Solar Sustained Vehicles (SSV):

A Consumer's Solution to Protection in an Age of Oil Dependence, Economic Uncertainty, and Global Warming[1]

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Draft, November 14, 2008

Abstract

This paper evaluates the fuel saving benefits of Solar Sustained Vehicles (SSV) from a consumer's perspective. An SSV is a vehicle that is partially or fully powered by electricity (as with plug-in hybrid electric or electric vehicles) that is bundled with a grid-connected photovoltaic (PV) system at the time of sale to offset its electricity consumption. The paper suggests that SSV's provide the following types of protection: (1) initial capital cost protection; (2) near-term financial protection; (3) long-term fuel-price fluctuation protection; (4) environmental protection; (5) national security protection; and (6) electric utility outage protection. Results based on a case study for a customer in the state of New York indicate that consumers would benefit from dramatic fuel cost reductions for the next 30 years. The conclusion is that consumers could purchase SSVs to protect their own economic interests while simultaneously reducing U.S.' dependence on oil and reducing greenhouse gas emissions.

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[1] Special thanks to Jeff Peterson at the New York State Energy and Research Development Authority (NYSERDA) for his support of this work. Detailed review comments were provided by Jeff Ressler and Ben Norris (Clean Power Research). All opinions in this paper are those of the author and do not necessarily reflect the views, positions or opinions of NYSERDA or its staff.

Background

Figure 1 illustrates the negative economic effects of the U.S.' dependence on oil. Gasoline consumption for the fleet of motor vehicles in the U.S. has been increasing at a modest rate while gasoline prices have been increasing rapidly. Gasoline costs relative to the overall U.S. economy are reaching the oil crisis levels of the 1970s.[2] A majority of Americans are concerned about increasing gasoline prices, price uncertainty, the country's dependence on oil (in particular oil supplied by foreign countries), and the prospects of running out of oil. Concern about global warming and other environmental consequences of gasoline consumption contribute to the alarm, and consumers seek ways to avert potential catastrophe.

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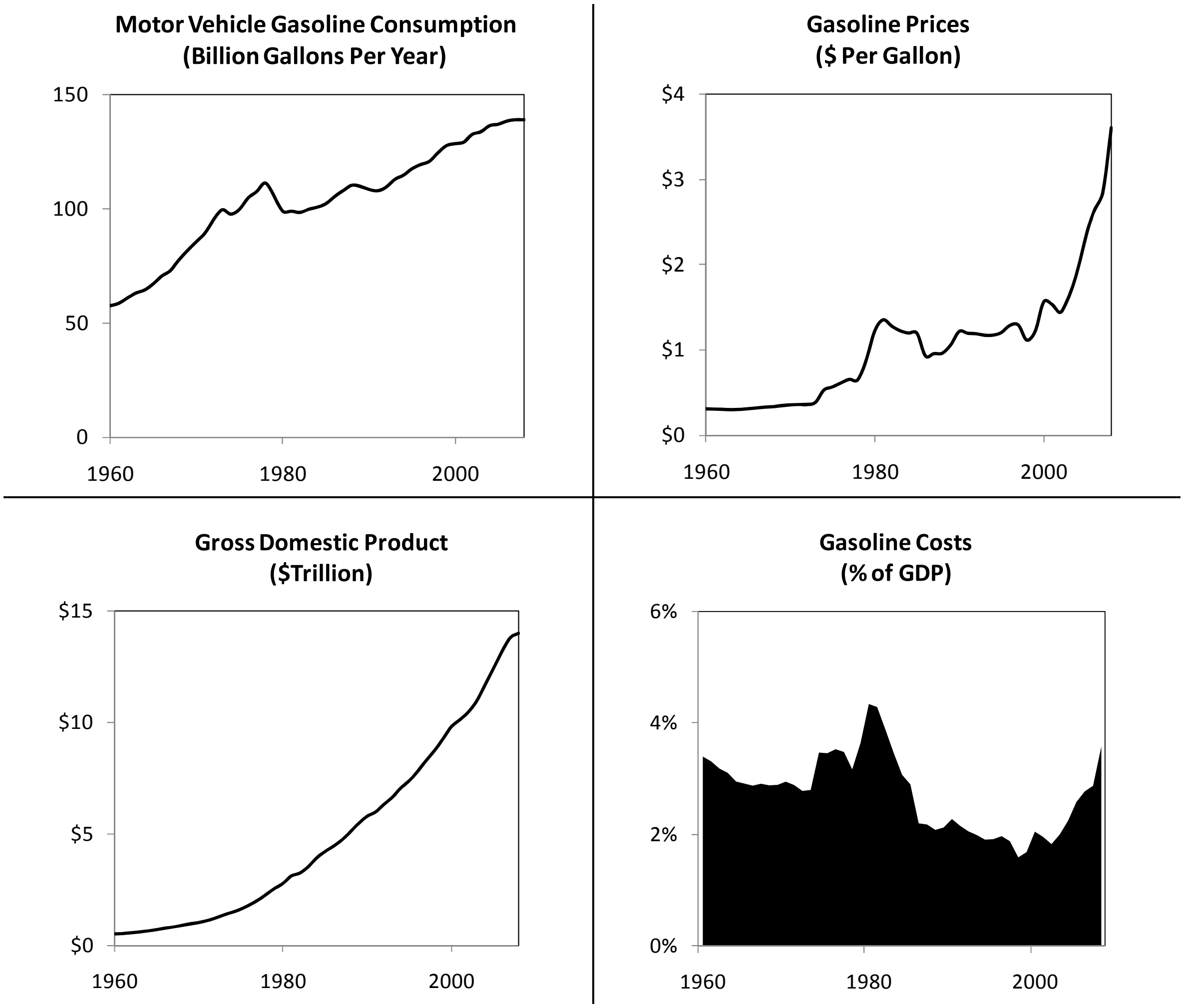
[2] Gasoline consumption is based on the column "Motor Gasoline" in barrels x 42 gallons per barrel from Table 5.13c, www.eia.doe.gov/emeu/aer/petro.html for consumption through 2007. 2008 consumption is assumed to be the same as 2007. Gasoline prices are from Table 5.24, www.eia.doe.gov/emeu/aer/petro.html. Data for 1960 to 1975 is for "Leaded Regular". Data for 1976 to 1977 is for "Unleaded Regular". Data for 1977 to 2007 is for "All Grades". Data for 2008, is from http://tonto.eia.doe.gov/dnav/pet/hist/mg_tt_usM.htm. U.S. GDP data is from http://www.bea.gov/national/xls/gdplev.xls. 2008 is assumed to be 1.5% higher than 2007.

Figure 1. The U.S. is paying a high economic price for its oil dependence.



Possible Solutions

Gasoline costs as a percent of GDP (i.e., the bottom right portion of Figure 1) are calculated by multiplying gasoline consumption times gasoline price divided by GDP. This suggests that two ways to reduce the gasoline costs relative to the overall economy are to reduce gasoline prices and reduce gasoline consumption.[3]

One option is to reduce gasoline prices by increasing supply. The difficulty of this alternative is that crude oil, from which gasoline is derived, is a world market commodity. Supply (and by extension, price) is based on world market conditions. World markets and production coordination among major oil producing nations establish prices, while increases in U.S. exploration, investment, and production have a limited impact on pricing.

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[3] A third option is to increase GDP. The U.S. GDP, however, has grown at a fairly steady rate for a long period of time. It is unrealistic to think that the GDP could be significantly increased in order to reduce the effect of gasoline prices relative to GDP. This option is not considered.

