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Assessing the Impacts of Rapid Uptake of Plug-in Vehicles in Nordic Countries

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Summary

The five Nordic countries (Denmark, Finland, Iceland, Norway, and Sweden) have an opportunity to become world leaders in the deployment of plug-in electric vehicles (PEVs), including battery electric, plug-in hybrid and hydrogen fuel cell vehicles. The benefits of rapid deployment of these technologies would include not only the direct energy savings and CO2 reductions they would provide, but also the possibility to accelerate a global transition to very low carbon vehicles and fuels. This report outlines pathways for achieving such goals, and analyzes the costs and benefits associated with a rapid Nordic PEV deployment effort.

This project builds upon the IEA project “Nordic ETP 2012”, conducted in cooperation with the five Nordic countries during 2011-2012. That project provided a recommended pathway to achieve very low energy-related greenhouse gas emissions in these countries in the 2050 time frame. It includes all energy sectors. This analysis focuses on the transport sector and further explores the implications of achieving a very low GHG transport future in the Nordic countries, in particular three aspects: the detailed roll-out requirements and feasibility for PEVs and associated energy infrastructure in order to reach Nordic 2050 targets, the likely costs and benefits of this roll-out, including the value of fuel savings and CO2 reductions, and the external benefits for other parts of the world if Nordic countries follow this pathway (e.g. how might this help reduce costs or increase confidence for other regions to follow suit with similarly aggressive strategies?).

We conclude that Nordic countries are well positioned to take a leadership role in advancing uptake of PEVs. Their relative wealth and purchasing power, strong concerns about climate, strong interest in clean technologies, presence of low-carbon fuel and electricity generating potential, and the existing vehicle-related tax structures (particularly in Norway and Denmark) all contribute to this position.

Although it would be challenging, it appears possible for the Nordic countries to transition to selling only PEVs by 2040 in terms of new cars and passenger light trucks. As shown in Figure 1, this would lead to a rapid build-up of PEV stocks, reaching more than 10 million on the roads of these countries by 2050. It would also lead to a deep decarbonization of light-duty vehicles in these countries, approaching zero grams/km CO2 emissions by 2050. It also appears that this transition can be done at relatively low cost, at least relative to the size of the vehicle and fuel sectors; the incremental costs of transitioning to a PEV-dominated system may be only 1% more than the costs of taking a status-quo route with internal combustion engine vehicles. In fact, although vehicle purchase costs would rise (or need to be subsidized to avoid rising), the value of fuel savings in our *Rapid Transition Scenario* (RTS) is well above the additional vehicle costs, leading to a net cost reduction to consumers over time. This is explored in some detail in the cost section of this paper.

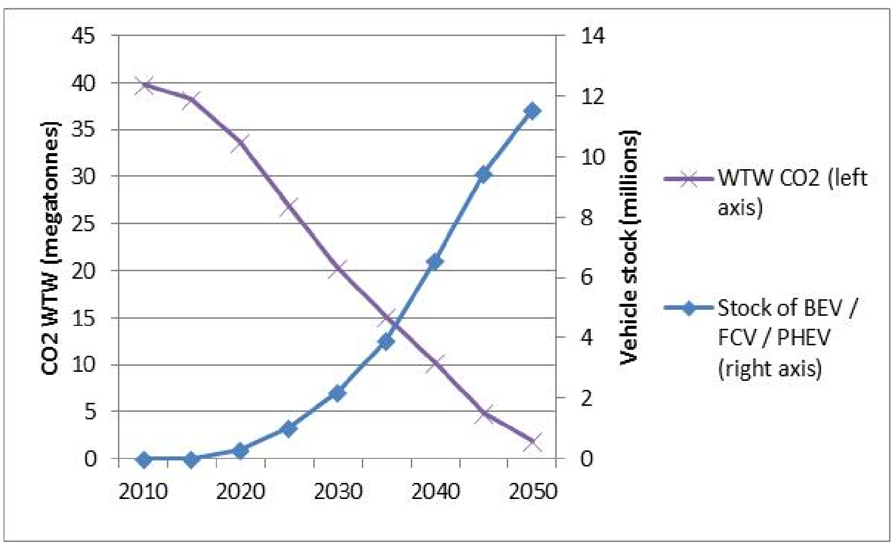

Figure 1: Advanced Technology Vehicle stocks and CO2 reductions in Nordic Rapid Transition Scenario (RTS)

If this scenario plays out across Nordic countries, what might it mean for transport decarbonization in other countries around the world? While the Nordic countries account for a very small share of the world's vehicle sales, it is very possible that Nordic leadership would help other countries to move faster. This could relate both to setting an example and showing a fast transition is possible but also by helping to "buy down" the costs of PEVs; reducing these costs through helping achieve scale production and learning, and optimizing infrastructure development, that will help make it less expensive for other countries (particularly developing countries) to follow a similar path. Cooperation and technology transfer between Nordic countries and other regions can help in this regard.

While it is difficult to predict what "spillover" effects could occur, our "Global RTS" (Figure 2) shows a possible global transition where other countries and regions follow the Nordic lead. An overall fairly rapid transition then occurs around the world, with most OECD countries phasing out sales of non-PEVs by 2050, China following close after, and the rest of the world well on the way to this end point. The net global effect on CO_2 is about an 80% reduction by 2050, compared to a *4°C Scenario* (4DS) where LDV CO_2 emissions reach about 8 Gt worldwide by 2050.

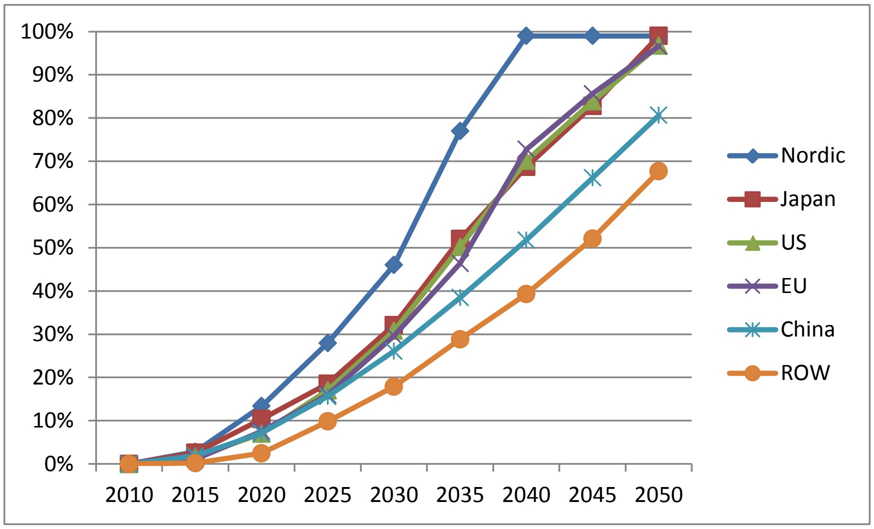

Figure 2: Penetration of Advanced Technology Vehicles by Region in RTS

Overall, there are good reasons why Nordic countries should seize the day and move toward a rapid transition to advanced technology vehicles. Some key polices are in place in each of the countries. A sustainable funding mechanism to help lower the price of PEVs over perhaps the next 10 years so they are attractive to consumers without further support is probably the greatest requirement, and this can be achieved through policies such as CO2-based vehicle taxation systems. These are now in place to varying degrees in the different Nordic countries and in some cases may just need to be fine-tuned over time. Other incentives such as roadway and parking priority access, and installation of recharging infrastructure are also in place in various ways in the different countries, and such incentives have proven valuable, but must be managed carefully, particularly as the PEV car stock grows. Further work on optimizing policy packages, and ensuring sustainable funding streams (while preserving government revenues), is needed. But the basic elements are already in place, particularly in Norway.

Introduction

This research project is designed as a direct extension of the analysis conducted in IEA's *Nordic Energy Technology Perspectives 2012* (NETP). The NETP report covers a wide range of details in the analysis, and presents a range of implications associated with these scenarios. The full report was published in early in 2013 and is available at http://www.iea.org/etp/nordic/.

At the core of that analysis is a study of scenarios of the future energy system for the Nordic region. As this region is relatively small, with a very open economy, analysis of the regional energy system is made in a global context. Consequently, the analysis is tightly integrated with the global perspective presented in the IEA's broader publication *Energy Technology Perspectives 2012* (ETP)[1]. In ETP three global scenarios were presented: the 2°C Scenario *(2DS)*, representing a vision of a sustainable energy system of reduced Greenhouse Gas (GHG) emissions, consistent with the globally agreed objective of limiting average temperature rise to 2 C; the 4°C Scenario (*4DS),* reflecting pledges by countries to cut emissions and boost energy efficiency; and the 6°C Scenario, reflecting a scenario in which no new policies are introduced. The NETP also contains a new *Carbon Neutral Scenario* (CNS), which pushes to even deeper CO2 reductions than 2DS and reflects the current actual CO2 reductions of the Nordic countries.

