The Environmental Impact of Lithium-Ion Batteries

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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INTRODUCTION

As autonomous vehicles boom in popularity, their advertisement of healthy environmental practices warrants an investigation into the true impact of their modern fuel, the lithium-ion battery. As with any new and rising technology, the public is often largely uneducated about what goes on behind the scenes in its production. On the surface, autonomous vehicles using lithium-ion batteries can bring many benefits to the table, most prominently, they do not consume fossil fuels and produce zero emissions. In addition, they are rechargeable which means they can have a long service life. However, there are a number of downsides that come with these seemingly enormous environmental benefits. In this paper I answer the question: what is the true environmental impact of lithium-ion battery use in autonomous vehicles, specifically in their production and disposal?

In this paper I use a theoretical apparatus to analyze my findings: Actor-Network Theory (ANT). ANT allows its user to study societal relationships between human and nonhuman actors (Cresswell et al., 2010). More specifically, within ANT, techniques such as blackboxing will be used. Blackboxing is the idea that these frameworks aim to open the 'black box', or understand the internal complexities of a system to gain a more in depth analysis of the formation of the technology. In regard to lithium-ion batteries, they are put in this black box by many of the actors in the network including policymakers and manufacturers. The details of their creation, use, disposal, and environmental effects are largely hidden from the public. What ANT aims to do is open that black box to reveal how the human and non-human actors play a role.

In parallel, the campus vehicle team, a team of University of Virginia Mechanical Engineering students under the advisory of Professor Tomonari Furukawa, are developing an autonomous golf cart platooning system. Even the golf carts that will be worked on by the campus vehicle team, provided by Club Car, contain lithium-ion batteries whose maintenance and disposal must be considered (Club Car, 2022). At this scale any effects are arguably negligible, but it only confirmed the breadth of applications and uses of these batteries.

In this paper I argue that the widespread use of lithium-ion batteries has created significant environmental impacts, including air and water pollution, land degradation, and the depletion of scarce natural resources. In the following sections I discuss the processes of creation for lithium-ion batteries, a number of their significant applications, the environmental impacts of their use and disposal, and a variety of safe alternatives.

THE CREATION AND APPLICATIONS OF LITHIUM-ION BATTERIES

The development of lithium-ion batteries has revolutionized the way we consume and use energy. These batteries are now used in a wide range of applications, from consumer electronics to electric vehicles. In recent years, there has been a significant increase in the use of lithium-ion batteries, driven mostly by the rapid growth of the electric vehicle market as well as the adoption of renewable energy sources. Electric vehicle sales and market share doubled in the year coming out of the pandemic (IEA). This increase in use has led to concerns about the environmental impact of the production, use and disposal of these batteries. Investigating this research question will allow policymakers to explore any possible ways to reduce their negative effects on the environment.

Most autonomous vehicles, especially those developed by Tesla, the top-selling electric vehicle brand, use lithium-ion batteries to power the car (Wayland & Kolodny, 2022). These rechargeable batteries have been around since the 1970s and are used in a number of applications on top of autonomous vehicles due to their light weight and high energy density. To enable the car to drive itself Tesla needs to ensure that it can provide enough power to the computer systems and electric motors and this is achieved through lithium-ion batteries. As the technology continues to improve, the use of lithium-ion batteries will become increasingly important and prevalent which prompts the question of how safe they truly are.

As the lithium-ion battery industry continues to accelerate alongside its electric vehicle counterpart, the mining of its necessary materials will only increase. The raw materials that are used to make these batteries combine lithium, cobalt, graphite, and traces of nickel and manganese. The most significant resources in this production are lithium sourced from Chile or Bolivia and cobalt which is largely sourced from the Democratic Republic of Congo (Eggert, 2022). However, China is becoming an increasingly large player in the electric vehicle industry and companies like Ganfeng Lithium and Contemporary Amperex Technology Co., Limited (CATL), who supply lithium and batteries to Tesla, source some of their materials internally in various provinces in China (Lambert, 2022). Companies similar to those above typically take lithium from brine pools or salt flats and then later process them to be used in the batteries.

