Seeing past the hype: why Natural Gas Vehicles (NGVs) may be more cost effective than Electric Vehicles (EVs) for fighting climate change

Prepared by A.J. Goulding, Yifei Zhang, and Van Hoang

February 18th, 2011

In the United States, approximately 34% of greenhouse gas emissions are derived from the transportation sector.[1] Such emissions could be reduced if Electric Vehicles ("EVs") and Natural Gas Vehicles ("NGVs") were used to replace Conventional Vehicles ("CVs"). EVs have zero emissions on the road but may indirectly cause emissions from fossil-fueled power plants. NGVs also have lower greenhouse gas emissions relative to CVs. Because the incremental cost of owning an EV exceeds that of owning an NGV, NGVs are in fact under many scenarios presently more cost effective at reducing greenhouse gases compared to EVs, even though EVs may produce fewer emissions overall. The advantage of NGVs becomes more significant in regions with intensive coal generation or considerably lower natural gas prices. Our analysis shows that unless the purchase price of EVs can be reduced significantly in the short to medium term, it is likely that NGVs will remain a more cost effective choice in reducing greenhouse gas emissions.

Table of contents

Table of figures

[1] EIA. < http://www.eia.gov/energyexplained/index.cfm?page=environment_where_ghg_come_from >. As of 2009.

1 Introduction and key findings

Although transportation is a major contributor to greenhouse gas emissions, policymakers have yet to focus directly on the most cost-effective means of reducing the impact of the sector on global warming. Conventional Vehicles ("CVs") produce greenhouse gases from the fuel – gasoline – that they burn. While Electric Vehicles ("EVs") are one highly publicized solution, EVs on a life cycle basis are not in fact zero-emitting. While having zero emissions on the road, EVs may indirectly contribute to greenhouse gas emissions, because the electricity used by EVs may be generated by CO_2 emitting coal plants in some regions. Like EVs, Natural Gas Vehicles ("NGVs") also produce fewer carbon emissions than CVs, due to the cleaner fuel they use. Although both EVs and NGVs produce fewer carbon emissions than CVs, NGVs are more cost effective than EVs in some regions at reducing emissions because their retail cost is significantly lower, despite individually being more CO_2 intensive.

In this paper, we analyze the incremental costs of owning an EV and an NGV and the corresponding environmental benefits compared to a CV. The analysis is performed on a national level as well as for selected states. Policy implications are then analyzed based on several possible future scenarios.

The key findings of our analysis are:

- ***On a national level, NGVs appear more cost effective at reducing carbon emissions, compared to EVs;***

- ***On a regional level, the cost effectiveness of NGVs is highest in states such as Illinois which rely heavily on coal generation as well as having low residential natural gas prices;***

- ***In states like Florida where residential natural gas prices are much higher than the national average, the cost advantage of NGVs is less;***

- ***The relative cost effectiveness of NGVs decreases as the incremental retail cost of EVs declines;***

- ***It is likely that NGVs will continue to be more cost effective in the short to medium term, given that the retail prices of EVs are expected to remain high for a long period of time;***

- ***The cost of a subsidy program designed to reduce CO_2 emissions from transportation by 20% would be $61 billion if targeted towards NGVs, but would rise to $181 billion if targeted to EVs exclusively, assuming the subsidy was designed to reduce the lifecycle cost of the vehicle to equal those of a CV; and***

- ***The shift to lower emitting transportation fuels may have an adverse effect on state and federal funding for highways, as combined state and federal lost tax revenues due to reductions in gasoline sales could be between $9 and $20 billion.***

As of 2007, according to the International Association of Natural Gas Vehicles, there were approximately 110,000 NGVs on the road in the US.[2] The number of EVs is significantly lower, at about 11,000.[3] To reduce passenger car greenhouse gas emissions by 20%, over 45 million EVs or more than 97 million NGVs would be required to replace an equivalent number of CVs.[4] In 2008, over 250 million vehicles were registered in the US, according to the Bureau of Transportation Statistics. Overall, the research suggests that, depending on the region, a portfolio of incentives targeting NGVs may be most cost effective overall.

To reach the above conclusions, we needed to answer the following questions:

- ✓ How do the life cycle costs of owning and operating CVs, NGVs, and EVs compare to one another?
- ✓ What is the reduction in carbon dioxide emissions achieved by an NGV or an EV when the emissions from electricity generation are taken into account?
- ✓ How do the incremental costs of NGVs and EVs compare when examined on a dollars-per-ton of avoided carbon dioxide emissions basis?

We explore these questions, and the underlying required assumptions, in the following sections. Our responses are based on an integrated cost-benefit analysis model using up to date, publicly available information from a range of credible sources.

2 Costs of owning an EV vs. an NGV

Examining the full cost of automobile ownership requires an understanding of several variables, including the cost of the vehicle, the number of miles it is expected to travel annually, fuel efficiency, and maintenance. Fuel costs vary by location; in this paper, we examine these based both on national and regional averages. Some ownership costs, such as insurance, are assumed to be similar across all three vehicle types, and thus are ignored.

For comparison purposes, we have chosen three models: the Honda 2011 Civic LX-S (CV), the Chevy 2011 Volt (EV), and Honda 2011 Civic GX (NGV).[5] At present, the Honda Civic GX is the

---

[2] International Association of Natural Gas Vehicles. <http://www.iangv.org/tools-resources/statistics.html>. More recent estimates suggest that the number of NGVs has grown to 130,000. See, for example, "Macro Analysts Begin Eyeing Natural Gas Vehicles." *Natural Gas Week* (5 Jul 2010): 12.

