Czech University of Life Sciences Prague

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Diploma Thesis

Future of lithium batteries for fuel cell development – case study LIVENT Technologies

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DIPLOMA THESIS ASSIGNMENT

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Engineering Ecology
Nature Conservation

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Future of lithium batteries for fuel cell development – case study LIVENT Technologies

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Objectives of thesis

Objective of the thesis:
The main objective of this research is to examine viability of the lithium batteries in the automobile industry from environmental and economical perspectives. In order to achieve that LIVENT Technologies company was chosen as a subject of the case study. This company is a comprehensive example that is able to present lithium batteries' industry. The main parameters that were focused and examined:

- Environment
- Electric and hybrid vehicles
- Lithium batteries
- Economy
- Customer behavior
- Recycling

Methodology

Methodology:

This research was divided in three parts.

First is the examination of the literature review on lithium batteries industry, current state of the examined industry and how it influences adjacent fields, as well as an environment.

In the second part LIVENT Technologies were examined, company's products and policies. For this publicly available information about the company was used.

In the third part information from the literature review was compared with information from examination of the case company.

The proposed extent of the thesis

60 pages

Keywords

Lithium, batteries, electric vehicles, hybrid vehicles, LIVENT Technologies, air pollution, green energy.

Recommended information sources

Bauer, C., Hofer, J., Althaus, H., Del Duce, A., & Simons, A. (2015). The environmental performance of current and future passenger vehicles: life cycle assessment based on a novel scenario analysis framework. Appl. Energy. doi:http://dx.doi.org/10.1016/j.apenergy.2015.01.019.

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Declaration

I declare that I have worked on my diploma thesis titled “Future of lithium batteries for fuel cell development – case study LIVENT Technologies” by myself and I have used only the sources mentioned at the end of the thesis. As the author of the diploma thesis, I declare that the thesis does not break copyrights of any other person.

In Prague on 31.03.2021 Balzhan Bekmaganbetova

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Future of lithium batteries for fuel cell development – case study LIVENT Technologies

Abstract:

The study was designed to examine the future of lithium batteries as a source of energy for fuel cell development on a case study of LIVENT Technologies. The research literature has discussed a history of lithium batteries, specifics of electric and hybrid vehicles, effects on the environment and recycling of used lithium batteries, economical aspects of electric vehicle market and consumer behavior. Electric vehicles with lithium batteries is undeniably environmentally conscious choice that is growing more popular with consumers. Recent technological developments and growing availability of electric vehicles make them affordable to population. LIVENT Technologies is a company with a main focus of developing lithium batteries for automobile industry. This research examines practices of the LIVENT Technologies with a focus on environmental sustainability as well as economical benefits. This research shows that LIVENT Technologies is striving to reduce its negative impacts on the environment and that lithium batteries are a legitimate tool to decrease environmental pollution.

Keywords:

Lithium, batteries, electric vehicles, hybrid vehicles, LIVENT Technologies, air pollution, green energy.

Budoucnost lithiových baterií pro vývoj palivových článků - případová studie LIVENT Technologies

Abstraktní:

Studie byla navržena tak, aby zkoumala budoucnost lithiových baterií jako zdroje energie pro vývoj palivových článků na případové studii společnosti LIVENT Technologies. Ve výzkumné literatuře byla diskutována historie lithiových baterií, specifika elektrických a hybridních vozidel, vliv na životní prostředí a recyklaci použitých lithiových baterií, ekonomické aspekty trhu s elektrickými vozidly a chování spotřebitelů. Elektromobily s lithiovými bateriemi jsou nepopiratelně ekologicky šetrnou volbou, která je u zákazníků stále oblíbenější. Nedávný technologický vývoj a rostoucí dostupnost elektrických vozidel je činí dostupnými pro obyvatelstvo. LIVENT Technologies je společnost s hlavním zaměřením na vývoj lithiových baterií pro automobilový průmysl. Tento výzkum zkoumá postupy technologie LIVENT Technologies se zaměřením na udržitelnost životního prostředí i na ekonomické výhody. Tento výzkum ukazuje, že společnost LIVENT Technologies usiluje o snížení negativních dopadů na životní prostředí a že lithiové baterie jsou legitimním nástrojem ke snižování znečištění životního prostředí.

Klíčová slova:

Lithium, baterie, elektrická vozidla, hybridní vozidla, technologie LIVENT, znečištění ovzduší, zelená energie.

Contents

1. Introduction

Human being's quality of life today depends on access to a plentiful supply of cheap energy. For a sustainable future, energy must be derived from non-fossil sources. Ideally this energy should be reliable and safe, flexible to use, economically viable as well as unlimited. Today the production and use of energy poses a serious threat to the global environment especially in relation to greenhouse gas emissions and climate change resulting from it. Accordingly, industrialized countries are exploring a whole range of new policies and technological solutions in order to achieve 'sustainability' that is, to maintain economic growth while providing security in the field of energy and maintaining the health of the environment. It is clear that the world is set to make major changes in its energy supply and utilization systems (Dell & Rand, 2001).

Today one of the issues that preoccupies the world is addressing the growing demand for energy while preserving the environment. As for carbon dioxide emissions, for example, it has increased up to five times compared to the 100 years ago. Its concentration also increased. Looking at oil consumption by sectors, the transportation sector consumes more than half of the total carbon and oxygen. In order to deal with this global environmental issue electric vehicles (EVs), and hybrid vehicles (HEVs) and fuel cell hybrid vehicles (FCHEVs) are likely to be evolving technologies to combat this phenomenon (Kojima, Ishizu, Horiba, & Yoshikawa, 2009).

The transition from gasoline and diesel engines to electric and hybrid vehicles is a long and complex process, all in order to reduce oil consumption and society's dependence on it. Electric immediacy can also decrease overall energy consumption and help us move to a more sustainable economy (Hanisch, et al., 2015). Hybrid cars provide a more efficient use of technology then standard engines which do not allow things such as: low speed driving with low power consumption as well as regenerative braking. Furthermore, electricity use can reduce overall air pollution in crowded and congested cities (Bauer, Hofer, Althaus, Del Duce, & Simons, 2015).

Consumers today are more aware of environmental problems of today's world and strive for keeping nature clean from pollutants but at the same time they are still looking for the solutions that are most suitable for them in terms of cost and personal benefit. Adapting the vehicle to the needs of the family and work life lead many consumers to still prefer the vehicles based on fossil fuels. Although many countries provide tax relief and even help subsidize vehicles consumers also look first at the cost of maintenance, daily driving distance, convenience of charging points and more. All of these factors cause concern among buyers and make them to go for traditional vehicles as a more practically convenient option (Ma, Fan, Guo, Xu, & Zhu, 2019). Research conducted in Europe shows that in the long run electric vehicles are the most lucrative (Wappelhorst, 2018). Despite this still not all consumers trust this data.

When looking at the automotive industry it can be understood that the future continues to evolve with the development of electric and hybrid vehicles, thus it is important to examine the effects of lithium-ion batteries in the long run as well. What happens when the car goes out of use and ends its lifespan on the road? It can be seen that there are many countries that recycle the batteries for the purpose of extracting the materials and reusing the production of new batteries.

Mining resources for batteries - including lithium, manganese and nickel, are cheaper than cobalt - nevertheless they have a negative environmental cost. Lithium spillage from a Chinese mine in the Tibet plateau polluted the Liki River and wiped out the abundant fish populations and destroyed pastures for yak herds. In South America, the process of producing lithium in the salt plains of Bolivia, Argentina and Chile is a water-consuming process that uses evaporation ponds, and some of the lithium penetrates and pollutes the aquifer. The demand for lithium for the production of batteries, especially in the automotive industry, is rising significantly. The continued availability of lithium can only rely on a strong increase in ore mining and processing (Denyer, 2016).

Therefore, this study examines the present and the future of lithium batteries, especially in the field of electric vehicles. Today you can see an explosive emergence of electric vehicles into the free market, all of these vehicles are powered by lithium batteries. In most cases we

see that these electric vehicles are designed to encourage the needs to switch to a greener consumption and give up the traditional vehicles which are powered by fossil fuels. But the question is whether electric vehicles are really green and helping to preserve the environment? Therefore, this research conducts examination of the LIVENT company which produces lithium for the purpose of making vehicles and the effects of lithium on the nature with the focus on environmental issues as well as the economy.

2. Review of the Literature

2.1. Background of lithium batteries industry

Since the 1990s ion orphan batteries have attracted a lot of attention from consumers and industries of various types, in part the reason for this attraction is an ever-growing number of personal electronic devices, such as laptops, phones, tablets, etc. The future demand for lithium batteries has been determined by media examination of developments in the broad electric market. These developments are already skyrocketing and this trend is going to continue in the coming decades. Due to their potential performance capability, growth of the markets and rapid increase in production leads the various industries to re-examine new technological solutions and try to adopt new technologies that are supposed to improve the battery life (Houde, 2019).

By the middle of the twentieth century, the number of gasoline-powered cars was significantly high, and the fumes emitted as a result of traveling through the congested streets worsened the harmful smog condition that surrounded large cities. This situation, combined with the growing recognition among the general public that usage of oil and its products as source of energy does not come without side effects, has sounded a warning to both automakers and oil companies. They were required to invest in electric vehicles and alternative energy sources in order to survive and keep competitive edge as a company (The Royal Swedish Academy of Sciences, 2019).

Electric vehicles and alternative energy sources both require powerful batteries that can store large amounts of energy. At that time there were only two types of rechargeable batteries on the market: the heavy lead battery that was invented as early as 1859 (and which still serves as a starter battery in gasoline-powered vehicles) and a nickel-cadmium battery developed in the first half of the twentieth century (The Royal Swedish Academy of Sciences, 2019).

The fear of the inevitable end of the global oil reserves has led the giant oil company "Exxon" to decide to diversify its activities. As part of its significant investment in basic research, the company recruited a number of researchers who were leaders in their field at the time in the field of energy, and gave them the freedom to explore as thoroughly as they wanted, as long

as their energy research was not based on oil and oil products (The Royal Swedish Academy of Sciences, 2019).

Researcher Stanley Whitingham was one of those researchers who came to Exxon in 1972. He came from Stanford University, where he studied solid materials with atomic-sized cavities to which ions could attach. This phenomenon is called intercalation. The properties of the material change when ions are trapped within them. In Exxon, Stanley Whitingham and colleagues began researching superconducting materials, including tantalum disulfide, which is capable of trapping ions within it. They added ions to the material and investigated how the electrical conductivity of the material was affected as a result.

Unfortunately, the research group that was preparing to produce the battery experienced a number of challenges and set-backs. As the lithium battery underwent repeated recharging, a lithium sediment layer formed on the lithium electrode. When particles of this layer reached the opposite electrode, the battery experienced a short circuit that could have led to an explosion. Firefighters were forced to put out a number of fires and eventually threatened to get the lab to pay fines for the special chemicals used to put out the lithium flames that occurred during the research (Micjael, 1999).

To make the battery safer, the researchers added aluminum to the metallic lithium electrode and replaced the electrolyte between the electrodes. Stanley Whitingham announced his discovery in 1976 and the company began producing this small-scale battery for a Swiss watchmaker who wanted to use it in solar-powered watches (The Royal Swedish Academy of Sciences, 2019).

The next goal was to increase the production volume of the rechargeable lithium battery so that it could power a car. However, oil prices dropped dramatically in the early 1980s and Exxon had to make cuts. The development work was put on hold and the patent on Whittingham battery technology was transferred to the ownership of three companies located in three different parts of the world. However, this situation did not lead to a halt in development. When Exxon dropped out, the development work was continued by researcher Goodinf (Micjael, 1999).

John Godinf, like many people in the 1970s, was affected by the oil crisis and wanted to contribute to the development of alternative energy sources. However, Lincoln's Laboratory

was funded by the U.S. Air Force which did not permit any type of research, so when he was offered a job as a professor of inorganic chemistry at Oxford University in the UK, he took the opportunity and entered the important field of energy research (The Royal Swedish Academy of Sciences, 2019).

John Goodainf was familiar with Whitingham's revolutionary battery, and his in - depth knowledge of the internal material of the electrodes led him to conclude that he could achieve higher potential if he replaced the sulfide metal with a metal oxide. Subsequently, several researchers in his research group were given the task of finding a metal oxide that gives rise to high voltage when it reacts with lithium ions, but one that will not decompose when the ions are subtracted from it (The Royal Swedish Academy of Sciences, 2019).

This systematic study was far more successful than John Goodinf have ever dreamed. Whitingham's battery produced no more than two volts, but Goodinf found that the battery containing the lithium-cobalt oxide in the cathode was almost twice as powerful, meaning it generated a value of four volts. One of the reasons for this success was John Goodinf's understanding that the batteries did not have to be manufactured in their charged condition, as was previously accepted. Instead, they could be recharged afterwards. In 1980 he published the discovery about this new, high-energy cathodic material, which was also lightweight, leading to the development of powerful batteries with high energy capacity. It was a clear step towards the wireless revolution (The Royal Swedish Academy of Sciences, 2019).

