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Environmental benefits of electrical vehicles

Externalities appeased with the use of lithium batteries

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Abstract

Road transportation creates several negative externalities; these are a key development challenge. The most important of which are environmental pollution, greenhouse gas emissions, congestion (time delay and extra fuel consumption), impacts in human health, noise, etc.

Based on the existing literature and theory, the author illustrates different the characteristics and magnitude of externalities associated with the use of road transportation and in what extent electric vehicles based on lithium batteries can mitigate those negative impacts in the environment and human health.

Fully electric vehicles based on lithium batteries are being introduced to the market. There are existing and proposed standards for the design and market considerations that must to be taken into account to reduce the risk of failure of this new technology as well as policy instruments aimed at reducing greenhouse gas emission. Although traditional fiscal instruments, such as fuel taxes and subsidies, are normally introduced for other purposes, they can also help to reduce these externalities. Multiple options apart of lithium batteries need to be used simultaneously to reduce effectively the different externalities arising from road transportation because most of those options are not mutually exclusive.

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1. Introduction

The general objective of the present work is to identify different externalities associated with use of road transportation, evaluating and measuring the impacts in a global and local scale on the Earth, with the subsequent impact on human beings. This work also aims at addressing the need to recognize that electrical vehicle technologies should be developed and measured in a way that can appease the negative externalities.

For this purpose lithium plays an important role in this thesis due to its properties and low environmental impacts, it is the most suitable raw material for creating rechargeable batteries for electrical vehicles.

This present work is design to show to what extent these lithium batteries can mitigate the negative impacts that these externalities associated with the use of transportation have.

This work contains a general overview of the lithium market and its application in rechargeable batteries that, as we shall see, increase the productivity and performance of batteries for electrical vehicles in a way that makes them more competitive compare to other types of batteries every day. With this it is intended to verify critical points that have to be taken into consideration when comparing different types of batteries.

Nowadays many technologies are stuck before they fully develop or start circulating in the market. In many cases because they are not competitive enough or they do not meet the specific requirements that need to be evaluated. When it comes to lithium batteries we can see that this is not happening. The industry is progressing, developing new technologies, decreasing costs, and improving the coverage of their products: not only batteries for vehicles are being developed, but also for computers, mobile phones, and technological devices, that push the use and development of this technology every day further.

This thesis has been divided in 4 main parts: a general background where it is intended to give better understanding about concepts and ideas that are applicable in the entire work, plus give the reader a necessary insight in the topic of externalities. Second, a chapter including the theory behind those important concepts that are included in the thesis, trying to go deeply into lithium concepts, batteries and negative externalities. Then we have a third chapter with the analysis and all the beneficial implications that electric vehicles bring when using lithium batteries. Moreover to what extent the negative externalities can be mitigated with the use of these batteries. Finally it is relevant to give recommendation and suggestions for what market consideration we need to consider in order to develop lithium batteries technologies and what are the customer need for this product.

With this division of the thesis we can systematize the information and create a standard wide general view for the problem formulation. Then it is intended to address certain indicators that can provide us acknowledge of the issues behind the use of road transportation.

The final result was the design of an analysis for the different benefits and positive implications of adapting electrical vehicles that use lithium batteries into the market based on the negative externalities and the critical points of the lithium market, in order to introduce modifications to the market share of road transportation. Finally the results are completely accepted by the mechanism of validation through the different sources we have acquired, since the results show that the switch to a new transportation based on these lithium batteries can effectively appease the negative externalities associated with transportation based on fossil fuels.

2. Background and problem formulation

2.1 Climate change, global warming and CO_2 emissions

The scientific evidence about climate change is unquestionable according to the most prestigious organizations about climate change topics.

The climate change is defined as a stable and durable change in the distribution of the weather's pattern in periods of time that can be decades or millions of years (Grafton, 2004). It could be a change in the average weather conditions or the distribution of events that surround that average (for example, extreme climate events). The climate change cannot be limited to a specific region, as it can cover the entire surface of the Earth.

The term specifically refers to the weather changes provoked by human activity, instead of weather changes provoked by natural processes of the Earth and the Solar System. It is in this sense and in the context of environmental policy that the term "climate change" has become a synonymous of "global warming". In scientific magazines, global warming refers to the increase in the surface temperature, while climate change includes global warming and all the other aspects that have influence in the proliferation of greenhouse gases.

The climate change evidence is based on observations on the increment in temperatures of the air and oceans, the melting of the ice and glaciers in the entire world and the increment of the sea levels.

Some unquestionable facts are the increment in the temperatures worldwide, 11 of the last 12 years have been the hottest years that they have registered since 1850. The increase in the average temperature in the last 50 years is almost double than the previous 100 years. The average global temperature increased 0.74 °C during the twentieth century (Uherek, 2010).

Additionally there is more CO_2 in the atmosphere; the carbon dioxide is the main contributor and dominant for the actual climate change and its atmospheric concentration has increased from a value of 278 parts per million in the pre-industrial era until 393 parts per million nowadays (Uherek, 2010).

Scientists worldwide have determined that the increment in the temperature should be cap to 2 °C in order to avoid severe and irreversible damage in the planet and subsequently disastrous effects in human society. In order to avoid this irreversible climate change and its effects, the emissions of greenhouse gases should reach a maximum roof in 2015 and then progressively decrease after that date until they reach a level of 50% for 2050 (Uherek, 2010).

The term global warming refers to the gradual increment of the temperatures in the atmosphere and in the oceans of the Earth, and the continuous increase that it is projected in the future.

It has been observed that temperatures in the Earth surface in the last 100 years have increased. We can observe an increase of approximately 0.8°C, and the largest part of this increase has been in the last 30 years.

There is no question about the increase in global temperature, but what is controversial are the source and the reasons of this increase in the temperature. Even so, the majority of the scientific community ensures that there is more than 90% certainty that the increase in global temperatures is due to the increase in the concentrations of greenhouse gases due to human activities that include deforestation and the burning of fossil fuels like oil and coal. These conclusions are supported by the scientific academies in the majority of the industrialized countries (Kolstad, 2010).

The projections based on the climate models were summarized in the Fourth Report of the IPCC (Intergovernmental Panel on Climate Change) in 2007. It pointed out that global temperatures likely will continue increasing during the XXI century. The increase would be between 1.1 and 2.9°C in the best scenario and between 2.4 and 6.4°C in the worst scenario where the emissions would be greater.

An increase in global temperatures will result in changes as we are observing now on a global scale. We can point out:

i. Increase in sea levels
ii. Changes in pattern and amount of precipitations
iii. Expansion in the subtropical deserts

It is expected that the increase in the temperature will be greater at the poles, especially in the Artic and it will be observed a retrieve in the glaciers, the permafrost and in the sea ice.

Other factors are more frequent extreme climates: this includes droughts, heat waves and heavy precipitations. It is expected the extinction of species due to the changes in temperature and variations in the performance of harvests.

Researchers hypothesize that if the increase in global average temperature is higher than 4°C compared to the preindustrial temperatures, in many parts of the world natural systems cannot adapt and therefore cannot support life in their surrounding areas. Eventually there will not be sufficient natural resources to sustain human life (Kolstad, 2010).

2.2 Global CO_2 emissions from transportation sector

The transport sector emits an extensive variety of gases with different characteristics, and the climate is altered directly and indirectly by them via chemical and physical processes. This is mainly because transportation is a large contributor of global emissions and has an impact on the stratospheric ozone (Eyring et al., 2007). Several research studies and investigations have been done in order to compare and measure the environmental impact of different transport activities: such as road transportation, aviation transport, shipping transport, etc., taking into account different trade-offs between changes in emissions resulting from technological or operational developments.

Some studies have shown that the transport sector in the world was the largest source of emissions made by human beings, accounting for 38% of the total emissions of nitrogen oxide (NO_x), and also the major cause of fossil fuel CO_2 with 21%, volatile organic carbon (19%), CO (18%) and black carbon (14%) (Berntsen & Fuglestvedt, 2008). As it has been seen, the transport industry causes both warming and cooling of climate since airborne chemicals produced by vehicles can trap incoming sunlight and warm the climate, while others cool the planet by locking the Sun`s rays. But there are important differences between transport sectors with respect to the size of temperature responses in the atmosphere. It has been determined that road transport has the largest effect on global mean temperature of all transport sectors. Recent studies pointed out that after 20 and 100 years the response of road transport in the net temperature is 6 times higher than for aviation for example (Berntsen &

Fuglestvedt, 2008). Aviation and shipping have a big short-lived warming impact but this is evident only during the first decades after the emissions. The same study suggests that if the emissions stay constant at 200 levels, the warming impact from the road transport will continue to increase and will be almost 4 times larger than that of aviation by the end of the century (Berntsen & Fuglestvedt, 2008). This is why it is relevant for this thesis to focus on the road transportation, specifically car transportation and not only look upon the impact on the environment and climate change but also elaborate an alternative solution.

2.3 Global CO_2 emissions from road transportation

As we have said previously, emissions from the transport sector, in particular from road transport, have significant impacts on the atmosphere and on climate change. This has initiated several studies and projects in order to analyse the different impacts during the life cycle of vehicles, materials, processes and products in the mentioned sector. A classic image of the life cycle`s stages of the vehicle is shown in Figure No 1 in Appendix, where we can identify four main stages: 1) raw material process, 2) production/fabrication, 3) usage, and 4) scrapping/recycling.

A brief analysis of this vehicle`s life cycle allows us to corroborate which are the main affected elements in the environment by this sector. And it is necessary to point out that the end of the life cycle is not the only environmental problem as some argue, since aspects like atmospheric emissions, the management of oils, acoustic contamination, fuel consumption that happen during the usage stage, also have significant influence (see Figure No 2 in Appendix) (Keoleian et al., 1996).

When we analyse the life cycle of the vehicle in order to detect the environmental impact that is produced in each of the stages, we could notice that the "usage stage" is where the highest impacts on environment and human health are concentrated, with 84% of total CO_2 emissions are emitted in this stage (see Figure No 3 in Appendix) (Løken, 2012).

For the purpose of this analysis we will focus on the "*use stage*" of vehicle since it is responsible for approximately 80% of the total primary energy consumption of the life cycle. Most of the emissions of CO_2 and CO emitted are issued during this stage (Løken, 2012). Moreover, the volatile organic compounds (for example, exhaust gases and evaporation of fuel) that the car generates are greater during this stage than in any other stage in the life cycle. As summary, Figure No 4 in Appendix shows that the main impacts on the environment of a vehicle are produced in the usage stage but also in the extraction and process of the raw materials. With this analysis we can justify better where to put our effort to reduce the impact.

The use of the car has essentially two effects on the environment:

- One produced from the emissions of CO_2, that affect on global warming of the Earth and the climate change, and hence, has a global impact (the emissions generated in one country have effects in the whole planet).
- On the other hand, there are also the effects produced from the emissions of gasses and particles (NOx, CO, etc.) that worsen air quality and which effects are local, i.e., it affect the health of the people who live close by or pass by the place where the pollution is produced.

In addition to these effects, there are other impacts that have to be mentioned referring to acoustic contamination and the land use for example, but this last impact is not an important part of this present work since we are focusing on the usage of EVs.