[3] According to estimates from EV World & Associates, LLC.

[4] We recognize that replacing such a large number of CVs with NGVs is unlikely over the near term; however, a concerted effort to replace a significant number of CVs with a mix of NGVs and EVs would nonetheless have a meaningful impact on greenhouse gas emissions.

[5] According to the EIA *Annual Energy Outlook 2009* (AEO 2009), the Honda Civic GX and Civic LX-S provide a uniform basis for comparison. Since the Chevy Volt is also a compact sedan, it provides a reasonable basis to compare with the Civic LX-S and Civic GX. Note, however, that the cost associated with loss of amenities such as cargo space due to the size of the NGV fuel tanks is not considered in this analysis.

only natural gas vehicle built by a major automaker in the US.[6] The Chevrolet Volt, which was launched in late 2010, is a Plug-in Hybrid Electric Vehicle ("PHEV") with zero emissions when runs in the electric mode.

Purchasing prices for CVs, EVs, and NGVs vary significantly. The 2011 Civic LX-S has a starting Manufacturer's Suggested Retail Price ("MSRP") of $19,155 according to Honda, while the MSRP of the Civic GX starts at $25,490.[7] The MSRP for Chevy 2011 Volt is $40,280, before the $7,500 federal tax savings.[8] Ownership cost is calculated as the annual loan payment assuming a 0% down payment and a 6.19%[9] interest rate with a 5-year term.

Figure 1. Comparison of annual operating cost, 2011

	CV		EV		NGV		
Operating cost							
Annual vehicle miles	12,165	miles	12,165	miles	12,165	miles	a
Fuel efficiency	29	miles/gallon	2.8	miles/kWh	247	miles/MMBtu	b
Fuel cost	$2.89	/gallon	$0.11	/kWh	$10.57	/MMBtu	c
Annual fuel cost	$1,213		$490		$521		d=(a/b)*c
Tire cost	0.65	cents/mile	0.65	cents/mile	0.65	cents/mile	e
Annual tire cost	$79		$79		$79		f=a*e/100
Maintenance cost	4.21	cents/mile	2.27	cents/mile	2.95	cents/mile	g
Annual maintenance cost	$512		$277		$359		h=a*g/100
Annual operating cost	$1,805		$845		$959		i=d+f+h

The annual cost of owning a vehicle includes the operating/running cost and ownership cost. Operating cost includes fuel cost, annual tire cost, and maintenance cost (see Figure 1). According to the Bureau of Transportation Statistics, each motor vehicle traveled 12,165 miles per annum on average from 2004 to 2008.[10] As shown in Figure 1, the Civic LX-S has a fuel efficiency of 29 Miles per Gallon ("MPG").[11] The Chevy Volt has a fuel efficiency of 93 MPG

[6] Honda Press Release. "Honda Begins Production of Civic GX Natural Gas Vehicles." 13 May 2009.

[7] Honda. *Honda Cars.* <http://automobiles.honda.com/>.

[8] By comparison, the Nissan LEAF, a battery-powered electric automobile, has been available for sale in the US, Japan, and Europe since December 2010 with a MSRP of $32,780 (excluding federal tax incentives) in the US. Leaf also has a slightly higher fuel economy of 99 MPG than Volt. In contrast to the Volt, which includes a gasoline engine to extend its range, the Leaf will be all electric and only has a range of 73 miles. Therefore, Leaf may not be a sufficient substitute for conventional vehicles. (Nissan. <http://www.nissanusa.com/leaf-electric-car/index#/leaf-electric-car/>).

[9] National 60-month auto loan averages for new cars from bankrates.com's latest weekly national survey of large banks and thrifts conducted 10 February 2011 (Bankrate. <http://www.bankrate.com/finance/auto/national-auto-loan-rates-for-feb-10-2011.aspx>).

[10] Bureau of Transportation Statistics, State Transportation Statistics. <http://www.bts.gov/publications/state_transportation_statistics/>.

[11] Honda. *2011 Honda Civic Sedan.* <http://automobiles.honda.com/civic-sedan/specifications.aspx>.

equivalent, which is equivalent to 2.8 miles per kWh, under the all-electric mode.[12] The Civic GX has an average fuel efficiency of 28 Gasoline Gallon Equivalent ("GGE") MPG, which is equivalent to 247 miles/MMBtu of natural gas.[13]

The 2009 average retail gasoline, residential electricity, and natural gas costs in the US are published by the Energy Information Administration ("EIA").[14] These prices are then extrapolated to the forecasted 2011 level using the EIA forecasted growth rate of retail gasoline, residential electricity and natural gas prices in its Annual Energy Outlook 2011 Early Release.[15]

Figure 2. Comparison of annual ownership cost, 2011

	CV	EV	NGV	
Ownership cost				
Price	$19,155	$40,280	$25,490	a
Loan term (years)	5	5	5	b
Loan rate (%)	6.19%	6.19%	6.19%	c
Annual ownership cost	$4,464	$9,387	$5,941	d=-PMT(c/12,60,a)*12
Annual operating cost	$1,805	$845	$959	e (from Fig.1 i)
Total annual cost	$6,269	$10,233	$6,899	f=d+e
Incremental cost		$3,964	$630	g=d(EV)-d(CV) or d(NGV)-d(CV)

The annual maintenance cost for a small conventional sedan is about 4.21 cents per mile.[16] Maintenance costs for EVs are generally considered to be less than those for CVs, because there are fewer moving and wearable parts to replace, such as fan belts, spark plugs, radiator hoses, muffler and radiators. NGVs have lower maintenance costs than CVs due to the cleaner fuel that is burned, which results in less wear and tear on the engine and extends the time between the scheduled maintenance. A 46% and a 30% maintenance savings are assumed for the EV and the NGV, respectively.[17] Annual tire cost is assumed the same for the three types of cars at 0.65

---

12 Chevrolet. <http://www.chevrolet.com/volt/>. The 93 MPG equivalent was assigned to Volt by the US Environmental Protection Agency ("EPA") in late 2010 and is significantly lower than the 230 MPG announced by GM in 2009.

