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"Efficiency - Equity - Clarity"

A Critical Evaluation of Electric Vehicle Benefits

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Abstract

This paper investigates electric vehicle benefits and costs. Similar analysis could be applied to other alternative fuels. This study evaluates various types of electric vehicles. "Conventional performance" electric cars are intended to substitute for petroleum powered vehicles. However, for the foreseeable future they will fail to do this; electric vehicles offer significantly less performance and have higher prices. As a result, they will not be widely purchased without significant subsidies, and once purchased the amount of petroleum vehicle travel they displace is likely to be low.

Neighborhood vehicles are low performace cars designed for short, relatively low speed travel. They can be battery-electric powered, or use other alternative fuels. They reduce a number of costs, including externalities and consumer costs, and they can make driving more affordable to some people who cannot otherwise drive. However, such vehicles cannot simply substitute for petroleum automobiles. Instead, they will need to be part of a more diverse and efficient transport system which offers travelers more choices and the incentive to use each option for what it does best. Neighborhood electric vehicles could provide mobility within a local area; travelers would shift to regional transit services or rent a petroleum powered vehicle when they needed greater speed, power or capacity.

This analysis indicates that conventional electric vehicle benefits are modest compared with the full costs of motor vehicle travel. Although they reduce air pollution and some energy externalities, they do not reduce other motor vehicle external costs, increase travel choices for non-drivers, or provide user savings. Local air pollution reduction benefits of electric cars may justify their use in areas with high air pollution costs. Far greater social benefits may be achieved by the broad use of neighborhood vehicles in conjunction with other reforms that increase travel choices and encourage more efficient transportation.

Introduction

During the mid-1970's utopian designers and builders became infatuated with geodesic domes. Enthusiasts published a series of *Domebooks* filled with instructions for dome design and construction, and idealized illustrations. Conferences and workshops where held, progressive builders developed dome construction skills, and dome buildings popped up like mushrooms across the landscape.

But builders and inhabitants soon found that domes have problems. Dome construction costs are high and a large portion of material are wasted; they are difficult to seal, their interior spaces are inefficient and inflexible, and they are aesthetically imposing. The *Domebook* editors realized their mistake, and in a move that upset many dome purists, renamed their publication *Shelter*, widening the scope of innovative solutions considered for housing problems. Geodesic domes are still built, but in relatively limited situations, reflecting their unique benefits and costs.

This history is now being repeated in the field of transport. Many people initially consider electric vehicles as the key to developing sustainable transportation. Books and magazine articles have been published heralding electric cars as the vehicle of the future, and highlighting their benefits.[1] Electric vehicle enthusiasts have organizations, newletters and conferences, and a few private companies produce electric vehicles.[2]

But electric vehicles have their problems. They provide fewer benefits and impose greater costs than proponents often claim. Overemphasis on electric vehicles may divert society's attention and resources from other strategies for addressing transportation problems. It is therefore important to have realistic assessments of the net benefits of electric vehicles. This paper attempts to provide such an analysis.

This analysis is particularly important because there are major public policy debates concerning the degree to which society should rely on electric or other alternative fueled vehicles as a strategy for addressing transportation problems, and particularly to what degree tax funding, tax exemptions, and regulations should be used to promote electric vehicle production. Similar analysis can be applied to other alternative vehicle drive systems, including LPG, methanol and compressed air.[3]

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[1] Seth Dunn, "The Electric Car Arrives - Again," *Worldwatch*, March/April 1997; Amory Lovins, *Supercars*, Rocky Mountain Institute (Snowmass), 1995; Roland Hwang, et al, *Driving Out Pollution; The Benefits of Electric Vehicles*, Union of Concerned Scientists (Berkeley), 1994; James MacKenzie, *The Keys to the Car*, World Resources Institute (Washington DC), 1994; Daniel Sperling, *Future Drive: Electric Vehicles and Sustainable Transportation*, Island Press (Washington DC), 1995; Sytze Rienstra and Peter Nijkamp, "The Role of Electric Cars in Amsterdam's Transport System in the Year 2015," *Transportation Research D*, Vol. 3, No. 1, January 1998, pp. 29-40.

[2] *EV World* (www.evworld.com).

[3] See www.zeropollution.com.

Types of Electric Vehicles

There are various types of electric vehicles being developed and produced. Some are intended to match the performance (speed and range), comfort (particularly air conditioning and heating) and carrying capacity of petroleum vehicles. These are called "conventional performance" electric vehicles in this paper. Others, called "neighborhood vehicles" in this paper, provide less performance.[4] A golf cart represents a minimum performance and price vehicle. Table 1 compares typical features of these vehicles.

Table 1 **Typical Electric and Gasoline Vehicles Compared**[5]

	Seating	**Weight** (lbs)	**Batteries**	**Range** (miles)	**Speed** (mph)	**Price**
Petroleum Car	4-5	2,000-4,000	1	300+	75+	$12,000-30,000
Hybrid Car (Honda VV; Tyota Prius)	4	2,000-2,500	nickel-metal hydride	300+	75+	$30,000-40,000[6]
Conventional Performance Electric (EV1)	4	2,970	26 Lead-Acid 1,175 lbs	70-100	65+	$25,000-35,000
Neighborhood Electric (Citi, Bombardier)	2	1,650	10 NiCd	65-90	40-55	$6,500-10,000
Golf Cart	2	1,000	6 Lead-Acid	15	15	$4,000-6,000

This table compares typical performance of various types of vehicles.

Hybrid vehicles use a small internal combustion engine to drive a generator which recharges batteries during vehicle operation.[7] They offer a mix of costs and benefits associated with both petroleum and electric vehicles. Hybrid vehicles are intended to provide nearly conventional performance with high efficiency and low emissions.

The type of battery used has major impacts on an electric vehicle's performance and price. There are more than a dozen types of batteries available which differ in recharge, energy storage, safety and price. Higher performance batteries, such as nickel-iron and lithium, are expensive (prices total $40,000+ for one vehicle's batteries) so lead-acid or nickel-cadmium batteries are used in most electric vehicles. Considerable research is attempting to improve battery performance and reduce costs, but progress is expected to be incremental, with no breakthroughs likely for the short- to medium-term.

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[4] "Low Speed Vehicles," *Urban Transportation Monitor*, 3 July 1998; Daniel Sperling, "Prospects for Neighborhood Electric Vehicles," *Transportation Research Record 1444*, 1995, p. 16-22.
[5] Based on various sources, including *Transportation Cost Analysis*, VTPI (www.vtpi.org); *EV World*; and consultation with electric vehicle designers.
[6] Currently selling at $20,000 due to company subsidies. Prices may decline to apprach that of a petroleum-powered vehicle as production increases.
[7] Amory Lovins, *Supercars: Advanced Ultralight Hybrid Vehicles*, Rocky Mountain Institute (Snowmass), November 1994; "Honda Readies "VV" Hybrid-Electric Coupe," *EV World* (www.evworld.com), 1999.

Travel Impacts

An important factor in this analysis is the effect electric vehicle ownership has on travel. Since electric vehicles generally offer less performance, comfort and carrying capacity than petroleum vehicles it is likely that they would be used less. Electric vehicles will typically be a household's secondary vehicle. Table 2 shows the expected vehicle travel effects of electric vehicles predicted by one survey.

Table 2 **Electric Vehicle Impact on Household Vehicle Travel**[8]

	Electric Vehicle	Gasoline Vehicle
Primary Vehicle: 100-mile range Electric	-42%	+10%
Primary Vehicle: 75-mile range Electric	-44%	+10%
Secondary Vehicle: 100-mile range Electric	-28%	+21%
Secondary Vehicle: 75-mile range Electric	-30%	+24%

When a multi-vehicle household owns an electric vehicle a significant amount of travel is shifted to petroleum fuel vehicles.