Another option is to reduce gasoline consumption.[4] There are multiple ways to accomplish this including:

- Shift to more fuel efficient modes of transportation (e.g., promote mass transit)
- Encourage conservation (e.g., increase gasoline prices through taxes)
- Increase vehicle fuel efficiency (e.g., increase efficiency standards)
- Power vehicles using alternative fuels (e.g., switch from gasoline to electricity)

The U.S. successfully reduced oil consumption in response to the 1970s oil crisis by increasing vehicle fuel efficiency standards and by switching fuels for power generation. As illustrated in the top left corner of Figure 1, there was a precipitous drop in gasoline consumption for several years in the late 1970s, and the long-term consumption trajectory is clearly lower than it would have been without any action. The response to high oil prices in the electric utility sector was to switch from oil to other fuel sources for power generation: utilities reduced oil consumption for electricity generation by more than 70 percent from 1978 to 1985.[5]

In the U.S., two effective responses to the 1970s oil crisis were to reduce consumption through efficiency improvements and fuel switching. These two responses were applied to two different sectors. The motor vehicle sector applied the increased efficiency approach. The electric utility sector reduced the amount of oil used to produce electricity by switching to other fuels.

A response that is available to the U.S. for the current oil crisis is that the efficiency and fuel switching solutions could simultaneously be applied to the same sector.

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[4] In general, a decrease in consumption will have the effect of reducing prices.

[5] Electric utilities consumed 638 million barrels of oil in 1978 and 175 million barrels of oil in1988. Table 5.13d www.eia.doe.gov/emeu/aer/petro.html.

Objective

This paper proposes and evaluates the benefits of Solar Sustained Vehicles (SSV) from a consumer's perspective. An SSV is a vehicle that is partially or fully powered by electricity (plug-in hybrid electric[6] or electric vehicles) that is bundled with a grid-connected photovoltaic (PV) system at the time of sale to offset its electricity consumption. Since the PV system associated with an SSV is designed to produce at least the amount of electricity typically consumed by the vehicle, the SSV is considered to be a vehicle powered by solar energy although the PV is not likely to power the vehicle directly.

This paper is intended to be the first in a series of papers that quantifies the benefits of SSVs, and focuses on the benefits to the consumer who purchases, owns, and operates the vehicle and the corresponding PV system. Subsequent papers will focus on societal and economic benefits accruing to other market participants including utilities, suppliers, and the state and federal governments.

Benefits of SSVs

While the focus of this work is on the consumer, it is useful to provide a brief overview of benefits of SSVs from multiple perspectives.

- Consumers
    - Achieve substantial long-term fuel cost savings
    - Generate electricity for subsequently purchased plug-in vehicles because the PV portion of the SSV will outlast the vehicle portion of the SSV
    - Protect against volatile gasoline and electric price increases
    - Personally improve the environment through reductions in tailpipe emissions, including greenhouse gases, particulates, and smog producing gases
    - Personally reduce U.S. dependence on foreign oil
    - Establish a home solar infrastructure that can be expanded to meet other electrical needs
    - Power critical house loads in the event of a power outage[7]
    - Reduce financial transaction costs and hassle by bundling two major purchases into a single transaction
    - Enhance convenience of fueling by plugging in vehicle at home rather than driving to a gas station

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[6] A plug-in hybrid electric vehicle (PHEV) is able to use electricity for propulsion – from an on-board battery, an on-board gasoline-powered generator, or both simultaneously – and it provides a means for charging the battery from a wall outlet. The battery is sized so that the vehicle can cover a limited range without need for the gasoline generator at all. Some resources on the subject include: Sherry Boschert, "Plug-in Hybrids: The Cars that Will Recharge America", New Society Publishers, 2006; S. David Freeman, "Winning Our Energy Independence: An Energy Insider Shows How", Gibbs Smith, 2007; David Sandalow, "Freedom From Oil", McGraw-Hill, 2008; Iain Carson and Vijay Vaitheeswaran, "Zoom: The Global Rate to Fuel the Car of the Future", Hachette Book Group, 2007; www.calcars.org; www.pluginamerica.com.

[7] The PV system could serve as the power source and the plug-in vehicle could provide the storage. More work is required to determine exactly how the system should be configured.

- Utilities
    - Improve asset utilization by increasing off-peak consumption and reducing on-peak production
    - Reduce natural gas consumption and exposure to natural gas price increases
    - Increase the market for wind power by being better able to satisfy the need for increased off-peak production
    - Manage off-peak load profiles to meet utility resources[8] and thus reduce costs

- State and Federal Government
    - Improve state and national security by reducing gasoline consumption and thus dependence on foreign energy sources
    - Avoid risks of turning to natural gas as a substitute for oil[9]
    - Protect the environment by reducing CO_2 and other emissions
    - Empower citizens by providing incentives directly to them rather than providing indirect benefits through some other mechanism
    - Enable proper stewardship of resources and take a key step towards a clean energy future
    - Create jobs in a growing global industry

- Industry
    - Auto Industry
        - Create jobs by stimulating demand to replace old cars with new PHEVs
        - Market and sell a more diversified set of products that protect companies against typical market fluctuations
        - Enhance clean industry image
        - Reduce long-term risk associated with unsustainable gasoline sales
    - PV Industry
        - Create jobs
        - Provide a powerful selling tool into the residential market
        - Introduce the mass market to customer-sited (distributed) PV with an initial small purchase, thus setting the stage for larger purchases later on (to offset more or even all of a customer's electricity consumption)

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[8] This assumes that the PHEV's are properly equipped with the necessary controls to charge based on utility preferences rather than customer demand.

[9] Most of the world's natural gas supply is in the same location as the world's oil supply. The U.S. would need to import much more natural gas to make all vehicles natural gas-powered than it would to maintain a fleet powered by electricity. The natural gas market has the potential to become as volatile and unpredictable as the oil market.

Analysis

Case Study

The following case study is intended to illustrate the economic impacts of an SSV for a consumer in New York. The technical and economic assumptions are presented in Table 1.

Table 1. Assumptions.

Household behavior	
Annual Miles Driven	12,000
Annual Home Electricity Consumption w/o SSV (kWh)[10]	6,820
Fuel from Gasoline for Plug-in[11]	25%
Retail Vehicle Price	
Conventional[12]	$19,674
Hybrid Premium (over Conventional)[13]	$3,921
Plug-in Premium (over Hybrid)[14]	$6,000
Vehicle Fuel Efficiency	
Conventional Vehicle Mileage (MPG)[15]	24
Hybrid Vehicle Mileage (MPG)[16]	44
Plug-in Efficiency (kWh/mile)[17]	0.2
Technology Improvement (Subsequent Vehicles)	
Gasoline Mileage Improvement (% per year)[18]	2%
Electric Efficiency Improvement (% per year)[16]18	1%
PV System	
PV Capacity Factor[19]	13.5%
PV Cost ($ per kW_{DC})[20]	$8,500
PV System Life (Years)	30
Gasoline Prices	
Current Gasoline Price ($ per gallon)	$4.00
High Price Escalation (% per year)	7.00%
Moderate Price Escalation (% per year)	3.50%

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[10] In New York, the residential sector consumes 48.4 billion kWh (http://www.eia.doe.gov/emeu/states/hf.jsp?incfile=sep_fuel/html/fuel_use_es.html) and there are 7.1 million occupied households (http://factfinder.census.gov/home/saff/main.html?_lang=en).

[11] This study takes the conservative assumption that the consumer purchases a plug-in hybrid electric vehicle rather than an electric vehicle. The economic results are more favorable for a consumer who purchases an electric vehicle.

[12] 2009 Camry LE 4dr Sedan (Automatic Transmission), http://www.carsdirect.com.

