A Road to Zero Emissions in Long Range Freight Transport

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by

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ABSTRACT

Climate change is a major concern around the globe, and the freight industry is a major polluter. The goal of the project was to create a roadmap towards zero-emissions in the Swiss long-haul freight transport industry. Working with the sponsor company, Designwerk, the roadmap was formulated with three main objectives: researching the best technology, determining the concerns of industry stakeholders, and creating a plan for implementation. Solutions were determined with battery-powered trucks in mind. The final roadmap shows a plan for phasing zero-emission technology into Switzerland. It was recommended that stakeholders should conduct more research into improving batteries for vehicles and that further research projects could be done on improving specific infrastructure.

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EXECUTIVE SUMMARY

The goal of the project was to create a roadmap towards zero-emissions in the Swiss long-haul freight transport industry. Due to climate change and global warming, environmental disasters such as extreme weather events and rising sea levels have been a topic of concern for people everywhere. Many countries have stepped up to propose goals to reduce their emissions from fossil fuels by certain years, with them agreeing that there should be a great reduction in emissions by the year 2050. With the prevalence of vehicles that use fossil fuels and combustion engines in the world, various companies are exploring ways to reduce harmful emissions by developing electric vehicles that produce no emissions by driving. Personal electric cars can be seen in many countries around the world today. Since freight transport is such a major piece in the economy of many countries, companies, such as our sponsor company Designwerk, have explored the possibility of fully electric long-haul trucks. Working with Designwerk, three main goals for a successful roadmap were developed:

1. The understanding of the concerns and needs of the stakeholders regarding the implementation of these transportation systems.
2. The implementation of the low- or zero-emission technology that is the best fit for Switzerland.
3. The assessment of the current and future political and industrial infrastructure needed for the implementation of the low- or zero-emission technologies.

These three goals became the three objectives for the project, and methods were chosen to satisfy the objectives in order to complete the project.

Table ES1: *The table of objectives and methods. The objectives are on the left side, and the method used to complete it is on the right side.*

Objective	Method Used
Objective 1: Assessment of the needs of industry stakeholders	Interviews conducted with stakeholders in the industry, such as fleet owners and truck manufacturers, to discover concerns about switching to zero-emission technology.
Objective 2: Determine the viability of zero-emission implementation in Switzerland	Literature review of peer-reviewed sources to determine what technology (battery electric, hydrogen fuel cell, or hybrid) would be best for implementation into Switzerland.
Objective 3: The roadmap towards zero-emissions	A combination of the first two objectives to create a priority list of stakeholder concerns and develop a strategy to address the concerns while implementing zero-emission trucks into Switzerland.

As seen above, interviews are conducted with industry stakeholders to understand their concerns about switching to any type of zero-emission technology. The interviews were coded and sorted into a list of priorities based on what the interviewee thought was the importance of the concern and how many times it was discussed in the interviews. The literature review focused on three different types of zero-emission technology already on the market: battery-powered, fuel cells that produce electricity from hydrogen fuel, and a hybrid combination of battery-powered electric and diesel-fueled combustion. The technologies were sorted into categories and pros and cons were developed for each to determine what would be the best for Switzerland. These two methods were combined into the roadmap, which detailed the best determined way to implement the technology into Switzerland. Below is an example of how the roadmap was determined.

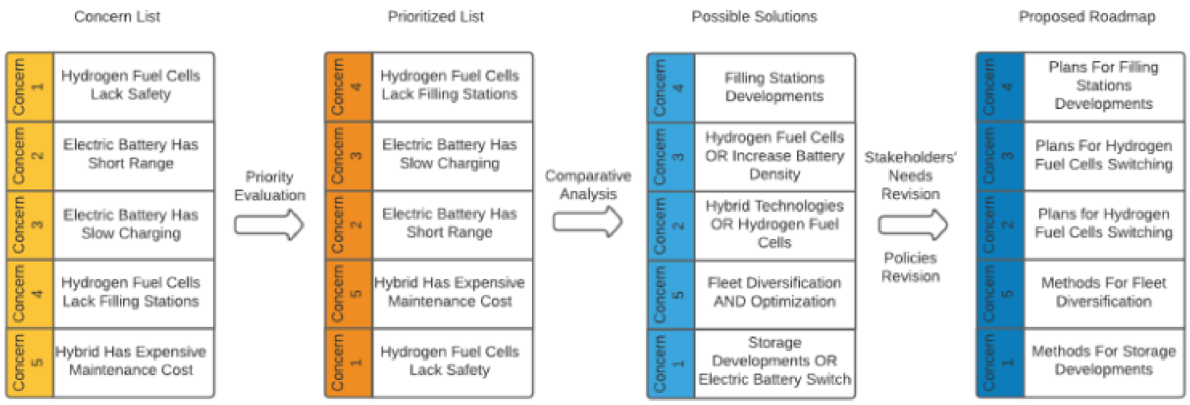

Figure ES1: *Chart of example roadmap formulation. The process of going from a list of concerns to a finalized roadmap is demonstrated.*

From our interviews we derived the following list of concerns and ordered them based on the focus and severity:

Table ES2: *Table of priorities. The level of priority is shown on the left, and the concerns determined to fit in that category are on the right.*

Priority Level	Concerns
High Priority	Range and charging times
Medium Priority	Price and infrastructure
Low Priority	Spent batteries

We found that overall, the biggest concern from fleet owners and drivers was the range and charging times of the electric freight transport vehicles. Currently the standard range of class 8 electric trucks, or trucks that weigh 16 tons or more, is around 250 miles and requires a charging time of two to three hours with the fastest chargers available in the market. These numbers are lacking when compared to those of diesel trucks, which can run upwards of 500 miles and have fast fueling time. While this may not be an issue for shorter travel routes, it quickly adds up for any travel between cities and outside of the country. Based on these concerns, as well as and the mandate that Swiss drivers must take a 45-minute break during the day, we concluded that for zero-emission vehicles to hold a firm stance in the market, they must aim for a charging time of around 45 minutes.

For our medium priority levels of concern, we found that the current price of zero-emission vehicles and the infrastructure available for the technologies dissuades stakeholders from making the switch. The initial purchase price of a battery-operated truck is much more expensive than diesel trucks, sometimes three or four times more. In addition to the starting costs, the total cost of operation (TCO) for the vehicles themselves was reported to be hard to calculate for three main reasons: electricity is cheaper than gas, it takes longer to refuel, and more frequent fuel stops are necessary. Furthermore, electricity prices may fluctuate during the day, since there are times of high and low production from varying renewable sources, such as solar power. The variability and unknown nature of the TCO calculations dissuades fleet owners from investing in the technology. We also found that the concerns over the lack of infrastructure in place for zero-emission technologies have limited the expansion of the technologies. While there are electric charging stations around Switzerland, they are almost exclusively for personal vehicles and their locations are spread out throughout the country. This creates "range anxiety", or the concern over the possibility of running out of charge while in the middle of a route due to lack of charging stations. Electric trucks can charge at storing facilities such as warehouses, but the installation of these chargers adds to the TCO for the trucks.

Throughout our interviews, there was a concern over the waste and disposal of batteries from trucks after their lifetime has ended. The lifetime of the batteries is currently shorter than the trucks, so truck manufacturers find themselves in a position where a truck could use up multiple sets of batteries through its life and have nowhere to dispose of them. The concern is further complicated by the fact that some types of batteries require rare earth materials that are difficult to extract. One alternative to wasting batteries is to reuse materials, but this is currently not as cost-effective as mining new materials. This causes a buildup of spent batteries, which has a negative effect on the environment. Finding a clean and cost-effective way of disposing of batteries is important for the future of this technology.

To fulfill the second objective, we created a literature review of multiple scientific articles and sources describing the properties, limitations, and advantages of implementing each type of zero-emission technology. The three types of technology that were considered are: battery-powered, hydrogen-fuel-cell-powered, and hybrid diesel and electric. From this, we concluded that the best possible option for the implementation of zero-emission technology in Switzerland would be the usage of battery-powered trucks. We determined that although battery-powered trucks have the shortest range and longest charging time out of all the technologies, they also have the best potential for growth. With the popularity of electric vehicles and the widespread usage of electric trains and tramways, the Swiss market already has a vast infrastructure in place for the generation and distribution of energy. With the increase in demand, this infrastructure can be more easily expanded, unlike hydrogen, where brand-new infrastructure for the supply and distribution of hydrogen would need to be built. Furthermore, battery-powered trucks are the most researched technology. Some are already on the market and continuously being researched, while research has barely scratched the surface of fuel cell and hybrid trucks. We also concluded that it is not as economically feasible to start production on hybrid trucks, since those types of vehicles could quickly become obsolete as policies are implemented to limit emissions from vehicles.

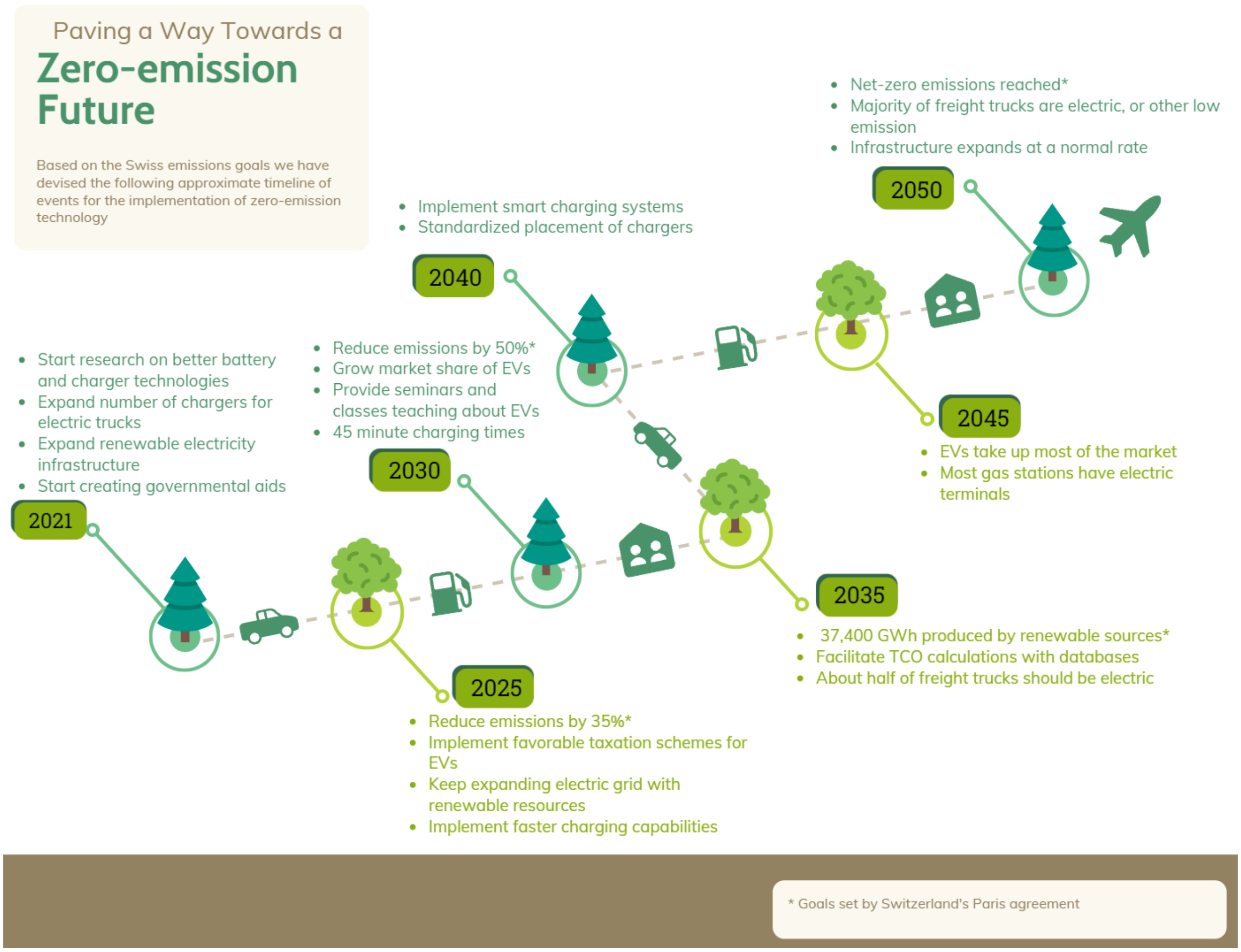

Figure ES2: *The proposed timeline for implementation of the roadmap. The dates on the timeline follow Switzerland's goals set by the Paris Agreement. The goals at each date were set by our construction of the roadmap. Made in Venngage.*

Finally, our roadmap of implementation of this technology based on the major concerns of the stakeholders and limitations of the infrastructure is as follows:

1. The first action taken should be the implementation of government tax incentives and grants for electricity suppliers, truck manufacturers, and independent companies with the purpose of expanding the research and development of zero-emission technologies.
2. Companies would then start to research major concerns of battery-powered trucks, and would focus on expanding the range of battery-powered trucks and decreasing charging time below the 45-minute threshold.
3. Once faster chargers are developed, they can be placed at rest stops experiencing high traffic volume to mitigate buildup of trucks waiting to charge.
4. With more chargers and more trucks, the electrical grid would have to be expanded to meet the demand. Optimally, this demand would be met by renewable sources, like hydropower.
5. The next step is to optimize the systems in place. This would be done using grid assisting technologies such as the vehicle to grid system, or V2G. This uses the batteries of electric vehicles as part of the electrical grid.
6. Simultaneous to the growth of infrastructure comes the standardization of the systems, like standardizing the distance between charging stations and optimizing the placement of faster chargers.
7. Once the system is standardized, the transition to electric vehicles can be facilitated. This can be done by providing workshops and seminars that teach about the benefits of electric trucks. Workshops to provide the certification for mechanics and operators to be able to repair the trucks can also be provided.

