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Technological breakthrough in the world of trucks. Electric and Hydrogen trucks.

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Abstract

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Abstract

The purpose of this thesis was to identify what a transportation company should know about alternative drivelines and how they can be ready for the changes in the trucking market. The study focused on hydrogen and battery-powered drivelines – as they are the most competitive and completed technologies, and the availability of the Finnish market for these technologies.

Data for this thesis were collected from internet sources, academic literature, and professional journals. This data were collected to gain insight into the available alternative technologies in the market and the current situation of electric and hydrogen trucks. For the empirical part, data was collected by semi-structured interviews with industry insiders who represent a truck manufacturer and a case company.

The result of this thesis was that already in 2024 electric and hydrogen trucks will be available for both local and intercity transportation. It was identified that hydrogen and electric trucks are more efficient than diesel trucks but they need more investment. Finnish infrastructure is not ready yet for electric and hydrogen trucks. However, it is expected that in 10 year-time the situation will be improved in a positive direction.

The thesis provides a case company with tips to help facilitate the transition to alternative drivelines.

Keywords

Electric truck, hydrogen truck, truck technologies, transportation Finland

Contents

1 Introduction

1.1 Background

The struggle for the future makes people think about the environmental consequences already today. Therefore, authorities implement pollution standards for the majority of different sectors, including the transport sector. In December 2020, Europe's truck manufacturers under the umbrella of the European Automobile Manufacturers' Association (ACEA) have signed an agreement that by 2040 all-new trucks sold need to be fossil-free to reach a carbon-neutrality in European Union by 2050. ACEA members with leading scientists from Potsdam Institute for Climate Impact Research agreed that climate change is the most fundamental challenge of our generation.

All members, namely Daimler, Scania, Volvo, DAF, Iveco, and Ford have signed a pledge to phase out traditional combustion engine vehicles by 2040 and instead of that focus on battery technology, hydrogen, and clean fuels. It is estimated that the largest truck manufacturers jointly will spend around 100 billion euros on new technologies.

The transition to alternative fuels affects not only truck manufacturers but also European economies and transport businesses in particular. In a short time, countries must build conditions including important infrastructure facilities and subsidies to meet new market needs. Tough competition in the transportation market force businesses to start thinking already today about what driveline will be more suitable for companies' needs to minimize costs and increase revenue.

1.2 Objectives

The purpose of this study is to identify what a transportation company should know about alternative drivelines and how they can be ready for the changes in the trucking market. The study will focus on hydrogen and battery-powered drivelines – as they are the most competitive and completed technologies, and the availability of the Finnish market for these technologies.

1.3 Limitations

The empirical study in this thesis focuses on the perceptions of European truck manufacturers and their products. Due to innovations and technologies which are still under development and piloting processes is one of the key competitive advantages of track manufacturers, they might not be interested to share certain characteristics and figures.

1.4 Delimitations

This study will not be focusing on the other alternative technologies such as hybrid and natural gas trucks.

This study will not be focusing on truck manufacturers and their products' characteristics from outside of the European Economic Area.

This study will be focusing only on Finnish market-specific trucking standards and regulations.

This study will be focusing only on case company-specific trucks.

1.5 Research question

The main question of this research is aiming to answer is: What a transportation company should know about hydrogen and electric trucks and how they can be ready for the changes in the trucking market?

The second question: What are alternative technologies to a diesel truck?

The third question: What driveline should a company choose for intercity transportation?

2 Zero Emission

2.1 Change drivers in the transportation industry

Life never stands still, on the contrary, it moves forward, develops, and evolves. In the same way, so that the business can meet the needs of people, the business must keep up with the times. Moreover, business is always under pressure from governments due to constant restrictions, prohibitions, regulations, and legislation.

In 2021, European Commission launched an updated proposal called “Fit for 55” whose main goal is to reach a 55% emissions reduction by 2030. European Commission identified that EU Member States' total amount of pollution reached a critical number, and it must be decreased soon. Therefore, to decrease the impact on the environment the “Fit for 55” policy was launched. The proposal includes a ban on combustion engines from 2035. That means all vehicles sold from 2035 should be driven by alternative fuels including trucks. (Hoof 2021)

Namely European Climate Law, EU Regulations and Directives are driving the change in the transport industry (Hoof 2021). Up to now, the combustion engine is the most common in Europe, therefore, these serious decisions completely will change the transport industry. In 10 years, countries, vehicle manufacturers, companies and drivers should prepare for the change. For a business to function, it must comply with all the rules. This also applies to heavy vehicle manufacturers. But how to do that in such a short time?

2.1.1 EU Regulations and Directives

One notable example of regulation which applies to heavy-duty vehicle manufactureres is a European Union Regulation 2019/1242 of the European Parliament and of the Council of 20 June 2019 setting CO2 emission performance standards for new heavy-duty vehicles and amending Regulations (EC) No 595/2009 and (EU) 2018/956 of the European Parliament and the Council and Council Directive 96/53/EC. According to this regulation, the European Union aims to achieve net-zero greenhouse emissions by 2050. Therefore, the EU introduced a plan to gradually reduce emissions and eventually get rid of them completely. (EUR-Lex 2019)

One of the key elements of this directive is to apply regulations to the logistic industry. Thus, more and more transportation companies are considering how to reduce emissions and become carbon-free already in close future. (EUR-Lex 2019)

Over the past 10 years, environmental issues have increasingly been discussed due to the large increase in emissions which contributes to global warming and pollution, and the distinction of flora and fauna. Thus, more and more transportation companies are considering how to reduce emissions and become carbon-free already in close future. To achieve that, the most promising option nowadays is to choose a sustainable business development model. Sustainability combines not only environmental issues but also contributes to economic and social aspects. (EUR-Lex 2019)

Additionally, to achieve the aim of Council Directive 96/53/EC, European Union has introduced directives that promote it:

- The Energy Efficiency Directive (EED) – To reduce 32.5% of the EU's overall energy consumption by 2030;
- The Renewable Energy Directive (RED) – To move from non-renewable energy sources to renewable (or green) energy;
- The Energy Performance of the Building Directive (EPBD) - In the long term, smart charging stations are a cost-efficient choice for both real estate owners and consumers;
- Market Design Directive and Regulation – With smart charging systems, consumers have a right to use, generate, store, and even sell energy without redundant charges. (Virta 2021)

2.2 Electromobility

The concept of electromobility is the way to achieve the goals of EU directives. Electromobility is the use of fully or partly driven electric vehicles such as electric/hybrid cars, e-trucks, e-buses, e-bikes, e-plains, trains, and other electric-powered vehicles. Electromobility contributes to the change of the automotive world, namely switching from an internal combustion engine to an electric motor to decrease emissions. One of the reasons is that according to the research made by World Economic Forum, transportation and storage is the fourth biggest source of CO2 in Europe (Figure 1). (Infineon 2021)

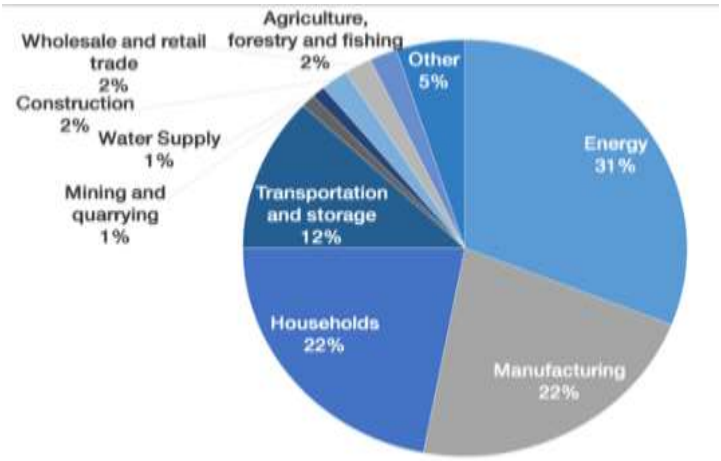

Figure 1. Sources of European CO2 emissions (Myers 2015).

The second benefit of electromobility is that low-emission cars also mean better air quality and less noise, especially in megacities, therefore having a positive effect on people's health.

Moreover, combustion engines use gasoline and diesel fuels which are made from fossil fuels like oil or gas, which are non-renewable resources, and it is estimated that oil reserves will last almost 50 years. (Infineon 2021)

Electromobility count that electric vehicle does not emit any CO2 when driving. However, e-cars are carbon neutral in a full sense if batteries and the electricity to power them are produced using renewable energy only.

2.2.1 Advantages of electromobility

The electric vehicle is regarded as eco-friendly. However, this is not the onliest benefit of the newest types of vehicles. Electricity is cheaper than fossil fuels, especially against the backdrop of rapidly rising fuel prices. Electric vehicle requires fewer repairs and less

maintenance. An electric motor has only 250 components that have to be made and assembled – compared with 2500 in a combustion engine. Moreover, there is no need to change filters and oil, and there are no belts and exhaust systems. The way to serve e-cars is to connect them to the internet and quickly update the software. (Infineon 2021)

Marketers say in the advertisement that the main advantages of an electric vehicle are:

Cleaner. Quiter. Electric. (Volvo 2021).

