Paper Number

Draft Copy – Effect of EV Utilization of Global CO_2 Emissions

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ABSTRACT

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INTRODUCTION

The increase of CO_2 emissions in the last quarter of century has risen at an alarming rate. In the U.S.A. alone the CO_2 emissions have increased by 50%, from 1 billion tons of carbon to 1.55 billion tons. The transportation industry contributes currently (1991 figures) 24.7% of the total emissions from the United States. Transportation utilization has grown faster, however, but more efficient vehicles allow fore more travel without increasing the CO_2 proportionally. The advancements made in the 1980s have reduced emissions by 21 million tons of CO_2 per year on average.

Electric Vehicles have been a proposed method of reducing the CO_2 emissions due to transportation. Electric vehicles produce no emissions while driving, making them ideal candidates for heavily polluted, concentrated, localized areas such as urban cities. However, it is debatable if electric vehicles are feasible on the global scale of CO_2 reduction. This study compares the amount of emissions produced charging the electric vehicles with the amount of emissions produced by operating a conventional vehicle for equivalent usage. Conclusions are drawn about the advantages and the emissions reductions (if any) that are found by electric vehicle usage.

TRENDS OF U.S. CO_2 PRODUCTION

This portion of the paper will focus of the ratio of the total energy usage (and thus CO_2 production) and transportation energy consumption in the United States. Because the U.S. is globally the foremost producer of emissions from transportation, such is a study is crucial to initial understanding of the problem. The transportation industry in the U.S. has now consumes over 27% of the total energy in 1991, and that number has most certainly increased since then, vs. less than 25% in 1970. With transportation consuming a larger share of the energy budget, any changes in CO_2 production due to technological advancements such as electric vehicles will have a greater impact.

With multiple other countries approaching the CO_2 emission levels of the United States such as Canada, France, Germany, Italy and UK (see further breakdown in Section 3.1) the impact of electric and/or advanced vehicle technology can be extended from the U.S. study. Large developed countries such as the former Soviet Union republics, the People’s Republic of China, and India represent a very large share of the next century’s transportation energy budget as well.

TRANSPORTATION ENERGY USAGE AND CO_2 PRODUCTION

The total CO_2 emissions from the United States alone have increased by half from 1 billion tons of carbon in 1970 to 1.55 billion tons in 1992. This increase represents multiple sources, including electric plants, transportation, and industrial sources. This increase reflects a total energy consumption increase of about 1% per year between 1970 to 1991. The transportation industry energy use increased at a rate of 1.6% per year in the time span, faster than the average total energy annual growth rate. This is reflected in that the transportation industry gained a greater share of the transportation energy budget from 24.5% in 1970 to 27.3% in 1991. In 1993, the U.S. transportation energy reached 22.8 quadrillion Btu.

A direct correlation can be drawn between energy production and CO_2 emissions. CO_2 is a unique greenhouse gas because it has a stable physical relationship to energy use. Emissions such as NOx and Sulfates can be reduced by combustion techniques and exhaust technologies such as catalytic converters. However, fossil fuels contain a fixed amount of carbon, thus releasing a fixed amount of CO_2 upon utilization. Thus, CO_2 emissions trends closely follow energy trends (this concept is covered in more detail in section 2.5 and Table 2.3). A note must be made that hydroelectric and nuclear power are exceptions.

Between 1970 and 1991 the U.S. emissions from energy use increased with an annual growth rate of 0.8%, from 5,554 million tons (mmt) to 6566 mmt in 1991. During the same period the CO_2 emissions from transportation rose at a growth rate of 1.67%, rising from 1146 mmt to 1624 mmt. Thus, the total amount of transportation emissions rose from 20.6% to 24.7% [1].

Table 1. Increase of Energy Use by the Transportation Industry

	1970	1991	Δ	% Change
Total CO_2 Emissions	5554 mmt	6566 mmt	+1012 mmt	+0.80%
Transportation CO_2	1146 mmt	1624 mmt	+478 mmt	+1.67%
% Share of Emissions	20.6%	24.7%	+4.1%	
% Share of Energy	24.5%	27.3%	+2.8%	

Inspecting Table 2.1, the most striking feature is that the transportation industry claimed 27.3% of the energy and only contributed 24.7% of the emissions. This is primarily due to the fact that the electric utility industry uses coal, which is significantly higher in carbon content than the fuels used in transportation. Note must be taken on this fact when considering electric vehicles because any emissions that are avoided by using an electric vehicle is deferred to the coal-burning electric utilities used to charge the vehicle's battery.