In this report we present a follow-on analysis, where we push further into transport and look at transition scenarios for new technologies and fuels for light-duty vehicles in more detail. Here a new *Rapid Transition Scenario* (RTS) is introduced and compared to the IEA 4DS, 2DS and other scenarios. This new scenario results in a complete phase out of new conventional (standard gasoline and diesel)

Internal Combustion Engine (ICE) vehicles in Nordic countries by 2040, replaced by electric vehicles, plug-in hybrid vehicles, and hydrogen fuel cell vehicles. By 2050 almost all light-duty vehicles on Nordic roads are zero-emission, at least at the vehicle tailpipe. This analysis explores the relationship between sales of these vehicles and fuels, incremental vehicle costs and fuel savings, stock turnover effects, and ultimately the results in terms of energy use and CO2 emissions going out to 2050.

We next consider a range of policies that could bring such a future about, in the context of policies currently in place and being considered by Nordic countries to realize their current targets. We suggest additional policies that may be needed for success. Finally, we look at how success in these efforts could impact the adoption and use of new technology vehicles in other regions of the world, looking first at the EU and then worldwide. We address the question, "can Nordic countries play a leadership role that helps to trigger a faster transition to very low carbon vehicles around the world?"

More specifically, we ask the following questions:

1) **What are the detailed rollout requirements** for advanced technology vehicles and fuels in order to reach 2050 targets, and are these feasible? In other words, how does the transition to these new vehicles and fuels look over time, and what must be achieved in the next 5-10 years to ensure that countries are on the correct path toward 2050 targets?
2) **What are the likely costs and benefits of this roll-out?** Taking into account the current costs, and cost increments, associated with electric vehicles, plug-in hybrids, fuel cell vehicles, and biofuels, and the expected decline in these costs over time, along with refueling infrastructure, what are the likely overall net costs of the roll out? How do these costs compare with the costs of the vehicle/fuel system in general (what are the incremental costs), and how do these costs compare with some of the expected benefits (reductions in petroleum use and fuel costs,

reductions in CO2 emissions, possibly other external costs). Do these costs and benefit estimates suggest that the scenario provides net costs or benefits to the countries involved?

3) **What might be the external benefits for other parts of the world if Nordic countries follow this pathway?** If Nordic countries follow this scenario, they are likely to be at the front of large-scale adoption of these vehicles and fuels and, while this may mean higher costs for them since they will be early adopters, this could also mean lower costs to other countries and regions who later follow suit. Since the Nordic countries account for only a small share of the world's population and vehicle purchases, this segment of analysis also looks at how many advanced vehicles would be adopted if other countries follow the Nordic lead, and how this might help to build markets and reduce costs, while cutting oil use and CO_2 emissions, given assumptions on cumulative vehicle production and learning.

The IEA NETP Analysis in Review

Since this study takes the IEA Nordic Energy Technology Perspectives study [2] as its starting point, it is worth reviewing some of the key transport assumptions and findings in that study.

In terms of the present situation, the study shows that surface transport (excluding air travel) accounted for about 36% of energy-related CO2 emissions in the five Nordic countries; passenger light-duty vehicles (LDVs) accounted for nearly half of this, and well more than half when excluding both air and shipping. In terms of passenger travel, Cars and light trucks account for the vast majority in all Nordic countries, outside of air travel (Figure 3).

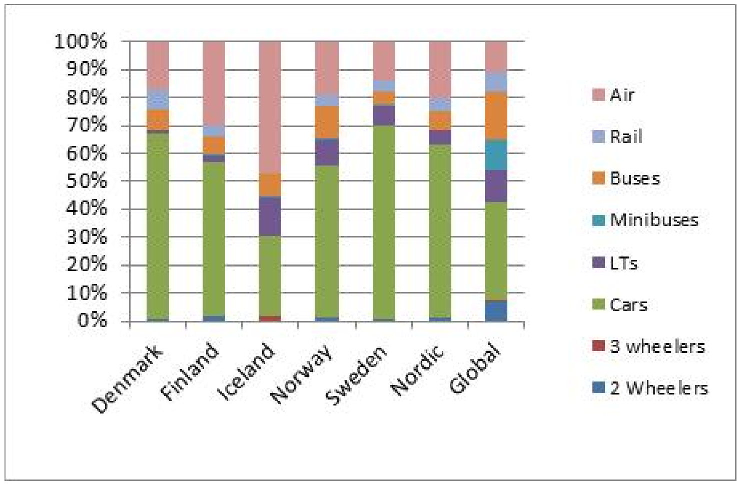

Figure 3: Modal shares of passenger travel for Nordic countries and worldwide average (includes international air travel)

In terms of trends, passenger car sales have generally been rising since the early 1990s, though fell precipitously after the economic crisis in 2008 (Figure 4). They have since recovered but it is unclear if there will significant growth in the future. Over this same period, total vehicle stocks have grown more slowly, total vehicle travel has grown more slowly still, and energy use has been nearly constant, reflecting efficiency improvements that have offset vehicle travel growth.

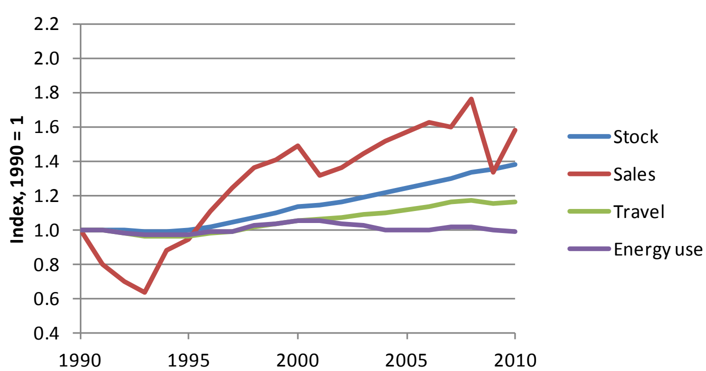

Figure 4: Trends in Nordic light-duty vehicle sales, stock travel and energy use

The basic IEA Nordic transport projection for the future (as embedded in 4DS) is shown in Figure 5. Energy use across all modes is fairly flat, while the use of oil-based fuels declines slightly – but not a lot – out to 2050. Despite some increase in the use of biofuels and electricity in transport, petroleum based fuels remain at about 90% of transport fuels in 2050 in this scenario. While it may be conservative, it reflects a finding that without additional policies, the IEA does not expect to see a "revolution" in transport propulsion systems or fuel types over the coming 4 decades.

This current analysis focuses on a different future for light-duty vehicles. Through the use of very aggressive policies, it should be possible to achieve a deep market penetration of plug-in vehicles and hydrogen-fuel-cell vehicles by 2040.

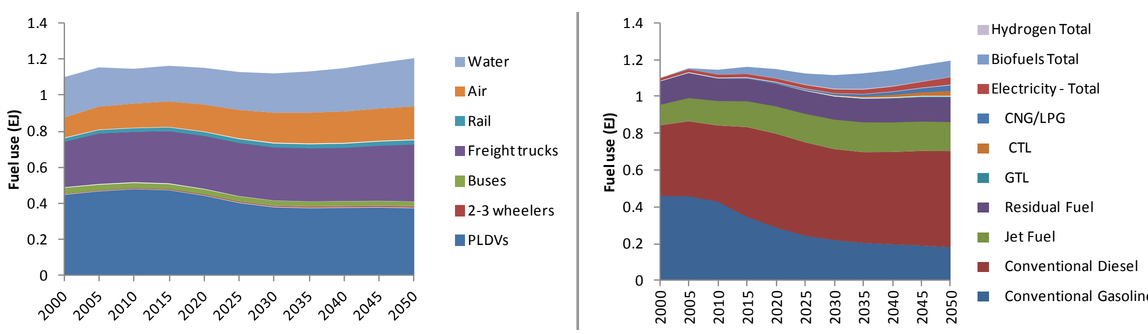

Figure 5: Fuel use by transportation mode and fuel type in IEA 4DS scenario (Nordic countries)

The sales of light-duty vehicles in the 4DS reflects this dominance of petroleum fuel – very few plug-in or fuel cell vehicles are sold in this scenario (Figure 6). However, the IEA also has developed a 2° scenario (2DS), which for light-duty vehicles has a strong penetration of plug-in vehicles and hydrogen fuel-cell vehicles. Beyond conventional and hybrid vehicles, plug-in hybrids and fully electric vehicles account for about 40% of sales in 2050, with fuel cell sales another 15% or so. (Note that in the IEA projections Nordic LDV sales increases significantly between 2015 and 2020 as economies strengthen, then flatten out as market saturation is reached.)