[13] 2008 Prius Base 4dr Sedan, http://www.carsdirect.com.

[14] http://www.reuters.com/article/Autos08/idUSN1853705720080918.

[15] Toyota Camry, http://www.consumerreports.com.

[16] Toyota Prius, http://www.consumerreports.com.

[17] Plug-in Toyota Prius, http://avt.inel.gov/phev.shtml; Chevrolet Volt, http://gm-volt.com/chevy-volt-reasons-for-use-and-cost-of-operation.

[18] While the gasoline mileage and electric efficiency improvements will not affect the efficiency of the first vehicle that is purchased, they will affect subsequently purchased vehicles. This is important because the PV system should be expected to last about 30 years, which is much longer than the likely life of the first vehicle.

[19] Clean Power Estimator, http://powernaturally.cleanpowerestimator.com/.

[20] PV Incentive Program Data, http://www.powernaturally.org/.

Electricity Prices	
Current Rate Structure Price[21]	Table 3
High Price Escalation (% per year)	7.00%
Moderate Price Escalation (% per year)	3.50%
Incentives	
Plug-in Incentive[22]	$3,000
NYSERDA PV Incentive ($/kW)[23]	$4,000
NY State PV Tax Credit (%)[24]	25%
Federal PV Tax Credit (%)[25]	30%
Financial	
Loan Rate	5.75%
Loan Life (Years)	7
Marginal Federal Income Tax Rate[26]	28%
Marginal State Income Tax Rate[27]	5.9%
Emissions	
CO_2 Emissions (lbs per gallon of gasoline)[28]	19.4
CO_2 Emissions (lbs per kWh of electricity)[29]	0.91

While there is broad public interest in both electric vehicles (EV) and plug-in hybrid electric vehicles (PHEV), the stronger interest appears to be with the PHEVs because they are not limited in range. As a result, for purposes of this analysis, the plug-in will be assumed to refer to the PHEV.

The SSV includes a PV system sized to deliver the annual energy required by the PHEV. As presented in Table 2, the PHEV will require 1,800 kWh per year. This can be met by a 1.5 kW_{DC} PV system, a fairly modest home PV system (many residential PV systems are about 5 kW).[30, 31]

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[21] LIPA TOU Rate Structure, Code 188.

[22] http://www.dailytech.com/Toyota+Unhappy+About+Proposed+7500+Tax+Credit+for+Chevy+Volt/article12980.htm.

[23] http://www.powernaturally.org/Programs/Solar/incentives.asp.

[24] http://www.tax.state.ny.us/pdf/2007/fillin/inc/it255_2007_fill_in.pdf.

[25] http://www.irs.gov/pub/irs-pdf/f5695.pdf. The $2,000 cap has been removed with the passage of H.R. 1424.

[26] http://www.irs.gov/pub/irs-pdf/i1040tt.pdf.

[27] http://www.tax.state.ny.us/pdf/2007/inc/nys_tax_rate.pdf.

[28] http://www.epa.gov/oms/climate/420f05001.htm.

[29] Data for New York, http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.

[30] Actual data for PV systems installed as part of the California Solar Initiative are available at https://csi.powerclerk.com.

[31] NYSERDA hosts the Clean Power Estimator on its website, a tool that can be used to estimate PV system output. According to this tool, a 2.5 kW_{DC} system is estimated to produce 2,955 kWh per year. This implies that the consumer will require a 1.52 kW_{DC} system to offset the vehicle's need for 1,800 kWh of electricity with PV generated electricity 2.5 x (1,800 / 2,955) = 1.52.

Table 2. PV size calculations.

Miles Supplied By Electricity (Miles)	9,000
Plug-in Electrical Efficiency (kWh per Mile)	0.2
Electricity Required by Plug-in (kWh)	1,800
PV Required to Offset Vehicle Electricity (kW_{DC})	1.52

Figure 2 presents a residential customer's demand for electricity for a typical day in July as it currently exists (left side of the figure) and the demand with an SSV (right side of figure). There are several things to notice in this figure. First, the PV reduces consumption during the middle of the day (on-peak periods) and the plug-in increases consumption during the night (off-peak periods). Second, such a load profile may be particularly well suited to wind that peaks at night. Third, the modified profile has the potential to be very attractive from a utility's perspective, a perspective that will be discussed in subsequent work.[32]

Figure 2. Current residential electricity demand by time of day for a typical household in July (solid black line) compared to demand with an SSV (dashed red line).[33]

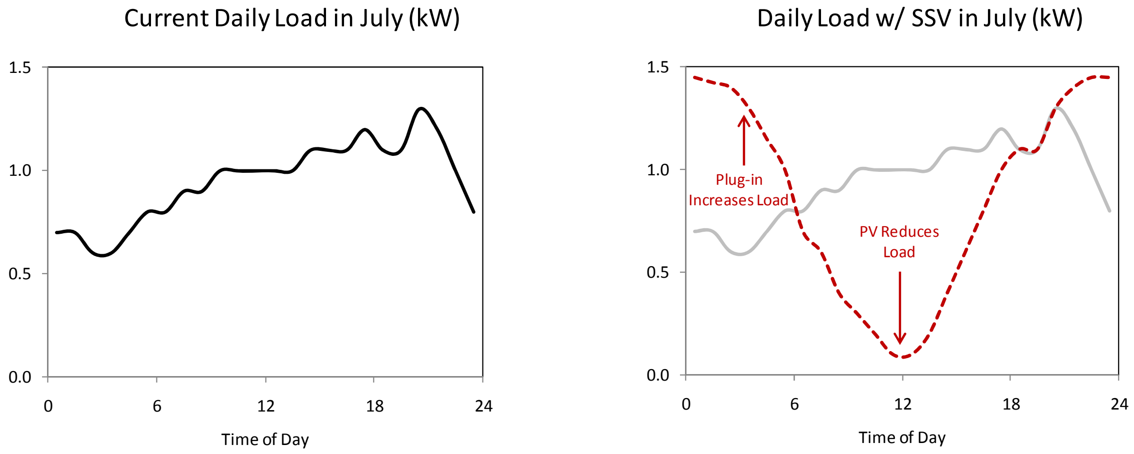

Table 3 presents the annual electric utility bill for: (1) a typical household; (2) a typical household with a plug-in; and (3) a typical household with an SSV. The results suggest that the plug-in will cost the consumer an additional \$268 per year in electricity while the SSV will save the consumer \$129 per year. While the PV system is sized to meet the annual electricity requirements of the PHEV, the savings come from the fact that there is a price differential between the value of on-peak electricity (when PV produces the most electricity) and off-peak electricity (when the PHEV is charged). It is generally true throughout the U.S. that there is a differential between the value of on-peak and off-peak generation.[34] The exact differential

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[32] A discussion of this idea can be found at http://www.teslamotors.com/blog4/?p=62.

[33] The load profile analysis was performed using QuickQuotes (http://www.solarquickquotes.com).

[34] The on-peak period for this rate structure is weekdays 10 AM to 8 PM and the off-peak period is all other hours

should be investigated by location in subsequent work (see Appendix B for some additional initial results for other utilities in NY).

Table 3. Annual electric bill.[35]

	Summer		Winter		Bill	
	On-Peak	Off-Peak	On-Peak	Off-Peak	Total	Change
Electricity Price ($/kWh)	$0.38	$0.16	$0.19	$0.14		
Plug-in Charging (kWh)	0	600	0	1200		
PV Output (kWh)	443	283	638	436		
Base Consumption	790 kWh	1,622 kWh	1,429 kWh	2,979 kWh	$1,258	$0
Consumption w/ plug-in	790 kWh	2,222 kWh	1,429 kWh	4,179 kWh	$1,527	$268
Consumption w/ SSV	347 kWh	1,939 kWh	791 kWh	3,743 kWh	$1,130	($129)

Table 4 presents the total incentives that are available for a 1.52 kW_{DC} PV system. The PV incentives equal $9,404 in this particular case study.