This indicates that electric vehicle travel is likely to be used 28-44% less then if it were a petroleum vehicle. As a result, if 10% of the total fleet consists of electric vehicles, only 5-7% of total vehicle travel is likely to be by electric vehicles. This represents a change from previous vehicle pollution control technologies, in which newer, cleaner vehicles tended to receive the greatest use. This has a major impact on the cost effectiveness of electric vehicles, as will be discussed later in this paper.

Most households are unlikely to purchase an electric vehicle as their only vehicle in the current market since vehicles are chosen based on "peak" demands for power, range and capacity. Alternative vehicle ownership options, such as carsharing and station cars, may allow more households to choose electric vehicles.[9] This allows drivers access to a pool of rental vehicles. These alternatives allow consumers to use the most appropriate vehicle for a particular trip, such as a neighborhood electric vehicle for local travel and a larger, petroleum powered vehicles when needed. However, there is currently little incentive for households to make such a choice, since owning and operating a high performance petroleum-powered vehicle is as cheap, typically costing the same or less than alternative fueled vehicles with less performance.

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[8] Thomas Golob, David Bunch and David Brownstone, "A Vehicle Use Forecasting Model Based on Revealed and Stated Vehicle Type Choice and Utilization Data," *Journal of Transport Economics and Policy*, Vol. 31, No. 1, January 1997, pp. 69-92.

[9] Todd Litman, *Evaluating Carsharing Benefits*, VTPI (www.vtpi.org), 1999; National Station Car Association (www.stncar.com); Victoria Nerenberg and Martin Bernard, "The EV Station Car Debate," *Mass Transit*, November/December 1995, pp. 72-78.

Cost Analysis Framework

For this evaluation we use a comprehensive transportation cost analysis framework, which includes the twenty cost categories that are summarized in Table 3.

Table 3 **Transportation Cost Categories**[10]

Cost	Definition	Distribution
1. Vehicle Ownership	Fixed vehicle expenses.	Internal-Fixed
2. Vehicle Operation	User expenses that are proportional to travel.	Internal-Variable
3. Financial Subsidies	Vehicle expenses not paid by the user.	External
4. User Travel Time	Time spent traveling.	Internal-Variable
5. Internal Accident	Vehicle accident costs borne by users.	Internal-Variable
6. External Accident	Vehicle accident costs not borne by users.	External
7. Internal Parking	Parking costs borne by users.	Internal-Fixed
8. External Parking	Parking costs not borne by users.	External
9. Congestion	Delay each vehicle imposes on other road users.	External
10. Road Facilities	Road construction and maintenance expenses not paid in proportion to road use.	External
11. Roadway Land Value	Opportunity cost of land used for roads.	External
12. Municipal Services	Public services devoted to vehicle traffic.	External
13. Equity & Option Value	Reduced travel choices, especially for non-drivers.	External
14. Air Pollution	Costs of motor vehicle emissions.	External
15. Noise	Costs of motor vehicle noise.	External
16. Resource Consumption	External costs resulting from the consumption of petroleum and other non-renewable resources.	External
17. Barrier Effect	The disamenity motor traffic imposes on pedestrians and bicyclists. Also called “severance.”	External
18. Land Use Impacts	Economic, environmental and social costs resulting from low density, auto oriented land use.	External
19. Water Pollution	Water pollution and hydrologic impacts from motor vehicles and roads.	External
20. Waste Disposal	External costs from motor vehicle waste disposal.	External

This table defines the costs considered in this analysis.

These costs are divided into three categories, depending on how the cost affects travel decisions. Internal-fixed costs (such as vehicle ownership and residential parking) affect vehicle purchase decisions, but have little effect on individual trip decisions. Internal-variable costs (such as vehicle operation, travel time and accident risk) do affect individual trip decisions. External costs do not directly affect consumer decisions, although they may affect public policies over the long term.

The key question for this analysis is how much these costs are affected by a shift to electric vehicles. Table 4 indicates which costs are likely to increase or decrease for two types of electric vehicle relative to a petroleum fuel vehicle. These cost impacts are described in detail below.

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[10] Todd Litman, *Transportation Cost Analysis; Techniques, Estimates and Implications*, Victoria Transport Policy Institute (Victoria), 1996.

Table 4 **Cost Impacts of Electric Vehicle**

	Costs Typically Reduced by Electric Vehicles	**Costs Generally Unaffected by Electric Vehicles**	**Costs Typically Increased by Electric Vehicles**
Conventional Performance Electric Vehicle	Air pollution Noise Resource externalities (energy)	User travel time Congestion Accidents (some variation) Parking Roadway land value Barrier effect Equity & Option value Land use impacts Municipal services Water pollution (unknown)	Vehicle ownership Vehicle operating Road facilities[11] Resource externalities (batteries) Waste (batteries)
Neighborhood Electric Vehicle	Vehicle ownership Accidents Parking Barrier effect Air pollution Noise Land Use Impacts Equity & Option Value Water pollution Resource externalities	Congestion Land value Municipal services	User travel time Vehicle operating Road facilities[7] Waste (from batteries)

This table shows how costs typically differ between gasoline and neighborhood vehicles.

Vehicle Ownership and Operation Costs

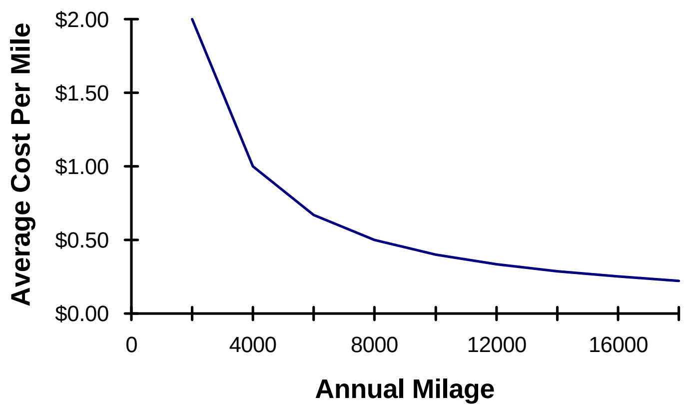
Conventional performance electric cars are currently relatively expensive to produce (150% to 200% the price of a comparable petroleum car).[12] Their ultimate market price is uncertain. Although some researchers believe that electric vehicle production costs can decline in the future, there is little likelihood that conventional performance electric vehicles will be cheaper than comparable petroleum vehicles due to the relatively expensive materials they require for competitive performance.[13] Neighborhood vehicle prices range from $5,000 to $10,000, depending on features.[14] Electric vehicles also require battery recharging systems, which range from about $50 for a basic 12-volt battery

[11] Although road facility costs do not actually increase, electric vehicle use does not contribute to dedicated fuel taxes so their subsidy is greater based on the cost analysis framework used in this report.
[12] Frank Kreith, Paul Norton and DenaSue Potestio, "Electric Vehicles: Promise and Reality," *Transportation Quarterly*, Vol. 49, No. 2, Spring 1995, 5-21.
[13] Frank Field III and Joel Clark, "A Practical Road to Lightweight Cars," *Technology Review*, Jan. 1997, pp. 26-36. Because electric vehicle performance is currently lower than that of gasoline vehicles any technological improvements will be used initially to increase power and range rather than reducing costs.
[14] Daniel Sperling, "Prospects for Neighborhood Electric Vehicles," *Transportation Research Record 1444*, 1995, p. 16-22.

charger, to $500 for a typical home-based recharge system, and $2,000 for an advanced inductive recharge system.[15]

Average vehicle ownership costs are highly dependent on the number of miles the vehicle is driven, as illustrated in Figure 1. For example, a vehicle costing $4,000 per year in fixed costs averages 36¢ per mile if driven 11,000 miles per year, but increases to 56¢ per mile for a vehicle driven 7,150. A portion of these higher costs may be recouped over the long term since a lower mileage vehicle lasts long and is worth more for resale, but the current value of these savings is small because they are several years in the future.

