Taking charge

Introducing fast chargers in Norway

About ZERO

Zero Emission Resource Organisation (ZERO) is an environmental foundation contributing to limiting human made climate change. ZERO will contribute to limiting the threat posed by climate change by promoting carbon-free energy solutions. In our view, emission-free alternatives exist for all energy use, and ZERO works continuously for their realisation.

ZERO initated a project to promote fast chargers in 2010. This report is a collection of some of the knowledge gathered, aiming to make it easier for businesses and municipalities to understand, take charge, and set up fast chargers.

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Table of contents

Glossary

AC: Alternating current. AC charging means using an onboard charger, that is, an AC/DC converter onboard.

DC: Direct current. DC charging indicates using an offboard charger, that is a charger located at the charging station, and not in the vehicle.

IEC: International Electrotechnical Commission, an international body for electrical standards.

CHAdeMO: Japanese and international association to promote DC fast charging.

Charging station: A location where one or more charging points are located.

Charging point: A single outlet for EV charging.

Charger: The electrical unit that that converts power grid AC current to a DC current suitable to charge a battery.

EV: Electric vehicle.

Range anxiety: The fear of running out of battery capacity.

ICE: Internal combustion engine

kWh: Kilowatt hour, equal to 1000 watt hours. A unit of energy, usually used for electrical energy, but also equivalent to other measures of energy, such as 3.6 megajoules, or 859 800 calories.

kW: Kilowatts, a measure of power, or energy per second.

Schuko: From German Schutzkontakt, a colloquial name for a type of household contacts used in Norway and other countries in Europe.

SAE: An organization for standards in aerospace and automotive industries.

Transnova: A Norwegian governmental agency supporting transport oriented infrastructure and demonstration projects.

Introduction

The auto industry across the globe is gearing up for electric mobility to adapt to a changing world with new expectations and new emission standards. Electric vehicles have gained strong political backing to become part of the solution for the transport sector to reduce CO2 emissions, to become more energy independent, and to reduce local emissions in cities. Faster charging is widely regarded as one of the success factors for electric vehicle in further penetrating the market. Fast charging has been technologically feasible, and used in several applications for years. This change in momentum for EVs is not a result of a sudden technological breakthrough. What is new is the international focus on the electrification of the transport sector, combined with an emerging large scale introduction of fast charging capable vehicles. This positive climate for electric vehicles, where political momentum and industrial investments are strong, should be used to reach a critical mass for electric vehicles, and move them out of demonstration phase and into the mainstream.

One of the steps in taking the EV to the next level is to promote fast charging, to remove some of the perceived obstacles that are linked to the limitations of the battery. Fast charging in the course of minutes, and not hours will increase the range, increase operation time of the vehicles, and make drivers feel more confident about getting where they want.

Norway has a fleet of electric vehicles that is comparably large, and several incentives to encourage electric mobility are implemented. Vehicles from the Norwegian brands Think and Buddy, together with electric versions of Peugeot 106 and Citroën Saxo have made up most of the fleet for the last decade, while Mitsubishi's electric city car was introduced in late 2010, and has already made a significant addition to the total vehicle fleet.

Fast chargers for EVs are seen as expensive, and some public investment support is expected to be necessary in an early phase. The enough vehicles are on the road, fast charging could be made profitable. Investment costs per vehicle is estimated to be at around NOK 3000, and a basic national grid could be afforded at about NOK 40 million.

The first experiences with CHAdeMO DC fast charging in Norway are currently being collected. This report aims to be an early resource for stakeholders in this field, and it is written in English to promote cooperation between Norwegian and international businesses, politicians, and organizations.

Recommendations

At this stage we see that fast chargers are not likely to be installed in significant numbers without financial support. There are a number of issues concerning location, business opportunities, safety etc. that have not been resolved. The government agency Transnova is instrumental in test projects and this kind of infrastructure deployment and should be continued with a significant budget increase.

CHAdeMO fast charging is in an early phase in several European countries, including Ireland, Portugal, the Netherlands, and Estonia. A closer network for the exchange of experience from the use of fast charging in Europe should be established.

The incentives for EVs should be continued in Norway until there are at least 100 000 zero emission vehicles on the road.

Further prosjects should be supported to encourage EV taxis and goods deliver, assisted with fast charging.

Background on EVs and charging in Norway

Almost halfway through 2011, there are about four thousand EVs in Norway. The total number has steadily increased the last few years, with a sharp increase at the introduction of Mitsubishi i-MiEV in the market. This is the first EV for sale in Norway with fast charging capabilities. The i-MiEV has been warmly welcomed since its arrival, making it not only the most sold EV, but also in its size segment, regardless of drive train. There is reason to believe, however, that this popularity is as much a result of the EV incentives (see fact box), and of its appeal as a normal, well equipped, and safe vehicle, as of the fast charging capability.

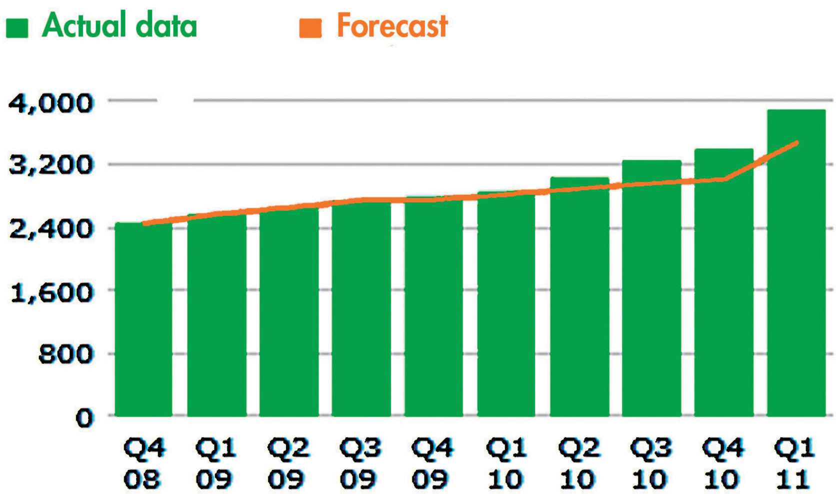


Figure 1: The green columns indicate number of EVs in Norway, while the orange lines is the earlier prognosis set by Grønn Bil (Grønn Bil, 2011a).