2.3 Energy in Europe

In 2020 the share attributable to renewable energy in Europe was 20% (Appendix 2) and in the world is even less. Looking at Figure 2, the rise of renewable energy and the fall of fossil energy is visible in the past 10 years. (Eurostat 2019)

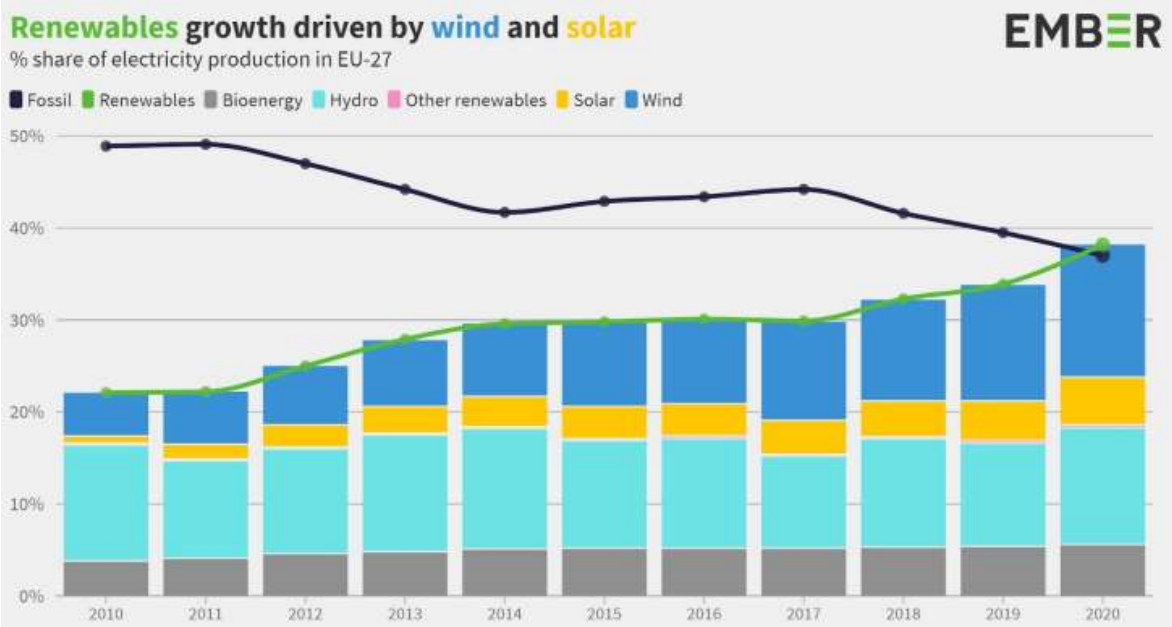

Figure 2. Renewables growth by source (Taylor 2021).

The main component of electromobility is power, green energy in particular. There are two main types of green energy, renewable energy, and highly efficient nuclear plants. Renewable energy comes from natural sources with low emissions of carbon. The sources of renewable energy are solar energy, wind energy, hydroelectric power, biomass energy, geothermal energy, and marine current power. (Infineon 2021)

Not all sources of natural energy are beneficial for the environment. Large hydroelectric dams impact a lot of wildlife by changing water streams and flooding territories. (Infineon 2021)

However, is it enough to fulfill all current needs of energy plus all-electric vehicles? So far only Norway and Iceland are ready for that. Sweden, Finland, and Latvia are in the top 5 (Appendix 2). This means, that in the coming 4-5 years Finland will be ready for switching fully to electromobility. Only countries that can cover renewable energy for the needs of transport can fulfill the need for electromobility and be truly carbon neutral. Therefore, the question comes up: Are electric vehicles the key to solving the emissions problem?

To fulfill the need for electromobility, the European Commission has proposed to label nuclear power as green energy at the end of 2021. The proposal says that nuclear energy is a key to assistance in the transition to cleaner energy. Moreover, it says that some of the gas plants with high standards would be considered green:

It is necessary to recognise that the fossil gas and nuclear energy sectors can contribute to the decarbonisation of the Union's economy. (European Commision 2022)

2.4 Electromobility in long term

2.4.1 What was Volkswagen's diselgate scandal?

In 2015, the United States Environmental Protection Agency (EPA) found:

In over 590,000 diesel motor vehicles, Volkswagen had violated the Clean Air Act as the vehicles were equipped with "defeat devices" in the form of a computer software, which was designed to cheat on federal emissions tests (TheIndianEXPRESS 2020).

Then, later on, Volkswagen confirmed the violation, and totally over 11 million cars worldwide were involved in a scandal. In 2020, Volkswagen says that the diesel scandal cost it 31.3 billion euros. (Staff 2020)

Moreover, in mid-2021, BMW and Volkswagen were fined by European Union for „colluding on emissions technology*"* (Ewing 2021).

2.4.2 How did the electric car become common?

The world began to speak about electric cars on masse about 7 years ago when against the backdrop of a diselgate scandal with Volkswagen, Tesla company managed by Elon Mask and some other car manufacturers including BMW decided to take advantage of this situation and introduced a new type of a car – Electric Vehicle (Figure 3). (Carey & Steitz 2021)

Figure 3. BMW iX – the most modern and luxurious electric car in 2022 (BMW Suomi 2022).

Because of the diesel scandals and global warming, the EU actively is discussing a ban on diesel and petrol cars by 2035 in principle and this contributed to the rapid creation of directives aiming to support electric vehicles. (Carey & Steitz 2021)

Currently, more than 70 percent of all car markets use „dirty power“. To ensure that electric vehicles are zero-emission, their electricity must come from green sources only, and not from non-renewable resources. Moreover, the production of the battery must also be carbon neutral. (Hubik 2017)

Similarly, under the pressure of the government and constant tightening of emission standards more and more regular and commercial vehicle manufacturers are increasing the production of electric vehicles. Thus, the question of increasing electricity production pops up.

According to Hubik, it was already predicted in 2017 that European Union will face a shortage of electricity (Hubik 2017). Researchers warned that all decisions should be made deliberately related to electricity. Despite this, in January 2022, Europe faced an energy crisis (The Economist 2022). The situation is exacerbated by the pandemic and the

shortage of natural gas. If electricity rises in price and there is not enough of it (and this has already happened), then all services and goods will rise in price.

According to the research made by the International Council on Clean Transportation, at the latest in three years' time, electric vehicles will overtake gasoline and diesel ones in terms of climate footprint (Infineon 2021). Therefore, most European countries must urgently increase the production of green energy, otherwise, people will speed up climate change and global warming. The author believes, that in three years it is impossible to increase the production of green electricity to achieve a break-even point in emissions.

2.5 Green energy of Finland

To analyse the implementation of The Renewable Energy Directive in Finland, green and renewable energy production was studied.

Finland is one of the world leaders in the production of green energy. The utilization of renewable sources of energy has already reached 40% and in the close future, it will achieve the result of 50%. The key target of the Finnish National Energy policy is to reduce greenhouse gas emissions and move from fossil energy to green energy. (Gronlund 2020)

In 2021, Finland got its fourth nuclear reactor. They produce 27.4% of electricity in total. Moreover, a fifth reactor is under construction and one more is planned. That will contribute to nuclear power about 60% of all electricity production in Finland and replace coal. Already

Energy supply	TWh in 2020	Percentage share of total energy consumption
Nuclear power	22.3	27.4%
Hydro power	15.7	19.2%
Wind power	7.9	9.7%
Solar power	0.2	0.3%
Net imports	15.0	18.4%
Peat, coal, natural gas, oil	20.4	25%
Total	**81.6**	**100%**

Table 1. Total energy consumption by source (TWh) in Finland 2020 (Statistics Finland 2022)

today, Finland is able to produce about 60% of green energy (Table 1). This is a very high number in comparison to other EU states. (Statistics Finland 2021)

According to Table 1, Finland produces enough green energy to take advantage of electromobility without environmental impact.

2.5.1 Electricity prices in Finland

The situation with electricity prices is very unstable because of different events happening nowadays in the world. Europe's electricity shortage only exacerbates this. Because of Finnish high volume production and nuclear power plants, the situation in Finland is better than in neighboring country Estonia, where the average price since March 2021 is 0,15 €/kWh (Eesti Energia 2022). In Finland, the average electricity price since March 2021 is 0,09 €/kWh (Helen 2022). However, prices since January 2022 increased a lot in Finland as well which shows in Figure 4. Important to take into consideration the nightly rate is lower

Figure 4. Energy prices 2022 in Finland (Helen, 2022).

than the daily rate. The nightly rate is lower on average and is applied Monday to Sunday from 10 pm to 7 am (Caruna 2015).

3 Overview of Trucking

3.1 The new roadmap of trucking by 2040

In addition to European Union Directive 96/53/EC, at the end of December 2020, Europe's truck manufacturers and European Automobile Manufacturers' Association (ACEA) have signed an agreement that by 2040 all brand new trucks sold must be fossil-free to reach a carbon-neutrality in European Union by 2050. ACEA members with professors from Potsdam Institute for Climate Impact Research (PIK) agreed that climate change is the most fundamental challenge of our generation. (ACEA 2020)

All members, namely Daimler, Scania, Volvo, Daf, Iveco, and Ford have signed a pledge to phase out traditional combustion engine vehicles by 2040 and instead of that focus on battery technology, hydrogen, and clean fuels. However, earlier in November, the UK Government introduced its ban on the sale of vehicles with a combustion engine by 2030. (Hill 2020)

The new commitment will not only bring carbon emissions down but will also improve air quality levels which will bring a positive effect on human health. (Hill 2020)

3.1.1 New technologies

According to a report made by Financial Times, it is estimated that the largest truck manufacturers jointly will spend around 100 billion euros on new technologies. Meanwhile, ACEA and European Union are committed to preparing refueling and recharge infrastructure for the new transport and creating enabling commitments. (Hill 2020)

According to the DAF Competition book 2021, each European truck manufacturer is developing alternative drivelines to a diesel truck. There are four different technologies. However, the biggest accent is set to hydrogen and electric trucks because only those technologies are green. Most important, hydrogen and electric trucks fulfill the requirements of EU directives.

3.2 Finnish truck market

There are eight big competitors on the Finnish market: Volvo, Scania, Mercedes-Benz, Iveco, DAF, SISU, MAN, and Renault. Based on Statista, 2423 trucks were sold in Finland in 2021 (Figure 5). All mentioned above manufacturers sell diesel heavy-duty trucks with the purpose of transportation of more than 16 tons and some of them with an alternative

LNG fuel. They all have a wide range of different combinations for all kinds of heavy-duty transportation. (Statista 2022)

Despite tough competition, Volvo and Scania lead by a wide margin. Most probably, that is related to the power unit characteristics and features of Finnish road trains. In Finland, it is legal to have a load of up to 76-104 tons in comparison to 40 tons in Europe. Therefore, 400-500 hp engines that are common in Europe are not suitable for such weights. Adapted to such cargoes Scania with their V8 engines 530 hp, 590 hp, 660hp and 770 hp, and Volvo with 550 hp, 650 hp, 750 hp engines. (Volvo 2022 & Scania 2022)

Moreover, nowadays it is possible to find in a product list an electric truck from all European truck manufacturers except Finnish truck manufacturer SISU. However, only trucks from DAF and Volvo are suitable for long-range heavy-duty transportation. Others, sell trucks that are suitable only for urban transportations on short distances.