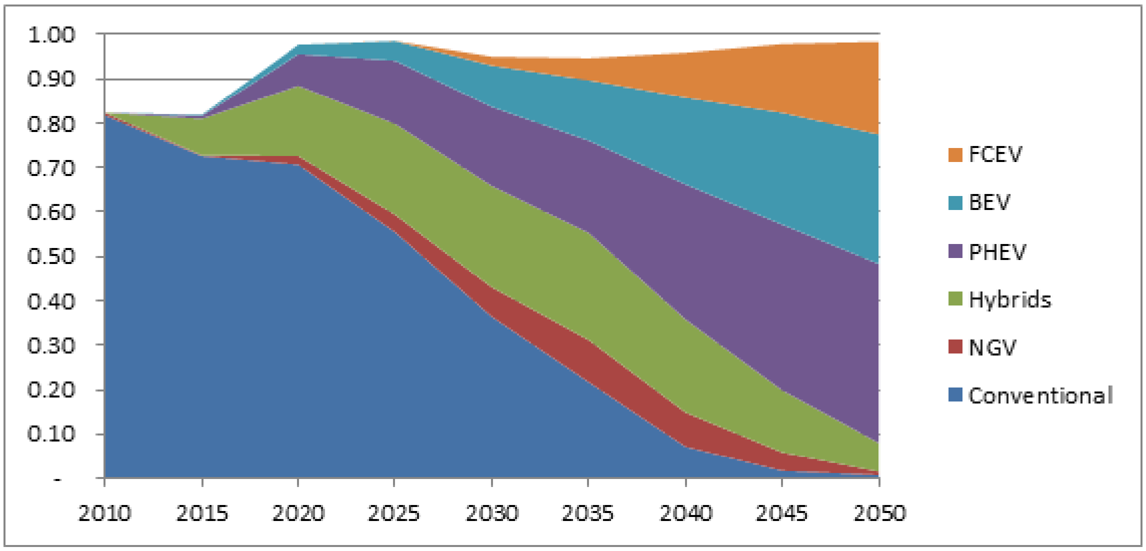

Figure 6: Light-duty vehicle sales by technology type in IEA 2DS (Nordic countries)

Side Panel: Types Of Vehicles Considered in this Study

The vehicle types considered in this study include hydrogen fuel cell vehicles (FCEV), battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV), hybrids (HEV), and conventional gasoline and diesel vehicles. Together FCEVs, BEVs and PHEVs are termed Plug-in Electric Vehicles or PEVs. FCEVs and BEVs are driven by electric motors and thus have similar driving characteristics. FCEV's are fueled with hydrogen gas, which is converted to electricity by a fuel cell. Basic FCEV designs have small traction batteries (~ 1-2 kWh) to support regenerative braking and burst power demand. Larger traction batteries can be added that can add plug-in electric capability if desired. BEVs are plug-in, battery-powered vehicles. FCEVs feature longer driving ranges than BEVs, and may cost less over the long run, however they will require a new hydrogen-refueling network. BEVs are more efficient than FCEVs and can be recharged at home or at public charging stations.

Plug-in Hybrids (PHEV) are gasoline or diesel internal combustion engine (ICE) vehicles that include an electric drive motor and a battery pack that allows the vehicle to run in an electric dominant mode for an initial driving range (typically 15-60km), but less than most dedicated electric vehicles. PHEVs require outlet recharging to operate as intended. Hybrid vehicles (HEV) are gas or diesel vehicles with a small electric drive motor and a small battery (1-2 kWh). They are charged by regenerative braking and do not require, or allow plug-in recharging.

Natural Gas Vehicles (NGV) are internal combustion engine vehicles that are powered by natural gas. They and do not play a significant role in the scenarios considered in this study. Conventional Vehicles (CV) are standard gasoline and diesel vehicles.

The Rapid Transition Scenario (RTS) For Nordic Countries

Although the IEA scenario for light-duty vehicles is ambitious, it seems possible to push even further, in line with an aggressive strategy to reach a near zero-CO2 emissions target for light-duty vehicles by 2050. In order to achieve this, nearly all LDVs on the road by 2050 will need to be either plug-in (BEV or PHEV) or hydrogen fuel cells. It is not difficult to construct this type of scenario. Figure 7 shows this *Rapid Transition Scenario* (RTS) in terms of new car sales through 2050. Figure 8 shows it in comparison to the IEA 4DS and 2DS cases. In the RTS, sales of conventional internal combustion engine (ICE) vehicles and even non-plug-in hybridized cars are ended by 2040; all new vehicles are then either plug-in hybrid (PHEV), pure battery electric (BEV) or fuel-cell electric (FCEV). Although PHEVs will still use some liquid fuel, by 2040 this may be a small share, with long electric range PHEVs (60 km), dominating this vehicle type.

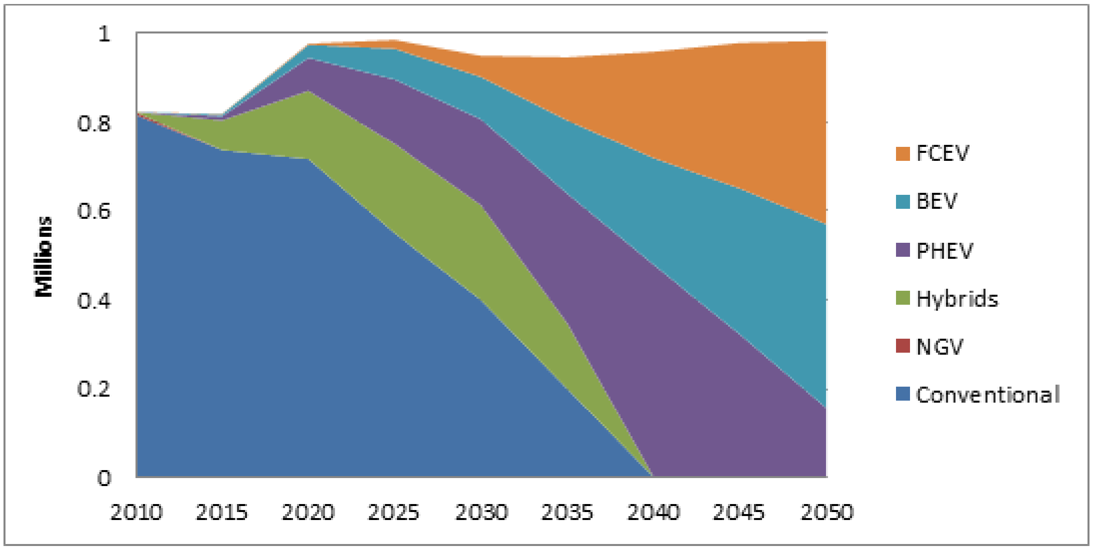

Figure 7: Light-duty vehicle sales by technology type in Rapid Transition Scenario (RTS) for the Nordic countries

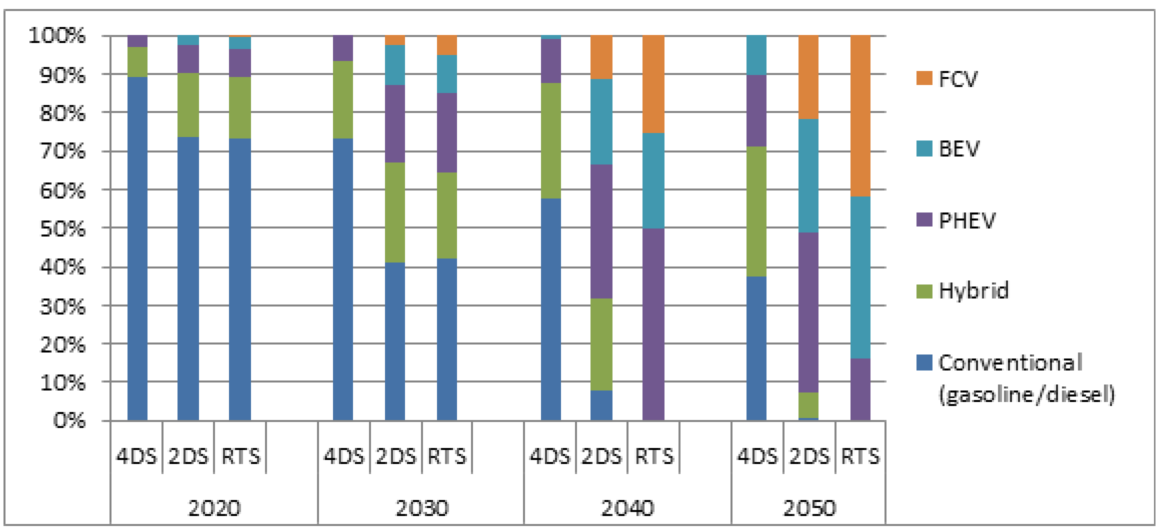

Figure 8: New LDV Sales Shares -- Comparisons of IEA 4DS, 2DS, and RTS

The effect of the RTS sales shifts result in a slow but steady build-up in PEV stocks (Figure 9). By 2050, PEVs represent over 90% of light-duty vehicle stock in Nordic countries. Conventional ICE vehicles are nearly completely phased out.

