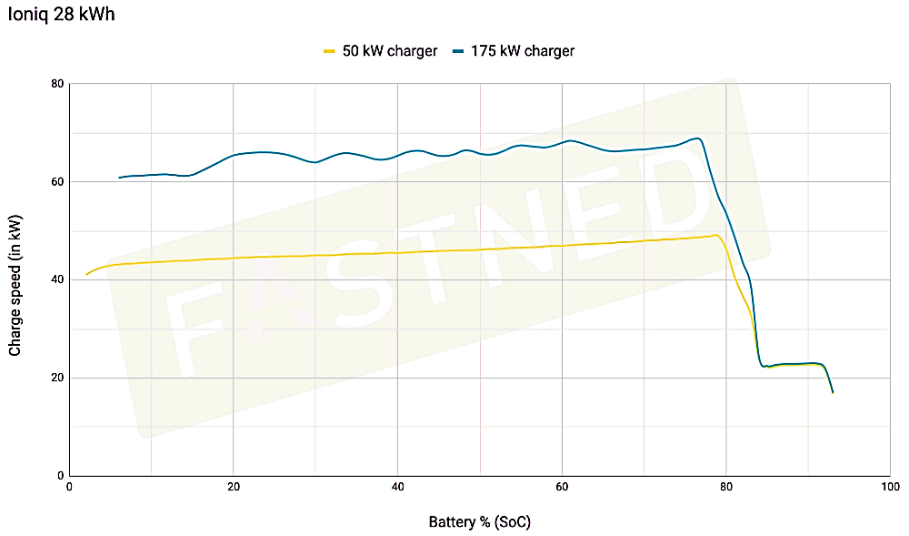


Figure 6.6 Charge Curve illustrating the charge speed for 50kW and 175kW charger in Hyundai Ioniq

charge speed of the Ioniq at both chargers are presented.

On an average the Hyundai Ioniq charges 100 kW in 15 to 25 minutes. After reaching the 75% the charge speed requested by the car will decrease, and above 85% the charge speed is dropped to 22 kW.

6.3.7 Nissan Leaf and e-NV200 (Evalia)

For the Nissan Leaf and e-NV200 Evalia the charge speed is up to 50 kW for all the chargers. In the charge curve shown in Figure 6.7, the charge speed of the Nissan Leaf and e-NV200 is presented. On average both cars charge 100 km of range within 20 to 25 minutes. Charging behavior mostly depends on the battery size. For the 24 kWh edition the fast charging is done till 25 percent, charging will gradually decrease after this. The 30 KWh edition charger can do charging till 80 percent and gradually decline after this point. In case of the 40 kWh edition, the fast charging is till 60 percent and then it slows down after this level.