In the West, however, as oil has become cheaper, interest in investments in alternative energy technology and in the development of electric vehicles has increased. Things were different in Japan - electronics companies there were already desperate in their search for rechargeable and lightweight batteries that could power innovative electronics, such as video cameras, cordless phones and computers. One of the people who became acquainted for this purpose was Akira Yoshino from the company Asahi Kasei. Or as he put it: I just sniffed the direction the trends were headed. You could say I had a good sense of smell (Micjael, 1999).

When Akira Yoshino decided to develop a functional rechargeable battery, he was already familiar with the Godinf cathode which was composed of lithium-cobalt oxide, so he experimented with a number of carbon-based materials as the anode. Researchers already

knew that lithium ions could be incorporated into the molecular layers of graphite, but the graphite disintegrated on contact with the electrolyte in the battery. Akira Yoshino's revolutionary idea came when he tried, instead, to use petroleum coke, a by-product of the oil industry. When he charged the petroleum coke with electrons, the lithium ions were drawn into the material. Next, when he activated the battery, the electrons and lithium ions flowed towards the cobalt oxide in the cathode, which had a higher potential (The Royal Swedish Academy of Sciences, 2019).

The battery developed by Akira Yoshino was stable, lightweight, with a high capacity and produces a high voltage of four volts. The biggest advantage of a lithium-ion battery is that the ions are integrated within the electrodes. Most other batteries are based on chemical reactions that cause the electrodes to change with certainty, even if at a slow rate. When charging or using a lithium-ion battery, the ions flow between the electrodes without reacting with their environment. This means that the battery has a long lifespan and that it can be charged hundreds of times before its performance becomes poor.

Another big advantage lies in the fact that the battery does not have pure lithium. In 1986, when Akira Yoshino checked the safety of the battery, he took precautions and used a special device designed to test devices with potential for explosion. He dropped a large piece of iron on top of the battery, but nothing happened. However, repeating the experiment with a battery containing pure lithium resulted in a serious explosion. The success of the battery to pass the safety test was essential to the future of the battery. Akira Yoshino says it was "the moment the lithium-ion battery was born." (The Royal Swedish Academy of Sciences, 2019)

In 1991, a large Japanese electronics company began selling its first lithium-ion batteries, leading to a revolution in the electronics world. Mobile phones have shrunk in size, computers have become portable and music players and tablets have been developed for the first time. As a result, researchers around the world have scanned the periodic table of elements to develop even more efficient batteries, but none have yet invented a more efficient lithium-ion battery system. The capacity and voltage it produces is above all else. However, the lithium-ion battery has undergone changes and been improved: among them improvements, researcher John Goodainf has replaced cobalt oxide with phosphorescent iron, a replacement that makes the battery more environmentally friendly (The Royal Swedish Academy of Sciences, 2019).

Like everything else, the production of lithium-ion batteries has a detrimental effect on the environment, but these batteries also have many environmental benefits. The batteries enabled the development of cleaner energy technologies and the development of electric vehicles, and thus they contributed to reducing the emission of greenhouse gases and harmful particles (Micjael, 1999).

Thanks to their work, researchers John Goodainf, Stanley Whitingham and Akira Yoshino, created the right conditions for a wireless and fossil-free society, making the greatest contribution to humanity and even winning the Nobel Prize in 2019 (The Royal Swedish Academy of Sciences, 2019).

2.2. The environment

Emissions of air pollutants are a potential danger to humans, animals, plants and the environment, while some of the pollutants come from natural sources, but most are the result of human activity - energy production, transportation, industry and agriculture (Miao, Baležentis, Shao, & Chang, 2019).

In the process of producing energy by burning fossil fuels air pollutants are emitted into the environment that are especially harmful due to additives in fuels such as sulfur and lead. These emissions are coming both from stationary sources such as chimneys, commercial and industrial facilities, and from mobile sources such as vehicles, trains, aviation and shipping (Miao, Baležentis, Shao, & Chang, 2019).

Key air pollutants emitted during fuel combustion: carbon monoxide (CO), sulfur dioxide (2SO), nitrogen oxides (NOX), hydrocarbons (HC), suspended solids particulate matter SPM)), lead (Pb) and emissions of carbon Dioxide (2CO), which is a greenhouse gas (gas generated naturally or due to human activity. Greenhouse gases are one of the causes of the greenhouse effect and global warming) (Rand, Woods, & Dell, 1998).

What is the greenhouse effect? The Earth is surrounded by an atmosphere that contains various gases. The gases in the atmosphere allow, on the one hand, the passage of radiation from the sun, and on the other hand absorb the radiation coming from the earth. After

absorbing the radiation, heat is emitted into the atmosphere, and it reaches the surface of the earth. Thus, the temperature of the earth does not fall below the range required for subsistence. This phenomenon is described as the greenhouse effect due to the resemblance to what happens in a greenhouse for growing plants (Rand, Woods, & Dell, 1998).

Over the years and technological and industrial development humanity has caused increased emissions of gases which amplify the greenhouse effect in the atmosphere. Actions such as fuel combustion cause carbon dioxide emissions, and cattle raising causes methane emissions. An increase in the amounts of these gases in the atmosphere increases the greenhouse effect and thus continues to raise the Earth's temperature and also affects precipitation and other climatic phenomena (Rand, Woods, & Dell, 1998).

Most countries in the world, through the activities of international bodies, have agreed to significantly reduce greenhouse gas emissions from human activities. As part of the efforts on the subject, the United Nations Framework Convention on Climate Change (UNFCCC) was signed in 1992. Under the Convention, among other things, the signatory states must calculate inventories of greenhouse gas emissions emitted from their territory. The IPCC (Intergovernmental Panel on Climate Change) was established by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP). The IPCC aims to centralize scientific knowledge on the subject, quantify climate change, present its implications and publish calculation guidelines. IPCC provides the UNFCCC with a scientific infrastructure for outlining global policy on the subject of Greenhouse Gas Emissions (IPCC, 2020).

When the emission sources of the gases are classified to different levels, this pattern can be seen: vehicle fuel combustion makes up only about 20% of the total energy consumption, but air pollution from vehicles constitutes about 60% of the mass of air pollutants emitted per year into the atmosphere (IEA, 2020).

Air pollution from transportation has a more severe effect than that caused by stationary sources, for two reasons:

Proximity of the source of pollution to the affected population is a prominent factor of adverse effects associated with vehicles. Emissions of air pollutants from vehicles are mostly made within large population concentrations and at a ground level, so their effect is

immediate and concentrated. This is in contrast to emissions from industrial sources, which are usually made in more remote industrial areas and from higher chimneys. The more distant the emission source and the higher the emission, the more efficient the possible contamination of the pollutants emitted into the atmosphere, which causes a significant decrease in their concentration and impact on the population (Rand, Woods, & Dell, 1998).

The mixture of pollutants emitted from vehicles, which includes nitrogen oxides, hydrocarbons, carbon monoxide and particulate matter, is particularly active and serves as a major factor in the formation of photochemical air pollution manifested in the formation of high concentrations of ozone (Litman, 2020).

To these facts must be added the increase in the level of motorization and in the concentration of vehicle activity in urban areas. Air pollution from vehicles is considered one of the most serious problems of the major cities in the world, from Los Angeles to Bangkok, from Paris to Athens, from Mexico City to Manila. The increase in the number of vehicles leads to an inevitable increase in the relative share of pollution originating in vehicles, within the total amount of air pollutants emitted into the atmosphere (IEA, 2020).

Life cycle analysis indicates that total vehicle pollution includes not only the air pollution emitted while traveling, but also that there are other sources of pollution that occur during other stages of the life cycle of cars, fuel and transportation infrastructure: soil pollution, water pollution and air pollution during mining and production of the raw materials needed for cars (iron, aluminum, glass, petroleum for plastics and more); Pollution during the manufacturing process; Pollution from various discharges from cars and during recycling efforts; Air pollution resulting from tire production and disposal; Air pollution resulting from the production of asphalt from oil; Air pollution due to the construction of infrastructure for motorized land transportation such as asphalt and concrete roads, interchanges and more; Air pollution for the operation of transport infrastructure such as electricity for lighting and for traffic control lights; Air pollution during oil production as well as while refining gasoline or diesel in refineries, another source of pollution is the recycling vehicles by scrapping process (Litman, 2020).

2.3. Electric and hybrid vehicles

The field of transportation accounts for more than half of the world's oil consumption, and much of it is used to drive vehicles. In the UK, for example, in 1999 road transport accounted for 77% of all oil consumed by the transport sector. The aviation sector is also a major area for oil consumption. Although even with the late shift towards remote work in many business sectors still flights are as popular and prevalent as ever due to tourism (Rand, Woods, & Dell, 1998). A more efficient way to use oil and oil products is needed. In recent years there has been a significant improvement in engine technology, and in Europe a growing trend of shifting to a smaller and more economical vehicles is occurring. Also, many governments provide various fuel taxation policies, with the goal of reducing consumption (Dell & Rand, 2001).

More widespread adoption of electric vehicles in full or in part will significantly contribute to improving urban air quality. This is why population of California, for example, has bought many electric cars and more recently hybrid cars as well. However, if the electricity that is used to power these cars is generated by fossil-fueled power plants the contribution to energy sustainability and the development of CO2 emissions will be minimal. The overall effect on the environment on a global scale is not particularly different between oil-powered vehicles and electric vehicles, because in practice the location of the pollution simply shifted from the place of vehicle’s usage to the source of its electricity. Therefore, the contribution that electric and hybrid vehicles provide to global energy sustainability is insignificant unless it also comes with a source of sustainable non-fossil based electricity generation (Rand, Woods, & Dell, 1998).

In order to focus international attention on the potential of renewable energy transport, Australia introduced in 1987 a competitive race for small electric cars - the Global Solar Challenge. The rules of the race stipulated that electricity for cars was required to use solar energy as a sole power source of the car. Competitors from 19 countries took part in the race, although the cars in the competition were not the most practical the race succeeded in providing a much-needed visibility to the electric cars movement, and helped jump-start the development of electric and hybrid car (Dell & Rand, 2001) s.

Even today most of the major car manufacturers in the world are pursuing the development of battery-powered electric vehicles. Several companies have progressed beyond the prototype stage and produced vehicles in small quantities for sale: the Peugeot 106, the Citroen AX and the Renault Clio (all French vehicles powered by alkaline batteries); the General Motors EV1 (lead – acid); the Toyota RAV4-EV (nickel – metal hydride) (Dell & Rand, 2001).

If countries decide to instill the culture of electric vehicles, significant preparation is required in the transportation field. There is a need to establish a suitable infrastructure for "refueling" the electric vehicles powered by batteries. This implies creating and maintaining public points for the purpose of charging vehicles in offices and car parks, shopping centers, etc. (Rand, Woods, & Dell, 1998). Studies in the UK, for example, have shown that in order to provide a sufficient electric charge these points must be supplied with appropriate tech with strong export capability to support a national fleet of vehicles. The cost of installing a charging network will be significant. It has been successfully proven that lead acid batteries can be charged in a short period of time (approximately 15 minutes), but this comes with an increase in power consumption, as well as the size and cost of charging equipment (Dell & Rand, 2001)

2.4. Lithium batteries

The current technology of lithium-ion battery production is reaching the limit of its capacity, especially in large applications like transportation vehicles. There are two reasons for this: first, materials engineering has probably exhausted its efficiency; and secondly, obtaining the natural resources it needs turns out to be a particularly problematic task. Cobalt is an important element in the paint industry and in the production of hard materials, but its main use today is for rechargeable batteries in the cathode (positive electrode) of the battery. The forecast is that by 2020 about 62% of the demand for cobalt will be for battery production (Global Energy Metals Corp, 2020). In 2016, 123,000 tons of cobalt were mined worldwide (USGS , 2020). A car like Tesla, for example, uses 22 kilograms of cobalt in its battery, and a hybrid car uses about 1.8 kilograms (Global Energy Metals Corp, 2020).

The competition for the resources has recently led Apple to consider purchasing cobalt directly from mining companies - rather than being dependent on the battery makers of its

devices. Other large companies that need it quickly followed. In fact, cobalt is not so rare and ranks 32nd in its relative availability (Farchy & Gurman, 2018).

However, there is another problem: about half of the world's cobalt comes from one country - the Democratic Republic of Congo (Global Energy Metals Corp, 2020). This huge country in Central Africa is rich in natural resources, but prolonged civil wars and political corruption have left it as one of the poorest countries in the world (Amnesty International, 2016).

The indices of human development and its public corruption are at the bottom of the table in the Democratic Republic of Congo. The cobalt is mined there, at times, in illegal mines, without any real adherence to working conditions, safety and environmental protection. As a result, the supply chain is very problematic - ranging from centralization in mining and processing and ending with human rights violations and child labor (Amnesty International, 2016).

Mining resources for batteries - including lithium, manganese and nickel, are cheaper than cobalt metals - also has a negative environmental cost. Lithium dripping from a Chinese mine in the Tibet plateau polluted the Liki River and wiped out the abundance of fish and pasture for yak herds. In South America, the process of producing lithium in the salt plains of Bolivia, Argentina and Chile is a water-consuming process in evaporation ponds, and some of the lithium penetrates and pollutes the aquifer (Denyer, 2016).

