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Electric Vehicles and Hybrid Electric Vehicles (Safety; Components; Simulation)

PROSPECTS FOR NEIGHBORHOOD ELECTRIC VEHICLES IN THE USA

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Abstract

Neighborhood electric vehicles (NEVs) are a promising strategy for easing the growing tension between demands for greater automotive travel and calls for improved environmental quality. By reducing performance and driving range expectations, NEVs overcome the energy storage problem of larger electric vehicles, while still serving the mobility demands of many travelers. The introduction of NEVs is likely to be slowed by a web of road and vehicle rules designed around the standard vehicle of the past and by uniform vehicle-size expectations on the part of consumers, government regulators, and roadway suppliers. The energy and environmental benefits are potentially so large, however, and the opportunity to create more human-scale communities so promising, that it would be irresponsible not to pursue NEVs in a more deliberate fashion.

Introduction

As cars proliferated during the course of this century, people came to rely on them more, creating a spiraling dependency. As dependence on cars increased, cars began to dominate land use patterns and transportation infrastructure. Streets were made wider and sidewalks narrower or non-existent. Now, most people in suburban neighborhoods often do not consider walking, bicycling, or even riding transit. Automobility has spiraled upward, creating, in an iterative fashion, increasingly auto-centric infrastructure and social behavior.

Some excesses of automobile dependence can be avoided, but, at least for the US and other affluent countries, private transportation is here to stay into the foreseeable future (1). The growing tension between demand for greater automobility and demand for more environmental quality can be eased, however, with more environmentally benign vehicles. One strategy is to use very small electric vehicles, for now referred to as neighborhood electric vehicles (NEVs). Not only will they

reduce environmental degradation, but they also could be a catalyst in creating more environmentally-benign, human-scale communities.

The Challenge

Motor vehicles of today are capable of carrying 4 or more people, accelerating quickly to 100 km/h, and cruising comfortably at 120 km/h. These attributes are desirable for some trips. As long as all vehicles are expected to serve all trips, large powerful vehicles will be preferred. But this all-around capability comes at a cost, not only in terms of the direct costs of vehicles, fuels, and roadspace, but also external environmental costs and the indirect costs of maintaining an auto-centric transportation system. Multiple vehicle ownership allows an increasing number of households the flexibility to specialize their vehicles. Almost 40% of households own 2 vehicles and an additional 20% own 3 or more (comprising a total of 54 million households with 2 or more vehicles) (2). Moreover, for most trips and households, large, full-powered vehicles are not necessary. About half of all trips are less than 5 miles, made by a single person traveling at relatively low speed (3).

The problem is a uniformity of expectations by consumers, government regulators and highway suppliers. All vehicles are expected to satisfy all purposes; all roads are built to serve all vehicles; and all rules are designed for the standard vehicle of the past. The result is a strong inertia that discourages innovation and change.

The time is ripe for change. Continued attachment to (large) cars holds back policy demands. The continued attachment to familiar vehicles frustrates efforts to reduce energy consumption, adopt battery-powered zero emission vehicles, and create more human-scale neighborhoods.

Small cars are one outlet for relieving these pressures. They provide an opportunity not only for greatly reducing energy and environmental impacts, but also to catalyze the creation of more human-scale neighborhoods. Neighborhood vehicles are a compelling concept that deserves to be tested and nurtured. The potential drawbacks -- principally safety of occupants -- are few and can be mitigated, while the potential social, economic and environmental benefits are hugely positive. But realizing those benefits requires overcoming the hegemony of large vehicles.

One Size Does Not Fit All

The key to introducing small cars is dispensing with the "one size fits all" mentality that pervades the transportation system (4). Changes must be made in rigid safety regulations that discourage innovation, automaker hostility to small cars, standardized infrastructure designs that discriminate against small vehicles, and traffic control rules that serve only large vehicles.