8. Databases can be created to easily facilitate the total cost of operation calculations to ease the transition into an all-electric fleet for the remaining truck owners.

To conclude the report, our findings are as follows:

- The industry stakeholders have a wide variety of concerns about the switch to electric vehicles, with the determined highest priority being the charging times of the vehicles.
- Based on the current technology, research, and infrastructure in Switzerland, battery-powered electric vehicles are currently the best technology to be pursued in an effort reach net-zero emissions.
- The best way to kickstart fleet owners investing in zero-emission technology is to have government support in the form of tax incentives and research funding.
- Improvements to the vehicles are the top priority, but efforts to improve the electric infrastructure are also necessary.
- Providing information to fleet owners about the total cost of ownership of an electric truck will allow more people to confidently switch to zero-emission technology.

Some recommendations for stakeholders include working with the Swiss government to help fund future improvements and research into zero-emission technology, as better technology will convince more people to make the switch from diesel. This also includes lobbying for improved policies that support the switch to electric vehicles. Some sponsor recommendations include spending time to understand the total cost of ownership for their vehicles, as knowing how much it will cost and how long it would take to return the investment is important for potential buyers. Recommendations for future projects include researching how to improve the electric infrastructure in Switzerland and how to make total cost of ownership information more available to potential buyers.

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EV – Electric Vehicles

BEV - Battery Electric Vehicles

PHEV - Plug-in Hybrid Electric Vehicles

FCEV - Fuel Cell Electric Vehicles (Hydrogen fuel)

ICEV- Internal Combustion Engine Vehicle

CO_2 - Carbon Dioxide

V2G – Vehicle-to-grid

NDCs - Switzerland's Nationally Determined Contribution

GWh – Gigawatt-hour

kWh – kilowatt-hour

1. INTRODUCTION

The industrial revolution marked the beginning of a huge leap forward in terms of technological innovation that has only increased to this current day, and with it came many improvements across all aspects of society. However, with these major improvements came one great side effect: global warming. Many of the technologies developed that are still used to this day are powered by the burning of fossil fuels, a process that releases high amounts of carbon into the atmosphere creating an environment akin to a greenhouse. This greenhouse effect traps heat from the sun in the atmosphere that would otherwise dissipate into space. This has caused a slow but steady increase in the temperature of Earth, which has been linked to many environmental problems such as rising sea levels, more frequent natural disasters, and famine. Therefore, one of the largest problems facing society today is attempting to switch to alternative fuel sources to mitigate these effects without causing a standstill in the global economy. These problems can only be solved by changing the infrastructures created back in the industrial revolution to one that is based around renewable sources of energy and is more mindful about the environment.

One of these infrastructures is the roadways used to transport large quantities of goods across the land via heavy-duty trucks. These trucks primarily run on a diesel engine, which produces a significant amount of carbon emissions. Any vehicle with an internal combustion engine, like a diesel truck, requires fuel, oxygen, and heat to produce the power needed to run. The byproducts of that reaction are carbon dioxide and nitrous oxides, two chemicals which are harmful to the environment and are a major cause of global warming. Currently, alternative fuel sources cannot compete with the range, price, and availability of traditional diesel engines. However, as technology advances and begins to compete with diesel-powered trucks, many are looking to implement alternative fuel sources into long-distance road transportation. Such an implementation would require a large investment in upgrading infrastructure as well as an initiative for the manufacturers and buyers of these trucks to switch to greener alternatives.

As one of the main methods of transporting goods across land, diesel-powered trucks account for a significant amount of the carbon dioxide emissions of the world. Thus, creating a demand for a greener competitive alternative that could make a significant difference in the global effort against emissions. However, for this a solution more than just greener vehicles are needed. A worldwide upgrade in the infrastructure and support of these vehicles would be necessary as well. Since this is a massive undertaking, many regions are looking to implement a new system on a smaller scale. The first regions to attempt this are a model for future areas and provide valuable information to those attempting a similar project. Even for smaller areas, this is still an extensive project that requires a lot of research, innovation, and planning before a financial investment can be made. While this will take time, it is a step in the right direction towards fewer emissions from trucks, the transportation industry, and the world. Therefore, to assist us in this great endeavor we had our sponsor, Designwerk, a Swiss based startup company specializing in the development of electric trucks and batteries. Their mission is to reduce carbon emissions in Swiss road transportation, and to change the people's opinion on electric trucks and the viability of future alternative fuel technologies.

The work done by companies such as Designwerk have assisted in creating a global shift in opinions towards the problem of global warming, with many nations having promised to implement systems and regulations meant to limit the effects of pollutants and sources of greenhouse gases on the environment. Policies such as The Paris Agreement, signed by 196 different countries, ratified, and regulated by the United Nations, promise to limit the rising temperature to 1.5 degrees Celsius below pre-industrial standards. Switzerland, being one of the countries that signed the agreement, promised to reduce the reliance of its economy on the burning of fossil fuels and the usage of nuclear power replacing them with more renewable sources of energy. Based on this, a demand for the creation and implementation of greenhouse gas-reducing technologies was born, which is where this project came in.

The goal of this project was to develop a roadmap towards the introduction of low- or zero-emission technology into the Swiss freight transportation industry. This roadmap was created to address the rising concern over greenhouse gas emissions and air pollution caused by vehicles as well as to combat its underlying effects on the worldwide climate change problem. Through a collaborative effort with Designwerk we created a roadmap based on three objectives:

1. The understanding of the concerns and needs of the stakeholders regarding the implementation of these transportation systems.
2. The implementation of the low- or zero-emission technology that is the best fit for Switzerland.
3. The assessment of the current and future political and industrial infrastructure needed for the implementation of the low- or zero-emission technologies.

Through this roadmap we hope to create the groundwork that would be built upon for the implementation of these technologies in the near future to create a greener world.

2. BACKGROUND

In this chapter, we will begin by discussing three possible low- or zero-emission fuel sources and their benefits and shortfalls. Next, we will talk about the attitude towards reducing emissions in Switzerland, both in general and within the trucking industry. We will finish with some of the possible concerns about this technology within the road transportation industry. Long-distance freight transportation refers to shipping goods overland via truck and is defined as a trip of 500-1000 km (300-600 miles) per day or around ten hours of driving time. Using typical diesel engines, these vehicles use a lot of fuel and are responsible for a large portion of carbon emissions. Implementing low- or zero-emission technology into this sector of the economy will significantly decrease carbon emissions and help combat climate change. When discussing infrastructure throughout this project, the term refers to structures that aid in road transportation. This includes gas stations and electric charging stations as well as the means to transport gas and electricity to these structures.

2.1. Exploring Alternative Energy Sources for Vehicles.

2.1.1. Potential Alternative Energy Sources

Different types of zero-emission technology on the market function in different ways and are important to consider when determining the best fuel source for a vehicle in production. Some zero-emission options are battery power, which runs on electricity, and fuel cell power, which runs on hydrogen. Hybrid technology, or a mixture of any of the current technologies used for vehicles, is another option for vehicles that might not eliminate emissions but could be a good intermediate step on the path to zero-emission transport.

2.1.2. Implementation of Battery Technology in Transport Vehicles

Battery technology is a zero-emission fuel source that has been widely developed and applied to many vehicles (Wen et al., 2020). This type of fuel source uses electricity instead of gasoline to operate, which means that the electric motors installed in the cars do not produce any tailpipe emissions, or emissions coming from the car itself (Liu et al., 2021).

Batteries are a prime model for zero-emission technology, but the current level of technology available on the market has drawbacks for its implementation. The range of the battery-powered vehicle is directly dependent on the energy density of the battery (Wen et al., 2020). It is estimated that the technology for the lithium-ion batteries will reach an energy density of 400 kWh/kg, or kilowatt-hours per kilogram, by 2025, according to the industry policy “Made in China 2025” (Wen et al., 2020). As the energy density increases, the safety factor of the battery will decrease, meaning the battery is less likely to be implemented into battery-powered vehicles due to safety concerns for the operators of the vehicle. Further research into battery technology is necessary to safely increase the energy density of the batteries for electric vehicle use. The driving range of the vehicle is a key factor to consider when producing electric vehicles, especially with long-range or heavy-duty trucks, because a lower driving range requires more frequent charging causing an increased demand of energy from the power-grid from circulation of electric vehicles.

Nevertheless, the drawbacks of the current technology have not deterred the progress towards the implementation of battery power in vehicles. With recent analyses of current battery technology showing that medium and heavy-duty trucks with new batteries can travel 300-500 miles on a charge with a recharging time that is less than 30 minutes (Liu et al., 2021). While this may not be sufficient for long-range freight transport, it is evidence that the technology is improving, and it will continue to improve as the knowledge about the field increases. One such improvement can be seen with the usage of electric vehicles as energy storage while connecting to the electric grid through a charger, a system known as Vehicle-to-grid (V2G). With this V2G system, any electric drive vehicle can be charged during times of low energy demand and discharged at times of high (Kempton et al., 2005), effectively serving as temporary storage for the grid. When combined with sources of renewable energy such as solar panels and wind power that have high and low times of production, this system could serve as a steppingstone for both the expansion of electric batteries and renewable energy sources.

2.1.3. Implementation of Hydrogen Fuel Cells in Transport Vehicles

Another prevalent type of zero-emission technology is hydrogen power. About 50 million metric tons of hydrogen are produced worldwide, and 68% of the hydrogen produced is made from steam reforming of natural gases (Ajanovic & Haas, 2019). Steam reformation is a process where the hydrogen source, which is often an organic compound like methanol or ethanol, reacts with steam and a catalyst under high temperatures and pressures to produce the hydrogen (*Hydrogen Production*, n.d.). Ethanol is a promising source of hydrogen because it is less toxic than methanol and can be produced from biomass like agricultural wastes, making it a renewable resource (Vaidya & Rodrigues, 2006). Hydrogen is employed by vehicles that use fuel cells. Fuel cells are devices that convert fuel directly into heat and electricity via continuous oxidation-reduction reactions in the system (Vaidya & Rodrigues, 2006). Since hydrogen is the fuel source in fuel cells used for vehicles, the only emission produced is water vapor, which makes it a zero-emission technology.

A majority of the fuel cell vehicles on the market use proton exchange membrane technology, which uses a solid polymer to facilitate proton movement between the anode and cathode of the fuel cell, which produces electricity (Ajanovic & Haas, 2019; Singla et al., 2021). This fuel cell is the most widely utilized technology due to the quick starting and stopping times for energy production, as well as its simplicity (Singla et al., 2021). The efficiency of this fuel cell is around 40% to 60%, and it operates around 50 to 100 °C (Singla et al., 2021). This type of fuel cell is expensive and accounts for approximately 50% of the costs of producing a fuel cell vehicle, although as the technology advances it is estimated that the price will decrease to slightly above 50 USD per kW by 2030 (Ajanovic & Haas, 2019).

Hydrogen fuel cells implemented into passenger vehicles have already shown some success. Many commercially available fuel cell vehicles contain both a battery for energy storage and a fuel cell system for energy production. The fuel cell is also lighter than a traditional battery-operated system, which could benefit the implementation of fuel cells into heavy-duty vehicles that have to follow a specific weight limit (Singla et al., 2021).

As hydrogen fuel cells become more popular for use in vehicles, issues with the demand for hydrogen and the safety of the technology will arise. The production of hydrogen is currently a greater cost than the production of fossil-based fuels like gasoline, making fossil fuels more economically viable unless policies are put into place that limits emissions and tax fossil fuels

(Singla et al., 2021). The technology for the production and storage of hydrogen is not at the same level as the production and storage of fossil fuels, so the number of hydrogen vehicles that can run and be produced is limited by the amount of hydrogen that is produced. A safety factor to consider about fuel cells is the combustion of hydrogen gas, as the fuel cells operate at high temperatures and a faulty system could lead to combustion (Singla et al., 2021). All fuel cell vehicles are outfitted with ventilation and leak detection technology, which improves the safety of the vehicles (*Safe Use of Hydrogen*, n.d.). Along with the economic viability of hydrogen production, the cost of the vehicle production must be considered as well, since the costly fuel cell implemented into the vehicle will raise the price above the vehicle's fuel by fossil fuels and internal combustion engines currently on the market.

2.1.4. Implementation of Hybrid Technology in Transport Vehicles

Hybrid vehicles are also utilized to reduce emissions while reducing the shortcomings of other low- or zero-emission fuel sources. A hybrid vehicle uses two different forms of power, the most common combination in road transportation is gas and battery. These two systems work together to reduce the carbon emissions of the vehicle while addressing some of the concerns over range and charging time. The three main types of hybrid vehicles are parallel hybrid, series hybrid, and plug-in hybrid.

Parallel hybrid vehicles use both a traditional engine and an electric motor that work side by side. The vehicle speed and charge of the batteries influence the operation mode of the vehicle. The vehicle can be powered completely by the battery when the speed is low enough or the battery has sufficient charge (Alegre et al., 2017). It can also be powered solely by the engine if the batteries are low on charge. They can also be used in tandem to provide power at the same time. The battery can be charged both by the engine when it is producing more power than the vehicle needs and by regenerative braking technologies (Alegre et al., 2017). Regenerative braking generates an extra charge to the battery during the braking process.

Series hybrid vehicles are completely powered by an electric engine but use a gas engine to charge the battery. These operate more like a standard all-electric vehicle, although the engine noise can be heard while the battery is charging (Ducusin et al., 2007).

Plug-in hybrid vehicles use batteries that can be charged using an outside power system, but also have a gas engine to extend the range of the vehicle (Samaie et al., 2020). They run like electric vehicles until the battery charge runs out and they switch to a traditional engine.