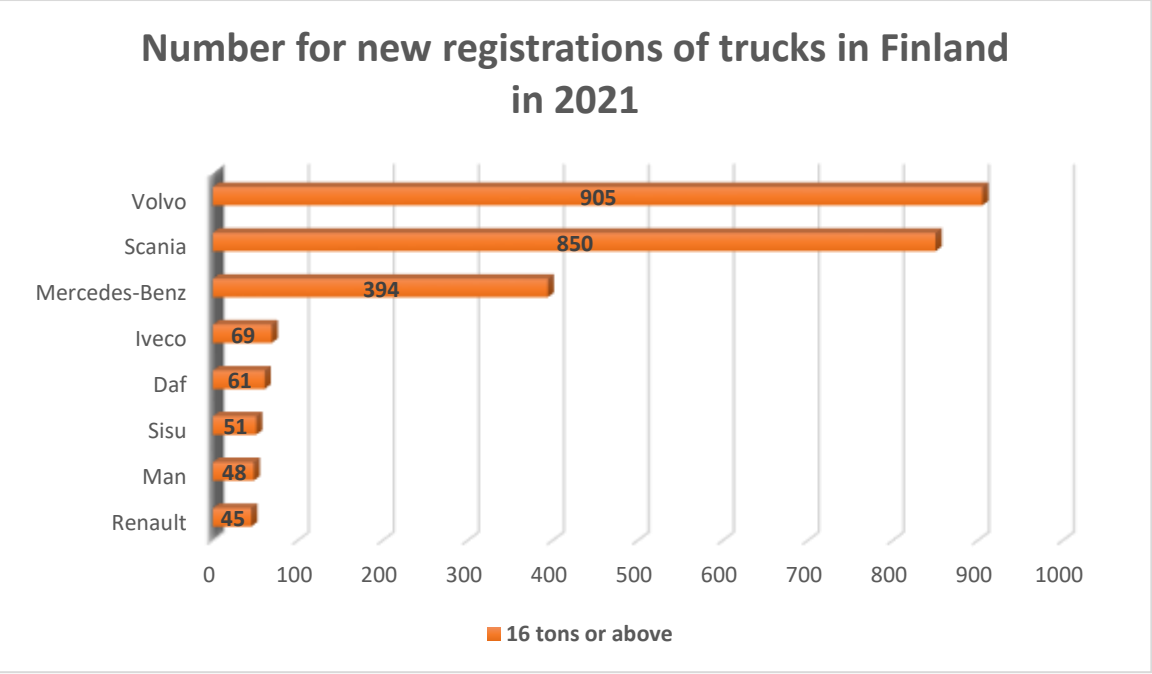

Figure 5. The figure for new registrations of trucks in Finland in 2021, by brand and weight (Statista 2022).

Regarding hydrogen trucks, it is impossible to buy a hydrogen truck from any manufacturer right now. However, almost each of them has test trucks. Those trucks are tested by companies by making real deliveries to develop new technologies before mass production.

All manufacturers understand the potential of electric and hydrogen trucking markets in the coming future. Therefore, each manufacturer wants to create the most advanced product for a customer. There will be a lot of competition in this segment soon. Many new players want to join the game and the majority of them have experience in the production of regular

cars. These companies include Toyota in cooperation with HINO, Tesla, FORD, and Hyndai. Newcomer companies are NIKOLA and HYZON. Both of them already have a production factory in Europe. (DAF 2022)

3.2.1 Standards for heavy road transport in Finland

It took only one year for the PITKÄ (LONG) (Figure 6) sign has become familiar to all drivers in Finland (Traficom 2020). What happened?

In 2013 Finland and Sweden decided to revise the European Union directive „The Weights and Dimensions Directive“ of 1996 which sets maximum vehicle weights and dimensions for both national and international road transport in the EU. However, based on the directive, all member countries can decide their own rules for vehicles used only in national transport. Therefore, Finland and Sweden decided to be the first to use this opportunity for the benefit of their economies. In 2019, Traficom even increased road train measures and made easier bridge rule than in Sweden. After over five years of testing High Capacity Transport (HCT) up to 104-tonne giant trucks and many other combinations Finnish Transport and Communications Agency Traficom finally gave the green light to use road trains on the allowed roads. Traficom researched that bigger capacity transport brings certain advantages if you approach it with care and take into account all safety measures. (Lahti 2020)

Figure 6. Road trains trucks with PITKÄ sign (ammattilehti.fi 2020).

Firstly, heavier and bigger transportations decrease emissions by up to 15% (because fewer truck-power units are used). Secondly, fewer drivers are needed which contributes to better safety and less traffic. Last but not least, flexible rules and standards create more favorable

conditions for transport companies to choose the most optimal configuration for the customer's needs. That contributes to price reduction and eventually the development of local companies. (Lahti 2020)

To understand the magnitude of the situation, one should look at Table 2.

After one year of public exploitation of new-standard HCT trucks, Traficom confirmed with confidence that the safety requirements for road trains have been effective and traffic safety has not declined. This case is a great example of how Finland supports its domestic business. Based on Finnish “road success“, already Estonia, Denmark, Netherlands, and Germany started to test on their national roads HCT trucks. (Lahti 2020)

Characteristic	**Finland**	**Europe**
Max road train Length	34,5 m	18,75 m
Semitrailer Length	13,6/14,8/16/17,5/19 m	13,6 m
Number of Axels	8-axle/9-axle/10-axle/10+	5-axle
Max road train Weight	68 t/76 t/84 t/>104 t	40 t
Max Height	4,40 m	4,00 m
Common combinations Truck + dolly(s) + trailer(s)	A-double (26-34.5 m) B-double (20-34.5 m) B-triple (34.5 m) AB-double (34.5 m)	Truck + trailer/semitrailer

Table 2. Comparison of road train’s characteristics in Finland and Europe (Lahti 2020).

3.3 Nordic climate vs truck

That is not a secret that Finland is one of the coldest countries in the world with constantly changing weather and road conditions. Therefore, transport should be adopted for that. For companies, that only means bigger expenses.

For many years, on the market, it is possible to buy more expensive than regular Diesel special winter Diesel fuel which will not freeze at - 40 °C. That contributes to the reliable operation of the engine even in severe frosts. However, at low working temperatures and additional friction with snow, the fuel economy can drop by 30-34%. (Neste 2022)

Moreover, trucking companies have to buy chains. Sometimes, companies install expansive winter tires. For the comfort of drivers, manufacturers began to integrate autonomous heating installations called Webasto. The main engine remains switched off while an additional small diesel engine heats the cabin and keeps the oil of the main engine warm. (Webasto 2022)

If for a diesel truck this only affects additional costs for an electric truck that also affects the range which could drop by 35-40%. Moreover, cold weather slows the chemical and

physical reactions that make batteries operate. As a result, that leads to a shorter lifecycle of a battery and longer charging time. (Hajman 2021)

4 Alternative technologies

4.1 Diesel truck

A diesel engine-powered truck is the oldest configuration of a truck which is still in use since 1923 (Daimle 2011). Throughout history, after the combustion engine was invented and significantly developed, the diesel engine is still the most common in cumercial vehicles.

To make a diesel engine work O2 and diesel fuel is needed. As a result of combustion, CO2 is released inside the engine.

With the increase in cargo transportation around the world, it has been noticed that diesel engines in aggregate have a great impact on the environment. Moreover, diesel fuel is made from non-renewable oil that will eventually lead to its completion unless the volumes of use are greatly reduced.

Against the background of all this, emissions standards were introduced.

4.1.1 Euro emissions standards for heavy-duty diesel engines. DEF (AdBlue).

In the fight for the environment, in 1992 Europe introduced the „Euro“ emissions standards for all vehicles including heavy-duty diesel engines which are used in diesel trucks. It is commonly referred to Euro I ... Euro VI, however, sometimes numerals are also used: Euro 1 ... Euro 6 (DieselNet 2021). In this research, roman numerals are referencing emissions standards for heavy-duty engines.

It is clearly visible from Figure 7 that emissions of one brand new diesel truck with Euro VI are equal to 20 diesel trucks with Euro I.

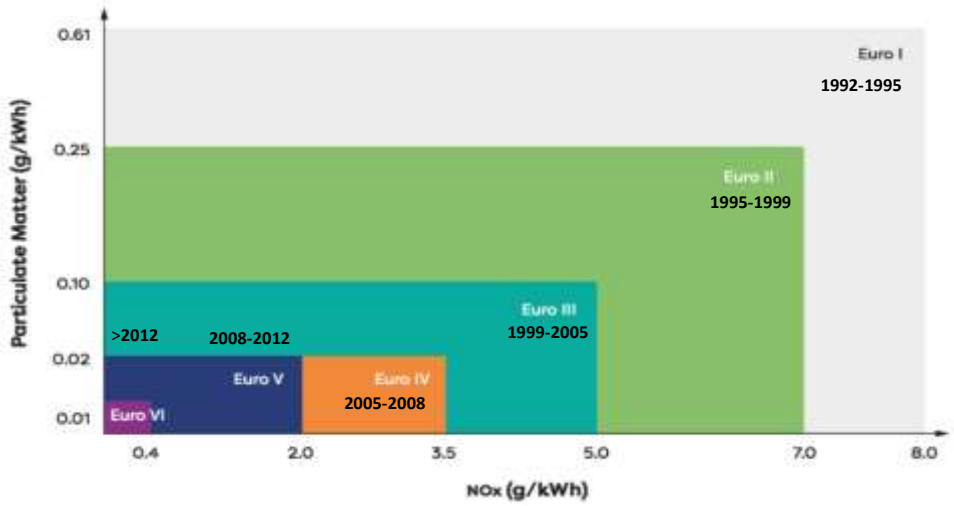

Figure 7. Development of European Heavy-duty Legislated Emissions Limits (AECC 2020).

DEF (AdBlue)

To meet Euro emission standards many modern diesel vehicles use DEF (Diesel Exhaust Fluid) and AdBlue (abbreviation used in Europe). This applies not only to trucks, ships, and heavy commercial vehicles but also to some regular cars (Eurol 2020).

AdBlue is a clear mixture of demineralised water and pure urea (32.5%). It is designed to reduce harmful emissions of nitrogen oxides (NOx) from diesel vehicles to non-hazardous gases, to comply with more stringent emission standards (Eurol 2020).

AdBlue is used in vehicles with a Selective Catalytic Reduction (SCR) catalyst. An SCR catalyst ensures that exhaust gases are treated before they leave the vehicle. All modern diesel European trucks are equipped with an SCR system. (Eurol 2020)

4.1.2 The paradox of emission standards

While the world is struggling with emissions and global warming, Africa became a tool for lower emissions figures and fulfillment of global warming requirements (Figure 8).

