The Improvement of Battery Technology: Using Geels' Multi-Level Perspective to Understand the Dark Story Behind the Screens

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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

"I think that if you don't do the full analysis of what the origin of the electrical power is, where it comes from, how you get batteries into these cars, what the cost is in terms of CO2 and the environment, I think the analysis that we are going to save the planet with electric cars is nonsense."

-Sergio Marchionne, 2017

Traditional analysis of Lithium based batteries tends to dictate the strengths of renewable energy without signifying the environmental cost of Lithium. It is crucial, just with technologies before it, to discuss the ethical aspects of the materials used in consumer products. With the push towards a cleaner and healthier environment, companies have also started to make a switch to using more environmentally friendly materials in the battery. With President Biden's orders to establish electric vehicles as the next step beyond gasoline, an ever-growing amount of scrutiny has been placed on lithium batteries. As Azevedo et al. said in their article, "Over the next decade, McKinsey forecasts continued growth of Li-ion batteries at an annual compound rate of approximately 30 percent" (Azevedo et al, 2022).

The public has been increasingly aware of renewable energy sources, and they try to decrease their carbon output. Despite other renewable sources emerging in the marketplace, lithium-based batteries have seen a major rise in demand. As people demand better technology and companies try to innovate, we are at a stop-gap phase where we are transitioning to more renewable sources of energy. Due to lithium being the lightest metal, as well as having the best electrochemical potential with the largest energy density compared to weight, lithium was immediately recognized as the optimal metal for battery technology (Hiden, 2021). However, the implications of using such a toxic material have created unforeseen consequences to the environmental landscape. For example, lithium mining causes water supply issues, an increase in global warming, prevents land growth, and adds additional waste into the environment. This is due to who mines the lithium, how the process to mine the lithium occurs, and the lithium's' life cycle. For example, lithium-ion batteries would only last a few years of daily recharging before

they are deemed useless (Apple, n.d). All these conditions are leading to an unsustainable future that, conversely, has convinced people it helps the environment. Alternatives to lithium, however, reduce the impact on the environment, such as greenhouse gasses, battery waste, and harmful mining consequences.

If awareness and education does not improve, consumers will continue to believe that they are helping in the environment by buying into renewable energy. Moreover, as the demand increases for lithium, the water supply in third world countries will continue to dwindle and potentially be poisoned. Also, the children mining lithium will continue in similar, unmanaged conditions. All these effects are detrimental to third world countries and will continue to create catastrophic consequences if not managed properly**.** In this research paper, I argue the consequences of using lithium as a resource for a renewable future prevents a cleaner environment. To support this claim, I will analyze the current sociotechnical system by using Geels' multi-level perspective. This will help in the understanding of how different levels impacted the growth and use of lithium. Furthermore, I will improve the understanding of lithium and quantifiably state the negative impacts on the environment even if it is touted as the renewable source of the future.

Environmental Effects

Why does the removal of Lithium matter?

Lithium based batteries are a non-renewable mineral that is the source of the renewable energy market (Xanders, n.p). Therefore, demand for lithium is rapidly increasing per year because the economy is trending towards the renewable energy sector. Unfortunately, the process of mining the lithium comes at a great cost. The extraction of any resource is harmful to the

environment. However, removing lithium from the environment can result in soil degradation, water shortages, biodiversity loss, and can contribute to climate change (Campbell, 2022). Lithium mining, more specifically, destroys the soil structure and leads to unsustainable water table reduction (Brooks, 2021). Friends of the Earth, an environmental organization founded in 1969, corroborated the report that lithium extraction inevitably harms the soil and air contamination. Furthermore, depending on the area of the world where mining takes place, the manufacturing techniques would emit more carbon into the atmosphere than others. For example, China, a country that holds a significant amount of lithium production, uses a less advanced manufacturing technique than the United States. According to the U.S. Government Publishing Office, one study found that producing a lithium-ion battery in China would emit about three times as much carbon dioxide as producing the same battery in the United States (U.S. Government Publishing Office, 2019).