The emissions of CO2 from a vehicle has grown significantly in recent years, about 80% between 1990 and 2008, faster than the average rate of 50% growth of total emissions and way above the limit that the Kyoto Protocol established (Severance, 2011).

2.4 Development of road transportation

One of the most characteristic inventions of the last century was the vehicle. The first prototypes were created in the late XIX century, but the attempt to obtain a driving force to replace the horses is back to the XVII century. The history of the automobile goes through the three phases of the great propulsion power: steam, gasoline and electricity.

The first steam vehicle was created by Nicolas Gugnot in 1771 but it was too heavy, noisy and fearsome. During decades many inventors encouraged by this creation built many steam powered vehicles, but none of them had any significant success. However, during the second half of the XIX century, it was a growing need of a mechanic vehicle that could “walk the streets”. The invention of the steam vehicle failed because it was a heavy machine and hard to drive.

But in 1896 Henry Ford invented the first vehicle using gasoline. He was convinced that the United States needed an unlimited amount of cars because of the large distances that the country possesses. He recognized the main defects of the European cars: that they were targeted to sport or wealthy people but not to the common population. During that time United States needed cheap and widespread transport means. Henry Ford reached this objective and his model T was successfully sold during that period. In the beginning it took more than 12 hours to assemble only one car. With the improved mass production line, this time was reduced to 1 hour and 30 minutes.

With the time, cars increased in demand and were more used for different purposes. Then cars appeared with their own identity: more luxury and style that satisfied other needs from consumers.

The oil crisis in 1970 and 1980 forced the car companies to build low consumption models. Mass production today tries to cut costs in accordance with the current demand and competition.

It is difficult to measure the total impact of the vehicle in the life of man. But the car definitely produced important social and economic changes. Nowadays there is a wide range of different vehicles: luxury, cheap, electric, hybrid vehicles that satisfy all the different requirements from the customers.

2.5 Traditional petrol/diesel combustion engine

Since the commercial production of petrol in the middle of the XIX century (1850) the improvements and innovations have been significant when it comes to engines. By the end of the century there was a multitude of varieties of engines used in all kind of applications. Nowadays the internal combustion engines are essential and they are produced according to different designs and a wide range of power capacity despite all the problems associated with it: like energy crisis, oil dependence, air pollution, increased levels of CO_2, etc.

The diesel engine was invented in 1883, by the engineer Rudolf Diesel. He studied high engine thermal efficiency, using alternative fuels in internal combustion engines. For years, Diesel worked on fuels other than gasoline, based on principles of compression engines without spark ignition, which dates back to the steam engine. That is how in the late XIX century (1897), it was produced the first engine that used light oil, which in those years was used to light street lamps: this light oil is known as fuel oil (Guillen et al., 2010).

The main advantage of the diesel engines compared to gasoline engines is the low consumption of fuel and lower emissions of CO_2 than gasoline engines. But the disadvantages are mainly price, maintenance costs and functionality.

2.6 Electric vehicles (EV)

An electric vehicle is an alternative fuel vehicle powered by one or more electric motors. They can be powered either by an external power station, by stored electricity originally from an external power source, or by an on-board electrical generator. Just like a vehicle with an internal combustion engine, which is designed specifically to work by burning fuel, an electric vehicle obtain the traction from an electric motor, but the energy can be supplied in different ways:

- External supply of the vehicle throughout its journey, with a constant supply of energy, as it is common in the trolley or the electric tram.
- Energy supplied to the vehicle in the form of a chemical product stored in the vehicle by an on-board chemical reaction that produces electricity for the electric motors. An example is the hybrid car (not plug), or any other vehicle with fuel cell battery.
- Energy generated on board using nuclear energy, such as the nuclear submarine and aircraft carriers.
- Energy generated on board using solar power generated with photovoltaic panels, a method for producing clean electricity, while the other methods described depend on whether the energy consumed comes from renewable sources in order to say whether it contaminates or not.
- Electrical energy supplied to the vehicle when stationary (plug-in), which is stored on-board with rechargeable systems, and then consumed during their displacement. The main forms of storage for this are:
    - Energy stored in lithium batteries. The most used technology nowadays.
    - Electrical energy stored in super-capacitors. Technology is still in an experimental level.

- Kinetic energy stored with flywheel with frictionless, which works by accelerating a rotor to a high speed and maintaining the energy in the system, then when the energy is extracted from the system, the rotational speed is reduced because of the principle of conservation of energy.

* It is also possible to have hybrid vehicles, whose energy comes from multiple sources, such as:
  - Rechargeable energy storage and a permanent direct connection system.
  - Rechargeable energy storage and burning fuel system based, that includes electricity generation with an internal combustion engine, and the mixed propulsion with an electric motor and combustion engine.

2.6.1 Hybrid vehicles

A hybrid vehicle combines a motor driven by electric energy from batteries and an internal combustion engine (see Figure No 5 in Appendix). The latest models are based on the patents of the engineer Victor Wouk.

One of the great advantages of the hybrid is that they efficiently use 30% of the energy they generate, while conventional gasoline vehicles use only 19%. This efficiency improvement is achieved by batteries which are stored on-board the vehicle and safe kinetic energy that is generated as heat during the braking. This energy in conventional propulsion systems is lost. Many hybrid systems can pick up and re-use this energy by converting it into electrical energy through so-called regenerative brakes. Some studies have shown that hybrid engines with diesel or gasoline are an important option when people consider buying a new car since the efficiency has made them to last longer and being cleaner (Guillen et al., 2010).

So on one hand it combines a small engine, big enough to use in the vast majority of cases, with good performance and low power consumption and therefore emissions, with an electrical system able to perform two vital functions: develop an extra supplement of energy and with absolutely no extra fuel consumption.

The combination of a combustion engine always operating at peak efficiency and the recovery of energy by braking (especially useful in short length distances), make these vehicles very good for achieving better performance than conventional vehicle, especially in busy roads, which concentrates most of the traffic, so it reduces both fuel consumption and emissions. Electric vehicles use batteries charged by an external source, which in some cases causes them autonomy operation problems.

Since the larger consumption of vehicles is within the city, hybrid engines constitute significant energy saving: Through the use of hybrid technology, they can achieve reduction in fuel consumption of up to 80% in the city and 40% in roads, compared to conventional vehicles.

Electricity can be used as energy “currency” since the electric engine consumes electricity regardless of the source used to generate it.

In conclusion, with respect to energy efficiency, the hybrid vehicle is a milestone never achieved before.

The main problem would be consumer demand due to the extremely low price of fossil fuel (compared to other energy sources). This has been possible since oil is a source that humans have found easily available, and this fact does not contribute to raise awareness of energy savings. Moreover there are other major challenges for this type of vehicles, like the current costs of producing batteries, the weight and its limited storage capacity (Becker, 2009).

2.6.2 Plug-in hybrid vehicles

A plug-in hybrid vehicle is a vehicle which batteries can be recharged by plugging in the vehicle to an external source of electric energy. It shares some characteristics both with a hybrid vehicle and with an electric vehicle, since it has an internal combustion engine (gasoline, diesel, etc.) and an electric motor with a battery package that can be recharged by plugging it into the electric supply system (see Figure No 6 in Appendix).

The electric range of a plug-in vehicle is designated as PHEV-(miles), where the number represents the distance in which the vehicle can travel exclusively with electric energy supplied by the battery. For example, a vehicle PHEV-20 can travel 20 miles without using the propulsion internal combustion engine. We can say that this plug-in vehicle obtains its energy from a battery, that is rechargeable from an external source of electricity, and it is built as a light-vehicle.

It is estimated that the cost of driving a plug-in hybrid only with electricity is less than one fourth of the cost of gasoline from a conventional vehicle. Moreover it is expected that the users would recharge their vehicles during the night (low demand hours), when the cost of electricity is cheaper (Valdes Dapena, 2012).

Compared to conventional vehicles, plug-in hybrids reduce air pollution, the dependence on oil and fossil fuels and the emissions of greenhouse gases that contribute to global warming.

One of the barriers for the adoption of electrical vehicle is the driver’s fear of the depletion of the battery before reaching the destination. Plug-in hybrids can solve this problem with the conventional engine they have that uses gasoline, which starts working as soon as the battery is depleted (Keoleian et al., 1997).

Disadvantages of the plug-in hybrids are its high costs, the bigger size of the battery-package and its additional weight and its durability. And even though it is supposed that most of the consumers would recharge them during the night in the garage of their houses, many people live in apartments, condoms, dorms, and urban centers that do not have their own garage. And those who park their vehicles in public areas cannot plug-in the vehicle during night. Moreover, people who do have garage also will need to recharge at their work place, shopping center or other public areas. Then it is needed that cities have public recharge stations: but this infrastructure almost does not exist and it requires huge investments from governments and private companies.

2.6.3 Hydrogen vehicles

This vehicle uses hydrogen as its source for motive power, which is made from methane or other fossil fuels, but it can be produced from a wide range of sources, such as wind, solar or nuclear. Hydrogen is not a pre-existing source of energy like fossil fuels, and it has to be produced and then stored as a carrier (like batteries).

The motive power generated by the hydrogen can be made using one of these two methods: either by burning hydrogen in an internal combustion engine (in the same way as gasoline), or by reacting hydrogen with oxygen in a fuel cell to run electric motors. In this way the fuel cell acts in the same way as a battery.

The fuel cell vehicle is considered a zero emission vehicle because the only sub-product of hydrogen consumed is water, which additionally can move a micro-turbine.

However there are huge economic challenges associated with implementing wide-scale use of hydrogen cars as it is stated that hydrogen cars is one of the least efficient, most expensive ways to reduce greenhouse gases since there are more readily available solutions to reduce the use of fossil fuels in vehicles (Valdes Dapena, 2012).

2.7 Emphasis of the thesis work

For the purpose of this thesis, we focus on electric vehicles that use lithium batteries. The reason behind this is that lithium is a mineral resource that, because of its high specific heat property, is used in heat transfer applications, and its high electrochemical potential is a suitable anode for electric batteries. Moreover the low environmental impact might reduce the negative externalities associate with the use of cars. Lithium is a moderately abundant element in the crust of the Earth. The lithium battery is designed for the storage of electric energy that uses as electrolyte a lithium salt that supply the necessary ions for the reversible electrochemical reaction that takes place between the cathode and the anode.

2.8 Problem formulation

As we all know the transport sector causes both benefits and costs. Some of these costs have no direct tangible value, so it is necessary to use other kinds of procedures that allow measuring them monetarily. We will focus on the negative externalities associated with transportation and especially to what extent the various externalities, associated with the environment, can be removed by the transition to electric vehicles that use lithium batteries.

This might depend, among other things, on how the electricity for these vehicles is produced and how efficient they are. If the electricity is produced using fossil fuels, then the stock externalities are moved from the consumption to the production (from the wheels to the well, so to speak).

Therefore road transport impact issues on climate change are becoming imperative: the projected efficiency developments of vehicles and the introduction of biofuels will not be enough effort to balance the estimated growth in both passenger and cargo transportation. (Guillen et al., 2010). Technical measures, like adoption of lithium batteries in electric cars, could offer a significant reduction potential, but government interventions would be needed as markets do not initiate the necessary changes. Additional reductions would require a firm development of low carbon fuels to generate electricity, an increase in vehicle fuel efficiency and reduction of absolute transport volumes. It has to be pointed out that road transport will continue to be a crucial sector in climate change mitigation in the future (Edwards, 2009).