The "one size fits all" philosophy is, even apart from this new class of neighborhood and commuter cars, becoming increasingly anachronistic. The principal force for change is increasing affluence and car ownership. With the growing abundance of

vehicles, no longer must each vehicle serve every purpose. Vehicles can be designed to respond to more specialized desires of consumers -- as is already happening. Recent examples of this shift toward more specialized vehicles, albeit in a more modest fashion than proposed here, are small and large vans, 2-seater sports cars, minivans, and sport utility (luxury 4-wheel drive) vehicles.

Defining Neighborhood Electric Vehicles

The general defining characteristic of NEVs is their specialization for local travel. They will have low top speeds and low power needs. Most NEVs will be very small, accommodating one or two persons plus storage space, but some may be larger so as to accommodate families with children. NEVs range from top-end NEVs that are intended to travel on arterial streets at speeds of up to 70 km/h, to bottom-end NEVs, with top speeds of about 30 km/h. Bottom-end NEVs would have separate right-of-ways, only mixing with other motor vehicles in specialized circumstances, such as streets with stringent speed and vehicle size restrictions. The driving range of NEVs need not exceed 50 km or so, since they are only driven on short trips and can be readily recharged each night.

Beyond Golf Carts: Three Examples

While there are several communities across the country where an electric golf cart would be a perfectly serviceable NEV, we should not confuse them with NEVs -- even bottom-end NEVs would be significant upgrades from golf carts. Consider, for instance, a prototype vehicle made by trans2. While it resembles a golf cart in top speed and carrying capacity, it has superior performance, safety, and comfort. Its lower center of gravity and front wheel drive provides improved stability, cornering and maneuverability; car-like suspension provides better responsiveness; the vehicles are outfitted with windshield wipers, horn, side view mirrors, and three-point seat belts anchored to the frame; and the vehicle has a tall, visible profile, a full array of gauges, and lockable storage areas. It has a range of 40 km, four wheels, and 2 seats. It is intended to be used on low-speed residential streets or separate lanes or roads dedicated to low-speed vehicles, perhaps including bicycles.

Two vehicles from Denmark exemplify higher performance NEVs. One step up the speed/performance scale is the City-El made by City-Com. It has a top speed of 50 km/h, driving range between 30 and 50 km, three wheels, and one seat plus storage space. Both larger and faster, the Kewet El-Jet has a top speed of 65 km/h, range of 50 km, four wheels, and seats two with storage behind the seats. The Kewet and City-El are essentially hand-built using primitive technology. If the vehicles were mass-produced in a modern factory, their cost would be dramatically reduced.

The Case For NEVs

As indicated above, the time is ripe for NEVs. Several trends and forces are converging to enhance the environmental, economic, and social attractiveness of NEVs. The potential benefits are large as detailed below.

Environmental Benefits

The environmental and energy benefits are the most obvious. NEVs are far more attractive environmentally than either gasoline or general-purpose electric cars. Because of their light weight, they consume only a fraction the energy of conventional-size EVs and gasoline vehicles, and therefore emit only a fraction the quantity of greenhouse gases and criteria air pollutants. Even if the powerplants that supply electricity to NEVs burn primarily coal, NEVs would contribute little pollution or greenhouse gases. But the environmental and energy benefits will be even more impressive than a straightforward technical analysis would suggest because NEVs replace the most polluting and inefficient trips of gasoline vehicles: short, slow urban trips. During short trips and the first few minutes of longer trips, gasoline vehicles emit 10 times or more pollutants per kilometer than they do after the catalysts are warmed up. For electric vehicles, there is no catalyst and no cold-hot distinction. Emissions from the last mile are as low as from the first.

For instance, compare a Kewet (750 kg including batteries) with a subcompact gasoline car. Assume that trips average 4 km, speeds vary between zero and 55 km/h per hour, about 60% of the trips are from a cold start, and electricity for the NEV comes from an average mix of U.S. powerplants (52% coal in year 2000). In this case, relative to a gasoline subcompact, the NEV would reduce carbon monoxide by 99%, hydrocarbons by 99%, and nitrogen oxide emissions by 92% (5).