Who owns Lithium and why did we use Lithium?

Lithium, an abundant yet finite resource, has been found in the countries of Chile, Argentina, and Bolivia. Together, according to the U.S. Government Publishing Office, those countries hold 75% of the world's entire supply of lithium beneath their salt flats. Also, China holds a significant amount of lithium, and global reserves estimate 14million tons. Due to having an abundance of material, as well as a need to improve battery technology for cars and various smart products, big corporations have moved towards a more renewable future. Apple, the biggest technology corporation in the world, notes that compared to traditional battery technology, lithium-ion charges faster, last longer, and have a higher power density for more battery life in a lighter package.

Who is mining the lithium and related minerals?

Besides lithium, a major component that goes into lithium-ion batteries is a mineral called cobalt. Children are being used to mine lithium and cobalt in unregulated mines for profit. In the case of cobalt, 60% of the world's supply comes from the Democratic Republic of Congo, where large numbers of unregulated mines use children as young as seven as miners (McKie, 2021). With the case of Lithium, in Tibet, a toxic chemical leak from the lithium mine poisoned the local Lichu River in 2016 and triggered protests. Due to the mines being unregulated, as well as the materials they are mining being unsafe, fatal lung ailments are prone to happen mining these materials. The United States further corroborated this report by acknowledging that mining these minerals needs to be carefully implemented otherwise long-lasting injuries can manifest. The Mine Safety and Health Administration (MSHA) have been working to improve health standards to prevent silicosis (US Department of Labor, 2022). Unfortunately, however, due to the increase of lithium mining, there has been an increase in major unforeseen environmental waste.

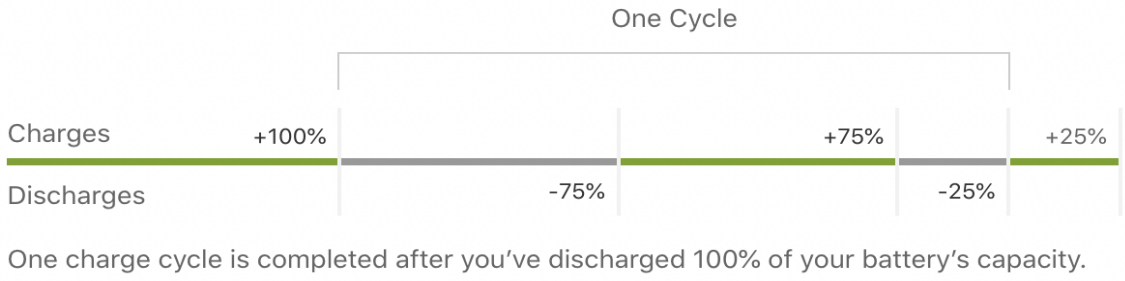

Figure 3. What exactly is a charging cycle?
Apple

Environmental waste

Typical smartphone users would upgrade their phones every two or three years. This happens when either their contract with their carrier is finished or the battery on their smartphone

goes bad. A battery, when charged over a couple years, will degrade over cycles of charge. A cycle is when the battery loses 100% of its charge, a cycle has occurred. For example, if the battery dropped from 100% to 25% and then charged back to 100%, once the battery drops to 75%, we can say the battery discharged a full cycle. The figure below gives a more visual example of what a battery cycle entails. Typically, if the battery can hold 80% of its original charge, which is around 500 cycles, the battery is considered bad and needs to be disposed of. This is because at the 80% threshold, batteries fail to hold a charge that will not impact the day-to-day use of the device. Currently, the batteries need to be carefully disposed of or a fire could ensue. However, eventually the batteries would end in a wasteland. Companies have been trying to recycle the lithium in the batteries as a means to prevent the planet from needing to use more of its resources. These companies, now, are not yet profitable.