According to the United Nations report, millions of highly polluting vehicles (trucks including) from developed countries are being “dumped” in developing nations. The half goes to Africa, another half to Asia and Latin America. (McGrath 2020)

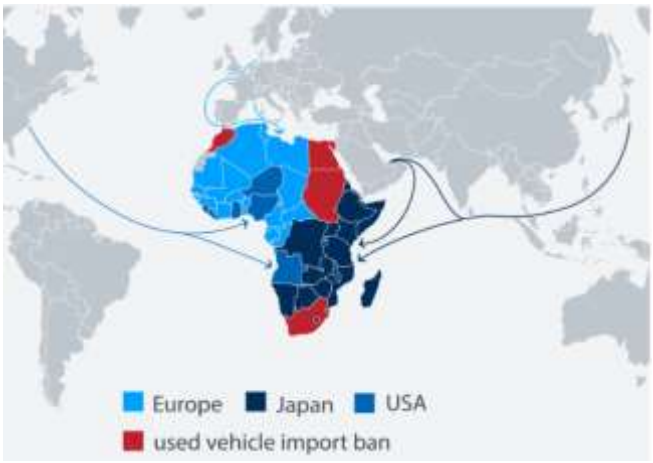

Figure 8. Trade in used vehicles to Africa (Deutsche Welle 2018).

Moreover, European truck manufacturers such as DAF, Volvo, and Scania continue to sell brand new Euro III trucks to the Middle East and Africa (DAF 2021 & BAS TRUCKS 2022 & Scania East Africa 2021). To remind, Euro III was introduced in 1999.

4.1.3 Diesel fuel price

The situation with diesel fuel prices is very unstable because of different events happening nowadays in the world. Since 2020, diesel price has increased by 67%. In 2020 the average diesel fuel price in March was 1,39 €/l, 1,50 €/l in 2021, 2,33 €/l in 2022. (Tilastokeskus 2022)

4.2 Gas truck

If a trucking company is looking for sustainable and lower fuel costs transport, CNG- and LNG-powered trucks could be an option. The current technology allows using of the same engine CNG and LNG are produced from both natural gas and biogas depending on the source (Volvotrucks 2022). Moreover, the possible range of a twin fuel tanks truck with biogas inside can be up to 1700 kilometers (Scania 2022).

In comparison to a European diesel truck, gas trucks potentially reduce the CO2 footprint by up to 100% (using biogas). The gas engine is not a new technology, it became in mass use after the gas liquefication, and gas transportation technologies were developed. Moreover, the possible range of a twin fuel tanks truck with biogas inside can be up to 1700 kilometers (Scania, 2022).

However, the underdeveloped infrastructure for gas stations repels many from choosing a gas engine. Additionally, when transporting heavier loads, gas is less efficient than diesel. Nevertheless, the gas truck is a great option for urban distribution transports, snow plows, and waste collection because it used to carry relatively light cargo, has lower emissions, and is up to 10 dB quieter than comparative diesel engines (Freightliner 2022).

4.2.1 CNG vs. LPG vs. LNG fuels: the difference

CNG

Compressed Natural Gas (CNG), is the gaseous product of petroleum and that product is separated during the distillation process. Key elements of CNG are methane, nitrogen, carbon dioxide, and propane.

Advantages: cheap, the greenest gas, readily available today. Disadvantage: poor energy density and needs more space – more weight (Freightlainer 2022).

LPG

Liquified petroleum gas (LPG), is a liquefied gas and is a by-product derived while extracting crude petroleum (UTI 2020).

Advantages: emits less than petroleum (however, the dirtiest gas), has a high-octane rate, and increases engine longevity.

LNG (Biogas)

Liquified Natural Gas (LNG) is a natural gas converted to liquid. However, biogas (LBG) is a 100% renewable form of energy and it can be produced almost from any organic waste. The main components of LNG and biogas are methane, nitrogen, ethane, carbon dioxide, and propane (UTI 2020). Due to similarities in composition and power at the gas stations, it is customary to combine the concept of LBG with LNG. However, biogas significantly reduces emissions.

Advantages: not toxic, occupies 1/600 the volume of natural gas which means less weight, cost-effective for storage and transportation, and energy density comparable to diesel fuel (UTI 2020).

Therefore, due to high efficiency, less pollution, and low occupancy, biogas and LNG are the choices of many long-haul trucking companies.

4.3 Hybrid truck

The hybrid truck adds to the list of alternative technologies in the world of trucks. There are two types of hybrid technology – PHEV and MHEV (Appendix 3). Thanks to the choice of power, the hybrid truck is designed for both long-haul and urban operations.

The hybrid truck is currently being tested by many truck manufacturers and is still not in mass production. Currently, only one European truck manufacturer sells a hybrid truck - Scania.

The hybrid truck takes the strength of both electric and the diesel engine. The electric and diesel power can be combined under heavy loads, only electric power could be used on city streets at low speed and the traditional combustion engine powertrain is a great option for a highway.

Hybrid technology is relatively old technology. The first mass hybrid car was produced already in 1997 by Toyota (Toyota 2022). However, why did hybrid trucks never see mass production until now?

4.3.1 PHEV and MHEV

The Plug-in hybrid electric vehicle (PHEV) uses the electricity power received through the charging cable attached to the vehicle's port by a plug. In that case, the power charging station is used to charge a vehicle's integrated battery. Depending on battery capacity, charging station limits, battery temperature, power station temperature, and the battery level is being charged up, define how long it takes to charge a battery. (Muhonen 2016)

The powertrain works by recovering energy when driving downhill on slopes steeper than one percent, or when braking. The recovered energy is stored in the vehicle's batteries and used to power the truck in electric mode on flat roads or low gradients (Volvo 2022).

A Mild (sometimes light) Hybrid vehicle (MHEV) is the second variation of a hybrid vehicle. The difference is that it uses a smaller battery so that it cannot drive on battery power alone. The role of the battery is to help an engine perform more economically and gives extra power when it is needed. Energy recovery is the onliest way to charge the battery in that vehicle. (KIA 2022)

4.4 Electric truck

As it was mentioned earlier, the electric truck is one of the most rapidly developing technologies in the world of trucks. The electric truck is a quiet truck that enables emission-free operations. The electric truck is a perfect option for high-capacity grocery deliveries, crane services, container transportation, and more in metropolitan areas. Potentially, it also operates in zero-emissions zones or during daytime not accessible for a diesel truck (Volvo 2022).

Additionally, more and more companies want to be carbon-free, therefore, they have to order ecological transport, where electric truck appears.

Like any invention, in addition to the advantages, there are challenges relating to electromobility. The lack of noise concerns the challenge of electromobility. Pedestrians used to hear the noise of the vehicles especially in cities and along highways. As was mentioned earlier, electric vehicles significantly less make noise than vehicles with engines. In times of headphones and loud music, it will take time to use that feature first. Only after that, we can speak about safe traffic for the weakest group of it – pedestrians. From July 2019 the majority of European manufacturers integrated the Acoustic Vehicle Alerting

System (AVAS) which supposes to generate electronic noises similar to regular cars up to a speed of 20 km/h. If the electric vehicle goes faster, the noise of its tires can be heard anyway by pedestrians. (Infineon 2021)

Currently, almost all European truck manufacturers have an electric truck on their product list. There are Volvo, Scania, DAF, Renault, and Iveco. However, because of the battery limits and long charging time, current technologies guarantee only a 250-400 km range. Thus, the electric truck is not an option for an everyday basis intercity transportation.

As was mentioned earlier, it is important not to forget that electromobility can be equal to zero-emission technology only if the energy was produced from green energy sources. Therefore, if we take into consideration that currently only 29 percent of electricity generated in 2020 was renewable, we cannot speak about electromobility as an absolute carbon-neutral technology in closest future. (C2ES 2019)

Nevertheless, despite the low range and slow charging speed, engineers are constantly looking for new solutions. For instance, over the past couple of years, the charging time decreased from 8-10 hours just for 90 minutes, and the range was increased from 150 kilometers up to 400 kilometers. It cannot be denied that by 2030 the technology could be improved and will allow intercity transportation as well.

4.4.1 Electric truck infrastructure for fleets in Finland

According to ACEA, up to 100 truck charging points will be in use all around Finland by 2025, and by 2030 that number will expand to 350 (Figure 9). The planned figure already looks big enough to be able to operate electric trucks not only in cities but also in intercity transportation. However, if we compare Finland with other countries the situation is not as good as could be. By 2030 Sweden will have 1 200 charging points, Denmark 900, and Germany 14 250. That only means that Finland has areas for development and investment.

But do not forget that the installation of a charging station is relatively cheap concerning the construction of a gas station. There is also an option to install private chargers at warehouses and loading/unloading points (Chargepoint 2022). The biggest provider of charging solutions for businesses Chargerpoint has a wide range of solutions. That will significantly scale the net of charging points and will make the operation of electric fleets more accessible.

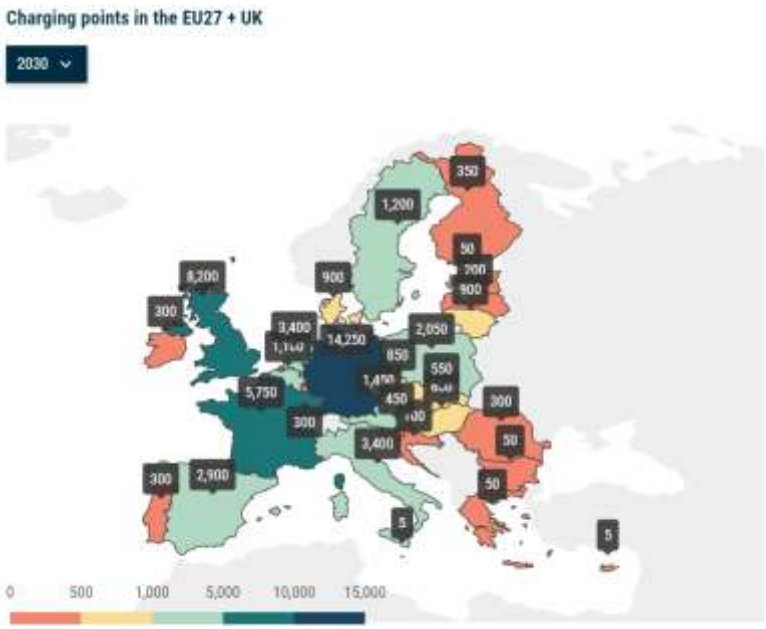

Figure 9. Truck charging points in Europe by 2030 (ACEA 2021).