3. Theory

3.1 Market of lithium

Lithium is a metal which has diverse uses. During the past 40 years lithium has been widely used in the aluminum industry, in the manufacture of glass and ceramics, in fat and lubricants, in the treatment of air conditioning, in thermoplastic and rubbers, in pharmaceutical industry etc. However the use in batteries has driven the most significant growth in demand for it (Guillen et al., 2010).

The technologic boom through the development of lithium batteries has meant that this mineral resource has become an almost irreplaceable input in modern life. Each of the billions of cell phones, personal computers, power tools, PDAs or MP3 players, among others, need batteries for operation.

But the attracted interest from international markets for this mineral is due to the projections of future demand for electric and hybrid electric vehicles (AECOM, 2009). The measures that many developed countries have undertaken in reducing the CO_2 emissions, to tackle the effects of global warming, calls for increase in other sources to replace fossil fuels like oil as the main fuel for vehicles. In this sense the development of economically viable models of electric vehicles and hybrid electric vehicles, has progressed rapidly. It is estimated that by the end of this year there will be at least ten vehicle manufactures offering electric or hybrid electric models using lithium batteries. There are almost two million such vehicles already on the road (Guillen et al., 2010).

By 2020 rechargeable batteries would represent the main application of lithium with 42% of demand for lithium (in 2007 this figure was 27%). The projected demand indicates also that by 2020 the batteries for electric cars will represent 25% of the lithium demand. This is mainly because when we analyze the trends of new prototypes of hybrids and electric vehicles, it is expected that by 2020 these types of cars will capture about 12% of the global supply for vehicles. The high expectations of future demand for lithium have caused an increase in the prices of this resource in recent years. Between 1998 and 2008, the average price of lithium increased by more than 20 times, which means an annual average increase of around 13%. And as it was mentioned before, rechargeable batteries would be the key factor for this. The main buyers of this mineral for lithium batteries purposes are Japan and South Korea.

3.2 Rechargeable batteries for electrical vehicles

A rechargeable battery is a device capable of storing energy through electrochemical reactions of oxidation/reduction. Batteries are secondary generators, i.e., they cannot function without being supplied with electricity through what is called a charging process. Subsequently, the chemical energy of the active materials of the electrodes transform to electric energy through red-ox reversible. These reactions red-ox are necessarily associated with a transfer of electrons between reactants. In the case of the red-ox electrochemical reactions, such electronic transfer takes place through an external circuit where there is an application which supplies electricity (Cena, A. & Santamarta, J. 2009).

The basic unit of a battery is the electrochemical cell, and a battery is made by two or more cells. In order to increase the voltage and/or the capacity of the accumulator, these cells have to be connected in series, in parallel or in a combination of both.

The benefits of a battery will depend largely on the characteristics of the cells used in their manufacture. The most widely used electrochemical parameters to characterize a battery are:

i. *Electromotive force, voltage or power (E).* The voltage of an electrochemical cell is given by the difference between the power red-ox of the active materials of the cathode and the anode. It is very important to dispose cells with high power, since this allow the reduction in the number of cells that must be connected in series in order to increase the voltage of the battery. The electromotive force of the cells is measured in volts.

ii. *Specific Capacity (Q).* The capacity is the parameter that indicates the total quantity of electric charge that the battery is able to store. The most common unit used to express the capacity is the ampere hour (Ah). When we compare different battery technologies, it is very useful to normalize the value of the capacity to the total mass ($AhKg^{-1}$) or to the total volume (AhI^{-1}) of the battery. Both normalizations are significant, since both weight and total volume of the battery, are magnitudes that are important to reduce in order to handle an optimal application of the battery in the electric vehicles.

iii. *Specific Energy (W).* The specific energy indicates the total quantity of electric energy that can be stored in the battery. This parameter is very important since it includes both parameters previously mentioned. Thus, the specific energy of a battery related to its mass is given by W_m= *E*Q/Weight of the battery*. The specific energy related to its volume, also known as energy density, is given by W_v= *E*Q/Volume of the battery.* The units used for both energies are $WhKg^{-1}$ and WhV^{-1} respectively.

iv. *Life Cycles.* The life cycles of a battery are the numbers of cycles of charge/discharge which can be carried out until the capacity of the battery reaches 80% of its nominal value. It is highly recommendable that the batteries have more than 500 life cycles if they are going to be used in electric vehicles.

It is important to mention that at the time of deciding which technology of batteries is the most ideal in electrical vehicles, aspects such as a low environmental impact or that batteries are easily recyclable, play a very important role. Finally, to be able to have batteries at a low or moderate price, is another parameter that has to be taken into account when they have to take a decision.

3.3 Advantages and disadvantages of different types of batteries

3.3.1 Lead-acid battery

The main advantages of the lead-acid batteries are:

- High voltage. Among the electrochemical batteries that are based on aqueous electrolytes, these are the ones which have the highest nominal voltage, E=2,0 V.
- High power. The lead-acid batteries are capable of supplying a high intensity current, and therefore high power. This property is justified due to the quick kinetic of the

reaction of the electrodes in these batteries. In electric vehicles, this property is useful during the period of acceleration of the vehicle.

- Technology easy to implement. The manufacture of the lead-acid batteries is facilitated since i) the initial mixture of $PbOH_2SO_4$ that is used in the manufacture of both electrodes (cathode and anode) is the same, ii) the electric conductivity in the active materials of the electrodes is high, so it is not necessary to add any additional component to improve the electric response of the electrodes, iii) the current collectors and the electric connections between the elements of the battery are made in lead and iv) nowadays, the battery manufacturing of lead-acid have reached a considerable degree of automation.
- Low cost. Clearly, the main advantage of these batteries is its low price, around 100-125 US$/Kwh (Guillen et al., 2010). Nowadays, it is the cheapest technology of electrochemical batteries on the market and it will probably continue to be so.
- Mature Technology. The technology of the lead-acid batteries, after 150 years of its development, is well known and it is mature.
- Components easily recyclable. The technology for recycling the components of these batteries is highly developed. And in some countries they recycle almost 95% of all batteries used.

On the other hand the disadvantages of the lead-acid batteries are:

- Low specific energy. Of the three technologies for batteries analyzed in this section, lead-acid batteries are the ones which have the lowest specific energy (10-40$WhKg^{-1}$). These low values are a consequence of the high specific weight of the lead components that are used in these batteries.
- Moderate cyclability. When there is a deep discharge in the battery, i.e., when a larger part of the capacity of the battery is used, the number of cycles of charge/discharge that remain is moderate, typically 400-800 cycles. This limitation reduces the average life of the battery when it is used in electric vehicles.
- Gassing. During the stage of charging the battery, it may form hydrogen and oxygen in the electrodes. This emission of hydrogen is very risky, since this is a flammable gas.

- Strong environmental impact. Beside the strong contaminant side of the lead components, some configurations of lead-acid batteries include antimony and arsenic as components of the current collector grid. These elements may result in stibnite and arsine (highly toxic compounds).

Application of lead-acid battery in electrical vehicles

The lead-acid batteries were chosen by the General Motors engineers to launch their revolutionary model GM-EV1 in 1997 (see Figure No 7 in Appendix). This vehicle has an honor place in the history of electric vehicles, since it was the first EV to be commercialized in series. The low cost of the lead-acid batteries and the maturity of its technology were the main reasons why GM used these batteries in the GM-EV1. Then maximum speed of this car was 130 Km/h and it had an autonomy of 140 Km. Its battery system was able to store 16,3 kWh and it was made up by 26 accumulators of lead-acid without maintenance. Unfortunately, surrounded by a controversial decision, GM decided to recall this vehicle from the market in 2004 (Guillen et al., 2010).

Nowadays, the lead-acid batteries are being used in the electric vehicle Reva-i, that is produced by the American-Indian company Reva Electric Car (see Figure No 8 in Appendix). This is the best-selling electric urban car in the world. It has small dimensions, and it was designed to cover the very basic needs of mobility in an urban area, especially under high traffic conditions and low speeds. It is driven by an eight lead-acid battery system, with a nominal voltage of 48 V, capacity of 195 Ah and 9,36 kWh of specific energy. The charging time of the batteries is 8 hours (with a conventional plug). The autonomy of the Reva-i is between 65 and 80 Km. Even though these are reduced values, it is considered appropriate for a large number of displacement in a city. Beside the consumption of this car is very low, it is estimated that the cost per 100 Km traveled is approximately 8 nok (Guillen et al., 2010).

3.3.2 Nickel-metal battery (NiMH)

When we look at the advantages and disadvantages of a new technology of batteries it is necessary to take into account the existing technologies in the period of time when these were introduced on the market (Cena & Santamarta, 2009). In this case, when NiMH batteries started to be commercialized, the existing batteries were the lead-acid and the nickel-cadmium. In comparison to these two technologies the main advantages of the NiMH batteries are:

- More specific energy. The NiMH batteries have a specific energy (60-80 $WhKg^{-1}$) which is highly superior to the lead-acid ones (10-40 $WhKg^{-1}$) and greater than its predecessor, the alkaline battery of nickel-cadmium (~ 60 $WhKg^{-1}$).
- Tolerate fast recharges. Typically, the NiMH batteries are capable to accept fast recharges with duration of 1 to 3 hours. In hybrid electric vehicles this is an important parameter in order to take advantage of the energy generated during the regenerative braking.
- Low environmental impact. The substitution of cadmium in the anode for metal hydride significantly reduces the environmental impact of the battery, since cadmium is considered toxic even in small concentrations.
- Do not require maintenance.

The limitation or disadvantages of the NiMH batteries are:

- Moderate number of life cycles. The metal hybrides suffer severe corrosion; this produces a significant reduction in the rechargeability of the battery. Thus, the number of cycles that can take place in a NiMH battery ranges between 600 and 3300 cycles.
- High cost. The NiMH batteries can reach a price which is four times higher than the lead-acid accumulators.
- Lower electrochemical performance at high current. In comparison to the NiCd batteries, the performance of the NiMH accumulators decreases more when they utilize high current.
- Moderate “memory effect” which takes place when we recharge the battery before it is completely depleted; then part of the energy storage is lost forever. So, even though they have a lower memory effect than the NiCd batteries, they still have this.

Application of nickel-metal batteries in electrical vehicles

It is said that the transition from the existing internal combustion cars to future zero-emission electric vehicles, is not going to be direct, but is going to pass through a stage of hybrid electric vehicles (HEV).

The HEV, as we have mentioned in the previous section, besides of having a combustion engine, they have a small electric motor that functions with batteries. This engine is responsible for starting the car after a short stop, for example, starts in the traffic lights, and it complements the combustion engine in the acceleration process. The big advantage of using batteries in these vehicles is that they can store electric energy that is generated during the regenerative braking. Nowadays, the HEVs on the market also have NiMH batteries to drive the electric motor. This is because of the fact that in the years when these vehicles were designed the NiMH batteries were the accumulators that better accomplished the requirements that the HEV demanded.

The HEV that had most commercial success is the Toyota Prius, with more than one million sales around the world (see Figure No 9 in Appendix). The most significant advantages of this vehicle are its low consumption of gasoline (~3,5 liters per 100 Km) and its low level of emissions (107 g of CO_2/Km) (Cena & Santamarta, 2009).