Lack of Water

There is a major lack of water near the residential areas where the lithium mining is located. Lithium is processed through water plants, in which brine is used to refine and produce the material. Due to the process of how lithium is being mined, there is a lack of water in several countries who supply the minerals. In Chile, lithium-mining companies, such as SQM, are playing a major role in damaging the local environment. In fact, mining lithium is taking 65% of Salar de Atacama's water supply in Chile (Brooks, 2021). The process to mine lithium requires pumping water into it as shown in figure 1 (U.S. Government Publishing Office,

Figure 1. Effects of Water pumping on the shore. U.S. Government Publishing Office, 2019

2019). This is one of the major environmental impacts on earth. Along with the removal of water, however, the increase in demand of lithium batteries has been devastating to the earth.

Removal of earth

As the surge in consumer electronics rose, the surge in mining for lithium rose along with it. To compensate for demand, up to 30 million tons of earth must be dug up to produce the 60,000 tons of lithium required for each year. This vast removal of dirt has huge implications on the destructive consequences brought onto the environment. Putting this into perspective, about 1 tablespoon of lithium can produce 1 cellphone. Referencing the previous section, this means that 500,000 gallons of water would make 190,000 cellular phones (Xanders, n.d). Figure 2 gives a visual representation of how much earth removal is required to mine lithium. In this figure, we can see the amount of land that turned gray due to the mining. The surrounding areas, however, have a grasslands view. This amount of earth removal is detrimental to the native animals in the area and can uproot existing species. Unfortunately, this seems to be the only way to effectively mine the lithium required for these devices. Therefore, we should be looking for alternatives to lithium-ion batteries.

Figure 2. The visual effects of removing 30 million tons of earth. Source: (KBOO, 2021)

The future of Lithium Batteries

"We know we'll run out of dead dinosaurs to mine for fuel and have to use sustainable energy eventually, so why not go renewable now and avoid increasing risk of climate catastrophe?

Betting that science is wrong and oil companies are right is the dumbest experiment in history by far." – Elon Musk, Founder, Tesla

Elon Musk, founder of Tesla, and Erich Pica, Friends of the Environment President, state that Lithium is a better solution than using non-renewable solutions such as fossil fuels. In fact, they say that lithium-ion batteries can be used as a sustainable solution, even if it is a finite resource. However, in the market of ideas, universities and companies are considering using other options to renewables as the process to refine lithium is incredibly straining on the environment. These companies include the major players in the market, such as Samsung, LG, Panasonic, and ATL. With the help of research studies from universities, such as the University of Seoul, University of Maryland, and University of California, companies can invest in more environmentally friendly, and longer lasting batteries.

Several companies and universities are investing in finding more environmentally friendly and longer lasting battery solutions to the lithium-ion battery. Graphene batteries, researched by Samsung and various institutes in the Republic of Korea, offer higher electrical conductivity than lithium-ion batteries and can charge a cycle without degrading. Solid-State batteries (SSB) have been promoted as the next stop gap in battery technology. In fact, Bill Gates and Volkswagen are working with QuantumScape to release the technology in vehicles (Ruffo, 2020). The only difference, however, between a lithium-ion battery and an SSB, is that the electrolyte is replaced with a solid one, hence the 'solid' in solid state battery. Lithium is still a core ingredient in that battery type. SSBs also cost eight times more money to manufacture compared to a normal lithium-ion battery (Mulfati, 2021). Therefore, I will not be arguing for this battery technology, as we have already discussed the impacts of lithium mining on the environment. My research aims to make a better understanding of the environmental impacts of lithium batteries. Hopefully, I will inform the reader on more environmentally friendly solutions

to the issues plaguing the renewable market. Furthermore, my aim is to inform the user on different battery technologies that will create a cleaner environment. Lithium is an easily manufactured battery material, however, as our technology develops researchers can find more sustainable battery solutions to solve the environmental waste problem. Lithium has been rapidly developing over the course of the past decade, where the goal is to reduce environmental pollution. In an effort to keep the renewable future, companies have taken significant steps forward to simplify the transition with fossil fuel powered technologies, and renewable energies.