Nevertheless, the ability to shorten charging times is seen as key to making electric vehicles meet the needs for more users. Users, the media, car manufacturers, transport politicians and environmental organizations agree that reducing the charging time is important for a shift towards an electric transportation system. At this point, however, there is limited experience as to how much fast charging affects the potential for EV sales and use. Fast charging rolled out for public use is in its infancy. As a technology it is not new, as high power chargers have been used in industrial appliances, such as forklifts and aircrafts. The driving forces behind the current focus on fast charging is not a sudden technical breakthrough in chargers that provide a high charging current, but rather that developments in battery technology has made it safer and more economically feasible, while EVs have become more attractive as a way to change the transportation sector.

Fast charging is a general term for charging at higher power than the usual. In Europe, the usual way to charge an EV is by using a normal household socket, which can also be found in the around 2500 publicly available charging points in Norway. This is part of the success factor for EVs so far. Being able to charge at millions of locations has made it much easier to be an early adopter of electric vehicles than bio fuel or hydrogen vehicles. Car manufacturers, users, power utility companies, and fast charger manufacturers all agree that what we now regard as normal charging will remain the backbone of tomorrow's charging infrastructure as well. Though connectors and communication standards may, and should evolve, there are good reasons why most of our charging should remain at relatively low power: The investments are low; the impact on the power distribution grid is manageable; the battery stress is limited; and perhaps most importantly – for most users charging at night will cover the daily driving range. In 2009, the average daily transport distance was 42 km (TØI 2009a, p 18).

EV incentives in Norway

EVs enjoy strong incentives in Norway.

Bus lane access

Free public parking and charging

No toll roads

No ferry fees for the vehicle

Exemption from vehicle excise tax and VAT.

Reduced yearly vehicle fee

Reduced company car tax

There are still several reasons to look into fast charging. The most obvious is an increase of range: if there is a readily available infrastructure for fast charging, the driver can simply take a break while charging the car, before the journey continues. Other times, the range might be sufficient in reaching the destination, but the recharging duration too long to allow the driver to return in time, or too long for commercial EV use, such as taxi operation or goods delivery. Though closely related to the first benefit of fast charging, the actual use of the chargers can help determine where the location is the most advantageous to the user. Together with a good network of normal charging points, fast charging can remove some of the so called range anxiety – a fear, with or without good reason, of running out of electrical charge, and in that preventing drivers from using an EV, or from getting one altogether.

The change

The auto industry is investing heavily in the overlying trend that is the electrification of road transport, including hybrids, plugin hybrids, pure electric vehicles, and fuel cell hydrogen vehicles. The momentum of this change has increased in the last few years, and some of the most tangible changes have come from Japan. For instance, Nissan is investing in production facilities for its Leaf, in Japan, the UK and the US, while Mitsubishi is pushing its i-MiEV and European counterparts through Citroën and Peugeot. At the same time, Toyota has emerged as a large scale electric motor producer through their ramping up of the Toyota Prius hybrid. In Europe, Renault is launching four new EV models in 2012. This change in momentum, from where, in the early 2000s, the auto industry was waiting for the future benefits of the hydrogen vehicle, while tackling the problems of the day with more efficient internal combustion enginges (ICE) engines, to a broad and intensifying focus on battery electric vehicles, is a change in framing, according to EV analyst Shannon Arvizu.

From around 2000 the auto industry was reluctantly meeting governmental demands for local air quality, by introducing some electric vehicles. By the end of the decade the framing had changed, where EVs were seen as a possibility for revitalizing a stumbling industry, while stimulating a change in environmental standards. At the same time, climate change had largely taken the position of local pollution, and thus making it possible to feed renewable energy into the transportation sector. In the USA, as well as Japan, there is also an increasing focus on energy independence (Arvizu, 2011).

A larger introduction of EVs has also led to a larger focus on EV related infrastructure, and increased user friendliness, and fast charging is one of these amenities. The Mitsubishi i MiEV is the first commercial EV in Norway that offers fast charging, with the technology called CHAdeMO. At the same time a range of off-the-shelf CHAdeMO fast chargers is available. Several other vehicles will support this technology, which is currently some years ahead of the competition. This is the reason why the Japanese industrial fast charging solution CHAdeMO is presently the de facto fast charging standard.

CHAdeMO is the outcome of a cooperation between Japanese auto makers (Fuji Heavy Industries (Subaru), Mitsubishi, Nissan, and Toyota) and Tokyo Electric Power Company (TEPCO). The CHAdeMO association has members from across the world, and aims to prepare the ground for international roll-out of, at the time being, primarily Japanese EVs. European members include: Norwegian EV manufacturer Think; the Italian company Micro-Vett, which specializes in refitting vehicles from Fiat and other Italian brands; and PSA Peugeot Citroën. No other European auto makers are members, while many large systems and equipment actors are, such as Siemens and ABB.

This has made the CHAdeMO association currently the strongest fast charging trend, with the most momentum. At the same time, European and US auto makers are also retooling for electric vehicles. International standards are in development, and there is reluctance from, for instance, German auto industry, to adapt to Japanese technology. Therefore it is difficult to predict which changes will be required in 2013-14, when several more European brands are expected to release vehicles on the market. It is, however, important that early mass produced EVs are popular enough to drive the change forward in the years to come.