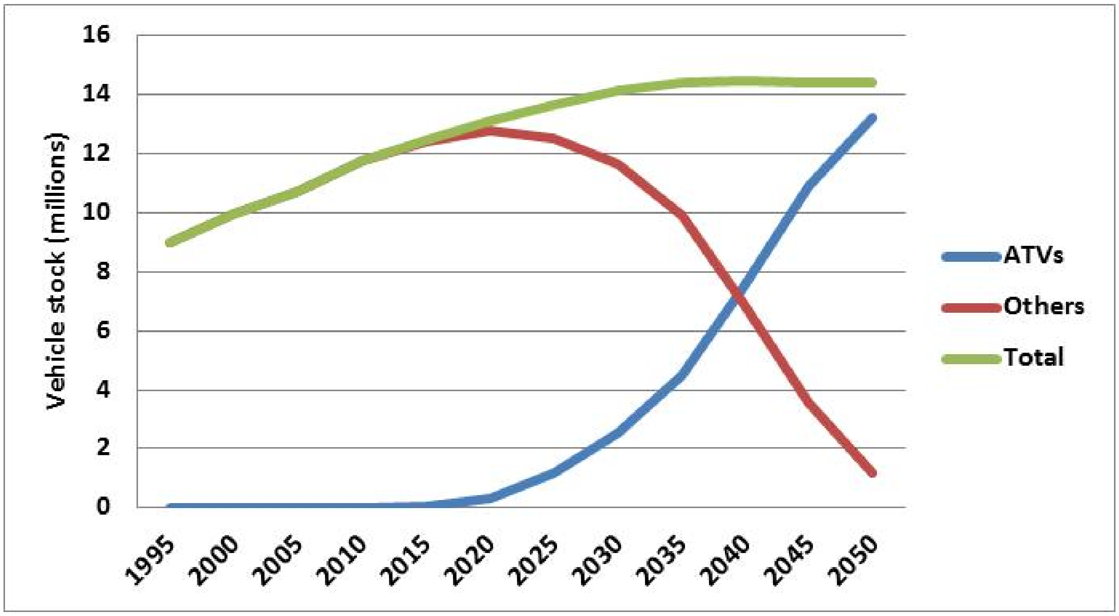

Figure 9: Penetration and stock build-up of Advanced Technology Vehicles (PEVs) in Nordic countries

The CO2 impacts in this scenario will depend in large part on the life-cycle emissions of the fuels used. It is assumed that by 2050 near-zero GHG feedstocks and conversion pathways provide all electricity and hydrogen. As the IEA NETP study shows, this would be the case if the entire energy economy follows a strong carbon reduction (e.g. 2DS) pathway. The remaining liquid fuel provided by then might be primarily advanced biofuels, hopefully also a near-zero net GHG fuel.

Vehicle construction also has GHG impacts [14]. The materials and processes involved in building BEVs, PHEVs, and HFCVs are substantially different from those used in ICEVS. According to an analysis by Delucchi and Lippman[15], however, vehicle lifecycle emissions are a secondary factor to the fuel lifecycle (e.g. feedstock production/conversion). Although BEVs are somewhat more emissions-intensive to build at the current time, by 2050 they are projected to be similar to conventional vehicles, partly because the car manufacturing industry around the world is expected to decarbonize.

Figure 10 shows the total CO2 emissions for the 4DS and RTS scenarios, this includes Tank to Wheels (TTW) and Well to Tank(WTT). For 4DS, CO2 emissions stabilize at just over 30 MT in 2030, with a small upward shift in WTT, and a small downward shift in TTW, running through 2050. The RTS scenario makes steady, substantial declines in CO2 through 2050, dropping to about 3 MT of CO2 by 2050, a 90% decrease compared to 4DS. That bulk of that decrease is attributable to TTW, i.e. by transitioning to more efficient vehicle types. The RTS scenario goes negative on WTT in 2040 due to the use of biofuels[1].

[1] The CO2 emissions accounted for in this study include those from the full fuel cycle (fuel production through vehicle emissions) but not emissions associated with vehicle production or disposal. These are expected to be farily similar for most types of vehicles but will become more important as vehicles become more and more efficient. Future research could investigate this aspect.

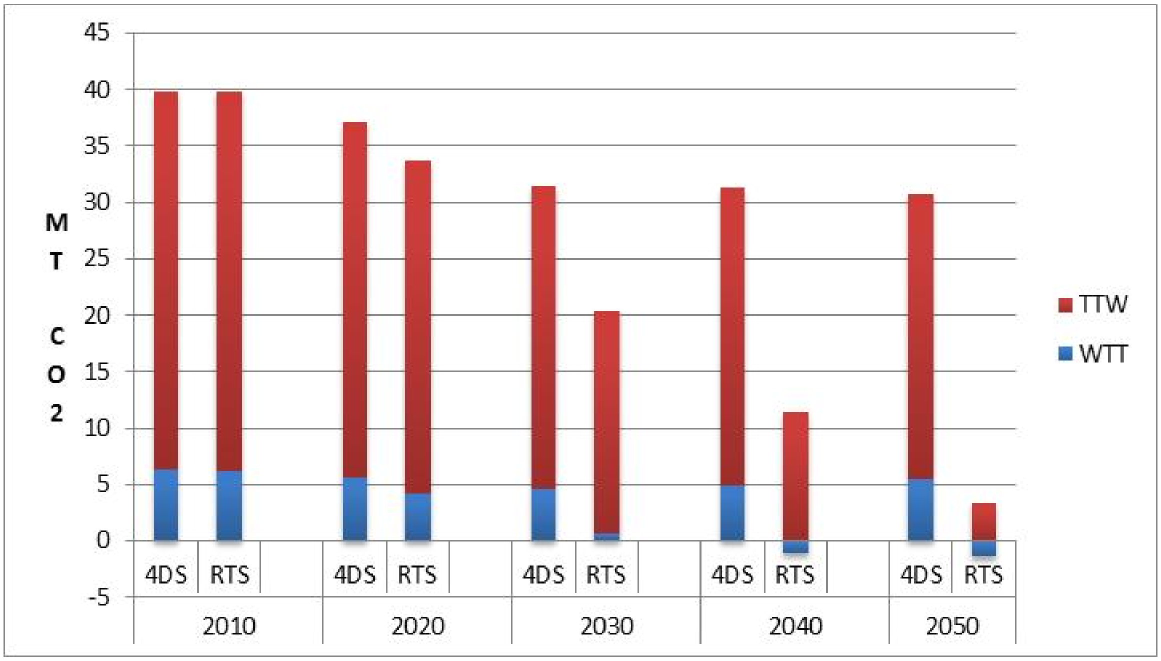

Figure 10: Well-to-wheel CO2-eq emissions by scenario an year

Considerations in Rolling out Advanced Technology Vehicles

What are the roll-out requirements for advanced technology vehicles and fuels – and refueling infrastructure - in order to reach 2050 targets and are these feasible? In other words, how does the transition to these new vehicles and fuels look over time, and what must be achieved in the next 5-10 years to ensure that countries are on the right path toward 2050 targets?

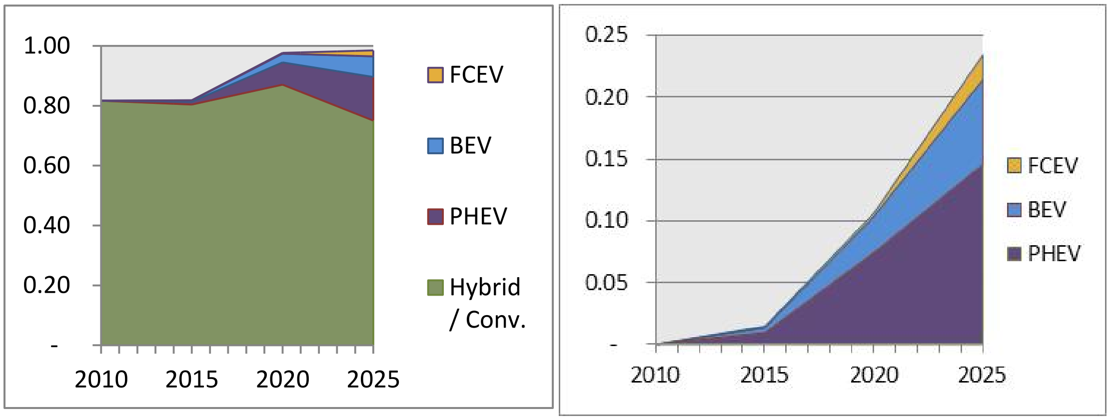

Figure 11: Sales of PEVs in Nordic countries in RTS to 2025 (millions)

Side Panel: Refueling Infrastructure Considerations for Electric and Hydrogen Vehicles

FCVs, BEVs, and PHEVs require new refueling infrastructure to support them. In general the more advanced the vehicle, in terms of its difference from a conventional ICE, the higher the infrastructure roll out requirements. A mild PHEV with a 16km electric range, for example, can be fully charged on a standard outlet in a few hours[3]. PHEVs do not require electric charging, but drivers will typically want to keep them charged in order to maximize their electric operation time. In cold climate locales where engine block heaters are common these low capacity EVs would have many places to top off their electricity stores. In the Nordic context, an important factor to consider with battery vehicles is their cold weather range. The waste heat from the internal combustion engine is used to heat conventional vehicles. Electric and hydrogen fuel cell vehicles do not generate useful waste heat, they must use fuel directly for heat. Preliminary research from Japan on the Mitsubishi i-Miev (aka Citroën C-Zero, Peugeot Ion) suggests that BEVs may lose up to 60% of their range at 0°C , mostly due to heating related energy consumption [4]. These range losses will further decrease in sub-zero temperatures. Fuel cell vehicles will be less affected by cold weather related range losses due to their greater range, and the potential to recycle fuel cell process heat to the cabin [5].