Geels' Multi-level Perspective and the Analysis of Lithium-Based Products

Geels' Multi-level Perspective allows us to investigate a sociotechnical system with a wider lens than other typical forms of analysis. As demand for battery technology starts to grow, the lithium-ion battery seems like a stopgap towards a brighter, more renewable future. Not only are there many factors playing into the research, development, and manufacturing of the renewable market, but also the rapidly changing environment is also creating a need for different hierarchical levels to respond appropriately to the landscape. Therefore, for this analysis, it will be best to use a broader framework that will categorize each level systematically. I will be using Geels' multi-level perspective, a theoretical and methodological approach to social theory, in this analysis.

Summary of Multi-level Perspective

Originally developed by Arie Rip and Rene Kemp, Frank Geels and Johan Schot further refined the analysis. Geels' multi-level perspective is a means for explaining how technological transitions come about through interaction processes within and among the three analytical

levels. As shown in the figure below, the analytical levels are composed of niches, regimes, and landscapes. For the purposes of this paper, I will explain each level in detail and its application to lithium.

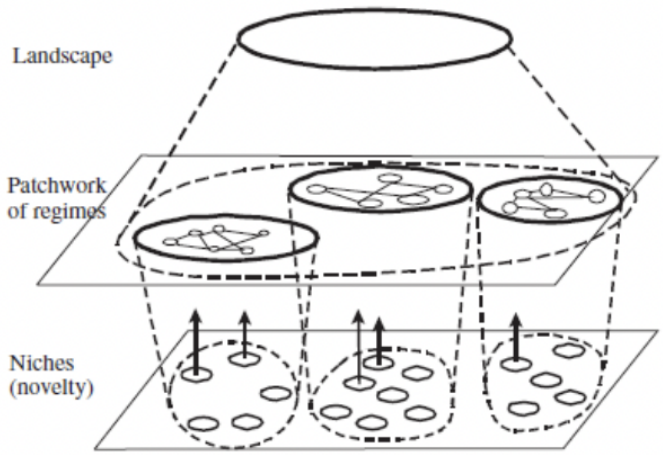

Figure 4: Multiple Levels as a Nested Hierarchy
Source: (Geels, 2002, p.1261)

Explaining the Niche level

Niches are spaces where small networks of actors develop radical innovations on the margins of the regime (Geels and Schot, 2007). The niches provide opportunities for society to learn about: the functionality of alternative designs, user preferences, appropriate public policies and so on (Genus et al., 2008, pg. 1439). As time progresses, research and learning through experience will allow the product to be developed over a significant portion of time. However, over-emphasizing the nice role can cause the product to enter the mainstream and potentially may or may not break through in the marketplace. The changes in the landscape can determine whether the product thrives as well. This stage is very fragile to the environment surrounding it. To transition from the niche to the regime, technological breakthroughs typically occur. However, if tensions emerge between parts of the regime, the niche innovations can fill in the

gaps. Steward (2012, pg. 6) emphasized the point, “Niches provide a vast array of possible innovations and regimes act as the selection environment.”

Explaining the Regime Level

The regime is "a coherent configuration of technological, institutional, economic, social, cognitive and physical elements and actors with individual goals, beliefs or values" (Holtz, Brugnach and Pahl-Wostl 2008, p. 629). In a more tangible example, this level would emphasize corporate culture, set economic and social regulations from the government or other authority figures, and provide a coherent showcasing of the technology present. Regimes can slowly change over time. However, to change regimes there needs to be an outside intervention from, typically, the landscape for a transition to occur (Geels, 2014). If there is no outside intervention and the regime is seen as solving problems, it is very hard for a transition to take place. In fact, Geels states that, “Regimes actively resist change.”