FAST CHARGING, TECHNICALLY

The standardization of charging is currently a work in progress. In a mature market a safe and harmonized system is expected. Preferably there should be a charging standard that ensures that an EV charging cable would be the same from country to country, from vehicle to vehicle. In normal charging today we see that the plug in the vehicle end differs between vehicles, and the plug in the infrastructure end differs between countries. This is similar to how a charger for an HP laptop bought in Norway will have different plugs in each end, compared to an Apple laptop bought in the US. For EVs this needs to be resolved both for normal charging and fast charging. In Norway, all the public charging points offer the same outlet (a normal household socket, the so-called Schuko) for all vehicles, and the user has to bring the cable that connects to the vehicle. In a more mature market it would be desirable that the charging points present a cable with a plug that could be connected to any vehicle.

Important standardization institutions in this field are the International Electrotechnical Commission (IEC) and the Society of Automotive Engineers (SAE). For normal charging (single-phase, see illustration), one such emerging standardized plug for vehicle connection is the so-called Yazaki plug, or SAE J1772. This features some basic communication for increased safety and functionality. For instance, it makes it possible to immobilize the car while plugged, and to communicate how much power it is able to deliver. This plug standard is incorporated in the IEC 62196 set of standards for charging of electric vehicles, and is also used in the Mitsubishi i-MiEV, Nissan Leaf, and the Toyota Prius plug-in hybrid, among others. For vehicles deployed in Norway so far, these are equipped with a Schuko plug in the infrastructure end of the cable.

Another plug that has been widely used for EV charging is the so-called Mennekes plug, which is a type 2 plug under the IEC 62196 set of standards (see fact box). It allows for charging with single-phase, and three-phase from 16 A to 63 A, effectively covering a power range from from 3.7 kW to 43 kW. The Mennekes plug could be used as an infrastructure plug (to connect the charging cable to the charging station), a vehicle plug (the plug inserted into the vehicle), or both.

What fast charging really is may need an extra explanation. While most users will refer to the time it takes to charge the car fully, or how many kilometers you will get per minute, the most important concern of power grid owners is how much power is drawn from the grid. Right now the general use of the term in Norway is syn-

IEC 62196

The IEC standard 62196 includes a set of connectors and charging modes for electrical vehicles (also based on earlier standards). It defines four modes of charging, and three types of connectors with suggested physical implementations of these.

The four modes are:

Mode 1: Normal, slow charging, with a normal household socket.

Mode 2: Same as mode 1, but with an in-cable protection, to prevent damage and fire due to electrical faults related to the ground connection. This is the most common charging mode today.

Mode 3: Slow or fast onboard charging using dedicated EV plugs, and protection.

Mode 4: Fast charging using an external charger, as for instance CHAdeMO.

Plug types:

Type 1: Single-phase vehicle coupler.

Type 2: Single- and three-phase vehicle coupler.

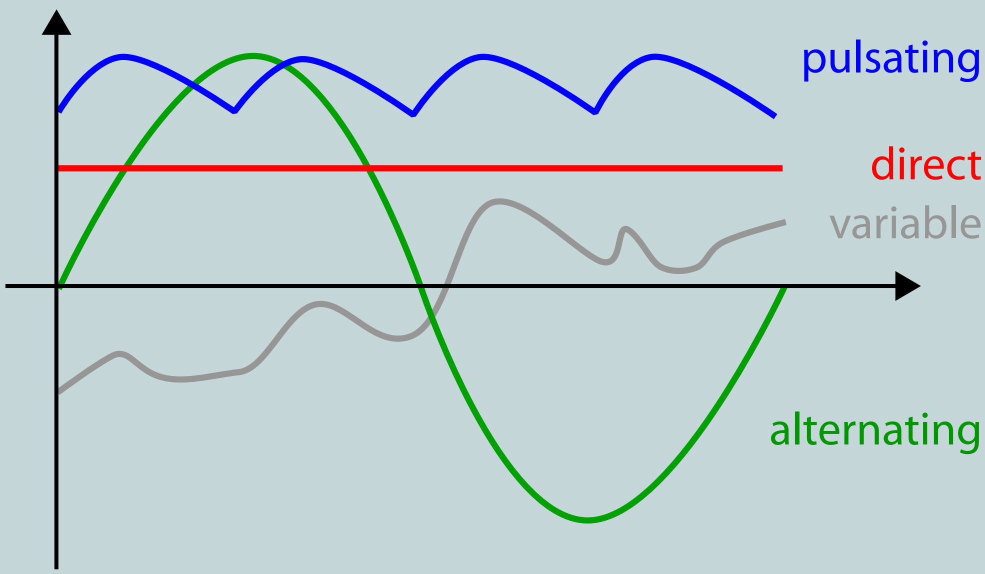
Type 3: Single- and three-phase vehicle coupler with the possibility to physically close the plug.

A suggestion for an implementation of the type 1 plug, is the SAE 1772 standardized plug, often called Yasaki (a large producer of this plug), which is used in several cars already. A type 2 implementation is the so-called Mennekes plug, which is extensively used by the German auto industry. So far a DC type plug, like the one used with CHAdeMO chargers have not been implemented in the standard.

Electric energy

The flow of energy (power, expressed in watts, W) in an electric circuit, and into a battery is determined not by the electric current alone, but by the product of current and voltage. This product is determined then, by multiplying voltage (volts, V) with the current (ampere, amps, A). In Europe the normal voltage is 230 V and a standard circuit can handle 16 A. EVs then, can charge at a maximum of 230 V × 16 A = 3680 W, or 3.68 kW (kilowatts).

