# An Electric-Drive Vehicle Strategy for Sweden[1]

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## Abstract

The large environmental impacts caused by Sweden's transport sector can be mitigated by exploiting a variety of technological innovations, especially electric-drive technologies. This paper explores an electric-drive vehicle strategy for Sweden. The strategy takes into account unique attributes of Sweden and the state of knowledge and experience with electric-drive technology.

Sweden's "unique" attributes include inexpensive and clean electricity, a strong environmental ethic, and a strong automotive sector (with strong domestic industrial commitments to buses and trucks). The state of knowledge and experience with electric-drive vehicles is characterized as follows: virtually all versions of electric-drive technology are seen to be environmentally superior to internal combustion engine vehicles; some are potentially superior in terms of consumer desires; costs of batteries will drop but remain expensive; major automotive companies have mostly abandoned plans to build and market conventional-sized battery-electric vehicles, but are on the verge of deciding whether to make major investments in fuel cell electric vehicles; many automakers are beginning to make major investments in hybrid electric vehicles; and electric-drive buses are gaining increasing attention as a strategy to reduce emissions in urban areas.

Given these observations, we explore the following strategy for Sweden:

• *industrial policy* of designing and manufacturing heavy duty vehicles (buses and trucks) powered by electric drive;

• *environmental policy* of deploying small electric vehicles for on and off-road transportation applications, as well as heavy duty electric-drive vehicles targeted by industrial policy.

[1] This paper is an abridged version of Sperling, D. and T. Lipman (2001), *International Assessment of Electric-Drive Vehicles: Policies, Markets, and Technologies*, prepared for KFB, Stockholm, Sweden.

## Problems and Challenges

For better or worse, vehicle saturation is nowhere in sight -- not in Sweden, the US, nor anywhere else. How can demands for higher levels of accessibility be reconciled with demands for clean and safe physical environments, especially given the reality of finite petroleum resources? And for Sweden and other countries with automotive industries, what industrial opportunities present themselves?

Thanks to rapid innovation in lightweight materials, energy storage and conversion, power electronics, and computing (as well as communications and information management), cars will soon be far more efficient and benign, much safer and easier to operate, and will host a cornucopia of new services and gadgets. While this technological transformation is inevitable, the technological details are difficult to predict. Normal uncertainty in cost, performance, and market response will persist, as with all new technologies, but in this case additional uncertainty results from the pivotal role of government. Because the marketplace largely ignores air pollutant and greenhouse gas emissions and energy security concerns, governments intervene by adopting rules and incentives to accelerate the commercialization of socially beneficial technologies. In this paper we briefly review the international experience with advanced environmental vehicles, and propose a set of strategies that fit Sweden's situation.

## Overview Assessment of Electric-Drive Vehicles

It is becoming widely accepted that the next generation of vehicle technology will utilize electric-drive propulsion. In this paper, we consider three classes of "electric-drive vehicles": battery electric vehicles (BEVs) that store wall-plug electricity on board; hybrid electric vehicles (HEVs) that generate some or all of their electricity on board using a combustion engine; and fuel cell electric vehicles (FCEVs) that convert chemical energy into electricity on board using a fuel cell system.

The transition from a long-established technology to a new promising set of electric-drive technologies is difficult for the automotive industry and the world at large. There is considerable debate over the technological details of these propulsion systems, and the rate at which they are likely to be commercialized. Such transitions are inherently disruptive, and naturally slowed by vested interests and conservative personal and organizational behaviors. During these transition periods, especially in this case where large market externalities are involved, governments can play a particularly influential role. Indeed, in the case of certain technologies, such as many hybrid vehicle options, one can imagine a modest set of government regulations and incentives resulting in large market penetration.