Each of these technologies provides advantages and disadvantages when implemented into vehicles and will require a significant financial investment. Therefore, a comprehensive analysis of each is essential in finding a solution to the issue of climate change within road transportation. When considering which fuel source or combination of fuel sources to implement, the infrastructure required, and geographical features are all considered.

2.2. Assessing the Stakeholders in Switzerland's Freight System.

2.2.1. The Current State of Greenhouse Reduction Policies in Switzerland

Switzerland's current political standing about climate change prevention is quite favorable towards the introduction of policies for the reduction of greenhouse gasses. The implementation of one of the most crucial policies in current Swiss history was the Paris Agreement introduced by the United Nations that legally binds all the countries that have signed it to implement "economic and social transformation" to reduce greenhouse gas emissions as to limit the effects of global warming to 1.5 degrees Celsius when compared to preindustrial levels (United Nations, 2021a). With the signing of the Paris Agreement, Switzerland pledged to carry out a plan to reduce its net greenhouse gas emissions by 35 percent of what it was in 1990 by the year 2025 and reduce it by 50 percent by the year 2030, and by the year 2050 to have a system of zero-emissions implemented throughout the entire country (United Nations Framework Convention on Climate Change, 2021b). This policy, known as Switzerland's Nationally Determined Contribution (NDCs), is a contract that is legally bound to be reported transparently starting in 2024 to the United Nations climate change committee.

2.2.2. Swiss Plan for Emission Reduction

The first step in the implementation of Switzerland's NDCs was the creation of the Energy Strategy 2050, or ES2050, a policy that is targeted towards the implementation of renewable energies in the Swiss market via the replacement of nuclear power and fossil fuel generation with renewable sources of energy. The goal of this plan is to reach certain milestones of energy production in the span from the year 2017 to 2050. These goals are the generation of 4,400 GWh by 2020, 11,400 GWh by 2035, 37,400 GWh by 2035 using clean renewable energy sources (Swiss Federal Office of Energy, 2020). These goals are planned to be accomplished by increasing the grid capacity for electricity as to allow for the increase in the renewable generation and to not overload the current system, increasing taxation proceeds on CO_2 generation as to disincentivize its usage, and slowly ruling out nuclear power plants in Switzerland (International Energy Agency, 2021). With fossil fuels being the primary source of energy in Switzerland, the target was to reduce fossil fuel consumption by 20% and increase the share of clean renewable energies in the market by 50% from 2010-2020 (Discover Switzerland, 2021). Another part of this plan was to increase the regulation of emissions from both cars and utility vehicles. Car emissions had a regulated reduction to 95g of CO_2 per km and utility vehicles had a reduction to 147g CO_2 per km. With the implementation of policies such as this, one can conclude that the current climate of Switzerland is highly receptive to new and innovative solutions for global emission reduction.

2.2.3. Concerns over the Implementation of Zero-Emission Technologies

Even though the overall political standpoint of Switzerland is supportive of the implementation of zero-emission technologies, stakeholders in the freight industry could have concerns about the current state of the technology. According to de Bok (2020) “The stakeholders behind urban freight transportation are diverse and have very heterogeneous preferences” (p.2). The diversity in opinions comes from the wide range of groups that are affected by the implementation of these policies. Different groups, such as manufacturers, truck owners, drivers, and even consumers have different concerns, all of which must be addressed in any implementation plan.

2.2.3.1. Concerns of the Freight Owners over the Implementation of the Technology

One of the most prominent groups affected by these implementations is the freight-owning companies. Each freight company has its profits directly tied to the performance of its trucks, so they are likely to raise several economic concerns over the feasibility of these vehicles. One concern is the average purchasing price of electric freight vehicles compared to conventional freight transportation. In general, electric trucks have a higher initial cost than diesel trucks. With a study on the project FREVUE (Freight Electric Vehicles in Urban Europe), it was found that electric trucks weighing between 7.5 and 19 tons would cost four to five times more than their diesel counterpart (Quak, 2016). This cost increase is mainly because most large electric freight vehicles are tailor-made and produced in smaller batches. The initial price combined with a higher repair cost due to a lack of “efficient and competitive manufacturing services” (Quak, 2016, p.4) made these policies unattractive to some companies.

Alternatively, most of these concerns have been mitigated in multiple ways. For instance, the average cost of electric freight vehicles has decreased via the implementation of “purchase subsidies” meaning the help at the time of purchase from government funded programs and incentives to make these technologies competitively viable. Policies such as granting tax and fee exemptions, decreasing or eliminating parking fees, and enabling access to environmental zones for electric transport vehicles have also decreased the cost of owning these vehicles. This, combined with the growth of electric vehicle manufacturing in Switzerland over the past few years, has made the usage of electric vehicles more viable in the Swiss economy (Plananska, 2020). With the addition of new electric vehicles requiring less maintenance and have an overall lower operation cost (Quak, 2016) the possibilities for a business to have long-term profits from the implementation of new zero-emission technologies are more likely than ever before.

2.2.3.2. Concerns of the Operators over the Implementation of the Technology

The implementation of these changes also affects the infrastructure on a more individual level with the effects it may have on the operators of the electric freight vehicles. This includes both the logistic operators who manage the routing and deliveries as well as the drivers that must manage the vehicle itself. In a study done on the feasibility of zero-emission vehicles in multiple European countries, Quak et al (2016) describe how most logistic operators had positive responses to the management of electric freight transport vehicles. However, they had mixed responses to whether the implementation is viable as a replacement for conventional freight vehicles (Quak et al., 2016). Their concerns mostly extended from the lack of market and infrastructural support, with a specific critique for vehicles over 3.5 tons in weight. They were concerned about the economic consideration of operating, managing, and repairing these vehicles as well as the reliability of the vehicle overall. This shows that when considering a proposal, a good foundation of government incentives and subsidies must be implemented to ease the financial burden that would be brought by the implementation of these systems.

Vehicle drivers also have concerns. After running the electric freight vehicles, most drivers were happy with them due to some advantages that the electric vehicles had over the conventional ones (Hovi et al., 2020). Advantages such as the improved technological features of the vehicle, easier maneuvering, and facilitated parking in the city were expressed by drivers as being a benefit of the technology (Quak et al., 2016). When asked about their concerns over technology, most drivers mentioned range anxiety, which is anxiety about not being able to make it to a destination and being stranded without fuel. A case study done on battery-powered truck operators showed that long-range drivers experience range anxiety when driving the trucks due to the varied delivery environments and the need for the truck to make more frequent stops at stations that have electric charging. Other concerns included trusting recent technology and the ability to recruit new drivers due to the change in the driver's license caused by heavier trucks (Hovi et al., 2020). According to a study done in Poland on the reduction of harmful emissions in road networks, electric vehicles with an average range of 175km would require a charging station every 110km to ensure smooth traveling with a factor of safety of 5% (Bednarski et al., 2020). The advances in battery technology and charging technology would alleviate some concerns of the truck drivers experiencing range anxiety.

2.3. Conclusion

In the background, we discussed the current states of technology in reducing emissions, identified their advantages and disadvantages as well as their efficacy under Switzerland's standards. We also clarified the main stakeholders and their expectations and their concerns about a low- and zero-emissions freight transport system in Switzerland. These dilemmas and debates were confirmed and clarified in our effort to design a roadmap that could provide helpful insight into the transition from diesel to zero-emission in freight transport systems of Switzerland.

3. METHODS

The goal of this project was to develop a roadmap to introduce low- or zero-emission technology into Swiss long-range freight transportation that will assist the sponsor, Designwerk, in addressing the rising concerns of global warming and greenhouse gas emissions by vehicles. This goal was achieved through the completion of three main objectives:

- Interviews with stakeholders in the freight industry
- A literature review of zero-emission technology
- The creation of a roadmap for the implementation of low- or zero-emission technology that satisfies the stakeholder needs

Research and modeling methods were utilized in addition to interviews to complete these objectives.

3.1. Objective 1: Assessment of the Needs of the Stakeholders.

One of the most essential aspects of our project was to determine the stakeholders' needs and concerns. We identified four major stakeholder groups: truck manufacturers, electricity suppliers, fleet owners, and operators. We were able to understand their needs through conducting interviews with people in these categories. This allowed us to survey people within the industry while still being able to complete it within seven weeks. Our project sponsor, Estefano Esparza, and our sponsor company, Designwerk, were able to provide the contact information of many participants. The rest was found through companies within our target industries in Switzerland.

3.1.1. Data Collection for Interviews

Due to the nature of the pandemic at the time of conducting the project, our interviews were conducted online via Zoom and Microsoft Teams. Finding and reaching out to potential participants occurred at the beginning of the project to provide as much time as possible to find a meeting time. Our interviews were planned around the participant's schedule.

Truck manufacturers were the first interview group. This was divided into two subgroups: diesel engine truck manufacturers and low- or zero-emission truck manufacturers. Our sponsor company falls into the latter group and provided most of the interviews we needed in that category.

Fleet owners were also an important group. They will have a difficult decision to make in terms of cost mainly because the current low- or zero-emission technology is more expensive than the traditional vehicles and there are still concerns over range and charging times, but the desire to switch to greener transportation methods as well as current and future laws and regulations could provide future revenue sources.

When arranging meetings, one thing that we emphasized to our participants is that we were not trying to sell them something or convince them to switch to greener fuel sources. Our goal for these was to gain information about how to best implement green energy sources into road transportation and not to sell them a product or push a political agenda. If our participants thought we were pushing something on them, they would have been less likely to give us useful information.

The interviews required at least 2 students to be present: one to facilitate the discussion, and one to take detailed notes during the process. If permission was given to record the interview, notes were taken along with a transcribed version of the interview.

3.1.2. Data Analysis for Interviews

For the analysis of the interview transcripts, we developed a codebook to assist in sorting through the information gathered in the discussions. The codebook consisted of certain phrases or words that could come up in an interview. By looking at the transcript and the detailed notes taken from the groups, certain phrases from the interviewees were sorted into the pre-determined categories designated in the codebook. This gave us information about the frequency that certain issues were discussed during the interviews.

Concerns: Highlight red for major concern, yellow for minor concern

Concern:	**Quote:**	**Analysis:**

Figure 1: *This structure was used to code useful information from our interviews. This allowed us to be able to look back at the key points of discussion without watching the whole interview again.*

The coded interview transcripts were used to develop a priority list of issues. Along with the frequency of discussion, factors such as the reaction of the speaker to the idea and the perceived gravity of the issues were taken into consideration.

The list was based on the frequency of the concerns brought up, the gravity of the issue, and the participants' advice. The priority list helped us determine what needs to be done for low- or zero-emission trucks to catch up to diesel trucks and produce potential incentive programs that could be adopted by the region. We also used the interviews to gain an understanding of the types of infrastructure improvements that would have to be made for the increased electricity demand for zero-emission trucks.

3.1.3. Limitations of Interviews

Originally, the plan was to use focus groups to survey the needs of our stakeholder groups. As we began reaching out to companies, we found it difficult to find willing participants since we did not offer any incentives. We adapted to use interviews with interviewees that would have belonged to one of the focus groups instead because we were able to get a couple of responses in each stakeholder category. Focus groups would be better for the purpose of our project, as we would have been able to have many different opinions on the subject in a short period of time. However, the timeline to complete the project limited the time we had to find potential interviewees. Despite this, we were still able to get the data we needed.

3.2. Objective 2: Literature Review to Determine the Viability of Zero-Emission Implementation in Switzerland.

To determine which method of zero-emission freight transportation is the most viable for the implementation in the current Swiss economic climate, we performed a literature review to compare the types of zero-emission technology that were currently being researched and could be integrated more in the future. The research focused on three main types of vehicles: battery-powered, hydrogen-fuel-cell-powered, and hybrid electric vehicles.

The review describes the physical properties of each type of technology, such as the full charge ranges of the vehicles, the time it takes to charge them, and the initial cost of the vehicles. The evaluation provided us with insight into which fields each type of low- or zero-emission technology excels, and which fields may dissuade the opinions of investors.

3.2.1. Data Collection for Literature Review

We posed several questions to guide the literature review to determine what the most viable technology for implementation into Switzerland was and how it could be implemented. Some of the questions included:

- What type of technology is most efficient in terms of range and time?
- What types of technology are most profitable in the long and short run?
- What systems would require to be implemented for each type of technology?
- What systems are already in place for the technology?

- And what limitations does each type of technology have for its operators?

Using these questions, a guide for sorting through sources in literature was created. When a source was found through a database like GreenFILE or Scopus, it was sorted and coded in a table made in Excel. Each source was analyzed to determine the most relevant information in the writing. Information about the source was entered into the table to reference it easily. Color codes were made to distinguish what type of information could be found in each source. Any data that was designated to be used in the roadmap was recorded and cited with the number of the source written in the chart so that it could be easily referenced.