The amount of energy a battery can hold is usually denoted as kilowatt hours (kWh), which is the energy unit by which customers are charged from their electric energy company. A 60 W light bulb turned on for 24 hours will use a total of 1.44 kWh (60 W × 24 hours = 1440 Wh). This amount of energy could power a household electric heater for about an hour, or run a Think City EV for about 10 km. The Think City has a battery of 24 kWh and can use that energy to move about 150 km. To charge a battery of 24 kWh should take approximately 8 hours at 3 kW (3 kW × 8 h = 24 kWh). In reality the charging speed will vary, depending on what kind of battery technology is used, what the ambient temperature is, at what state of charge the battery is, etc.



Figur 2: The horizontal axis is time; the vertical axis is voltage, or current. Our power grid provides electric current that is alternating (AC), typically at 50 Hz. That means it is going up and down 50 times per second. In an electric cable, the current would go back and forth. To charge a battery we need a direct current (DC), a current that is going one direction, and a battery charger converts AC to DC. To provide enough power to a fast charger, we use three connections with alternating current, peaking at different times. This is called three-phased, as opposed to single-phased, as shown above.

onymous with CHAdeMO charging at 50 kW, but this is simply a choice made by the founders of the CHAdeMO association, as to which power level would give the most beneficial combination of charging speed and investment costs. Let's take a moment to look at the basics of how charging works.

An electric vehicle contains a rechargeable battery, much like a laptop or a mobile phone. The battery is a way to chemically store energy that can be released as an electric current. When connected, the battery will provide an electric current to run the car's motor. To charge, this current is reversed, and current is forced into the battery, with a battery charger. A common analogy is to see the battery as a tank of water: The water flowing through a pipe out of the tank can make a turbine spin. When the tank is empty, the water flow needs to be reversed through the pipe to refill the tank. In a normal household power outlet, however, the electric current does not run as water through a pipe. It is an alternating current (AC) as shown in the green line in the graph underneath. The current goes back and forth, back and forth – suitable for making a light bulb glow, or an electric panel heater produce heat, but not to charge a battery. We need a continuous, direct current (DC, as shown by the red line), and to get that we use a charger, that rectifies an alternating current and makes it direct (an AC/DC converter).

Two Think City and a Fiat e500 from Micro-Vett charging during the 2010 ZERO Rally. With normal charging, the actual charger is located within the vehicle. An in-cable protection can be seen in the foreground. Photo: ZERO

Unlike laptops and mobile phones, that use separate chargers, most EVs have built-in chargers. These are designed to let the car charge as fast as possible given the limitations of a household power outlet. A Mitsubishi i-MiEV can charge its battery in about 7 hours this way. To reduce the charging time, the access to power has to be increased, as well as the capacity and size of the charger. At some point, the charger will have to be of a size, weight and price, so that it no longer makes sense to keep it in the car, but rather at the charging station. This is the case with the CHAdeMO technology, charging at up to 50 kW, or 15 times the power of a normal charger. At this power it would be hard to fit the charger in the car, and the additional costs would be unacceptable. In addition, knowing that normal charging is sufficient for every day use, and that the availability of a 50 kW power draw is limited, it makes more sense to equip each charging point with a charger, rather than each and every vehicle.

Why settle for a 50 kW charger, and not 10 kW, or 250 kW? Several other fast charging initiatives have explored higher powers. Since the total charging time is not linearly depending the power, but the infrastructure costs are increasing with higher power, the CHAdeMO association argues that a reasonable middle ground lies somewhere between 30 kW and 70 kW, as visually indicated by the image below. Of course, the power a battery can handle is also an aspect to be considered. Another hands-on problem is the size and weight of the cable connecting the vehicle to the station, which should not be too heavy for users to operate. However, with time, investment costs and battery capabilities could change, and influence these preferences.

In Japan more than 600 CHAdeMO chargers are installed, awaiting a massive rollout of electric vehicles. As an example, and rule of thumb for fast charging infrastructure, the CHAdeMO association indicates that one fast charger per 200 vehicle will be necessary. Right now there are only a few thousand EVs on the road in Japan. Nissan, who has launched the Leaf, has installed fast chargers at all their dealerships, to help stimulate a successful rollout of their vehicles. Currently the more than 600 (both private and public) fast chargers should be able to provide a sufficient infrastructure for 120 000 vehicles in Japan. The chargers are deployed early to encourage potential buyers of the EVs.