In any case, it seems certain that electric drive technology will eventually supplant internal combustion engines -- perhaps not quickly, uniformly, nor entirely -- but almost inevitably. The question is when and in what form. Based on the cost, environmental, and market analyses presented in ~~this report~~, we believe that the following can be stated with some confidence:

- BEVs are unlikely to replace many conventional-sized private vehicles in the foreseeable future;

- the most attractive applications of pure battery EVs in the foreseeable future appear to be as off-road vehicles and small, limited-performance urban and neighborhood vehicles, with the potential for significant market penetration in some locations;

- FCEVs are the first choice of automakers as the vehicle technology of the future;

- HEVs are seen by automakers as a fallback choice for the consumer vehicle market if FCEV costs do not drop to competitive levels or other problems are encountered with FCEV commercialization;

- HEV and FCEV technology may emerge as attractive options for various medium and heavy-duty vehicle applications.

There can be many reasons and many ways to participate in the advancement of electric-drive vehicles, and to benefit from that technology. While air quality is currently the strongest motivation in most countries for promoting advanced environmental vehicles, that need not be the case in Sweden.

## Sweden's Situation

Sweden has a distinct set of circumstances, beliefs and values that indicate which environmental vehicle strategies are most attractive and most likely to be effective. While the country has a relatively small population of just under 9 million, it has several attributes that attract it to electric-drive vehicles. It has an affluent population, a societal commitment to environmental quality, limited hydrocarbon resources, abundant hydroelectric power, a strong and globally integrated industrial sector, and a longstanding history of international leadership.

Sweden's affluent population of almost nine million inhabitants experiences a relatively high level of environmental quality, and is strongly committed to enhancement of environmental quality. Air pollution is not a major problem, even in Stockholm, and large stretches of unspoiled land are within easy reach of all inhabitants. Most electricity is produced "cleanly" by domestic hydro and nuclear power, and most other energy – oil, natural gas, and coal -- is imported.[2] Abundant forests and the absence of domestic sources of fossil fuels have led the country to develop an expanding biomass energy industry, mostly to produce electricity. Biomass has not been used to produce commercial supplies of transport fuel, however, because of the continuing high cost of converting it to liquid fuels (such as ethanol).

Although a lightly populated country, Sweden is home to several leading industrial companies, especially in the automotive and information technology industries. Its industrial sector is well integrated into the global economy. The two domestic car companies, Volvo and Saab, have recently come under control of Ford and General Motors, respectively, but continue to retain some independence. The nation's truck suppliers, Scania and Volvo Bus and Truck, are major players internationally, with Volvo ranked third in the world in heavy truck production (over 16 tons) and Scania ranked sixth.[3]

The motor vehicle industry is an important component of Sweden's economy. In 1998, 368,000 cars, 100,000 trucks and 15,000 buses were manufactured in Sweden, of which the vast majority were exported (86%, 96%, and 96%, respectively). Exports of vehicles, parts, and accessories accounted for 14% of total exports, and the three major vehicle suppliers employed 65,000 people in Sweden.[4]

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[2] Swedish National Energy Administration (1998), *Energy in Sweden, 1998*, Stockholm. www.stem.se.
[3] Bilindustrif_reningen (1999), *Bilismen i Sverige 1999*. Bilindustrif_reningen, Stockholm.
[4] Ibid.

Sweden is also home to a large telecommunications and information technology industry, which could play an instrumental role in creative "new mobility" transportation system linkages using small and specialized vehicles.

The high level of affluence, combined with large land areas and a strong domestic automotive industry, has led to fairly high levels of car ownership. Car ownership is now approaching 450 cars per thousand capita, greater than the EU average, and is increasing at a faster rate than GDP.[5] [6]

One other attribute of relevance is the country's sense of international presence and leadership. Many Swedes have played leadership roles in international organizations and the country has committed itself to international initiatives, well out of proportion to its size and wealth.

In summary, given these circumstances, Sweden might consider targeting some technological opportunities where it already has strong capabilities, but would probably be advised to curb its desire to be a leader in the use of environmental vehicles. Below, we review the current and evolving status of electric-drive vehicles and suggest initiatives which might be most attractive to Sweden, from the perspective of industrial and environmental policy.