Table 4. PV Incentives.

PV Incentives	
NYSERDA Incentive	$6,088
Federal Tax Credit	$2,055
NY State Tax Credit	$1,712
Taxes on State Tax Credit	($451)
Total	$9,404

Results

The results of the analysis are summarized in Table 5. The final row in the table is expressed as a monthly cost of ownership including both loan payment and fuel cost.

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[35] The utility bill analysis was partially performed using QuickQuotes (http://www.solarquickquotes.com).

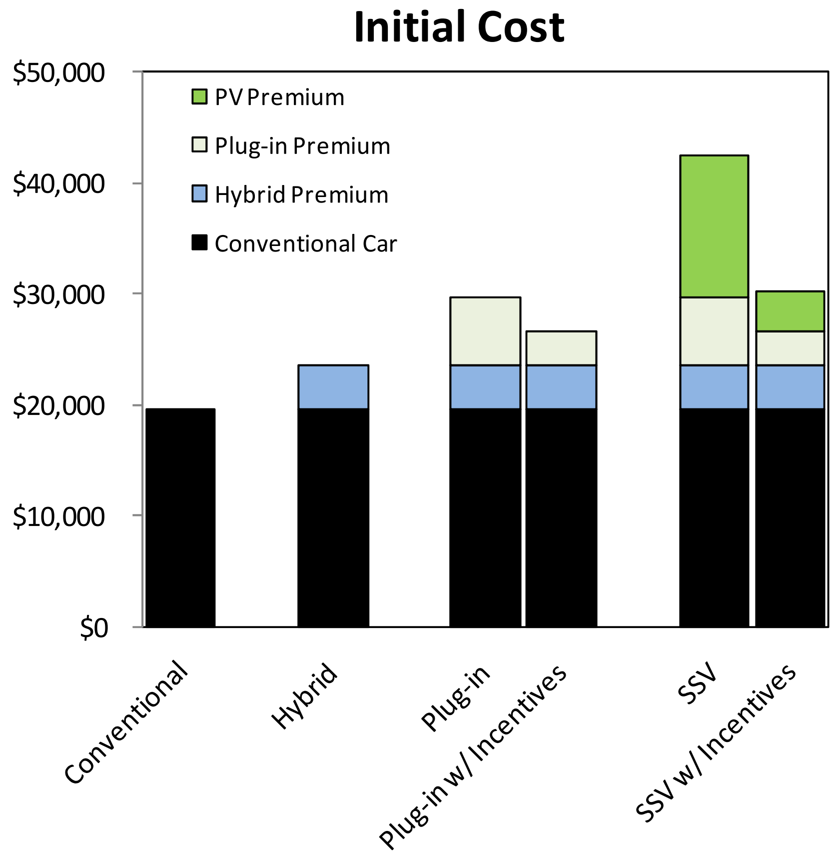
Table 5. Monthly cost of ownership.

	Conventional	Hybrid	Plug-in	SSV
Fuel Cost				
Miles Per Year	12,000	12,000	12,000	12,000
Miles per Gallon	24	44	44	44
Percent of Miles from Gasoline	100%	100%	25%	25%
Percent of Miles from Electricity	0%	0%	75%	75%
Annual Gasoline Consumption (gallons)	500	273	68	68
Annual Electricity Consumption (kWh)	0	0	1,800	0
Annual Gasoline Cost	$2,000	$1,091	$273	$273
Annual Electricity Cost	$0	$0	$268	($129)
Total Annual Fuel Cost	$2,000	$1,091	$541	$144
Monthly Fuel Cost	$167	$91	$45	$12
Capital Cost				
Conventional Car	$19,674	$19,674	$19,674	$19,674
Hybrid Premium	$0	$3,921	$3,921	$3,921
Plug-in Premium	$0	$0	$6,000	$6,000
PV Premium	$0	$0	$0	$12,938
Total Cost	$19,674	$23,595	$29,595	$42,533
Incentives				
Plug-in	$0	$0	$3,000	$3,000
PV	$0	$0	$0	$9,404
Total Incentives	$0	$0	$3,000	$12,404
Capital Cost After Incentives				
Conventional Car	$19,674	$19,674	$19,674	$19,674
Hybrid Premium	$0	$3,921	$3,921	$3,921
Plug-in Premium	$0	$0	$3,000	$3,000
PV Premium	$0	$0	$0	$3,533
Total Cost	$19,674	$23,595	$26,595	$30,128
Monthly Loan Payment	$285	$342	$385	$437
Monthly Cost of Ownership (Loan + Fuel)	**$452**	**$433**	**$430**	**$449**

Capital Cost Protection

Figure 3 presents the initial capital cost of the four alternatives both with and without incentives. The costs for the conventional car, hybrid premium, and PV premium are based on published data for actual cars and systems. The plug-in hybrid cost premium is estimated and it is assumed that an incentive will be available for the plug-in portion of the SSV. The figure illustrates how the availability of incentives provides protection for consumers who are concerned about paying too much for newer technologies with the expectation that prices will decline in the future.

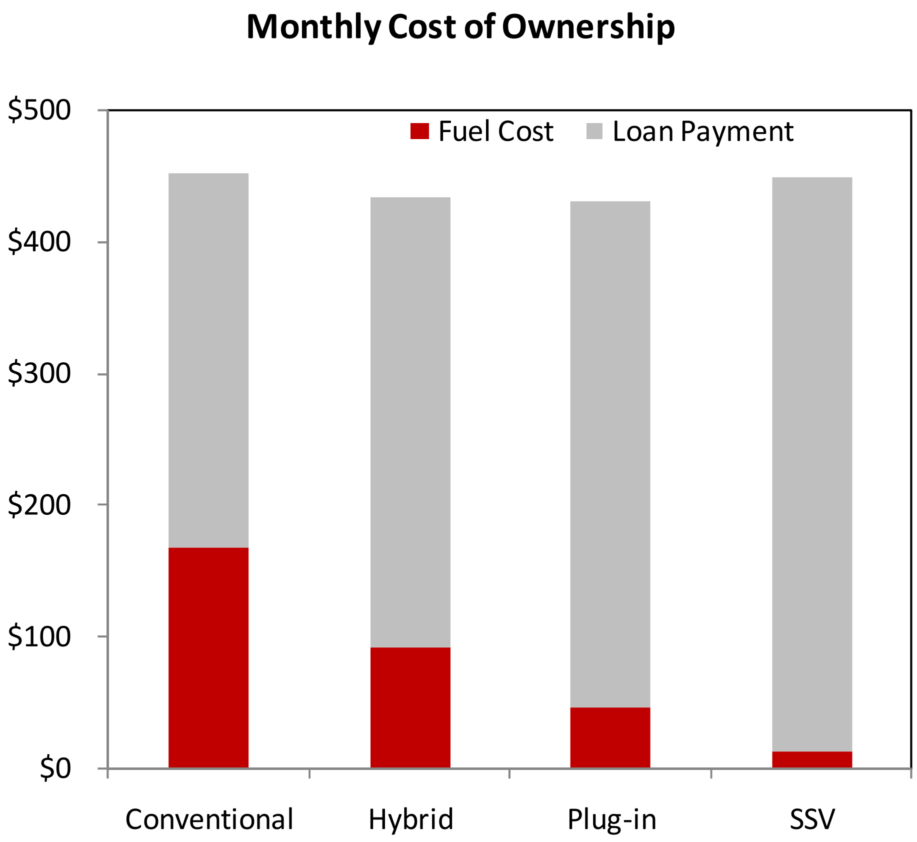
Figure 3. Initial capital costs for the various alternatives.