Figure 1 **Average Cost Per Vehicle Mile By Annual Mileage**[16]



Average vehicle ownership costs decline with increased mileage.

Conventional performance electric vehicles consume 0.25 to 0.5 kWh per mile, so energy costs average 1-6¢ per mile based on typical residential energy rates, or about one-third the fuel cost of an average automobile, and neighborhood electric vehicles consume about half this amount, costing 1-3¢ per mile.[17] An additional financial and energy cost is the requirement for a garage exhaust fan to prevent possible hydrogen gas build up when electric vehicles are being recharged. A 60 Watt fan operating during an 8-hour recharge cycle consumes approximately 0.5 kilowatts, costing approximately $18 per year.[18]

[15] Amy Bricker, et al. *Environmental Impacts and Safety of Electric Vehicles,* International Center for Technology Assessment (Washington DC), 1997, p. 27.

[16] Assumes $4,000 annual fixed costs, which is typical of newer vehicles, not including residential parking, based on *Facts and Figures '97,* American Automobile Manufacturers Association (Washington DC), 1997.

[17] This apparent lower fuel price of electric vehicles partly results from the fact that they pay no road user taxes as petroleum fueled vehicles do, which average 2-3¢ per mile for a typical gasoline vehicle. This factor is taken into account in the section on roadway costs, which are defined as roadway expenses net of user charges such as fuel taxes.

[18] Assuming 6¢ per kWh, 300 recharge days per year.

Electric vehicles require battery pack replacement approximately every 500 cycles, which typically averages 20,000-30,000 miles at a price of $2,000-$3,000 for a conventional performance electric vehicle, resulting in an average cost of 7-15¢ per mile of vehicle operation.[19] Neighborhood electric vehicle battery costs are cheaper, in the $500-1,000 range, because they need fewer and less sophisticated batteries.

Insurance, licensing, and residential parking costs are comparable to gasoline vehicles. Engine maintenance is often cheaper, but maintenance costs for other components (body, steering, accessories, etc.) are comparable or higher, since they tend to be relatively expensive to minimize weight and energy use. Tire costs may be higher if electric vehicles weigh more due to batteries, or if special tires are used to optimize efficiency.

If calculated to include battery replacement costs, conventional performance electric vehicles have operating expenses comparable to or higher than a typical petroleum vehicle. According to one life cycle cost analysis, electric vehicle operating costs range from slightly less than a conventional petroleum vehicle to about 20% more, assuming equal annual mileage.[20] Another study found that electric car operating costs were estimated to average $28¢ per mile, compared with 21¢ for a comparable gasoline vehicle.[21] Neighborhood vehicles are cheaper to operate than a typical petroleum car, since they require less energy, and fewer and cheaper batteries.

Conclusion

For this analysis, conventional performance electric vehicle ownership costs are assumed to be 150% of an average petroleum vehicle, and annual mileage is estimated to be 35% lower, resulting in an average cost of 46¢ per mile.[22] Operating costs, including fuel, tire replacement, battery replacement and maintenance, are estimated to average 14¢ per mile under off-peak and 16¢ per mile under peak (congested) travel conditions. Neighborhood electric vehicles are assumed to have ownership costs half of a conventional automobile, and 50% annual mileage, averaging 20¢ per mile, plus operating costs averaging 5¢ per mile under off-peak and 6¢ per mile under peak period travel conditions.

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[19] Assuming a lead-acid battery. Costs for nickel-cadmium or other alternative batteries are higher.

[20] Mark Delucchi, Quanlu Wang and Daniel Sperling, "Electric Vehicles: Performance, Life-Cycle Costs, Emissions and Recharging Requirements," *Transportation Research A*, Vol. 32, No. 3, 1989, pp. 255-278.

[21] Norma Gurovich and Stephen Ahearn, *Potential Uses of Zero Emission Vehicles in Arizona State Fleets*, Arizona Dept. of Commerce Energy Office, Nov. 1991.

[22] Jack Faucett Assoc., *Cost of Owning & Operating Automobiles, Vans & Light Trucks 1991*, FHWA (Washington DC), April 1992 estimates Intermediate Automobile ownership costs average $2,205 per year over a 12-year vehicle life. Increased by 50% to represent electric vehicles equals $3,304 per year, divided by 7,150 annual miles equals 46¢ per mile.

Financial Subsidies

A significant amount of public and private funding is being spent on electric vehicle development. According to one estimate, commutative electric vehicle development research expenses total about $1 billion.[23] This research subsidy is estimated to average $10,000 to $20,000 per conventional performance electric vehicle produced in the near term under 1990 Clean Air Act "zero-emission" vehicle requirements. However, it may be inappropriate to allocate such development costs just to current electric vehicles, since there may be many long term, widely distributed benefits. For example, battery improvements may have applications besides vehicles.

In addition, in order to meet electric vehicle sales requirements mandated by the clean air law, automobile manufacturers discount electric vehicles, cross subsidizing their retail price by $10,000 to $20,000 per vehicle.[24] It appears appropriate to consider these a subsidy of current electric vehicle use.

Conclusions

It seems reasonable to acknowledge that conventional performance electric vehicle sales are subsidized at least 10¢ per mile, based on $10,000 averaged over a 100,000 average operating life for an electric car. This represents the lower bound of subsidies, since it ignores development costs, uses the lower bound of estimated subsidies, and ignores the time value of money (since this cost occurs before benefits). This cost would not apply to neighborhood electric vehicles which use existing technologies.

Travel Time

By definition, conventional performance electric vehicles travel at the same speeds as typical petroleum vehicles. Neighborhood electric vehicles are slower, and because of their limited range require alternative, usually more time consuming strategies for longer-distance trips, such as transferring to a petroleum powered automobile, or public modes such as bus, train or air travel.

The incremental travel time cost for neighborhood electric vehicles depends on users' travel patterns (people who only drive at relatively low speeds would see no incremental cost), and travel choices available (such as the ease of renting a petroleum powered automobile or using public transportation modes for longer trips). Assuming average vehicle travel, the incremental travel time cost of neighborhood electric vehicles would be large. For example, a neighborhood electric vehicle with a maximum speed of 40 mph takes 60% longer to travel a given distance than a 65 mph vehicle. Assuming that three quarters of automobile travel occurs at 65 mph, and one-quarter at 40 mph or slower, this implies a 45% average increase in overall travel time.

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[23] Richard de Neufville, et al., "The Electric Car Unplugged," *Technology Review*, January 1996, p. 32.
[24] Ibid, p. 36.

In practice, however, consumers who purchase neighborhood vehicles voluntarily would self-select to be people who either seldom travel at higher speeds or have alternative travel options, such as a petroleum power automobile or good transit service. Thus, the actual incremental travel time would likely be moderate.

Conclusions

Conventional electric vehicles have no incremental travel time costs. Neighborhood electric vehicles are likely to have actual travel time incremental costs greater than zero, with an upper bound of about 45% for a 40 mph top speed model, based on current travel behavior. However, given viable choices for longer distance trips, actual incremental time costs should be much lower. A 25% average travel time increase is assumed here.