The increase in the demand for lithium for the production of batteries, especially in the automotive industry, is rising significantly. The continued availability of lithium can only rely on a strong increase in ore mining and processing. Today mining technologies needed to establish a fully sustainable society do not exist. To create a sustainable and environmentally conscious society we need to create and establish sustainable mining practices. Currently, 2/3 of the world's production of lithium is produced from saline, a practice that evaporates an average of about half a million liters of brine per ton of carbonate. Moreover, the extraction is chemically intensive, extremely slow and provides large amounts of waste. This technology depends largely on the geological structure of the sediment, the chemical composition of the salt and the climatic and weather conditions. Therefore, it is difficult to adapt from one successful utilization to new deposits. It takes several years of simulations and piloting before large-scale production is achieved. As a result, this technology is

struggling with the current increase in demand. Today, only 5 industrial-scale facilities operate worldwide, highlighting the disadvantages of this technology. (Flexer, Baspineiro, & Galli, 2018). All five companies have received a lot of government support, usually the incentives are extended to several years to ensure that the companies can stand by their promises. Some of these incentives are: sales tax reduction, business tax reduction, tax credit, discounted electricity rates and more (Electrive, 2018; Ayre , 2015).

2.5. Economy

Research published by the Lux Research Institute in the United States shows expected report for lithium-ion batteries and cost reduction forecasts. Lux noted that the electric vehicle market is developing slowly and the key to accelerating development is, as usual, lowering the prices of batteries and lithium-ion batteries. The report states, however, that there is a limit to lowering the prices that existing technologies can offer and long-term commercial feasibility of electric vehicles will have to wait until the development of a new technological generation (Lux Research, 2012).

The Lux report is interesting because it sets numbers for the challenge. According to Lux calculations, the best price that can be reached with existing lithium-ion technologies, mainly by manufacturing batteries according to sizes, is $ 397 per kWh. This is a significant improvement over the prices of lithium-ion batteries in use today, it is still very far from the optima cost of advanced batteries (X <$ 150 per kWh), which the Lux report estimates is necessary for electric vehicles to penetrate the consumer market. Electric vehicles are developing new components such as lithium-air, lithium-sulfur and magnesium-ion and solid-state lithium-ion batteries (Lux Research, 2012).

Distributed and networked energy storage technology also encounters serious cost barriers. The initial assimilation prices of energy storage systems are too high to be viable. The economic challenge for storage stations, however, compared to storing energy in cars, is not a part of the costs of the battery itself as it is in the costs of assessment, monitoring and self-management after its implementation (Gallo, Simões-Moreira, Costa, Santos, & Santos, 2016).

Intending to address the issue, the US Department of Energy's Advanced Research Projects Agency (E-ARPA) has announced a new initiative designed to identify groundbreaking

developments in the field of diagnostics, forecasting and energy storage systems management capabilities. The initiative focuses on encouraging the creation of teams of companies and researchers from across various industries and sectors competing for E-ARPA funding options for energy storage management systems (Gallo, Simões-Moreira, Costa, Santos, & Santos, 2016).

E-ARPA's initiative aims to encourage the creation of new and more stable relationships between the software, management and battery industries. Business sectors that historically do not necessarily work together in a collaboration. It is clear that innovation is needed in order to lower energy storage prices and innovation must be expressed in technologies and systems that are different from what we know today (Lux Research, 2012). However, in order to find the technological innovation in question and promote it, it is important to identify where it may come from. Valuable innovation, such as influencing mature technologies such as the automotive industry and the electricity transmission network will not be created in a vacuum or in a laboratory only (Gallo, Simões-Moreira, Costa, Santos, & Santos, 2016).

In order to promote an innovation that has an impact, battery manufacturers, vehicles and transmission companies with real experience in using existing technologies - limited as they are today - should be allowed to work together and find solutions on how to increase system capacity and reduce the cost. The development of a new technological generation is important, almost critical, for the future of the energy storage industry. However, one should avoid the temptation to believe that these new technologies will suddenly emerge from without lengthy research efforts (DiChristopher, 2018).

Rechargeable electric cars have quite a few advantages: the engine is quieter and more efficient and needs relatively little maintenance, charging is cheaper than fuel and overall emissions are low and focal (concentrated mainly around power plants), compared to non-focal emissions from non-electric vehicles. But on the other hand, the battery is expensive, heavy, its overall lifespan is relatively short and it takes a long time to charge it relative to the duration of refueling. Even the batteries of smaller devices are not free from problems arising from their complex manufacturing process (DiChristopher, 2018).

In 2030, the number of electric cars in the world is expected to rise to 125 million (as of 2017, there were 3 million cars in the world). One of the driving forces in this is a direction of the

Chinese government, which has set a target of 5 million electric vehicles by 2020 in its five-year plan. This strategic decision aims to develop an early commercial advantage in the global market and also to fight the difficult situation of air pollution in the Chinese urban centers. China, therefore, is a major player in the production of lithium, nickel, cobalt and iron, and also depends on them for the realization of its economic and environmental goals (DiChristopher, 2018).

The UK government is investing a quarter of a billion pounds to develop efficient, long-lasting, safe, lightweight and mostly recyclable batteries under an initiative called the Faraday Challenge (named after Michael Faraday, the pioneer of electromagnetic research). UK government expects that by year 2025 prices of batteries for electric vehicles will stand at £ 50 billion. In addition, starting in 2040 it will not be possible to purchase a non-electric vehicle in the UK (BBC, 2017).

Dozens of scientific studies in the field of batteries operating under the British venture have not yet matured into a commercial move. Today hundreds of start-ups with investments amounting to hundreds of millions of dollars are operating in the field of batteries and accumulators. For example, a company called Ionic Materials in the US wants to find a replacement for electrolyte, the chemical solution that is inside the battery and allows the passage of ions that produce the electric current. Instead of a solution, the idea is to use a solid material: a polymer. This will make the battery lighter, safer, cheaper and less dependent on cobalt (Ionic Materials, 2020).

Car companies are also investing in this development trend, but they are also exploring other solutions within the existing technology, such as reducing the use of cobalt and using nickel or sodium instead of lithium. These solutions lack the benefits of solid electrolysis (Heelan, et al., 2016).

Either way, it seems that a real technological breakthrough in the field of batteries and accumulators is expected to have a real positive economic and environmental impact (Heelan, et al., 2016).

The availability of materials for battery production will also affect the price of vehicles. Recycling old batteries and putting reusable metals back into production of new batteries can help reduce the cost of vehicles. Today most of the lithium batteries are landfilled or

discarded at the end of their life cycle. One reason for this is that environmental regulations regarding batteries over their lifespan are incomplete or not implemented in many countries (including the US). Only a small number of batteries that have completed their lifespan reach existing recycling facilities (Heelan, et al., 2016). There are also a growing number of electric vehicles that will reach the end of their lives in the coming years. If recycling regulations are implemented in more countries, it will be possible to recycle batteries properly and even reduce the price of electric vehicles on the market. Electricity can lead to supply problems for the production of lithium batteries. Supply problems and unavailability of products will lead to an increase in raw materials and this will lead to an increase in the price of consumer vehicles (Steward, Mayyas, & Mann , 2019).

Lower cost of recycled materials is expected to be a major motivator for recycling. Large volume recycling methods have been shown to help reduce the cost of raw materials and recycling has lower environmental impacts compared to monthly materials extraction. Battery recycling and the production of new batteries from recycled materials can result in saving of 43% of new materials from mines (Steward, Mayyas, & Mann , 2019).

Another part of the recycling process of electric vehicles and batteries that factors in its promotion are not only undeniable benefits to the environment and minimization of waste, but also a social impact. At every point of product life and recycling process new job opportunities are created, also population feels more involved in creating a greener environment. Goverments often do not see the whole picture in relation to product creation and recycling at the end of product use, but this process can not only lessen the strain on mining industries by improving the availability of materials, but also create more jobs, thus improving the country's economy (Bonsu, 2020).

2.6. Customer behavior

Consumers today are very conscious of the purchase process, especially when it comes to buying a new vehicle. The main factors that affect all consumers in the process of purchasing a new electric vehicle are: the cost of the vehicle, the number of charging stations, gas prices, government incentive policies, family needs, vehicle condition, pollutant emissions and more. These are just some of the factors that affect the buying decision when purchasing an electric vehicle. Understanding the factors that influence the consumer to purchase an electric

vehicle can help vehicle manufacturers increase the market. It can also help governments of the countries that are interested in reducing air pollution in their densely populated cities in particular (Ma, Fan, Guo, Xu, & Zhu, 2019).

But with all the available support and incentives what ultimately pays off for consumers? A regular, electric, or hybrid vehicle?

In a study that examined the costs of purchase, fuel and taxes of Volkswagen Golf vehicles, cars of the electric, hybrid, petrol and diesel versions were compared. For four years, the pure electric version was the cheapest in all examined locations - UK, Germany, France, Netherlands and Norway - due to a combination of lower taxes, fuel costs and a purchase price subsidy (Wappelhorst, 2018).

This study recommends that in order for consumers to continue to purchase electric vehicles the following steps must be taken (Wappelhorst, 2018):

- Give significant tax benefits for low-emission vehicles at the point of purchase. Tax payments or tax benefits at the time of purchase have a stronger impact on consumer choice than annual tax payments.
- Ensure continued tax benefits for low-emission vehicles during their use. Lower taxes and lower costs for electricity consumption compared to higher taxes and a total price for petrol and diesel can serve as an incentive for consumers to choose electric vehicle.
- Consider vehicle emissions as part of the company's taxation system. Corporate cars play an important role in Europe because they constitute the highest rate of new car listings in markets like France, Germany and the UK.
- Regularly balance and re-adjust the tax system to sustain itself. To ensure a self-sustaining taxation system, vehicle-related taxes should take into account all vehicles, ensure that high-emission vehicles generate tax revenue to provide tax relief for low-emission vehicles, and be adjusted annually or once every two years per changes in market structure.

Electric cars offer the biggest savings compared to diesel in Norway (27%) because battery-powered vehicles are exempt from heavy registration tax. The ICCT analysis has been updated following the recent cut in UK grants for the purchase of electric cars. This shows

that British drivers see the smallest savings - 5%. In Germany, France and the Netherlands, savings range from 11% to 15% (Carrington, 2019).

Eventually the need for incentives will decrease as the price of new vehicles drops to an equal price with vehicles powered by fossil fuels. Most likely this will happen between in the years 2025-2030. In addition, price is not the only factor that will influence the decision to purchase: consumers' confidence that there will be enough charging points for the vehicle is crucial, as well the costs of maintenance. As showed by analytics hybrid vehicles were often the most expensive to operate, partly due to high numbers of purchase of vehicles with two engines (Wappelhorst, 2018).

2.7. Recycling

Recycling is an important part of product life, it is a process during which separated waste is taken and reused as an existing raw material which is then integrated into the creation of new products. Recycling allows the use of different materials that would otherwise be discarded as waste. It changes the purpose of products that passed their lifespan and places them into the production cycle once again. Recycling preserves raw materials on one hand and reduces the amounts of waste and pollution on the other hand, and is therefore widely known and promoted for its educational, economic and ecological importance (Jacobi, 1998).

When examining the lithium-ion battery, it is evident that it contains toxic organic substances, some of which are volatile, thus making it difficult to recycle in a preliminary mechanical process such as grinding, organic matter can be neutralized by its oxidation (Micjael, 1999). Full oxidation creates carbon dioxide and water and also releases all the metals, including the iron shell and copper parts of cations from the battery (Cotton & Wilknsin, 1988). To safely recycle lithium-ion batteries first neutralization of the toxic organic matter which will allow the recycling of metals of commercial value is needed. Then the metals that pose an environmental risk have to be separated to be discarded in the waste burial sites. This can be carried out by combustion (pyrometallurgical treatment). Full combustion solves the problem of organic matter. The resulting ash contains the metals, some of the ash comes out with the smoke (ash flay) and some remains as solid at the bottom (ash bottom). The treatment of the ash is complex and problematic process (Ikeue, 1993).

In the research literature, a number of hydrathological treatments (wet treatment) are proposed. There are reports from Japan that a full cycle of cobalt and lithium can be carried out, with full extraction of the metal cations with the help of hydrochloric acid from the battery contents (Zhang & at al, 1998). The battery was treated by mechanical means to remove the contents. Then cobalt is extracted with a liquid / liquid method, that uses D2EHPA and sodium carbonate to separate lithium (Sony Corp, Sumitomo Metal Mining Co, 1996)

Today Sony in Japan is reporting the construction of a recycling facility of cobalt lithium-ion batteries operating on these processes. The above treatments ignore the problematic nature of the preliminary mechanical process (Sony Corp, Sumitomo Metal Mining Co, 1996):

- An environmentally problematic mechanical process due to organic substances contained in the battery, some of which may be volatile, toxic and even explosive (there is a danger of an instantaneous discharge of a charged or semi-charged battery).
- A mechanical process poses technical problems that are spared in the wet process.