Number	Type of Technology	Database	Last Name	First Name	Source	Title	Link	What information can we use?	Data Type	Data Type	Data type
EX	Electric	JSTOR	Smith	John C.	E	Electric Cars	[link]	info abt motors and how far they can drive			
1	Electric	GreenFILE	Liang	Jiayu	Catalyst (15:	HIGHLIGHTS (	http://sea	Pushing legislation for e. trucks			
2	Hydrogen	GreenFILE	Liu	Nawei	Mitigation &	Evaluating na	https://do	A model simulating costs of implementing FCETs			
3	Electric	GreenFILE	Osieczko	Kornelia	Journal of E	Factors that i	https://do	Info abt implementing trucks/ other sources			
4	Electric	Scopus	Lai	X	Energy, 238	Remaining di	https://do	how the range of ellectric vehicles may be affected by temperatute and over time			
5	Electric	Scopus	C.A	Sam	Sadhana - A	Bidirectional	https://do	charging technology for electric vehicles			
6	Electric	Scopus	Calearo	L	*Renewable*	A review of d	https://do	effects on electric grid			
7	Electric	google sch	Thalman	Philipe	Swiss Journa	Lowering CO2	Lowering (	tax rates for electric freight transport			
8	Electric	google sch	Walz	Kathrin	CIRED 2020	Synthetic Cha	2020_09_	charging patterns of electric trucks			
9	Hydrogen	GreenFILE	Yanfei	Li	Energy Polic	Economic cor	https://do	lots of info abt the cost of hydrogen production			

Figure 2: *An example of the literature review sorting chart. Information used to cite the source was entered, along with the basic summary of the source to easily reference it. The sources were colored based on the type of technology discussed and the type of data in the source. The content of the chart can be found in Appendix B.*

Color Codes:	Highlight entire row EXCEPT NUMBER IN BEGINNING
Electric	Red
Hydrogen	Blue
Hybrid	Yellow
Other	Green
Type of Data	Highlight the "Data" boxes at the end.
Quantitative (Numbers)	Purple
Social Info	Pink
Geographical Info	Orange
Technical Info	Gray

Figure 3: *The color-coding scheme for the literature review sorting chart. The codes were used to easily recognize the type of data each source had to quickly find the necessary information*

3.2.2. Data Analysis for Literature Review

We gathered technical data for several types of low- or zero-emission technology and created a comparative analysis of the technologies. All the types of zero-emission technology were compared by being examined for the benefits and drawbacks of each technology. We used the technology comparison to determine which of all the types of researched zero-emission transportation would be the best fit for implementation in the Swiss marketplace. This fit was based on which method of transportation was most beneficial, which was defined as the technology with more benefits than drawbacks.

3.3. Objective 3: The Roadmap Towards Zero Emissions

Our roadmap was a written report composed of concerns, suggested developments, and ways to achieve them, with the concerns categorized into a list by priority. Our roadmap was also in compliance with “Switzerland’s Long-Term Climate Strategy;” a mandate derived from the Paris Agreement in 2015 on achieving net-zero emissions by 2050 in Switzerland. In this mandate, the Swiss government highlighted 10 strategic principles to develop a sustainable zero-emission system. Along with these principles, the roadmap was designed to align with Switzerland’s Energy Perspective 2050+, a proposed development in the energy infrastructure that would ensure a secure power supply while zero-emission technology is being implemented. An infographic summarizing our findings creatively and succinctly was also produced to add to the report and can be found in Appendix C.

3.3.1. Data Collection for the Roadmap

The information collected from the literature review and the interviews were used for the data collection of the roadmap. From the literature review, comparisons of the different zero-emission technologies were made, which was used to develop a plan for the most efficient technology implementation into the roadmap. This determined the theoretical costs of travel for a zero-emission truck. The interviews were used to assess the needs of the stakeholders in the implementation of zero-emission technology. Their concerns were considered to develop the plan for the roadmap. Each concern was sorted into a priority list of things to address from most prevalent to least prevalent. Several metrics were used to determine the priority of the concern, such as the frequency it was discussed and the perceived importance of the issue. We evaluated the prioritized list using our comparative analysis to derive a solution for each priority.

3.3.2. Data Analysis for the Roadmap

Using the information gathered from the literature review and the interviews, we developed potential solutions to each item on the priority list. The final solutions were determined by analyzing the information gathered during the project. These became the basis for a plan of implementation into Switzerland, which led to the formation of the roadmap of ways to implement zero-emission technology into Switzerland. Figure 3 is an illustrative example of our roadmap formulation process.

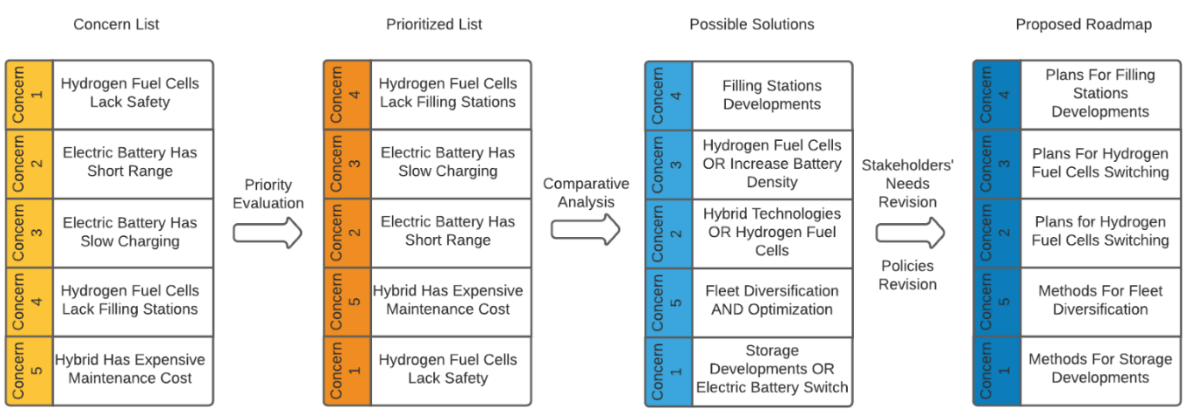

Figure 4: *The roadmap formulation process described in Objective 3 using examples for demonstration purposes. Created in Lucidchart, www.lucidchart.com*

The priority of the concerns was used to determine what solutions were implemented first into the roadmap. The roadmap itself was a timeline of implementation of the final solutions for each concern. It was a way to determine how each solution would fit together and create a future path to zero-emission freight transport.

3.3.3. Limitations of the Roadmap

The formation of the roadmap was dependent on database sources and the thoughts of industry stakeholders. Although the data from the literature review was from peer-reviewed sources, it was not guaranteed that the technical information collected from the sources about the zero-emission trucks was taken under the same set of conditions. This would have let outside factors influence the data collection for the truck. Since the project is a theoretical roadmap, speculation about the technical data from the trucks was expected and considered. The roadmap was also a basis for future implementation into Switzerland. Much of the roadmap was based on expectations from the Swiss government, as well as expectations about where the zero-emission technology would have progressed in the future. As such, the roadmap was developed as a theoretical plan based on speculation of future technology, which was considered during the planning of the project.

3.4. Summary

In summary, the two main methods of data collection for our project were interviews with the stakeholder groups and a literature review of the diverse types of low- or zero-emission technology. The main purpose of the interviews was to determine the most pressing concerns the stakeholders had about the implementation of this technology, which was analyzed to determine a priority list of concerns for the stakeholders. The literature review was used to determine the best source of this technology to implement moving forward, which was analyzed based on pros and cons of each technology. These two methods were used to create our roadmap, which consisted of several concerns to be addressed, practical solutions to those concerns, and a plan to solve each of them.

4. RESULTS

Interviews with stakeholders and a thorough literature review were utilized to determine suitable zero-emission technologies for Switzerland as well as understand the needs and concerns of Swiss freight industry stakeholders. These were used to create a priority list of implementations for the creation of the final roadmap towards net-zero emissions.

4.1. Interviews

We used interviews to collect data. We reached out to many people within two main stakeholder groups: fleet owners and truck manufacturers. Some of the contacts came from our sponsor while others came from our own research of businesses and people in and around Switzerland. Going into the interviews, we already had an idea of the main concerns facing companies about the switch to greener fuel sources, however we wanted direct input from the people and groups who would be most affected by wide scale change in this industry. The purpose of the interviews was to confirm what we had found through our research and see if there were any issues we did not think about. We did not talk much about hybrid and hydrogen trucks because that technology is much less prevalent in the industry. We recorded the interviews, with permission from our interviewees, and coded them based on the type of data that was collected (i.e., concerns, suggestions, questions) and the importance of the statement. The quote from the interview was pulled out of the recording and put next to the topic it pertained to, so that we could look back at the major points of the interview without having to rewatch the whole video recording. In sections 4.1.1 and 4.1.2., all information stated was given by the interviewees.

4.1.1. Fleet Owners and Drivers

This stakeholder group gave insight into the fiscal and technical issues for integrating low- or zero-emission technology. Two major concerns about the trucks themselves are the range and charging time. These two issues go hand in hand since the trucks have much shorter ranges and take much longer to charge than diesel vehicles. While this is not as big of an issue for shorter travel distances, long haul trucks would be severely impeded by the limited range and increased charging time of battery-operated vehicles. Swiss drivers are mandated to take a 45-minute break during the day, usually lining up with their lunch break; this is an ideal time to charge up the battery and the stakeholder group remarked that the ability to charge their battery all or most of the way would greatly increase the effectiveness of the truck.

Another major concern is the price. The purchase price of a battery-operated truck is much more expensive than a diesel truck and can be three to four times more expensive. Since diesel trucks have been around for a long time, it is easy to calculate a lifetime total cost of ownership, but since battery-operated vehicles, or BEVs, are new to the market, there is not data on the total lifetime cost, only predicted scenarios. There are many factors outside of the upfront cost to consider when comparing BEVs and diesel trucks. Fuel is a major cost consideration since diesel fuel is expensive, especially in Switzerland where it is over six dollars a gallon, while electricity is cheap (because fossil fuels are scarcer and more cost more to produce) and would be a considerable cost deduction. While electricity is cheaper than gas, it takes longer to refuel and more frequent fuel stops are necessary, causing the truck to be able to travel less per day than a diesel truck. This factors into the amount of money the company can get out of a truck in its lifespan. BEVs are heavier than diesel vehicles, meaning BEVs carry less cargo due to maximum weight limits, but in Switzerland this is offset by the fact the BEVs are allowed to be heavier. Another factor is possible taxes for vehicles with CO_2 emissions and incentives for those with BEVs. CO_2 taxes have already started to be implemented in Switzerland, and they will most likely continue to increase as alternative vehicle technology improves. The many contributing factors towards total lifetime cost of ownership make it difficult to put a value on total cost of ownership of electric trucks to compare to traditional trucks, which is a disadvantage towards the newer, unproven technology.

Another point brough up during the interviews was lack of infrastructure in place. While there are electric charging stations around Switzerland, they are almost exclusively for personal vehicles. Electric trucks need to return to their warehouse to recharge, which adds to the price of the investment since owners must purchase and install the chargers. This creates a problem since if a company wants to ship outside of the range of their starting point, they need to know that they can stop and charge somewhere and the technology is not in place yet for them to be comfortable doing that.

Overall, the consensus from this stakeholder group was that while it would be a good idea to begin looking into battery technology now, although those vehicles still have a lot of catching up to do before they reach the level of diesel vehicles. Their main concerns were over range, charging time, price, and infrastructure. They stated that there are many types of freight transport operations and BEVs are better suited for certain types, like short-range operations. Some other transport operations, like long distances across different countries, will take a long time to catch up to their diesel counterparts. All of the factors listed above make it difficult for the owner to assess whether it is worth the switch, but they agree that it is important to continue to pursue this technology.

4.1.2. Truck Manufacturers

Our conversations with truck manufacturers gave us information about the issues faced with creating and selling electric trucks. Similar to fleet owners and drivers, truck manufacturers have concerns over range anxiety and charging time. Battery technology and charging stations are not equal to the range capabilities and refueling times of their diesel counterparts, so electric truck manufacturers need to not only be in the truck business, but the battery and recharging businesses as well. At this stage, these companies need to be involved in every aspect of the industry, and the investment in the other areas of interest adds to the cost of the vehicle.

Price is a larger concern for owners and drivers than it is for manufacturers. While the manufacturers are confident in their trucks ability to offset the initial cost of the vehicle with the savings from cheaper fuel and tax deductions, shipping companies find it more difficult to justify the higher cost especially with the reduced range.

One concern that truck manufacturers do not share with owners and drivers is what to do with spent batteries. The lifetime for batteries is less than the lifetime of the truck, so they will have to be replaced during the lifecycle of the truck. This does not cause any problems for the truck; however, it does create the issue of what to do with these batteries. The raw materials of the battery can be reclaimed to produce future batteries, but this is not as cost effective at the moment as mining new materials. This causes a buildup of spent batteries either in storage or landfills, which has a negative effect on the environment. Finding a clean and cost-effective way of disposing of the batteries is important for the future of this technology.

This stakeholder group is optimistic about the future of battery technology. They see it as the best way to fight climate change in this industry, and while the trucks still have a lot of catching up to do, they have the potential to rival diesel trucks. As the technology improves over the coming years, the gap between the two types of vehicles will close. These truck manufacturers are looking to address the concerns over range, charging time, price, and spent batteries in order to introduce large-scale changes to the total emissions in road transportation.

4.1.3. Priority List

In order for battery technology to become widespread in road transportation and make a difference in the fight against climate change, many issues must be fixed so that electric trucks can compete with diesel trucks. The two most pressing concerns are limited range and long charging times. Electric trucks need to stop much more frequently to refuel, which severely limits the distance they can travel in one day. Another limiting factor in distance traveled per day is the charging time. It takes multiple hours to charge the battery enough to continue driving, contributing to distance restrictions. These concerns are the biggest problems facing the implementation of this technology and unless they are addressed, widespread changes cannot occur.

The next most important concerns are infrastructure and price. The technology can gain traction even with a steep price tag; however, companies are less likely to switch over if it costs more than a diesel truck. There are a lot more factors to consider than just upfront purchasing price, such as fuel prices, tax incentives, and maintenance costs, but initial cost is still a hurdle, especially for smaller companies. Currently, there is very little infrastructure in place to support electric trucking. The only places that currently have electric truck chargers are the shipping companies themselves.