13 Honda. *2011 Honda Civic GX Overview.* <http://automobiles.honda.com/civic-gx/>. Based on a heat content of 113,500 Btu/gallon for gasoline (average of summer and winter). (EPA. "Fuel Economy Impact Analysis of RFG." <http://www.epa.gov/oms/rfgecon.htm>).

14 2009 is the most recent year where price information for the entire year is available. 2010 price information will be released by the EIA by April 2011.

15 EIA. *2011 Annual Energy Outlook Early Release.* 16 December 2010.

16 AAA. "Your Driving Costs." 2010 Edition. Page 6.

17 A study conducted by the EPRI suggested that a compact Hybrid Electric Vehicle with 60 miles all-electric ranges ("HEV 60") has a maintenance cost that is 35% lower than that of a CV. Based on EPRI's calculation, we excluded the oil change costs estimated for the HEV 60 because an all-electric vehicle does not require oil changes, which results in 46% maintenance cost savings for an EV compared to a CV (EPRI. *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options for Compact Sedan and Sport Utility Vehicles)*. Palo Alto, CA: 2002. An NGV could save up to 40% of maintenance costs (Kansas Gas Service.

cents per mile.[18] The resulting annual operating costs in 2011 for CVs, EVs and NGVs are estimated to be $1,805, $845 and $959 respectively, assuming the fuel cost stays at the forecasted 2011 level.

As illustrated in Figure 2, the resulting annual ownership cost for the CV, EV, and NGV is $4,464, $9,387 and $5,941 respectively. The total annual cost, including operating and ownership costs, is $6,269, $10,233 and $6,899 respectively. The incremental cost of owning and operating an EV is much higher than that of an NGV.

3 Environmental benefits of owning an EV vs. an NGV

As mentioned in Section 1, both EVs and NGVs produce fewer Greenhouse Gas ("GHG") emissions compared to a CV. According to an analysis by the California Air Resources Board ("CARB"), burning Compressed Natural Gas ("CNG") produces about 68 grams of CO_2 equivalent emissions per mega joule ("MJ") burned (this includes all methane emissions), while gasoline and diesel fuel produce approximately 94 – 95 grams of CO_2 equivalent emissions per MJ.[19]

Figure 3. Cost to reduce GHG emissions, EV vs. NGV, 2011

	CV		EV		NGV		
GHG emissions							
Annual vehicle miles	12,165	miles	12,165	miles	12,165	miles	a
Fuel efficiency	29	miles/gallon	3	miles/kWh	247	miles/MMBtu	b
GHG emissions	94.5	grams/MJ	483	grams/kWh	68	grams/MJ	c
Conversion factor	121	MJ/gallon	n.a.		1,055	MJ/MMBtu	d
GHG emissions (grams/year)	4,796,692		2,115,302		3,537,903		e=(a/b)*(c*d)
GHG emissions (grams/ton)	907,185		907,185		907,185		f
GHG emissions (tons/year)	5.29		2.33		3.90		g=e/f
GHG reduction (tons/year)			2.96		1.39		h=g(CV)-g(EV) or g(CV)-g(NGV)
Cost to reduce GHG emissions ($/ton)			**$1,341**		**$454**		Fig 2. g/h

Although EVs do not produce GHG directly, emissions produced by power generation should be considered. The Electric Power Research Institute ("EPRI") conducted a study on the marginal CO_2 emissions produced by EVs in various regions in the US. Based on the overall US generation mix, EVs are expected to produce marginal CO_2 emissions of 483 grams per kWh in 2010.[20] As shown in Figure 3, compared to a CV, an EV could reduce GHG by 3 tons per year, while an NGV reduces GHG by about 1.4 tons per year.

<http://www.kansasgasservice.com/saveenergyandmoney/naturalgasvehicles.aspx>). For the sake of conservatism, we assumed a 30% maintenance savings.

[18] AAA. "Your Driving Costs." 2010 Edition. Page 6.

[19] Natural Gas Vehicles for America. "NGVs and the Environment." <http://www.ngvc.org/about_ngv/ngv_environ.html>.

[20] EPRI. *Plug-In Hybrid Electric Vehicle Environmental Analysis–Electric Sector Modeling of CO_2 Emissions*. Palo Alto, CA: 2006. This is not expected to change significantly in 2011. Although the EPRI study does not specify whether the marginal CO_2 emissions of EVs are fuel cycle emissions, it does compare such emissions to fuel