One issue that arises from this is lithium mining's massive reliance on other resources. The estimates vary heavily but roughly half a million gallons of water are used to mine only one ton of lithium (Bauer, 2020). As the world leader in lithium production, Chile's lithium mines are under pressure to supply this scarce resource to the exploding industry. Moreover, Chile has a naturally dry climate wherein mining activities consume 65% of the area's water (Bauer, 2020). Taking water from the surrounding communities and wildlife will soon become disastrous if these mining rates continue to rise. Not only does the mining process consume enormous amounts of water, the process also produces myriad toxic chemicals that can leak into local water supplies and drastically harm nearby communities (Kaunda, 2020). In addition, the majority of lithium mines in Chile and Bolivia are in areas with fragile and diverse ecosystems that can easily be harmed by harsh mining.

Land degradation has been shown to be one of the most environmentally impactful results of mining the various materials for lithium-ion batteries. In some cases, land is completely stripped of its vegetation and topsoil in order to extract the necessary elements from the soil (Kaunda 2020). On top of land degradation, this process can lead to water contamination, soil erosion, and a flatout destruction of nearby ecosystems that wildlife and communities are dependent on (Jose et. al., 2021). Furthermore, the mining process releases dust and chemical particles into the atmosphere, leading to air pollution and possible environmental health issues. In addition, the use of heavy machinery in these processes can trample and destroy biodiversity near the mines.

Many heavy duty machines are used to mine the natural resources necessary to produce lithium-ion batteries including excavators and bulldozers. These machines in combination with drills and jackhammers crush and remove the earth that protects the lithium-rich ores. Other forms of machinery are used in later processes like refining the lithium with toxic chemicals and finally combining it into its usable form. The question then arises of how much of an offset is provided from the benefits of lithium-ion batteries, to the emissions that are put out by the massive, diesel-fueled machines that are necessary to mine its raw materials. Zeke Hausfather, a climate scientist, illustrated that making a typical lithium-ion battery in the United States for a Tesla Model 3 results in roughly 4,500 kilograms of CO_2 emissions (Nguyen, 2021). If the battery were to be produced in Asia, where Tesla currently sources a significant amount of their batteries, emissions would total roughly 7,500 kilograms of CO_2 for one battery. This can equate to about 1.5-2.5 years of driving a gas powered car fueled by fossil fuels (Nguyen, 2021). Some countries including Chile are making efforts to mine more sustainably using pumps and refinement, but the offset is not yet close to enough. It is evident that when we open the black box of the lithium-ion battery we can see how the actors in the network related to their creation play a different role than when the black box was closed. The potentially disastrous effects of mining along with the horribly managed mines are revealed.

Once the mining companies have sourced the necessary materials, they can be refined for processing into a lithium-ion battery. The final steps include assembling the anode and cathode along with an electrolyte to allow the movement of ions between the positive and negative electrodes. Once in use, these batteries are praised for their rechargeability and their longevity while most do not comprehend the emissions that come as a result. More importantly, when the batteries die a larger problem arises in solving the issue of disposing of or recycling the batteries and their toxic materials.

THE USE AND DISPOSAL OF LITHIUM-ION BATTERIES

Lithium-ion batteries have revolutionized the way we power our electronics, but the unknown effects that may arise from their usage and disposal has raised concerns about their environmental impact. Lithium-ion batteries often absorb the positive press about the reduction of greenhouse gasses via their role as the source of power in electric vehicles. This was the main reason that I chose to investigate whether or not they truly deserve that title. I found that the disposal and use of lithium-ion batteries could potentially result in a significant environmental impact, including depletion of natural resources and greenhouse gas emissions.

A majority of the emissions that are associated with lithium-ion batteries come from their use of the electricity grid (Nguyen, 2021). This causes harmful emissions as the batteries charge and discharge every single day. In other words, the power used to charge the batteries often comes from fossil fuels anyway, so is there really any actua benefit in terms of CO_2 emissions? However, this problem is temporary as nations across the world continue to work to decarbonize the electric grid, meaning that these secondary emissions will decline in years to come.

Being used in consumer electronics, like cell phones and laptops which are often replaced every few years, alongside autonomous vehicles, the batteries hazardous chemical composition requires a proper disposal method. More often than not it is best practice to recycle these batteries and companies such as Tesla guarantee that 100% of the lithium-ion batteries are recycled. (Noyes, 2023). Many other companies and municipalities offer battery collection services to ensure that they can be taken care of and recycled properly. Due to the complex level of chemical reactions that occur when producing and using lithium-ion batteries, the materials involved can decay to a point past a recoverable status. (Seddon et al., 2019). Moreover, these batteries are so intricately designed that it makes it both difficult and expensive to recover any viable quantity of material from a used battery. These issues mean that used up batteries can simply stack up in factories over the years. What then can companies do to ensure that their dangerous toxins will not end up in landfills? If these lithium-ion batteries are disposed of in landfills they can leak out their chemicals into both the soil and groundwater which poses serious health threats to any nearby life (Sambamurthy et. al., 2021). Another bad disposal practice is incineration. In some cases, lithium-ion batteries would be incinerated; however, this can just as equally release those chemicals as gaseous toxins into the environment (Lombardo et. al., 2020). The increasing greenhouse gas emissions through production and electrical grid overload combined with the contamination of soil and groundwater through disposal poses a hazardous threat to the environment and public health.