Explaining the Landscape Level

The top-most level of Geels’ multi-level perspective is the landscape. The landscape represents a macro level of the sociotechnical system. The system can include factors such as oil prices, economic growth, wars, cultural norms, environmental problems, and immigration. The landscape plays a significant role in the system, as the niche and the regime levels rely on the landscape to drag up technologies. Landscapes are slow to change, but they can produce massive changes on all levels. For example, the recent pandemic in the global economy has shifted our landscape completely. Citizens wearing masks has become a cultural normality, economic growth has dropped, oil prices drastically increased and many others.

System Level View

In figure 5, Geels provides an in-depth systematic look into the multi-level perspective. In this specific example, Geels referenced the pathway from horse drawn carriages to automobiles. Initially, the landscape puts pressure on the regime, which in turn allows the niche to start looking for novelties. For example, pressure from global climate change triggered a response from the U.S. government to invest in lithium batteries. In the technological niche

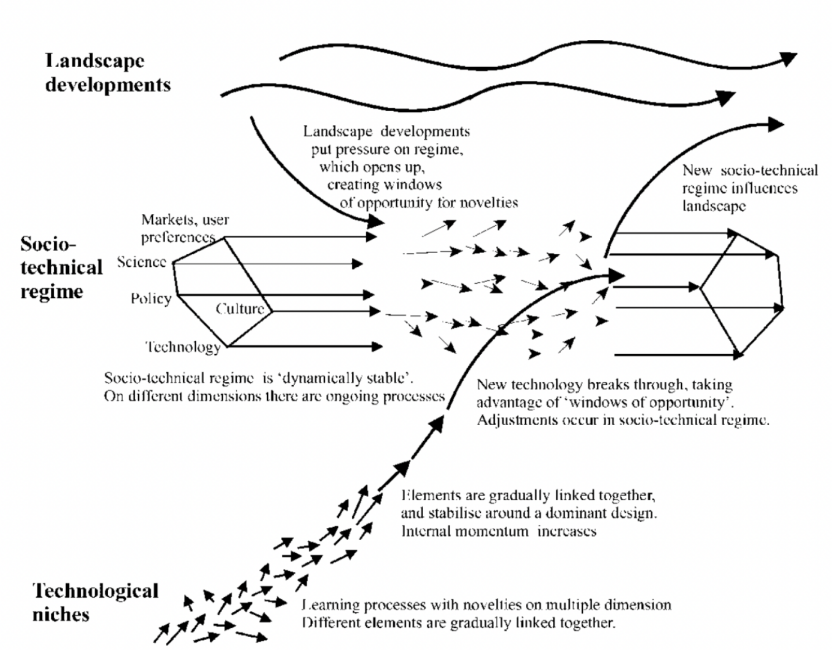

Figure 5: A dynamic multi-level perspective on transitions. Source: Geels, F.W. 2005. The Dynamics of Transitions in Socio-Technical Systems: A Multi-Level Analysis of the Transition Pathway from Horse-Drawn Carriages to Automobiles (1860–1930)

section, there are a variety of innovations, where learning processes with novelties are gradually linked together to produce a dominant design. Once the dominant design is established, the new technology breaks through, taking advantage of the window of opportunity. Lastly, the new socio-technical system influences the landscape, and the cycle repeats itself with new technologies and landscapes.

Geels' and its application on the Lithium battery sociotechnical system

In the case with lithium, consumers demanded more technologies with battery technology capability. As a result, they also demanded more lithium to be mined. In turn, a feedback loop was created in which the demand of lithium would increase exponentially. However, as mentioned previously, lithium battery technology is a temporary stopgap to allow time for more environmentally friendly solutions to surpass lithium battery technology. Each not technological milestone takes a significant amount of time and research to develop. It is important to identify critical players in the industry and analyze lithium battery technology at multiple levels in the ecosystem. The following results will discuss the actors in the network and how they interact with one another.