Although plug-in vehicles can be charged on standard home electric lines, owners will want to have home chargers. These will allow for full overnight charging of a normal 160km range BEV, and are programmable so that drivers can manage charging times (usually to take advantage of late night electricity rates). These chargers are estimated to cost $1000, based on current prices. High speed public chargers will also be necessary at a rate of 1% of the BEV stock. Block heater outlets can be used to trickle charge BEVs and PHEVs year round. In cold weather block heater outlets can be used to pre-heat BEVs and FCVs to a comfortable temperature, reducing the heating load on their fuel sources.

FCV infrastructure is more challenging than EV infrastructure because it requires an extensive new network of hydrogen refueling stations[6],[7]. Hydrogen must be manufactured from a feedstock. Steam Methane Reforming (SMR) is likely to be the most common method of hydrogen production in an early roll out. As the name implies, the hydrogen is generated from methane, which makes it a fossil based fuel in that case. However hydrogen can be made from many feedstocks including electricity from renewable or fossil sources, biomass, and high temperature electrolysis, which uses the process heat from nuclear power plants [8]. The fact that hydrogen can be made from many feedstocks makes them flexible fuel vehicles. In the end, a hydrogen fuelled vehicle is as carbon intensive as the source of its hydrogen.

RTS - Refueling Infrastructure Requirements

Building refueling infrastructure to support HFCVs is a bigger undertaking than for electric vehicles, since virtually no commercial hydrogen production or distribution systems exist in any countries, whereas most homes and many public locations (particularly in cold climates) already have slow-charge plugs available, and would be relatively easy (though not necessarily cheap) to upgrade to faster charging.

Hydrogen Refueling

For HFCVs, a hydrogen station network will need to be developed and supported by an H2 distribution system. A critical element is the strategy for deploying stations in relation to the ramp up of vehicles on the road. Stations can be rolled out over time, but because the hydrogen transport network isn't developed to handle mass adoption of hydrogen fuel it will take considerable planning to optimize the system while also trying to minimize the initial investment. Studies will need to be done of travel behaviour in order to develop a hydrogen station siting plan that will make drivers comfortable both in terms of fuel availability and the economics.

One important difference between conventional vehicles and the PEVs (hydrogen and battery powered vehicles) considered in this study is the decreased range of the latter. While EVs can mostly recharge at home, hydrogen vehicles will need a network of refueling stations early on so that drivers are confident they will not be stranded. The reduced vehicle range shouldn't be a big problem for the urban refueling network, but may require a denser inter-city refueling network than current provided for conventional liquid-fuelled vehicles. This may be especially true where these vehicles are driven in extreme climates where running out of fuel could be deadly for stranded drivers. The stations will have to be spaced closely enough to keep intercity drivers with a safe reserve of fuel.

Initially, even in urban areas it will be important to ensure that there are enough hydrogen stations to support the initial HFCVs in operation – these vehicles must be able to find refueling within a few kilometres from all points in the city. Such a network will give consumers confidence that they can own HCFVs and move around without "range anxiety", and hopefully help spur sales. But since this means a fairly large number of stations relative to the number of vehicles initially in operation, the stations may not be initially profitable and will probably need to be subsidized for a period of time.

In many areas it may be possible for a few well-positioned petrol stations to be used for locating initial hydrogen stations. Eventually, as the number of HFCVs rises, the location of stations will cease to be the primary concern, and will be replaced by needing to ensure a sufficient number of stations to serve all the vehicles on the road (for example, to ensure enough fuel is available and avoid excessive queuing at stations). Recent research in California suggests that one station can serve about 750 cars in use, since most vehicles only refuel about once per week.

Initially, hydrogen-refueling infrastructure can be as simple as mobile tank dispensers that can be placed where desired and refilled using trucks delivering hydrogen from central stations. A few such stations already exist around Nordic countries (Figure 12). Larger hydrogen refueling stations can store hydrogen from tanker trucks or create hydrogen on-site using steam methane reforming (SMR), making hydrogen from pipeline natural gas. Eventually, dedicated pipelines could deliver hydrogen but this would require a very large system. Here we assume a progression of system in this manner, from relatively simple, small-scale approaches to larger scale approaches as demand grows. This will also help minimize costs over time[7].

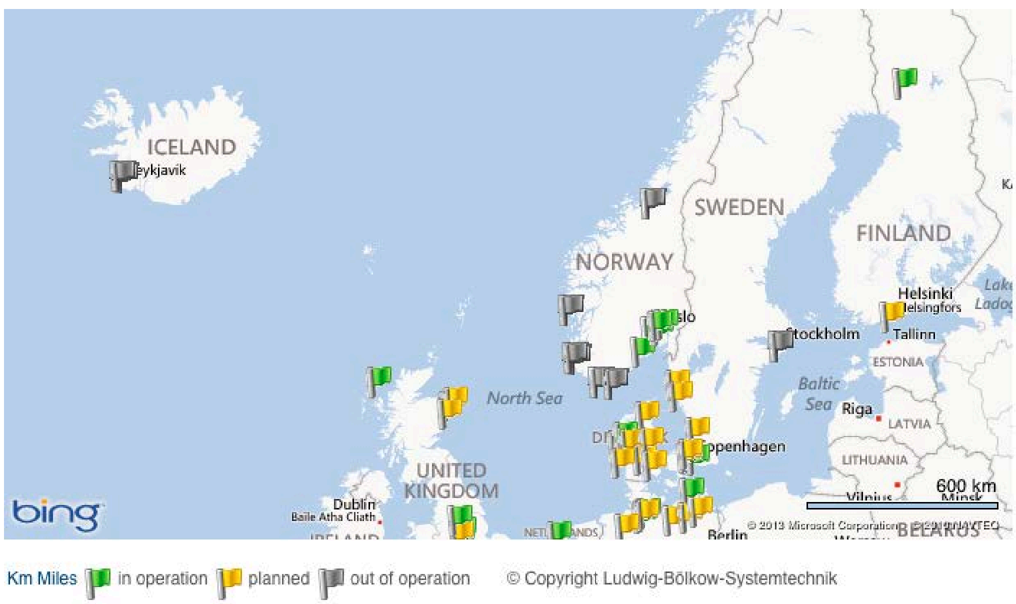

Figure 12: Hydrogen stations Nordic nations (source: http://www.netinform.net/H2/)

The results of this hydrogen infrastructure exercise are shown in Figure 13. Hydrogen refueling infrastructure is initially very expensive at over $75,000 per vehicle, but this number is a result of the small number of vehicles available to spread the costs over. Once the initial roll out and more cars hit the road the average costs per car fall and stabilize at about $1600/vehicle on the road. This longer run steady-state cost is not very high in the context of vehicles that will likely cost $30,000 and up.

It should also be noted that the cost of hydrogen fuel includes the cost of raw production and the feedstock costs; these are considered separately in the following section, which compares vehicle and final fuel costs across technologies and fuels. Even with infrastructure costs, when amortized into the cost and (untaxed) retail price of fuel, hydrogen can be competitive in the range of $1.00/litre gasoline-equivalent at large scale.

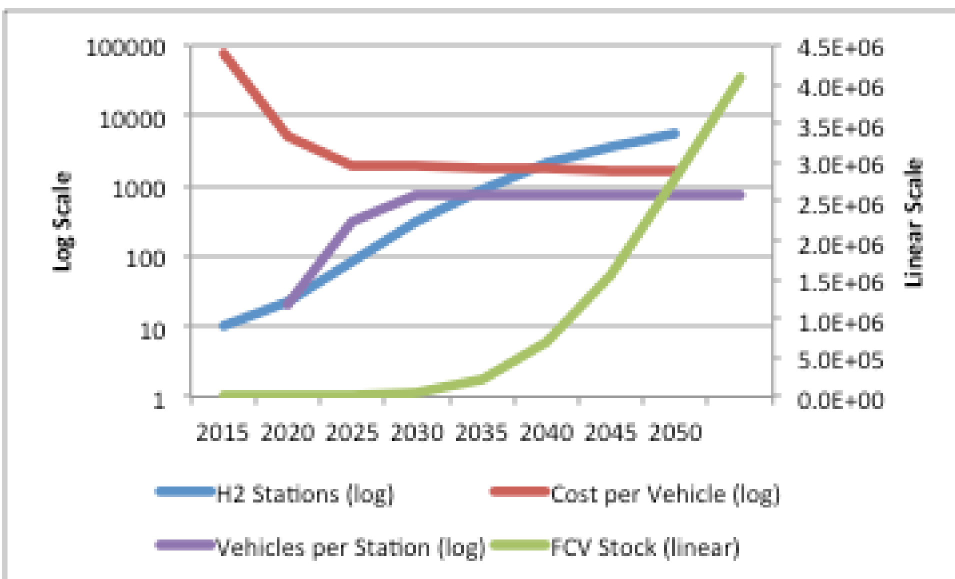

Figure 13: Hydrogen infrastructure projections for Nordic countries

Electricity recharging

The infrastructure analysis for BEVs is simpler than for FCEVs and mainly requires considering the cost of home and public chargers. Based on current estimates of large-scale sales, home fast chargers are assumed to cost $1000/per car, and one home charger is assumed for each car sold. EVs can typically be charged from home outlets rated as low as 13 Amps, however it is generally expected that EV owners will prefer a charging station that will allow them to charge faster (e.g. 230V/32A) and to better manage their charging schedules. In addition to home chargers we expect public chargers to appear in increasing numbers as the BEV/PHEV fleet grows in size. We assume that public charging stations will occur at a level of 1% of home charging stations, though this is quite uncertain. But 1% would mean 10,000 public chargers in a system with 1 million electric vehicles, which would be a considerable number. Obviously for each percentage increase in this ration, the costs would rise commensurately. The cost of the public chargers is estimated at $20k per installed unit.