3.3.3 Lithium ion battery

The Lithium ion batteries represent the most advanced technology for electrochemical accumulators since they have the following advantages:

- High voltage. The Li-ion batteries have the highest nominal voltage that ranges between 3 and 4 V. These values can be up to three times higher than those shown in the NiMH batteries.
- High specific energy. Of the three technologies that are being used in EV, the Li-ion batteries are the ones which have the highest specific energy, both mass (80-170 $WhKg^{-1}$) and volumetric (170-450 $WhKg^{-1}$). These values are almost twice as large as in NiMH batteries and four times higher than the lead-acid batteries.
- High number of life cycles. These batteries have a very good rechargeability.

- Moderate to low environmental impact. As in the case of the NiMH batteries, the lithium batteries are free of high toxic materials like lead, cadmium and mercury.

Some of the current disadvantages of the Li-ion batteries are:

- High cost. However it is projected that the cost will decrease dramatically since the demand for these batteries will grow and there will be a huge research and technological development for Lithium applications, plus introduction of new cathode materials is expected. Moreover the supply of Lithium is expected to grow since producer countries of this raw material are investing large amounts of money to extract and produce more.
- Loss of yield at high temperatures. Several Li-ion batteries have shown a loss in its electrochemical properties when they work at temperatures higher than 50°C.
- Low tolerance to abuse. The Li-ion batteries degrade when they are under abuse conditions, i.e., when it is overloaded or discharged. Thus, when the battery is discharged under 2 V, it degrades quickly. This also happens when it is overloaded. Also the battery can suffer from an uncontrolled heating process so called “thermal runaway” that in extreme situations can cause fire in the battery.

Application of lithium battery in hybrid electric vehicles

It is projected that the lithium ion batteries will be the most used technology in electric vehicles and hybrid cars. In fact they are already being used in commercial cars with high autonomy like the Tesla Roadster (see Figure No 10 in Appendix). This sport car can accelerate from 0 to 100 Km in 3,7 seconds. One of the main characteristics of this car is its high autonomy (360 Km with one single charge). In order to have such a good performance the Tesla engineers have worked on cells that are quite similar to the ones in laptops. This system operates with a voltage of 367 V, it is capable of storing 56 kWh of electricity and its total weight is 450 Kg. (Cena & Santamarta, 2009).

The Tesla engineers have put special emphasis on the safety of the battery. Thus, they have included several control systems such as current-limiting, pressure detectors, etc. They also have achieved to be able to charge the battery in three and a half hours. The price of this Tesla Roadster is approximately US$100.000 (Cena & Santamarta, 2009).

Nowadays the three battery technologies that are being used in electric vehicles are Lead-acid, Nickel-Metal Hydride and Lithium ion. Figure No 11 in Appendix shows a comparison of the different performances for each battery, the environmental impact and the cost for these technologies.

3.4 Externalities regarding the use of vehicle

With the introduction of electric vehicles that use lithium batteries there will be a change in the externalities associated with transportation. Regarding different emission factors for different pollutants and economic values it is possible to distinguish these externalities. For that purpose they have to take into account greenhouse gas emissions from both fossil fuel and electricity, and air pollution arising from vehicles. Greenhouse gas emissions will be different for the different types of fuel used in the different engine configurations both combustion and electric.

3.4.1 Stock externality, CO_2 and environmental implications

We define the stock externality of conventional cars as the externality associated with individual consumption or purchase and use of cars that lead to the production of a public bad: in this case the emission of CO_2 that produce the greenhouse effect in the whole planet.

The impact on climate change according to different studies is motivated primarily by the emission of greenhouse gases such as carbon dioxide (CO_2), methane (CH4) or nitrous oxide (N2O) (Fuglestvedt et al.,1999). The assessment of this impact is highly complex because it has global and long-term effects, of very different nature: flooding, impacts on agriculture, human health effects, changes in precipitation, increased chances of natural disasters, etc. (Fuglestvedt et al., 2003).

Nowadays the economic activities that affect climate mostly are agriculture and energy. Of these, the latter is probably more significant, especially taking into account that transportation is an important sector that consumes a vast amount of energy. In this sector, emissions of carbon dioxide, particulate matter, and heat are of significance for the global climate.

The impact caused by the mobility is measured primarily by the energy consumption of the activity. Transportation in private vehicles is considered among the largest consumers of energy and therefore emitters of air pollution. Hence we put special emphasis on this type of mobilization.

The use of vehicles as private transport is a major source of atmospheric pollution at a global level. Among the main substances that are emitted is carbon dioxide or CO_2. These are responsible for the greenhouse effect, and road transportation accounts for 40% of total emissions of CO_2 that the transportation sector emits into the atmosphere (Fuglestvedt et al., 2008).

The interaction between carbon dioxide and the climate is as follow: the combustion of fossil fuels leads to emissions of carbon dioxide into the atmosphere. When it is in the atmosphere, the residence time is very long. Then since a selective absorption of radiation takes place, the increased atmospheric concentration leads to increased surface temperatures. Some studies have shown that doubling atmospheric concentrations of CO_2 would eventually lead to a global mean temperature increase of 3°C, some other studies are even more severe in this predictions (Uherek, 2010).

This externality is important and requires action because individual burning of fossil fuel in conventional vehicles does not take into consideration the climate costs. It will affect not only the global climate, but also the environment for hundreds of years into the future (Norman, 2001).

Therefore it is important to try to control the CO_2 emissions in some way. And the replacement of conventional vehicles for electric vehicles that use lithium batteries is an important alternative. But they need to create proper incentives for nations, producers, and consumers to implement these measurements at an individual level.

There is a lack of mechanisms on market level and political level to ensure that the problem can be controlled. Moreover the question that emerges is how to allocate resources so as to eradicate this carbon dioxide issue. Then again, any non-fossil fuel energy source is an option for this objective since they have no significant CO_2 emissions.

3.4.2 Externality associated with the use of fossil fuel as non-renewable resource

Fossil fuel has been essential for the development of our modern society since it is used to provide energy and input materials in numerous industries and sectors: especially transportation. Since fossil fuels cannot be refilled with an imaginable time horizon, continuous extraction will sooner or later lead to physical or economic depletion (Fuglestvedt et al., 2008).

One of the focuses of exhaustible resource economics has been the finite supply of fossil fuel. And we can see that they have emphasized the long-term externality problem related to the use of oil, the atmospheric accumulation of carbon dioxide and the possibility of global warming: CO_2 emissions arise as a result of use of resources that are finite and exhaustible as fossil fuel. In economic terms, pollution from the use of fossil fuels is counted as a negative externality, and since the transportation sector is one of the largest users of it, it is a negative externality from the use of transport. It reduces the welfare of all people

3.4.3 Flow externality associated with local pollution

Vehicular congestion not only creates global atmospheric pollution due to emissions of greenhouse gases, but it also produces local air pollution, noise, traffic accidents, etc. (Capuz Riso et al., 2008).

Among the main substances that are emitted are sulfur dioxide, lead, carbon monoxide, volatile organic compounds, particles and nitrogen oxides. Some of these emissions not only have effect on global warming and climate change but they also provoke acid rain and they affect the quality of the air in local areas.

This type of air pollution causes severe effects on human health, a fact that is highly proven through studies that confirm that the increment in pollutant substances and particles is followed by an increased number of people hospitalized for respiratory and cardiovascular diseases and reduced pulmonary functionality. According to a recent European Commission study, air pollution causes more deaths than traffic accidents. Moreover there are population groups that are more affected by this contamination than others because they are more vulnerable (infants, pregnant women, people with heart or respiratory disease and elderly people). And depending on the type of contaminant, its concentration, time of exposure, seasonal fluctuations and the receiver sensibility, the effects will be higher or lower (Capuz Riso et al., 2008).

Another direct consequence of the excessive use of private transport is noise that is provoked, although some time ago they did not spend much time or put much attention to it. This externality has social and environment effects, and also consequences for human health. The noise is a main polluter and it can generate specific pathologies, besides affecting the quality of life in a city.

Noise affects human health since it disturbs sleep and can also cause physiological, psychological, or behavioral changes because of the stress generated; resulting in a problem for human health and welfare of communities. It also causes headaches, depression and irritability. In long term it can also create a hearing loss problem due to direct exposure to noise.

From the social point of view, many daily activities are affected by this factor, such as development of educational activities or any other activity that involves communication: such as tourism for example, which may be affected due to loss of attraction for people who value tranquility and peace (Eyring et al., 2009).

3.4.4 Network externality of electric vehicle

The decision about which type of transportation to adopt is very important since it determines the network externality generated by this decision. The network externality in this case is the result that one consumer`s usage of the vehicle has on the value of the vehicle to other users (Becker, 2009). Because of the high degree of consumer interdependence in the transportation sector this network externality is high. For the electric car usage the network externality is relevant for those cars that need battery charging or switching infrastructure. For such vehicles to reach high popularity in the world, huge investments in service network for batteries must be made in order for these to be competitive compared to the existing combustion gasoline fueling infrastructure in terms of price, range and reliability.

There is also a broad network of human capital with specific training in combustion engine repair and maintenance. Then the electric car industry will require investments in order to encourage proliferation of a new network of mechanics who offer drivers a viable alternative to the existing fossil fuel based network (Becker, 2009).

4. Methodology

In order to develop the themes described above and define the evaluation criteria, it has been performed a series of document research, readings, and for understanding the importance and purpose of a critical literature review for this thesis work.

Reviewing the literature critically is a key point for this thesis, and it has provided the foundation on which this work is built. That is why, for the purpose of this thesis, it has been used literature to help the understanding of the problem and identify ideas with subsequent use of data. This is known as deductive approach (Saunders, 2009) in which we have developed a theorical and conceptual framework, which has been supported with the use of data, information, examples, etc.

All this literature has contributed to help to refine further the problem formulation and objectives. Moreover it has highlighted research possibilities that might have been overlooked in research to date, as the use of lithium batteries for example.

All the secondary data used in this work has contributed to discover explicit recommendations and provided insight into research approaches, strategies and techniques that has been appropriate for this problem formulation and objectives.

As structure for a critical review, it has been useful to think of the review as a funnel (Greenhalph, 1997) in which it has:

1. Started at a more general level before narrowing down to the specific problem formulation and objectives;
2. Provided a brief overview of key ideas and themes like the use of lithium;
3. Summarized, compared and contrasted the research of different writers about externalities and electrical vehicles;
4. Narrowed down to highlight previous research work relevant for this thesis;
5. Provided an account of findings for this work and showing how they relate;
6. Highlighted those aspects where this thesis will provide fresh insights;
7. Lead the reader into subsequent section for this work, which explored all these issues.

For the development of this work, it was required to divide the methodology in seven different parts:

- Problem formulation
- Objective formulation
- Criteria formulation
- Data collection for the Lithium market and rechargeable batteries
- Evaluating secondary data
- Analysis of externalities
- Recommendation and discussion

4.1 Problem formulation

As we have already explained, the problem lies in the consequences of transportation, both benefits and costs. Moreover, different evaluations agree that the use of vehicles in road transportation bring several negative externalities that affect the whole world population. After reading and documenting many sources it has been decided to focus on these negative transportation externalities and find out to what extent these various externalities can be removed by the conversion to electric vehicles that use lithium batteries. It is not a question about internalizing these externalities, but finding alternatives with less pronounced externalities.