4 Incremental cost to reduce GHG

4.1 modeling results

Figure 4. Summary table, incremental cost to reduce GHG, EVs vs. NGVs, US

	CV		EV		NGV		
Operating cost							
Annual vehicle miles	12,165	miles	12,165	miles	12,165	miles	a
Fuel efficiency	29	miles/gallon	2.8	miles/kWh	247	miles/MMBtu	b
Fuel cost	$2.89	/gallon	$0.11	/kWh	$10.57	/MMBtu	c
Annual fuel cost	$1,213		$490		$521		d=(a/b)*c
Tire cost	0.65	cents/mile	0.65	cents/mile	0.65	cents/mile	e
Annual tire cost	$79		$79		$79		f=a*e/100
Maintenance cost	4.21	cents/mile	2.27	cents/mile	2.95	cents/mile	g
Annual maintenance cost	$512		$277		$359		h=a*g/100
Annual operating cost	$1,805		$845		$959		i=d+f+h
Ownership cost							
Price	$19,155		$40,280		$25,490		j
Loan term (years)	5		5		5		k
Loan rate (%)	6.19%		6.19%		6.19%		l
Annual ownership cost	$4,464		$9,387		$5,941		m=-PMT(l/12,60,j)*12
Annual operating cost	$1,805		$845		$959		i
Total annual cost	$6,269		$10,233		$6,899		n=m+i
Incremental cost			$3,964		$630		o=n(EV-CV) or n(NGV-CV)
GHG emissions							
Annual vehicle miles	12,165	miles	12,165	miles	12,165	miles	a
Fuel efficiency	29	miles/gallon	2.8	miles/kWh	247	miles/MMBtu	p
GHG emissions	94.5	grams/MJ	483	grams/kWh	68	grams/MJ	q
Conversion factor	121	MJ/gallon	n.a.		1,055	MJ/MMBtu	r
GHG emissions (grams/year)	4,796,692		2,115,302		3,537,903		s=(a/p)*(q*r)
Conversion factor (grams/ton)	907,185		907,185		907,185		t
GHG emissions (tons/year)	5.29		2.33		3.90		u=s/t
GHG reduction (tons/year)			2.96		1.39		v=u(CV-EV) or u(CV-NGV)
Cost to reduce GHG emission ($/ton)			**$1,341**		**$454**		w=o/u
					$887		

Although EVs may reduce emissions by a greater amount than NGVs relative to CVs, their greater cost means that the cost per ton of avoided emissions is also much higher. Figure 4 compiles the tables presented in the previous figures, and demonstrates the full cost benefit analysis and shows the incremental cost of using an EV versus an NGV to achieve the same amount of benefits. Although an EV could reduce GHG emissions by two times the amount that an NGV could, the incremental cost of owning and operating such a vehicle is seven times higher. The net result is that while more NGVs are required to achieve the same result as EVs, the total cost per ton is less than one third for NGVs relative to EVs.

The annual incremental cost of owning and operating an EV compared to a CV could reach $3,964, while that of an NGV is only about $630. Owners are paying $1,341 to reduce one ton of GHG emissions by owning an EV, while they are paying only $454 to reduce the same amount

cycle emissions of CVs. Therefore, we assume the 483 grams per kWh marginal CO_2 emissions are fuel cycle emissions. However, we exclude from consideration the environmental impact of recycling or disposing of the EV batteries.

contact:
A.J. Goulding/Yifei Zhang
617-494-8200
yifei@londoneconomics.com

of GHG by owning a NGV.[21] Based on this data, the cost advantage of an NGV is about $887 per ton.

4.2 other barriers and benefits

Two considerations affecting the respective benefits of NGVs and EVs are the availability of refueling stations and the potential for additional revenues from ancillary services markets.

Despite the apparent volumetric cost advantage of NGVs, the lack of an extensive natural gas refueling infrastructure may remain a hurdle. Consumers will not consider purchasing NGVs unless they can get refueling when and where they need it. Currently there are over 1,500 NGV fueling stations in the US, over half of which are available for public use.[22] In addition, BRC FuelMaker and IMPCO manufacture, distribute, install, and service their Vehicle Refueling Appliances (VRA) and Phill, the Home Refueling Appliance (HRA).[23] VRAs are designed mainly for commercial use while Phill appliances are smaller units designed for consumer use. Once installed, Phills allow consumers to fuel their NGVs indoors or outdoors from their own home. Only about 11,000 VRAs and 2,000 Phills have been sold worldwide.[24] The magnitude of the volumetric cost advantage of NGVs relative to EVs, however, would allow for significant investment in NGV infrastructure while still being more cost effective than EVs. Furthermore, the cost of modifications to garages and home electrical systems to accommodate EVs are often overlooked. In some cases, these modifications may be more costly than purchasing an HRA.[25]

---

[21] It is worth noting, however, that $950 per ton is a higher cost alternative for addressing greenhouse gas emissions than, for example, purchasing offsets, and remains well above projected emissions reduction credit prices under most proposed cap and trade programs in the US.

[22] Natural Gas Vehicles for America <http://www.ngvc.org/about_ngv/index.html>; see also: Woodyard, Chris. "Natural-gas powered cars: who even knows they exist?" *USA Today* (5 Jul 2007). <http://www.usatoday.com/money/autos/2007-05-08-natural-gas-usat_N.htm>. Approximately 10 million vehicles are part of a fleet in the US. Heavy vehicles in fleets account for about 7.7% of total VMT, and are an obvious target for NGV incentives. (US Department of Transportation Federal Highway Administration. "Highway Statistics 2007." Dec 2008. <http://www.fhwa.dot.gov/policyinformation/statistics/2007/vm1.cfm>).

[23] IMPCO Technologies. <http://www.impcotechnologies.com/fuelmaker.asp>.

[24] Presently, BRC FuelMaker manages the manufacturing and sales of VRAs and Phills outside of North America while IMPCO handles the distribution of these refueling units within North America. Each Phill unit costs about $4,000. (NGV Global. "BRC FuelMaker Integration Nears Twelve Month Milestone." 19 Apr 2010 <http://www.ngvglobal.com/brc-fuelmaker-integration-nears-twelve-month-milestone-0419> and Woodyard, Chris. "Natural-gas powered cars: who even knows they exist?" *USA Today* (5 Jul 2007). <http://www.usatoday.com/money/autos/2007-05-08-natural-gas-usat_N.htm>).