The aggregate cost breakout of the RTS infrastructure scenario is shown in Figure 14 and Table 1.

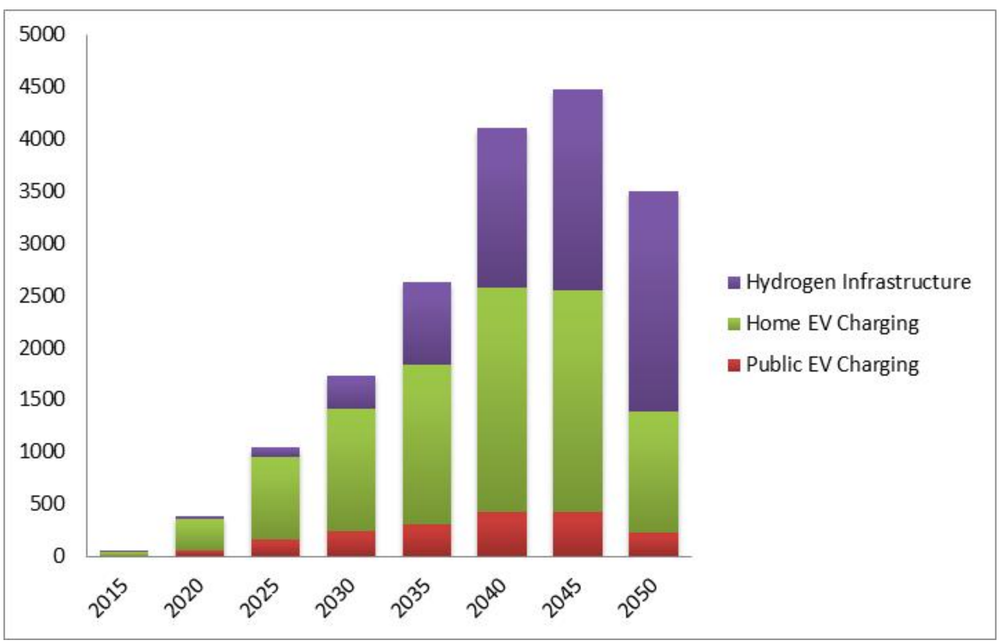

Figure 14: Total incremental costs for refueling infrastructure by year

	2015	2020	2025 - 2030	2035-2050
HFCV hydrogen infrastructure cost/vehicle	**$75,000**	**$5000**	**$1870**	**$1600**
EV/PHEV Home Charging cost/vehicle	**$1000**	**$1000**	**$1000**	**$1000**
EV/PHEV Public Charging cost/vehicle	**$200**	**$200**	**$200**	**$200**

Table 1: Fuel Infrastructure costs per vehicle and cost reductions over time

These hydrogen infrastructure cost estimates assume an early roll out in which the ratio of stations to vehicles is large (1 station per 20 vehicles) [7], [9]–[11]. This leads to high station costs on a per vehicle basis. But, as the vehicle stock increases station costs per vehicle stabilize at about $1500 per vehicle. EV infrastructure costs, in contrast, are estimated to cost a constant $1200/vehicle which covers a $1000 home charging unit and public charging stations at a rate of 1 per 100 EVs.

RTS – Overall Costs of Scenario

Putting the fuel infrastructure investment costs into the context of all vehicle and fuel expenditures over the coming decades, one can gauge the scale of the cost challenge for achieving a nearly fully decarbonized light-duty vehicle sector in Nordic countries by 2050. A number of key assumptions are made for these calculations that are consistent with IEA methodologies. These include:

- Current and expected future costs of different vehicle technologies and vehicle types (Figure 15) are made in a consistent fashion and are built up from the specific technologies contained in each type, based on studies by the IEA and the US National Research Council [1], [12]. For example, a plug-in hybrid is assumed to have the same cost as a conventional hybrid, except for the additional cost associated with the additional batteries and charging system. A full BEV, in contrast, has additional costs from a large capacity battery system, but its cost also reflects the benefit of removing the internal combustion engine and its system components.
- The costs of key technologies such as batteries and fuel cells for 2015 are based on current costs under low-to-medium-volume production (below 50,000 units per year), and these costs decline over time as a function of increases in scale as well as learning and optimization. These are consistent with a range of studies and in fact are somewhat conservative on battery cost reduction rates compared to the NRC study [12]. Also consistent with the NRC study, we assume one set of batteries lasts the life of the vehicle; this appears likely to be true of battery packs in the relatively near term, if not already. Though obviously the need to replace batteries during the life of the vehicle would add considerably to overall cost and decreases cost-effectiveness commensurately.

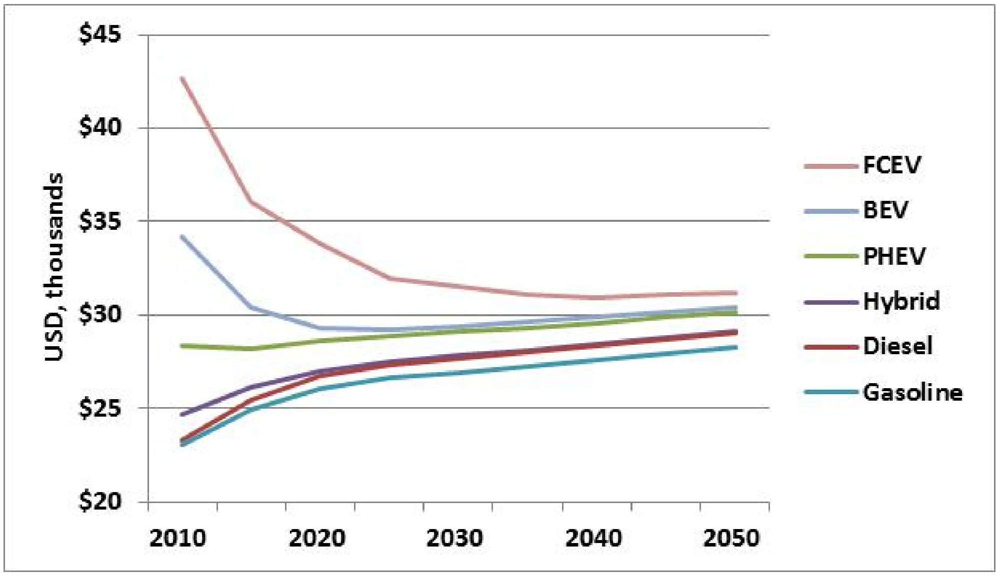

Figure 15: Cost-based price of a representative light-duty vehicle by technology type

- Costs of fuels reflect both the infrastructure costs described above and the operating and resource costs of producing each fuel and delivering it to vehicles. The infrastructure costs described above, as well as other fuel cost and resource price assumptions, are consistent with IEA assumptions and projections from ETP 2012.
- Total expenditures on all light-duty vehicles are based on the projected sales volumes and the average cost of base vehicles in each future year, and reflect the increased sales of new technologies along with their price increments. Only the cost of new vehicles is included in each year‘s total.
- Total expenditures on fuels in each year are the sum of the expenditures on all fuels for light-duty vehicles in that year, reflecting the volume and price of each fuel sold.

This approach captures all spending on new car purchases, along with fuel purchases for all cars on the road, in each year. It does not include the non-fuel cost of operating cars (such as maintenance and insurance) – these are assumed to be similar for all vehicle types so are not expected to vary across scenario. In fact, this approach underestimates the fuel savings from PEVs in a given year since it includes the cost of all PEVs sold in that year but only the fuel savings associated with them in that year, whereas they will continue to provide fuel savings for many more years. For example, costs summed for 2020-2025 include all vehicles sold in that time period and the fuel savings from all vehicles operating in this time frame; but much of the fuel savings associated with the vehicles sold in this time frame will occur over the following 10-15 years. With growing vehicle stocks, this creates a lag in fuel savings, and stopping in 2050 misses a large quantity of fuel savings between 2050-2060 even if no more PEVs were sold.