A smaller issue to be considered is the spent batteries. The batteries will have to be replaced, and they cannot be disposed of in the traditional way. Currently, there is not a cost-effective way to break down the battery and take out the important elements such as lithium, cobalt, and copper. While this is a concern that need to be addressed in the large-scale fight against climate change, it is not a necessity for the implementation of low- or zero-emission technology.

Based on the importance of the concerns given by the stakeholders, the concerns were given a priority level. A concern was given a level of either high priority, medium priority, or low priority. As seen in Table 1, the concerns with the highest priority will be addressed first in the roadmap, while the low priority concerns will be addressed later.

Table 1: *The concerns of the stakeholders organized by priority.*

Priority Level	Concerns
High Priority	Range and charging times
Medium Priority	Price and infrastructure
Low Priority	Spent batteries

4.2. Literature Review

Our second main method of data collection was a literature review. Using sources provided in the databases at the WPI library, we researched different methods of low- or zero-emission fuel sources to compare them and decide which source or sources would be best to implement. We researched three types: battery powered vehicles, hybrid vehicles, and hydrogen fuel cells. Below are our findings about each technology, followed by a comparison of the three and our analysis of which one is best for the future of Switzerland. While low- or zero-emission personal vehicles are becoming more popular, this technology in trucks is still in its infancy. Therefore, there is not much data for trucks of this kind, so many of our sources deal with personal vehicles. We have analyzed these sources to determine how the data gathered from them can apply to trucks.

4.2.1. Battery Technology

The usage of battery electric vehicles, or BEVs, is far from a new idea, with the first known BEVs dating back to the 1800s where a small-scale implementation of battery technology was developed by a blacksmith in Vermont (Matulka, 2014). In recent years, the technology was able to grab a significant hold on the market due to the effort of companies like Tesla Motors and Google's autonomous car division, which have been able to change the public opinion of electric vehicles from a far-off technology only possible in fiction to a reality that can be achieved within our lifetime. Due to this change in perspective, many companies have seen the expansion of this market as a great business opportunity, with big manufacturing companies such as General Motor promising to spend $35 billion to have an 40% electric fleet by 2025 ("GM's Path…", n.d.). This effect was not lost on the Swiss marketplace, where in this year alone electric vehicles accounted for 5,000 new registrations, or just over 4% of all newly bought vehicles in Switzerland ("Electric Cars: Is the Tide Now Turning?", 2020). Furthermore, the federal government's goal is to increase the electric vehicle share in the market to 15% by 2025 (Bradley, 2021). Part of the growth of appeal came from the fact that BEV are far more efficient at transforming energy from one form to another. Electric engines work in a one-step conversion between electric potential energy to mechanical energy, while internal combustion engine vehicles, or ICEVs, work by transforming the chemical potential of fuel to a heat producing combustion. Because of the absence of energy loss from heat, the average electric engine has an efficiency of 60-70% power conversion while ICEVs have efficiencies in the 15-17% range (Richardson, 2013). With government support and the appeal of a more efficient technology, battery-powered vehicles quickly became a popular prospect for the worldwide switch to zero-emission technology.

Although BEVs are the most popular technology, they do not come without their caveats; most of the major problems regarding battery technology come from the production of the batteries and their effect on the grid. For one, many people criticize that the demand created from BEVs on the electric grid will be met with the increase in energy production from fossil fuel-based sources. While that may be a possibility, it would still result in a minimum of 10% decrease in CO_2 emissions due to the higher efficiency of electric engines compared to combustion engines (Richardson, 2013). Although, as stated in the Swiss Paris Agreement plan (detailed in section 2.2.1.), generation of energy by renewable methods is expected to be increased to 11,400 GWh by 2035 (Swiss Federal Office of Energy, 2020), which would be able to account for a large portion of the increase in electric vehicle demand. Other environmental concerns include the acquisition of the materials necessary for the creation and development of the batteries. Lithium-ion batteries are currently the most common type of battery, and types such as magnesium cobalt oxide batteries (NMC) and nickel cobalt aluminum oxide batteries (NCA) require rare metals as well as over 20 different materials sourced internationally (Melin, 2019). These materials require extensive mining to extract. Due to this, many people fear that the increase in production of EV batteries to reduce CO_2 emissions from vehicles would be counterintuitive due to the increase in CO_2 produced in gathering materials.

Due to the monetary and environmental expense of materials, the concerns over EV battery decay over time have become a topic of dispute. An EV battery is considered at the end of its life after it can no longer hold 80% of its original charge or after about 4000 cycles of charging and discharging. Based on a two cycles per day model, one at the start and end of operation, this would approximate to 2000 days or about five and a half years (Bhagavathy et al., 2021). The life expectancy of a freight transport truck is around 10-15 years, so the ideal battery should have a lifespan comparable to the trucks. Unfortunately, the life of a battery is heavily dependent on several factors that are hard to predict such as: temperature, charging rates, and remaining state-of-charge (SOC) of the battery. For instance, higher rates of charging, or C-rates, speed up the degradation of certain battery types by a significant amount. Charges above 4C or charging times below 15 minutes can cause alterations in the chemical composition of the battery, causing permanent damage and reduction in life expectancy (Bhagavathy et al., 2021). But with the implementation of battery management systems (BMS) some of these degradations can be mitigated. For one BMS have current limiting capabilities that prevent the batteries from receiving high currents from the grid in a way that may damage the system. They also come equipped with overcharging prevention for when their batteries are left charging overnight, as well as energy conservation systems that can implement the V2G system described in section 2.1.2. While not a perfect technology, battery powered vehicles are a great contestant as the technology used in all future generations due to the extensive research done on the topic as well as the infrastructure already in place.

4.2.2. Hybrid Technology

Hybrid technology is one of the most common commercially available technologies on the market. The most common type of hybrid is the plug-in hybrid electric vehicle, or PHEV, which can run on both fuel and electricity. While not a zero-emission technology, this type of vehicle can reduce the level of emissions produced by approximately 70%. PHEV's produce approximately 40g CO_2/km, which is significant compared to a gasoline vehicle that produces an average of 140g CO_2/km (Thiel et al., 2010). Hybrid trucks could be fueled by biodiesel, which is a renewable resource that burns cleaner than fossil fuels and could further benefit the environment (*Alternative Fuels Data Center: Biodiesel Benefits*, n.d.). The vehicle can drive about 20-40 miles on electricity, and the rest of the range is from gasoline and the combustion engine. The battery charging for the car is fast, since the battery is smaller and not the main source of power in the vehicle. The vehicle is also heavier, since the power system has both a combustion engine as well as a battery-powered engine and battery (Thiel et al., 2010).

A major benefit of hybrid technology is the fact that there are not a lot of major infrastructure adjustments that need to be made for implementation. There are currently around 5,700 charging stations in Switzerland, and the number is planned to grow significantly in the future as Switzerland pushes further towards electric power for vehicles (Bradley, 2021). The quick charging times for the smaller batteries in the vehicles means that the implementation of more stations does not need to be a high priority. Hybrid technology is very prevalent in motorized vehicles, with a significant reduction of emissions as well as ranges and fueling times comparable to diesel. The technology could be a good steppingstone in the path towards net-zero emissions in the future.

4.2.3. Hydrogen Technology

Hydrogen technology is a relatively new and unutilized technology in vehicles compared to the more popular electric vehicles that are charged. Hydrogen has a lot of industrial uses, such as chemical production and fertilizers (Li & Kimura, 2021). Currently, most of the hydrogen is produced via the steam reformation of fossil fuels, but there are many lesser-known methods of hydrogen production, such as electrolysis, where hydrogen is produced from the splitting of water molecules. This technology could have absolutely no emissions if the electricity used for the process is from a renewable source (*Hydrogen Production: Electrolysis*, n.d.). The capital expenditure of hydrogen production varies wildly based on factors such as the location of the hydrogen plant, which pathway the plant is using to produce hydrogen, and the type of electricity used to run the production. In a study conducted by Rahil & Gammon (2017), it was estimated that electrolysis production could reduce the production cost of hydrogen to about $3.83/kg. For a comparison, a similar study (Rahil et al., 2018) demonstrated that a similar setup with the current technology would have a hydrogen production cost of \$12.40/kg-\$13.60/kg. The high production costs of hydrogen are currently a large factor in the hesitancy of moving towards hydrogen as a fuel source.

There are currently some hydrogen fuel-cell passenger vehicles in production, as well as some hydrogen trucks in the planning phases. A typical passenger FCEV can drive over 300 miles on a full tank, which is around 5kg ("Alternative Fuels Data Center: Fuel…", n.d.). This size of tank can be filled in about 4 minutes ("Alternative Fuels Data Center: Fuel…", n.d.). Fuel cell trucks are not available on the market, but Nikola, a company researching fuel cell technology, advertises their planned fuel cell trucks as having a 20-minute fueling time ("Nikola Two…", n.d.). Currently, the price of hydrogen is around \$16/kg in the United States, specifically California, however many manufacturers are offering three years of free fuel included in the price of purchasing the vehicle ("Cost to Refill…", n.d.). Another main factor in the price of the vehicle is the high cost of the fuel cell used to produce energy. The main fuel cell technology currently being used, the protein exchange membrane, uses platinum as a catalyst for the process, but technology phasing out platinum for a lower cost material is currently being researched (Xie et al., 2020). Presently, FCEV's have the highest dollar to kilometer ratio of any vehicle on the market (Li & Kimura, 2021). Factors such as high production cost and low demand are influences on this steep price. The car is also heavier than traditional cars, as it contains an electric motor, a battery, and the fuel cell used to produce electricity ("Alternative Fuels Data Center: How…" n.d.). In a truck, however, this would not make a dramatic difference since the truck is already very heavy.

Hydrogen has an extremely promising future, but the necessary investments in hydrogen infrastructure might dissuade people from pursuing the technology. In a scenario presented by the International Energy Agency in 2015, it was estimated that $900-$1900 would have to be invested per FCEV produced and sold (Li & Kimura, 2021). This estimate was based on an assumed 250 million cars sold. This has not stopped countries from investing in research into the technology. In 2020, the German government allocated €7 billion to support the hydrogen market and South Korea announced a plan to develop 1200 hydrogen fueling stations by 2040 (California Air Resources Board, 2020). Companies like Toyota, Hyundai, and Volvo are also making an effort to design hydrogen-powered long-range trucks.

Hydrogen is a clean energy source that is slowly making its debut in the industry. With the proper infrastructure investment, it could be a completely clean energy source. Much of the hesitation around the technology comes from its high price, but countries and companies around the world are attempting to bring about change in the industry.

4.2.4. Comparison

Battery-powered electric, fuel-cell hydrogen, and hybrid technologies each have their own unique benefits and downsides, but one type of technology had to be chosen to implement into the Swiss freight industry. Factors such as the physical aspects of the vehicle and the existing infrastructure for the technologies were considered in the decision to make the technology the focus of the roadmap. The choice made was not necessarily the overall best zero-emission fuel source, but it was the technology that would be most easily implemented. This choice would need to convince the most stakeholders in the Swiss freight industry to actively participate in these changes. This decision was also tailored specifically to Switzerland, where we considered the geography and the systems already in place for the country.

Table 2: *Comparison of three low- or zero-emission trucks on the market or currently being produced. Note that not all these trucks are currently on the road and the data may be theoretical from the manufacturer's website.*

Comparisons	**Futuricum FH SEMI 40E (6x2T) (Bosshard, 2021)**	**Nikola Tre FCEV (*Nikola Tre: Fuel-Cell Electric Daycab Semi-Truck*, n.d.)**	**Scania Plug-In Hybrid Truck (*Plug-in Hybrid Truck*, n.d.)**
Type	Battery-powered electric	Fuel-cell Hydrogen	Plug-in Hybrid
Weight	Approximately 40,000 lbs.	N/A	N/A
Range	250 miles	Up to 500 miles	37 miles pure electric + diesel range
Charging Time	14.6 hours with 44kW charger, 3.1 hours with 150kW charger	Up to 20 minutes	35 minutes + regenerative breaking
Battery Capacity	340 kWh	N/A	90 kWh
Price	$450,000	$268,782	N/A
Best Use	Medium-/Short-Haul	Long-Haul	Long-Haul

Table 1 shows a comparison of different trucks that are currently being produced by companies around the world. Although the numbers are not quite accurate, as some of the vehicles are not in production and the numbers are just estimates from the company, it gives a picture of how far each technology has progressed. Currently, battery vehicles have the shortest range due to the amount of charge batteries can store. Hybrid trucks have the highest range, as the truck has both an electric range and a diesel range. The charging times of each vehicle vary; BEV charging can range from three to 14 hours, PHEVs have a fast charge time and a fast fueling time, and FCEV fueling takes about as long as gas fueling would take. For trucks, hydrogen fuel would be the fastest with the current technology, as it is comparable to gas fueling. Electric charging could become much faster in the future with research into fast chargers for trucks. Fuel prices vary considerably based on the technology. In places that have hydrogen fuel, it is the most expensive on the market. In places that do not, electric charging is significantly cheaper than gas and diesel. For the weight, PHEVs are the heaviest due to the number of components needed to run the truck, although this is not demonstrated for the example truck as the information is not available. Fuel-cell vehicles are the technology that costs the most, since the parts of the fuel cell used to generate electricity are expensive. In Table 1, the price of the FCEV truck is lower than the available information of the BEV truck, but the price for the Nikola Tre FCEV is higher than the cost of the truck itself, as there are other benefits like charging stations and maintenance costs bundled into the price of the lease from Nikola. PHEVs and BEVs are also more expensive currently because of the production cost of the batteries, but as technology progresses these costs will go down.