Researchers from the UK offer a complete recycling process of cobalt, lithium, and electrolytes. The first stage in the process is mechanical grinding of the batteries in an inert and dry atmosphere (due to electrolyte maintenance and safety considerations), the second stage is the extraction of the electrolyte with organic solvent. After extraction, the rest of the battery is treated with an organic solvent, after which, the battery remains are treated with an additional organic solvent to dissolve the PVDF polymer that sticks the electrodes together. After filtration, the residue is recycled electrochemically, the cobalt sinks as oxide (CoO (s)) while the lithium remains in solution as hydroxide (Micjael, 1999). The disadvantages of this process:

- The mechanical part of process is problematic and not automatic.
- Overall long and complicated process
- Electrochemical redox requires a clean solution and special working conditions.

In lithium-ion batteries, lithium undergoes a redox oxidation process. Lithium is the lightest metallic element (molecular weight MW = 6.94gr / mol) belonging to the alkali metal family (Cotton & Wilknsin, 1988). It is marked Li and its electronic array is $1S^2\ 2S^1$. It has a single

electron at the last level, so it is easy to line it to a state of LI^{1+} . The electric potential for the oxidation process for lithium redox is the highest:

$$LI^{1+} + e^{-} \rightarrow Li^{0} \qquad E^{0}{}_{vhe} = 3V$$

Its high potential and light weight make lithium the ideal candidate for chemically storing electrical energy.

A typical electrochemical cell is composed of anode and cathode insulated by an insulating foil (separator). The cathode (positive) contains $Li_x\, CoO_2$ and organic carbon and PVDF polymer coated by aluminum foil. The anode (negative) contains carbon and organic PVDF polymer coated by copper foil. The entire cell (anode and cathode) contains a liquid electrolyte capable of working through the insulator, the electrolyte container of LiPF6 solution, within an organic solvent (Micjael, 1999). The following is the cell's charge and discharge circuit:

$$Li_{1-x}CoO_2 + Li_xC \Leftrightarrow Li_{1-x+dx}\, CoO_2 + Li_{x-dx}C$$

On the same principle, manganese-based batteries have been developed instead of cobalt, since the manganese is cheaper. But the efficiency and performance of this type pf battery is less good.

The weakness of lithium - its high reactivity - is also its strength. In the early 1970s Stanley Whitingham used the energetic power of the lithium atom to release its most external free electron while developing the first ever functioning lithium battery. In 1980, John Goodinf doubled the potential of a lithium-ion battery, creating the right conditions for greater power from the battery. In 1985, Akira Yoshino was able to replace the pure and flammable lithium from the battery and instead use lithium ions, which are safer than pure lithium. This replacement has enabled researchers to provide a finished and safe product for industry and everyday life. Lithium-ion batteries have provided humanity with the undeniably great

benefit - by enabling the development of laptops, mobile phones, electric vehicles and providing storage of energy generated by solar and wind power (Micjael, 1999).

The choice of lithium was not a random; In the battery, electrons are supposed to flow from the negative electrode - the anode - to the positive electrode - the cathode. Thus, the anode must contain a substance that easily gives up its electrons, and of all the elements known to us, lithium is the element that gives up its electrons most easily. The result is a rechargeable lithium battery that operated at room temperature with tremendous potential.

The number of batteries for electric vehicles will increase greatly in the coming years. Opponents of electric vehicles see this is another opportunity to dismiss or criticize, but its proponents see that this is another opportunity to make the environment cleaner.

The benefits of driving an electric vehicle are well known and recognized. Electric cars do not emit toxic gases and reduce noise pollution in city centers. In recent years, with declining battery costs (the most expensive component in the electric vehicle today), along with various incentives given by different countries to those who choose not to pollute, car prices are also gradually declining and are becoming a real option for the general public.

But alongside the optimism exist reasonable doubts. The production of electric cars is still polluting and the fact that the battery needs to be replaced once every 260,000 km or so, or in seven to ten years (in private cars) and every three to four years in large vehicles (buses, trucks) is a cause of concern (Sony Corp, Sumitomo Metal Mining Co, 1996).

Electric vehicle batteries (and batteries powering everyday electrical devices) contain environmentally toxic substances that cannot simply be thrown away. Recycling is a solution to this, so that these products do not become an additional burden on the planet (Zhang & at al, 1998).

And of course, the more electric cars there are, the more batteries there are, respectively. The British Guardian reports that if the signatories to the Paris Agreement (signed at the 2015 climate conference) meet the goals they have set for themselves, then by 2030 140 million electric vehicles will travel worldwide (for comparison, there are currently about 3 million electric cars). These cars will produce about 11 tons of lithium-ion batteries that will need

recycling. This is a conservative assessment; some researchers are predicting more than half a million electric vehicles by 2040 (Steward, Mayyas, & Mann , 2019).

2.8. Urgency of lithium battery recycling

It is clear that in order to minimize the environmental damage caused by lithium batteries they need to be recycled or reused. Developing ways to recycle and reuse these batteries will be positively beneficial both for the environment and for the basic rights of thousands of people employed in particularly poor conditions in the lithium and cobalt industries, particularly in Congo (Steward, Mayyas, & Mann , 2019).

Today, battery turnover percentages are still very low (one estimate speaks to 5% of batteries in Europe) but these numbers are expected to increase significantly in the coming years, with the maturity of the first generation of electric cars that will release thousands of batteries (Steward, Mayyas, & Mann , 2019).

What makes reusing these batteries a must on the one hand and a real possibility on the other, is the interesting fact that they cease to be useful for electric vehicles at a stage when they still contain 70% -80% of capacity. This stage is when they are no longer good enough for cars, because it shortens the driving range. In other words, after serving the electric vehicle for between four and ten years and reaching the end of their life cycle in the role of powering the vehicle - these batteries can still store and discharge electricity for another seven to ten years (Argusmedia, 2020).

There are several ways to recycle lithium-ion batteries (Steward, Mayyas, & Mann , 2019):

1. Mechanical process is applicable to any type of battery, it is energetically cheap and enhances leaching of metals, its main recovered product is Li2CO3. But unfortunately, in order to recover materials other than metals it must be combined with other recycling methods, usually it goes together with hydrometallurgical processes.
2. Hydrometallurgy is also had a wide range of applications, but it is best suited for recovery of Co and Ni. Also, during this process anodes of the batteries are not recovered and usually destroyed.

3. Smelting or pyrometallurgy can be used for any types and configurations of batteries. Its main drawback is the need for additional measures to avoid release of toxic gases. During this process in addition to Co, Cu and Ni some amounts of Fe may also be recovered.
4. Direct recycling (supercritical CO2) allows for almost all materials of the battery to be recovered, with a slight caveat – these materials may perform worse compared to raw materials.

2.9. Recycling experiments and reuse of lithium batteries

The big car manufacturers are not waiting and are already reusing these batteries or planning to do so real soon. This is without a doubt the new tone for the industry. In Japan, Nissan has initiated a project called The Reborn Light in which it uses old lithium batteries in order to illuminate streetlights and slightly ease the congestion of the country's electricity grid. The batteries are charged daily with the help of solar panels and turn on the streetlights every night in the coastal city of Naime, where the factory that produces the flashlights is located (The Rebon Light, 2020).

Renault has more far-reaching plans and is sending arms to a number of ventures in the field of recycling and reusing the batteries of its electric vehicles. For example, Renault announced that it plans to build a huge system for storing electricity using old batteries of electric vehicles. At the end of the process, the system will store energy from 2,000 batteries and serve about 5,000 households, through the national electricity grid (PRESS & BLOG, 2017).

In addition, Renault, along with Powervault, began a pilot of recharging batteries, which are charged via solar panels, in 50 households. The project saves each family about 30% of the cost of power consumption (PRESS & BLOG, 2017).

Another intriguing venture was launched by Renault together with the Electric Company in Portugal - the first smart island. The Portuguese island, Porto Santo, is expected to become an energetically sustainable island that provides itself with all the electricity needs. The initiative aims to turn the island into a smart electric ecosystem by producing renewable energy generated by wind and solar and storing it in the batteries of cars taken off the road. An interesting and unique aspect of this venture is the so-called vehicle to grid (or V2G for

short). That is, reverse energy transfer: from the vehicle to the power grid. During peak hours, electric vehicles are supposed to provide energy stored from the sun and wind for the benefit of the island's electricity grid (Virta, 2020).

Tesla also aims to recycle and reuse as many parts of its cars as possible, including the batteries. The company's policy strives for a 'closed circle' situation. That is, the batteries that come off the road will immediately undergo recycling or reuse in the company's plants. As of 2020 the company has announced that it will make every effort to extend battery life by scrapping and recycling. But still around 15 million tons of discarded lithium-ion batteries will be discarded in 2020-30, according to estimates by Australian Resources and Neometals Project Development and Germany's SMS Group, creating significant disposal problems worldwide. The increasing adoption of electric vehicles and declining battery costs that attract mass market buying will increase the need for more recycling (Argusmedia, 2020).

Efficient collection of orphan batteries from electric vehicles will help restore some of the valuable materials and will save a lot of new raw materials for the production of new batteries. The turnover of electric vehicles for the purpose of extracting precious metals has reached about 95% in the European Union (EuroStat, 2020). In the United States, too, exists a process for recycling vehicles, and about 86% of vehicles after the end of their lives go through a recycling process (Junk Car Medics, 2020). By law only 5% (by weight) of the vehicle can be sent to the landfill. All other materials have to be recycled. Still there are many cases of illegal abandonment or storage of discarded vehicles in car lots that operate without a license (Steward, Mayyas, & Mann , 2019).

Not to be overlooked and overshadowed by the importance, scale and seriousness of abovementioned initiatives, there exist creative and fun ways to re-use lithium batteries. For example, in an casual and personal activity such as camping. The x Opus, also from Nissan, makes the camping experience more environmentally conscious and enjoyable by reusing electric vehicle batteries. Their product a highly upgraded tent will allow campers to use electrical household items outdoors by integrating recovered lithium battery in its design (Nissan , 2019).

In conclusion, it is only natural that if industry strives for a cleaner environment should also be preoccupied with the pollution it itself creates. Admittedly, the practice of electric vehicle

battery recycling is making its first steps (or rather, its incarnation) but it is clear that developers and researchers are already developing solutions and within a few years a dramatic improvement in this part of the electric vehicle industry is to be expected.

3. Aim and Methodology

3.1. Aim

The main purpose of this study is to examine the present and future of lithium batteries, especially in the field of electric vehicles. Explosive entry of electric vehicles to the free market is clearly seen, and all these new vehicles contain lithium batteries. In most cases we see that these electric vehicles are designed and marketed with a goal to encourage the switch to a greener consumption and to let go the traditional vehicles which are powered by fossil fuels.

Many governments around the world encourage the use of electric vehicles and even provide incentives and subsidies to vehicle manufacturers and consumers that encourage the production and purchase of electric vehicles. But the effects of lithium mining, manufacturing of lithium batteries and its continuous use are not always clear to the consumers and car manufacturers. In the last decade there has been a significant increase in electric and hybrid vehicles on the roads in different countries, but the effects of these vehicles are still not properly researched.

After examining the research literature, the question arises as to whether electric vehicles are really green, sustainable and help preserve the environment. Therefore, this work conducts research and examination of the industry on the example of the LIVENT company which produces lithium for the benefit of making the electric and hybrid vehicles while focusing on environmental issues as well as the economical.

3.2. Methodology

First, the literature research on the subject was conducted; the various effects of the production process of the vehicles were examined starting from the process of extraction of the necessary resources to the end of the life stage of the vehicle and its options beyond the cycle. Pollution associated with the transportation of the almost all cities greatly affects the lives of the residents as well as the health of the global environment. Society’s need to move to cleaner transportation options and infrastructure is prevalent.

In order to examine the production process of the lithium and this research examined automotive industry, with a focus on the company LIVENT, which produces lithium for various uses as well as the automotive industry as a source of electricity. This organization also has a contract with Tesla for the production of electric vehicles. Statistical data in the public data is focused on the global scale of lithium mining and distribution. With the directed focus on LIVENT company such data is unusable. Therefore, statistical analyses of a publicly available data were foregone.

In order to obtain the information for the purpose of conducting this research, a number of main sources were used:

- Company's website - https://livent.com
- Inspiring Tomorrow - https://livent.com/wp-content/uploads/2020/06/Livent_2019SustainabilityReport.pdf
- Investor Presentation - https://ir.livent.com/overview/default.aspx
- Many View Livent As An Electric Vehicle Play, But It's Actually A Play On Lithium Prices - (Trainer, 2018) (Trainer, 2018) https://www.forbes.com/sites/greatspeculations/2018/10/11/many-view-livent-lthm-as-an-ev-play-but-its-actually-a-play-on-lithium-prices/?sh=5269e7c37629 ,
- Energy Efficient Mobility Systems - (U.S. Department of Energy, 2019) - https://www.energy.gov/sites/prod/files/2020/06/f76/VTO_2019_APR_EEMS_COMPILED_REPORT_FINAL_compliant_.pdf

After examining all the available information about the company, it was divided into different categories in which we focused on in this study: analysis of the company, vision, the various products that the company offers, declaration of sustainability, use of resources, environment, economy, effects on consumers for the use of electric vehicles. The only subject LIVENT company is not mentioned on the company's website, media publications or other sources is the recycling process of their products.