The results of this exercise are shown in Figure 16 (bolder colors for vehicle costs by vehicle technology type and lighter colors for fuel costs by major fuel type). An important result is that the total cost of new vehicles and all fuels is very similar in the RTS case as in the 4DS case. This reflects generally slightly higher costs for vehicles in RTS but with fuel cost savings that partially offsets this (Figure 17). In fact by 2050 the total costs of RTS are significantly below 4DS (about $1 billion less in that year), for three reasons: first, the costs of advanced technology vehicles drop over time as their sales volumes rise, so that their overall incremental cost doesn't change much; and second, fuel costs in RTS decline because less fuel is used (and the difference widens as more and more high efficiency vehicles are added to the fleet). Finally, the cost of oil rises over time relative to hydrogen and electricity.

These results are important since many think there will be high net costs for shifting to an alternative fuel, low CO2 vehicle world. While that is true in the near term, the numbers of vehicles is too low to have that big an impact relative to the overall spending on vehicles and fuels that occurs in the market (note that the net increase in cost of around $1 billion per year to 2025 is relative to total spending on vehicles and fuels of $35 billion per year). Even in the longer term, if the incremental costs of new vehicle technologies decline in proportion to their sales volume, then their total costs do not rise much. That is the case in this scenario, based on on the current understanding of potential technology cost reductions for components such as batteries and fuel cell systems. If plug-in vehicle costs reach parity with conventional vehicles by 2050 as assumed here, the end result is an overall vehicle/fuel system that in the long term is cheaper than a conventional vehicle future. This is certainly speculative, but many studies project such parity will occur well before 2050 if large volume production is achieved and maintained over time [12].

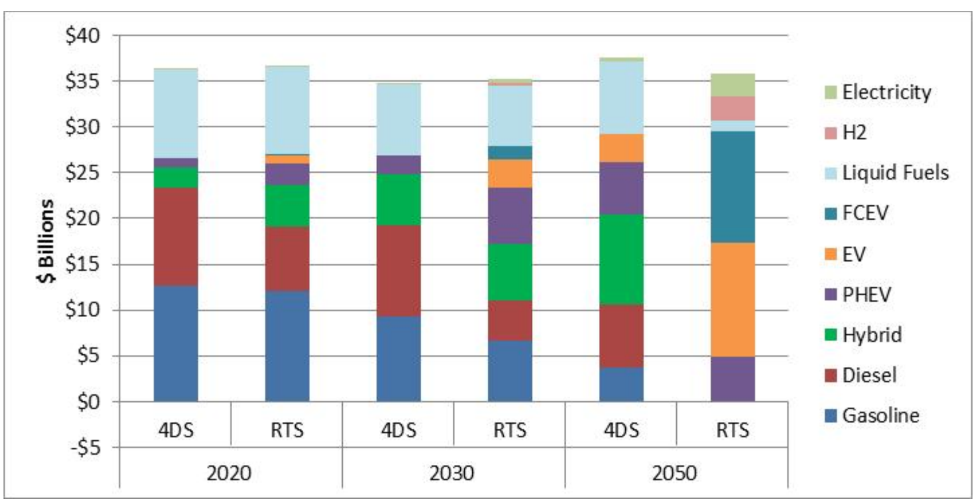

Figure 16: Total cost of vehicles and fuel by scenario and year

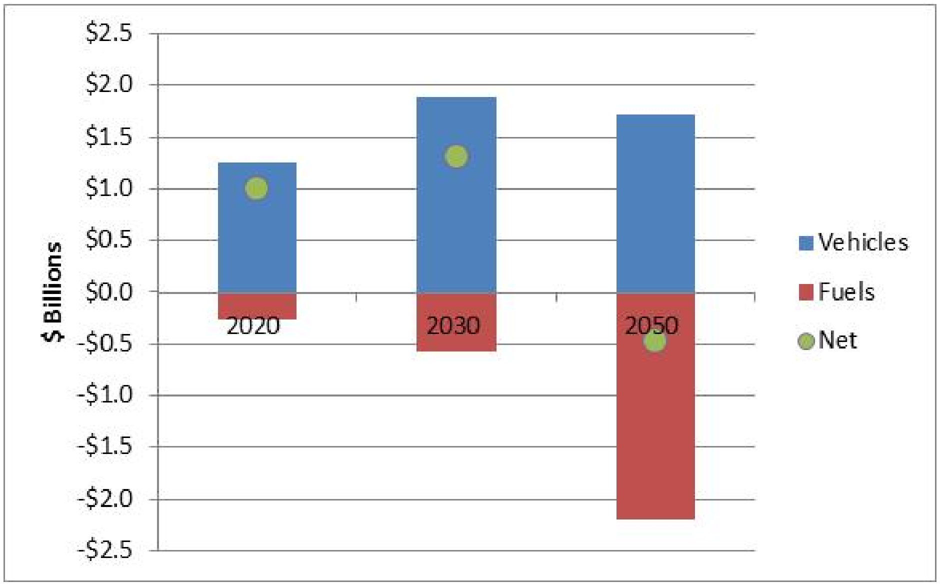

Figure 17: Net changes in RTS vehicle and fuel expenditures by year compared to 4DS scenario

RTS - Policy Requirements

In order to achieve a rapid penetration of PEVs, Nordic nations will need to pioneer implementations of policies designed to get these vehicles on to the roads. It is unlikely that many consumers will opt for more expensive advanced technology and alternative-fueled vehicles when the price differential is large. In fact as shown in Table 2, Nordic nations are trying out a range of policies that make driving PEVs either cheaper or more convenient relative to conventional cars. Notable are vehicle taxation rules that either add fees to the purchase of conventional vehicles or cut fees (or add rebates) to the purchase of PEVs. Most of the Nordic countries have such a policy in place. Other policies include advantaged or free access to parking and reduced tolls.

Is this enough? It appears that Norway currently has the most effective mix of policies, but there is debate about its cost efficiency and financial sustainability. A study by the group Grønn Bil, estimates the state subsidy for Norwegian EVs at $3336 per year [13]. Other Nordic countries also have significant policies in place that should help rapidly bring in PEVs. Each country should monitor the situation and adjust policies accordingly.

When designing incentives it is important to consider not only the makeup of the fleet in terms of drivetrains, but also the usage intensity of the vehicles. PEVs are most productive when they are used as replacement for conventional vehicles with high *vehicle kilometers travelled* (VKT). Taxis, for example, are a good target for early conversions to FCEV and BEV given their high VKT. The higher the VKT, the more the fuel savings benefit. Incentives can be designed to encourage intensively used vehicles towards alternative technologies.

Table 2. Current vehicle tax and incentive systems in Nordic countries

Country	Standard Vehicle Taxes	Advanced Vehicle Incentives	Other Policy Elements
Denmark	Registration tax is 105% of vehicle price for first 8428 Euros, and 180% of the remainder above that. The registration tax is to make drivers share road costs, and to discourage vehicle purchases. [16]	EVs under 2000 kg exempt from registration tax and annual circulation tax. The exemption runs through 2015. It does not apply to hybrid vehicles. Free parking is available in some municipalities[2].	Funds to support investments in recharging stations for EVs and to promote the infrastructure for hydrogen cars. DKK 70 million for development of charging infrastructure. 16 HFCV vehicles and 2-3 active hydrogen stations, with more planned. Denmark has full national EV battery switching network through Better Place.
Finland	Car registration cost is between 12-49% of vehicle's value, depending on its CO2 emissions[17].	EUR 5 million reserved for vehicles participating in national EV developing ending in 2013; The car registration tax is based on CO2 emissions. Rates vary from 5 to 50%. EVs pay the minimum rate (5%) of the CO2 based registration tax. As of 1 January 2013 EVs are exempt from the annual circulation tax which is differentiated based on CO2 emissions. Rates for normal cars vary from € 20 to € 600[2].	Planned h2 fuel station in Helsinki. Minimal hydrogen activity. Finland currently has a stock of 309 registered electric vehicles [18] .
Iceland	Vehicles with engines under 2000cc are taxed at 30%, over 2000cc at 45%. Vehicles must meet EURO 4 standards to be registered[19].	The Icelandic legislature has exempted EVs from VAT up to more than EUR 10,000, as well as hydrogen cars and hybrids to nearly EUR 7,000. This is a temporary measure, set to expire at the end of 2013[2]. Free parking for EVs in Reykjavik[19].	There are about 11 EVs in Iceland. Iceland was aggressively pursuing hydrogen technology in 2008, but h backed off due to economic issues. No known HFCVs at this time[20] .