NEVs also greatly reduce energy use and greenhouse gases. NEVs would use less than 1/2 the energy of a typical EV subcompact (based on actual data from the Kewet as well as from simulation models) (5). This energy reduction translates to more than a 60% reduction in carbon dioxide emissions, relative to a subcompact gasoline car, even with today's coal-dominated mix of powerplants (using the same assumptions as for the emissions estimate above). The reductions would likely be even more dramatic in practice because electric vehicles are relatively more energy efficient than gasoline cars at the slow speeds typical of NEV driving.

Land Use and Mobility Benefits: NEVs as a Catalyst

NEVs also address a variety of social ills associated with increased automobility: lack of mobility by the poor, elderly, and physically disabled; consumption of large quantities of land; and marginalization of the most environmentally benign forms of travel, walking and bicycling.

Increased mobility for those cannot drive because of physical disabilities is especially compelling. The ease of driving a NEV makes it accessible to a broad range of individuals, including the expanding elderly population (the over-50 population in the U.S. is expected to almost double between 1990 and 2020, from 63.5 to 112 million). One option for making already easy-to-drive NEVs more accessible to mobility-impaired individuals is with wheelchairs in the driver's location. Other options are to adapt the already simple driving controls to hand controls and to partially or fully automate the controls.

While the use of NEVs, would provide an opportunity to shrink lane widths and parking spaces and expand the capacity of existing roadspace, their greatest contribution may ultimately be to open transportation planning to non-motorized travel. Over time, autos have come to dominate the thinking and actions of local governments. Governments have focused their attention on creating a safe and accommodating environment for cars -- building abundant roads and parking spaces, and imposing traffic controls to assure speedy, safe travel. Mathematical travel demand models, used to prioritize new transportation investments, usually ignore bicycling and walking. The most long-lasting effect of NEVs might be, paradoxically, to reverse the trend toward less non-motorized travel.

The appearance of NEVs, even in small numbers, forces a rethinking of rules and investments preoccupied with the auto. More importantly, the use of NEVs provokes planners, politicians, zoning boards, and others who plan and approve urban development and transportation infrastructure to rethink their auto-centric rules and plans. While the details of integrating NEVs into each local neighborhood would need to be worked out (as indicated later), the existence of NEVs provides an opportunity for more intimate and integrated neighborhoods, enhanced mobility, and the creation of a more hospitable environment for pedestrians and bicyclists. NEVs could be the key to easing tension between those who applaud the mobility benefits of the auto and those who blame it for destroying the social fabric of modern communities (6).

Infrastructure Changes to Accommodate NEVs. Standardized roadway designs discourage efforts to introduce a neighborhood car. All roads are built to serve larger, faster vehicles and all rules are designed for the standard vehicle of the past. A new paradigm of road design is needed that does not revolve around conventional cars. One might argue that the road system should be designed to serve pedestrians, bicycles, NEVs, conventional cars, and service trucks, in that order. Such a road system might look very different from that found in most suburban communities today.

Today's municipal engineers and planners rely on design standards and priorities that discourage and even preclude smaller vehicles, and often ignore pedestrians and bicyclists. They build wide streets in neighborhoods; streets that are empty most of the time and consume large amounts of space. Professional guidelines call for a minimum street width of 6.7 m (22 feet), even though cars are less than 2 m wide. This design standard effectively disperses the neighborhoods, making car travel even more necessary. If developers prefer to build narrower roads, they must go through an arduous appeals process. This car-centric mentality discourages innovative designs, including the use of narrow roads suited to NEVs.

Safe Vehicles or Safe Systems?