To examine the research question, verified information available to public on the company's website and released in media, as well as other Internet sources was used. All the data collected was divided into several categories and compared with the research literature and

the data of the organization, thus allowing to draw conclusions which helped answer the research question.

4. Company analysis and findings

4.1. About the company

LIVENT is an independent company traded on the stock exchange since its IPO on October 11, 2018. LIVENT starts its journey in the lithium market in 1940s. During that time Lithium Corporation of America partnered with the government of USA to develop new lithium technologies. FMC Corporation took over by purchacing the lithium business in 1985. In 1991 they began supplying Sony Electronics with a lithium raw material for the first lithium-ion batteries used in handheld video cameras, allowing them to make the camera smaller, more portable and user-friendly. The company currently has seven operation locations in the world (two plants in Argentina, two plants in China, and one plant in the USA, UK and India) and ten offices worldwide (Argentina, UK, USA, India, Singapore, China, South Korea and Japan).

The company currently employs about 800 people worldwide and has an annual revenue of 443 million USD.

The company’s extensive experience in the production of high-quality lithium products, constant technological development and high-density cathode technology make LIVENT into a company capable of many of manufacturing large lithium batteries for the automotive industries. The LIVENT company develops and manufactures lithium batteries for a variety of different industries in the world, and the automotive industries in particular.

The company's main competitors are: Orocobre, FMC, Tianqi Lithium, Pilbara Minerals, Chemetall, Albemarle

4.1.1. The company offers additional lithium-based products

Energy storage systems and batteries - LIVENT product that provides long-lasting, durable batteries, ensuring green energy with high-performance based on lithium compounds - lithium hydroxide, high-purity lithium metal.

- **Polymers** - Lithium products are a key to producing polymers in a wide variety of applications, such as fuel-efficient tires and vehicle interiors, to different asphalts for better and stronger roads, as well as various flexible adhesives and sealants.

- **Grease** - Lithium hydroxide is added to simple and complex lithium oils, thus creating a wide range of lubricants.
- **AEROSPACE** - LIVENT helps advance the field of aviation through lithium applications that make planes and rockets lighter and more durable, thus allowing them to fly longer distances and carry more cargo while staying fuel efficient.
- **Agrochemical drugs** - Lithium products are a crucial ingredient in many medications and agricultural chemicals. For example, drugs used to treat and manage heart diseases, obesity, HIV and many other have LIVENT's xylitium butylithium and other organolithium products in their composition. LIVENT in partnership with large agrochemical companies works to create and develop herbicides and fungicides that enable farmers to improve their production and yield. Butyllithium is a major synthesizer that allows the safe use of chemical agricultural compounds in agriculture.
- **INDUSTRIAL** – LIVENT strives to improve a variety of different products such as submarines, concrete, air filters, glass, metals, paints and more.

LIVENTs innovations in the field of lithium application are not the only thing making this company so promising, it is also a leader in lithium extraction and purification technologies. LIVENT's brine resource in Argentina contains high concentrations of lithium with low levels of other elements. This together with a proprietary purification process that was first replaced and commercialized by FMC extracts lithium chloride from salt with 95% purity rating. Also, it helps to reduce production time for lithium carbonate from salt, compared to conventional solar evaporation methods.

4.1.2.The company's sustainability statement

LIVENT makes its commitment to sustainability known to their customers, investors and to the general public in the company's sustainability statement. In it LIVENT stresses the importance of protecting the local environments and communities through the responsible resource management. The company received a gold rating for the sustainability of ECOVADIS 2020, and this achievement places Levant in the top 3% of all companies surveyed in the group. ECOVADIS evaluates the companies across a number of important areas that show how sustainable the company really is, these areas are human rights, ethics, sustainable vehicles, the environment.

4.1.3.The company's vision

The vision of any company shows how they see themselves and their path forward. LIVEN focuses on a number of core factors: safety, growth and prosperity, responsibility, support and celebration of diversity, constant innovation. LIVENT strives to be the technological leader able to deliver high-performance lithium products that will satisfy the growing demands of the free market. The company supports expertise, collaboration, quality and consistent delivery. Cultivation of these qualities help the company to continue to drive forward.

4.2. Resource Management

Responsible environmental protection is essential for creating a safe, stable business model that will be able to grow and develop.

LIVENT uses a comprehensive system to manage and record environmental parameters such as water flow, chemical transport and salinity, to protect the environment.

The company has production facilities across the globe.

The whole process starts at the company's production facilities in the "lithium triangle" in South America, which is a source of 50% of all lithium resources in the world. The company's site is located 4,200 meters above sea level in the Andes Mountains of Argentina. They draw brine from El Salar del Humbra Morto to produce lithium.

Preserving a responsible environment is essential for working in Salar. LIVENT uses a comprehensive system for managing and recording environmental parameters such as water flow, chemical transport and salinity to monitor the state of the surrounding environment. LIVENT is now expanding its operations in Argentina and state that at every stage of the process they ensure that the expansion will not adversely affect the ecosystem.

Their current production utilizes water from the Trapica aquifer. In order to ensure responsible usage of water and to overstrain the aquifer, a secondary water source, the Los Patos River, will be used for the expansion. LIVENT have installed monitoring wells at both

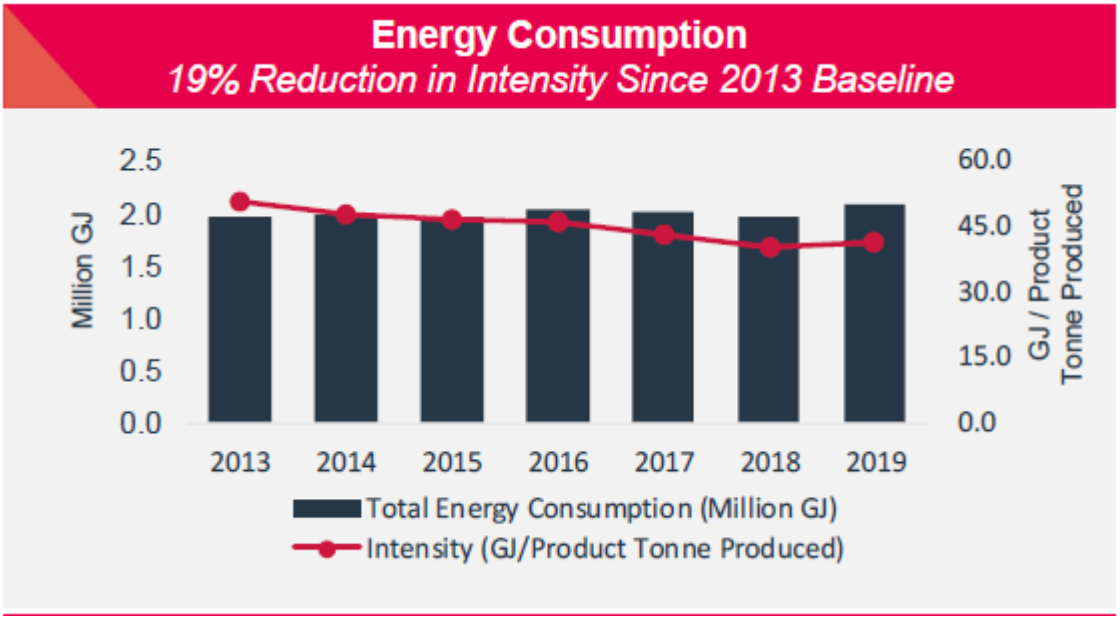
water sources to monitor water levels, charge rate and water chemistry to ensure sustainable water use.

Energy use, greenhouse gas emissions (GHG), water use and waste disposal are the important factors of production process that have strong effects on the environment. Because LIVENT has grown in recent years, its management have focused on increasing production capacity while making effort to significantly reduce their environmental impacts and resource consumption.

4.2.1. Global energy use

Through progress in improving energy efficiency, the year 2019 saw a reduction of energy by 19% when the base year is 2013

In 2019 LIVENT reduced their energy consumption by 19%, through improvement of energy efficiency, with the 2013 being the base year.

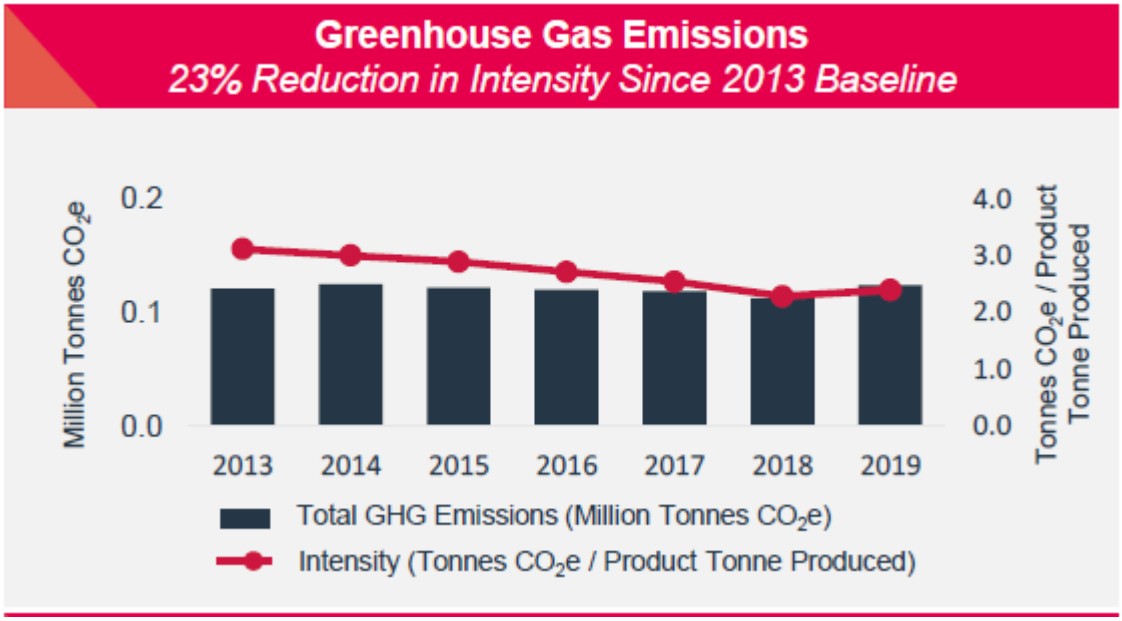


(Source: Livent, Resource Management)

4.2.2. Global greenhouse gas emissions

A significant improvement in energy use and a combination of the use of natural gas for supply led to a reduction of greenhouse gases by 23% in 2019 compared to 2013.

Although large amounts of greenhouse gases are created during the production of lithium, the company is still trying to improve the processes and try to reduce the greenhouse gases emissions.

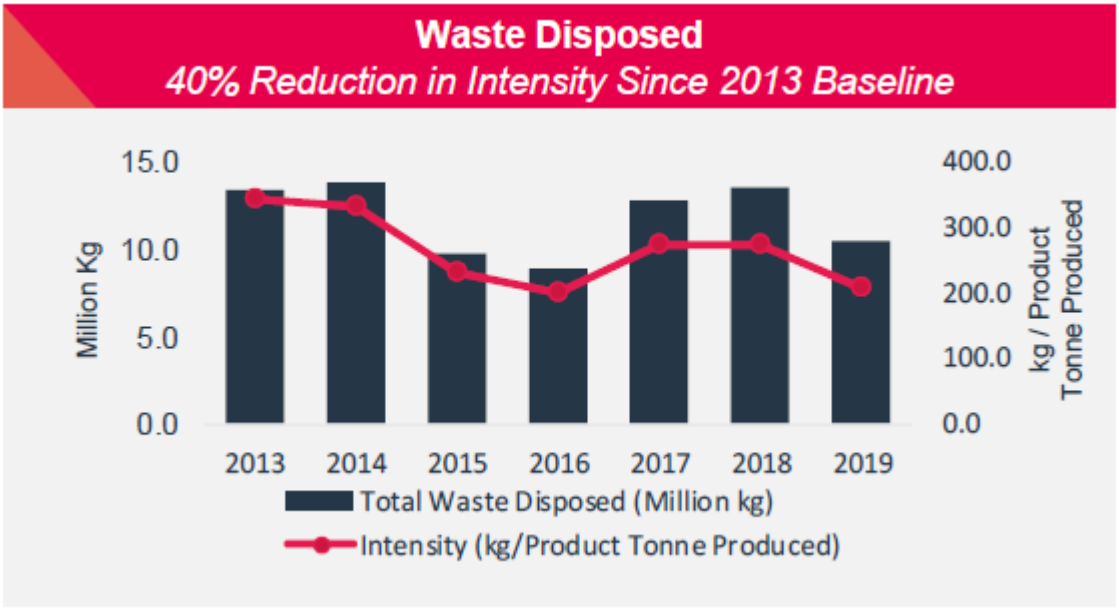


(Source: Livent, Resource Management)

4.2.3. Waste disposal

- The company continues to focus on minimizing waste generation and finding opportunities for production for the surplus materials produced from the process. The company reduced the volume of waste removal by 30% in 2019 compared to 2013.