Accident Costs

Conventional performance electric vehicles reduce some risks (particularly those associated with petroleum fires and burns from hot engine surfaces)[25] and increase others (such as those associated with battery chemicals, electrical shocks, and crashes with pedestrians and bicyclists [because electric vehicles are quiet at lower speeds]).[26] Because electric vehicles designers strive to minimize weight they may offer reduced crash protection, although this may be offset by special design features. Batteries add hundreds of pounds of mass to vehicles, which may increase the risk for some types of accidents and reduce others. In most vehicle accidents, however, electric vehicles are likely to have risks similar to a petroleum powered vehicle. Perhaps a more important factor is whether drivers will become less cautious if they perceive electric vehicles as being safer.[27]

Neighborhood electric vehicles and golf carts have substantially different accident risk because they are relatively slow, small, and light.[28] International research indicates that each 1-mph decline in traffic speed typically reduces accidents by 5%, and fatalities by 8-9%.[29] This indicates that the speed reductions associated with neighborhood electric vehicles should result in large accident cost savings. On the other hand, because they are small and light, neighborhood electric vehicles may offer occupants less protection from certain types of accidents, such as impacts with larger vehicles traveling at higher speeds.

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[25] About 10% of current motor vehicle deaths involve fires. However, some of these might have been fatal even if no fire had occurred.

[26] Amy Bricker, et al. *Environmental Impacts and Safety of Electric Vehicles,* International Center for Technology Assessment (Washington DC), 1997.

[27] Research indicates that if drivers think their vehicle is relatively safe they will take more risks. Gerald Wilde, *Target Risk*, PDE Publications (Toronto), 1994.

[28] One insurance company representative estimates that the cost for insurance for golf carts used on public roads would be about half that of a conventional automobile. Moira Wellwood, quoted in "Golf Carts Ruel on Protection Island," *Times Colonist* (Victoria), 31 August 1997.

[29] D.J. Finch, P. Kompfner, C.R. Lockwood and G. Maycock, *Speed, Speed Limits and Accident*, Transport Research Laboratory (Crowthorne, UK), 1994.

Some researchers argue that vehicles that deviate significantly from average highway traffic speeds have relatively high accident rates by forcing other vehicles to pass.[30] However, it is unclear how much of this incremental risk results from traffic interactions, and how much has to do with driver characteristics (people who tend to drive slower than average often fall into other risk categories, such as elderly, inexperienced drivers, drunks, etc.). Neighborhood electric vehicles would usually be driven only on lower speed roads, provided that consumers have other travel options, such as public transit or petroleum vehicles for longer distance travel. Since these tend to have low accident rates, this should reduce accident risk. It is therefore unclear how neighborhood electric vehicles would affect overall per capita accident rates.

Conclusions
Conventional performance electric vehicles are assumed to have the same accident costs as petroleum automobiles. Occupants of neighborhood electric vehicles probably bear somewhat reduced accident costs and impose much lower costs on others due to their lower speeds. Neighborhood electric vehicles are assumed to have half the internal accident costs and a quarter of the external accident costs of an average automobile.

Parking Costs
Conventional performance electric vehicles are assumed to have parking costs equal to an average automobile. Neighborhood electric vehicles can use slightly less expensive parking costs because they are relatively small, although their per-mile parking costs are higher due to their lower annual mileage.

Conclusions
This study assumes that conventional performance electric vehicles have the same parking costs as an average automobile. For residential parking this is divided by 35% less annual mileage, resulting in 7.7¢ per mile average cost in urban conditions and 3.8¢ per mile in rural conditions. A neighborhood electric car can use a 40% smaller parking space 50% of the time, for a 20% total savings. However, since they travel 50% less than a petroleum car, their cost per mile is 8¢ in urban conditions and 4¢ in rural conditions.

Roadway Costs
This is defined as roadway costs net of user charges. A number of "roadway cost allocation" studies have calculated the costs of providing roadways for various vehicle classes.[31] These indicate costs of 2-5¢ per automobile mile.[32] Part of the reason that

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[30] Charles Lave, "Speeding, Coordination, and the 55 mph Speed Limit," *American Economic Review*, Vol. 75, No. 5, 1985.
[31] Joseph Jones and Fred Nix, *Survey of the Use of Highway Cost Allocation in Road Pricing Decisions*, Transportation Association of Canada (Ottawa), August 1995.
[32] Base on cost values from *Highway Cost Allocation Study*, California Department of Transportation (Sacramento), 1987, scaled to incorporate additional roadway costs from Douglass Lee, *Full Cost Pricing*

electric vehicles appear inexpensive to operate is that there is no roadway tax comparable to the 1-3¢ per mile fuel tax on petroleum. By avoiding roadway taxes, electric vehicle travel is subsidized more than other vehicles. Electric vehicle travel therefore increases net roadway external costs (roadway expenses minus user payments).

Conclusions
Electric vehicles impose roadway use costs comparable to conventional fuel automobiles (estimated to be 3.1¢ per vehicle mile) but pay no user fees. As a result, this can be considered an external cost of electric vehicles.

Equity and Option Value

Equity and option value refer to the benefit of having a variety of travel choices, particularly for disadvantaged people. Because conventional performance electric vehicles are relatively expensive and have the same licensing and operating requirements as petroleum vehicles, they do not appear to provide equity or option benefits. However, neighborhood electric vehicles are less expensive than conventional cars and may be useable by some people who are physically unable to drive an automobile, and so would offer some equity and option value benefits.

Conclusions
Conventional performance electric vehicles have the same equity and option value cost as petroleum automobiles. Neighborhood electric vehicles have half this cost, since they can be used by some lower income households, but not for the very poor, or nondrivers.

Air Pollution

Electric vehicles have no tail-pipe emissions, but it is an exaggeration to call them "zero-emission vehicles." Emissions are typically reduced and some are shifted to locations that impose lower costs due to better controls, better ambient air conditions, or fewer people exposed. Emission impacts depend on how electricity is generated. Even in areas with some renewable energy sources the marginal unit of electrical generation is usually fossil fuel (natural gas or coal) for the foreseeable future. As a result, more electrical consumption usually means more smokestack emissions.

Since most households will purchase an electric vehicle instead of a new petroleum powered vehicle, air pollution reductions should be compared with new vehicle emissions rather than the fleet average.

A recent study found electric vehicles produce 33% of the air pollution costs of an average gasoline car if electricity is generated by natural gas and 80% if by coal.[33] Other

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of Highways, USDOT, National Transportation Systems Center, (Cambridge), January 1995. See Litman, 1997 for analysis details.

[33] Center for Transportation Research, *Texas Transportation Energy Savings: Assessment of Control Measures, Technologies and Policies,* Texas Sustainable Energy Dev. Council (Austin), 1995, p. 99.

studies find that electric vehicles reduce VOC and CO emissions, but smaller NOx and SOx reductions, and 50% reductions in CO_2 emissions.[34] A study of greenhouse gas emissions reduction strategies found that electric vehicles reduce lifecycle CO_2 equivalent gasses only 11% compared with a petroleum vehicle, although this increases to 90% for a solar-electric vehicle.[35] Another study estimates that electric vehicles reduce CO_2 emissions by 20%.[36] An OECD study concludes that electric vehicles may increase CO_2 emissions if electricity is generated with fossil fuel.[37] Results of a study comparing lifetime emissions for new petroleum and electric vehicles, based on Southern California electrical generation mix, is shown in Table 5.

Table 5 **Lifetime Emissions For Gasoline and Electric Vehicles (kilograms)**[38]

Pollutant	Average Gasoline	ULEV Gasoline	Electric
ROG	89-119	46-54	0.49
CO	531-1,072	198-478	2.76
NOx	110-121	60-66	24.28
PM_{10}	2.5	2.5	1.11
SOx	11.8	11.8	13.8
Carbon	19,200	19,200	5,509

Alternative fueled vehicles reduce, but do not eliminate air pollution emissions.