Safety may be the most controversial aspect of small cars. Safety regulators in the U.S. are diligent, determined, and effective. Their mission is to increase the survivability of vehicle occupants in an accident. Safety debates are guided by this

regulatory mission. But this regulatory approach is narrow; it misses the larger benefits that result from a safer system. Vehicle safety could be enhanced, for instance, by limiting the mixing of large and small vehicles or by controlling speeds on NEV-designated roads, using speed bumps and other "calming" techniques. Moreover, local residents along speed-controlled and vehicle-restricted streets benefit by being liberated to bicycle and walk in relative safety. Unfortunately, safety data do not exist for such a transportation system to determine how large and important these safety benefits might be.

The narrowed safety debate will therefore probably focus on the undeniable physical reality that an occupant of a small car is clearly more vulnerable to injury than an occupant of a larger car, all else being equal. But even at this level, it is not evident that occupants of very small cars will be at greater risk, because all else need not be equal. The small car could be made safer through better design and use of safety devices inside the cabin. As an extreme example, race car drivers survive crashes at 240 km/h by using ultra-stiff shells with internal restraints.

Currently there are no safety regulations or laws specific to EVs of any size or type -- although several proposed rules regarding recharging, crash avoidance, and crash-worthiness were issued in the early 1990s -- and none specifically targeted at small vehicles. They currently promulgate standards only for light duty passenger cars and trucks, motorcycles, and golf carts. These standards however are neither necessarily consistent nor above reproach: for more than a decade, minivans met less stringent safety standards than cars, though they were (and are) used disproportionately for families and children.

A class of lightweight vehicles was recognized the National Highway Traffic Safety Administration in the past. In 1967 a broad exemption from the standards was granted for four-wheeled vehicles weighing less than 450 kg, on the grounds that it was impossible for such vehicles to meet the general standards; that exemption was subsequently removed in 1973. NHTSA subsequently rebuffed several efforts to re-instate a similar exemption, reflecting its insistence on all vehicles meeting the same standards (9, 10). It is uncertain how difficult it would be to obtain an exemption or to create a new category for NEVs.

Potential NEV manufacturers are left with two options: they may petition for an amendment to any impractical standard, and may apply for a temporary exemption. Amendments are difficult to win. Exemptions may be granted for 2500 vehicles per year per manufacturer on the basis of substantial economic hardship (for manufacturers of less than 10,000 vehicles per year), to aid in the development of new vehicle safety or low emission engine features, or if the vehicles provide an equivalent level of safety. A NEV would easily qualify on the low emission criteria, and possibly on the other two grounds as well. The exemptions are renewable; but it is uncertain how many renewals would be granted.

The safety of NEVs is possibly the most critical issue in determining how and where to introduce NEVs. Unfortunately, little evidence is available to make a reasonable

determination, largely because the safety record is sensitive to the design of the vehicle, and how and where it is used. What is needed is bolder thinking. Safety regulators must consider safety in context: the context we suggest here is slow and small cars and bikes in specially-designed neighborhoods or on specified roadway infrastructure.

Liability

NEVs are smaller and therefore inherently less safe, all else being equal, than conventional vehicles. But this difference does not automatically imply that a manufacturer or anyone else is more vulnerable to legal action. Indeed, legal precedent suggests that NEVs need not necessarily create any extra liability risk (11).

Product liability falls into three categories: strict liability, negligence, and warranty. Neither negligence nor warranty violations are relevant as NEVs do not present any new or unique negligence or warranty issues. Strict liability may be due to design, manufacturing, or warning defects. In determining liability risks for NEVs, one question is pivotal: Do NEVs pose any unreasonable danger to the user?

A NEV clearly poses a danger: if the vehicle hits a truck, the occupants are likely to suffer more injury than if they had been in a two ton luxury car. Is it, legally speaking, an unreasonable danger? Perhaps not. Legal precedent suggests that the danger is unreasonable only if the danger is not clear and obvious to the user of the vehicle. As long as a vehicle appears to be very different from a conventional vehicle, which by definition they will, then the liability risk is low.