4.5 Hydrogen truck

Hydrogen is the last option in the list of alternative trucking technologies that we take into consideration. Hydrogen is surely an option in both the short and long term for powering trucks. Practically, there are two various options:

- using hydrogen as a fuel for the combustion engine;
- or a fuel cell that uses hydrogen to generate electricity which powers the electric motor. (DAF 2022)

In both cases, if the green hydrogen is applied, we can reach a 100% reduction in CO2 emissions (DAF 2022) because when hydrogen is consumed, it produces only water (Figure 10).

Figure 10. Fuel cell that uses hydrogen to generate electricity. How it works. (Nikola Motor 2022)

Currently, there are only two key players on the market: DAF in cooperation with Toyota and Paccar, and Nikola Motor in cooperation with Iveco. Both of them already finalising their products and making presale marketing. In the case of Nikola Motor, their truck TRE FCEV will be available in 2023 (Figure 11), and the hydrogen DAF truck will be available in 2024.

Figure 11. Hydrogen truck TRE FCEV from Nikola Motor (Nikola Motor 2022).

Despite this, the internal combustion engine with hydrogen technology offers huge potential in heavy-duty long-haul transportation in the future (DAF 2022).

Important to mention that technology is constantly developing. As a combustion engine with hydrogen was made based on old diesel engine technology, there are not so many areas for development. That is why a fuel cell concept attracts more investments. The fuel cell technology will be more efficient in the future and will allow having a more economical but at the same time more powerful engine. (Jasper 2020)

5 The future of hydrogen technology

5.1 Hydrogen in transport

There are many ways to reduce pollution made on the roads. Hydrogen can be used as fuel in vehicles, which emits only pure water. The hydrogen car scores with electric cars, for example, with faster refueling and greater range. (Woikoski 2022)

Hydrogen is already widely used in Europe as a fuel for heavy transport, ships, trains, buses, and cars (Woikoski 2022). For instance, already in 2014, the Toyota company launched the production of the first-generation passenger car – Mirai (Toyota Global 2020). According to SNE research, 11 200 hydrogen fuel cell vehicles were registered globally in 2021 which is 91% more than in 2020 (FuelCellsWorks 2021). This means only one thing, hydrogen transport is becoming more accessible to the user.

5.1.1 Are hydrogen vehicles safe?

The most frequently asked question from the potential users of a hydrogen car is, does hydrogen safe? To answer this question different tests were made by Toyota. According to tests, existing technologies make it possible to consider a hydrogen car as safe as any other vehicle on the road. (Toyota Europe 2022)

For instance, Mirai's fuel tanks are bullet-proof and made from carbon-fiber-wrapped which absorbs five times the crash energy of steel. Moreover, car manufacturers integrate sensors designed to stop the hydrogen and any leak of hydrogen will rapidly escape safely back into the atmosphere. (Toyota 2022)

Figure 12. Hydrogen safety, the explosion of a hydrogen car (left picture) vs gas car (right picture), (Leachman 2017).

Nevertheless, according to another research made by Washington State University and The National Highway Transportation and Safety Administration (Leachman 2017), the hydrogen car is even safer than a gas car under the most dangerous circumstances (Figure 12).

5.2 Hydrogen production

The world's most abundant element, hydrogen, is the hot topic of the day. Hydrogen does not exist as such, but all hydrogen to be used must be produced. More than 80 million tons of hydrogen are produced annually. Indeed, much of the hydrogen debate has centered on how hydrogen is produced in an energy-efficient and environmentally friendly manner, and where it can and should be used as a zero-emission energy source. (Woikoski 2022)

Hydrogen can be produced by steam reforming from biogas or natural gas, or by electrolysis from deionized water. Those are the most common methods. Additionally, hydrogen is also produced in chemical industry processes as a by-product, the end product of which is pure hydrogen when reduced and processed. Through biological reactions, hydrogen also can be produced. The most innovative method to produce hydrogen is a solar-driven process such as photobiological, photoelectrochemical, and solar thermochemical. In solar-driven processes light is used as the agent for hydrogen production. (Energy 2022)

5.2.1 Hydrogen production in Finland

Gasgrid Finland (a Finnish state-owned company and transmission system operator) conducted a study on the potential of the hydrogen economy and the development of the hydrogen market. The analysis shows that Finland has opportunities to become the leading country in the hydrogen economy of the future, both as a hydrogen producer and as an exporting country. (Gasgrid Finland 2020)

According to Gasgrid Finland’s vision, thanks to the gas market, Finland will enable a carbon-neutral society by 2035. Therefore, Finland actively develops transmission platforms, pipelines, services, gas markets, and raw material systems. Moreover, according to another study, Finland has production potential for green hydrogen: 50 TWh/year in 2030 and up to about 150TWh/year in 2050 (Gasgrid Finland 2021). By the way, Finland’s total power consumption is 81.6 TWh/year (Statistics Finlan 2020).

One of the biggest hydrogen producers in Finland is Woikoski since 1913. They produce environmentally friendly hydrogen using electrolysis plants and alkaline electrolysis and polymer electrolysis technologies. They also have advanced processes for extracting and

purifying by-products. In 2014, they have created the largest hydrogen production plant in Europe which uses electrolysis (Woikoski 2022).

Hydrogen storage is constantly evolving in Finland. Finnish companies are involved in an EU project to test the storage and transport of hydrogen by bonding hydrogen to an organic carrier molecule. The new technology can significantly reduce the cost of storing and transporting hydrogen (Woikoski 2022).

5.3 Hydrogen accessibility and price in Finland

Even though Finland has such grandiose plans for the construction of hydrogen plants and its transportation for some reason they do not cover the use of hydrogen in the transport industry on the local market. According to ACEA, by 2030 Finland will have only up to five hydrogen refueling stations for trucks. The quantity is so small that even on an interactive map Finland is marked with red color (Figure 13). Red means that the amount of stations is extremely low and it will cause inconvenience to users. For example, by the same time, Sweden or Denmark will have 20 hydrogen refueling stations. (ACEA 2021)

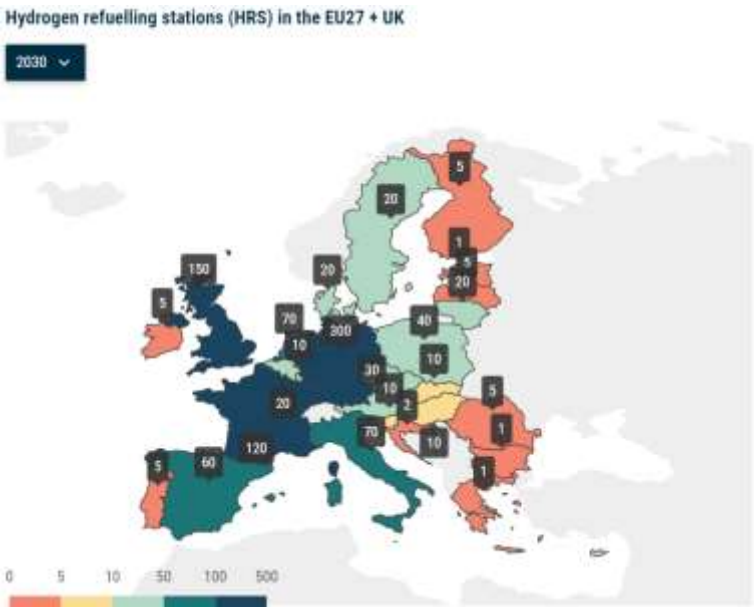

Figure 13. Truck hydrogen refueling stations in Europe by 2030 (ACEA 2021).

In this case, if Finland aims to be carbon neutral by 2035 and not be an outsider in the world of vehicles the government should think about how to attract investments for building more hydrogen stations in the region already.

For a long time, it was believed that hydrogen costs much more than diesel fuel. However, against the backdrop of recent events, diesel has become as expensive as hydrogen and

sometimes even more expensive. According to Linde, one of the biggest sellers of different gases worldwide, the cost of hydrogen is 1 179 euros for 600 liters which is equal to 1,95 euros/liter (Linde 2022).

6 Empirical Research

6.1 Methodology of this study

The author of this study has chosen to use an inductive approach to the study since there is no theory to test and known premisses and interviews are used to generate conclusions (Streefkerk 2019). The interviews aimed to identify characteristics of recently developed or currently testing trucks which will be used to build a theory based on the findings. This enables the author to collect data that is not available in public sources. As the answers from the interviewees are based on hydrogen and electric trucks both characteristics and operational costs, in major conditions it is possible to measure the data in numbers.

The author has chosen to use a mixed approach. In a mixed approach, numerical data can be measured and analyzed through statistical comparisons, while qualitative data is concerned with discovering facts about phenomena (McLeod 2021). The use of a mixed approach allowed the author to gain as much information as possible by not limiting the conversation to just a questionnaire and to gain as much information possible. Numerical answers will be displayed and compared in tables.

According to Alsaawi (2014, p.3), there are three types of interviews: structured interviews, unstructured interviews, and semi-structured interviews. The author has chosen to use the semi-structured interview method which abled variation in the questions to promote further discussion.

6.2 Interviews with industry insiders

Since the thesis focused on hydrogen and battery-powered drivelines – as they are the most competitive and completed technologies, and the availability of the Finnish market for these technologies, the participating interviewee was selected carefully from the field which is currently most aware of the latest technologies in the trucking industry. Moreover, an interview with a case company representative was also arranged to get company-specific information for making delimitations and getting opportunities to apply for studies.

Due to innovations and technologies which are still under development and piloting processes, they are among the competitive advantages of track manufacturers, truck manufacturers might not be interested to share certain characteristics and figures. Therefore, the number of possible interviewees operating in the field was a limiting factor. This was expected of difficulties with meetings arrangements. All truck manufacturers were contacted via different channels, however, only one person showed a desire to meet.

The author is confident that for this research one interview with an industry insider is enough and under these conditions, the research is still reliable, the information provided by the interviewee will be verified from available sources. An industry insider has more than 15 years of experience in the Nordic trucking market, additionally, he is an expert in hydrogen and electric trucks.

6.2.1 Data collection and data analysis

The data regarding Finnish trucking market-specific information and accessibility for applying innovations will be gathered from publicly available sources. Characteristics and figures about hydrogen and electric trucks will be gathered in a face-to-face interview with an industry insider. The author records the conversation with an industry insider to transcribe them after the interview has been completed. To verify the collected data the author will search for publicly available sources. Results will be reported according to the author's research objectives and questions. The data regarding company-specific information, needs, and diesel truck expenses will be gathered in a face-to-face interview and comments will be made on paper at the same time.