[25] Recent estimates of the cost of installing a home electric vehicle charging station range from $1,000 to $5,000. (Abuelsamid, Sam. "Another cost of going electric: installing home charging gear." *Autoblog Green*. 23 Mar 2010. <http://green.autoblog.com/2010/03/23/another-cost-of-going-electric-installing-home-charging-gear/>; Woodyard, Chris. "Obama stimulus to pay for 15,000 home electric-car charging units." *USA Today* (17 Jun 2010). <http://content.usatoday.com/communities/driveon/post/2010/06/obama-stimulus-to-pay-for-15000-home-electric-car-charging-units/1>; Randazzo, Ryan. "Massive stimulus grant boosts electric-car charging company, creates jobs." *The Arizona Republic* (14 May 2010).

EVs may be able to participate in organized markets and potentially earn additional revenues as price sensitive load or by providing ancillary services. Although there has been discussion regarding additional payments to EV owners for providing such services, our analysis excludes such payments from consideration. As discussed in a recently issued report[26], EVs have the potential to actively interact with the electricity grid through two mechanisms. The first is a one-way 'managed charging', also called dynamic pricing ("DP"). EV consumers will determine the charging time given hourly prices published by that ISO/RTO day-ahead or hour-ahead. DP will encourage EV charging during off-peak periods, during which electricity prices are relatively low. In this case, there is also the potential that EV charging load could be treated as price sensitive demand, with further payments for curtailment.

A second mechanism is called 'enhanced aggregation' ("EA"), by which EVs are capable to offer resources back to ISO/RTO markets, serving as a sort of 'mobile battery'. Two-way real time communication is needed to manage the interactions and EVs can be treated as ancillary market assets. The aggregators will monitor the EV load variations and optimize energy over a multi-hour period. In cases where the electricity grid is overloaded, EA can help ISO/RTOs to curtail some EV load, using price signals from the DP regime. This function is similar to demand response resources in some ISO/RTOs. In addition, EVs may be able to offer energy back to the grid during super-peak periods.

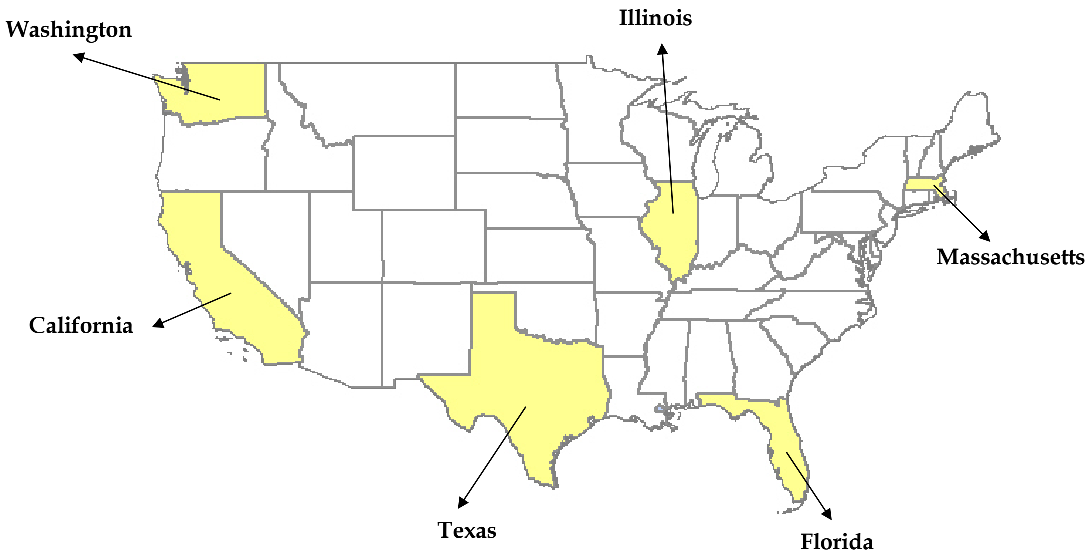
We are skeptical that systems will be in place over the near term to allow for such services to be provided by EVs, and for payments to be made for them, particularly in the period of the next decade. As such, we do not include offsetting payments to EV owners to reduce the net cost of the associated GHG emissions reductions.

<http://www.azcentral.com/arizonarepublic/business/articles/2010/05/14/20100514biz-ecars0514.html>; Clean Car Options. "EV Fuel Infrastructure Cost." 2010. <http://www.cleancaroptions.com/html/ev_fuel_infrastructure_cost.html>).

[26] For example, a March 2010 report commissioned by the IRC/RTO Council estimates that gross annual revenue for a 15 kW plug-in electric vehicle providing regulation service 80% of the time at an average payment of $40/MWh is $4,200. The $40/MWh price for regulation service is based on average regulation service price of $35-40/MWh in CAISO, ERCOT, ISO-NE, NYISO and PJM in 2006-2009 (KEMA. *Assessment of Plug-in Electric Vehicle Integration with ISO/RTO Systems.* March 2010). Similarly, AES, PJM, and the University of Delaware recently carried out a demonstration of vehicle-to-grid plug-in electric vehicles participating in the regulation market where it aggregated three 18 kW vehicles with a 1 MW stationary battery trailer. These vehicles were predicted to earn $7-10 over the 18-20 hours they were expected to be plugged in and contributing regulation service, which amounts to $2,500 to $3,500 per year (PJM Interconnection. Testimony of Kenneth Huber to the United States Senate Energy and Natural Resources Committee. 10 Dec 2009 <http://www.v2g-101.com/images/2009-12-10_S_Senate_testimony_Ken_Huber_-_PJM.pdf>). However, potential revenues from sales of ancillary services cannot be achieved without incurring the cost of the new infrastructure required to allow mobile source participation in ancillary service markets. In addition, such studies may not appropriately account for any additional costs of recharging after ancillary services sales have been made, depending on the type of service provided. Studies also ignore the impact that the increased supply of ancillary services may have on the market price for such services.