Near-Term Financial Protection

As illustrated in Figure 3, the initial SSV cost after incentives is about 50 percent higher than a conventional vehicle. The critical item of concern to most consumers, however, is the monthly cost of ownership (i.e., the cost of both loan payments and fuel costs). As illustrated in Figure 4, the monthly cost of ownership is similar for all alternatives when the package is financed using a 7-year, 5.75 percent auto loan.[36]

Figure 4. The monthly cost of ownership for all alternatives is similar.



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[36] This cost of ownership does not account for any repair costs. The repair costs for plug-ins are likely to be lower than the repair costs for conventional vehicles.

Long-Term Financial Protection

A key benefit that SSVs provide over plug-ins is the long-term financial protection from the effects of both gasoline and electricity price increases. A consumer only needs to purchase the PV system for the first plug-in; the PV system will outlast the life of the plug-in vehicle. In fact, if the PV system lasts 30 years and the average vehicle lasts 7 years, the PV system will still be operating after the consumer has purchased their 5th plug-in. That is, the consumer only needs to purchase one PV system to provide all the electricity needed by more than 4 vehicles over the course of 30 years.[37]

One of the costs that consumers are concerned with is the potential future fuel cost to operate a vehicle. Over the next 30 years, fuel efficiency and fuel prices are likely to change. Assume that the general industry trend is that mileage will increase by 2 percent per year for internal combustion engines and that the electricity consumption will decrease by 1 percent per year for electric vehicles. The mileage and efficiency of subsequently purchased vehicles by this particular consumer are presented in Figure 5.

There are several things to note in the figure. First, the figure is a step function. This is because a particular consumer will only realize general industry efficiency gains when they subsequently purchase new plug-in vehicles. Second, the figure on the left is increasing while the figure on the right is decreasing. Both sides of the figure, however, communicate the same message: vehicles are getting more efficient over time. The difference is that "miles" is in the numerator on the left side of the figure while "miles" is in the denominator on the right side of the figure. U.S. consumers typically think in terms of miles per gallon (a number that needs to be inverted to convert to efficiency) while the electrical vehicle world communicates in kWh per mile.

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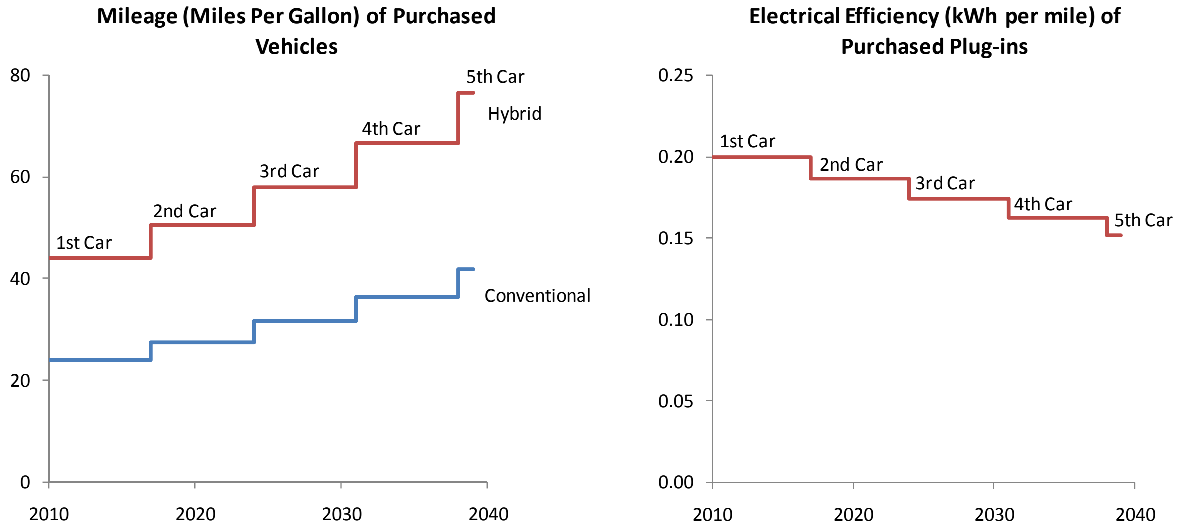
[37] It is assumed that through incentives and rising public adoption, the capital premium will decline for plug-ins relative to conventional vehicles such that at some point, incentives for the plug-in portion of the purchase are no longer required. This is, of course, the purpose of the incentives, to be a temporary bridge. Likewise, since the capital costs decline, the incentives decline. This 30-year window presumes that the incentives are ultimately negligible (or that technology costs will drop below conventional costs so that it is a wash).

Figure 5. Gasoline mileage and electrical efficiency of purchased vehicles.



Offsetting the benefit of technological improvements, however, are probable gasoline and electricity price increases. Figure 6 presents the average annual historical retail gasoline prices since 1970. It then projects what future fuel prices will be if they increase at: (1) a moderate rate of 3.5 percent per year[38] or (2) a high rate of 7.0 percent per year.

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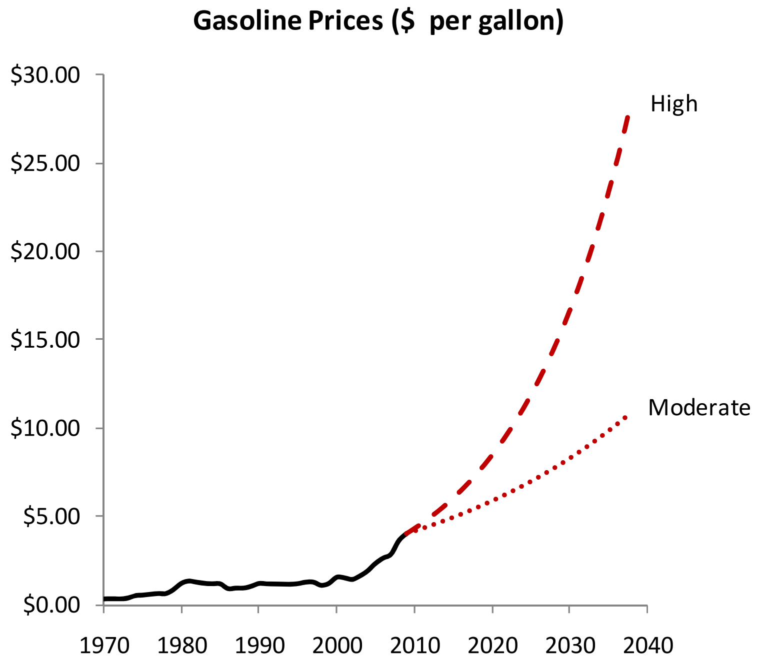
[38] According to the U. S. Inflation Calculator (http://www.usinflationcalculator.com/), the rate of inflation change from 1960 to 2007 was 600%. Let i be the annual inflation rate. This implies that $(1+i)^{47} = 6.0$. This is true when i = 3.89%

Figure 6. Historical and future gasoline prices.



In addition, electricity rates are likely to increase. Assume that electricity rates increase at a rate of either 3.5 percent or 7.0 percent per year. Table 6 and Table 7 repeat the electric bill analysis presented in Table 3 with the increased rates and reduced plug-in charging requirements for subsequent vehicles.

Table 6. Electricity bill analysis after 30 years with annual 3.5% electricity price increases.