Even though overall energy production produced more CO_2 than the transportation energy production, non-CO_2 producing power generation such as hydroelectric or nuclear has increased in the United States from 16.9% to 28.5% [2]. Thus with the evaluation of more statistics, it can be proven that the CO_2 emissions per unit energy produced as a whole has declined. Diesel fuel has increased popularity as a transportation fuel from 18.8% in 1970 to 23.69% in 1991 [3]. Since diesel fuel contains more carbon per unit Btu, there was an increase of CO_2 production per unit of transportation energy use.

TRANSPORTATION GROWTH TRENDS

Personal and freight transportation has increased tremendously in the past two decades due to several factors. The United States has maintained an almost constant population growth rate of +1% per year over the last decades, from 205 million in 1970 to 252.2 million in 1991 (18.7% increase). During the same amount of time, personal transportation has increased from 2245 billion passenger-miles (pm) to 3998 billion at a growth rate of 2.8% per year, a 43.84% increase. An interesting fact is that light truck personal transportation has increased at a rate of 5.9% per year, indicating the popularity of the pickup truck for commuter applications [4]. Taking into account the population growth, the per capita increase of commuter miles has been from 10,950 miles per capita to 15,822 miles over the same period of time.

Table 2. Passenger Transportation Trends (U.S.)

	1970	1991	Δ	%
Population	$205x10^6$	$252.2x10^6$	$47.2x10^6$	+18.7%
U.S. GNP	$\$2702x10^9$	$\$4528x10^9$	$\$1826x10^9$	+40.3%
Miles per Capita	10950	15822	4872	+30.8%
Total pm	$2245x10^9$	$3998x10^9$	$1753x10^9$	+43.8%

It is obvious that from this table the increase in transportation is not because there are more people (18.7% population growth vs. 43.8% increase of miles driven). However, the increase of transportation seems to mirror the increase of GNP more closely (40.3% GNP growth correlates to a 43.8% increase of miles driven). Thus two contributing factors of increasing transportation energy usage can be attributed to population growth and economic growth.

Freight transportation increased at a more rapid rate than personal transportation, from 2467 billion ton miles (tm) to 3689 billion tm, a 49.5% increase at a rate of 1.9% per year. It should be noted that air freight now handles 8.86 billion tm, growing at a rate of 5.3% per year. In comparison, truck freight handles 1150 billion tm per year.

IMPROVEMENTS IN TRANSPORTATION EFFICIENCY

Technological advancements in the transportation industry have resulted in a variety of efficiency improvements. Many of these improvements are driven by availability of advanced technology that increases marketable performance while increasing efficiency. Other improvements are brought on by government, public opinion, or legislation. More details on these factors will be brought up in section 3. The Bureau of Transportation Statistics ranks several different types of vehicles based upon their average energy efficiency, expressed as Btu per passenger-mile. It must be pointed out that this statistic reflects how much energy is required to transport one person per mile. A crowded city bus scores high marks in this category compared to a pickup truck with one commuter driver, because the city bus carries more passengers per unit energy than the commuter vehicle. These efficiencies are depicted as Figure 2.1.

An interesting note is that the transit bus passenger-mile energy efficiency has decreased. This can be attributed to a general propensity to travel in personal commuter vehicles rather than in public transit busses.

CHANGES IN TRANSPORTATION ENERGY USAGE

The preceding sections detailed the increase of the transportation sector and its attributing causes, which are important to realize if this analysis is to be applied on a global scale in order to make observations about future trends. Next, a scientific and statistical analysis needs to be done to compute the weights and effects of the energy usage in the transportation sector. The beginning of this study is to examine the carbon content of various fossil fuels and rank them accordingly:

Table 2.3 Common fossil fuels and carbon content [6]

Fuel	Grams of CO_2/gJ	Tons of CO_2/billion Btu
Hard Coal	94.2	99.2
Ship Oil	78.1	82.4
Diesel	73.8	77.9
Aviation Gas	71.2	75.1
Gasoline	71.2	75.1
Jet Aviation Fuel	70.8	74.7
Rail Diesel	70.0	73.9
Natural Gas	56.1	59.2

Conversion was made based on 1 Btu = 1055 joules. All hydrocarbon bound carbon is assumed to be eventually converted to CO_2. True combustion does not result in 100% conversion because incomplete combustion can result in CO (which is rapidly converted to CO_2 in the atmosphere) and CH_4, an important greenhouse gas. It is assumed that the amount of CO_2 produced by incomplete combustion is not significant, even more so considering the advanced engine technologies available presently.