5 Regional differences

Figure 5. States chosen for analysis

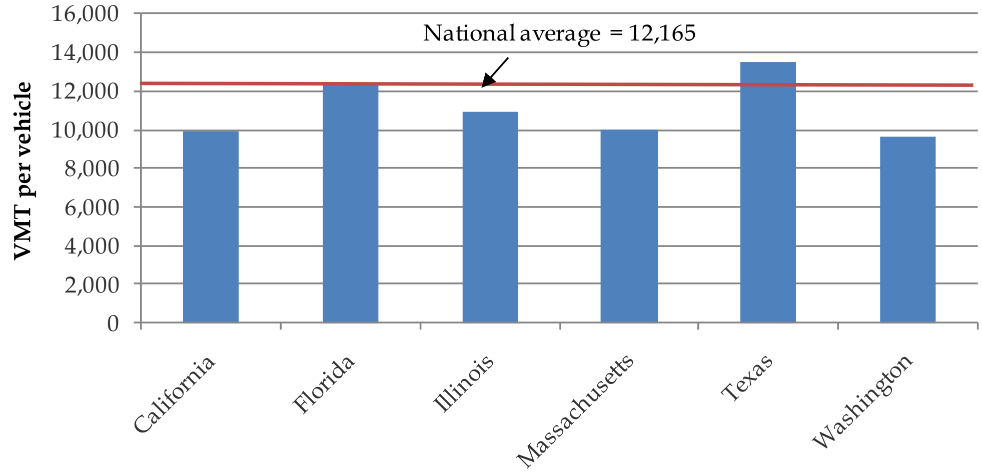


In addition to analyzing this issue on a national level, we have also conducted an analysis on the regional level, given the diversity of power generation sources and power markets across the US. On one hand, the marginal CO_2 produced by EVs varies from region to region, depending on the local fuel mix to generate electricity. On the other, delivered power and natural gas prices as well as retail gasoline prices are also different regionally. In addition, the vehicle miles traveled varies among the regions. For the purposes of our analysis, we have chosen six states to analyze the cost effectiveness of EVs and NGVs in different regions. California, Florida, Illinois, Massachusetts, Texas, and Washington were chosen to represent the range of US regional markets in terms of fuel source for power generation, miles traveled, and fuel and electricity prices.

Figure 6 shows the vehicle miles traveled per vehicle in the six states as compared to the national average. Lower population density states such as Texas have an above average amount of miles driven per vehicle, while urban states such as Massachusetts have a below average amount.

Figure 7, Figure 8, and Figure 9 show the monthly average retail gasoline, residential electricity and natural gas prices estimated for 2011, calculated based on 2009 actual historical prices escalated by the EIA AEO 2011 growth rate. Retail gasoline prices are relatively high in California and Washington. Retail electricity and natural gas prices vary more among the states. Retail electricity prices reach as high as $0.15/kWh in Massachusetts and California while being as low as $0.08/MWh in Washington. Retail natural gas prices in Florida are more than double those in Illinois.

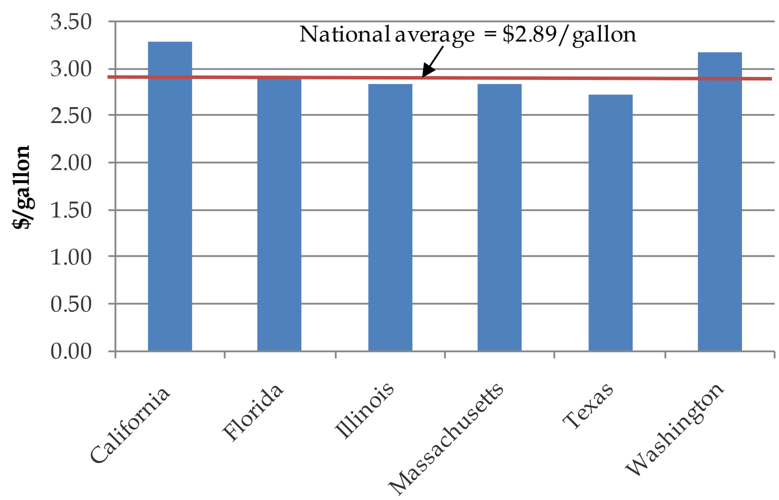
Figure 6. Average amount of vehicle miles traveled per vehicle by state



Source: US Department of Transportation. Federal Highway Administration, Highway Statistics 2004-2008.

Note that the vehicle miles traveled is a five-year average.