An exception would be if a manufacturer could have significantly improved vehicle safety at a small cost. NEV manufacturers might be vulnerable to this argument since there will be considerable experimentation initially in NEV designs. NEV manufacturers are protected somewhat if their designs are determined to be state of the art in manufacturing at the time of production, but this, as well as most other liability determinations, is highly subjective. In the opinion of one product liability expert, NEVs pose no greater liability than any other vehicle, as long as appropriate effort is made to avoid risks (11). One exception to this conclusion may be three-wheeled vehicles with the single wheel in front; this configuration is widely considered more dangerous than the single-wheel-in-back configuration.

An option, from both a safety and liability perspective, may be to create designated areas for NEVs: for instance, "drive-slow" zones. A NEV involved in an accident while in such a zone would be assumed not to be at fault -- just as is the case with pedestrians in crosswalks.

Traffic Control Rules And The Golf Cart Precedent

For a vehicle to be operated on a public road in the U.S., it must be registered with the state's department of motor vehicles and in compliance with federal safety standards for passenger vehicles or motorcycles, or hold a special exemption. In

many states, three-wheeled NEVs will be registered as motorcycles. In some states, even 4-wheeled NEVs may be allowed under existing vehicle classifications; Arizona, for instance, allows golf carts to register as recreational vehicles and be licensed as motorcycles. Given these, the only restriction facing the use of golf carts in Arizona is that they must not impede the flow of traffic.

One scenario of entry by NEVs into urban communities is suggested by recent urban experience with golf carts, such as that in Palm Desert, California. A recent opinion by the California State Attorney General allows golf carts to operate along any street with a speed limit of approximately 40 km/h (25 mph) or less, but does not allow them to travel along or cross a street with a higher speed limit. Faced with this opinion and opposition from Caltrans (the state transportation department) and the California Highway Patrol, an act of the California State Legislature was required to authorize an electric golf cart transportation demonstration project in Palm Desert.

Accordingly, in January 1993 Palm Desert instituted a program of cart inspection and registration and established a system of designated golf cart paths. The golf carts must be electric, registered with the city (but not the state) and outfitted with headlights, turn signals, mirrors, horn and reflectors. Streets with speed limits less than 25 mph are open to cart travel, as well as a system of cart lanes along higher speed streets and separate cart right-of-ways.

Palm Desert's treatment of golf carts illustrates how NEVs could be accommodated in local communities, even without the blessing of federal safety regulators; NEVs that cannot meet safety standards designed for conventional cars could be treated by local and state governments as special cases, and accommodated accordingly. The challenge is to do so in a manner that is safe.

ZEV Mandate

Most instrumental of all in aiding the introduction of neighborhood cars will likely be the ZEV mandate. As major automakers confront the high cost of meeting the ZEV mandate with EVs which attempt to mimic full-size gasoline cars, they may become increasingly receptive to new approaches. Recognizing the relatively poor energy storage characteristics of batteries, they may conclude, for reasons listed below, that smaller EVs are economically and environmentally superior and technically more sensible than larger EVs.

NEVs are arguably the most compelling application of battery-powered electric propulsion. NEVs do not suffer from the shortcomings of batteries as do larger EVs, simply because they require relatively little energy and power. Their low energy needs are due to low weight, low top speed, a short driving range. In addition, the low weight of the battery pack allows for a lighter structural design, and therefore still greater weight and energy reductions. Though based on simple designs and relatively unsophisticated engineering, the City-El described above carries only 110 kg of conventional lead-acid batteries, costing $250; the Kewet, 270 kg of batteries; and the trans2, only 130 kg. In contrast, a typical subcompact EV would need over

450 kg of lead-acid batteries (GM's very energy-efficient Impact prototype carries 410 kg). Under mass-produced conditions, NEVs should prove to be much cheaper to own and operate than a full-size gasoline or electric car.

As major automakers begin to recognize the relative ease of building a cost-competitive NEV, they will likely reconsider their historic disinterest in small EVs. The key question will be: Will there be a market for what is easiest and cheapest to build?