### *Swedish Electric-Drive Vehicle Initiatives*

A variety of organizations in Sweden have undertaken programs to introduce electric-drive vehicles, dating back to 1992 when the Swedish National Board for Industrial and Technical Development (NUTEK) issued a procurement. Through various mechanisms and with funding from various sources, and often in cooperation with government buyers elsewhere in Europe, Sweden has imported over 500 BEVs. About 50 of these are small "neighborhood electric vehicles", ~~are small BEVs,~~ mostly Kewets made in Denmark (production has since ceased and reportedly been moved to Germany).

The other major Swedish activity with electric-drive vehicles has been with transit buses. Electric-drive buses are gaining increasing interest internationally because they operate on fixed routes with known power demands in urban areas where pollutant emissions are most damaging. Growing concern over high particulate matter and nitrogen oxide emissions from diesel engines is drawing heightening interest in these clean alternatives. Only small numbers of electric-drive buses are in use, but their popularity seems to be growing. In Sweden, 17 electric-drive buses are in use and being tested. Ten of these are from Neoplan, a medium-sized bus manufacturer in Germany, six are from Scania and one from Volvo. Five are battery-powered, and 12 are HEVs. Half of the HEVs burn bio-ethanol in their internal combustion engines, and half burn diesel fuel.

The Swedish government, through the Swedish Transport & Communications Research Board (KFB), has provided $13 million over seven years for research, development and demonstration of electric and hybrid vehicles. The program is co-financed with approximately $13 million by various industry and government sources. Over 40 different

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[5] European Conference of Ministers of Transport (OECD) (1998), *Statistical Report on Road Accidents 1993/94*, OECD Publications, Paris, France.

[6] Tengstrom, Emin (1999), *Towards Environmental Sustainability? A Comparative Study of Danish, Dutch, and Swedish Transport Policies in a European Context*, Ashgate Publishing, Aldershot, England and Brookfield, Vermont, USA.

demonstration and research projects have been conducted. Other activities include a Swedish "PNGV" program, with about $220 million being provided by the automotive industry, and a program of the Swedish Foundation for Strategic Environmental Research that jointly funds with industry a six-year $10 million research program on lithium polymer batteries and solid polymer fuel cells.

## Candidate Technologies for Sweden

Given the above assessment, with the understanding that Sweden is a small country with an economic and environmental interest in advanced technologies, what initiatives seem most compelling? We answer in two stages. Here, in this section, we identify and examine two sets of technologies that we judge most relevant to Sweden's interests and circumstances. In the recommendations section that follows, we suggest specific actions Sweden might consider in pursuing those two sets of technologies.

### *Small BEVs: An Environmental Policy Initiative*

The only type of BEVs likely to prove attractive in the foreseeable future are small passenger BEVs and limited performance off-road BEVs.[7] Sweden does not have the industrial or research base to launch a BEV industry, but there are two other factors that make BEVs an attractive option to pursue: a very clean electricity supply system, and a strong environmental ethic.

Small BEVs include various off-road vehicles, and range from very small golf cart-like vehicles with top speeds of about 35 km/h up to highway-capable vehicles with top speeds of about 100 km/h and ranges (per charge) of about 160 km. Here we limit ourselves to an examination of the prospects for on-road vehicles.[8] The largest of the small passenger BEVs include the Toyota e-com, Nissan Hypermini, Ford Th!nk, and Honda City Pal prototypes (all similar in size to the DCX Smart). There are others as well from smaller automotive and industrial companies.

Much was learned in the 1990s about the market for BEVs. It was learned that the demand is potentially significant – that BEVs do indeed have some strong consumer attractions -- but that the market is likely to evolve only under certain conditions and only with considerable marketing effort. This assessment is especially applicable to small BEVs. Generally, it was learned that customers are conservative and slow to embrace new vehicle attributes; must be exposed to intensive informational and education campaigns before they accept new attributes; are highly sensitive to purchase prices; are strongly influenced in their search behavior by environmental attributes but not in their purchase behavior; often value home recharging and the superior driving feel of electric-drive vehicles; and demand widespread retail availability of new fuels, even in the case of early adopters and even when home fueling is available.[9] In the case of small BEVs, all of the above lessons apply (though the

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[7] Harrop, P. and G. Harrop (1999), *Electric Vehicles are Profitable: Where, Why, What, Next?* Footnote Publications, Hampshire, UK.