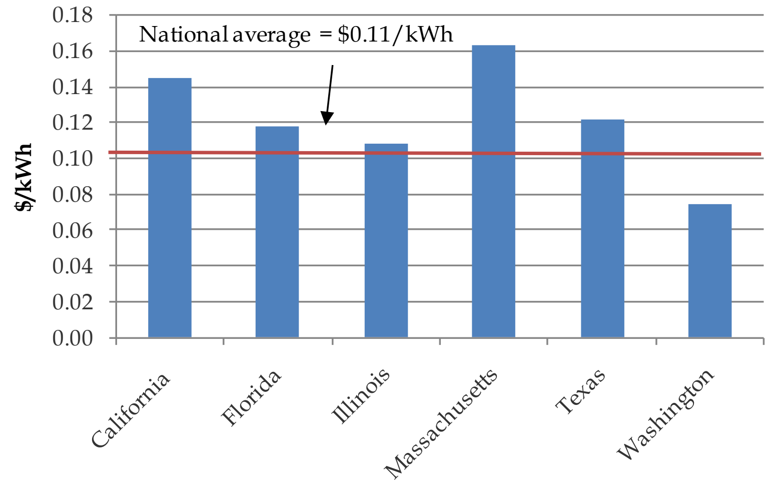
Figure 7. Annual average retail gasoline price by state, 2011 (estimated)



Source: EIA, escalated by LEI.

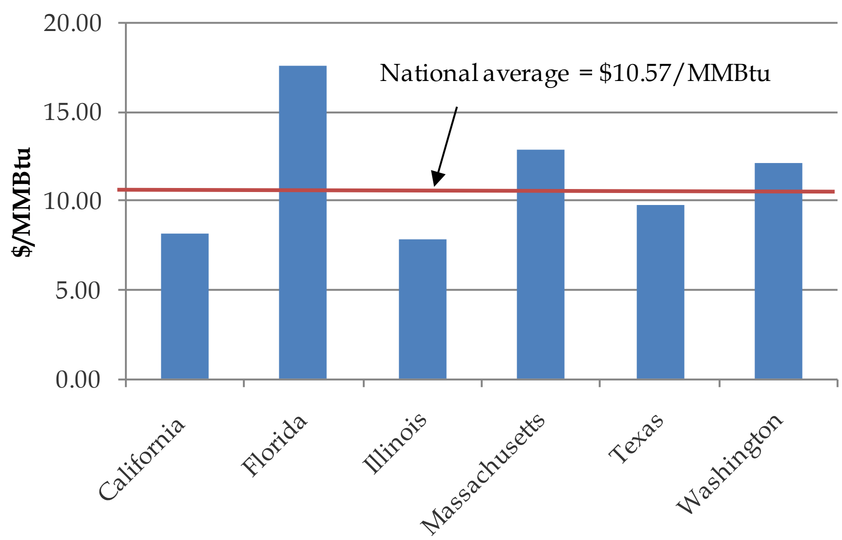
Note that EIA does not provide gasoline prices for Illinois. The price published by EIA for the Midwest region is used here as a proxy.

Figure 8. Annual average retail electricity price by state, 2011 (estimated)



Source: EIA, escalated by LEI.

Figure 9. Annual average retail natural gas price by state, 2011 (estimated)



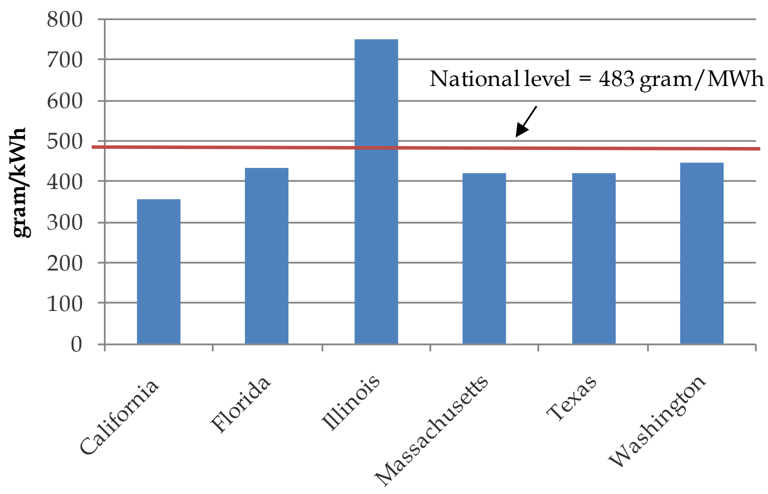
Source: EIA, escalated by LEI.

Lastly, we demonstrate the marginal carbon emission[27] variation by state in Figure 10. Among the states, California has the lowest marginal carbon emission, while Illinois has the highest

[27] The marginal carbon emission is the carbon emission from one kWh of electricity being generated. Note that the EPRI study cited may underestimate marginal carbon emissions for California, because it appears to exclude consideration of power imports to California, which include imports from large out-of-state coal stations.

marginal carbon emission, which is due to the larger proportion of coal used in electricity generation in Midwest.

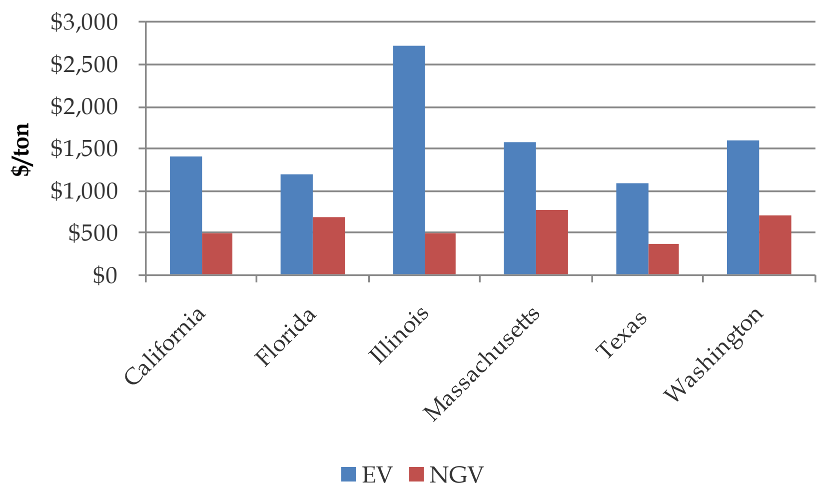
Figure 10. Marginal carbon emission by state, 2011 (estimated)