6.3 Current situation

The set of questions studies how the industry insider perceives the marker at the moment when this thesis is being conducted.

6.3.1 Interviewee opinion about hydrogen trucks

The hydrogen truck is the future for long distances. The hydrogen truck is the direct competitor of a diesel truck, and it can be used for any needs.

There is one difference in how manufacturers are doing when it comes to hydrogen trucks. The interviewee's company produces hydrogen trucks based on combustion engines. The hydrogen combustion engine is very complicated in development. This is why at the same time companies develop hydrogen trucks with battery and fuel cell technology. According to the interviewee, a hydrogen truck that uses a normal engine needs less investment. Therefore, the final price for a hydrogen truck with a combustion engine is lower than for a fuel cell truck. In addition, the customer should pay for a very expensive battery.

Since hydrogen trucks are not yet for sale, specifications and prices will be conditional but reasonable.

The engine power of a hydrogen truck is a company secret. However, it will be a little bit more powerful than a diesel truck of a case company which will be around 550 hp and 400 kW. Moreover, it will be suitable for so-called „Nordic Weights“ up to 76 tons. (DAF 2022)

Consumption of a hydrogen truck will be around 5% less than a diesel truck with the same power. Since hydrogen technology is relatively young, it is developing all the time. Therefore, the consumption will be even better and better overtimes.

6.3.2 Interviewee opinion about electric trucks

Even though that hydrogen trucks are multi-purpose trucks, electric trucks are going to exist. Both hydrogen and electric trucks are the future. Electric trucks will be for local distributions with a weight of up to 28 tons. Otherwise, the electricity consumption will be so high that not one battery will be able to last for a long time. Therefore, that will negatively affect the truck range and charging performance. However, because of rapid technological development, in 1.5 years an electric truck will be used up to 50 tons as well. (DAF 2022)

Electric trucks will be around 370 kW in 1.5 years and their consumption will be around 110 kW/100 km (Volvo 2022).

6.3.3 Interviewee opinion about the current stage of developing hydrogen and electric trucks

Companies are ready and they do produce electric trucks already now. Electric trucks can be used also for a long distances if to use a 3-axel long truck with a box. This allows the installation of an additional battery, thereby increasing the range. In this configuration, the current truck can drive around 250 kilometers but already in one and half years, the figure will be 400 kilometers. With this figure, the electric truck is getting closer to fulfill long distances transportation. Moreover, if an electric truck comes for a delivery or a lunch break and the driver puts it for charging, the truck can drive 500 kilometers daily. (DAF 2022)

Manufacturers will be able to give a price to the end customer of a hydrogen truck already in 2 - 2.5 years, meaning that Europe including Finland will see hydrogen trucks on the roads three years from now. The advantage of a hydrogen truck is that fuel tanks can fit everywhere, meanwhile, the truck has only one place for a battery. With a maximum amount of hydrogen tanks, the range of a truck can be up to 1500 kilometers (Hampel 2021). On average, the normal range will be 800-900 kilometers in Finnish conditions.

6.3.4 Interviewee opinion about purchase terms of hydrogen and electric trucks

The price of a hydrogen truck with a combustion engine will cost more than a diesel truck by 10-12% (DAF 2022). A fuel cell hydrogen truck will cost two times more than a diesel truck (Rob 2021). Regarding an electric truck, it will cost 3 times more than a diesel truck.

It is very efficient for transportation companies to repair trucks at home repair shops both guarantee cases and maintenance. Therefore, as it is with diesel trucks, it will be possible to do the same with hydrogen and electric trucks if the company wants to invest in special tools and mechanics' education. Moreover, in most cases, the guarantee policy for hydrogen and electric trucks will be similar to a diesel truck policy.

For transportation companies, it is quite good when the driver can fix some minor accidents on the road as it is with a diesel truck. A hydrogen truck will be as fixable as a diesel truck. An electric truck is not repairable on the road at all.

The lifecycle for a hydrogen truck is the same as for a diesel truck. However, the lifecycle for an electric truck will be only eight years. It means in eight years it is needed to change the battery which will be potentially a huge expense (Agaiby 2020).

6.3.5 Interviewee opinion about hybrid trucks

Since the author did not find a reason why hybrid trucks are still not on sale, it was decided to ask the interviewee about that.

Hybrid trucks are ready, it is quite easy to do a combination of diesel and battery. Nevertheless, there is one crucial reason which does not allow companies to produce hybrid trucks. As it is known, different legislations play against manufacturers or limit them especially related to pollution. The main reason is that European Union did not approve the hybrid truck as a green truck. Therefore, as a manufacturer, you do not get any point to produce them. Moreover, as a transportation company, it is possible to ask for support to purchase an electric truck in Finland. The interviewee said, if countries will implement a subsidy for a hybrid truck, at least DAF is ready to produce hybrid trucks from tomorrow.

7 Results. What should know the case company about Electric and Hydrogen trucks?

7.1 Truck price

Buying a new truck is a big investment for the company. Case company buys its trucks for certain needs with extra equipment. Therefore, in calculations, there are truck costs and additional equipment costs. Additional equipment means the installation and purchase of a thermal box that is installed on a rigid chassis. Moreover, since the company mainly uses road trains with two semi-trailers the company trucks should be equipped with a more powerful engine. Currently, the most common engine in the company has 530 horsepower.

The tax amount in Finland (where the case company operates) is 24%. Therefore, all calculations include 24% tax.

According to Table 3, the difference between a total diesel truck price with additional equipment and a hydrogen truck with a combustion engine is around 15 000 euros. However, if we compare the total diesel truck price and electric price the difference is significantly more and reaches 253 000 euros. However, there is a subsidy possibility from the Republic of Finland for the purchase of electric vehicles which reaches 40 000 euros. Therefore, the difference between diesel and electric trucks decreases, however, still remains at a big level.

	Truck price with tax	Subsidy (max)	Additional equipment	Total
Diesel	126 480 €	0 €	71 000 €	197 480 €
Hydrogen	141 657 €	0 €	71 000 €	212 657 €
Electric	379 440 €	40 000 €	71 000 €	410 440 €

Table 3. Driveline price including 24% tax in euros (Table: Anton Tsernjakov)

Currently, it is visible that the purchasing price of an electric truck is huge. However, further in this study other criteria that affect operating costs will be considered and the conclusion will be made only after an analysis of all the data.

Moreover, in close future will be introduced a fuel cell electric truck which is powered by hydrogen as well. Its price will be twice as a diesel truck price and it is predicted that it will get a special subsidy from European Union.

7.2 Truck characteristics

A case company uses trucks mostly for food transportation with up to 50 tons. Based on this number it is visible from Table 4 that a hydrogen truck is perfectly suitable even for heavier transportation. However, an electric truck is less powerful and could be used for lighter trips.

	Range average	Total weight up to	Engine power (max)	Consumption
Diesel	1500 km	76 t	530 hp (390 kW)	36 l/100km
Hydrogen	1500 km	76 t	550 hp (400 kW)	34,2 l/100 km
Electric	400 km	50 t	370 kW	110 kWh/100 km
Company Need	**500 km**	**50 t**	**530 hp (390kW)**	**36 l/100km**

Table 4. The truck average range, total weight, engine power and consumption by different drivelines and company needs (Table: Anton Tsernjakov)

Since company truck trips are usually 500 kilometers per day, a hydrogen truck is perfectly suitable for those conditions. Meanwhile, in 2024 an electric truck can drive only 400 kilometers with one battery but if there will be a possibility to plug in the truck and charge it during the lunch break or at loading points, the range could be increased without unnecessary stops up to 500 kilometers. However, since a case company drives 50 tons on average, by reaching an electric truck's maximum weight capacity very likely the range will be less than 500 kilometers. Accordingly, an electric truck does not suit all company needs.

The hydrogen truck does not experience any difficulties with a range. Moreover, the consumption of a hydrogen truck is less than a diesel truck which has a positive effect on fuel costs.

7.3 Fuel costs

Fuel costs are the biggest item of expenditure in trucking companies. However, fuel prices change constantly. Therefore, before making annual calculations, it is important to identify that due to rapidly changing fuel and electricity prices following prices were included (Table 5):

- Diesel – Average price in March 2022
- Hydrogen – Average price in March 2022
- Electricity – Average price in last six months November 2021 - April 2022.

It is impossible to predict the further pricing for fuels in 2030. Therefore, the author will provide a case company with an easy-to-use table where the company can change fuel prices based on market conditions even in a five-ten-years time and get accurate results.

	Consumption	Fuel cost	1 km cost
Diesel	36 l/100 km	2,33 euro/l	0,84 €
Hydrogen	34,2 l/100 km	2,00 euro/l	0,68 €
Electric	110 kWh/100 km	0,09 euro/kWh	0,16 €

Table 5. Truck 1 km cost by different drivelines (Table: Anton Tsernjakov)

7.3.1 Annual fuel expenses

To show the difference in fuel expenses, it was decided to calculate expenses in total after 1, 5, and 8 years of operations (Table 6). 5 years represent the average truck leasing term and 8 years represent the lifecycle of a battery.

The difference between hydrogen and diesel fuels in 5 years is 123 840 euros. The smaller consumption of a hydrogen engine and a cheaper hydrogen fuel price lead to significant savings in the operation of a hydrogen truck concerning to a diesel truck.

The cost for electricity which is needed to drive the same amount of kilometers (160 000; 800 000; 1 280 000) will be smaller by around 525%. According to Table 6, in 5 years of electric truck operation, the case company can save up to 543 000 euros, and in 8 years 869 000 euro on fuel costs if it will switch from a diesel truck.

	1 km cost	1 year (160 000 km)	5 years (800 000 km)	8 years (1 280 000 km)
Diesel	0,84 €	134 208,00 €	671 040,00 €	1 073 664,00 €
Hydrogen	0,68 €	109 440,00 €	547 200,00 €	875 520,00 €
Electric	0,16 €	25 600,00 €	128 000,00 €	204 800,00 €

Table 6. Annual fuel expenses (Table: Anton Tsernjakov)

7.4 Truck operational expenses

Fuel is not the only operational item of expenditure. Therefore, in calculations maintenance and repair, lubricants, tires, and other variable costs were included (Table 7).