[8] The off-road market for these vehicles in Sweden and globally is large and growing, but analysis of this market is sparse and we are unable to assess the specific opportunities in Sweden.

[9] See, for instance, Bunch, D., M. Bradley, T. Golob, R. Kitamura, and G. Occhuizzo (1993), "Demand for Clean-Fuel Vehicles in California: A Discrete-Choice Stated Preference Pilot Project." *Transportation Research.* 27A:3, 237-254: Garling, A. and Thorgersen, J. (2001). Marketing of Electric Vehicles, Business Strategy and the Environment (in press); Golob, T., D Brownstone, D S. Bunch and R Kitamura (1996), *Forecasting Electric Vehicle Ownership and Use in the California South Coast Air Basin.*. University of California, Irvine, Institute of Transportation Studies, RR-96-3

vehicles will require fewer retail recharging outlets since they will be used only for local trips and therefore more likely to be charged at home).

Generally, though, it will be a slow and arduous process building a market for BEVs, and even more so for small BEVs, though easier in some markets and locations than others. It will be especially slow and arduous in affluent OECD market regions, since customers have little experience with small vehicles, government safety and traffic rules often limit the use of small vehicles, and few or no incentives exist for their use.[10] Nonetheless, it is our judgement that the large economic, environmental and land use benefits of small BEVs justify strong public support, and that the provision of modest incentives, such as preferred parking, could greatly increase the attractiveness of such vehicles to consumers.

Several key factors influence the demand for small BEVs in Sweden. On the one hand, the relative lack of traffic congestion and parking difficulties in Sweden may undermine demand for small BEVs. On the other hand, high levels of affluence, high car ownership rates, and high environmental awareness suggest that small BEVs could find a market as a second car.

With regard to the potential for marketing small BEVs in Sweden, it is important to note that car ownership continues to grow. As of 1998, 27% of households in Sweden had no cars, 55% had one, 16% had two, and 2% had three or more.[11] Small BEVs could be of interest to each of these groups – as a convenient low cost means of mobility that either supplements or replaces current vehicles, or as the principal means of travel for households in city centers.

Moreover, most vehicles are not used intensively and most car trips are short. In Sweden, about 40% of trips are less than 2.5 km and 50% less than 5 km, half of which are by car.[12]

Even though most trips are not long and most vehicles are not used intensively, it is well known that individuals purchase cars that can satisfy some "marker" need (such as a once-per-year family trip to visit Grandmother, an occasional need to dispose of large amounts of trash or, in the case of BEVs, the ability to travel from work to home to get a sick child and bring her to a hospital without recharging).

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August 1996. 256 pp.; Kurani, K.S, T. Turrentine, and D. Sperling. (1994) "Demand for Electric Vehicles in Hybrid Households: An Exploratory Analysis," *Transport Policy*, v. 1, n. 4; Kurani, K.. T. Turrentine and D. Sperling (1996), "Testing Electric Vehicle Demand in 'Hybrid Households' Using a Reflexive Survey," *Transportation Research* D. Vol 1, No. 2.

[10] Stein et al, 1994). Kurani, K.S., D. Sperling, T. Lipman, D. Stanger, T. Turrentine and A. Stein (1995), *Household Markets for Neighborhood Electric Vehicles in California*, Institute of Transportation Studies, University of California, Davis, RR-95-6, 200 pp; Lipman, T.E, K.S. Kurani and D. Sperling (1994). "Regulatory Impediments to Neighborhood Electric Vehicles: Safety Standards and Zero-Emission Vehicle Rules," *Transportation Research Record* 1444:10-15; Stein, A., K. Kurani and D. Sperling (1994), "Roadway Infrastructure for Low Speed, Mini-Vehicles: Processes and Design Concepts," *Transportation Research Record* 1444:23-27.