Actors in the Lithium Battery Ecosystem

As with any system, it is important to understand how the system interacts with one another. In the case with lithium technology, there are several actors playing a part of the lithium-based socio-technical system. Each actor in the group plays a role in one or more levels to ensure the functionality of a progressive system. For example, the government and regulators would support the niche's every growing number of technologies. Table 1 gives a simplified breakdown of the proceeding steps in this section. On the left side of the table, there are identified actors in the network. On the top side, there are different levels in the hierarchical chain. Governments and regulators will encompass federal, state, and local law makers. External factors such as oil prices, economic growth, and environmental problems will cause the landscape level to change. Therefore, the regime and niche level will need to respond

accordingly. Industry stakeholders and lobbyists, such as the battery manufacturers, will need to respond to the ever-growing displeasure of the global climate crisis. Industry stake holders and lobbyists include manufacturers invested in the battery technology ecosystem. Popular electronics manufacturers, such as Apple and Tesla, have been believed by the public to have a positive impact on our earth with their zero carbon emission policies. Tesla vehicles, as well as Apple iPhones, are using lithium-ion batteries for their power source. Researchers, such as those in Japan's has a National institute for Materials Science (NIMS), will work with industry stakeholders such as battery manufacturers at Samsung and Panasonic to create better battery technology. Lastly, the environmentalists, such as Erich Pica, the Friends of the Environment President, will create more awareness about environmental issues.

Role	Landscape	Regime Level	Niche Level
Government and Regulators	Citizens create pressure on regulators to enact environmentally friendly.	Brings forth regulations to keep the environment healthy	Funding the Scientific Researchers
Industry stakeholders and lobbyists	Reacts to changes in the environment and responds accordingly	Propel new technologies into the consumer realm to comply with regulations	Invest in the niche technologies by the Scientific Researchers
Scientific Researchers	The pressure from citizens and government allows researchers to get funding and develop new technologies	Advise regulators and industry stakeholders on better technologies	Help develop new environmentally friendly battery tech
Environmental Advocates	Identifies issues with the climate	Advise regulators and industry stakeholders on environmental changes	Create more awareness about environmental issues

Table 1: Simplified Breakdown of the Lithium Network

What each level does with respect to lithium

The niche level contains the scientific researchers developing new and more environmentally friendly battery technologies. The niche will respond to the changes in the landscape and start researching better way of manufacturing and creating battery technology. The regime, on the other hand, uses the issues with the landscape to fund the niche level and help propel new technologies into consumer hands. Using the help of the regime, niche levels are able to explore battery technologies besides lithium ion as well as identify improvements to lithium-ion batteries. Table 1 brings a very clear view of how each level and actor interacts with each other.

Interaction between levels

As mentioned previously, the largest actor in the landscape level is climate change. Environmental problems have been allowing the niche region to react with newer technologies and prevent a worsening climate. In fact, Japan' National institute for Materials Science research next-generation battery technologies, which cover battery cell assembly to material analysis. Samsung, ATL, LG, and Panasonic are also investing in redesigning the lithium-ion battery in which they remove cobalt from their batteries to comply with more environmentally friendly regulations. This further provides insight on new lithium battery technology actively being in the niche layer, while previous iterations of the technology are in the regime.

As the technology in the niche level begins to mature, the regime level will help enact laws to prevent the growth of environmental unfriendly technologies. A clear example would be the gas-powered vehicle. The law makers and the industry stakeholders in lithium will promote

more environmentally friendly technologies brought by the niche level. On the political side of the spectrum, the United States Government announced that half of all vehicles sold in 2030 must be zero-emissions, as well as announcing a $900 million plan to build a network of EV chargers in 35 states. California, for example, has preemptively taken steps to ban the sales of new gas-powered vehicles by 2035 (Newburger, 2022). With the ban of gas-powered vehicles, in the niche level, lithium batteries can be more heavily developed and iterated upon in major universities and companies. Both the government and companies are enacting laws to ensure that climate change is not an issue.