4.2 Objective formulation

The objective in the present work is to identify different negative externalities associated with the use of road transport and how electric vehicles that operate with lithium batteries can mitigate these problems.

4.3 Criteria formulation

An analysis of externalities associated with the use of road transport should incorporate all the criteria that are considered relevant and affect the different stakeholders in the process of the use of vehicle.

The number of criteria could be enormous since it should include economic criteria (costs, economic development, safety supply, energy diversification), sociocultural (cultural aspects, risk perception), environmental (global impact, regional and local), and technical (reliability, operability, flexibility) criteria.

But, on the other hand it is convenient to reduce the number of criteria used in a reasonable number (Saunders, 2009). This allows that the criteria are weighted properly because stakeholders tend to ignore objectives that they consider less important.

This reduction contributes to eliminating redundancy between criteria, which might magnify a greater consideration to a criterion that has been taken into account. Hence, it is necessary to find equilibrium when we select the criteria.

From an economic point of view we should choose the costs of implementing electric cars (investment, operation and maintenance, energy supply, battery cost, and commissioning).

Among the environmental impact/criteria; we have to choose the most relevant at a global and local level, since it is in this scope the internalization of externalities takes place. The most significant impacts of the externalities are the global warming produced by the CO_2 emissions, local pollution caused by SO_2 and NOx emissions, and the generation of tropospheric ozone due to the nitrogen oxides, among others.

These impacts should be introduced in the analysis of physical terms, measuring the effects, such as the loss or alteration of habitat, increment of mortality, and increment in the risk perceptions.

Therefore the impacts should be expressed in terms of emissions of the pollutants that produce them, these are: CO_2 emissions, SO_2 emissions, NOx emissions.

4.4 Data collection for the Lithium market and rechargeable batteries

Something that had to be done is to collect and reanalyze data that have already been collected for some other purpose. Such data are known as secondary data (Saunders, 2009), and in order to have a better understanding of the dimensions of the lithium market and the forecasted projections for the different uses of lithium batteries, it was necessary to assure this information and document it since these data can provide a useful source from which to answer, or partially answer, the question about what is the business behind lithium.

In this case the secondary data acquired included both raw data and written material. But also include non-written material, such as pictures, lectures, presentations (eg. "Toyota the role and the environment", seminar at NHH), etc. These data were analyzed both quantitatively and qualitatively. This type of data was very useful to help to triangulate the findings based on other data such as written documents.

Lithium, although it will never replace oil, is an attractive industry because it is associated with green technologies such as electrical vehicles, which need batteries to store energy.

4.5 Evaluating secondary data

It was very important that all the information and data that were collected, be collected with a specific purpose in mind: to meet the formulation problem and objectives. Unfortunately, secondary data sometimes use to be collected for a specific purpose that differs from the formulation problem or objectives (Saunders, 2009). Consequently, we had to be rigorous in order to identify whether the data we are considering may be inappropriate to the work or not. And in some cases when that has happened it had to be compared with an alternative source. Common reasons for these problems are that this includes the data being collected a few years earlier and therefore not being current.

4.6 Analysis of externalities

After reading and documenting all the necessary and available information, the externalities associated with the use of road transportation were defined. After we used existing theory to formulate the problem and objectives, we used theoretical propositions that helped us to devise a framework to organize and direct the data analysis. With this approach we commenced with and utilized theory in qualitative data, we could later on develop a work for the purpose of the thesis.

For each externality in this work, there was a process for systematizing and structuring the information to create a common relationship, such that critical points and criteria are more understandable

By doing this, it was possible to detect possible weaknesses in data collection, the need to revise literature sources or identify new problems that can enrich the main analysis. The systematization of the information to develop more structure involves the following:

- Selecting and evaluating the information that need to be collected play a key role in creating the foundations for later on initializing the analysis. Here we could distinguish between all the information that were obtained, that was relevant for the intended purposes and present evidence, arguing and contrasting the specific aspects for each externality. By selecting the information we attempted to prevent an indiscriminate use of information that might lead to a superficial treatment of the topic and to a non-organized work.

- Classify the information, which is, reviewing in detail the data that we have selected, and recognize what is useful for analyzing each externality that we have raised. The use of various sources in the collection of data allows us to compare data to recognize similarities and differences between cases and situations, and to identify milestones.

- Answer the problem formulation and objectives, given the specific aspects to be analyzed, it is necessary to think about how to analyze each of the externalities given the problem formulation that guided the data collection.

4.7 Recommendation and discussion

Finally it was conducted a discussion where it was concluded with recommendations after analyzing the findings. There were two important points to bear in mind when writing and suggesting the recommendations. The first was to have in mind the facts we presented in the previous chapters, since many get confused about the different findings and analyses they might be discovered.

The second point links to the first one. It is important to have consideration of the way we present our recommendations. Since the purpose of this work is to communicate the answers to the problem formulation to the audience as clear and logical as possible.

5. Analysis

Three of the most important challenges that our society is facing this century are: 1) to reduce the CO_2 emissions in order to abate climate change; 2) improve the quality of air in big cities and 3) reduce the dependence on oil.

The development of electric vehicles (EV) is one of the most efficient alternatives to pursue these objectives. Electric vehicles are more efficient than the classic internal combustion cars; sometimes an electric motor can be four times more efficient than a thermal engine. Beside this, EVs are more respectful with the environment. Some projections suggest that the use of hybrid electric vehicles will reduce the levels of CO_2 emission by more than 30%.

In the case of electric vehicles that use lithium batteries, their emissions are zero at its point of use, so we might tend to think that the use of these ones on a big scale in large cities will reduce the air pollution and will establish valuable synergies with renewable energies. Thus, for EVs that are rechargeable with electricity from renewable sources, its total CO2 emission (including the emissions produced in the origin) will be almost zero. On the other hand the use of renewable energies in transportation will reduce the dependence on oil.

Lithium batteries are an essential component for the EV since they are responsible to store and supply the electric energy that these vehicles need for its functioning. The features of autonomy, maximum speed, charging time, cost etc. will depend on the technology of the battery. For all these reasons, the subject matter of rechargeable batteries is one of the most important in the field of electrical vehicles.

5.1 Beneficial impact of electric vehicle with lihtium batteries

It is unquestionable that the adoption of electric cars along with the use of lithium batteries will impact the trade balance, business investments, employment, health care, associated costs and greenhouse gas emission indeed (AECOM, 2009)

5.1.1 Impact on stock externality, CO_2 and environmental implications

A significant reduction in the transportation-related emission will lead to achieve a major reduction in greenhouse gases, especially CO_2, and this can be accomplished by introducing electric vehicles based on lithium batteries. Both domestic and international efforts have to be made into this goal. In the United States for example, the transportation sector accounts for nearly 30% of the energy usage and motor gasoline accounts 20% of the economy`s greenhouse gas emissions (Becker, 2009).

The adoption of lithium batteries in hybrid electric cars will bring substantial reductions of CO_2 emissions if the source of the energy is non-polluting, that is renewable electricity production.

In order to achieve this goal, it is very important where the energy comes from. If electricity to power electric vehicles is produced by non-carbon sources the range of greenhouse gas reductions across different scenarios is much better. Indeed these reductions in CO_2 emissions are lower if the electricity to power these vehicles is produced using non-carbon intensity from the grid. That is why it is said that this system is very suitable for the Norwegian model since almost 99% of the electricity generation comes from renewable energy (Løken, 2012). Then the problem of taking the issue from the wheel to the well disappears. An advantage that is seen with an electric vehicle charging system relying on network operator is that this might centralize the purchase of electricity in these network operators, and then the additional generating capacity can be purchased wholesale from non-carbon sources.

However not all countries rely on renewable sources of energy like Norway. In United States only 9,7% of the energy is produced by hydropower and the main source is coal with almost 48% (see Figure No 12 in Appendix).

In the OECD countries the share of electricity production from fossil fuels has gradually fallen from 75% in 1971 to 67% in 2009. This decrease was due to a progressive move away from oil, which fell from 20.9% to 5.1% (OECD, 2011). Oil has been replaced in particular by a dramatic growth in nuclear electricity generation, which rose from 2.1% in 1971 to 13.4% in 2009 (see Figure No 13 in Appendix). However we can notice that the share of coal remained stable at 40-41%. The share of hydro-electricity is 16.2% and due to large development programmes in several OECD countries, the share of new renewable energies, such as solar, wind, geothermal, biofuels and waste increased. However, these energy forms remain of limited importance (see Figure No 14 in Appendix): in 2009, they accounted for only 3.3% of total electricity production (OECD, 2011).

5.1.2 Impact on externality associated with the use of fossil fuel

Electric vehicle development and adoption may have large macroeconomic consequences. Approximately 40 percent of the worldwide petroleum demand comes from road transportation, 20-30 percent of global emissions and 20 percent of employment in OECD countries (Uherek, 2010). A technology shift, as large as the one with electric vehicles, will have not only environmental consequences but also imply economic changes in general and with respect to the transportation sector in particular.

The most direct impact of electrification of vehicles would be to decrease the economy`s consumption of petroleum and subsequently CO_2 emissions, greenhouse gases, pollutions etc. Approximately 70 percent of the petroleum is used in transportation and nearly 40 percent of the oil is used in road transportation. Depending on the price, oil has accounted for between 30% and 60% of the United States deficit over the last decade (Becker, 2009). Depending on different scenarios we see that our analysis concludes that electric vehicles with lithium batteries will lead to significantly lower oil consumption and pollution to some extent. And in several countries with trade deficit the impact will be even bigger since decreasing the amount of oil imported will decrease oil consumption and therefore the current trade deficit. Moreover it is pointed out that financial flows associated with petro dollars are a main contributor to worldwide financial inequity, therefore the implementation of electric vehicles will considerably diminish the transportation sector`s dependence on petroleum-based fuels and thereby diminish the problems associated with the oil dependency in most of the countries in the world (Brey, 2009). Therefore petroleum import, regarding the trade balance, will become highly impacted by electric transportation development: which is valid for the energy required to power these electric vehicles, as almost all of OECD domestic electricity is produced from domestic sources.

There is close relationship between the use of a vehicle and petroleum. Almost 95% of all transport use oil as a source of power. Moreover, transportation accounts for almost

50% of all oil demand in the world and 40% is consumed by road transportation (Fuglestvedt et al., 2008).

Projections from the Energy Information Agency (EIA) point out that in the upcoming years the demand for oil will significantly increase, mainly as a consequence of economic growth and population growth. On the other hand, the supply will grow with much more difficulties, because of the depletion of the reservoirs, and moreover, a quality deterioration (more difficult access, less quality of the oil, more investment in technology), as well as lack of investment in exploration and exploitation of new deposits (Downey, 2009). Predictably, tensions between demand and supply will result in price increase, although the sudden slowdown in the world economy may also introduce some nuance in the evolution finally observed, with levels of prices significantly higher than the ones observed in the last 25 years.