The amount of CO_2 produced by combustion of each fuel is governed a fixed physical relationship based on the carbon content per Btu yield. When undergoing incomplete combustion, utilization of fossil fuels can result in emission of long-chain hydrocarbons, which break down into methane and CO_2. Thus the actual 'greenhouse' emission is not only based on the carbon content but combustion method. The combustion technology combined with the exhaust technology also can result in a wide range of NOx and sulfate emissions.

Next, a table was constructed using the statistics of Sections 2.2-2.4 and the values of Table 2.3 to compute the actual CO_2 production resulting from each factor:

Table 2.4. Breakdown of driving forces in terms of CO_2 emissions [1]

Increase of CO_2 production for each decade	1970-1980	1980-1991
	mmts CO_2	Mmts CO_2
Efficiency	-54.33	-177.80
Transportation Mode	37.96	1.89
Economic Growth (GDP)	79.80	191.13
Population Growth	87.01	100.21
Other Interactions	-20.73	-37.41
Changes from Passenger Transportation	**129.70**	**78.02**

Increases of Btu use for each decade	1970-1980	1980-1991
	Trillion Btu	Trillion Btu
Efficiency	-725.98	-2369.35
Transportation Mode	508.20	27.91
Economic Growth (GDP)	1062.76	2545.30
Population Growth	1158.78	1334.55
Other Interactions	-277.06	-498.01
Changes from Passenger Transportation	**2333.37**	**1040.41**

During the period of 1970-1980 the transportation sector increased CO_2 production by 315.75 million metric tons (mmt) per year. Because of primarily efficiency gains in personal automotive technology, CO_2 production was reduced to average 162.223 mmt per year. This is key in the study of electric vehicles because for an electric vehicle to compete with standard combustion types there must be a clear advantage. With vehicle technology increasing efficiency and reducing emissions at the current pace, it will remain to be seen if EVs will hold a clear advantage.

Notice again, it is indicated that the economic growth as seen with the GDP contributes largely to the increased use of passenger transportation. Population growth (thus more individuals owning vehicles or using public transportation systems) was the second largest contributing cause.

CONCLUSIONS ABOUT CO_2 PRODUCTION IN THE TRANSPORTATION SECTOR

The most significant observations obtained in this section are listed below:

- Passenger transportation has increased at a rate of 2.8% per year whereas the population increase is only 1.0% per year.
- Per capita miles traveled per year has increased 30.9% between 1970 and 1991.
- Transportation CO_2 emissions only accounted for 20.6% of the total emissions in 1970. In 1991 that number increased by 4.1% to 24.7%.
- Transportation consumed 24.5% of the total energy consumed in the United States in 1970 and 27.3% of the total energy in 1991, a difference of 2.8%.

Passenger transportation technological advancements have saved 227 trillion Btu of energy and 21 million tons of CO_2 per year on average from 1980 to 1991.

TRENDS OF GLOBAL CO_2 PRODUCTION

As automotive technology continues to advance and transportation becomes more available, the economy and society is dictating people to travel more now than ever before. This is not only true for the United States but also in almost every country in the world. Considering that transportation accounted for 24.7% of total CO_2 emissions in the U.S., other countries are facing similar statistics. Table 3.1 lists several major transportation-related CO_2 contributing countries. Notice that some omissions include China, India, and the former Soviet Union republics due to lack of available data.

Table 3.1. Some major transportation-related CO_2 contributing countries [7]

	Emissions (mmt/year)		
	CO_2	HC	NOx
Canada	9928	2100	1942
USA	76000	22800	20300
Japan	*5013*	*1503*	1339
Austria	1126	251	211
Belgium	839	*356*	317
Denmark	602	106	241
Finland	660	112	284
France	5200	2185	2567
Germany	8960	1860	3090
Greece	695	82	196
Ireland	497	62	71
Italy	4036	496	1550
Netherlands	1368	452	500
Norway	632	158	125
Portugal	533	91	248
Spain	3780	739	778
Sweden	1250	410	328
Switzerland	711	311	196
Turkey	3707	201	380
UK	5127	1954	1932

GOVERNMENT AND PUBLIC INITIATIVES

Government policy toward CO_2 regulation, especially in the transportation sector, has oscillated dramatically in the last decade. Early optimism about the technology associated with electric vehicles resulted in numerous 'mandates' that a certain percent of the automobile fleet in particular countries be electric. As electric vehicles became a reality and their poor performance, range and cost became obvious these mandates were delayed, decreased, or in some cases, removed altogether.