	Summer		Winter		Bill	
	On-Peak	Off-Peak	On-Peak	Off-Peak	Total	Change
Electricity Price ($/kWh)	$1.03	$0.43	$0.52	$0.39		
Plug-in Charging (kWh)	0	450	0	899		
PV Output (kWh)	443	283	638	436		
Base Consumption	790 kWh	1,622 kWh	1,429 kWh	2,979 kWh	$3,413	$0
Consumption w/ plug-in	790 kWh	2,071 kWh	1,429 kWh	3,879 kWh	$3,958	$545
Consumption w/ SSV	347 kWh	1,788 kWh	791 kWh	3443 kWh	$2,881	($531)

Table 7. Electricity bill analysis after 30 years with annual 7.0% electricity price increases.

	Summer		Winter		Bill	
	On-Peak	Off-Peak	On-Peak	Off-Peak	Total	Change
Electricity Price ($/kWh)	$2.69	$1.13	$1.35	$1.03		
Plug-in Charging (kWh)	0	450	0	899		
PV Output (kWh)	443	283	638	436		
Base Consumption	790 kWh	1,622 kWh	1,429 kWh	2,979 kWh	$8,952	$0
Consumption w/ Plug-in	790 kWh	2,071 kWh	1,429 kWh	3,879 kWh	$10,383	$1,431
Consumption w/ SSV	347 kWh	1,788 kWh	791	3,443 kWh	$7,558	($1,394)

Table 8 summarizes the gasoline and electric fuel costs.

Table 8. Scenario data (nominal results for 30 years in the future).

	Conventional	Hybrid	Plug-in	SSV
Inputs				
Miles per Gallon	43	78	78	78
Percent of Miles from Gasoline	100%	100%	25%	25%
Annual Gasoline Consumption (gallons)	282	154	38	38
Annual Cost w/ 3.5% Gasoline Price Increase	$3,054	$1,666	$416	$416
Annual Cost w/ 7% Gasoline Price Increase	$8,012	$4,370	$1,093	$1,093
Annual Cost w/ 3.5% Electricity Price Increase	$0	$0	$545	($531)
Annual Cost w/ 7% Electricity Price Increase	$0	$0	$1,431	($1,394)

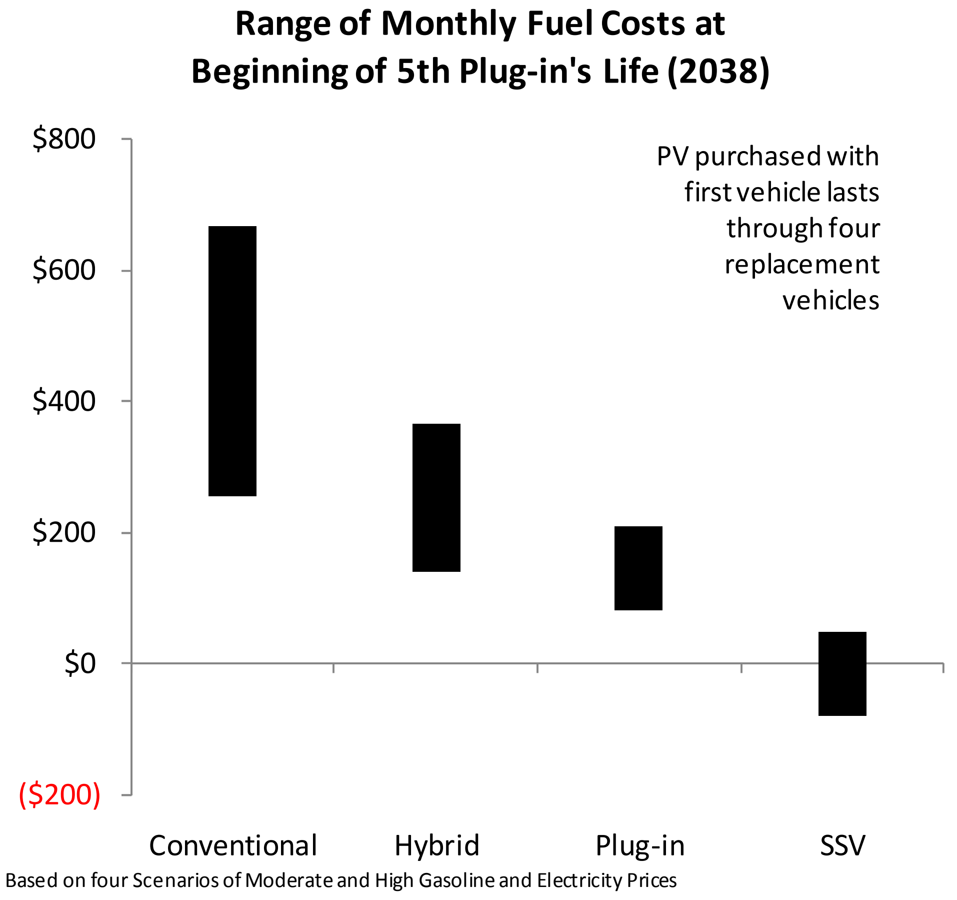
In order to create a set of scenarios, both gasoline and electricity costs need to be combined. Table 9 presents four scenarios (since there are two gasoline and two electricity price scenarios) and Figure 7 summarizes the results graphically. The SSV is clearly superior to the other alternatives under all scenarios. In fact, in three of the four scenarios, the customer will be saving money in 30 years. And in the worst case scenario, the customer will pay a total of less than $50 per month in fuel costs. This compares to a high of almost $700 per month for a conventional vehicle.

Clearly, SSVs provide an exceptional level of future fuel cost protection.

Table 9. Future monthly fuel costs after 30 years.

	Conventional	Hybrid	Plug-in Hybrid	PV Plug-in Hybrid
Scenarios				
7% Gasoline, 7% Electric Price Increase	$668	$364	$210	($25)
7% Gasoline, 3.5% Electric Price Increase	$668	$364	$136	$47
3.5% Gasoline, 3.5% Electric Price Increase	$255	$139	$80	($10)
3.5% Gasoline, 7% Electric Price Increase	$255	$139	$154	($81)

Figure 7. SSVs provide best long-term fuel cost protection under all scenarios.



Environmental Protection

In addition to having very different levels of fuel cost protection, the alternatives also have very different levels of CO_2 emissions.[39] Table 10 and Figure 8 present the annual CO_2 emissions associated with each of the alternatives. The SSV has the lowest CO_2 emissions of all alternatives. A conventional vehicle has seven times as many CO_2 emissions as an SSV.

Note that the state of New York has a relatively clean electrical generation system when compared to certain other parts of the U.S. Emission results will be different for other parts of the country. Furthermore, the emission reductions with SSVs will be even greater if the PV-produced electricity reduces natural gas consumption (because of the daytime production) and increases wind-production (because of the night time off-peak charging).

Table 10. Annual lbs of CO_2 emissions for the four alternatives.