For the infrastructure, electric charging is already very prevalent all over the world. Many cities in places like Switzerland have a large number of electric chargers and existing electric-powered systems like trams and trains. Hydrogen is not abundant at all in the world as a fuel source, with it being nonexistent in many places and scarce in places where there is implementation. If hydrogen were to become the main zero-emission technology in Switzerland, many infrastructure changes would have to be made, such as: hydrogen production plants, hydrogen fueling stations, and modes of transportation allocated to moving hydrogen around the country. Electricity is already widely available for charging vehicles, and there is already infrastructure in place to move electricity around the country as vehicles are not necessary like they would be for hydrogen. Due to this, most of the money allocated to this would be used for upgrading infrastructure. It would be less expensive than having to install completely new infrastructure all over the country, making it more appealing to investors and stakeholders. This makes any electric charging vehicle the best choice for Switzerland.

With the comparisons of each technology completed, it was decided that the battery-powered trucks would be the most efficient and effective way reduce emissions in Swiss truck transport. Electric vehicles already have a lot of existing infrastructure that is used in the country, and a lot of money is already being allocated towards the research and production of battery-operated trucks. Some are already on the market and continuously being researched, while research has barely scratched the surface of hydrogen-powered technology. Full electric vehicles are more beneficial than hybrid vehicles because they produce no emissions from driving. Hybrid vehicles could be a good steppingstone towards an all-electric fleet, but many countries are planning on implementing policies for emission reduction and reduction in the amount of combustion vehicles on the road. It was determined it is not as economically feasible to produce more hybrid vehicles and start production on hybrid trucks, as those types of vehicles could quickly fall out of style. Also, due to the proximity of cities and the small size of the country in terms of maximum drivable distance, the limited range of BEVs is still enough to allow travel across the country. We determined that battery-powered electric vehicles have the most benefits and the least downfalls for Switzerland and was the type of technology that was pursued in the roadmap.

4.3. The Roadmap Towards Zero Emissions

The roadmap was our proposed plan for implementation of zero-emission technology into Switzerland. The information used to construct the roadmap was taken from the literature review, the interviews, and other researched knowledge about Switzerland and their policies. The results were formatted based on the roadmap formulation chart, which was Figure 3 in the Methods section. Each section of the chart was used as a section in this results section.

4.3.1. List of Concerns

From the interviews conducted, some concerns of industry stakeholders were identified. Based on the coding of the interviews, these concerns were sorted into high, medium, or low priority concerns using information like the number of times discussed and the perceived urgency of the topic by the interviewed person.

The highest priority concerns for implementation are range and charging times. For fleet owners, the amount of time not spent moving products outside of the mandated breaks for drivers is money lost. With the current state of the technology, the range of the trucks is low, and the charging times are high. For more fleet owners to adopt this technology, there must be less time spent charging and more time spent driving.

The medium priority concerns are the price of the vehicle and the infrastructure available for electric trucks. The current price for electric trucks can be three or four times higher than diesel trucks, which is a major investment for fleet owners. The infrastructure available specifically for battery-powered long-haul trucks is limited, which makes it hard for owners to ship goods across the country. These concerns are important for the further development of the electric truck industry and improving infrastructure and lowering the price will lead to the use of more electric trucks.

The low priority concerns are important to the industry in the long run, but not important enough to prioritize their development over the high priority concerns. The main low priority concern is the idea of spent batteries. The batteries for the trucks are currently very expensive, and the worry of both truck owners and truck manufacturers is that they will have to spend more money with repetitive purchases, since they currently must dispose of spent batteries without any sort of recycling.

Each concern from the stakeholders was considered, but in order develop a roadmap the concerns had to be prioritized for implementation.

4.3.2. Priority List

The priority list was developed based on the severity of the concern and the path that would be best for the roadmap. This list was used to plan out the roadmap.

1. Charging times
2. Range
3. Infrastructure
4. Price
5. Spent batteries

4.3.3. Possible Solutions

Our team came up with a solution for each problem in the priority list. These solutions were generated from our research and data gathered from the interviews. These are only possible solutions; however, the determined solutions would provide a good basis for further, more specific plans for implementation of zero-emission technology.

1. Fast Chargers

The highest concern on our priority list is charging times. The best way to alleviate this concern is to develop fast chargers. At this stage it takes hours to refuel an electric vehicle and minutes for a diesel truck, so fast chargers would have the ability to close this gap significantly. These are already under development, including the Megawatt charger that is being researched by our sponsor company, Designwerk. In order to satisfy the needs of the stakeholders, the goal of the project is to produce a charger that can charge an electric truck all or most of the way during the required 45-minute break all drivers must take. This will allow electric truck drivers to cover similar distances to their diesel counterparts and allow them to be much more competitive replacements.

2. Improved Batteries

Currently, electric trucks need to stop more frequently to refuel than diesel vehicles, and with the already increased charging times, this prevents them from traveling large distances in a single day. A battery that can last as long, or longer, than a full tank of diesel fuel will create a more competitive market. While more batteries would improve the range, it also adds weight to the vehicle which limits the amount of cargo it can carry. Instead, a battery that can store more energy or run more efficiently is the best solution to this problem.

3. Infrastructure Upgrades

Electric truck chargers are uncommon in Switzerland and almost exist exclusively at the storage facility for the vehicles. The most important upgrade is the addition of fast chargers such as the Megawatt charger at intermediate stops along the major truck routes in Switzerland. This will allow truck drivers to refuel at the places where they already stop throughout the day. An increased number of slower truck chargers will also be needed, particularly at the loading and unloading points for the trucks. More electric vehicles will cause an increase in the use of electricity and some upgrades to the grid would be needed. This could be mitigated with the fast chargers using V2G software in order to take some of the strain off the grid, but some upgrades would still be needed. These solutions should all be implemented as soon as possible to successfully integrate this technology. A future step would be electrified roads, which use energized coils underneath roadways to inductively charge vehicles (Connolly, 2017). This would allow the vehicle to charge while driving and improve the range.

4. Lowering Purchasing Cost

A high purchasing price was one of the significant factors that restricted the adoption of e-mobility in corporate fleets. Due to the scope of our study, we could not examine how truck manufacturers justify their purchasing price (MSRP - Manufacturer's Suggested Retail Price). However, we recognized that the global supply and the maturity of primary alternative-fuel components such as battery packs, fuel-cell tanks, electric motors, and structural materials had a much more profound impact on the MSRP than the demand for alternative-fuel vehicles. That is, cost prediction models for zero-emission freight trucks often rely on the market price of the mentioned components to give qualitative estimates on the MSRP (Welch et al., 2020). Under this notion, with the current rate of advancement in research, the maturity of alternative energy technologies and their production soon should mitigate the concern of the high purchasing price. In the present, governmental funding and incentives would play a key role in assisting freight industry stakeholders transitioning away from diesel technologies. For instance, the U.S government tax programs for domestic battery production allowed automakers to produce more cost-effectively, thus driving the MSRP lower. Exemptions in access fees at major ports could also promote switching from diesel-powered trucks, which Switzerland was already experimenting with regarding fuel-cell vehicles (CALSTART).

5. Battery Recycling

The scope of battery recycling technologies was out of our scope of study. However, we suggested that as the usage of heavy-duty batteries scaling up in the future, more battery recycling facilities should be opened to perform the logistics on recycling or disposing of these batteries. The designated facilities for such batteries are necessary because heavy-duty batteries are much more dangerous until fully discharged and the process of dismantling them requires significantly more time (Kelleher Environmental, 2019).

4.3.4. Proposed Roadmap

For the roadmap to be successful, the first steps must be taken within the government of Switzerland. This is a relatively new technology, so without any help it would be extremely expensive to implement. The high cost of entry could be off-putting to fleet owners, as they will not be persuaded to invest in new technology if it costs more money for a worse product in terms of profits earned by the fleet. Therefore, we suggest that the government puts into place tax incentives for electric vehicles and supplies some funding to companies researching ways to improve technology for electric vehicles. The tax incentives could be things like raising the prices of diesel to force people to switch to an electric source or providing some sort of bonus to fleet owners for purchasing a fully electric vehicle. This would allow more money to flow into the industry and provide companies with more resources to improve their products. General research funding would accomplish this as well, so a combination of the two would significantly increase the money companies have for research and development.

The funded projects should mainly address the two biggest stakeholder concerns: charging times and range. For charging times, lots of time and funding is currently being devoted to the creation of the megawatt charger, an extremely fast electric charger that would charge a battery-powered truck during the mandatory break required by truck drivers in Switzerland. A charging time of only 45 minutes would greatly improve the viability of electric trucks in the industry, making the switch to electric much smoother logistically for fleet owners who are concerned about the time cost to them. Since this technology is still being developed, more funding for the project would allow it to come to fruition faster. Once the charger is manufactured, it can be placed at rest stops with high traffic first to help charge the largest number of trucks with its small country-wide footprint. Since range is also an issue, research by different companies or groups will also be funded, since the second highest concern is the range of trucks. The battery is the focus in expanding the range of the truck, but other paths that could be taken are looking into the layout of the truck to see if it could be more energy efficient or improving other parts like the motor.

With an increase in range, more fleet owners will consider this option and start to make the switch.

With more chargers and more trucks, the electrical grid would have to be expanded. Switzerland already has a vast network of electrical lines due to the electrification of public transport, but it is not currently equipped to handle something like a majority of trucks on the roads becoming electric. Funding would have to be allocated towards expanding the grid for this to happen. Ideally, most of the electricity used to power Switzerland would be renewable sources due to the goal of a zero-emission process. The country has a lot of renewable energy sources available but expanding the existing technology to produce more energy would be necessary. Renewable energy sources also have production fluctuations based on the time of day and the weather. New technologies such as a possible use of batteries in truck chargers storing energy could improve the grid for more powerful charging and help always keep a consistent amount of electricity at all chargers. This improvement could also standardize the price of electricity to be more like gas prices.

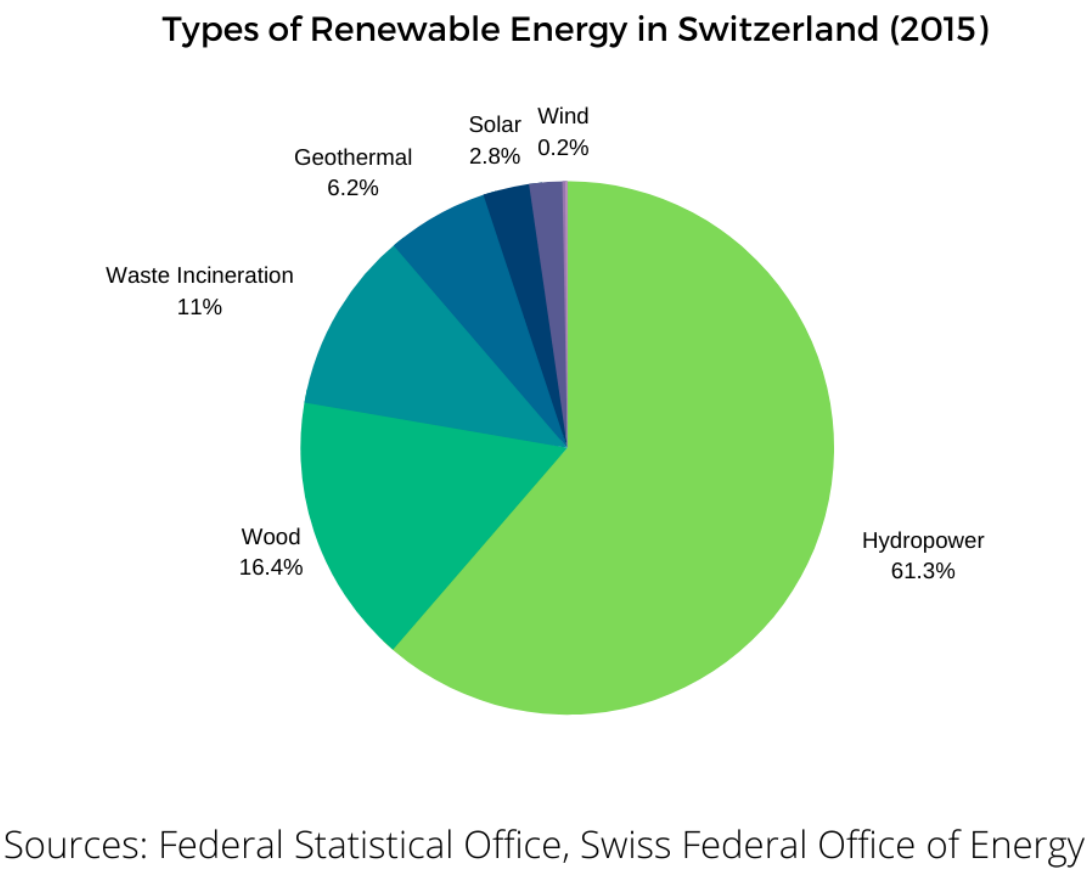

Figure 5: *Graph of renewable energy sources in Switzerland. Renewable energy makes up 23% of energy production in Switzerland. Made in Canva. Source: aboutswitzerland.org*

After the improvements in the technology and infrastructure are made, there comes a concern over the standardization of the systems that are going to be implemented. As of right now, there is some insecurity over the fact that each electric truck will be slightly different from its competitors. This could cause some hesitancy in purchasing a truck due to the idea that there might not be chargers that would fit with a specific truck, or that an external adaptor is needed for charging. Standardization in the industry would relieve some of that hesitancy. As of right now, the insecurity that comes from the specialized needs of every different type of electric freight transport causes upcoming fleet owners to hesitate in purchasing new EVs, thus requiring standardization in the industry. First and foremost, the biggest factor that must be standardized would be the charging facilities in place around Switzerland. Currently, gas stations are standardized so that there are constraints on how close or how far each station should be from each other as to maximize long distance trips (He et al., 2019) A goal for standardization would be applying this same principle to electric charging stations. The stations must be planned in a way that would ensure most electric trucks could traverse the longest possible distances without having to worry about running out of power. A study must be conducted across the mayor roads and cities in and around Switzerland to determine the required positioning of minor and major charging stations. This can be done by analyzing the volume of vehicles driving through certain roads and the type and range of said vehicles. By doing this, a maximum distance between stations can be derived and the location of major charging facilities can be planned.