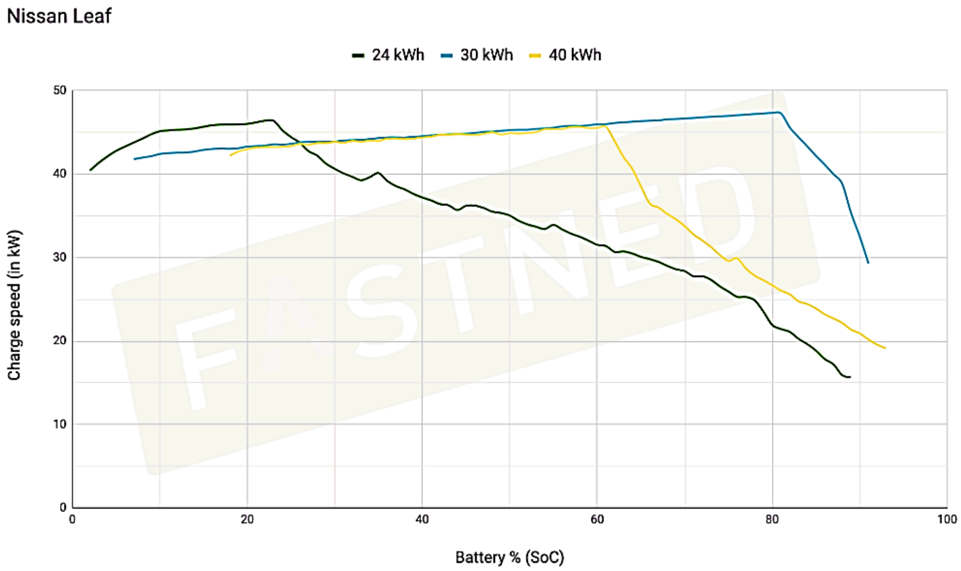


Figure 6.7 Charge Curve illustrating the charge speed for 24kW, 30kW and 40kW charger in Nissan Leaf

6.3.8 Volkswagen Golf e golf

The charge speed is up to 40 kW at all of our chargers. In the charge curve below you can see the charge speed of the e-Golf. On average, the e-Golf charges 100 km of range in 20 - 25 minutes. Charging behavior largely depends on battery size:

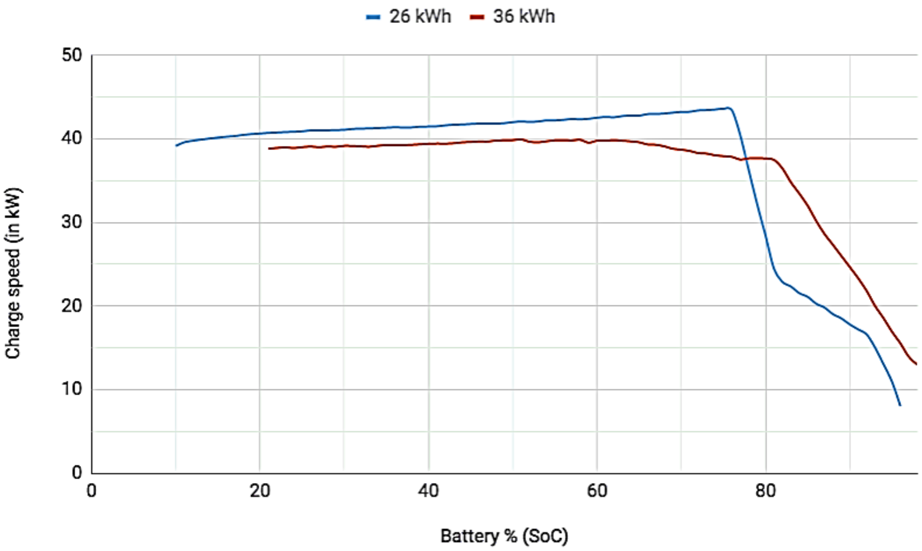


Figure 6.8 Charge Curve showing the charge speed for 26kW and 36kW charger in Volkswagen Golf e golf

a) 26 kWh edition: fast charging until 75%, charging will go slower after this
b) 36 kWh edition: fast charging until 80%, charging will go slower after this

6.4 Analysis of EV batteries and charging time:

The Table 6.1 presents approximate time to charge an electric vehicle of the given model. Timing shows 100% charge for all but rapid charging, which is refer to for 0-80% as most rapid chargers reduce before 100% charge to protect the battery and maximize the overall efficiency. It should be noted that the times shown are only a guide, as rarely will an electric vehicle needs to be fully charged from zero percent.