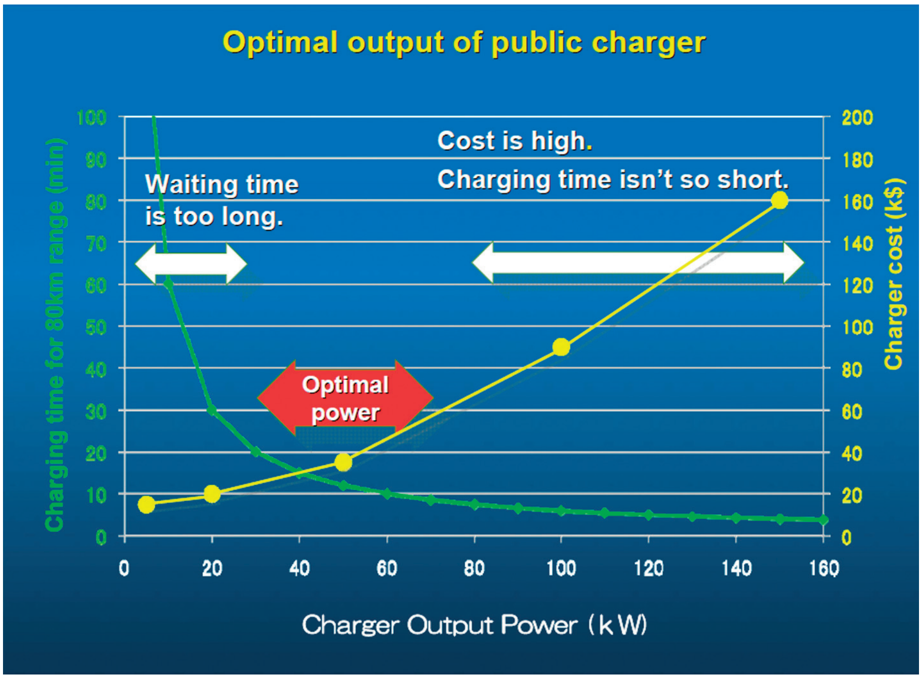


Figure 3: Optimal output of fast charger. Illustration: CHAdeMO

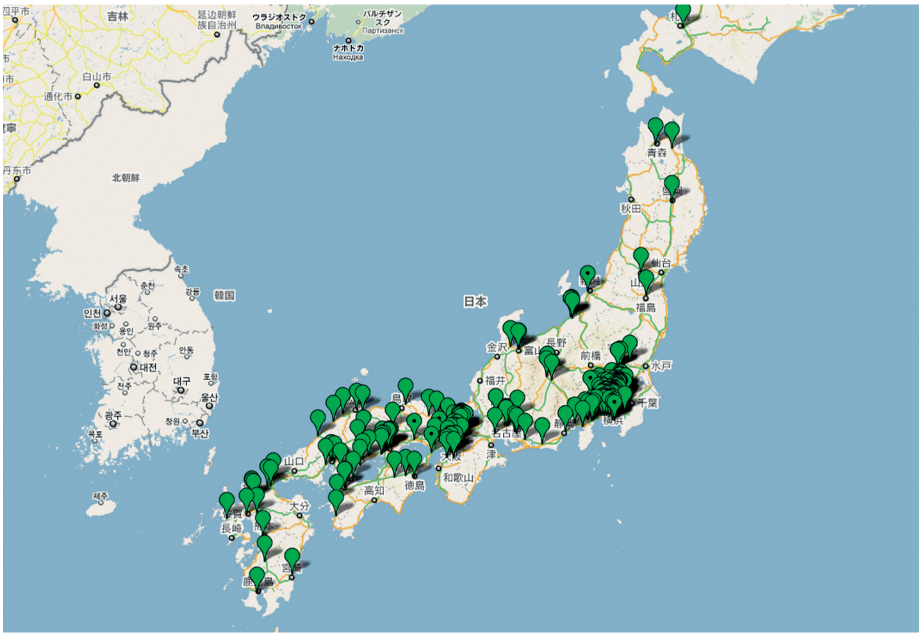


Figure 4: CHAdeMO fast charger deployment as of May 2011. Illustration: CHAdeMO (Google Inc)

Installing a fast charger

To install a fast charger a high power connection line is required. Most chargers require a 400 V three-phase connection with a high current capacity (63 A or more). At most locations this means it is required to make a new connection to the local transformer station. These stations are dispersed in the power grid and can be found where high voltage power lines need to be transformed down to usable voltage levels in industrial, commercial and residential use. Typically, these stations in Norway provide 400 V three-phase and 230 V single-phase voltages to customers, though 400 V is more common in new installations. If there is not enough capacity at such a station, an additional investment (in the range of several hundred thousand NOK) in the transformer needs to be made to install a fast charger. Generally, this makes it infeasible to install a fast charger today. Further, some sort of concrete foundation needs to be made, and usually a shelter to protect the charger from snow, rain, and dirt is wanted. If customers are required to pay for charging, a payment solution can also amount to around NOK 50 000. All in all, this usually amounts to a total investment cost of NOK 400 000 to 600 000 (€ 50-75 000), even when no further power grid investments are necessary. With one charger per 200 vehicles, this would mean an investment cost of about NOK 3000 per vehicle.

Other charging technologies

In 2011 CHAdeMO is the only fast charging technology available in Norway. There are, however, some other notable trends and technologies in EV charging, and we'll briefly look at some of them.

Other DC charging

CHAdeMO is only one of several technologies to DC charge EVs, that is, with a large off-board charger. In September 2010, several German auto makers announced that they will create a system for fast charging in combination with a flexible normal charging. This system is likely to consist of an AC type 2 plug physically connected to a high power DC plug. In this setup the user will not have to consider the differences between AC and DC charging, and the DC charger can potentially benefit from the AC plug communication system, and thus make it smaller. This system is a few years into the future. However, most of the issues pertaining to fast charging will be similar between CHAdeMO charging, and other systems. If this system at some later point becomes a widely used standard in Europe, CHAdeMO fast chargers, at least by some manufacturers can be modified to meet different standards. Nevertheless, the chargers built today will be needed for the next 10-15 years to accommodate the CHAdeMO compliant cars that are being sold now.

Battery swapping

Charging a battery takes time, and even with fast charging, this time is not insignificant. The idea about battery swapping is to reduce charging times at stations by replacing the entire battery instead of charging it. The empty battery could then be charged at a lower speed. This system has been used in industrial applications, especially in fork lifts. In the auto industry, the most prominent company advocating battery swapping is Better Place. Its founder, Shai Agassi, has raised hundreds of millions of dollars into this project, which is launching early projects in Israel and Denmark together with Renault-Nissan. There are advantages and disadvantages with battery swapping over fast charging: The obvious advantages are that "recharging" of a vehicle will be much faster, with swap times of only about 3 minutes. Secondly, the batteries could be charged slower between use, and probably improve battery life. Thirdly, as advocated by Better Place, it would make it possible to separate the investment of the car from the investment of the battery, much like a conventional car is not sold with fuel, and this would make the up front cost of an EV more competitive with that of a conventional car.