Gasoline vehicle tailpipe pollution is estimated to cost approximately 4.4¢ per mile,[39] although this refers to the fleet average, not new vehicles, and therefore overstates actual pollution cost savings from a shift to electric vehicles. Unit pollution costs are considered 4-5 times higher in Los Angeles, due to its geography, but the vehicle fleet there is less polluting per mile than the national average (particularly new vehicles that would be purchased in place of an electric) due to tighter emission standards and inspection and maintenance programs, so per-vehicle-mile costs are assumed to average 2-3 times higher there than elsewhere in the U.S.[40] Motor vehicles also produce tire particle,[41] brake lining,

[34] Quanlu Wang and Danilo Santini, "Magnitude and Value of Electric Vehicle Emissions Reductions for Six Driving Cycles in Four U.S. Cities," *Transportation Research Record* 1416, 1993, p. 33-42; Frank Kreith, Paul Norton and DenaSue Potestio, "Electric Vehicles: Promise and Reality," *Transportation Quarterly*, Vol 49, No. 2, Spring 1995, pp. 5-21.

[35] Leo Dobes, *Transport and Greenhouse; Costs and Options for Reducing Emissions*, Bureau of Transport and Communications Economics, Australian Gov. Publishing Service (Canberra), July 1996, p. 296..

[36] Sytze Rienstra and Peter Nijkamp, "The Role of Electric Cars in Amsterdam's Transport System in the Year 2015," *Transportation Research D*, Vol. 3, No. 1, January 1998, p. 31.

[37] *Electric Vehicles: Technology, Performance and Potential*, OECD (Paris), 1993.

[38] Roland Hwang, et al., *Driving Out Pollution: The Benefits of Electric Vehicles*, UCS (Berkeley), 1994.

[39] Donald McCubbin and Mark Delucchi, *Social Cost of the Health Effects of Motor-Vehicle Air Pollution*, Institute of Transportation Studies, (Davis), August 1996, the central range of estimates in Table 11.7-6.

[40] McCubbin and Delucchi, 1996, Table 11.7-7B.

[41] Brock Williams, et al., "Latex Allergen in Respirable Particulate Air Pollution," *Journal of Allergy Clinical Immunology*, Vol. 95, 1995, pp. 88-95.

and road dust air pollution. Electric vehicles may reduce these emissions because they tend to be aerodynamic and use regenerative braking, but do not eliminate them.

In a recent study using a standardized approach to valuing emission reductions, electric vehicles (Zero Emission Vehicles) were found to be among the least cost effective of 21 vehicle pollution control strategies considered, with estimated costs 1-2 orders of magnitude higher than the least-cost options.[42]

Conclusions

Conventional performance electric vehicles are estimated here to produce one-third the air pollution costs of a petroleum automobile, and neighborhood electric vehicles are estimated to produce half that amount. This represents the higher end of this benefit because it is based on current fleet emissions. Actual emission reductions may be somewhat lower.

Noise

Electric vehicles reduce engine noise, although most do produce a whine while operating. At highway speeds they create about the same amount of noise as a comparable gasoline vehicle due to tire and wind noise. Their greatest noise reduction benefit occurs when they are stopped or operating at low speeds, which is significant because the greatest vehicle noise pollution costs appear to result from moderate and low speed travel on local roads. However, this is a mixed blessing since it means that pedestrians and bicyclists have less warning of approaching vehicles. For this reason, some designers are adding noisemaking devices to electric vehicles in order to provide a warning to other road users.

Conclusions

Conventional performance electric vehicles are assumed here to reduce noise costs to one-third of a petroleum automobile. Neighborhood electric vehicles are even quieter, since they can only operate at low speeds, and so are estimated to impose half of that cost.

Resource Consumption Externalities

Consumption of energy resources results in various external costs, including environmental damages, financial subsidies and macroeconomic costs.[43] These costs are particularly high for petroleum, since it is a relatively limited resource that is increasingly imported in the United States. Electrical consumption also imposes external costs, both directly (such as the environmental costs of the power distribution system) and because a major portion of electricity is generated by coal and petroleum fuels. One study estimates that for the foreseeable future (until the year 2010), more than half of all electrical generation in the U.S. will be by coal, and another 15-20% by oil or natural gas, while in

[42] Michael Wang, "Mobile Source Emission Control Cost Effectiveness: Issues, Uncertainties and Results," *Transportation Research D*, Vol. 2, No. 1, March 1997, pp. 43-56.

[43] "The Real Cost Of Energy," Harold M. Hubbard, *Scientific American*, 264/4, April 1991, p. 36.

Southern California the primary fuel is natural gas.[44] Even where a portion of electricity is generated from renewable energy sources, the marginal unit of generation is typically either natural gas or coal in most areas.

At 0.25-0.5 kWh/mile, conventional performance electric cars consume the total energy equivalent of 30-60 mpg of gasoline.[45] Neighborhood electric vehicles consume 0.18 kWh/mile.[46] As described earlier in the air pollution section, the marginal unit of electrical generation in most regions for the foreseeable future is provided by non-renewable resources such as coal, natural gas or petroleum.

Conclusions
Electric vehicles significantly reduce resource consumption externalities by reducing total energy consumption (they are approximately twice as energy efficient as an average automobile) and by allowing greater flexibility in the primary fuel used compared with petroleum fuel vehicles. External energy consumption costs are therefore estimated here at 1/4th that of a petroleum fuel car for a conventional performance electric car, and 1/8th for a neighborhood electric car.

Barrier Effect
The barrier effect refers to the degradation of the pedestrian and bicycling environment by motor vehicle traffic.[47] In addition to imposing costs directly on pedestrians and bicyclists it causes a shift from non-motorized to motorized modes which imposes incremental costs on society. The magnitude of the barrier effect is affected by traffic speeds and volumes. A reduction in vehicle speeds reduces this cost.

Conclusions
Conventional performance electric vehicles are assumed to impose the same barrier effect cost as an average automobile. Neighborhood electric vehicles are slower, so we assume a 20% reduction in barrier effect impacts for this study.

Land Use Impacts
This refers to various costs associated with automobile dependent land use patterns, particularly low density urban expansion (urban sprawl). These costs include reduced greenspace and aesthetic degradation (since the amount of land devoted to roads and parking per capita tends to increase), increased municipal service costs, and increased per

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[44] Mark Delucchi, *Emissions of Criteria Pollutants, Toxic Air Pollutants, and Greenhouse Gases, from the Use of Alternative Transport Modes and Fuels*, UC Transport. Center (Berkeley), No. 344, Tables 16 & 19.
[45] Assuming a heat conversion rate of 9,000 BTU/kWh and 135,000 BTU/gallon gasoline.
[46] Citi technical specifications published by Pivco (Stanseveien, Norway), 1997.
[47] Julian Hine and John Russel "Traffic Barriers and Pedestrian Crossing Behavior," *Journal of Transport Geography*, Vol. 1 No. 4, 1993, pp. 230-239; J.M. Clark and B.J. Hutton, *The Appraisal of Community Severance*, U.K. DoT, TRRL (Crowthorne), Report #135, 1991.

capita motor vehicle travel.[48] Although many factors can affect these costs, they are related to total motor vehicle use, and particularly higher-speed and distance travel that allows urban expansion.

Conclusions

Conventional performance electric vehicles impose the same land use impact costs as a petroleum powered automobile. Neighborhood electric vehicles contribute less to this cost, since they are not suitable for high speed, long distance trips that encourage urban expansion, so their land use impact costs are assumed to be half of an average automobile.

Waste Production

Electric vehicles reduce some wastes, such as used oil and coolant, but do produce hulks and tires, and are likely to increase battery wastes.[49] Since the single lead-acid battery used in petroleum vehicles is the largest use of lead (motor vehicle production consumes 75% of the lead used in the U.S.),[50] an increase in the demand for batteries by one to two orders of magnitude would significantly increase lead waste disposal problems. Lave, et al. estimate that production of batteries for electric vehicles could significantly increase heavy metal pollution.[51] Other researchers dispute their analysis,[52] but at least some increase could be expected. It is therefore unlikely that electric vehicles reduce overall waste production costs, and quite possible that they increase them, particularly conventional performance electric vehicles that will require many batteries.