In fact, the niche allows the regime to grow in a more substantial way. Tesla, for example, is leading the market in electric vehicles. They have sold over 3 million vehicles due to the increase of regime level actions and the emerging technologies from the niche (Brown, 2022). Samsung and Panasonic, two major battery manufacturers, have worked with Tesla to remove cobalt from their batteries as part of their climate pledge, before a new technology comes to pass. This will help reduce the waste generated from mining the cobalt.

Conclusion

Lithium-ion batteries have, for a larger part of two decades, played a significant role in the development of portables and renewable energy. The results of Geels' multi-level perspective of the lithium-ion battery has shown that there are many different factors that are actively trying to alleviate the damage to the environment, caused by lithium batteries, by investing in newer more environmentally friendly technologies. Manufacturers of lithium batteries, consumers of lithium technology, and the countries who mine the mineral play a huge role in how the social system reacts with each other. I also discussed the fact that consumers demanding better batteries

have put more pressure on manufacturers to create denser lithium-ion batteries, harming the environment to a greater extent. Unfortunately, it is impossible to empirically state how much of that effect is due to the consumer, but we cannot deny the impacts. Therefore, I must acknowledge that Geels' multi-level perspective is the best method for a study involving multiple players at multiple levels.

In every level examined, there has been a major push towards renewable energy. The landscape has directly affected the niche and regime levels, the battery technology has been in development for several decades. While newer lithium battery technology is still in the developmental phase as well as being in the mainstream, we can see there are certain limitations to the technology. As the niche level continues to research more environmentally friendly ways to use battery technologies, the regime level actively working with the niche to bring forth solutions. In particular, lithium without cobalt promises reduced waste. Lithium has been proven to be a great stopgap while alternatives to lithium batteries are being developed. Due to the landscape putting pressure on the regime and the niche to make the necessary changes to accommodate the landscape, I would expect that alternatives to lithium-ion batteries will start emerging within the next couple of years as a more environmentally friendly option.

References

Azevedo, M., Baczyńska, M., Hoffman, K., & Krauze, A. (2022, April 12). *How lithium mining is fueling the EV revolution | McKinsey*. https://www.mckinsey.com/industries/metals-and-mining/our-insights/lithium-mining-how-new-production-technologies-could-fuel-the-global-ev-revolution

Batteries—Why Lithium-ion? (n.d.). Apple. Retrieved October 3, 2022, from https://www.apple.com/batteries/why-lithium-ion/ [Apple website]

Brown, K. (2022, November 4). *How many cars has Tesla sold? | U.S. news*. How Many Cars Has Tesla Sold? Retrieved December 14, 2022, from https://cars.usnews.com/cars-trucks/features/how-many-cars-has-tesla-sold

Campbell, M. (2022, February 1). *South America's "lithium fields" reveal the dark side of electric cars*. Euronews. https://www.euronews.com/green/2022/02/01/south-america-s-lithium-fields-reveal-the-dark-side-of-our-electric-future

C. L., & Print. (2017, July 23). *Op-Ed: Were the raw materials in your iPhone mined by children in inhumane conditions?* Los Angeles Times. https://www.latimes.com/opinion/op-ed/la-oe-merchant-iphone-supplychain-20170723-story.html

Hiden. (2021, February 25). A brief history of lithium-ion battery development. *Hiden Analytical*. https://www.hidenanalytical.com/blog/lithium-ion-battery-development/

Ex-tesla engineer says solid-state batteries are a "false hope." (n.d.). InsideEVs. Retrieved October 17, 2022, from https://insideevs.com/news/443450/ex-tesla-solid-state-batteries-false-hope/

Home. (n.d.). Friends of the Earth Europe. Retrieved October 3, 2022, from https://friendsoftheearth.eu/

Holtz, G., Brugnach, M., & Pahl-Wostl, C. (2008). Specifying "regime"—A framework for defining and describing regimes in transition research. *Technological Forecasting and Social Change*, *75*(5), 623–643. https://doi.org/10.1016/j.techfore.2007.02.010