There are also a few disadvantages associated with battery swapping. The main drawback is severe investment costs, both in the swapping station, and in the battery inventory. For instance, for many of today's EVs the production cost of the battery is up to 50 % of the cost of the vehicle. For a busy station this could require a high battery inventory to function properly. The other problem of battery swapping is battery standardization. For batteries to be swappable, they need to be the same. To make this work, the station either needs several types of batteries, or many models share the same battery layout.

Battery swapping is expensive, but few other EV initiatives have as much funding as the Better Place idea. Especially for closed fleets or in densely populated areas, it could prove to be viable soon.

Inductive charging

A number of projects and businesses are looking into wireless charging of vehicles. The concept is generally to charge using induction, which allows electrical energy to be transferred wirelessly, though over short distances. The same technology also has a prospected use in charging small electronic appliances, such as phones. In EVs this technology has proponents like the company WiTricity. Wireless charging could be a convenient way to slow charge vehicles at many locations instead of fast charging. For instance, buses could be allowed to charge for a few minutes here and there, without plugging in, instead of fast charging. However, wireless charging is significantly less efficient at transferring power compared to plugging in a physical connector.

A Mitsubishi i-MiEV fast charging at the opening of Norway's first CHAdeMO charger outside Stavanger. With CHAdeMO fast charging, the charger is located at the station, and not in the car. Photo: Lyse

Fast charging opportunities and challenges

Locations and range

Electric vehicles have a number of technical and environmental advantages over conventional fossil vehicles. As EVs reach a more mature development stage, we will experience vehicles that share much more of the DNA of cars that we already know, except they will have an electric powertrain. That means we will be able to experience the same comfort, passive and active safety as in fossil cars. The Nissan Leaf, which does not have a prehistory as a fossil car, is a good example of that. Nevertheless, limited range and long charging times will affect the appeal and use of EVs. Fast charging provides part of the solution to the issues. When setting up fast chargers, some perspectives should be evaluated concerning range, charging times, and so-called range anxiety.

Range is the most striking limitation of EVs today. Most commercial vehicles today have an average range of about 100 to 150 km. This is sufficient for most private users for everyday use, as average daily driving lengths are below typical EV ranges in most countries. In Norway, 42 % of households (TØI, 2009b) have more than one vehicle, and EVs could replace many of these without much compromise. Being able to cover a larger area is still an important issue to resolve to have EV owners use their EVs more (instead of a fossil alternative), and to make EVs more attractive to new buyers. A typical "test" for EVs today is whether the EV can take them to their summer house, or to a skiing resort. With fast charging we can increase the operating range of EVs. Right now, the majority of EV sales are in and around Oslo. The drive from Oslo to Lillehammer, for instance, is about 190 km, a range that would be challenging for most of today's EVs. An attractive thought for many is to create a charging corridor along the way, to recharge quickly along whe way whilst having a cup of coffee.

A close knit grid of fast chargers would make EVs capable of covering an even larger portion of people's transportation needs, but chargers would probably have to be available every 40-60 km for maximum effect. Even though a Nissan Leaf could manage the distance with one only charge on the way, we would have to take into consideration adverse road and weather conditions, with snow and cold weather (increasing rolling resistance, reducing lithium-ion battery capacity, and spending energy on heating) or even hot weather (reduced range due to air conditioning in the car). Under difficult circumstances an urban vehicle like the Mitsubishi i-MiEV could see the driving range reduced to as little as 50-60 km. Even with vehicles that can run longer, it could help the drivers' confidence if they knew they didn't have to stop at each and every station. The range of much of the E-roads between Oslo, Stavanger, Kristiansand, Bergen, Trondheim, and up to Tromsø, would consist of more than 4000 km of road. If charging stations were to be spaced out evenly, 50 km apart, this would require roughly 80 charging stations. If we assume costs based on early experiences, of NOK 4-500 000 (€ 50-60 000) and only one charger per station, this would amount to expences of about NOK 40 million (€ 5 million). Some costs related to hardware should be expected to fall, while installation costs at many rural locations might be increased. Though no funding for this is available right now, the total costs of a simple national range extending network of fast chargers are not appalling.

Another aspect of a battery electric vehicle is that normal charging takes a long time. While charging during the night is sufficient for most daily use, there are times when the total driving distance will require more charging. This is true for for instance taxi drivers, or urban goods delivery, health services and other use in the workplace, or for daily commuters who would like to pick up someone from the airport after work. What is common for all these uses is that there is not really a lack of opportunity to stop and charge, but the time windows are not large enough for normal charging. A taxi driver has free time during the day, but normal charging of a Think City takes a whole shift. The commuter wishing to pick someone up from the airport might not be in a hurry, but probably does not want to charge for three hours at the airport.

These problems related to long charging times are, of course, closely related to those of range. The main difference is in how to approach a deployment of the infrastructure. If the issues of charging time are perceived to be the most important, we would first aim to place chargers in urban areas, at airports, business areas and shopping centers, rather than along highways. As described later, it could also affect how much charging should cost, and how costs should be calculated.

The last perspective on fast charging is the psychological. Imagine that the commuter, who was planning to pick up his friend after work, did not trust the EV's range to be sufficient to go to the airport and back without running out of charge. In the fear of being stuck along the highway, or having to rely on the good will of a gas station owner to let him charge for a couple of hours, the commuter decides to take an ICE car instead, or not to go at all. This is refered to as range anxiety, and most often occurs when the driver lacks knowledge about the car's capability, the total distance, or the location of chargers. The result of all this is that EVs are used under their potential, and possibly that some potential EV buyers refrain from doing so.