However this scenario of scarcity of oil (known as peak oil) will accelerate improvements of efficiency in vehicles and the introduction of new technology. Internal combustion engines of gasoline and diesel will evolve drastically, reaching reduction in consumption and emissions. But moreover the peak oil will accelerate the development of new sources of energy, essentially in the field of hybrids and electric motors for vehicles, like lithium batteries (Downey, 2009).

5.1.3 Impact on flow externality associated with local pollution

Environmental aspects of transportation-related pollutants are very important, but the health aspects are also significant: the pollutants associated with emissions from light vehicle transportation include also airborne or above ground emissions (sulfur dioxide, nitrous dioxide, particulate matter, volatile organic compounds) and furthermore some runoff pollutants (heavy metal, oils, and grease) (Eyring et al., 2009). All these aerial pollutants are known to cause respiratory disease, intensifying existing heart disease and are well known as a cancer-causing agent. These pollutants are also known for causing smog and acid rain. The relation between health costs associated with each type of pollutant and the health impacts of electric vehicle deployment show that as electric vehicles grow to constitute a larger proportion of the light-vehicle fleet in the world, the airborne contamination from internal combustion engine vehicles declines considerably.

Moreover the impact is even bigger when the electricity to power electric cars is produced exclusively by non-polluting power sources (new renewables and hydroelectric for example) instead of using a mix grid for electricity production. The health benefits of electric vehicles using lithium batteries is approximately twenty times larger when vehicles are charged using non-polluting sources of energy. Much of this difference comes from the negative health impact of increasing the sulfur dioxide emissions from the existing stock of coal and fossil fuels like oil.

The impact on health as a function of the electricity source places an additional advantage on electric vehicle network operators: centralizing the purchasing power of electric vehicle drivers into a few network operators will allow them to source their electricity from the wholesale market (Brey, 2009). It is almost impossible to direct electricity in the grid from various sources. Therefore this must be achieved by purchasing "certificate of origin" of electricity, or similar, in order to provide evidence of compliance with an obligation on electricity production, supply and consumption, to use energy of a specific type. This can be either voluntary or non-voluntary.

Another real benefit of the use of electric vehicles is that they are extraordinarily silent. The problem associated with noise of conventional cars does not exist in electric cars since they do not have vibrations related to the combustion and explosions inside the engine, nor do they have shakes or the possibility of exhausts.

6. Recommendation discussion

6.1 What electric vehicle customers need

If electric vehicles that operate with lithium batteries are to continue to grow and to serve us well as a foundation of modern life, they must meet three basic needs:

6.1.1 First customer need: Affordability

If electric cars that use lithium batteries become too expensive, they will place a significant burden on family budgets. Nowadays customers have supported clean energy standards that have price control, such as subsidies. If the car companies ignore affordability, however, this new technology of lithium batteries in electric cars can come to an inglorious end. Nevertheless car companies can learn a lesson from their own experiences when they have used batteries in electric vehicles, like lead-acid or NiMH.

6.1.2 Second customer need: Energy always there

Customers expect their supplier of energy for the car´s battery to always "keep the engine on". This means they will be able to recharge the battery whenever it is needed (as they can do today with diesel).

This will be increasingly important as other energy sources, such as oil, begin to decline. Our entire economy and, indeed, way of life is threatened by the Peak Oil coming soon.

The economic disruptions from high oil prices may destroy millions of jobs if we have not prepared alternative ways to fuel our society. Thus, an increased use of lithium batteries in electric vehicles is a core solution to end our addiction to oil. Then a well-connected supply chain of energy for the batteries must be prepared to meet this challenge.

6.1.3 Third customer need: Clean power

The car industry has long operated without paying the cost of externalities (in a damaged world) inflected upon society by their pollution. Now, however, the society is insisting that the harm must be stopped. Currently conventional cars emit huge amounts of carbon dioxide. With a string of extremely destructive weather events now garnering public attention, there is a strong public support for technology changes to limit GHG emissions. Climate impact studies have indicated severe droughts, floods, sea level rise, and other impacts of climate change that can cause hundreds of billions or even trillions of dollars of economic losses.

Because of all this, lithium batteries are seen by consumers as a clean source of energy.

6.2 Market considerations for lithium batteries

In order to develop a market for electric vehicles with lithium batteries and to assure a transition from conventional engine vehicle to EVs, several issues have to be taken into consideration regarding the lithium batteries.

6.2.1 Cost of batteries

This is a critical factor when it comes to buy a new vehicle and it affects the market acceptance for electric vehicles using lithium batteries. However a reduction of battery costs is expected since there will be economies of scale as mass production kicks in and the industry move upwards on the learning curve. But it is important to highlight that without an upsurge in production this drop in costs will never come.

6.2.2 Standardization of the battery technology

Standard battery architecture is needed in order to open up the possibility of mass-production. And this becomes possible as the battery industry matures and develop standards that define voltage, currents, hardware, software, interconnects, cell and pack form factors, diagnostic systems, etc. (Guillen et al., 2010).

6.2.3 Production and disposal of lithium batteries

It is very important to develop an environmental policy around lithium batteries since it is expected they will expand their facilities for manufacturing and recycling. They have to regard production and disposal in an environmentally friendly and sustainable manner.

6.2.4 Value of the battery

The residual value of the battery and the development of secondary markets (e.g. telecom, backup power) are an important issue when it comes to usage. A high aftermarket price for the batteries would make batteries more attractive, covering some of the upfront cost. Then it would be advised to develop some kind of deposit scheme for returning the batteries, creating incentives for users to return and recycle them. Something more or less similar to what we see, here in Norway, with the plastic and glass bottles of liquids.

6.2.5 Life expectancy of the battery

Even though the latest expectations regarding lithium batteries life are very auspicious, it is still important to put attention to this matter and to continuously improve technology, since there is still a chance that producers will bring batteries to the market before battery lifetime issues are fully understood and resolved. The provision of producer's warranties and replacement guarantees will evidently be an essential factor in these issues. (Guillen et al., 2010).

6.2.6 Government Regulation & Legislation

It is very important to look in depth at the regulation and legislation of one country before making investment or any kind of business. As an example, we can look at the OECD regulations that, under the OECD Decision and Based Convention, lithium batteries are not listed as hazardous and therefore are not subject to amber import and exports controls. On the other hand lithium-metal batteries are catalogued and regulated as hazardous recyclable material and require control under federal regulations, while lithium-ion batteries are not.

Without government intervention there is no market incentive to take into account environmental damage, since its impacts is spread across many people and it has little or no direct cost to the polluter. Therefore, protection of the environment generally requires collective action, usually led by taxation. The flexibility of response associated with environmental taxes provides improvement on competitiveness of electrical vehicles based on lithium batteries as a low-emission alternative.

7. Conclusion

The present work confirms the initial hypothesis that the development of road transport generates negative externalities towards the environment and human health; moreover these externalities can be appeased by developing and improving electrical vehicles based on lithium batteries. Therefore it is now recognized that the car industry and society are considering these externalities and they are taking action through the development of new technologies based on lithium batteries that will reduce the negative consequences on the environment that road transportation has historically had in the last decades. For that reason, and given the subjectivity in relation to externalities, it is complicated to achieve a clear proposal for significant reduction of the negative impacts. But technological advances, in addition to willingness from the industry to do research, have produced a huge progress in this direction, and despite they are on the right track, they can always improve more.

Hence it is possible to notice the difference between using one technology or another with a system of indicators for recognizing the environmental impact, effects on human health, and also the economic and political implications associated with the negative externalities.

The different alternatives or variants available in the market to correct the externalities of road transportation are many and varied, but when we analyse them in depth and we interpret critical points, it is clear that the implementation of lithium batteries in electric vehicles shows a major improvement in the progress in that direction. Therefore, the analysis of externalities as a tool for studying the impact on the environment and people has shown that the main strengths of the use of electrical vehicles are that they are capable to appease the negative impacts in which lithium batteries play a key role in helping to reduce greenhouse gas emissions, local pollution, and negative effects on human health among others things.

But to make this possible it is necessary to take into account the needs of the customers: 1) affordability, the new electrical vehicles based on lithium batteries as a product has to be accessible in prices for everyone; 2) clean energy, customers nowadays demand for new sources of energy that are environment friendly, so it is necessary that the supply for this energy comes from renewable clean energy. In this sense Norway is a very good example in which almost 99% of the energy generated comes from renewable hydroelectric power plants; 3) power always there, it is needed to have a system where the consumers have the chance to recharge the batteries almost wherever they want, in a way that assure the connectivity from one point to another.

These customer considerations have to be also aligned with some market considerations that create some parameters to measure the success of lithium batteries in electric vehicles. These are:

- Cost of the battery
- Standardization of the battery technology
- Production and disposal of lithium batteries
- Value of the battery
- Life expectancy of the battery
- Government regulations & legislation

There is an ever growing demand for electrical energy storage to support electric vehicles. And as we see lithium-ion has recently emerged as the premier rechargeable battery chemistry due to the increased energy density over other technologies. However, on-going application demands require higher energy concentrations to reduce battery size and volume characteristics.

Finally it is important to point out that the implementation of the measures mentioned above and further development of new technologies based on lithium batteries, might initiate an important contribution to reduce global warming, and along with that it will improve many of the deficiencies caused by road transportation, namely pollution and negative impacts on human health.