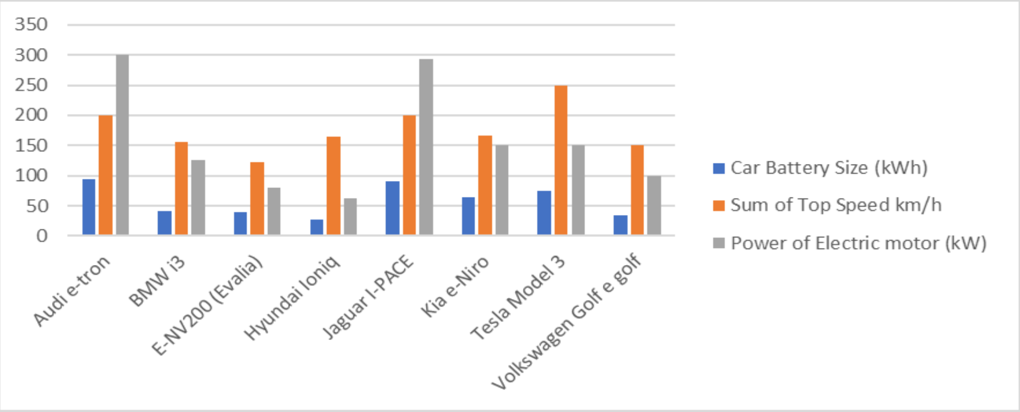


Figure 6.9 Comparative analysis of different vehicles' battery size, top speed and Electric motor Power (kW)

Other factors that might vary the charging time include in-vehicle energy loads, ambient temperature, any lower and upper charge restrictions to prolong battery life

Table 6.1

and protect against potential damage, and charging rates slowing down as the maximum charge is reached.

Car Model	Battery Size (kWh)	Fast charging at 50kW 0-80% (minutes)	Slow charging at 3kW 0-100% (hours)	Top Speed km/h	Power Electric motor (kW)
Audi e-tron	95	90	31	200	150*2
BMW i3	42	35	11	155	125
Tesla Model 3	75	60	22	250	150
Jaguar I-PACE	90	90	30	200	294 (2)
Kia e-Niro	64	60	26	167	150
Hyundai Ioniq	28	30	9	165	62
E-NV200 (Evalia)	40	25	8	123	80
Volkswagen Golf e golf	35	35	12	150	100

6.1 Comparison Analysis of EV batteries and their charging time using various parameters

A comparative analysis of battery size and their time to charge is presented in Figure 6.9. If the size of battery is same, then time for charging either for fast and slow are same as shown in Figure 6.10.

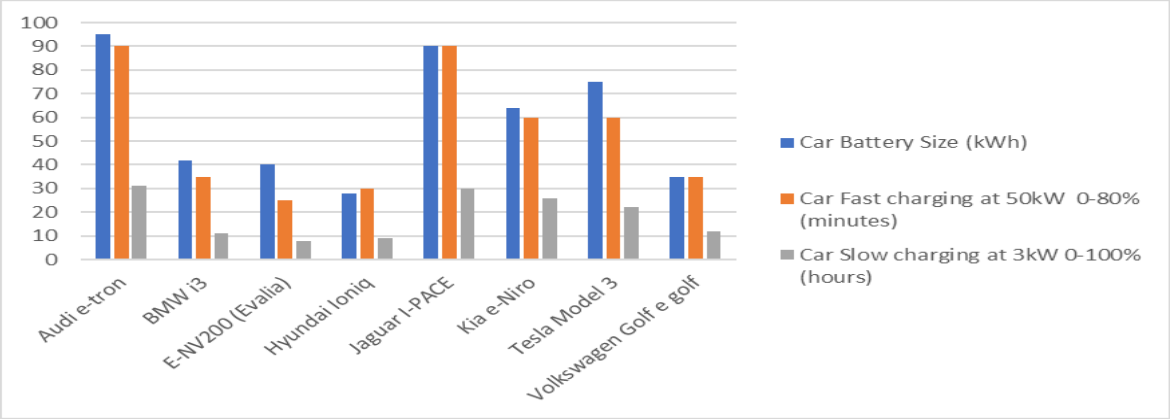


Figure 6.10. Comparative analysis of different vehicles' battery size and their charging time

7 Photovoltaic System

It is feasible for RES (renewable energy sources) to replace the present fuel energy as source of generation for electricity. Electricity is considered as a part of economic development among the nation. Now a days, world is diverting to use its resources for green environment. The combustion of fossil fuels results in a harmful health hazards due to the emission of dangerous gases. Most of our centralized energy system is fossil fuels which delivered high cost of electricity [14].