The low oil prices in the 1980s have also contributed to the loss of interest in electric vehicles. The economy in the 1970s drove technology to search for alternative and possibly cheaper transportation that was not dependent on an imported fuel that looked like was in a shortage. A slight resurgence of research is now underway to develop vehicle technology to reduce urban pollution.

Governments in USA, Japan and some European countries have developed ways to encourage further research [8]. Some particular government regulations regarding CO_2 vehicle emissions include (1993 data).

Some notable U.S. trends include:

- Some U.S. state governments (most notably California due to severe urban pollution) have required a sales percentage of ultra low emission vehicles (ULEVs) or electric vehicles. Many local governments have developed incentives (e.g., tax) for fleets and individuals to operate ULEVs or EVs.
- The U.S. federal government aggressively funds hybrid electric (HEV) and electric vehicle research at both national laboratories and independent research facilities.

Japan has integrated a very aggressive plan called the 'Electric Vehicle Market Expansion Program' that specifically targets government and private fleets:

- Government fleet vehicles of Tokyo and Osaka have been targeted to migrate to electric vehicle use, and private enterprises offered financial incentives to switch to EVs.
- Financial incentives and government subsidies are offered to private utility companies and delivery firms to migrate to EVs.
- Future incentives are planned for individual automobile owners. In 1993, these incentives were only 4% of the cost of an electric vehicle, which is not a significant amount compared to how much more expensive an EV is in comparison to a standard automobile.

All major automotive industries in Europe now have electric vehicle programs, many of them offering electric versions of existing models. In 1993, there were in excess of 25,000 EVs operating in Europe, primarily in UK.

- UK, Germany and Denmark impose a vehicle tax based on vehicle weight, which discourages the use of EVs. Temporary tax measures have been put in place to avoid this problem.
- Many European countries tax vehicles on engine size, which is EV operators avoid.
- The European Community has determined that based upon current EV development, EVs will have the capability of reducing urban pollution by 20-30% [9].
- The German government aggressively funds EV development and offers tax exemption for EV operators.

- In France 90% of electricity is produced by nuclear power or hydroelectric thus any use of electric vehicles will yield a major reduction of CO_2 emissions. Local governments are offered substantial subsidies to migrate to EV use.

An optimistic forecast [10] from the European Community has deterimined that the combined markets for electric vehicles will reach 2.1 million vehicles by 2010:

Table 3.2. Forecast of electric vehicle sales

		2000	2005	2010
USA	Total	16,860,000	17,290,000	17,360,000
	EVs	163,500	721,500	1,007,300
	ICE	16,696,500	16,568,500	16,352,700
Japan	Total	7,560,000	7,590,000	7,630,000
	EVs	73,500	266,500	485,500
	ICE	7,486,500	7,323,500	7,144,500
Europe	Total	17,410,000	18,110,000	18,640,000
	EVs	37,800	222,800	612,200
	ICE	17,372,200	17,887,200	18,027,800

This table is surprising in that it predicts electric vehicle production in the U.S. will increase from 1,000 vehicles (approximately current rate) to 163,500 in the year 2000. The developers of this table probably were considering the California air restrictions board legislation, which required a certain percentage of vehicles sold in California to be electric. This legislation has been reduced and some measures have even been removed. Thus the year 2000 estimate for electric vehicles sales is not probable. However, the Japanese market has indicated that it is moving toward electric vehicles at a rapid pace.

IMPACT OF ELECTRIC VEHICLES ON CURRENT CO_2 EMISSION LEVELS

The bulk of the data contained in this section is derived from a joint effort study done by the U.S. Department of Energy (DoE) and the Electric Power Research Institute (EPRI) [11]. This study concentrated on *four basic scenarios of EV market penetration compared to two basic scenarios of gasoline vehicle development*. The study forecasts automotive emissions for each of the scenarios and generates emissions savings potentials. The goal of the analysis is to discover the benefit of displacing fossil fuel consumption from individual automobiles to centralized electric generation facilities.