	Conventional	Hybrid	Plug-in	SSV
Annual lbs of CO_2 Emissions				
Gasoline	9,700	5,291	1,323	1,323
Electric	0	0	1,633	0
Total Emissions	**9,700**	**5,291**	**2,955**	**1,323**

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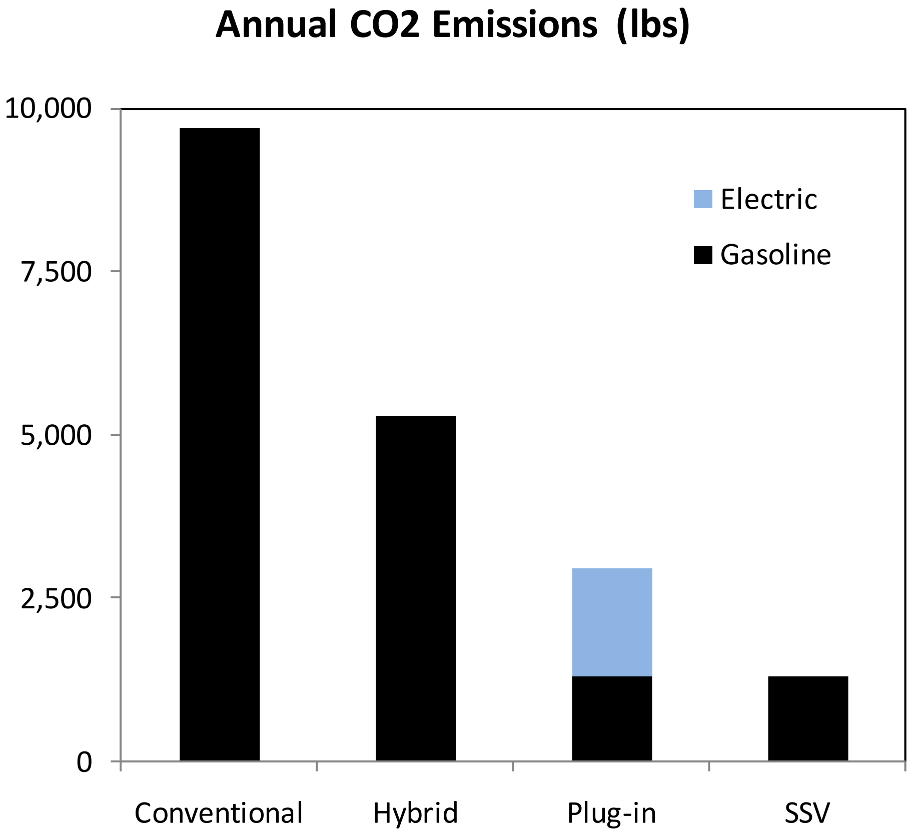
[39] A greenhouse gas tax would tilt the results even more in favor of the SSV since cost per mile for conventional vehicles would go up. For that matter, the cap and trade system and tighter RPS standards would also cause electricity prices to rise, and the SSV would therefore be further distinguished from plug-ins alone.

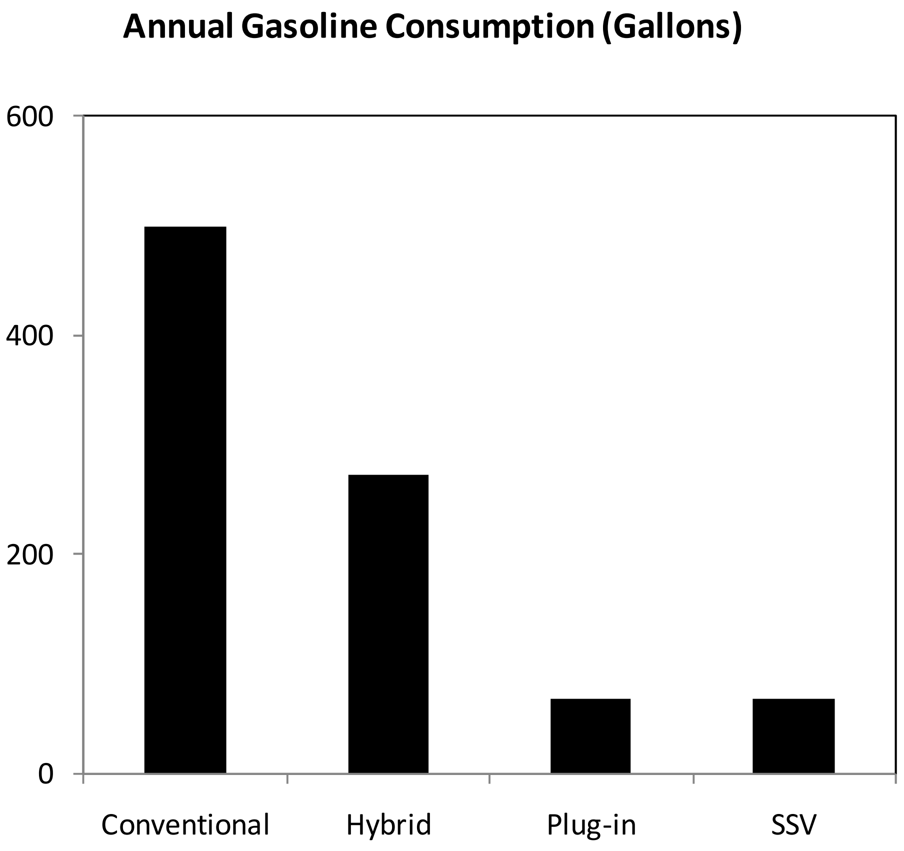
Figure 8. SSVs cut CO_2 emissions by an order of magnitude.



National Security Protection

Many citizens are concerned about the U.S.' reliance on oil, particularly foreign oil, yet feel that they can do very little about it. Both SSVs and plug-ins enable the American people to reduce the U.S.' dependence on oil. As illustrated in Figure 9, a conventional vehicle uses seven times as much gasoline as an SSV or plug-in.

Figure 9. SSVs and plug-ins greatly reduce gasoline consumption.

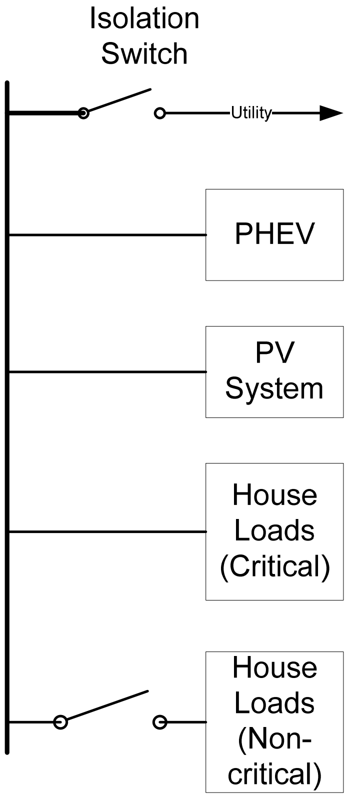


Electric Utility Outage Protection

Properly configured SSVs would provide protection to consumers in the case of electrical utility outages. This includes short-duration outages caused by local distribution issues or longer-term outages caused by natural or other disasters.

Figure 10 illustrates how an SSV could be configured to provide power to a dwelling's critical loads during an outage condition. While this may require a different set of connection regulations than are currently in place today, the PV system could be designed to operate such that it provides power to the home (or isolated, critical load circuits) during an outage condition and then uses excess power to charge the plug-in. The plug-in could provide power to critical loads when the PV is unavailable. It is feasible that a customer could operate for a long period of time under such a scenario.

Figure 10. SSVs could power critical loads during an outage condition.



Conclusions

This paper evaluated Solar Sustained Vehicles (SSV) from a consumer's perspective. An SSV is a vehicle that is either partially or fully powered by electricity (as in plug-in hybrid electric and electric vehicles, respectively) that is bundled with a photovoltaic (PV) system to offset its electricity consumption.

A case study was constructed for a typical consumer in the state of New York. Results indicate that SSVs could be very beneficial to consumers in a variety of ways.