Conclusion

Electric vehicles reduce some wastes and increase others, particularly heavy metals associated with battery production and disposal, which represents an uncertain but potentially serious problem. For this analysis the conventional performance electric vehicles are assumed to impose waste costs equal to a petroleum vehicle, and neighborhood vehicles half that amount.

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[48] Todd Litman, *Land Use Impact Costs of Transportation*, Victoria Transport Policy Institute (Victoria), 1996.

[49] Frank Kreith, Paul Norton and DenaSue Potestio, "Electric Vehicles: Promise and Reality," *Transportation Quarterly*, Vol 49, No. 2, Spring 1995, pp. 5-21; Francis McMichael, Lester Lave and Chris Hendrickson, "Electric Cars May Not Be Ready To Roll," *TR NEWS* 181, Nov/Dec. 1995, pp. 14-15.

[50] *Facts and Figures '95*, AAMA (Detroit), p. 54.

[51] Lester Lave, Chris Hendrickson, Francis Clay McMichael, "Environmental Impacts of Electric Cars," *Science*, Vol. 268, 19 May 1995, p. 993-995.

[52] See subsequent letters to the editor of *Science* after the Lave, et al. article; Jeffrey Kellogg, et al., *Environmental Impacts and Safety of Electric Vehicles*, International Center for Technology Assessment (Washington DC), 1996).

Cost Analysis Summary

The following vehicle types are considered in this analysis:

Intermediate Size Petroleum Car, High Air Pollution Costs (Petrol, High Pol.)
A medium sized car that averages 21 mpg overall, used under high air pollution cost conditions, such as Southern California, where pollution costs are three times higher than the national average.

Intermediate Size Petroleum Car, Average Air Pollution Costs (Petrol, Avg. Pol.)
A medium sized car that averages 21 mpg overall, used under national average urban air pollution conditions.

Compact Car (Compact)
A small, fuel efficient, four passenger car that averages 40 mpg overall.

Conventional Performance Electric Car (C.P. Elec.)
This is an electric car intended to maximize performance in order to compete directly with petroleum vehicles, based on current electric vehicle costs. Annual mileage is assumed to be 65% of an average automobile (7,150 miles per year).

Affordable Electric Car (Aff. Elec.)
This assumes the same performance and external costs as the previous category, but uses the same ownership and operating expenses as an average automobile (representing the possibility that these costs could decline significantly due to technological improvements.)

Neighborhood Electric Car (Nhd. Elec.)
A small, inexpensive, electric vehicle with 40 mph maximum speed. Annual mileage is assumed to be 50% of an average automobile (5,500 miles per year).

Station Vehicle
The same as the neighborhood electric car, except that due to rental or shared ownership, annual mileage is assumed to be the same as an average automobile (11,000 miles per year), which reduces average ownership and parking costs by 50%.

Table 6 indicates the estimated costs for each of the vehicle types.

Table 6 **Estimated Costs of Seven Vehicle Types**

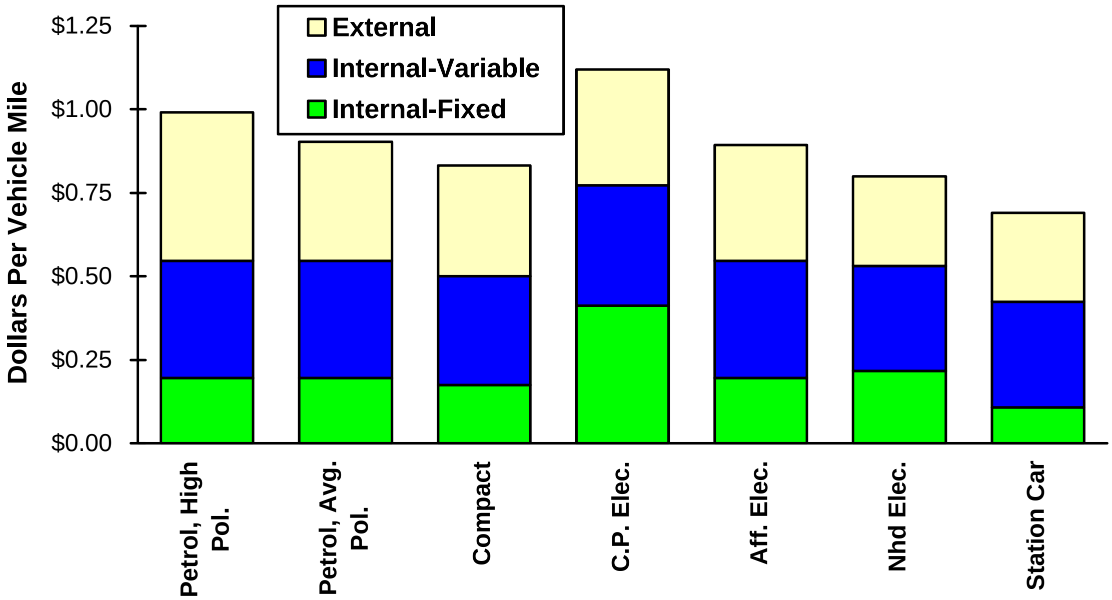
	Petrol, High Pol.	Petrol, Avg. Pol	Compact	C.P. Elec.	Aff. Elec.	Nhd Elec.	Station Car
Vehicle Ownership	$0.158	$0.158	$0.139	$0.354	$0.158	$0.154	$0.077
Vehicle Operating	$0.106	$0.106	$0.077	$0.115	$0.106	$0.042	$0.042
Operating Subsidy	$0.000	$0.000	$0.000	$0.008	$0.008	$0.000	$0.000
User Time	$0.195	$0.195	$0.195	$0.195	$0.195	$0.245	$0.245
Internal Accident	$0.050	$0.050	$0.055	$0.050	$0.050	$0.028	$0.028
External Accident	$0.027	$0.027	$0.025	$0.027	$0.027	$0.006	$0.006
Internal Parking	$0.038	$0.038	$0.035	$0.059	$0.038	$0.062	$0.031
External Parking	$0.062	$0.062	$0.058	$0.062	$0.062	$0.055	$0.055
Congestion	$0.073	$0.073	$0.073	$0.073	$0.073	$0.073	$0.073
Road Facilities	$0.012	$0.012	$0.012	$0.036	$0.036	$0.036	$0.036
Land Values	$0.018	$0.018	$0.018	$0.018	$0.018	$0.018	$0.018
Municipal Services	$0.010	$0.010	$0.010	$0.010	$0.010	$0.010	$0.010
Equity & Option	$0.004	$0.004	$0.004	$0.004	$0.004	$0.002	$0.002
Air Pollution	$0.132	$0.044	$0.036	$0.031	$0.031	$0.017	$0.017
Noise	$0.008	$0.008	$0.008	$0.002	$0.002	$0.002	$0.002
Resources	$0.021	$0.021	$0.010	$0.005	$0.005	$0.002	$0.002
Barrier Effect	$0.010	$0.010	$0.010	$0.010	$0.010	$0.008	$0.008
Land Use Impacts	$0.054	$0.054	$0.054	$0.054	$0.054	$0.027	$0.027
Water Pollution	$0.010	$0.010	$0.010	$0.005	$0.005	$0.010	$0.010
Waste	$0.002	$0.002	$0.002	$0.002	$0.002	$0.001	$0.001
Sum	*$0.990*	*$0.902*	*$0.831*	*$1.120*	*$0.894*	*$0.798*	*$0.690*

Figure 2 compares the magnitude and distribution of these vehicle types. Costs are divided into three major categories depending on how they affect travel decisions. Internal-fixed costs affect vehicle purchase, but not individual trip decisions. Internal-variable costs affect individual trip decisions. External costs do not directly affect consumer decisions.