A much used example of range anxiety, and how it can be ameliorated with fast charging, is from early use of CHAdeMO fast charging in Japan. In 2007, the Tokyo Electric Power Company (TEPCO) had a number of EVs for their staff to use in service operations in the city of Yokohama. The vehicles were little used. Drivers usually only travelled short distances, and when they returned they typically had more than 50 % charge left. The users felt uneasy when they had less than 50 km range left (Anegawa, 2011). When TEPCO installed two fast chargers in the area, the use of the EVs went up, drivers travelled farther from the headquarters, and when they returned they had much less battery capacity left, than they did before. Furthermore, this effect came even as the fast chargers were very little in use. The lesson is that fast charging removes some of the range anxiety that drivers experience, and this can be achieved with little actual use of the fast chargers. Of course this experience is small scale, and in an early phase of Japanese EV rollout. However, it does give a third perspective as to where and how to install fast chargers, especially in urban areas.

So where should initial fast chargers be placed? As mentioned, many of today's EVs in Norway are located in and around Oslo. Partly this is a result of several coinciding parameters: The congestion in and out of Oslo is significant. In the affluent communities west of Oslo commuters can easily benefit from driving in the bus lane, and purchasing an EV is possible for a number of private individuals. Fast chargers could be placed in this region to stimulate an already strong market. On the other hand, the users in this area still mostly have EVs that cannot be fast charged, and have for years shown that EVs can fulfill their daily needs without fast charging. A fast charger in this area would certainly support the EV fleet, but perhaps a fast charger investment in another area would have a greater payback. A fast charger could be interesting for existing owners if it represents a chance for fast charge when outside of the normal daily commute, and perhaps be reassuring to have locally for people considering to get an EV. In Norway we have very little experience so far, in how a fast charger affects driving, and purchasing patterns. Because of this, decisions on where to place chargers will be based on the discretion of the involved partners, and not to an insignificant degree based on the physical and practical boundaries that a location sets in terms of space, ownership, and power availability.

Through early Norwegian fast charging projects, and Transnova's installation support, we can gain some experiences and early best practices, as fast charging EVs get deployed in Norway. Authorities, EV communities, organisazations such as ZERO, car retailers and producers all agree that fast charging will be a very important initiative for a fast deployment and increased use of EVs. The opportunity is in getting early experiences that are relevant to a larger scale rollout of EV infrastructure, and ensure that Norway continues the positive drive that EVs currently have.

Pricing and business

Fast charging promises new opportunities for electric mobility, and both fast charging capable EVs and compatible fast charging stations are now readily available. When setting up a fast charging infrastructure, however, we are faced with some challenges. The most prominent challenges for anyone wishing to set up a fast charger today is related to cost, business models, location, power availability, and standards.

Compared to a normal charging point, a fast charger is fairly expensive. This is due to the fact that a fast charger is in fact a high power AC/DC converter with communication, safety features etc., while a normal charging point is not a charger at all, but simply a power outlet. In addition, fast charger manufacturers are still in a very early phase of product development and production. Their development costs are significant, and they do not know really how fast and to which degree European countries will roll out fast charging, or how many are really needed. Within some years, given that there are sales and some momentum in fast charging, prices are expected to drop. Today a fast charger costs between NOK 150 000 and 200 000 (€ 20 - 25 000) in a fairly simple setup without a payment solution. To install the charger, a new power cable is likely to be needed, including some digging work. The cost of this is proportionate to the distance between a power station and the location of the charger, but easily amounts to some tens of thousands, even with just a few meters. A rule of thumb is that the work costs related to an underground cable is about NOK 1 000 per meter, in addition to cable costs of about the same. Locating a fast charger near an electric transformer station is essential at keeping costs down.

The cost of installing a fast charger is currently an obstacle. For business actors wishing to sell fast charging to make money it is challenging to find a viable business model. First of all, the marked, that is, the number of fast charging capable vehicles is currently limited, and we don't know well how this will develop in the coming years. We also don't know how much EV owners will actually use fast charging, and how much it depends on the price of the charge. Charging at home is cheap (in NOK/km compared to gasoline), while the cost for fast charging will need to be much higher. Will customers accept the higher price to charge faster? In Norway a license is required to resell electrical power. Most potential fast charging operators do not have such licenses. Selling fast charging as a service per minute instead of as kilowatt hours, could be an easy way around this. This is also convenient because we would want people to move away from the charger when the charging is done, and not occupy the charger longer than necessary. At some level we will have to look at the purchasing cost of the power versus the income that the charging station offers.

Grønn Bil has looked at some simple calculations to see how and how much the charger needs to be used to be profitable given some preconditions. If a charger costs a total of NOK 620 000, and we assume a downpayment time of 5 years, 1.2 NOK/kWh, and yearly service costs of about NOK 10 000, Grønn Bil calculates that the charger installation will be profitable if it charges 6 cars per day (15 kWh) every day of the year, and at a price margin of NOK 5 per kWh. This would lead to a cost for fast charging of NOK 93 (+ VAT. 6.20 NOK/kWh × 15 kWh = NOK 93). The same calculation for an investment of NOK 220 000 yields a profit with 4 cars per day at a power cost margin of NOK 3, resulting in a 15 kWh price of NOK 63 + VAT (Grønn Bil, 2011b). A Nissan Leaf could charge its 25 kWh battery from 20 to 80 % in 20-30 minutes. The price per minute could then be from NOK 2 to almost 5. Given that charging speed goes down, as the battery gets more charged, we can assume that people would charge for shorter times when paying per minute instead of per kWh. From early experiences in Japan, it's been indicated that the average charging time is about 12 minutes.