Recycling of lithium-ion batteries is still at an early stage, and the recycling process itself has environmental implications as it requires a large amount of energy and resources. However, proper disposal and recycling of lithium-ion batteries can help reduce the environmental impact of their usage and toxic pollution. In addition, it helps to conserve natural resources. It is important to adopt sustainable practices such as responsible use, proper disposal, and recycling to minimize the negative impact of lithium-ion batteries on the environment.

Although lithium-ion batteries continue to prove massive upside, the uncertainty surrounding their disposal poses a serious environmental risk. This risk requires urgent attention by all parties involved. As described above, if not properly disposed of or recycled, these batteries can leak toxic chemicals, contaminating the environment. Again we can see how opening the black box of the lithium-ion battery leads to a new perspective on its actors. The policymakers are in the battery's network while closed, but when you open it you can see that they are involved in a drastically different way where you can see why and how the technology was put in the black box. Trends indicate that humanity's reliance on these batteries will only increase, thus it is crucial to find sustainable solutions for the issues detailed in this paper.

FRAMEWORK ANALYSIS

To analyze the evidence of environmental impacts of lithium-ion batteries detailed above, this paper will move forward with the Actor-Network Theory (ANT) framework. This methodology will allow the reader to understand how society and technology influence each other in their respective developments. Not only has the automobile greatly affected society since its inception, making humans almost fully reliant on their existence, but also society has shaped the development of cars themselves (Kline & Pinch, 1996). In this manner it will be evident which groups are most influential in molding the elements and arguments of this paper.

One of the key issues that would be addressed in this analysis is the trade-offs between competing environmental and social values that translate directly to global sustainability. This goes back to the idea that the potential negative effects from these batteries are shadowed by the advertisement of the exact opposite in electric vehicles' reduction of environmental impact. This analysis will aim to understand the challenges that arise from these two sides of the industry.

ANT is a methodological approach that concerns itself with the role of human and non-human actors in shaping social phenomena. I chose to use ANT as the analyzing framework in this paper because I felt it would be a useful pairing with my research question because it considers the various actors involved in the technology. It would investigate how these actors have contributed to the social processes that have influenced the environmental impacts of this technology.

There are two main groups that will be discussed as relevant to the ANT analysis in this paper: automobile companies and consumers. A much greater number of groups could be classified as relevant; however, for the purposes of this paper they will be out of scope. Primarily, consider the companies that supply autonomous vehicles and lithium-ion batteries to the consumers. They are directly responsible for funding the lithium-ion battery industry and continuing to drive the need for mining the raw materials. Thus, they should be vehemently aware of the possible effects in addition to the predicted estimations as autonomous vehicles are expected to be the future of transportation. As a company, they will certainly be focused on profiting to keep the business running, but they must enforce a strong ethical foundation to their practices to ensure that the safety of the environment that houses life on Earth does not further deteriorate. In regard to ANT, there are evident human and nonhuman actors to portray here with those that work for and run the companies along with the raw materials, cars, and batteries themselves (Latour, 2004). All of these actors have a direct role in their own environmental impact and the continuation or resolvance of that impact.

Another significant group that is heavily influential in the analysis of lithium-ion batteries and their environmental impact is the consumers, those that purchase any electronics, specifically autonomous vehicles, that contain these batteries. This group works directly under and arguably alongside the manufacturers due to the fact that without consumer interest in a product, there would be no product. Thus, if the mission is to eradicate gas-powered vehicles, consumers should understand this motion and its potential effects that may not be as efficient of a solution as is advertised by various companies (Conway & Oreskes, 2014). The ANT analysis of consumers and vehicles is slightly more nuanced as it is interesting to see how they have shaped each other over the past few decades. Humanity continues to have changing needs and these were heavily influenced by their immense dependence on the automotive industry. However, this works both ways in Actor-Network Theory as the human actors also influence the nonhuman actors in the sense that the consumers' needs are the priority for industries. The ever-encroaching threat of climate change has pushed human actors to shape the automobile industry to innovate and push out electric vehicles from a majority of car manufacturers (Bartlett). It is of utmost importance that both actors in this framework are aware of what unknown effects may arise from this solution to climate change.