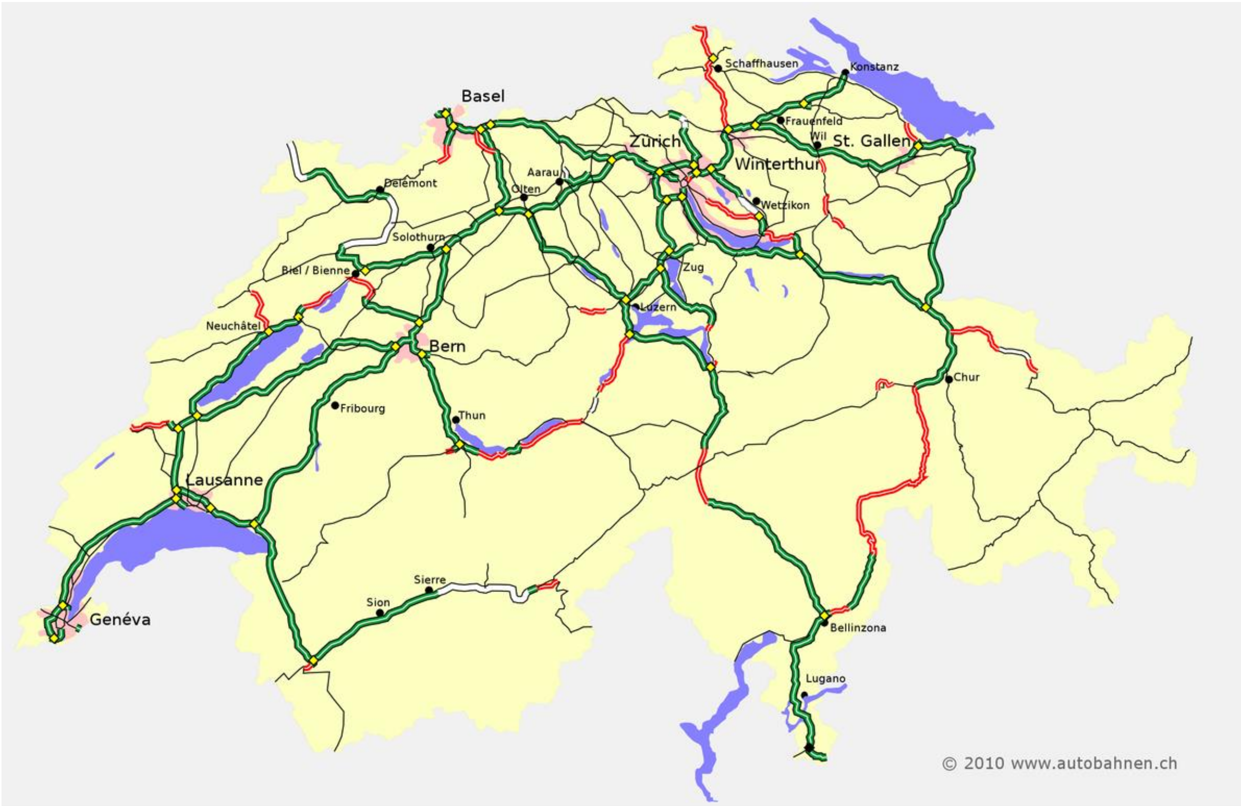

Figure 6: *A map of major roadways in Switzerland. Source: autobahnen.ch*

Apart from the location of charging stations one aspect that must be standardized would be the chargers themselves. In these stations, the new and faster chargers can be implemented with one requirement: the standardization of charging ports. By creating a universally used charging port or adaptor, truck drivers would be able to charge their vehicles at any location available instead of having to look for a specific location. Doing this would ease the process of route planning and would expand the places that any given vehicle can go. Efforts in standardization of chargers have already been taking place within coalitions like the CharIN group, who pledges to have standardized chargers for their EVs in the near future (Hamp, n.d.). With standardized chargers and planned out charging locations, the next step is determining the types of chargers to use at each location. With slow chargers, having the benefit of being able to increase the lifespan of batteries and the ability to implement the V2G system their usage should be maximized as much as possible, yet their long charging times make them inconvenient during hours of operation. Slow chargers should be maximized as much as possible due to their ability to extend a battery's lifespan and the implementation of a V2G system. The long charging times make the slow chargers inconvenient during the hours of operation of the trucks. Therefore, a system should be devised where at stationary locations such as warehouses and resting stops would have a higher number of slower chargers as to accommodate multiple trucks left overnight. Frequently traveled road locations and short stops such as ports and loading stations would have ideally have faster chargers to quickly allow the truck to continue its route. These systems would guarantee operators within Switzerland that their trucks would not run out of power.

Without such technologies being developed and improved constantly, performance metrics become highly speculative. Fleet operators have a difficult time deriving the total cost of ownership for their fleets from just spec sheets of such technologies. Switching to electric trucks, fleet owners rely on simple characteristics such quality, reliability and fuel consumption to first decide whether or not the vehicles are worth purchasing (Kampker et al, 2018). Through the interview, we also know that if fleet owners wish to determine the TCO on top of the initial assessment, they would have to put the newly owned fleets through real-world experimental operations. Such processes were often carried out using the fleet operators' corporate resources, which put extra financial stress on the company. On the other hand, other fleet operators still utilize the previous TCO models used for diesel fleets to for their new zero-emission fleets. However, this approach can potentially produce inaccurate TCO analysis in certain scenarios due to additional costs being unknown or omitted. We suggested a government initiative to open e-mobility workshops for companies on e-mobility at local levels to put less strain on businesses with zero-emission fleets. These workshops should focus on providing corporate mechanics with the knowledge for working with green technologies across various brands as they usually did not share a universal design. In United States, fleet operators can utilize modelling frameworks researched by government agencies such as T3CO from National Renewable Energy Laboratory ("Breakthrough Analysis... ", 2021). Thus, a designated TCO tool for the Swiss freight market would be a valuable resource to the industry.

Finally, with all the systems in place for the growth of the EV market, one more action is required: the spread of information. For the implementation of electric trucks to be successful, there must be widespread information for every stakeholder. Operators require training on how to charge the trucks, run them efficiently, and operate them in case of emergencies. Mechanics need certifications for maintaining and repairing EVs. Management staff need training in the different road systems, charging facilities, and regulations for EVs. Another important expansion of electric vehicles into the market is that fleet owners require standardized ways to make TCO calculations. With many factors affecting the price of operating an EV and a lack of information on operations, TCO calculations are challenging and speculative. To solve this, two main solutions are considered. One, information can be spread via government supported seminars and workshops that provide all the necessary information on what is required for the usage of EVs. Two, a database can be implemented that can keep track of the current technologies in place and assist with making TCO calculations. Through this spread of information, a lot more fleet owners and companies would be more willing to take part in the expansion of the EV market.

All integrations of the above policies should also consider the ethics regarding public sensibilities. Our research indicated that our stakeholders have positive opinions regarding the transition of their industry into zero-emission technologies. Yet, the energy shift in the freight industry can have negative spillover impacts on non-stakeholders. Thus, the design of the new energy system should aim to guarantee that such non-stakeholders can avoid or be well prepared for any potential shortcomings. Some guidelines on ethnic biofuel socio-energy system design mentioned in the 2014 IEEE International Symposium (Miller, 2014) conference are:

- The essential rights of the people should not be compromised under the development of alternative-fuel energy infrastructure.
- People should equitably inherit the cost and benefits coming from the transition into the green energy system. This involves but is not only restricted to the lowering of global temperature.

The ethical design of systems remains a deep concern and difficult topic to be properly assessed. Thus, governments and parties involved in implementing energy roadmap should take initiatives and be prepared to regulate and address socio-economic issues that arise during the process.

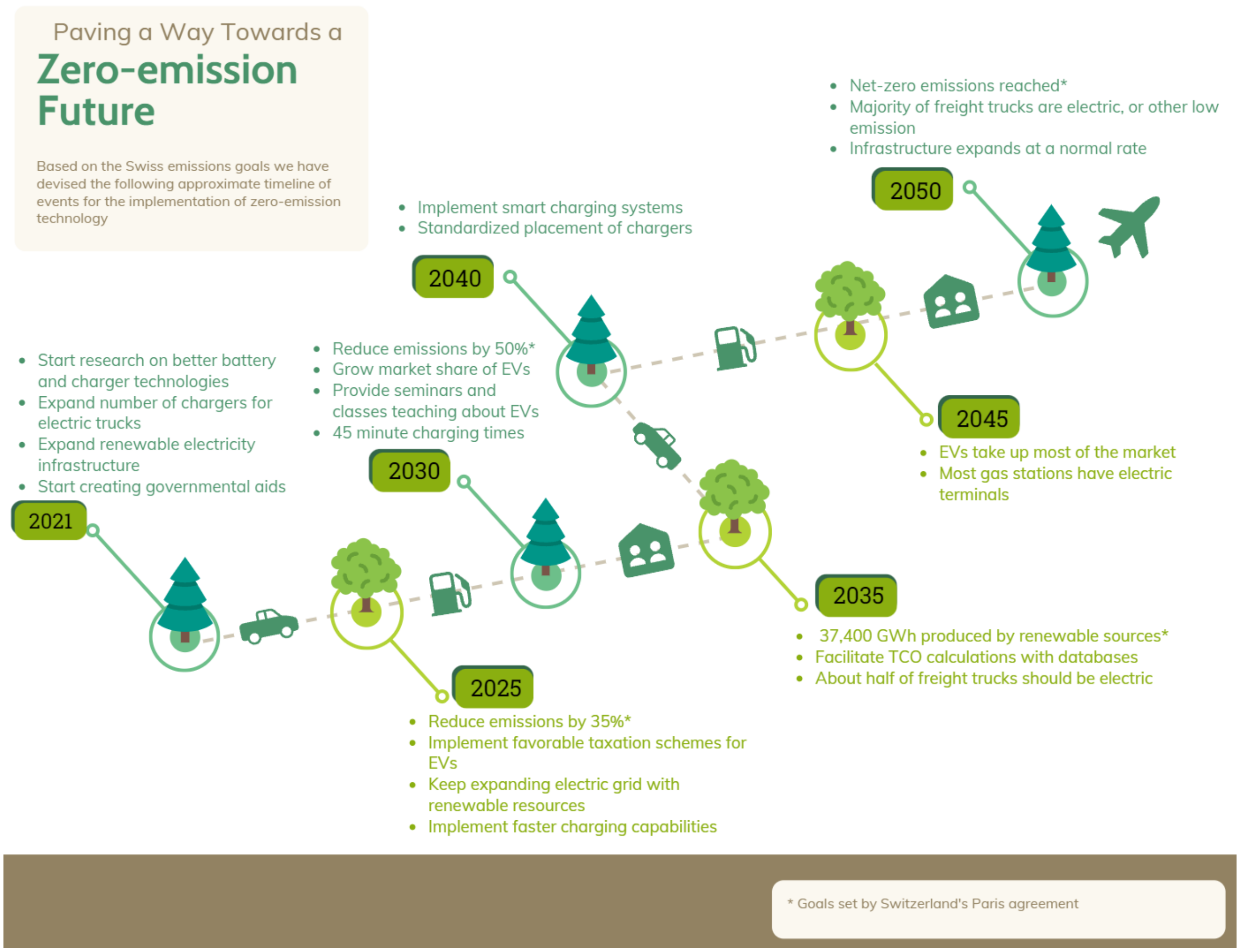

Figure 7: *The proposed timeline for implementation of the roadmap. The dates on the timeline follow Switzerland's goals set by the Paris Agreement. The goals at each date were set by our construction of the roadmap. Made in Venngage.*

5. CONCLUSION

Our goal for this project was to develop a set of potential solutions to combat issues with implementing low- or zero-emission technology into Swiss truck transportation. Below are our recommendations for all interested parties in this industry. From our research, acting on these points will allow this technology to improve and become more widespread, which will make a significant impact on the overall fight against climate change.

The needs of major stakeholders (truck manufacturers, electricity suppliers, fleet owners, and operators) of the freight industry were surveyed through online interviews. These interviews helped us gain the necessary information to evaluate our findings coming out of our literature review. Quotes from the interview with a shipment company highlighted two significant drawbacks of owning an electric fleet: range and charging time. Due to the nature of long-range freight transportation, this operation was most impacted by the two drawbacks. According to the fleet owner, purchasing price also makes it reluctant to acquire more electric trucks as the high retail price was not properly justified. The company also addressed the complexity of calculating the operating cost of its new electric fleet. Specifically, it was due to truck design variation from brand to brand, as well as the speculative cost of improving technologies. Like fleet operators, truck manufacturers were also worried about the two major shortcomings of electric trucks, and they planned to resolve this issue by developing faster chargers. With the life cycle of an electric truck being much longer than its battery, the logistics of recycling and disposing of spent batteries also posed another set of challenges for truck manufacturers in their e-mobility mission. Upon analyzing the concerns through the frequency of them brought up in the interviews, we identified that range and charging time should be prioritized first, following by price and infrastructure support, and finally old batteries. Aside from the interview, the literature review provided us with a broad insight into the entire alternative-energy system and its potential. As mentioned above, battery electric vehicles deliver economically sustainable performance for light and medium fleets, while fuel cell electric vehicles have a much faster refueling time than current technologies, and plug-in hybrid electric vehicles offer the best of both worlds along with an already extensive legacy diesel infrastructure. After considering governmental funding, current infrastructures in place, energy production, conversion efficiency, market momentum of electric vehicle purchasing, and future technology development trajectory, we determined that battery-powered trucks would deliver the most optimal operation for the long-range trucking industry.