When collecting experiences, and setting prices, it is also relevant to consider what kind of problem the fast charger is solving for the customer. If the charger is placed along a highway, for people to extend their range, they will want a full charge, and perhaps something to eat. If the charger is located in an urban center and the user wants a quick boost, the charging time is likely to be shorter. The willingness to pay for the customer, and the opportunity for additional sales for the charger owner, will differ between locations.

Business models, other than that of pay-as-you-go, could have some potential. To find new business opportunities, better value for users, and an infrastructure that does not simply emulate the existing gasoline infrastructure, some thinking outside of the box might be required.

There are two alternative business models that could be interesting, though they might need some more development than simple pay-as¬-you-go: Subscription models, and "pay-per-click" models. There are many ways to see subscription, and it could be used in combination with other payment systems. Basically the intention is to have users pay a monthly fee to be a part of a grid of fast chargers. The subscription fee would include free charging, or a lower price on charging, or a number of included charges. The reason why this model is attractive is that it could provide a way for fast charger operators to get a more stable and predictable income over time. Further, since fast charging could turn out to be a service that is wanted and required even if users don't use them, a subscription model could help make fast chargers a viable business. This sort of subscription model could also be combined with some sort of product bundling: an electric utility company could give EV users access to the fast charging network if they become power customers in their home or business, or some similar arrangement.

The pay-per-click model is known from the internet world, where a web site owner gets paid by each click an ad generates for another business, and could also be used in this context, in combination with other business models. If a company, such as an electric utility, wishes to own and run a fast charger, they might not own suitable locations for the fast chargers. Instead they might cooperate with a shopping center, restaurant, or a gas station, to have a fast charger located on their premises. Assuming that an EV owner would prefer to stop at a location with a fast charger, the electric utility could receive a fixed sum from the restaurant for each time the fast charger is used (in addition to the EV user paying), since the customer is likely to spend money at the location while charging.

Early experiences

At the time of this writing, the first public fast charging station is in operation outside Stavanger, and two more will be installed by the utility company Lyse during 2011. At the same time ZERO has been working on a project to install fast charging stations together with partners. Three locations are currently underway, in Oslo, Hamar (130 km north of Oslo), and Moss (60 km south of Oslo). In Oslo one station will be set up at a Statoil gas station; at Hamar one will be installed at a shopping center in cooperation with the local electric utility company Eidsiva, and regional authorities; and at Moss, another will be set up, with support from regional authorities, and the power utility company Ishavskraft.

ZERO's project has been supported by the government agency Transnova. Transnova aims at supporting demonstration projects and infrastructure facilities. It has earlier launched a support scheme for normal charging points, which resulted in 1830 installations in Norway. In 2011 Transnova launched a support program for fast chargers, where applicants can get support of up to NOK 200 000, with a total budget of NOK 3 million. If there is a sufficient amount of applicants, this could lead to a total number of 15 chargers, leading to a total potential of about 20 chargers through these mentioned projects. In total these could be a sufficiently large test ground to learn more about fast charging, and see what effects they will have on users and buyers.

ZERO's project has aimed to get different actors together and share ideas and plans, and cooperate with each other. Typically there have been some groups that have seen fast charging as interesting: First of all electric utility companies; they have regarded EVs, charging and fast charging as something which falls under their business and interest field. Their main issues are the interplay between viable business models and profitability, and social responsibility and public relations.

Further, municipalities and regional authorities see the work for an infrastructure for EVs as a way to promote a more sustainable transport sector. Most municipalities

Fast charger producers

A number of producers of CHAdeMO fast chargers already exist. Through the ZERO project, chargers from SGTE will be used, in cooperation with the Norwegian company Salto Ladestasjoner. The Lyse project outside Stavanger has been realized with chargers from the Dutch company Epyon. Other providers exist, such as Aker Wade, DBT, and AeroVironment, and others.

Charging with CHAdeMO. Photo: EB

have action plans for a decreased fossil share of overall transportation, and many have support regimes for EV infrastructure. Many municipalities have played an active role in the deployment of normal charging points. In Oslo, as one example, the city has a support program for normal chargers, and has also installed a few hundred charging points in the public sphere. Fast chargers, however, are a different story. Normal charging points are relatively cheap and safe, and can be left largely unattended in the streetscape. Fast chargers are generally considered to require some more surveillance, both for safety, and for protection against vandalism. For this reason city authorities are likely to seek cooperation with commercial actors for deployment of fast chargers.

Electric utilities, and municipalities, together with support from governmental agencies, such as Transnova, could prove to be a good basis for early rollout of fast chargers. However, while they may have good intentions, they typically lack the operator role for fast chargers. Shopping centers, supermarkets, gas stations, etc. are often mentioned as possible operators, or at least owners of the physical piece of land, on which the fast charger is to be placed. Such an operator needs to have a certain connection to the installed fast charger, as it would require some light maintenance and perhaps surveillance. However, most of these actors do not see EVs or EV infrastructure as a natural part of their operating business. While some may see an investment in a fast charger as a PR initiative, few see it as a potential part of their normal operation. In ZERO's fast charger project, the electric utility companies and the local authorities have been the major driving forces, even if the chargers may be set up at shopping centers. The exception at this point is Statoil Fuel & Retail that more actively seeks to include a fast charger at their facility, together with ordinary fuel (and, incidentally, a hydrogen fueling station).

It is early to tell whether the three charging stations set up with support through ZERO's project are optimal. Most likely they are too few for a strong synergy effect, and will benefit from more stations being installed in the region. Also, with Oslo and Hamar being more than 120 km apart, there probably will not be a strong cluster effect for Mistubishi i-MiEVs and similar vehicles before more stations close the gap.

Fast charger installments are so far heavily relying on the interest and good will of some partners, limited funding, and a finite number of cost effective locations. We will for the next couple of years see more fast chargers appear as a result of cooperation between public and private entities, and most likely supported by public funding.

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