Marketing NEVs

One important niche for NEVs is resort communities and facilities. These are often located on mountains, at seashores, and in other environmentally fragile areas, where clean and uncongested environments are highly valued. A subset of this market niche are owners of the approximately 3 million second homes in vacation areas of the U.S. Another subset of this market niche are areas such as Yosemite National Park where vehicle exhaust are damaging unique natural environments; a plausible strategy is to ban gasoline and diesel vehicles and replace them with electric buses and NEVs. The potential for daily and hourly rental of NEVs at these sites is large.

A second niche is neighborhoods and communities where speeds are controlled and communities are receptive to NEVs. Palm Desert, California, mentioned above, is one such community, and the demonstration project there has spurred interest from other communities throughout California.

A third market niche is mobility-impaired individuals, estimated to include about 10 million people in the U.S. NEVs are easy to drive partly because they operate at slow speeds and are small and easy to maneuver. This ease of driving can be enhanced by controls designed for hands only, similar to the thousands of motorized wheelchairs and many retrofitted gasoline vehicles. Another enhancement is the use of partially or fully automated controls. Partial controls could be installed on NEVs to aid with steering or braking and to avoid collisions. With the expanding population of elderly people, many of them mobility-impaired, neighborhood cars could become increasingly important as a means of transport.

A fourth market niche is new developments that can be designed specifically for NEVs. In California alone, neighborhood electric cars are being considered as integral elements in four new town developments covering over 40,000 hectares. Several developers are considering providing a neighborhood electric car with some or all homes sold in the new towns. The potential market in these new towns is in the hundreds of thousands. Industrial parks are another example of land use patterns which could readily be designed to accommodate NEVs.

These four market niches could be just the beginning. Initially, neighborhood electric cars will not be accepted in most locations because of safety problems in mixing with much larger vehicles, and because road and parking infrastructure is

not suited to their use. But as neighborhood cars gain acceptance in various niches, local governments and developers are likely to alter road and parking infrastructure to accommodate and even reward users of these vehicles. At the same time, lobbying groups will emerge to push for changes in liability and traffic control rules that hinder the market penetration of neighborhood EVs.

With varying levels of both NEV performance and commitment by local governments to providing NEV-centric infrastructure improvements, the total potential sales of NEVs will be difficult to estimate. But demonstration projects and surveys indicate that households throughout California are receptive to NEVs (12, 13). This reception is based on an expectation that, within the context of increasingly specialized household vehicle holdings, a NEV provides a superior transportation alternative if it is inexpensive to buy, cheap to operate and reliable.

Conclusions

NEVs are not a panacea for near term problems, but they are energy efficient, low-polluting, and scaled for neighborhood use. NEVs would use less space than conventional vehicles, provide the premise for lowering vehicle speeds in neighborhoods, and help create a more pedestrian-friendly setting, while still providing high levels of mobility. They also would be economical, in part because they are an ideal application of battery-powered electric propulsion. Indeed, it is a fortunate coincidence that the market applications in which electric vehicles are best suited -- short trips -- are also the applications in which NEVs provide the largest environmental benefits. NEVs clearly are an attractive option. They fit well into any vision of a sustainable transportation-energy future.

But will this good idea ever be realized? NEVs confront large perceptual, physical and regulatory barriers. There is a uniformity of expectations by consumers, government regulators, and highway suppliers that results in all vehicles being expected to satisfy all purposes, all roads serving all vehicles, and all rules being designed for the standard vehicle of the past. The result is a strong inertia that discourages innovation and change by vehicle suppliers and users. The success of NEVs will depend on an openness by regulators and highway suppliers to new types of vehicles, and entrepreneurial initiative by vehicle manufacturers.

Research into the potential market for NEVs is still fragmentary and speculative. It appears, though, that the long term market for NEVs could be millions per year in the U.S. Even in the short term, with little change in consumer expectations and various government rules, the market might be sizable. Market penetration will depend on a large number of factors related to ZEV and safety rulemaking, local initiatives to accommodate NEVs, liability rulings, rulings regarding traffic control, and the entrepreneurial initiative of manufacturers.

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