Norway	Progressive new vehicle purchase tax based on CO2 emissions (g/km) . Tax deduction for vehicles under 110 g/km. [21] [21] [22].	BEVs are exempt from VAT, vehicle purchase tax and road tolls. They are subject to reduced annual registration fee and lowered ferry fares (at most equal to those of MCs), and to favorable income taxation on company cars. Free parking and charging on public parking places, free drive in lanes for public transport, demonstration schemes[2] [21] [22].	12,557 Plug-in vehicles as of May 31, 2013, of which 12,074 are BEVs. Highest per capita in the world. 5 Active H2 Station- 4 in Oslo. About 15 HFCV and 15 H2 ICE cars. [23]
Sweden	LDVs taxed annually at a base rate of 360 SEK/yr + 15 SEK per gram over 100 g/km CO2 emissions. Diesel overage tax is 52.5 SEK per gram. Alt. fuel vehicles are taxed at 10 SEK per gram, overage [24].	Electric vehicles with an energy consumption of 37 kWh per 100 km or less and hybrid vehicles with CO2 emissions of 120 g/km or less are exempt from the annual circulation tax (ownership tax) for a period of five years from the date of their first registration. Moreover, for electric and plug-in hybrid vehicles, the taxable value of a company car is reduced by 40% compared with the corresponding or comparable petrol or diesel car. EUR 4,500 for vehicles with emissions of less than 50 grams of CO2/km. EUR 20 million was allocated for 2012-2014 for a "Super green car" rebate of SEK 40,000 (about USD $6000) for the purchase of new cars with CO2 emissions of maximum 50 g/km [2].	As of Summer 2013 there will be 3-6 HFCV vehicles in Sweden. No operating H2 stations, but work is in progress towards getting some operational [25]. There are about 1700 plug-in vehicles in Sweden [26], [27].

What might be the benefits for other parts of the world if Nordic countries follow this pathway?

If Nordic countries follow this scenario, they are likely to be at the front of large scale adoption of these vehicles and fuels and, while this may mean higher costs for them in early years since they will be early adopters, this could also mean some strategic advantages, such as expertise in system design and optimization, and some cost reductions due to scale economies.

Perhaps more importantly, early adoption by Nordic countries will help lower costs and speed commercialization of key technologies so that countries around the world may be able to adopt these technologies faster and at lower cost. Since the Nordic countries do account for a very small share of the world's population and vehicle purchases, the direct impacts of Nordic purchases may be small, but if other European countries adopt the Nordic example and rapidly adopt advanced technology vehicles in large numbers, this will amplify the benefits and also speed the rate of transport sector de-carbonization around the world.

Examples of how this could occur are shown in Figure 18 and Figure 19. In the IEA 4° scenario (4DS), there is some adoption of advanced technology vehicles around Europe, but the rates are fairly slow – averaging around 10% sales share in 2030 and 20% in 2050 (even this could be optimistic if current policies supporting advanced vehicle development and deployment are not continued). In this case, if the Nordic countries follow a rapid transition path, they would have a far higher share of PEVs by 2030, and also become the outright leader in Europe in terms of total sales of these vehicles (Figure 20), despite their relatively small market size. On the other hand, if other countries follow the Nordic lead (Figure 19 and second set of bars in Figure 20), this looks more like the IEA 2 degree scenario (2DS), and the total sales of PEVs around Europe would be far higher. As shown in Figure 20, in this latter scenario, the Nordic production of total European PEV sales drops to a relatively small share, but this is simply the benefit of the Nordic leadership helping to spur strong sales growth in other countries. Of course, it's also possible that other countries will follow a high growth path without any help from the Nordic countries, and this analysis does not attempt to sort out the probabilities of different scenarios. But certainly if the Nordic region follows a high growth path, this seems likely to help encourage other European countries to do the same.

Finally, it should be emphasized that the more rapid growth trajectory in Europe (Figure 19 and right hand side of Figure 20), if then followed by other countries around the world (albeit at a somewhat slower pace in non-OECD countries), is consistent with achieving a 2° scenario, and indeed is an important element in the IEA 2DS.

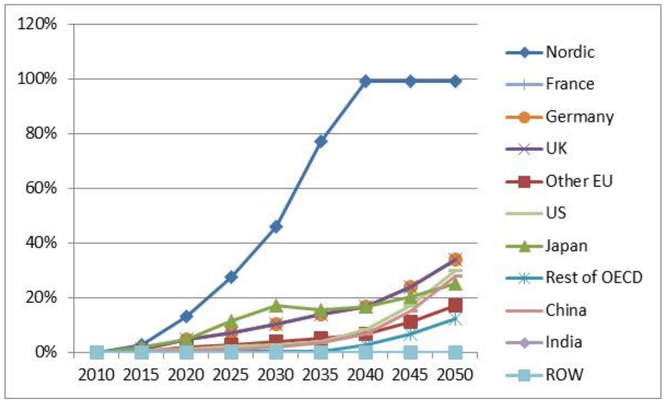

Figure 18: World sales share of PEVs without follow-on effects.

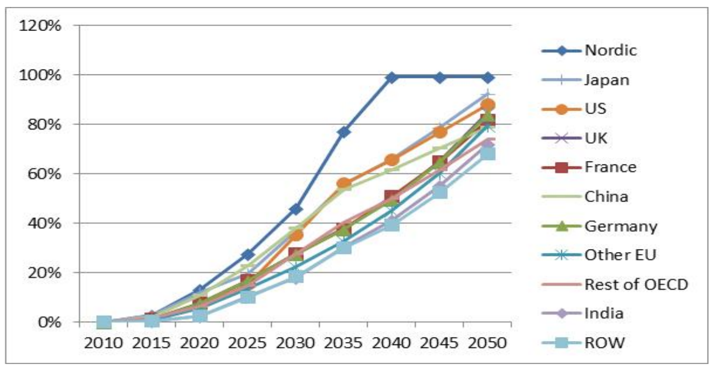

Figure 19: World sales share of PEVs with follow-on effects.

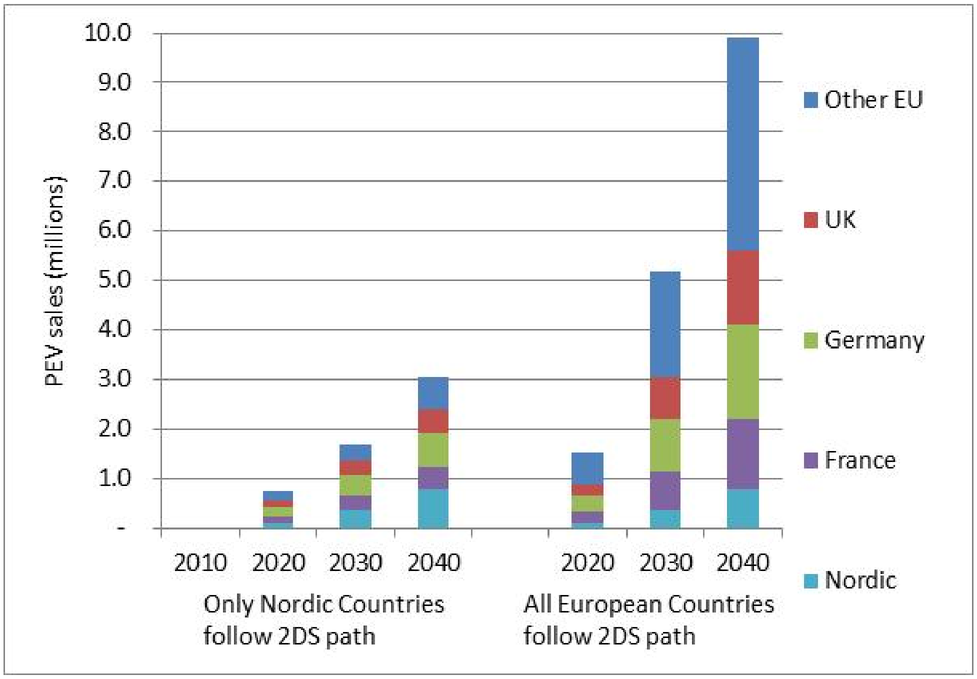

Figure 20: Total PEV sales in Europe under two scenarios

Conclusions and further research suggestions

The Nordic countries have taken an aggressive approach to promoting advanced technology vehicles, in particular plug-in electric vehicles. This report has investigated the nature of this initiative and the potential costs and benefits associated with it. Overall, while there will likely be considerable expense associated with promoting these new technology vehicles, there will also be important benefits, both private (fuel savings) and public (reduction in air pollutants and CO2 emissions). But there is yet another potential effect – the possibility that this initiative will help speed adoption of plug-in vehicles around the world, and help lower costs of technologies such as batteries faster than would otherwise occur. Given the small market size of the Nordic countries, it would seem important to leverage their actions by encouraging rapid uptake of PEVs in other European countries, which will no doubt be influenced by the Nordic leadership in this area.

Two possible areas for further research include a deeper investigation of the various policy levels for encouraging the uptake of PEVs – their relative effectiveness and cost, and identifying an optimal mix of policies in the Nordic (or any country's) context, and an investigation into the revenue impacts (gains and losses) associated with fiscal policies and changes in revenue streams as policies take effect. It should not be difficult to design policies that remain revenue neutral over time, or are easily adjusted to do so, but it requires some analysis to design such a system. In addition, more external impacts such as changes in pollutant emissions associated with the scenarios, and the importance of vehicle production/disposal emissions, could also be addressed.

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