[11] SIKA (1999) *Transport & Communications: Yearbook 1998 (in Swedish)*. Swedish Institute for Transport and Communications Analysis (SIKA), Stockholm. Table 3.10

[12] SIKA (1998), *The Swedish Transport Sector Today: Patterns of Travel and Transport*, Swedish Institute for Transport and Communications Analysis (SIKA), Stockholm.

Thus, for a small BEV to be accepted, most owners would need to have easy access to larger, longer range vehicles for occasional travel needs. This need could be filled by a second household vehicle, easy access to rental cars, or easy access to "shared cars".[13]

As car ownership increases, the opportunities to introduce a more specialized vehicle, such as a small limited range BEV, increase. Indeed, the proliferation of cars creates a favorable situation for small BEVs. The small BEVs become more attractive because car owners no longer require all vehicles to serve all purposes, and can substitute a lower-cost vehicle for larger more expensive all-purpose vehicles. And small BEVs are more attractive to society because use of the vehicles leads to sharp reductions in energy use, pollution, and space needs.

### *Electric-Drive Trucks and Buses: An Industrial and Environmental Policy Initiative*

Sweden is home to a major truck and bus manufacturing industry. As noted earlier, Volvo Bus and Truck and Scania are ranked third and sixth in the world, respectively, in production of heavy vehicles (over 16 tons). Almost all heavy buses and trucks everywhere in the world are powered by diesel engines and fuels. This pattern is unlikely to change in the case of trucks. Diesel fuel has a very high energy density, diesel engines are energy efficient and long-lasting and large trucks are often used for long distance transport. Thus, it is likely that most heavy trucks will remain powered by diesel engines and diesel fuel into the foreseeable future. Certainly, heavy trucks are likely to lag other vehicles in being switched to electric-drive technologies and alternative fuels.

The same can not be said for buses, though. Indeed, it is likely that the transformation of buses to electric drive will be faster than for any other vehicle type. In the US, about 1/3 of new bus orders in the late 1990s were for natural gas, and a growing number are for hybrid electric powertrains. As indicated above, 12 HEV buses have been purchased for use and testing in Sweden (plus Volvo is designing and testing two hybrid heavy duty trucks and two hybrid buses). Companies involved in heavy duty electric-drive vehicle technology development in Sweden include Volvo, Scania, Ericsson Communication System, ABB, Höganäs, and Ni-Me Hydride AB.

Buses are an early target market for several reasons: their pollution causes a disproportionate health effect because emissions tend to be in areas with high outdoor populations, diesel particulates are arguably the most serious health threat from vehicular pollution, and buses are usually government owned and managed and therefore more responsive to public policy. The bus market, though not nearly as large as the heavy-duty truck market, is important because the engines and drivetrains are the same as used in heavy-duty trucks. Thus, early penetration of the bus market leads naturally to later penetration of the larger truck market.

## Policy Suggestions for Sweden

Below we provide a list of policy and investment suggestions that might be pursued in support of the two initiatives proposed above -- to accelerate the use of small BEVs, and to

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[13] Shaheen, S., D. Sperling, and C. Wagner (1998), "Car Sharing in Europe and North America: Past and Future," *Transportation Quarterly*, 52:3, 35-52, 1998; Whitelegg, J., ed., (1999), "CarSharing," *The Journal of World Transport Policy and Practice*, 5:3, September; Salon, D., D. Sperling, S. Shaheen, and D. Sturges (1999), *New Mobility: Using Technology and Partnerships to Create More Sustainable Transportation*, Institute of Transportation Studies, University of California, Davis, UCD-ITS-RR-99-1, March.

develop and commercialize heavy duty electric-drive vehicles. This list is meant to be suggestive, not comprehensive nor definitive.

*Incentives for the purchase and use of small BEVs.* To accelerate the introduction of small BEVs as efficiently as possible, a necessary pre-condition is the adoption of incentives. These incentives might be both monetary and non-monetary, ranging from lower vehicle purchase taxes and registration fees to preferred parking in downtown areas. These incentives ideally would be adopted in a form that reflects the social benefits of these vehicles. Some effort should also be devoted to creating incentives for electricity recharging infrastructure at homes and for public stations, but the small energy requirements of these vehicles suggest that recharging infrastructure costs should be small.