8. Appendix

Figure No 1: Life Cycle of vehicle

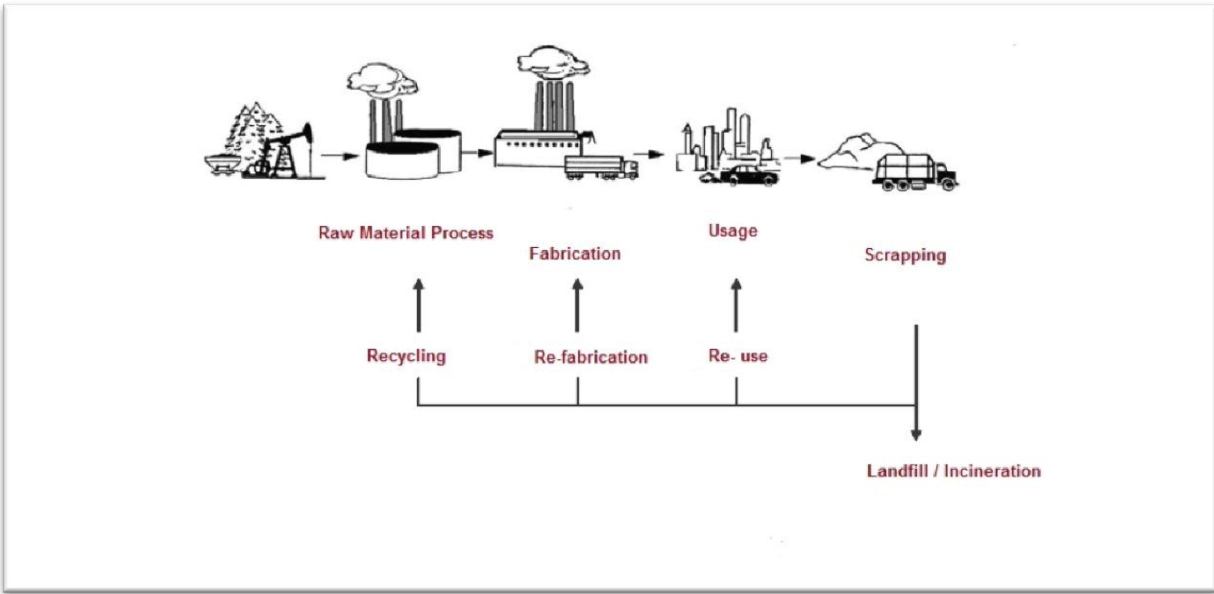


Figure No 2: Levels of impacts in different stages of the life cycle of vehicle

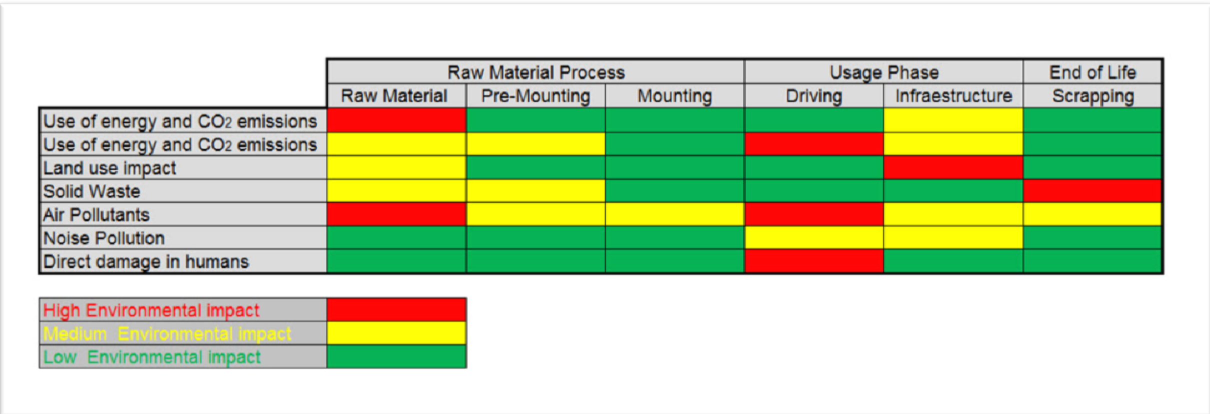


Figure No 3: % of CO_2 emissions emitted in the entire life cycle

	Production	Usage	Recycling
CO_2	16	84	0,1
NO_x	21	79	0,2
Particles	57	43	0
HC	13	87	0