Centralized energy system is the system which generates electricity and put it on grid for transmission and distribution (T&D). Green energy sources like wind turbines, gravitational and solar energy sources are called distributed energy resources (DER), operate on low scales. They are also called Distributed energy storage as they store energy from wind, water or sunlight. In recent years the share of electricity generation from green energy has been increased. The economic challenges remain the primary impediment to renewable energy group. The sunlight source of energy can be used a potential part in providing great economically advantage among the rest (RES) group. The demand of electricity in urban area is far more than that of rural area. According to World Bank collection of developed countries in 2016 almost 70 percent of population in Italy lives and work in urban area so the demand of electricity is much more in urban area [16]. Among the most promising renewable energy resources solar energy leads the rest. Solar photovoltaic energy converts sunlight directly in electricity. The electricity is in the form of DC current and can be stored in battery or gravitational energy storage system [14].

Gravitational energy storage means if the solar plant is generating more electricity than demand, so we can store it by using gravitational phenomena. When the demand is low a water pump operates on electricity which pump the water in the reservior at the to and when the demand is high reservior is open water flows down due to gravitation and water pump work as a gernerator.

Solar PV (photovoltaic) is energy is becoming popular because is require no additional resource (like, water or fuel). Unlike its maintenance cost is also less required. Over the last two decades the cost of installing and manufacturing of PV system has been decreased by 20 percent and doubling the capacity. A photovoltaic array is connected to the grid with a power conditioning subsystem which converts DC current to AC current. Therefore ES (Energy storage) is not necessarily required. In Recent years the development in in PV integrated grid has increased due to renewable initiative program making environment green. Germany has made 0.1 million roof programs. Japan has introduced 70,000 roof programs which begin in 1994. Solar application has increase in the mid of 90 to late 90’s. U.S. introduced 1 million solar roof initiative programs during this era [14].

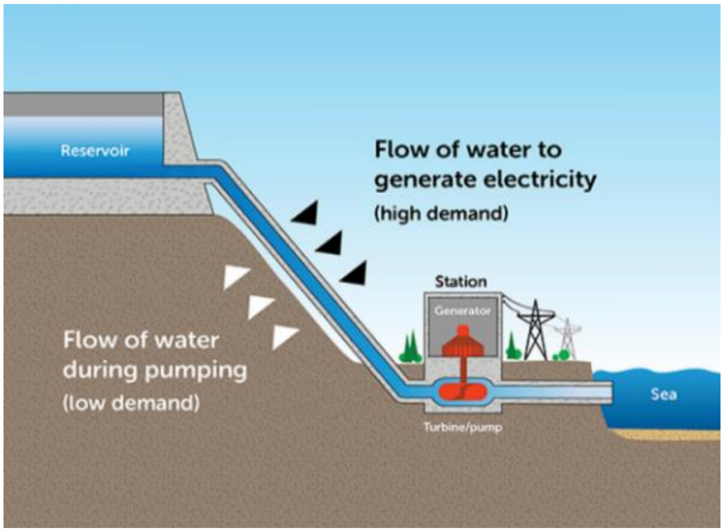


Figure 7.1 Distributed energy storage as they store energy from water as reservoir

The installation of photovoltaic grid system in various countries is supported by their respective government. The change in utility structure has changed the market in consumption and distribution point of view. Installation of photovoltaic system can help the consumers in saving money and improving the power quality supply because they are able to use their own solar energy at high demand time or the peak hours and they can send this solar energy to grid. Utility can also install photovoltaic grid connected system nearby substation or at the end of the feeder [14].