Lithium production process requires a substantial water use. Livent is taking measures in order to improve the consumption of resources by using new technologies and looking for new opportunities to reduce resource usage and consequent waste generation.



(Source: Livent, Resource Management)

4.2.4.Environmental Impacts

Through Livent's sustainability program, managed by their global sustainability leader in partnership with other business leaders, the company monitors the its efforts to reduce energy use, operational emissions and waste generation at facilities around the world. Specific performance goals across the company drive site-specific programs, tailored to local facilities and activities. Because Livent has grown in recent years, they have focused on increasing production capacity while making significant progress in reducing environmental impacts and resource consumption. When Livent became an independent company, it decided to maintain the environmental goals in 2025 that were set years ago as part of FMC. (LIVENT, 2019).

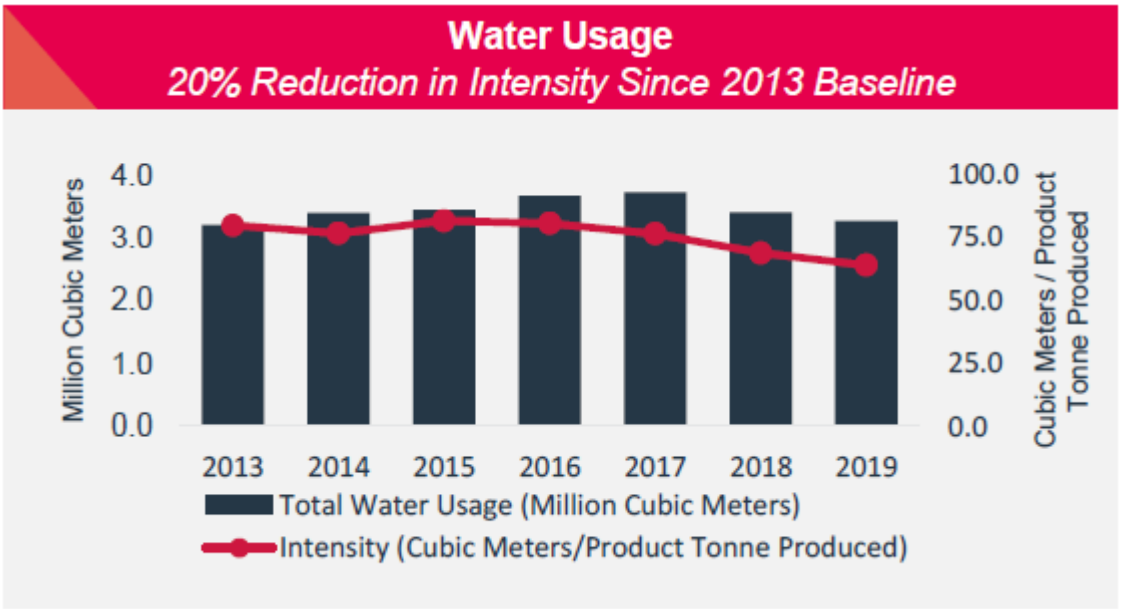
The targets are designed to reduce greenhouse gas emissions, energy, water and waste power by 2025, compared to baseline in 2013. The company slightly exceeded or almost achieved this 20% target across the board by the end of 2019, which is five years ahead of schedule.

In 2019, the Fénix plant accounted for the largest share of all of Livent's energy consumption. An increase in energy use in 2019 was due to the addition of two SA columns at the Fenix facility. As a result, energy intensity increased slightly in 2019 as well.

The organization has reduced waste power by 40% compared to base year in 2013. And they continue to look for ways to minimize waste streams from all parts of our value chain and maximize opportunities for reusable by-products.

4.2.5. Water use

In 2019, a 19.3% reduction in the amount of water used in production was made compared to 2013. The company is committed to reducing water use through process control and streamlining.



(Source: Livent, Resource Management)

After examining the data, it can be seen that the organization is committed to continue working closely with the third-party geology partners. Especially now when the company intends to expand activities in Argentina. These actions are designed to ensure that the company's future impact on the area is reduced. The organization intends to use a secondary water source, the Los Patos River, for the purpose of expanding the organization. This will reduce Libent’s reliance on the Trapiche aquifer. The organization has already installed monitoring wells in these two water sources to monitor water levels, rate of charge and water chemistry to ensure that the organization uses water sustainably. The Government of Catamarca has also conducted comprehensive environmental reviews of the organization's

current use and expansion plan for water with the help of independent third parties (LIVENT, 2019).

4.2.6.Lithium extraction practices

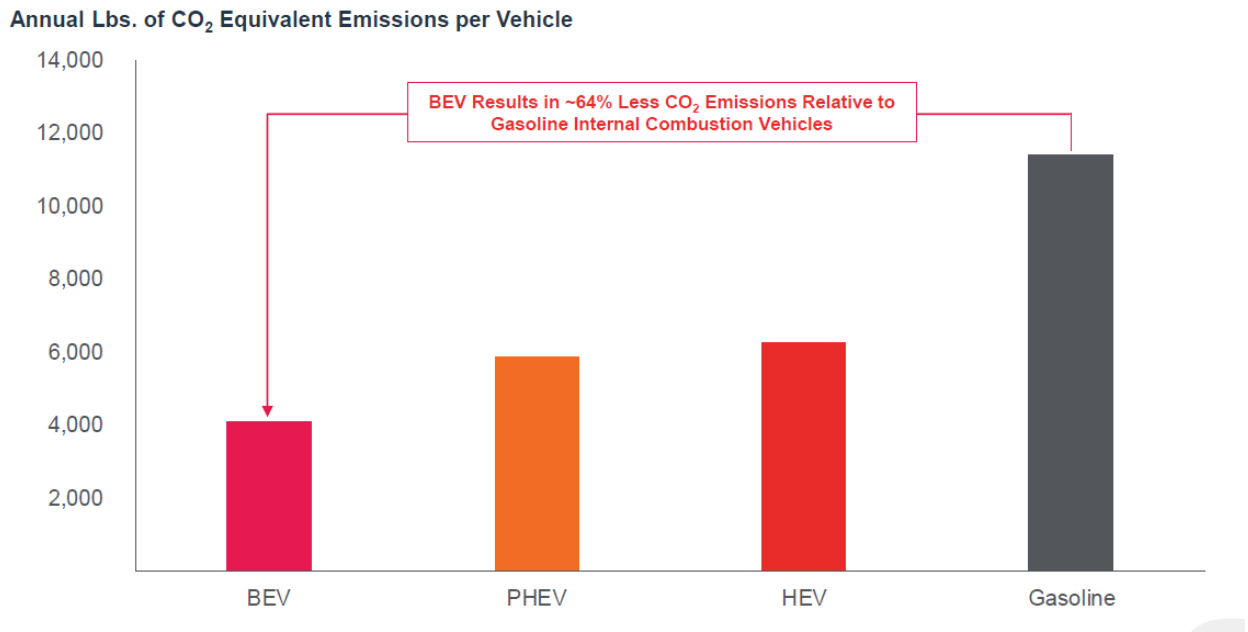
Current production of lithium by LIVENT is based at the Salar del Hombre Muerto in Catamarca, Argentina. There they use fresh water from Trapiche aquifer in order to produce Li2CO3 from the extracted brine. LIVENT states that their Environmental Management System, which is ISO 14001 certified, is able to comprehensively manage and record various environmental parameters such as water flow, salinity and chemical transport. Special Proprietary Selective Adsorption technologies utilized at the evaporation ponds speeds up the conversion time and helps reduce negative effects on the surrounding landscapes. Water is re-used and re-cycled in order to minimize the total water usage. Also, LIVENT employs a third-party geology firm to monitor and model the aquifer and the Salar, as well as conducting regular ecosystem studies with third-party specialists to monitor the state of local flora and fauna.

4.2.7. Livent's Environment statement:

According to the data from US administration, which makes a comparison between the different vehicles and their carbon dioxide emissions, it can be seen that regular petrol vehicles are the most polluting, then are the hybrid vehicles, and ultimately the least polluting vehicles are electric vehicles. This is about 64% less than regular gasoline vehicles.

Thus, it can be understood that the use of electric vehicles can help reduce air pollution in cities, especially in crowded cities.

True to the information in the report by USA government it can be seen that electric vehicles annually produce 64% less of CO2 emissions when compared to gasoline vehicles.



(Source: Energy Efficient Mobility Systems, U.S. Department of Energy, 2019)

BEV: Battery Electric Vehicle.

PHEV: Plug-in Hybrid Electric Vehicle.

HEV: Hybrid Electric Vehicle.

4.2.8.Economy

When looking at the company's data, it can be observed that Livent is focusing on its ties to the electric vehicle market (EV), but this remains a minority of its business in the meantime. In 2017, sales of lithium hydroxide for EV batteries accounted for only 24% of revenue. The other 76% of revenue came from sales of other lithium compounds used in industrial processes and pharmaceuticals.

But there is a lot of focus on the automotive industry market because the company's forecast and as well as the results of this research show that lithium demand will rise along with the increase in demand for electric vehicles in the free market. In 2018 the company announced that it intends to take advantage of the growing demand for lithium by dramatically increasing its production. The company stated in its S-1 that it plans to increase production capacity from 18.5 thousand tons in 2017 to 55 thousand tons in 2025, a threefold increase.

But LIVENT is not the only company that sees the growing demand for lithium. In the first six months of 2018, lithium prices fell from $ 25,000 per ton in March to $ 13,000 per ton in August, down 47%. As a result, the company's marginal profit decreases.

In particular, Livent should have a significant advantage over most new lithium manufacturers entering the industry. According to the same Roskill report mentioned above, Livent is the lowest cost lithium hydroxide manufacturer in the world, mainly due to the attractive location of its Argentine mine.

In addition, Livent is an integrated lithium producer, meaning it produces lithium compounds in addition to producing the raw materials. The company has over 60 years of expertise in the production of lithium compounds, which should give it a competitive advantage over newer manufacturers.

It remains to be seen how significant or durable these benefits are, but they should at least allow Livent to maintain superior profitability compared to other lithium manufacturers in the foreseeable future (Trainer, 2018).

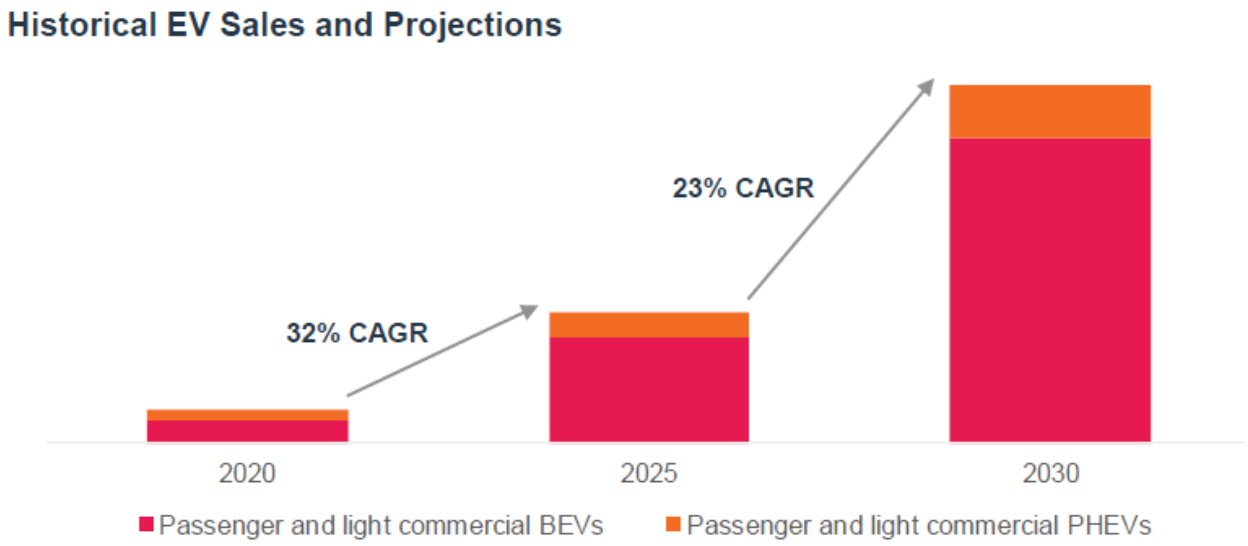
In November 2020 the company Tesla Inc TSLA.O will continue the contract with LIVENT until the end of 2021, for the purpose of supplying batteries for electric vehicles.

The Nemaska deal would help Livent boost lithium production as demand is expected to soar later this decade with electric vehicles going mainstream. (Ernest Scheyder, 2020).

The company also posted lower-than-expected quarterly results, and its shares fell 3% to $ 11.50 in late trading.