Figure No 4: Main impacts during the life cycle of vehicle

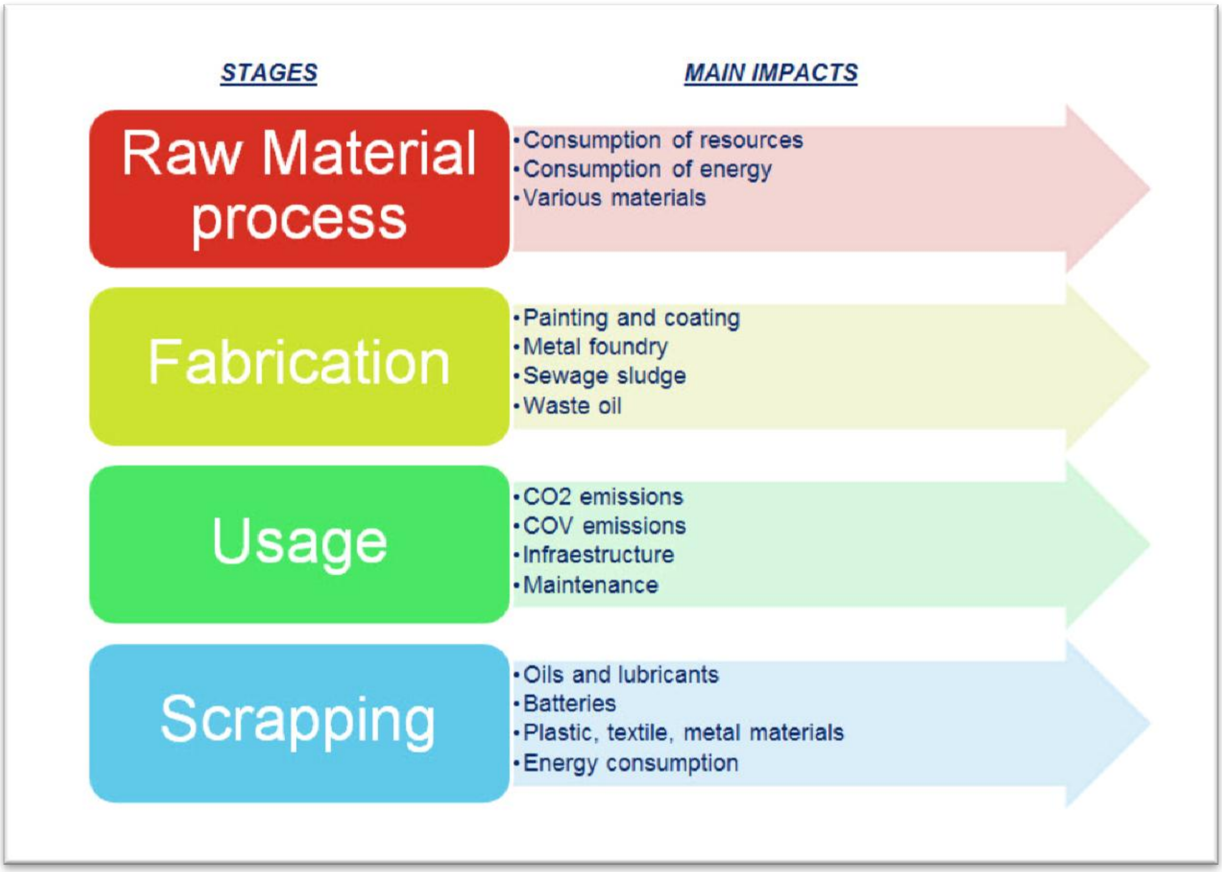


Figure No 5: Hybrid electric vehicle

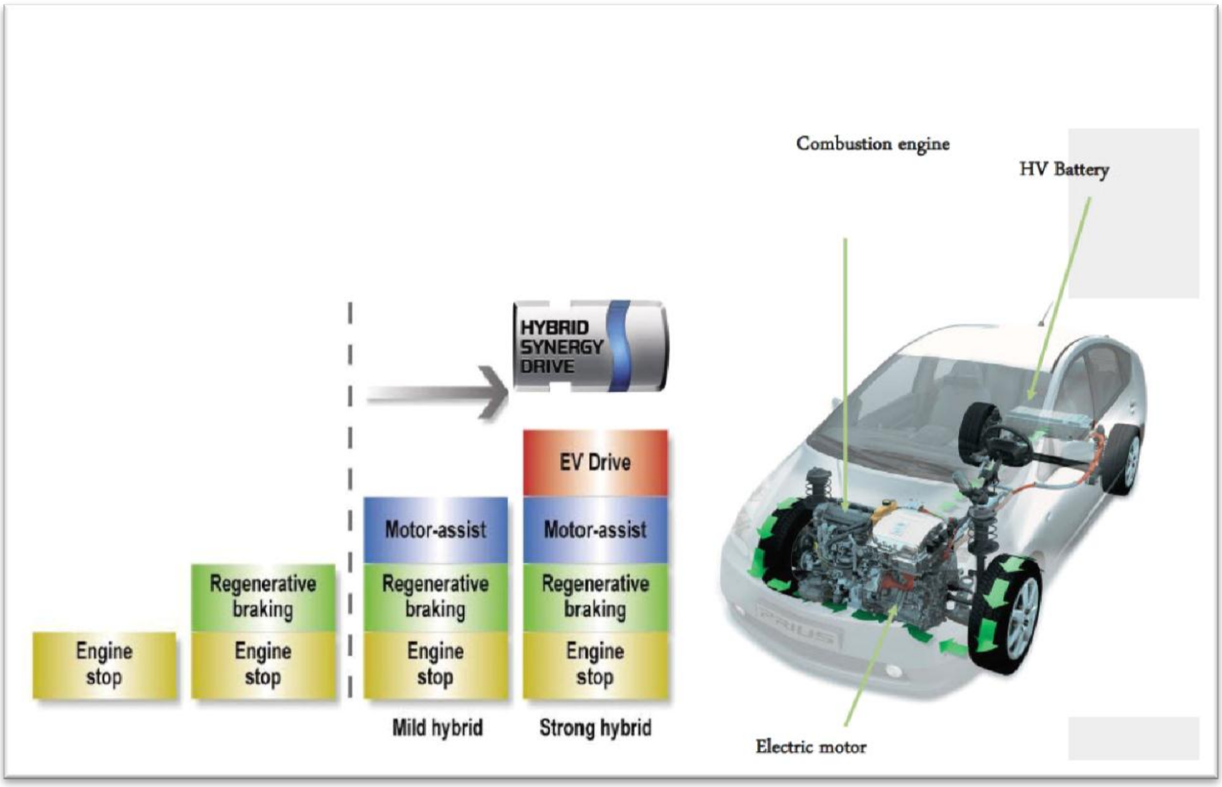


Figure No 6: Plug-in electrical vehicle

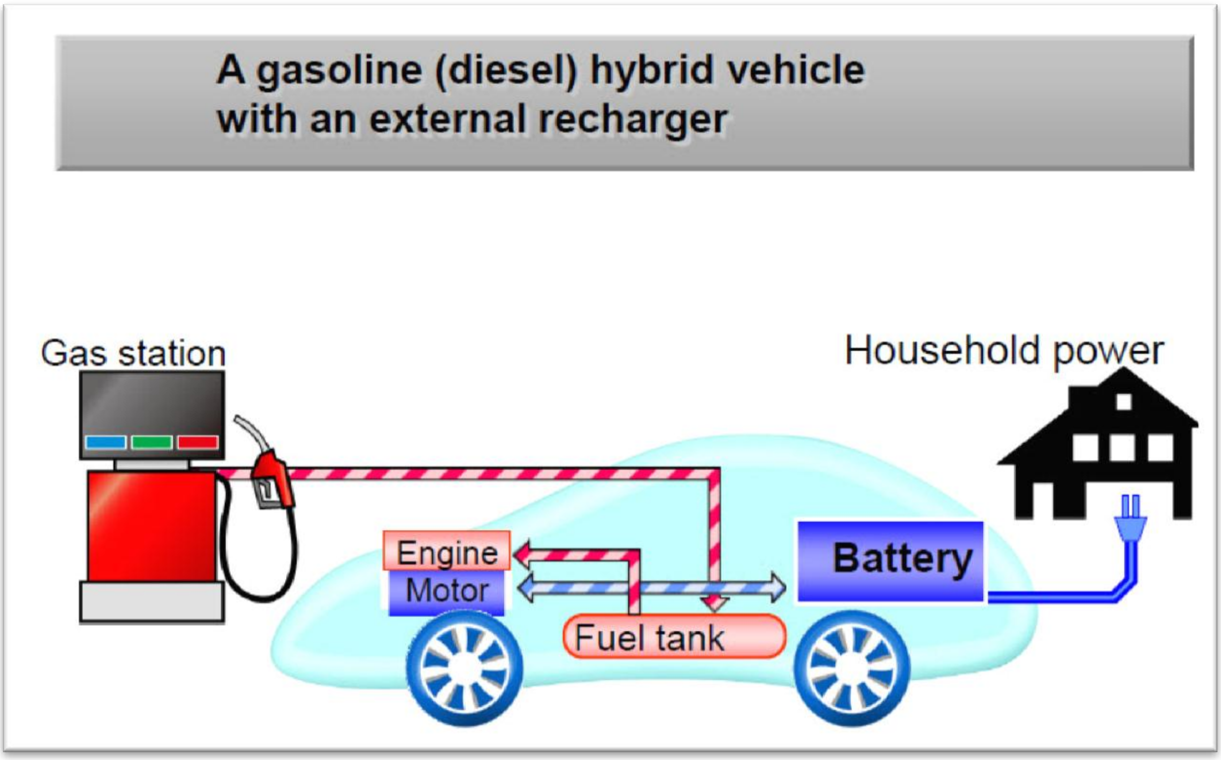


Figure No 7: General Motors, GM-EV1

Figure No 8: Reva I, electric vehicle

Figure No 9: Toyota Prius, hybrid vehicle

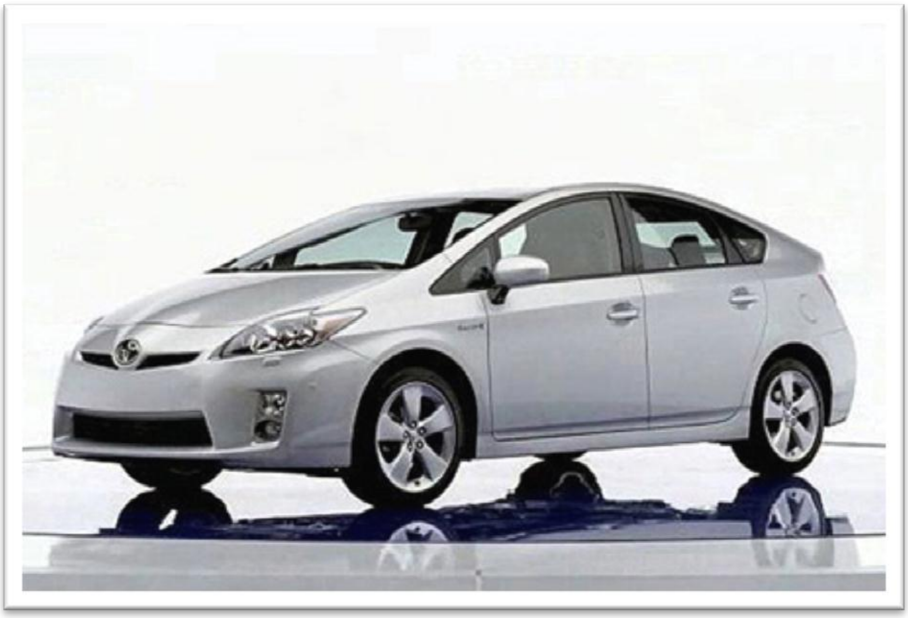


Figure No10: Tesla Roadster

Figure No 11: Comparison of performances for lead-acid, nickel metal and lithium-ion batteries

Battery	Lead-acid	Ni/MH	Li-ion
Voltage (V)	2,0	1,2	3,0 – 4,5
Energy (WhKg-1)	10 – 40	60 – 80	80 – 170
Energy (WhI-1)	50 – 100	250	170 – 450
Number of cycles (80%)	400 – 800	300 – 600	500 – 3000
Cost ($/kWh)	100 – 125	220 – 400	250 – 800
Environmental impact	High	Low	Moderate - Low

Figure No 12: Electricity generation by type in United States

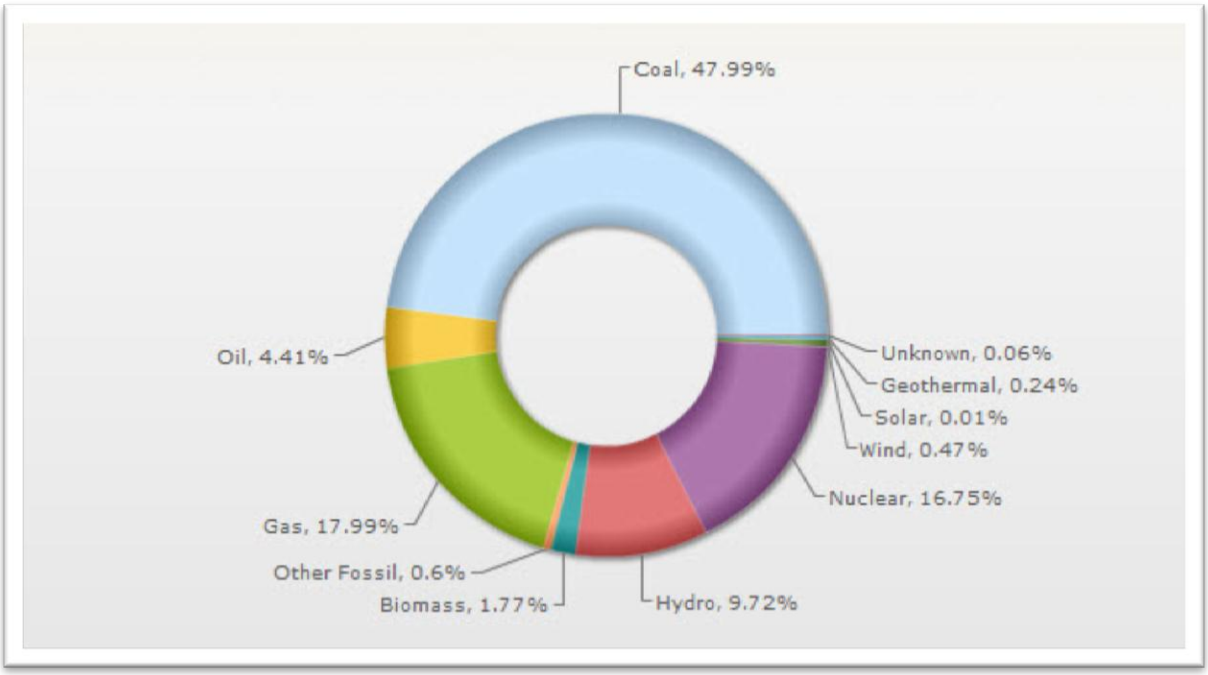


Figure No 13: Electricity generation by source type in OECD countries 1971-2009

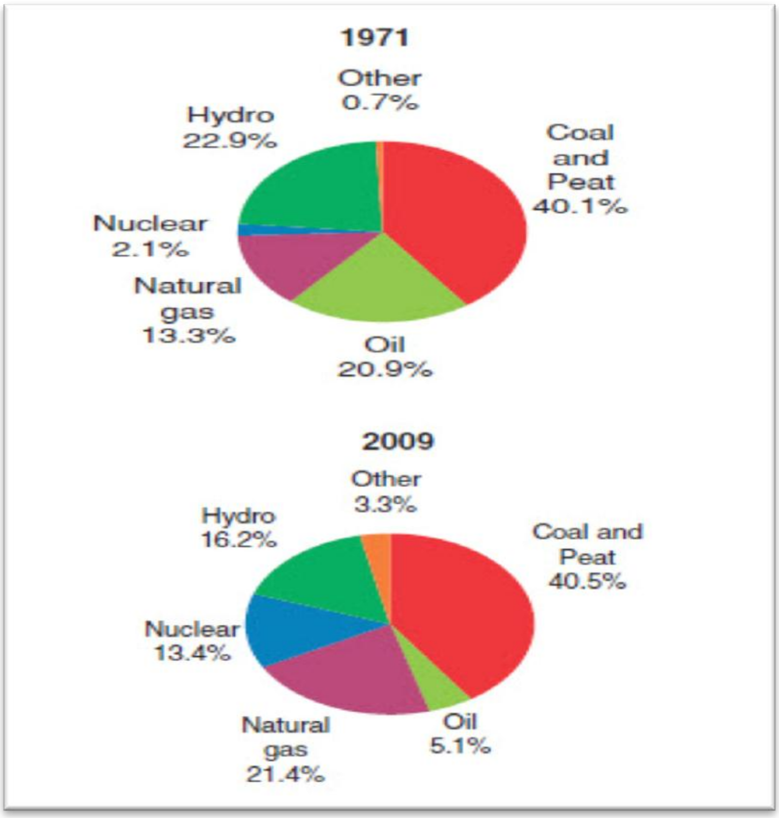
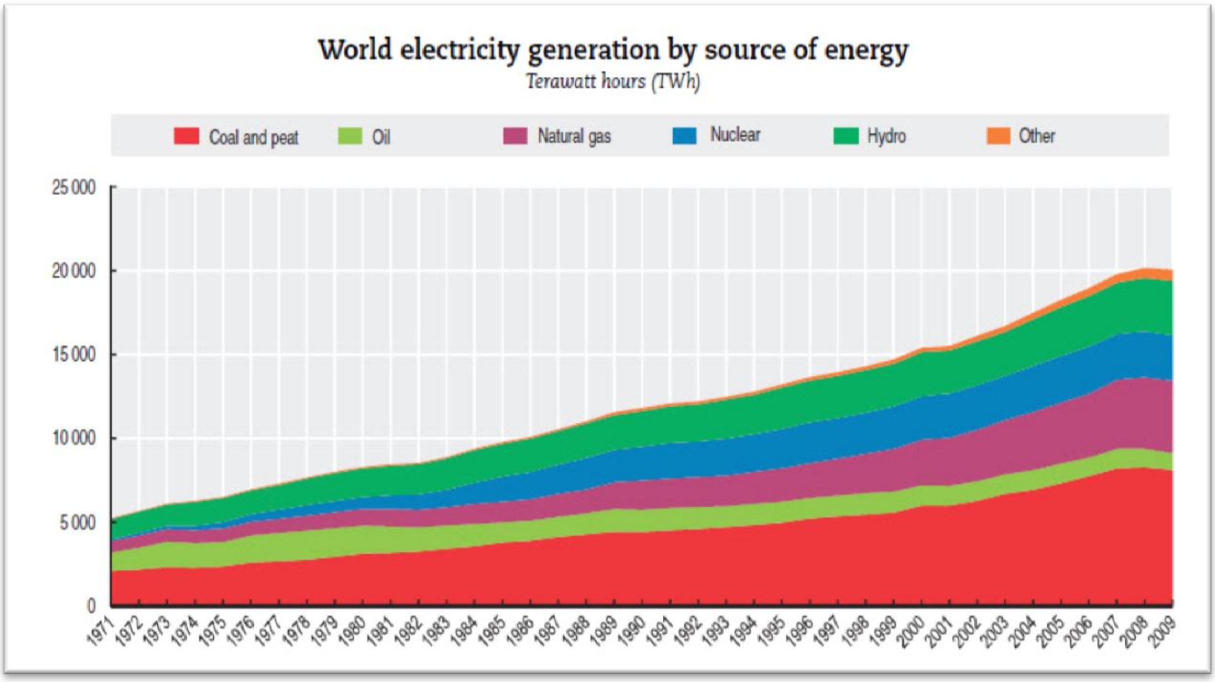


Figure No 14: Electricity generation by source type in the world 2009



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