The truck is like real estate that always needs cleaning, repairs, and care. The big expense is maintenance and repair. From Appendix 4 the most common scheduled maintenance costs could be found. It might affect directly and indirectly the company's expenses. Directly, when the company pays the repair bill and indirectly when the company calculates money that could be earned while truck idle time. According to case company information, the

annual maintenance costs of the diesel truck were 15 000 euros. With other costs, the total number is 29 000 euros. Since the company does not operate a hydrogen neither electric truck, estimated numbers were taken based on the given information.

Hydrogen truck is same in use as diesel truck and has the same amount of parts. However, a hydrogen truck is more reliable and the chance that it will break down is lower than a diesel competitor. Therefore, according to the TTSI hydrogen truck, maintenance costs will be twice lower (TTSI 2018).

	Maintenance and repair	Lubricants	Tires	Other VC	Total
Diesel	15 000 €	5 000 €	9 000 €	1 800 €	29 000 €
Hydrogen	7 500 €	5 000 €	9 000 €	1 800 €	21 500 €
Electric	7 500 €	0 €	9 000 €	1 800 €	16 500 €

Table 7. Annual operational expenses (Table: Anton Tsernjakov)

Regarding electric truck, it has ten times fewer parts to be broken. Moreover, lubricants are not used in this type of vehicle. However, EV is very complicated and needs special qualifications and tools to be fixed. Summing up, an electric vehicle requires twice less money for maintenance and repairs if it will be sold before the changing battery (FleetMainenance 2021). After eight years it is recommended to change the very expensive battery.

Besides maintenance expenses, there are some other operational costs which do not differ much from the type of transport. There are tires and carwashes.

7.4.1 Warranty

The case company operates and plans to operate only brand new trucks with a lifecycle of up to five years. Therefore, the flexibility of the warranty contract is very crucial.

Some time ago the case company provided its repair shop with a mechanic with a special qualification that allows fixing trucks without visits to dealer service. The biggest amount of costs is covered by a warranty.

Manufacturers will provide the same flexible warranty agreements for both hydrogen and electric trucks if the case company would invest in special tools and mechanic’s certification. The period and duration of the warranty will not be much different from a diesel truck.

7.4.2 Suitability for repairs on the road

It was identified that to save money the case company is hiring drivers who have repairing skills. That small advantage could save thousands of euros. Therefore it is important to

analyse the accessibility for repairs on the road for coming technologies such as hydrogen and electric truck.

A hydrogen truck with a combustion engine is possible to fix the same way as a diesel truck. There will be normal batteries and systems in the truck. Regarding electric trucks, it is not possible to fix them on the road at all. Moreover, if the truck will be discharged there is almost no way to charge it on the road with additional tools.

7.5 Infrastructure

Currently, a case company can fill their trucks anywhere at any time within a short period. According to ACEA estimations by 2030, Finland will be only five hydrogen fueling stations. Unfortunately, there is no geographical plan for station locations, but one of the stations will likely be located in the capital – Helsinki, as it was before. Therefore, trucks that periodically visit Helsinki will not face any challenges to fill hydrogen tanks there.

Infrastructure for electric vehicles and especially trucks will be more convenient. It is estimated that by 2030 Finland will have around 350 chargers for trucks. Moreover, there is a possibility to install chargers at loading points. That will contribute to more efficient truck operations. Last but not least, at night time when trucks mostly do not operate there is a possibility to charge trucks' batteries even with lower electricity rates. As a result that will save a big amount of spending.

7.6 Get ready for changes

To minimize risks, any changes require preparation. The same applies to the transition from the operation of a diesel truck to hydrogen or electric truck. From now, the case company has 8 years to prepare for that change.

In order not to cause a lot of pressure on the budget in the future, the author recommends thinking about investments already now. For example, the case company can plan the budget for the certification of its mechanic and buy special tools which will allow for repairing electric and hydrogen trucks at its repair shop. Additionally, this will allow to take advantage of the warranty and avoid towings to the dealer service.

If the company will decide to buy an electric truck, the author would suggest installing fast chargers in cooperation with partners at loading points. That will reduce truck downtime.

7.7 Calculation summary for a case company

To make the final comparison Table 8 was created. 1 year represents the annual truck operation costs which are equal to 160 000 driven kilometers; 5 years - 800 000 kilometers; 8 years - 1 280 000 kilometers accordingly. The most optimal years for calculations are 1,5 and 8 years because 1 year can be converted to any time, 5 years represent the average truck leasing term of a diesel and hydrogen truck and 8 years represent the lifecycle of an electric truck battery.

In calculations, labor cost and depreciation were excluded since they are fixed costs. Therefore, the final calculations include operating expenses, fuel expenses, and truck purchase price (Table 8).

According to Table 8, the electric truck will save up to 393 000 euros in 5 year-operation time. The hydrogen truck also shows a good result. In 5 year-operation time, it will be more efficient by 145 000 euros than a diesel competitor. For a company that owns more than one truck, these figures will be on a larger scale.

Total Cost	1 year	5 year	8 year	Savings (5 year)
Diesel	360 688,00 €	1 013 520,00 €	1 503 144,00 €	0,00 €
Hydrogen	343 597,00 €	867 357,00 €	1 260 177,00 €	146 163,00 €
Electric	452 540,00 €	620 940,00 €	747 240,00 €	392 580,00 €

Table 8. Total operating costs for 1, 5, 8 years by drivelines (Table: Anton Tsernjakov)

7.7.1 Net Present Value

The time value of money influences all financial decisions companies make. To find out the value of each investment in 5 and 8 year-time, the Net Present Value (NPV) calculations were made (Table 9). The interest rate is 10%.

Hydrogen truck			
Time	Net Cash Flow	Discount Factor	Present Value (PV)
0	-212 657		-212 657
1	30 000	0,9091	27 273
2	30 000	0,8264	24 793
3	30 000	0,7513	22 539
4	30 000	0,6830	20 490
5	30 000	0,6209	18 628
6	30 000	0,5645	16 934
7	30 000	0,5132	15 395
8	30 000	0,4665	13 995
	-32 657		-52 609,2

Electric truck			
Time	Net Cash Flow	Discount Factor	Present Value (PV)
0	-410 440		-410 440
1	94 000	0,9091	85 455
2	94 000	0,8264	77 686
3	94 000	0,7513	70 624
4	94 000	0,6830	64 203
5	94 000	0,6209	58 367
6	94 000	0,5645	53 061
7	94 000	0,5132	48 237
8	94 000	0,4665	43 852
	153 560		91 043,1

Table 9. NPV calculation for Hydrogen and Electric trucks (Table: Anton Tsernjakov)

Since diesel truck in comparison to hydrogen and electric trucks does not save the company money, NPV remains at the same rate as the purchase price -197 480. A hydrogen truck's NPV in 5 year-time is -98 933 and in 8 year-time is -52 609. An electric's truck NPV in 5 year-time is -54 106 and in 8 year-time is 91 043 accordingly. Therefore, in 5-year-time both electric and hydrogen trucks would not add value to the firm since NPV<0 but in 8-year-time, an investment in the electric truck would add value to the firm since NPV>0. Therefore, it would be worth buying an electric truck and selling it in 8 years and taking a hydrogen truck in lease and returning it in 5 years.

8 Summary and discussion

The present thesis has dealt with intending to figure out what are electric and hydrogen trucks and do they have a future. To answer that main research question the author researched existing alternative technologies and compared them to diesel, their possible impact on the environment, and Finnish market accessibility.

In the theoretical part of this thesis, the author found out that various directives and regulations have been adopted by the EU to minimize environmental impact by 2040. Thereby, truck manufacturers and trucking companies already thinking about how to achieve such goals. One of the most effective solutions is to review the entire line of vehicles with internal combustion engines and start to operate and produce green transport only.

To answer the main research question, what a transportation company should know about hydrogen and electric trucks and how they can be ready for the changes in the trucking market, the author analysed different characteristics and interviewed industry insiders for their opinions on the matter. The author found out that by 2030 hydrogen and an electric will be a mass production trucks but each technology has its advantages and disadvantages. Moreover, comparison tables were created.

The hydrogen truck is an option in both the short and long term for powering trucks. There are two various possibilities if the green hydrogen is applied and it is possible to reach a 100% reduction in CO2 emissions because when hydrogen is consumed, it produces only water. The hydrogen truck is more expensive than a diesel truck, but due to low operational costs in a long run, it is efficient for a company budget and more reliable. At this moment, trucks have 550 hp engines with up to 1500 kilometers range and any truck configuration can be chosen. The technology is new and engineers do not exclude the possibility that the technology will be improved. However, only 5 hydrogen refueling stations will be available in Finland by 2030.

An electric truck is an option for consideration. It is quite, cheap in operation but very expensive when buying. At this moment, electric trucks have a 370 kW engine with a range of only 200-250 kilometers. However, in two years the range will be 400 kilometers. If trucks will have an opportunity for charging at loading points and a driver’s launch brake time, the range could be up to 500 kilometers daily. An electric truck is efficient to use in a long run. The electric truck operation for 8 years might save a company 756 000 euros in comparison to a diesel truck if the truck will be sold before the battery change.

To answer the second research question, on the alternative technologies to a diesel truck, the author with help of industry insiders figured out that there are gas trucks, hybrid trucks,

hydrogen trucks and electric trucks. Based on the emission directives currently available and the prospects for these technologies soon, the hydrogen truck will serve as the main diesel truck replacement technology in intercity transportation and will be capable of any conditions that a diesel truck handled. An electric truck will serve as a truck for urban transportation due to low noise and cheap operation costs.

There are only two technologies that can replace a diesel truck and can be considered a green – hydrogen truck and electric truck. The author found out that talking about electromobility in its full sense it is important that green energy is used. Hydrogen can be produced by steam reforming from biogas or natural gas, or by electrolysis from deionized water and when hydrogen is consumed, it produces only water. Therefore, hydrogen in any form will be considered a green technology.

To answer the third question, after researching and studying the hydrogen and electric trucks, the author found out that for intercity transportation a hydrogen truck with a combustion engine will be as good as a diesel truck with its advantages such as lower operating costs and zero pollution. With the lapse of time, engineers will develop a hydrogen fuel cell truck that will be more efficient and powerful and will serve as another possible alternative.

Due to different limitations of the electric truck technology, it will not serve as a direct replacement for a diesel truck. Limited range and long charging time exacerbate the use of this truck over long distances between the cities. Trucking companies are looking for multifunctional trucks which will be suitable for a large number of tasks, though, an electric truck will be suitable only for specific and narrower purposes, such as local deliveries and operations within one city.