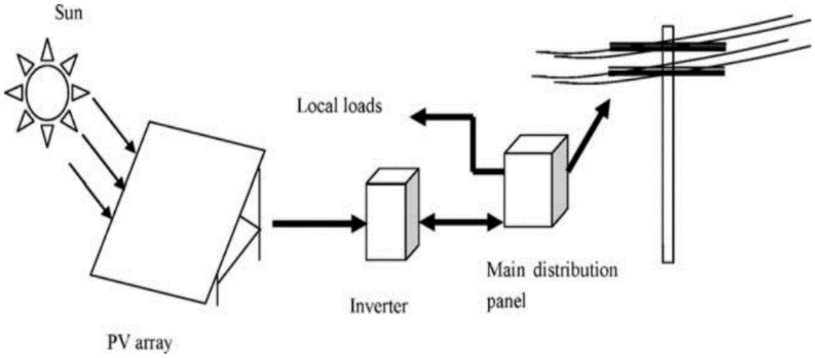


Figure 7.2 Overview of a Photovoltaic System

Grid is connected to PV system through inverter, whose input is Direct Current (DC) power coming from photovoltaic modules to supply AC power to electrical applications. Therefore, an inverter is considered as one of the key parts of photovoltaic system. The main component of PV integrated system is shown in the fig. it does not include any ESS (Energy storage system).

The inverter needs to supply maximum power by most commonly using a maximum power tracking function. The inverter generally delivers maximum power it is in phase with grid (unity power factor) and delivers as much power as it can for to the electrical grid under possible sunlight and temperature conditions [15]. An inverter is a device which is meant to convert DC input to AC output. They are mostly called as power condition system or power conditioners in PV applications

7.1 Technical Issues:

The Technical issues we face in grip interconnection with PV system are such as islanding. THD (Total harmonic distortion), Voltage variation (rise or fall) and electromagnetic interference. These are considered as more important issue in PV applications [11]. The efficiency of PV integrated grid system can be calculated by the performance ratio, defined as ratio of system efficiency of PV circuits and the nominal efficiency of PV circuit under slandered test condition also known as quality factor (Q). Now a days normally (70-75) percent in solar cells made of poly- and monocrystalline silicon [9].

The performance of grid-connected PV systems can be evaluated by investigating the performance ratio (PR) which is defined by the ratio of the system efficiency and the nominal efficiency of PV modules under STC. These values apply to systems using solar cells made of poly- and monocrystalline silicon [10].

To predict the performance of PV cells mathematical relationship has been developed using real time data for different of different type of cells to characterize different PV parameters. Different mathematical algorithms are developed to predict the individual component performance of a component in overall PV system [9]. These predictive based systems can tell us the future progress of the PV system. This predictive performance software's can helpful in long term PV performance as well as hour by hour simulation. This software is very useful to design a PV system with optimal configuration.

7.2 Islanding

This is the stage in at which part of the utility system that include both load and distributed system are powered up which isolated form the grid. It is the process in a portion of the power network is not connected with the power supply or main station, and load or the consumers are directly connected with the PV supply at this point voltage and frequency are maintain at nominal values. At this point of disconnection, it is necessary that the active and reactive power at point to disconnection of should be around zero. The disconnection of island must happen without short circuiting between the phase/phases to the ground. Any fault occurs will push voltage to very low value and all the PV system will be switched off, so islanding can be avoided. Islanding is a balanced condition in a disconnected part of a power network where the load is sustainable powered by the connected PV systems. A balance condition which of only few seconds cannot be categorized as sustainable [9].

The IEA Task V (Solar Resource Assessment and Forecasting) working group a period of five or more seconds is treated as a possible islanding

7.3 Electromagnetic Interference

Noise (radio frequency) caused by DC powered equipment. Inverter must not produce EMI or should be susceptible to normal EMI. The produced noise is radiated as a radio wave or in the dc/ac line through the conductor at the end of the distribution lines to home or office applications. To get the highest performance nowadays inverter power circuits changes from on to off in a very short interval of i.e. Micro seconds, Nano seconds. The step change transition is done in one step from zero to max and from max to zero [9-11].

Microprocess used in this system take part in clock operation to do the signals in this fashion and any related communication circuits. In the process of creating a square wave no of sign wave are added, into many MHz regions, therefore these Harmonics radiate in AM broadcasted band, as a part of this elements used in inverter are not linear, so which don’t produce exact wave form. These nonlinear elements turn the circuit in a mixer, which are the part of communicating devices combine these frequencies and obtain others. So the original signal is very much distorted. Strings of inverter that are connected to array of PV modules operate on same principle, but its low current and high voltages [13].