Ilgin, M. A., & Gupta, S. M. (2010). Environmentally conscious manufacturing and product recovery (Ecmpro): A review of the state of the art. *Journal of Environmental Management*, *91*(3), 563–591. https://doi.org/10.1016/j.jenvman.2009.09.037

Lithium extraction environmental impact · eco jungle. (2021, December 31). Eco Jungle. https://ecojungle.net/post/lithium-extraction-environmental-impact/

Long range forecast: Building the EV battery of the future. (2021, September 28). *Dcbel*. https://www.dcbel.energy/blog/2021/09/28/long-range-forecast-building-the-ev-battery-of-the-future/

McKie, R., & Editor, R. M. S. (2021, January 3). Child labour, toxic leaks: The price we could pay for a greener future. *The Observer*. https://www.theguardian.com/environment/2021/jan/03/child-labour-toxic-leaks-the-price-we-could-pay-for-a-greener-future

Geels, F. W. (2006). Multi-level perspective on system innovation: Relevance for industrial transformation. In X. Olsthoorn & A. J. Wieczorek (Eds.), *Understanding Industrial Transformation* (Vol. 44, pp. 163–186). Kluwer Academic Publishers. https://doi.org/10.1007/1-4020-4418-6_9

Genus, A., & Coles, A.-M. (2008). Rethinking the multi-level perspective of technological transitions. *Research Policy*, *37*(9), 1436–1445. https://doi.org/10.1016/j.respol.2008.05.006

Geels, F. W. (2014). Regime resistance against low-carbon transitions: Introducing politics and power into the multi-level perspective. *Theory, Culture & Society*, *31*(5), 21–40. https://doi.org/10.1177/0263276414531627

Petrova, M. (n.d.). *Here's why battery manufacturers like Samsung and Panasonic and car makers like Tesla are embracing cobalt-free batteries*. CNBC. Retrieved October 3, 2022, from https://www.cnbc.com/2021/11/17/samsung-panasonic-and-tesla-embracing-cobalt-free-batteries-.html

Product life cycle assessment shows true environmental impact. (n.d.). Retrieved October 3, 2022, from https://www.fmamfg.org/blog/product-lifecycle-assessment-shows-true-environmental-impact

Nations, United. (n.d.). *Renewable energy – powering a safer future*. United Nations. Retrieved October 27, 2022, from https://www.un.org/en/climatechange/raising-ambition/renewable-energy

Newburger, E. (2022) *California bans the sale of new gas-powered card by 2035.* CNBC. Retrieved December 14, 2022, from https://www.cnbc.com/2022/08/25/california-bans-the-sale-of-new-gas-powered-cars-by-2035.html

Rayner, S., Malone, E. L., & Pacific Northwest National Laboratory (Eds.).(327-399) (1998). *Human choice and climate change. 2: Resources and technology*. Batelle Pr.

Steward, T. (2012, November). *A Brief Introduction to the Multi-Level Perspective (MLP)*. https://projects.exeter.ac.uk/igov/wp-content/uploads/2012/12/DOWNLOAD-Multi-Level-Perspectives.pdf

United States Congress Senate Committee on Environment and Public Works, & United States Congress Senate (2019). Electric Battery Production and Waste: Opportunities and Challenges : Hearing Before the Committee on Environment and Public Works, United States Senate, One Hundred Sixteenth Congress, First Session, July 17, 2019. Washington: U.S. Government Publishing Office. [Congress 2019 hearing document]

US Department of Labor takes action to reduce miners' exposure to silica dust as work continues on an improved health standard | U.S. Department of Labor. (n.d.). Retrieved October 3, 2022, from https://www.dol.gov/newsroom/releases/msha/msha20220608

Xanders, M. (n.d.). *The earthly impacts of extracting lithium*. Tallahassee Community College. https://www.tcc.fl.edu/media/divisions/academic-affairs/academic-enrichment/urc/poster-abstracts/Xanders_Madison_Poster_URS.pdf