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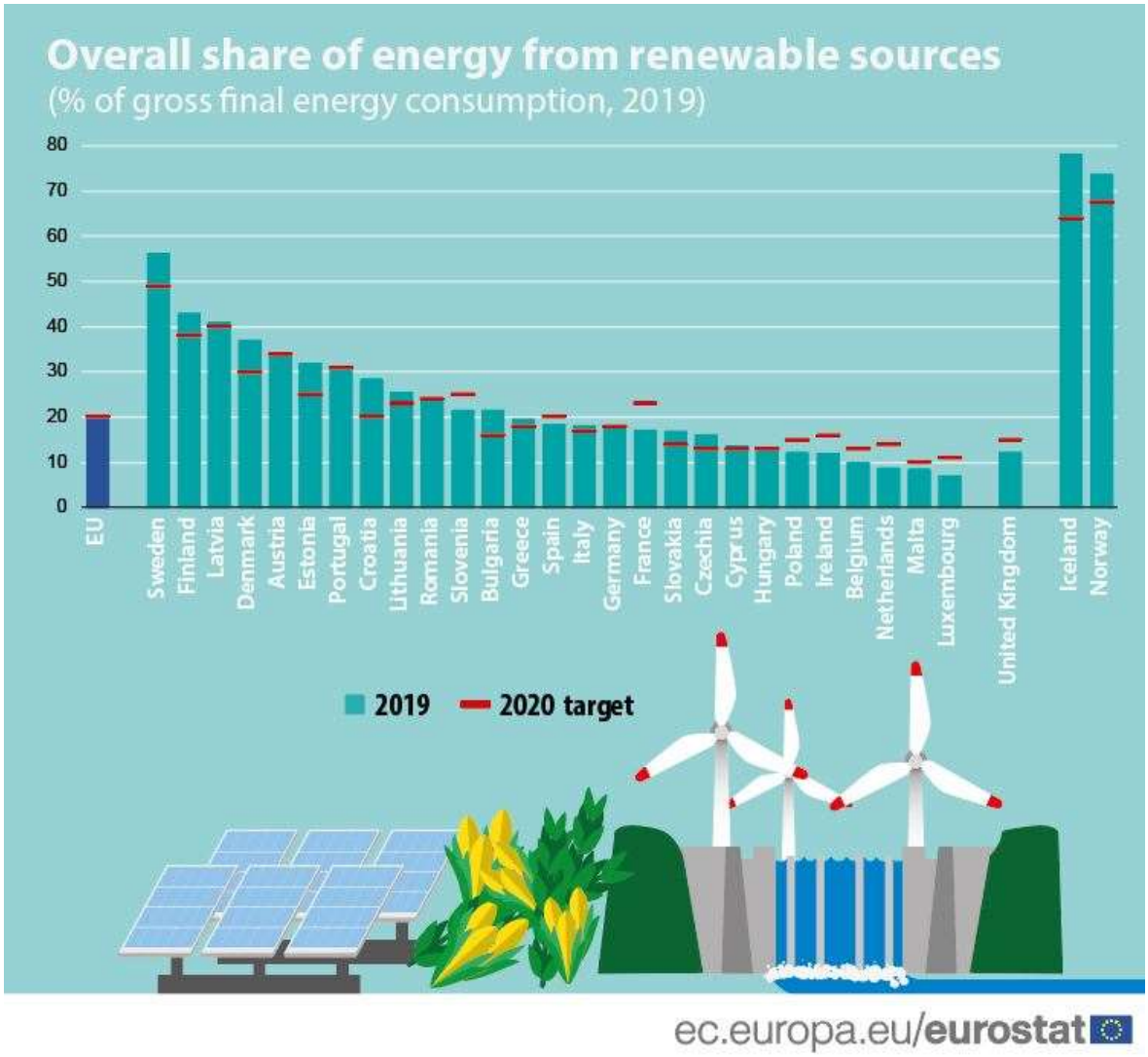
Appendices

Appendix 1. Interview questions with industry insider. Tsernjakov, A. 2022.

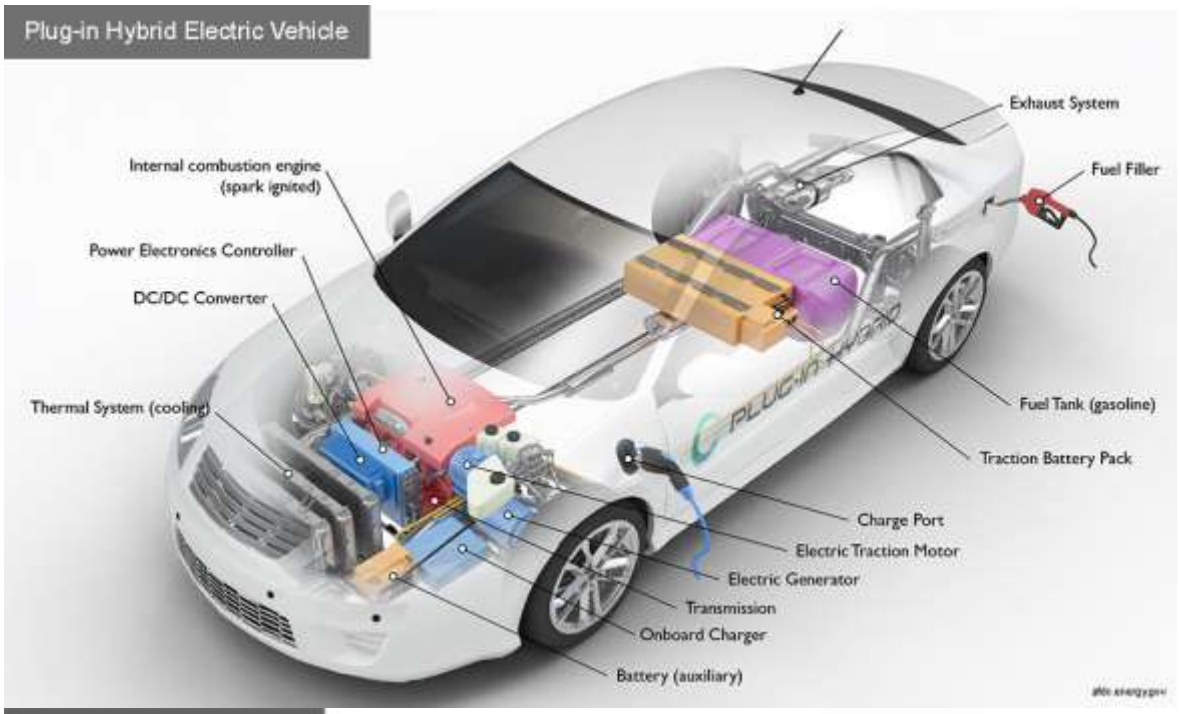
List of asked questions:

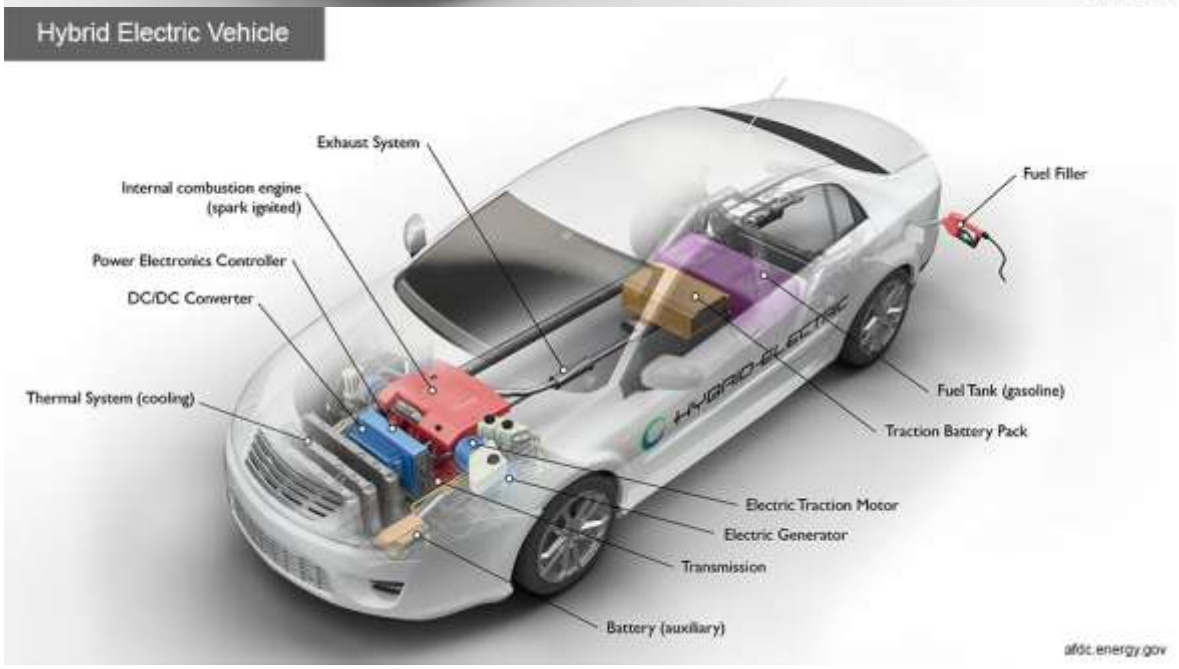
1. Do you see the future for hydrogen trucks?
2. What do you think about electric trucks?
3. What technology is more suitable for heavy and long deliveries?
4. What is the current stage of development of hydrogen and electric trucks for long-distance deliveries?
5. What are the characteristics of hydrogen trucks?
6. What are the charactersitics of electric trucks?
7. When will be hydrogen and electric trucks available for the end customer?
8. What is the consumption of hydrogen and electric trucks?
9. What is the estimated price of electric and hydrogen trucks?
10. What about maintenance and guarantee cases? Can the company repair hydrogen and electric tucks at its own repair shop?
11. Does hydrogen and electric truck as repairable as a diesel truck?
12. What is the lifecycle for hydrogen and electric trucks? Is it similar to a diesel truck?
13. Why hybrid trucks are still not in mass production?
14. Do you have any information about hydrogen fueling stations in Finland?

Appendix 2. Overall share of energy from renewable sources by EU countries. Eurostat. 2019. Retrieved on 1 April 2022. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Share_of_energy_from_renewable_sources_2019_data,15Jan2021.JPG



Appendix 3. Key Components of PHEV and MHEV vehicles. Energy. Retrieved on 1 April 2022. Available at https://afdc.energy.gov/vehicles/how-do-hybrid-electric-cars-work





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