5.1. Recommendations from our Project

Our first recommendation is for the Swiss government. For this technology to take off, a large investment will need to be made into a variety of different areas. Funding will need to be set aside to improve the infrastructure by adding chargers and improving the electrical grid. Also, providing companies with funding to research battery and charging technology will allow those aspects to improve faster. We recommend that the source of this funding would be to raise taxes for diesel trucks and fuel. Our results showed that there is still a large need for research and development as the technology in electric trucks is not up to par with that of diesel trucks. The best way to accomplish this is through government funding. As more trucks start to sell, the companies can provide more of the research money themselves, but to start off the Swiss government needs to assist in this endeavor. Our results also showed that the infrastructure is a concern, and this should also be up to the government to fund as well.

Aside from funding technology research, the government will have to assist businesses transitioning to new technologies with joint education conferences to mitigate the efforts individual companies have to put in training their workforce adapting to operating alternative-fuel infrastructure. Freight policies should favor zero-emission operations to outweigh the additional cost incurred. With these programs prioritized, the freight industry would be more ready to be independent from carbon-based fuels.

Our main recommendation for our sponsors is to continue their research in batteries and charging technology. This also applies to any other companies involved with truck manufacturing and charging stations. Our results found that charging time and range are the two largest issues facing the implementation of battery technology. Designwerk and similar companies are on the right track when it comes to resolving these issues; however, it will take much more research and development into these systems in order to make them competitive to diesel.

Also for our sponsors, and possibly a future WPI IQP team, we recommend doing a deeper dive into the total cost of ownership for potential buyers. One problem facing fleet owners is that they have a hard time doing a cost benefit analysis for switching to alternative fuel sources. A way to combat this is for truck manufacturers to create a model or formula to give an estimate of total cost of ownership based off of standard factors such as fuel prices and initial cost as well as buyer-specific factors such as travel distance and specific uses. This would give fleet owners a better understanding of the investment they are making and aid in their transition between technologies.

We recommend that fleet owners and drivers begin to look into switching from diesel trucks to battery powered trucks. While the technology is currently not as advanced as diesel, it is steadily improving. Beginning this process now will help to reach the emission goals set by the Swiss government and the Paris Climate Agreement.

5.2. Recommendations for Future Projects

Our project creates the opportunity for other projects to explore issues that we touched upon but will need deeper research beyond the scope of this project. The first possible project is researching specific infrastructure improvements. While this project determined that improvements to the existing infrastructure are necessary and discussed ways to fund them, more research needs to be done into how extensive these upgrades need to be. An analysis of truck traffic around Switzerland will need to be completed to determine the number of chargers that need to be built and where to build them. Also, the electric grid will need to be upgraded to accommodate these chargers and a future project could determine what these upgrades would look like and how extensive they would be. This would provide a more straight-forward plan for the Swiss government to act on this issue.

Another possible project is a total cost of ownership model. In this report, we have discussed the difficulties faced by fleet owners when conducting a cost-benefit analysis for switching trucks. A future project could create a model that allows fleet owners to get a better understanding of the investment they would be making and how it would pay off throughout the truck's lifespan. This would make a more transparent comparison between diesel and electric trucks, making their decision to switch easier and less speculative.

Also, seeing all our recommendations to completion would be a project in itself. Based on our suggestions, there is still a lot of work, research, and production that needs to be done. These will need to be carried out by Designwerk, similar companies, and the Swiss government in order to make the desired impact on carbon emissions.

5.3. Limitations

Our project faced several limitations during its duration. The first of those limitations being time. We only had seven weeks to complete this project, giving us a short window to gather data. We had some trouble getting interviewees even though we sent many invitations. If we had more time, we could have followed up and conducted more interviews to use for data collection. We even had a couple of companies that were willing to participate but were unavailable until after the conclusion of our project.

The pandemic also created a challenge for our project. It restricted the amount of time we could be on site working on our project from seven weeks to ten days and forced a lot of our meetings and interviews online. Since we were not on site, we had to deal with the time difference between us and Switzerland. This created a delay in communications at times and made it more difficult to schedule events.

5.4. Summary

In order to combat climate change, we need to drastically reduce carbon emissions across a variety of industries. Freight transport alone makes up about 8% of global emissions (Greene, n.d.). While this project focuses on Switzerland, implementing our recommendations would create a greener nation to serve as an example for the rest of the world to follow. Creating large-scale change in the fight against climate change will take a lot of research, funding, and brainpower on top of the advancements that have already been made. Taking these first steps are crucial and necessary for a sustainable future.

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7. APPENDICES

7.1. APPENDIX A: INTERVIEW QUESTIONS

Questions for Fleet Owners

- We understand that you have been working with our sponsor company, can you discuss the extent of your business with them?
- While switching your fleet to electric vehicles, what problems, if any, have you encountered?
- What were your concerns about switching technologies, and what convinced you to go ahead with it?
- What are your driver’s opinions of the switch?
- Do your customers have any opinions about electric transport vehicles?
- How have your routines changed since introducing the new technology?

Questions for Truck Manufacturers

- What have been your customers' main hesitations about switching to battery operated trucks?
- Range and charging time are two major concerns held by customers, how are you working to alleviate those concerns?
- Where do you see the future of this technology going?
- Is the increased weight of the batteries a concern?
- What is the lifecycle of the batteries?

7.2. APPENDIX B: LITERATURE REVIEW SORTING TABLE

Each source was defined with three categories:

- Type of tech: the main type of technology that is covered in the source (battery, hybrid, or hydrogen)
- Information: a brief summary of the content of the source
- Tags: used to categorize the data. The four tags are:
    - Quantitative data (any sort of numbered data pertaining to the technology)
    - Technical info (data about how the technology works)
    - Geographical info (information about how geography effects the technology)
    - Social info (information pertaining to people's thoughts about the technology)

Alternative Fuels Data Center: Fuel Cell Electric Vehicles. (n.d.). U.S. Department of Energy. Retrieved September 22, 2021, from https://afdc.energy.gov/vehicles/fuel_cell.html

Type of tech: Hydrogen

Information: Article on how fuel cell vehicles work

Tags: Technical info

Bhagavathy, S., Budnitz, H., Schwanen, T., & McCulloch, M. (2021, March 22). *Impact of Charging Rates on Electric Vehicle Battery Life | Published in Findings*. Findings. https://findingspress.org/article/21459-impact-of-charging-rates-on-electric-vehicle-battery-life

Type of tech: Battery

Information: Article on how factors like temperature and charging rate can affect battery life

Tags: Quantitative data, technical info

Bradley, S. (2021, March 26). *Electric cars are on the way, but is Switzerland ready?* SWI Swissinfo.Ch. https://www.swissinfo.ch/eng/electric-cars-are-on-the-way--but-is-switzerland-ready-/46469024

Type of tech: Battery

Information: Article about the future of electric vehicles in Switzerland

Tags: Social info

Electric cars: Is the tide now turning? (2020, October 19). Zurich.Ch. https://www.zurich.ch/en/services/knowledge/vehicles-and-travel/electric-car-switchover

Type of tech: Battery

Information: Article about the future of electric vehicles in Switzerland

Tags: Social info

GM's Path to an All-Electric Future | General Motors. (n.d.). General Motors. Retrieved September 22, 2021, from https://www.gm.com/electric-vehicles.html

Type of tech: Battery

Information: Publication about GM's plan to implement more battery-powered vehicles

Tags: Social info, technical info

Li, Y., & Kimura, S. (2021). Economic competitiveness and environmental implications of hydrogen energy and fuel cell electric vehicles in ASEAN countries: The current and future scenarios. *Energy Policy*, *148*, 111980. https://doi.org/10.1016/j.enpol.2020.111980

Type of tech: Hydrogen

Information: Report about hydrogen production

Tags: Quantitative data, social information

Matulka, R. (2014, September 15). *The History of the Electric Car*. Energy.Gov. https://www.energy.gov/articles/history-electric-car

Type of tech: Battery

Information: Article on the history of the electric car

Tags: Social info

Richardson, D. B. (2013). Electric vehicles and the electric grid: A review of modeling approaches, impacts, and renewable energy integration. *Renewable and Sustainable Energy Reviews*, *19*, 247–254. https://doi.org/10.1016/j.rser.2012.11.042

Type of tech: Battery

Information: Journal about the implementation of electric vehicles and their effect on the electric grid

Tags: Quantitative data, technical info, geographical info, social info

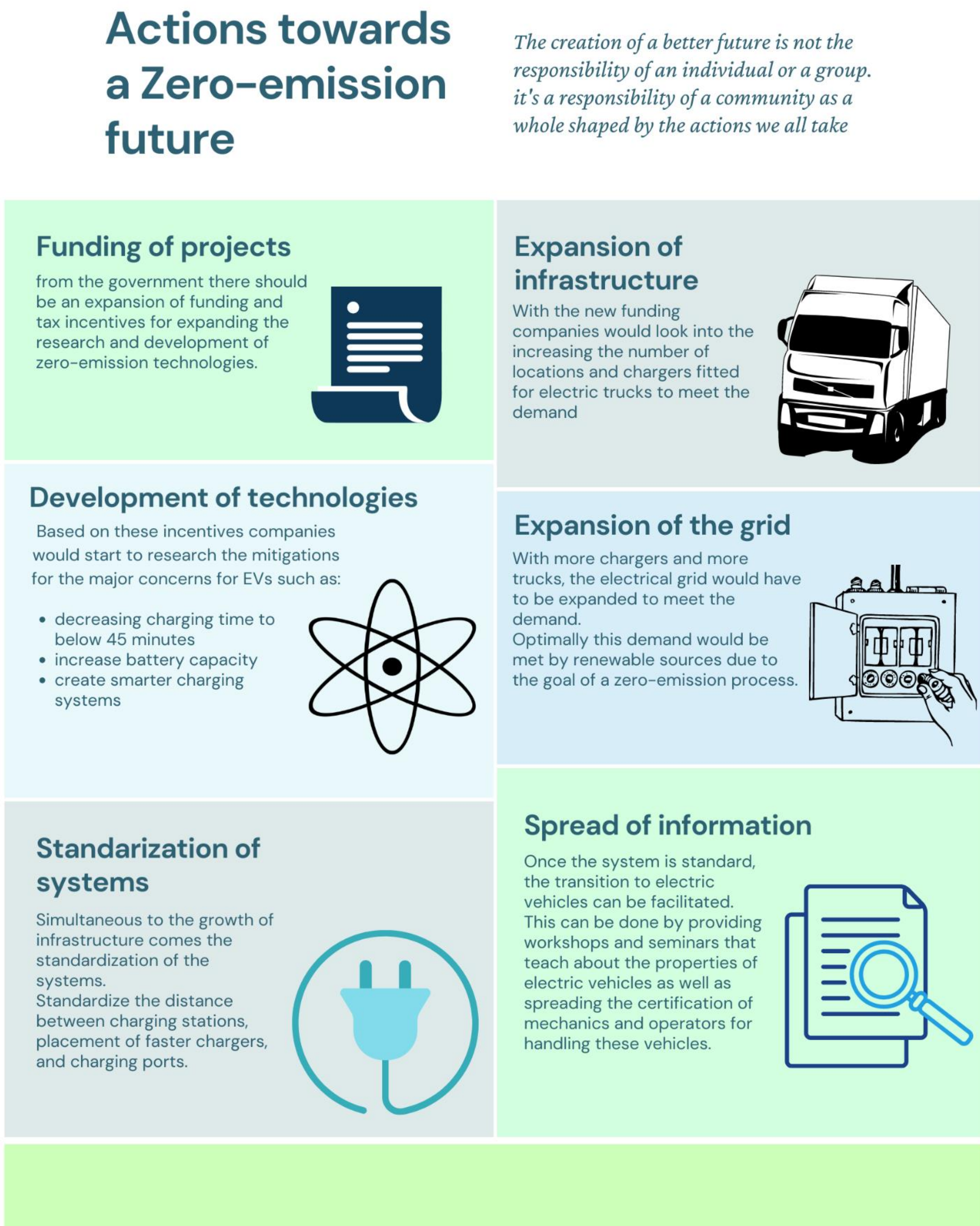
Thiel, C., Perujo, A., & Mercier, A. (2010). Cost and CO_2 aspects of future vehicle options in Europe under new energy policy scenarios. *Energy Policy*, *38*(11), 7142–7151. https://doi.org/10.1016/j.enpol.2010.07.034

Type of tech: Battery

Information: Report on price of electric vehicles

Tags: Quantitative data, technical info

7.3. APPENDIX C: ROADMAP INFOGRAPHIC



7.4. APPENDIX D: FUTURE RECOMMENDATIONS FOR SPONSOR

Our first recommendation is to continue your work with the development of the Megawatt charger. This will make your trucks much more competitive to diesel trucks and should really open up the market for electric trucks.

Another recommendation is to develop a model for total cost of ownership. One thing that we found is that fleet owners have a difficult time coming up with an accurate lifetime cost of the vehicle since there is not much data available yet. This model would be buyer specific and would combine set factors such as initial cost, fuel prices, and tax incentives with specifications from the buyer like length of route, weight of package, and the frequency of use. This would give potential customers a more transparent look at the investment they are making and allow them to make a decision based on more concrete information and less speculation. This could be another potential IQP project for WPI.

Once the Megawatt charger is completed, it will need to be produced and distributed to locations throughout Switzerland. This will require a review of potential places and the infrastructure at those places. This could be done by your company, but it would probably be appropriate for the Swiss government.