It should be noted emissions from EV battery recycling could be a potential concern. About 85% of used automotive batteries are collected and of those 95% are recycled. The process used to recycle batteries generally produces about 1g of NOx and 3.7g of CO_2 per ordinary automobile battery [12]. Assuming an EV battery on average is 120 times the size of the ordinary automobile battery (420 W-hr vs. 50 KW-hr capacity), an EV battery would require 120g of NOx and 450g of CO_2 per battery recycled. Considering the battery would have a usable lifetime of 400 charging cycles at 80 miles per charge (30,000+ mile battery lifetime, optimistic), the recharging emissions of 0.0001 g/mile of NOx and 0.014 g/mile of CO_2 would have to be entered into the total emissions computations. These numbers correspond to about 1% of that an ordinary automobile produces per mile.

MODEL SCENERIOS

Emission levels from six scenarios were computed for comparison purposes:

a. Electric and Hybrid Vehicle (EHV) are assumed to be high efficiency and electric utilities are assumed to have average emission rates. This is the best case scenario.
b. EVH are assumed to have marginal efficiency and electric utilities to have average emission rates.
c. EVH are assumed to have high efficiency and electric utilities to have marginal emissions rates.
d. EVH are assumed to have marginal efficiency and electric utilities to have marginal emission rates. This is the worst case scenario for EVHs.
e. Conventional Vehicles (CV) are assumed to be low efficiency. This is the worst case control scenario with (no EVHs and low efficiency CVs).
f. Conventional Vehicles are assumed to have high efficiency. Good case control scenario.

The first four scenarios apply to EVHs and the last two are control runs with only ordinary automobiles. Thus conclusions can be drawn when comparing an EVH scenario with a control run. Emissions considered in each case are six pollutants: CO_2, SO_2, CO, VOC (incomplete combustion hydrocarbons), and NOx. It should be noted that SO_2 and NOx are precursors to acid rain, SO_2 creates an localized aerosol that combats greenhouse warming and CO_2 and NOx are greenhouse gasses. The VOCs will decompose eventually into CO_2 or CH_4, which both contributes to greenhouse warming.

Conventional vehicles were modeled assuming that existing vehicles operated at the fuel efficiencies specified on Table 4.1-4.3 for the two control scenarios. The reason behind the decreasing mpg trend in light trucks is due to the increasing popularity of larger and more powerful engine options available. The Moblie4 computer model [13] was used to compute the gasoline vehicle emissions and *the CO_2 production was based on the physical equations of carbon content of fuel, fuel efficiency, CO_2 produced during fuel extraction, refinery operation and distribution*.

Table 4.1. Average vehicle fuel economy (mpg) ‘worst case scenario

Year	Automobiles	Light Trucks
1995	22.2	17.0
2000	22.3	16.8
2005	22.6	16.8
2010	22.9	16.9

Table 4.2. Average vehicle fuel economy (mpg) 'good scenario'

Year	Automobiles	Light Trucks
1995	27.8	17.0
2000	27.8	16.8
2005	27.8	16.8
2010	27.8	16.9

Table 4.3. Gasoline/Diesel percent market share for Light Trucks

Year	Gasoline	Diesel
1995	90%	10%
2000	76%	24%
2005	63%	37%
2010	58%	42%

Referring back to Section 2.5 and Table 2.3, and assuming that 98% of the carbon content of gasoline is burned in each combustion cycle and 99% conversion of Diesel fuel, the mass of CO_2 produced per gallon of fuel can be computed:

(mass of carbon per gallon) x conversion percent x 44/12 = mass CO_2

Grams per gallon are then converted into grams per mile using the fuel efficiency Tables 4.1-4.3.

The electric vehicle scenarios are divided into two subcategories, the high and low efficiency EVs. Low efficiency EVs require more frequent changing for equivalent miles traveled, thus the demands from the electric utilities are increased. Examining the loads on electric utilities,

Table 4.4. High and low EV efficiency cases and total annual charging
electricity use (GWhw)

	2000	2005	2010
Low Case	3,137	25,332	80,096
High Case	1,511	10,169	26,843

Electric utility plants are modeled by two factors: fuel types and emissions standards. The average and marginal emission calculations were performed using the fuel types (and thus average emissions content) and 1990 CAAA regulations on SO_2 and Nox. Table 4.5 indicates the breakdown of the different fuel usages.