7.4 Voltage Fluctuation Effects

Integration of PV system in distribution system can cause voltage fluctuation due to nature of these types of RESs. These issues are introduced due to the quality of voltages produced by PVs array. The quality of voltage can be affected by the weather condition, sunshine, temperature, clouds condition. These climate change in create irradiance fluctuation for the long as well short time period. Therefore, this affects the output voltage of PV in point of coupling. This disturbance in voltage fluctuation is characterized as rise and fall time and unbalance voltage [11].

7.5 Harmonic Effect

The penetration of PV system in distribution network, current and voltage distortion waveform is becoming an important issue. Due to the conversion of DC to AC by the inverter. The non-linearity results in harmonics are injected in AC main supply lines to the consumers [11]. Power quality of the system is a main issue that is been considered in the PV integrated system. Hence PV inverters are the main source which pushes current harmonics in the distribution system. Current harmonics can also distort voltage and disturb THD (total harmonic distortion with in the main AC supply [9]. Total harmonic distortion, or THD, is the sum of all harmonic components of the voltage or current waveform to the fundamental component of the voltage or current. THD is a concept in power systems and it should have low value [12].

We have seen that PV market has undramatic growth in last decade. The market has reached a total installed capacity of 40 GW noted in 2011 which produced a total of 50 TWh energy per annual. The investment on PV system is in homogenous in different countries [1].

7.5.1 PV Market in Europe

Most investments, although from different regulation and government policies, are about green environment programs. The main market of PV success is in European market. Currently, Germany leads the rest of Europe with 24 GW of PV system installed in the country at per data collected on 2011, which was followed by Italy 12 GW. Other countries like Japan, USA, China, and India are also contributing in this market [1].

With respect to power, PV energy RES is the best alternative for fossils fuels with economical point of view. Its draw backs are characterized by weather conditions or day and night shifting, or some natural disaster, which make PV a most reliable energy source. PV systems are well suited with LV distribution grids, unlike in wind turbines. So, it can be installed near to the distribution grid, in urban areas, public places or private house. If we consider the Italy scenario as of 2011, a total of 11 GW of installed PV capacity is in PV generation in Italy and since 2016 Italy has the total of 22.104 GW it is less in pervious year as compared to 2015 due to solar irradiance [1].

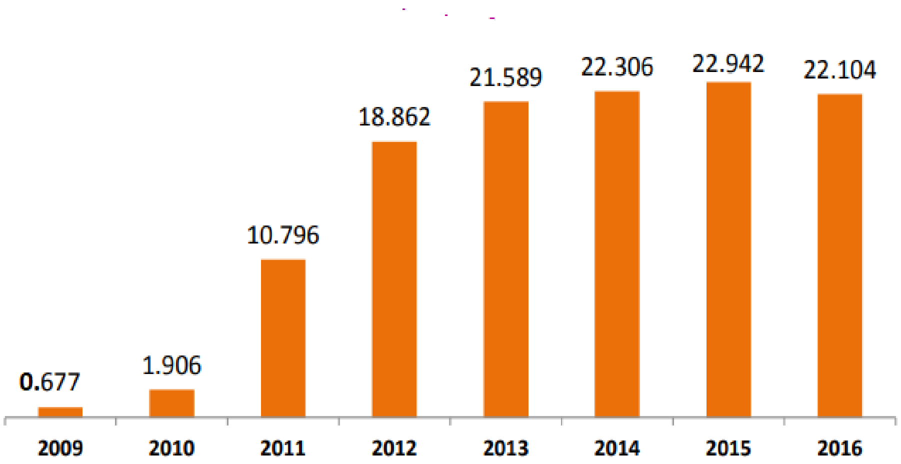


Figure 7.3 Comparison of PV Generation in Italy from Year 2009 to 2016

From power, aspect of PV has a good relation between supply and demand in LV grids. The demand of power is high in day and low in night so generation of PV is also relating with this point [2]. PV reduced the transmission and distribution losses and loading alleviation of LV grid components. The problem when the demand is low and PV generation is high it can cause power flow inversion in LV grid, which can lead to possible voltage fluctuation and distortion in voltage quality [1].