In view of the changing reality of today, today all projects for further development of the organization are frozen until the existing situation is clarified. But it can be seen that the company continues to look for new customers who will consume its products.

The company sees that demand will continue to grow according to the data presented in Investor Presentation in slide 12:



(Source: EV Volumes, Energy Efficient Mobility Systems, U.S. Department of Energy, 2019)

According to the data presented within five years from 2020 to 2025 there will be a freeze on demand of 32% and demand will continue to rise. The expectation is that demand will increase from 2025 to 2030 by another 23%.

According to these data, it is expected that governments will continue to support the transition to electric vehicles as well as continue to provide subsidies and incentives to increase attractiveness of electric vehicles to the consumers. Consumers will continue to purchase electric vehicles due to an increased awareness of air pollution and higher need for an environmental protection.

4.2.9.Factors influencing adoption of electric vehicles

The factors that influence the global shift towards electric vehicles can be divided into four groups.

First one is the growing environmental awareness on all levels of our society. Electric vehicles play a key role in lowering greenhouse gas emissions from global transportation and help decrease air pollution in cities and urban centers. Consumers as well as governments and corporations see this. That is why many major economies and governments are planning long-term policies to phase out traditional internal combustion vehicles.

Second group is the global government support. European countries announced several long- and short-term subsidies and incentives both for consumers and manufacturers of electric vehicles. Chinese government also announced a two-year plan of purchase incentives and tax relief for buyers of electric vehicles with longer range and higher overall vehicle efficiency.

Third group is technological improvements. Continued technological advances and development improved manufacturing process allowing electric vehicles to be more energy efficient. The adoption of better cathode materials with high energy density enable manufactures to reduce costs and to create electric vehicles with longer driving distances.

The fourth group is increasing availability. Leader of automotive industry offer more electric vehicles models across different types and platforms. Declining battery costs also make electric vehicles more affordable for the general public. This makes electric vehicles an available option for everyday use.

5. Results and Discussion

When we look at our environment, we can see that the effects of air pollution on our lives on Earth are changing and intensifying over the years. The massive industrialization that began as early as the 19th century and technological development increased human dependence on the use of fossil fuels for the purpose of improving daily life. The invention of electricity has led to a significant change and improvement in the lifespan of human beings around the world, but there are also negative aspects to this development. Human dependence on electricity leads to the constant need to generate electricity, and today most of the electricity is produced using fossil fuels as well as the use of various fuels to increase combustion and electricity production. Also, all motorized transportation relies on oil, while dependence and se of this transportation leads to an increase in global air pollution and in cities in particular.

Over the years humans have realized that the use of fossils as well as widespread use of oil leads to many damages. These damages not only affect the environment, air, soil, air and water but also public health.

Massive technological development is looking for solutions to create greener energy that pollutes less but still allows humans to continue to exist and work in everyday life, enjoying the luxuries of technological progress. Many industries today are trying to move to greener operations which are less harmful to the environment. But the road to significant change in this field is still far away (BBC News, 2018).

Many governments today invest a lot of money and efforts to preserve the environment. Part of this process is generating electricity from green sources. These sources are wind farms, electricity generation by water and more. But such a change in our processes is expensive and it takes a long time to fully adopt and implement. Even today in countries where there is an industry of green energy production they are still far from providing energy to the entire population of that country. That is, even in these countries, fossil fuels are still used to generate electricity for the benefit of residents and local industry (BBC, 2017).

One of the developing industries of recent years is the production of electric cars as well as hybrid cars. The main vision of these cars is to move away from gasoline or diesel as well as to provide other economic benefits for consumers while keeping pollutant emissions low.

According to car makers' statements, by 2030 most of the new models will be electric; Jaguar and Land Rover have announced that by 2020 all of their models will be electric, Renault, Nissan and Mitsubishi have set out this year with 12 motorized models and the Mercedes announced that in 2022, 50 of their models will be electric or hybrid (BBC, 2017).

Ultimately, those who will set the tone are the automakers that are responsible for the supply in the market. When they set a goal to switch to a different type of vehicles, they will most likely not invest any more money in designing a new gasoline engine. Also, the competition between the manufacturers will cause the transition rate to be faster than expected, as they will all want to be the ones offering more models of electric cars.

But, as long as electric vehicles remain more expensive than regular vehicles, it will be difficult to justify the transition to them. According to Bloomberg's forecast, around 2025, the price of the lithium battery, the most expensive component in electric vehicles, will fall, and electric vehicle prices will match the prices of vehicles with internal combustion engines. Then, buying an electric car will become financially worthwhile.

Thus, this study examined the research question “Is electric vehicles really green and helping to preserve the environment?”. This study conducted an examination of the LIVENT company, which produces lithium for vehicles, with a focus on environmental issues as well as the economy.

5.1. Environment

LIVENT is a company that offers energy storage systems and batteries based on lithium and also offers additional products such as polymers and grease based on lithium products and more. The company advocates for developing advancing technologies for the extraction and purification of lithium. However, the production process of lithium still requires many resources which greatly affect our environment.

The findings of the study show that LIVENT annually has an amount of energy for the production of lithium of about 2 million GJ, which is a considerably large amount of energy. Since 2013, the company has managed to reduce energy use by about 19% (as of 2019) (Livent, 2021).

And yes, the company is trying to reduce the use of greenhouse gases while incorporating the use of natural gas. These changes resulted in a 23% reduction in greenhouse gases in 2019 compared to 2013. As of 2019, it can be seen that the company still produces about 1.2 million tons of CO2 (Livent, 2021).

When looking at the data about the amount of global waste dumped by the company it can be seen that Livent is trying to reduce waste in the production process of lithium. Since 2013, the company has managed to reduce the amount of waste by about 40% (as of 2019) (Livent, 2021).

In terms of water use since 2013, the company managed to reduce water use by 19.3% as of 2019, this change was made by encouraging process change and the introduction of additional control measures.

All targets that were set to reduce greenhouse gas emissions, energy, water and waste power by 2025 were met according to the results and data, compared to baseline in 2013. The company exceeded this 20% target across the board by the end of 2019, and is five years ahead of schedule.

When examining the research literature, it can be seen that the forecast for the use of raw materials needed for electric vehicles is going to grow and even double by 2060. The use of raw materials will expand for a number of main reasons:

- **Economic growth** - Economic growth affects the demand for products for years, in order to produce new products raw materials are always required. There is also a forecast of an increase in the national product per capita that will lead to an increase in demand for new products, therefore leading to an increase in demand for raw materials.
- **Technological changes** - These changes occur rapidly and technological development requires many resources and raw materials. At the same time there is also an improvement in the production efficiency of the factories which changes demands for raw materials. The demand for raw materials is going to rise along with the technological changes that are taking place in the free market.

It is important to emphasize that not all demand for materials is growing. The need for metals (including lithium) is expected to increase significantly, especially in countries such as Brazil, Russia and India, Indonesia, China, South Africa and more (OECD - Economic Drivers and Environmental Consequences, 2018). In order to produce a car, many materials are needed, one of which is steel, the production of steel is one of the biggest pollutants in the world, and leads to significant greenhouse gas emissions in particular.

When examining the company's findings together with the OECD forecast it can be seen that the trends for significant change for the benefit of the environment are still far away. The main reason for this is that although the company is trying to reduce the use of energy as well as other natural resources, the growing demand for metals is going to lead to the need for further mining of many materials. Natural resource extraction is highly polluting to the environment, there is a great impact on the soil, water, air and great amount of waste is produced from the process of extracting the materials. Thus, it can be understood that despite all the efforts of companies to reduce environmental pollution, the expected demand for raw materials is going to bring many difficulties. And in order to maintain a greener process even in the more distant future and companies are required to adopt more technological changes as well as explore ways of changing the processes of production to be more environmentally friendly in the future.

All of these ultimately lead to the question of whether the products we consider today are really green and manufactured in a way that preserves the environment?

5.2. Electric and hybrid vehicles

When looking at the electric and hybrid wide market it can be seen that automakers are advertising electric vehicles as green vehicles that do not emit pollutants into the environment and help maintain the air quality of the cities in the world. It is questionable how true this really is. When examining the data of the Livent company, no information can be found in relation to emissions or pollution in relation to lithium batteries for electric vehicles. It is also important to clarify that in this study the focus was not on the other parts required to manufacture an electric vehicle, only on the battery itself. But the research literature shows that the use of materials such as iron (for the manufacture of car chassis), plastics and other

materials, often pollute the environment and the production process is no less dangerous than that of the ordinary vehicles (Hertwich, et al., 2019).

Although electric cars are an important technological breakthrough with significant potential environmental benefits, these cannot be harnessed everywhere and not suitable for every situation (Hawkin, Singh, Majeau-Bettez, & Strømman, 2012). Studies show that when electric vehicles are introduced in regions or countries that still rely on electricity generation by fossil fuels, or the combustion of heavy petroleum materials, at best, only a slight reduction of localized pollution can be achieved. Thus, electric vehicles are a means of keeping emissions away from the places of their use (cities, roads) instead of reducing them worldwide. Only limited benefits are achieved by electric vehicles that use natural gas electricity, in the absence of non-fossil based sources of electricity. That is, electric vehicles cannot always be classified as green. The main reason for this is that there is actually a shift in the localization of pollution. Instead of polluting the city with pollutants from gasoline and diesel engines, and the pollution will move to stationary places in power stations outside the city.

In contrast, combining electric vehicles with clean energy sources can allow for a drastic reduction of many environmental impacts in transportation, especially in terms of climate change, air quality and fossil fuel conservation. The many potential benefits of electric cars should therefore serve as a motivation for improving regional power plants, but their promotion should not override the commitment to improving the grid. Alternative vehicle technologies must be considered from the perspective of the benefits over time. While electric vehicles may offer slight benefits or even setbacks under an initial network, their development and market penetration should be assessed along with realistic long-term network development scenarios.

The change in emissions that electric cars are about to bring about - the elimination of pipe emissions at the expense of increased emissions in vehicle and electricity production networks - brings new opportunities and risks for policy makers and stakeholders. On the one hand, electric vehicles will accumulate emissions at a few point sources (power stations, mines, etc.) instead of millions of mobile sources, making it easier to control and streamline companies' transportation systems (Namdeo, Goodman, Mitchell, Hargreaves, & Echenique, 2019). On the other hand, the indirect nature of these emissions - embodied in internationally

traded goods such as copper, nickel and electricity - challenges us as a society. This raises the question of how serious we are in thinking about the life cycle and how much control and supervision over us, customers and policymakers believe should be exercised across production networks.

Another important point is that the use of electric vehicles requires a suitable urban infrastructure for the wide use of consumers. In order to encourage consumers to use electric vehicles, governments and car manufacturers must adapt the cities to the changing needs of the residents. Therefore, a large financial investment as well as many natural resources will be required in order to adapt the cities to the extensive use of electric vehicles.

5.3. Lithium

It can be seen that the process for lithium production is not a particularly green or environmentally-friendly. This lithium is the cornerstone of the process of manufacturing batteries for electric and hybrid vehicles. One of LIVENT's customers is Tesla - a manufacturer of electric vehicles and it is at the forefront of encouraging the automotive industry to move to green vehicles. But often the customers do not see the whole big picture when it comes to purchasing a new car.

Lithium is a major resource for the production of electric vehicle batteries, because without the lithium batteries that store the energy, it will not be possible to operate the vehicle. This is therefore a critical part of the vehicle. But it can be seen from the research findings that the lithium extraction process consumes many natural resources and affects the environment. LIVENT still pollutes the environment despite attempts to reduce energy use, water pollution, and greenhouse gas emissions. Today lithium batteries are considered the best batteries for electric and hybrid vehicles, the main reason for this is the energy storage capacity of these batteries. These batteries are not very large and the charge time is relatively short. That is why electric vehicle manufacturers have adopted these technologies. But the use of other raw materials also involves very polluting processes.

The only benefit of electric vehicles today is the reduction of carbon dioxide emissions in cities. In order to produce lithium batteries, the following materials are required - lithium,

manganese and nickel, cheaper metals than cobalt - but with a negative environmental price (Denyer, 2016).

The realistic solution to reduce pollution in the lithium extraction process is to perform a higher quality control on lithium manufacturers and individual material removal processes. And to encourage manufacturers to reduce the use of materials by adopting new technologies that use less resources and pollute the environment less. Another solution is to create a recycling process and extract materials in existing products.

5.4. Economy

The main factor driving the world today is money, all companies and organizations are working to generate economic profit. Few organizations are non-profit organizations. Therefore, the economic part is important and necessary even when considering the issue of the environment. The economic issue does not miss the field of electric vehicles and the lithium battery market. It can be seen that according to the company's data, LIVENT's lithium batteries currently constitute only about 24% of the company's lithium business. These data indicate that the market for delicate lithium batteries is not the business center of Livent. That is, there are growth possibilities and special opportunities for a market which is only at the beginning of its path. The research literature that examines the issue also sees that the electric vehicle market is developing slowly but in 2030 the number of electric cars is expected to increase significantly, as of 2017 there were 3 million electric cars in China, but it is expected to increase to 125 million vehicles. This is a significant increase. The expectation is that Livent will continue to invest a lot of resources to meet the future demands of the vehicle market as well as an increase in lithium tons (DiChristopher, 2018).