Table 4.5. Percent use of different fuel types

Coal	Oil	Gas	Nuclear	Alternative
57.4%	4.43%	6.8%	21.4%	1%

The alternative power utilities include hydroelectric and wind power most (>50%) of this type of power generation is found in the western U.S. Notice that nuclear holds a large portion of power generation in the U.S., but it is not nearly as comparable to France's nuclear efforts of reaching well above 75% of all power is non-fossil fuel. In cases where nuclear power is available, CO_2 production for the use of electric vehicles is significantly reduced.

SCENERIO RESULTS

Because the primary purpose of this review to study the impact of specifically greenhouse gasses, only the CO_2 emission results will be presented. For further details on the other are five pollutants (SO_2, CO, VOC, and NOx) please see Appendix I. Appendix I also has each of the scenario results broken down into six regional sections of the U.S. Table 4.6 shows the model results for CO_2 for each of the six scenarios.

Table 4.6. CO_2 Emissions in mmt/year for each scenario of EV utilization in the U.S.

	Scenario a	Scenario b	Scenario c
1995	5,197	6,822	6,896
2000	948,572	1,967,166	1,260,386
2005	5,735,672	14,265,967	8,477,902
2010	13,406,344	39,950,717	22,351,069

	Scenario d	Scenario e	Scenario f
1995	9,052	9,757	9,757
2000	2,615,800	2,356,751	2,228,850
2005	21,108,398	19,581,189	17,842,184
2010	66,665,956	64,452,227	54,187,308

There are several pieces of important *general* information to obtain from this table:

- Highly efficient EHVs combined with strict electric utility regulation (Scenario a) can reduce the CO_2 emissions due to transportation over 20%. Because transportation currently is responsible for 24.7% (Section 2.2) of total CO_2 emissions, it would be a reduction of 5.5% of total U.S. CO_2 emissions.
- Even the worst case scenario (case e) is better than poorly efficient EVHs and marginal utility plants (case d)!
- Conventional vehicles can compete within 25% with poorly efficient EVHs with good efficiency power utilities.

The result of this study indicates that if EVHs are to become (1) a reality and (2) a solution to CO_2 emissions then they must be highly efficient with efficient power generation utility infrastructure. Nuclear energy has a great advantage in this type of study, as does wind energy and hydroelectric systems. However, these types of production are either politically difficult, economically unfeasible, or produce emissions or effluents of their own.

CONCLUSION

There are several important realizations to be made about this study:

- Transportation in the U.S. is increasing at a rapid pace. Population has only increased at a rate of 1.0% per year but total miles traveled has increased by 2.8% per year. Per capita miles traveled has increased by 30.9% since 1970.
- Transportation related CO_2 emissions are responsible for 24.7% of the total CO_2 emissions in the U.S., yet transportation is responsible for 27.3% of the energy usage.
- Conventional gasoline vehicles will continue to compete in CO_2 emissions unless electric or hybrid vehicles and electric power utilities increase efficiency.
- Conventional gasoline vehicles compete favorably to marginally efficient electric vehicles when the electric utility emissions are factored in.
- Conventional vehicles will favorably compete economically unless a technological breakthroughs occurs to lower cost or governments employ financial subsidies initiatives.
- Several governments are funding and/or sponsoring major research efforts for efficient electric or hybrid vehicle technologies.
- Several governments are offering financial incentives or federal subsidies for automobile users to migrate to electric vehicles.

Comparing scenario a to scenario e (Section 4.2) it can seen that total U.S. CO_2 emissions can be reduced by 5.5% with the use of electric vehicles and efficient power utilities. This is a significant beginning but several things must be considered:

- Advanced electric utilities need to be developed before electric vehicles will become truly useful. At today's present technologies, there is not enough emissions advantage to use electric vehicles because they still need to be charged from emissions-generating power plants.
- Electric vehicle technology today is expensive and battery lifetime is short (~30,000 miles). Electric vehicle technology needs to expand beyond the limitations of electrochemical energy storage before high enough efficiency is to be realized.
- Developing countries and countries such as China, India, and the former Soviet Union republics have to be considered because their share of CO_2 emissions are going to increase considerably. If the U.S. switches to optimal EV usage, the global effect will be small in comparison to the emissions created from other countries. The technology must be universally applied for significant reductions.

CONTACT

This is where main author information is typed, if desired, such as background, education, e-mail address, and web address. This is an optional section.

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