Conventional performance electric cars reduce air pollution and energy externalities, but increase others, including marketing subsidies and roadway externalities (since they do not pay fuel taxes that internalize some road costs). Their current high ownership and operating costs make them most expensive overall, even compared with a petroleum vehicle driven in areas with high air pollution costs. This results, in part, from their relatively low mileage, which means that average ownership costs are high.

An Affordable Electric Car (assuming ownership and operating costs decline to become equal to current petroleum powered automobiles) has slightly lower total costs than an average petroleum powered car, but greater than a compact petroleum powered car. This suggests that strategies which encourage consumers to choose more efficient petroleum vehicles may offer more benefits than shifting to electric vehicles for the foreseeable future, even with optimistic projections of electric vehicle technological progress.

Figure 2 **Electric Vehicle Cost Comparison by Major Category**



This graph compares cost distribution of seven vehicle types based on the assumptions described previously in this paper.

Because they reduce various user and external costs, neighborhood vehicles are slightly cheaper than a compact cars overall, even taking into account a moderate increase in travel time. This assumes that trips that are unsuitable for such a vehicle, representing about 50% of total vehicle travel, will shift either to a petroleum vehicle or to public transit. A station car, in which ownership is shared, allowing more efficient use of an electric vehicle, results in the lowest total costs.

This cost analysis can also be used to evaluate equity and economic efficiency impacts. Table 7 indicates that conventional performance electric vehicles reduce external costs by an estimated 9¢ per mile under high pollution cost conditions. But this declines to just 1¢ per mile if pollution costs are average. Neighborhood and station cars reduce external costs by 9-17¢ per mile. The table also shows the portion of total costs that are internal-variable, which indicates inefficient pricing. Conventional performance electric cars have the lowest percent internal-variable costs due to the large portion of fixed ownership costs and financial subsidies per unit of travel. Neighborhood electric cars have more efficient pricing, while station cars have the most economically efficient price profile.

Table 7 **Internal-Variable as a Portion of Total Costs**

	Petrol, High Pol.	**Petrol, Avg. Pol.**	**Compact**	**C.P. Elec.**	**Aff. Elec.**	**Nhd Elec.**	**Station Car**
External costs / mile	$0.44	$0.36	$0.33	$0.35	$0.35	$0.27	$0.27
Internal-Variable	35%	39%	39%	32%	39%	39%	46%

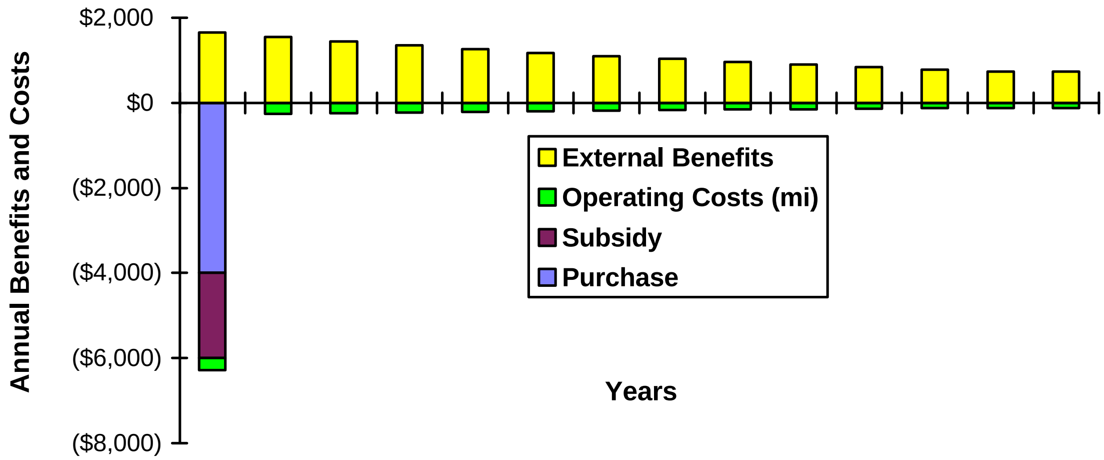
This table shows the difference in external costs and ratio of internal-variable to total costs for various types of electric vehicles.

Net Present Value Analysis

Net Present Value (NPV) is another way to evaluate electric vehicle benefits. For this analysis, costs and benefits are calculated for each year, over the estimated life of an electric vehicle. The results are depreciated back using a discount rate (7% is used here) to calculate the total net present value. This approach explicitly incorporates the time value of money, which has a major affect on long term investments such as vehicle purchases.

Only incremental (rather than total) costs and benefits are evaluated in this analysis. Figure 3 illustrates an example based on one set of assumptions. Table 8 shows the results of this analysis for various parameters of incremental purchase price or subsidy, incremental operating costs, incremental benefit, annual mileage and discount rate.

Figure 3 **Annual Costs and Benefits Illustrated**



This illustrates benefits (above the line) and costs (below the line) for each year of a vehicle's life based on the "Most favorable" parameters in Table 8. Because of discounting the present value of both costs and benefits decreases further into the future.

Table 8 **Net Present Value of Incremental Costs and Benefits**

	Purchase Price Premium	Subsidy	Incremental Benefit[53] (¢/mile)	Incremental Cost[54] (¢/mile)	Annual Mileage	Net Present Value
Most favorable	$4,000	$2,000	15	2.5	11,000	$11,915
Middle	$6,000	$7,500	7.5	4	7,150	-$11,373
Least favorable	$10,000	$12,000	4	8	5,000	-$29,292
Neighborhood	-$5,000	0	20	2.5	5,000	$14,561
Station Car	-$5,000	0	20	2.5	11,000	$26,034

This table illustrates values used to calculate electric vehicle impacts' net present value.

[53] Air pollution reduction and energy conservation benefits.

[54] Increased user operating costs and roadway externalities (reduced roadway externalities).

This analysis indicates that if production and operating costs can be reduced and performance increased to be comparable with petroleum vehicles, electric vehicles may provide net benefits in areas such as Southern California where air pollution costs are high. However, most estimates of benefits and costs result in negative net benefits. Neighborhood and station cars provide significant net benefits under all conditions because of their lower costs and greater benefits. Net costs and benefits are quite sensitive to annual mileage.

Optimal Selection and Encouragement of Electric Vehicles

Current electric vehicle incentives are "blunt" instruments for achieving their intended goals, since they rely on a secondary objective, convincing manufactures to *sell* electric vehicles, rather than on the primary objective, inducing consumers to *use* electric vehicles in place of petroleum vehicles. If current regulations are successful, 10% of vehicles sold after 2003 in some regions are to be electric, which may result in 10% of the total vehicle fleet being electric by about 2014. But, since electric vehicles tend to be driven less than petroleum vehicles, and because electrical production itself tends to produce emissions, the net benefit of this effort is likely to be just a 4-6% reduction in vehicle emissions. Other approaches for achieving electric vehicle goals are discussed below.

1. *Petroleum Price Increases*

The petroleum market will eventually provide an incentive for consumers to conserve energy. World petroleum production is expected to peak between 2007 and 2014 which should drive up wholesale prices.[55] However, even this will not necessarily provide an incentive for shifting to electric vehicles, at least for several more decades.

Since a third or more of fuel price consists of taxes, a tripling of wholesale price of petroleum would result in a doubling or less of the retail price. And because the existing vehicle fleet is not very efficient (more than half of all new vehicles now sold are high fuel consumption vans, trucks or luxury cars), consumers could adjust to a gradual doubling of petroleum prices by purchasing more efficient vehicles without increasing per vehicle fuel costs. As a result, even a doubling or tripling of the real wholesale price of petroleum need not force a significant shift to electric vehicles. From both consumers and a total energy perspective there is far more potential energy savings from improved petroleum vehicle fuel efficiency with only modest change in vehicle performance, than from a shift to electric vehicles. For these reasons, a price increase by itself is unlikely to significantly increase electric vehicles use.[56]

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[55] James MacKenzie, *Oil as a Finite Resource: When is Global Production Likely to Peak?*, World Resources Institute (Washington DC), 1997.