Confirmation of this trend can be seen by the company's announcement that it is expanding its lithium-cutting acquaintances as well as a massive investment of economic resources and technologies for the future to come. The company also brings a future forecast of demand and it can be seen that within five years from 2020 to 2025 there will be a freeze on demand of 32% and demand will continue to rise. The expectation is that demand will increase from 2025 to 2030 by another 23% (Livent, 2021).

The economic potential inherent in lithium batteries is significant and can bring many profits to the company if the management and reducing of resources is conducted properly. But another economic challenge is an understanding of the free market and figuring out a need for lithium. It can be seen that in the first six months of 2018, lithium prices have dropped significantly due to the entry of competitors into the market (Trainer, 2018). Which leads to higher competition as well as lower lithium prices. On the one hand, the new competition in the market brings an advantage on the part of consumers to lower prices. But on the other hand, there is a problem that an increase in lithium excision will lead to lower regulation and will continue to harm the world's natural resources.

Another economic challenge that has only recently arisen is the change that is taking place in the world today, the global epidemic is changing world globally. It can be seen that many countries have moved workers to work from home. This phenomenon has led many organizations to understand that working from home is possible and even more efficient than when employees come to the office. This also affects the car market. People travel significantly less and air pollution in major cities is declining. It can be assumed that it is a temporary phenomenon that will pass after the pandemic. But it can be seen that the signs today show otherwise, large organizations including Google, Facebook, Twitter, Intel informs employees that their roles of the organization will continue but they no longer need to work at the office. These organizations and many others have realized that employees are not required to be physically at work in order to be productive, and the economic savings of the organizations are significant. These organizations do not have to have large offices in strategic locations and it is possible to reduce employee flights to distant countries due to the ability to work from home and still communicate with everyone. All this will also lead to a change in the car market. These workers will significantly reduce travel time and the need to drive sometimes even disappears completely. In these cases, the car market and the electric car market in particular have seen a significant drop in demand. There is a need for a conversation about re-examining the car market and adapting the companies to the changing needs of the consumers. It may be that buying electric vehicles will become economically unprofitable for the automotive market as well as consumers. But at the moment it is not possible to understand the whole significance of the global epidemic on the electric vehicle market and the Livent company in particular.

5.5. Consumer Behavior

Consumer behavior is very important in the process of manufacturing products, especially new products. It is an important decision-making process that examines all the reasons for buying a particular product or service by the consumer (Molla & Licker, 2001). Ultimately purchasing intentions is a process in which the consumer examines all the possibilities available to them that can meet the existing need. An important part of purchasing intentions is related to the behavior, attitude and perception of consumers towards the product. The opinion of customers who have purchased the product is an effective tool to understand and predict the purchasing intentions of future consumers and what the purchasing process of these customers is. Consumers' buying intentions can change with time, price, quality, image and other alternatives available in the market. In addition, consumers are affected by other factors such as internal and external motives. Internal motives are the desire and will of the individual, external motives are criticism, communication, opinion of others (Rotondaro & de Oliveira, 2001).

The process of acquiring intentions of needs consists mainly of six different stages: product, knowledge, awareness, preference, interest, persuasion and acquisition. Customers believe that the low cost of an unknown product or brand are higher risk products than other products due to the risk of unsatisfactory product quality or alternatively brand reliability and responsibility for it (Cho, 2014). The buying decision-making process that forms the basis for understanding consumer behavior is built on a system of stimulus - consumer - response. There are two types of stimuli, marketing stimulus and environmental stimulus, both stimuli are designed to affect the consumer and to encourage shopping. Marketing stimulus contains the product, price, distribution, promotion and advertising. In contrast environmental stimulus contains the culture, society, economy, politics, technology. These characteristics are designed to influence the consumer. Consumers and their decision-making process consists of personality traits, content (emotions, beliefs, values, motivations, etc.), and processes (considered decision, or low-involvement decision) ultimately affect the individual's response, buying response, use, getting rid of, recommendation, word of mouth and complaints (Makgopa, 2018) .When talking about the process of buying a new car the involvement of most consumers is high and organizations are trying to predict the future consumer behavior and process of developing new products.

It can be seen that the Livent company performs this analysis as well. The factors that affect all the adoption of electric vehicles according to the Levant include 4 different categories:

- **Global government support for electric vehicle adoption** - Many governments today support the adoption of electric vehicles and provide subsidies to consumers and support for vehicle manufacturers. Which shows that governments understand the importance of adopting electric vehicles for the sake of preserving and improving the environment.
- **Technological advances** - it can be seen that technological improvement enables the creation of a competitive advantage if companies adopt new technological tools and helps with improving the automation of the lithium removal process as well as the manufacture of its products.
- **Environmental awareness** - electric vehicles are an integral part of reducing greenhouse gases, and is a part of growing global support for environmental protection. This awareness is pushing towards a transition to purchase electric vehicles produces, increases a demand for electric vehicles. Global companies also understand that change is needed and set goals within the company for switching to electric vehicles as well as greener energy consumption.
- **Increasing affordability** - More automakers are producing models for electric vehicles that allow for a wider range of prices to the consumer, also, a greater supply of different electric vehicles allows consumers to purchase an electric vehicle that suits their needs and budget. In addition, the cost of lithium batteries decreases over the years, which allows better price accessibility for a wider range of household vehicles.

The research literature shows that there are factors that may accelerate or slow down the adoption rate of electric vehicles (Houde, 2019):

- Changes in battery production costs and their effect on the final selling price of the electric vehicle.
- Technological improvements in lithium-ion batteries, especially for longer distances or faster charging
- Allocations that will be adopted by governments around the world such as, for example, financial incentives for the purchase of electricity, industrial development

policies, support for growth in the electrical vehicles field, regulations, taxation based on emissions, etc.

- Development of alternative technologies
- Changes in the price of oil
- Change in charging facilities

Understanding the market for electric vehicles allows LIVENT, to attract new investors to the company and to see in which direction the market for lithium batteries is developing. It can be understood from the findings and research literature that electric vehicle market is only in its infancy but the direction is clear. Electric transportation and not just electric vehicles are the future of our world. Lithium batteries today provide a good solution for electric vehicles but are still not the perfect solution in terms of air pollution. But proper marketing and understanding the needs of consumers allows the company to understand the changing needs of a market. Especially with the trend of increasing environmental awareness, more people are aware of the environmental damage that traditional vehicles bring with them.

In my opinion over the next few years we will see more electric vehicles on the roads in the world, and the Livent company sees the opportunity that exists in the market and is able to change the company according to the needs of the market.

Livent's main advantage is the field experience and is the seniority in the field of lithium batteries. Also, the constant effort with wich that the company is trying to reduce of the use of water sources as well as to lower energy consumption over the years can bring the company a competitive advantage in the lithium battery market.

5.6. Recycling

One of the challenges of this research is the fact that no reference from the Livent company product’s recycling could be found. One of the reasons for this may be that the company sells the products to other manufacturers such as car manufacturers and therefore the recycling of the products is not within the scope of LIVENT’s responsibility. Despite this, no reference to recycling was found in relation to other Livent products.

But when looking at the recycling range of lithium batteries it can be seen that when electric vehicles are out of use most of the batteries do not go through a recycling process. In total,

about 5% of batteries are recycled throughout Europe (Argusmedia, 2020). These are very small numbers, but these numbers are supposed to go up along with the increase with the number of electric cars on the road. The main advantage of recycling these batteries is that these batteries can still be utilized but that their capabilities are reduced by about 20% -30%. This means that these batteries can still store electricity for another 7-10 years (Argusmedia, 2020).

Vehicle manufacturers are beginning to understand the importance of vehicle recycling, and today there are also various projects to reuse lithium batteries after the end of the use of the electric vehicle. One of these uses is to store solar energy to illuminate streetlights. Or use these batteries to power solar power to households (PRESS & BLOG, 2017).

All of these projects are welcome and help prevent environmental pollution. But what happens after the batteries cannot store energy anymore? For a few years that the batteries can still store energy they can be reused in their original purpose, but after that these batteries are completely out of use. It is therefore important to consider additional alternatives in order to recycle the batteries at the end of their operation.

Studies show that it is possible to recycle lithium batteries and even extract valuable materials. The European Union sets aggressive targets for recycling obsolete cars, and car manufacturers are responsible for collecting and balancing vehicles. Under these laws only 5% (by weight) of the vehicle can be sent to the landfill and all other materials are required to be recycled (Steward, Mayyas, & Mann , 2019). So, in the future to come it will be seen that more lithium batteries will be recycled or reused.

Global resources are limited and eventually we will reach a situation where there will be no more raw materials left or alternatively the cost of extracting these materials will be significantly higher. But if the lithium batteries are recycled, it will be possible to extract the expensive materials and end up producing resources from the recycling stand on its own without the need for an additional resource pad. This process requires an understanding that environmental protection and responsibility depends on the vehicle manufacturers.

If Livent understands the advantage of reusing and recycling the lithium batteries after the end of its life cycle, the company will be able to utilize this resource in order to create a competitive advantage in the market, as well as reduce costs of lithium mining. Reuse will

not only reduce the costs of mining lithium, but also will be able to produce a new stock of lithium at a marginal cost of recycling the product and returning it to the market. This can be considered a double sale of the same product and creation of the urban mine, which overall can meet the lithium needs of the market.

5.7. Recommendations

- Critical materials for battery production - Old batteries are a source of resources that can be extracted through recycling, so called urban mining. It has high economic potential and helps to preserve the environment. The peak of the car market is only in its infancy and the peak will take place only in about 15-20 years so establishing a recycling infrastructure and resource extraction now will allow Livent to specialize in the field as well as gain a significant competitive advantage in the lithium field. Without this process the cost of cutting the materials will only increase and will result in a higher cost of extracting the materials from deeper layers of the soil. And will lead to an even a greater waste of natural resources.

- Another important part is looking at the global electricity generation industry, understanding that a significant and deeper change is needed to reduce greenhouse gases. If governments and states adopt greener electricity generation and not just adopt electric vehicles, it will lead to a significant change in greenhouse gas emissions, lowering increases and the need for oil and fossil fuels. A significant change in this area can bring many benefits to the environment as well as the lives of the people.

6. Conclusions

Today we are seeing a change in the automotive industry as well as a greater understanding of environmental issues by consumers. Today's consumers are interested in getting environmentally-friendly, green products and are also trying to save on fuel expenses. Especially now when fuel prices are constantly changing and affecting all households. The desire of consumers to save financially as well as use greener energy forces the automotive industry to meet this need. It can be seen that the development of electric vehicles has started in recent decades and today there are electric vehicles which can meet the needs of these customers.

The understanding that consumers are the ones who can bring about change in relation to reducing greenhouse gases, brings many countries and governments to encourage the adoption of electric vehicles.

In order to produce the electric vehicles, lithium batteries are needed that will store the energy. Livent company is one of the significant players in this part of the battery production. It can be seen from the research findings that Livent has a great impact on the environment. The process of mining lithium is damaging to the environment.

Production of electricity needed in order to charge electric vehicles is not always a sustainable process with no effects on the environment. Many countries still use fossil fuels to generate electricity. Using electric vehicles will only increase the need for electricity, which consequently may increase the use of fossil fuels and subsequent pollutant emissions at power stations. That is, the amount of air pollution will not change in its quantities, only the location of the most affected by pollution areas will change. So, when we look at electric vehicles market it is important to understand that a global process which will involve governments, car manufacturers, and material suppliers in a joint effort to reduce the harmful effects on the environment is needed. Without it electric vehicles will not be able to decrease the hazardous influence of automotive industry on the environment and replace fossil fuel based vehicles as a new solution.

6.1. Research limitations

It is important to examine the research findings very carefully; since due to Livent external policies the research was carried out by only using the existing publicly available information. This data and the results of its examination may change with access to the company's inside information. Also, the findings of the study may vary depending on the organization on which the research is focused on. In order to interested in obtaining unambiguous data, the entire lithium industry must be examined together with the vehicle manufacturers in order to see the whole global picture.

6.2. Recommendations for further research

- The effects of the increased demands for electricity and consequent shift of the localization of pollution from roads and cities to power plants need to be examined and investigated. Negative effects of air pollution in cities that have more electric vehicles may be very noticeable less strong, compared to the locations of power stations.

- Another interesting research that will help understand the future of electric vehicle market is to examine the long-term economic effects in relation to consumers' electricity expenses associated with charging electric vehicles. This economic impact may be beneficial and can lead to the widespread adoption of electric vehicles or alternatively it can solidify the belief and need of traditional vehicles running on fossil fuel.

- Another factor that should be examined is the economic viability of recycling lithium batteries and the amount of materials that can be extracted from these batteries for reuse. Understanding this economic viability can contribute to more companies encouraging a battery recycling process and even producing a new industry in a market that does not exist today.

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