The concept of blackboxing is relevant to the analysis of lithium-ion batteries' environmental impact since it refers to the process by which an object becomes a closed system, with internal processes that are hidden from view. In the case of lithium-ion batteries, the production process is often tightly controlled by manufacturers, with little transparency to the outside world regarding the environmental consequences of production. This paper in conjunction with the framework used in the analysis allow for the opening of the ‘black box’ to understand the hidden nuances of the technology and its adverse effects. Overall, ANT offers a valuable framework to consider the multiple actors implicated in the production, use, and disposal of lithium-ion batteries and encourages wider awareness of the environmental and social consequences of this technology.

By applying an Actor-Network Theory approach, it is possible to identify all of the factors that contribute to these sustainability trade-offs and generate controversies and conflicts among various stakeholders and concerned parties. This analytical perspective can help to enhance the transparency, accountability, and responsiveness of the lithium-ion battery industry. Moreover, one of the main goals of this paper is to foster a more reflective and participatory dialogue among the actors involved in shaping the environmental impact of this technology.

ALTERNATIVE SOLUTIONS TO REDUCE ENVIRONMENTAL IMPACT

This paper has developed various arguments about the negative impact that lithium-ion batteries can have on the environment. Although they are less damaging than cars powered by fossil fuels, they are certainly far from perfect. One solution to their difficulties is to use different forms of batteries with less toxic compositions. Zinc-air batteries are a possible alternative that use oxygen as a reactant to generate electricity and power. Similar to lithium-ion batteries they have a high energy density and long shelf life. These assets make them a popular choice for current applications in various medical devices. One issue is that they are not able to be recharged; however, they are considered to be an environmentally friendly option as they are recyclable and don’t contain any toxic or hazardous materials (Wang et. al., 2017). Some other promising alternatives include sodium-ion batteries and hydrogen fuel cells. Sodium-ion batteries are safer and more cost-effective than lithium-ion batteries and hydrogen fuel cells boast zero emissions. The challenge with these alternatives is ensuring they are powerful enough to provide energy to an electric motor and any onboard systems for an autonomous vehicle.

Another contributing factor to the emissions produced in the creation of lithium-ion batteries is the diesel burned by any necessary machinery. Researchers determined that many thousand tons of CO2 are burned and released into the atmosphere to create a singular lithium-ion battery. Although these numbers do seem daunting, they are certainly something that we should work towards reducing. One option is to use electric mining vehicles such as the eDumper, developed by eMining AG, that can repurpose the power generated by rolling into the mines to use net zero grid sourced energy (Borras, 2022).

The most pressing issue at hand is what options do companies and consumers have when a battery has reached its capacity and is ready to be exchanged. Lithium-ion batteries are able to be recycled safely in some cases, but there are no definitively outlined safe practices for disposal. Recycling is preferred as it reuses many of the materials and reduces the potential damage of releasing any toxic chemicals. Many state officials are beginning to pass legislation that requires possibly harmful batteries such as lithium-ion batteries to be recycled, and even instating programs through municipalities to provide any necessary recycling resources (US DOT, 2022). In addition to recycling, lithium-ion batteries can also be repurposed and used to power a variety of different devices, from laptops and cell phones to renewable energy systems. Moreover, once they are no longer useful to autonomous vehicles, these batteries can be used for energy storage in microgrids.

CONCLUSION

In conclusion, the environmental impacts of lithium-ion batteries are a rapidly developing issue that cannot be ignored. This paper illustrated evidence that the production, use, and disposal of these batteries have myriad negative effects. These impacts can have severe consequences on the environment and human health and it is essential that we explore alternatives. While lithium-ion batteries are currently the most popular and widely used form of battery in many applications, this paper detailed a few safer options. These alternatives, such as sodium-ion batteries and solid-state batteries, have a relatively lower environmental impact. Therefore, it is essential to explore and invest in these alternatives to mitigate the environmental impacts of lithium-ion batteries. In doing so, we can create a sustainable future without endangering our planet and its ecosystems.

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