Some parts in Italy and in other EU countries have started to experience such problems due to the high PV capacity installed. The Possible solutions are the reduction of output power of generators, the power feed-in by PV systems, grid reinforcement measures and installing an ESS (Energy storage system).

8 Conclusion

Electric Vehicles are one of the most significant technological breakthroughs with extensive potential of providing environmental benefits which cannot be harnessed in all conditions. Electric Vehicles (EVs) are useful particularly in the areas where electricity is mainly produced from coal, or heavy oil combustion. With such electricity mixes, local pollution can be reduced. Therefore, EVs are used to move emissions away from the road instead of reducing them globally. The electricity mix selection is considered to be a key issue for the carbon intensity of electricity mix which is accountable for the 70% of the variation in the analysis results. Technology or supplier selection (among which electricity mix is the most effective one) is not a simple task, and sometimes, in a paradoxical inversion, this parameter defines the choice of modeling. Electric Vehicles' production phase has proven to be extensively more environmentally intensive. Transportation electrification has to be accompanied by a refined policy focus with respect to life cycle management, and therefore the counter potential setbacks regarding the toxicity and water pollution. Electric Vehicles link the transportation sector with the electronic, the electricity, as well as the metal industry sector in an unprecedented way. Thus the developments in these sectors must be conjointly and constantly addressed so that EVs can contribute positively towards the mitigation of the pollution.

The global warming potential of approximately 26.6 kWh, 253kg battery pack was found to be 4.6 tons of CO_2 equivalents. Regardless of impacts group, the production impacts of the battery were caused primarily by the production chains of battery cell manufacture, negative current collector and positive electrode adhesive. The analysis of the sensitivity showed that the most effective method for reducing the overall climatic change emissions would be the battery cells' production using electricity of a cleaner energy mix. Reducing the requirements of the manufacturing energy or using electricity from cleaner sources, improving the lifetime of the battery and closing the material loop by recycling—impacts have to be decreased up to the level where EVs provide more advantages as compare to ICEVs. Electric Vehicles producers, consecutively can increase the lifetime of the battery by improving the powertrain efficiency

Recycling process study was conducted to recognize feasible process ways for lithium batteries 'recycling, to recover lithium and cobalt. Two alternatives were found; one of these is the hydrometallurgical process which involves steps such as Cryo-milling/Inert-milling, hydrolysis, precipitation of lithium, acid dissolution, purification of solution as well as precipitation of cobalt. The other alternative method is the pyrometallurgical process in which the batteries are smelted, afterward a hydrometallurgical process entailing acid leaching, purification of solution, precipitation of cobalt, slag leaching and lastly the precipitation of lithium.

The need of renewable energy i.e. photovoltaic and the main problems related to the distribution system are also reviewed in this research work. The issues regarding harmonics and voltage in photovoltaic as well as the various types of complications that may arise in the system are also explained and discussed in detail. Photovoltaic/battery can influence the mitigation of congestion and reducing the pricing, reduction of peak-load, and the commitment of expensive thermal units. This research work also focused on the megawatt size of the photovoltaic/battery system and the strategy for its utilization.

Accordingly, industrial rules have to be properly defined in several power markets to encourage the investment as well as the utilization of photovoltaic/battery system and other kinds of distributed and renewable resource. Similar to other standardization aspects, charging standards combine the three basic concepts of standardization which are performance, compatibility and safety. Over the globe, numerous experts are collaborating to finalize these standards, overcoming various regional and technological differences to obtain unified solutions, having a clear ultimate objective i.e. to allow every EV to charge safely anywhere in the world. It is nearly impossible to cover all the aspects related to the Electric Vehicle charging infrastructure in a single research work. Some of the topics like the environmental and economic impacts of photovoltaic and grid powered Electric Vehicle charging can be addressed in the future work of this research.

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