*Demonstrations of small BEVs.* These vehicles are unfamiliar to vehicle operators and travelers, traffic enforcement officials, infrastructure managers and operators, and business owners. For small BEVs to be introduced as passenger vehicles, changes should and in some cases must be made in various rules and practices, so that travelers feel and indeed *are* safe. It will take much time and effort, and partnerships will need to be formed with a variety of organizations. Demonstration projects can be costly and not very useful but, if conducted wisely and with clear goals, can also play a critical learning and educational role. The goal here is to learn what changes in the transport system are necessary to accommodate the vehicles, and to increase their exposure to potential buyers and users. Related demonstrations might focus on deliveries of e-commerce goods to neighborhoods, or integration of small BEVs into car sharing programs.

*Create "EV" standard for clean urban cars.* Sweden is not alone in considering the use of electric-drive vehicles in polluted and noisy city centers. Many other cities are exploring and enacting rules that prohibit vehicles with combustion engines on certain days and in certain areas. Sweden might want to coordinate with other cities and countries, or even take a leadership role, in developing a standard for "clean" urban cars. Such a standard could be used to enact traffic rules, adopt incentives, and create the framework for liability determinations. Adoption of this standard could be pivotal in the introduction of small BEVs.

*R&D funds for innovative, leading-edge technologies.* Careful strategic thinking should go into this program, since government funds are limited, government is not omniscient, and the resources of large industrial companies dwarf what might be made available by government. In this case, we suggest the highest priority be given to hybrid and fuel cell technologies for heavy duty vehicles, and that funds be directed at small entrepreneurial companies and major companies with relevant expertise but not traditionally involved in vehicle manufacturing.

*Demonstration of hybrid and fuel cell buses.* The role of the national government in this case is mostly to facilitate the testing of buses in actual operation. The intent is to help vehicle suppliers learn about bus operator and customer acceptance issues and problems. These tests can be rather limited.

*Fuel cell research.* We purposefully refrained from recommending a fuel cell strategy, given the apparent lack of investment in fuel cells in Sweden.[14] We suggest, however, that Swedish businesses and government seriously ponder this issue. It appears plausible that fuel cell

[14] A Swedish business magazine, *Affarsvarlden*, carried a feature story on fuel cells in its 26 January 2000 issue. It claimed that only one Swedish company listed on a stock exchange is connected to the fuel cell industry, and it is a small company that manufactures compressors for fuel cells.

technology will play a major role in powering a vast range of future products, from small consumer devices to home energy use, cars, and stationary electricity generating powerplants. Can Sweden afford to ignore such an important development?

These suggested initiatives and actions reflect our assessment of the state of knowledge, and our interpretation of what might be most advantageous for Sweden. We are not omniscient, however. Circumstances change. Surprises happen. To provide insight into our thinking, and therefore to aid those confronted with the difficult decisions of how to proceed, we provide some discussion of our general understandings and beliefs.

First, we suggest that actions taken by Sweden for the social good can create a halo effect for the entire country. That is, the country and its products will be seen more favorably and treated better in world dealings. Also, it could lead to more tourism.

Second, we are skeptical of a large government role in funding R&D, especially in a small country such as Sweden, but do believe that strategic support of research will have large payoffs. The greatest payoffs are likely to result from research funds directed at small innovative companies, universities that train the next generation of scientists and engineers, and long term research in general. We note that large industrial companies have R&D budgets that dwarf the resources of government; public R&D investments in those companies should be pursued with prudence. It is important, though, that major vehicle suppliers be involved to provide strategic insight.

Finally, Sweden needs to look to other partners and models. In the case of small BEVs, where Sweden would be a technology receiver, the critical partnerships are with other countries and regions also interested in deploying those vehicles. In the case of heavy-duty vehicle technologies, Sweden would be a technology supplier and, since no single company is likely to supply entire systems, companies need to form alliances and partnerships with other component and subsystem suppliers; thus the critical partnerships in this case are with other technology suppliers.

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