[56] Gordon Ewing and Emine Sarigollu, "Car Fuel-Type Choice Under Travel Demand Management and Economic Incentives," *Transportation Research D*, Vol. 3, No. 6, Nov. 1998, pp. 429-444.

2. *Pricing Pollution Externalities*

A second option would be to charge vehicle users directly for their air emissions. To be efficien and equitable such prices need to take into account variations in emission costs depending on how much, when and where a vehicle is used. A fixed annual charge per vehicle would not be optimal, although emission-based charges such as feebates can help encourage the purchase of less polluting vehicles.

Ideally, a special meter would calculate total emissions based on tailpipe sampling or similar measurements. A lower technology approach would be to determine average emission rates for various vehicle classes and multiply this times mileage and a price per emission for a given geographic area. For example, a 3 year old automobile of a certain model might be charged 6¢ per mile in Southern California. Residents in other areas could be charged less. This would result in costs ranging from about $60 per year for a relatively clean vehicle driven moderate mileage in rural areas, up to $2,000 or more for a high polluting, high mileage vehicle in an area with high pollution costs. In addition, pollution system checks and on-road sampling should be used to identify gross polluters, who would be required to have their vehicles fixed.[57]

This price mechanism would give consumers a direct incentive and several options for reducing emissions. They could simply pay the cost. They could reduce their mileage. Or they could choose a less polluting vehicle, of which electric vehicles would be an option. This system would create an incentive for consumers to *use* electric vehicles as much as possible, rather than just own them.

With mandates, households may be induced to purchase an electric vehicle but with current pricing it would usually be relegated to secondary status, to be used only when the primary, petroleum powered vehicle is unavailable. An emission charge would encourage drivers to choose the electric vehicle first, and only use the petroleum vehicle when its performance is specifically required or the primary vehicle is already being used.

Such a charge also supports transportation demand management (TDM) efforts. A 3¢ per mile average pollution charge represents a 20-40% increase in vehicle operating expenses, which could be expected to reduce total motor vehicle mileage by 5-12%.[58] This would provide a wider range of benefits to society than just air pollution reductions and energy savings, including reduced congestion, vehicle accidents, roadway and parking facility costs, and increased travel choices. Total benefits would therefore be far greater than would result from the sale of electric vehicles.

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[57] Stuart Beaton, et al., "On-Road Vehicle Emissions: Regulations, Costs and Benefits, *Science*, Vol. 268, 19 May 1995, pp. 991-993.

[58] Todd Litman, *Transportation Cost Analysis; Techniques, Estimates and Implications*, Victoria Transport Policy Institute (Victoria), 1996, Chapter 5.

There is often opposition to such charges on the grounds that they constitute a new tax, and that they impose an inequitable burden on the poor.[59] However, equity effects depend largely on how revenue is used.[60] If revenue is rebated to residents or is used to replace a regressive tax it can be revenue neutral and highly equitable.

3. *Least-Cost Selection of Emission Reductions*

"Least cost" is an analysis technique in which various strategies are evaluated in terms of their unit cost for achieving an objective, such as reducing pollution emissions. For example, various vehicle emission reduction options would be ranked from lowest to highest cost per unit of emission reduction. The most cost effective are then chosen.

Most analyses indicate that electric vehicles are not very cost effective relative to other emission reduction and energy conservation options, although they may become competitive in the future as technologies improve and petroleum prices increase. According to one study, the most cost effective approach is simply to select the lowest pollutant emitters from among conventional petroleum vehicles.[61] For example, the standard for hydrocarbon emissions is 0.25 grams per mile. Among mid-size automobiles tested in 1992, the minimum produced 0.06, the 25th percentile was 0.13, and the 50th percentile was 0.17 grams per mile.[62] A significant emission reduction could be achieved simply by limiting vehicle purchases to the 13 models that emitted less than 0.15 grams per mile. This approach was found to reduce three times as many emissions than would have been achieved by purchasing 30% of alternative fueled vehicle.

4. *Transportation Demand Management*

A variety of strategies can be used to reduce total vehicle travel.[63] Although most can only reduce a small portion of total travel, they provide multiple benefits. Strategies that encourage people to reduce their total driving (for example, by shifting to another mode or by reducing average travel distances) reduce air pollution and energy consumption the same as electric vehicles, but also reduce traffic congestion, parking demand, roadway facility costs, accident costs and some land use impacts. As a result, a percentage reduction in vehicle travel is worth more to society than a percentage shift from petroleum to electric vehicle travel.

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[59]Margaret Walls and Jean Hanson, *Distributional Impacts of an Environmental Tax Shift: The Case of Motor Vehicle Emission Taxes*, Resources for the Future (Washington DC), Paper 96-11, 1996.
[60] Todd Litman, "Using Road Pricing Revenue: Economic Efficiency and Equity Consideration" *Transportation Research Record 1558*, 1996, pp. 24-28.
[61] Gil McCoy, Kim Lyons, and Greg Ware, *Low Emission Vehicle Procurement Approach for Washington*, Washington State Energy Office (Olympia), June 1992.
[62] Gil McCoy, Kim Lyons and Greg Ware, *EmissionMaster*, Wash. State Energy Office (Olympia), 1993.
[63] COMSIS, *Implementing Effective Travel Demand Management Measures*, FHWA, Sept. 1993; Transport Concepts, *State of Transportation Demand Management Plans In Canadian Urban Areas*, Environment Canada (Ottawa), March 1995.

Conclusions

Electric vehicles provide air pollution and energy conservation benefits worth approximately 4-15¢ per mile in urban areas. Conventional performance electric vehicles are expected to cost considerably more to produce and somewhat more to operate than a petroleum vehicle for the foreseeable future. Only the most favorable assumptions indicate that incremental benefits of electric vehicles equal or exceed incremental costs for the foreseeable future.

On the other hand, lower performance electric vehicles offer several benefits to users and society. They are less expensive to produce and operate than other automobiles. In addition to reducing air pollution and conserving energy they provide safety benefits, and reduce parking requirements. Because of their lower performance they are only suitable for a portion of trips. These vehicles may actually be the best niche for electric vehicle use. For households to choose such a vehicle they would need to have other options for longer distance trips or when they need more capacity. This could include regional public transit, with station cars available at terminals, and vehicle rentals or cooperatives in residential areas to provide convenient access to petroleum powered vehicles when needed.

Focusing subsidies on a particular vehicle type reduces consumer choice, and is almost certainly not the most cost effective way of reducing air pollution. Society will not receive as much air quality improvement as it would with more flexible strategies. Electric vehicle sales mandates provide little incentive for owners to maximize electric vehicle use. Most households that purchase electric vehicles will use them as second vehicles that receive much less use than the households' petroleum powered vehicles. As a result, a considerable subsidy is being devoted to achieve a modest benefit.

A much larger benefit could probably be achieved by devoting the resources currently targeted at electric vehicles to improving the performance of the overall petroleum vehicles fleet, by increasing the range of travel choices, and by providing incentives for consumers to use the most appropriate vehicle or mode for each trip. With such strategies in place, electric vehicles, particularly neighborhood electric vehicles and station cars, could become attractive for many trips.

The necessary incentives could be provided by marginal pollution charges. Such a charge could be revenue neutral, and incorporate features that make them progressive with respect to income. Their only real cost would be transaction costs involved in collecting and redistributing the charges. Such a strategy could reduce far more pollution and save far more energy than electric vehicle mandates are likely to provide during the next half century. In addition, it would reduce total motor vehicle use by 5-12%, which would provide a number of additional benefits.

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