- Agency, state and federal incentives can offset the higher initial capital cost
- The monthly cost of ownership can be comparable to the cost of ownership of a conventional vehicle
- SSVs provide an exceptional level of fuel cost protection
    - Under most scenarios, consumers would experience fuel cost reductions for the next 30 years (and possibly eventually earn money)
    - Even a pessimistic scenario has consumers paying less than $50 per month in fuel costs 30 years from now
- The PV portion of the SSV only needs to be purchased once and then the electricity is free for all subsequently purchased plug-in vehicles for the next 30 years
- Consumers can lead the way for the U.S. to eliminate its dependence on oil because SSVs under this case study consume one-seventh the amount of gasoline of a conventional vehicle
- Consumers can lead the fight to reduce global warming because SSVs under this case study produce one-seventh the amount of CO_2 emissions of a conventional vehicle

The conclusion is that consumers can protect their own economic interests while simultaneously leading the U.S. to reduce its dependence on oil and address the issue of global warming through the purchase of an SSV.

The paper is the first in a series of papers that quantifies the benefits of SSVs. Additional perspectives will be addressed in subsequent papers including those of utilities, industry, and state and federal government.

Appendix A: Efficiency of Electric Motors in Vehicles

This appendix describes the efficiency of electric vehicles relative to vehicles powered by internal combustion engines.

Fuel consumption for U.S. cars is expressed in terms of miles per gallon while electric energy is commonly expressed in terms of kWh. Since a U.S. gallon of gas contains about 36.6 kWh of energy,[40] miles per gallon can be converted to miles per kWh by dividing by 36.6 kWh per gallon. According to Wikipedia, most internal combustion engines "retain an *average* efficiency of about 18%-20%".[41] A report by MIT lists efficiency as 16% for a particular vehicle.[42]

For example, the fuel consumption for the average U.S. passenger car was 22.4 miles per gallon in 2006.[43] This converts to a fuel efficiency for the average U.S. passenger car of 1.63 kWh per mile.

$$\frac{1\ gallon}{22.4\ miles} x \frac{36.6\ kWh}{1\ gallon} = 1.63\ kWh\ per\ mile$$

Figure 11 and Table 11 present test electrical efficiency data from the Idaho National Laboratory[44] for actual gas (or hybrid) vehicles that were converted to electric vehicles (or plug-in hybrid electric vehicles) and gasoline mileage data from the Consumer Reports website for comparable used cars.[45] The U.S. average car efficiency and the CAFE standard are presented for reference purposes.[46] According to these data, plug-in hybrid electric vehicles use about 25 percent of the amount of energy as comparable gas-powered vehicles.[47]

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[40] http://en.wikipedia.org/wiki/Gasoline.

[41] http://en.wikipedia.org/wiki/Internal_combustion_engine.

[42] Anup Bandivadekar, et. al., "ON THE ROAD IN 2035: REDUCING TRANSPORTATION'S PETROLEUM CONSUMPTION AND GHG EMISSIONS", MIT Laboratory for Energy and the Environment, Cambridge, Massachusetts, Report No. LFEE 2008-05 RP, July 2008, page 23.

[43] http://www.bts.gov/publications/national_transportation_statistics/html/table_04_23.html.

[44] Electric vehicle test results from Idaho National Laboratory, http://avt.inel.gov/fsev.shtml.

[45] Use car data from Consumer Reports, http://www.consumerreports.org.

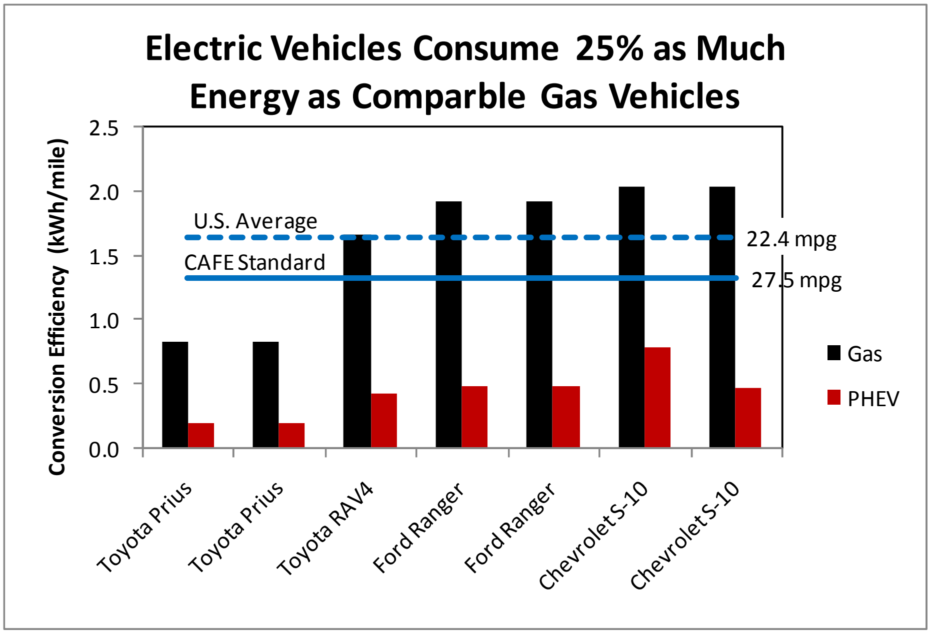
[46] The Corporate Average Fuel Efficiency Standard (CAFE) is currently 27.5 miles per gallon http://en.wikipedia.org/wiki/Corporate_Average_Fuel_Economy.

[47] This is consistent with other information, such as that presented by Sherry Boschert, *Plug-in Hybrids: The Cars That Will Recharge America*, page 36.

Table 11. Data from Idaho National Laboratory and Consumer Reports.

Plug-in Hybrid Electric Vehicle (PHEV)	kWh Per Mile[44, 48]	Gas Vehicle	MPG	Equivalent kWh Per Mile[45]	PHEV Energy Use Compared to Gas
2007 Hymotion PHEV Prius Conversion	0.20	2004 Prius	44	0.83	**24%**
2006 EnergyCS PHEV Prius Conversion	0.20	2004 Prius	44	0.83	**24%**
1998 Toyota RAV4 with NiMH Batteries	0.43	2001 Toyota RAV4	22	1.66	**26%**
1999 Ford Ranger with NiMH Batteries	0.49	1998 Ford Ranger	19	1.93	**25%**
1997 Ford Ranger EV with PbA Batteries	0.48	1998 Ford Ranger	19	1.93	**25%**
1998 Chevrolet S-10 with NiMH Batteries	0.79	1998 Chevrolet S-10	18	2.03	**39%**
1997 Chevrolet S-10 with PbA Batteries	0.47	1998 Chevrolet S-10	18	2.03	**23%**

Figure 11. Plug-ins offer large potential energy savings over internal combustion engine powered vehicles.



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[48] The 0.20 kWh per mile figure is consistent with what one web site has reported for the Chevy Volt. The site estimates that the car will use 8 kWh of electricity to travel 40 miles. http://gm-volt.com/chevy-volt-reasons-for-use-and-cost-of-operation/.

Appendix B: Analysis of Additional Time-of-Use Rate Structures

An analysis was performed for additional residential time-of-Use (TOU) rate structures for other parts of the state of New York to calculate the annual electric bill savings with an SSV. The utilities that were examined including:

- Long Island Power Authority (LIPA)
- Central Hudson Gas and Electric
- New York State Electric and Gas (NYSEG)
- Orange and Rocklin
- Rochester Gas and Electric (RG&E)

The results are presented in Figure 12. Results indicate that each of the rate structures results in a savings for customers due to the difference between the value of energy during on-peak and off-peak periods. In addition, several utilities have TOU rate structures that result in initial annual savings of around $100 per year.

Figure 12. Time-of-use rate analysis with SSV.