Source: EPRI. Plug-In Hybrid Electric Vehicle Environmental Analysis–Electric Sector Modeling of CO_2 Emissions. *Palo Alto, CA: 2006. 1012461. Estimated from Figure 3-4.*

Note: EPRI's study provides emission data on a regional basis, based on the former NERC geographic categorizations. For California, we have used the data for WSCC/CNV; for Florida, SERC/FL; for Illinois, MAIN; for Massachusetts, NPCC/NE; for Texas, ERCOT and for Washington, WSCC/NPP.

Figure 11. Implied incremental annual cost of reducing GHG emission by region



Note: Cost to reduce GHG emissions is based on the incremental annual cost of an EV or NGV over a CV and the reduction in GHG emissions due to the EV or NGV compared with the CV.

Figure 11 shows the regional cost to reduce GHG emission based on the inputs from the previous figures. In all of the six states, NGVs remain a more cost effective way to reduce GHG emission than EVs. NGVs have the least advantage in Florida, primarily due to the high residential natural gas prices (see Figure 9). Among these states, NGVs are most cost effective in Illinois, primarily as a result of the high carbon emissions from power generation (see Figure 10) combined with low residential natural gas prices (see Figure 9). NGVs in California also have a significant advantage over EVs, resulting from relatively low residential natural gas prices (see Figure 9) and relatively high retail electricity prices. NGVs have a minor cost advantage in reducing carbon emissions in Massachusetts; this advantage grows in Texas and Washington.

6 Policy implications

A number of policy implications arise from the above research. First, NGVs should be given more prominence in efforts to reduce GHG emissions from transportation. Second, current incentives may be insufficient to prompt switching, at least in the case of EVs. Third, regional differences in fuel costs and electricity generation sources need to be taken into account. Finally, a switch to alternative vehicle fuels may require a change in how we finance infrastructure in the US.

6.1 current incentives and their adequacy

There are a variety of incentives that currently exist for both NGVs and EVs. The Energy Policy Act of 2005 (EPAct 2005, §1341, Pub. L. No. 109-58) provides an income tax credit for businesses and individuals that acquire alternative fuel motor vehicles, including NGVs. The potential value of the tax credit varies depending on the size of the vehicle, the incremental cost of the vehicle, and the emissions performance of the vehicle. According to Honda, the Civic GX (only 2007-2010 models) purchased between January 1, 2006 and December 31, 2010 is eligible for up to $4,000 Federal Alternative Motor Vehicle Tax Credits. On the state level, many state governments, as well as regional and local governments, offer vehicle buyers and owners incentives to buy and operate NGVs. These incentives include tax deductions/credits, reduced license fees, reduced vehicle sale taxes, and lower registration fees. Some states also permit certain alternative fuel vehicles to operate in high occupancy vehicle ("HOV") lanes during peak rush-hour periods.

Similar tax credits are available for a new qualified plug-in electric vehicle purchased between December 31, 2009 and December 31, 2011. The minimum credit amount is $2,500, and the credit may be up to $7,500, based on each vehicle's traction battery capacity and the gross vehicle weight rating. On the state level, many incentives are offered by the local government, such as tax credits, rebates, electricity charging rate reduction, free parking, and so on.

Our analysis suggests that based on current prices, customers purchasing an EV would require either an upfront subsidy or tax credit of $17,008, or an annual payment over five years of $3,964. This compares to $2,705 upfront or $630 annually for an NGV. While current programs may be sufficient to incentivize transitioning to NGVs if appropriately publicized, the incentives may not be adequate to produce the desired behavioral changes in consumers with regards to EVs, unless customers themselves have a high willingness to pay for environmental attributes.

6.2 cost to reduce GHG emissions from transportation by 20%

Government policies, as well as the incentives, will significantly affect the future sales of EVs and NGVs. In order to derive policy implications, we have developed a model to estimate the total cost of EVs vs. NGVs to reduce carbon emissions from passenger cars by 20%. In 2008, GHG emissions from motor gasoline in the US reached 1,134.9 million metric tons, equivalent to 1,251 million tons.[28] During the same period, registered passenger cars accounted for 54% of total registered vehicles based on data from the Bureau of Transportation Statistics.[29] Assuming that passenger vehicles accounted for a similar percentage of the total emissions from motor gasoline, approximately 675 million tons were emitted from passenger cars.[30] A 20% reduction from this level would require elimination of 135 million tons of emissions.

Figure 12. Total cost of EVs vs. NGVs to reduce GHG by 20% under different scenarios

Sensitivity	GHG reduction efficiency ($/ton)		Total cost to reduce GHG by 20% (billion $s)	
	EV	NGV	EV	NGV
Current market condition	$1,341	$454	$181	$61
Power prices increase 20%	$1,374	$454	$186	$61
Price of EV falls 20%	$706	$454	$95	$61
Price of EV falls 30%	$388	$454	$52	$61
Unit GHG emission of power generation reduced to 400 grams/kWh	$1,181	$454	$159	$61

Based on the current conditions as detailed in the previous sections, NGVs are more cost effective in reducing GHG emissions (see Figure 12). The total cost, relatively to CVs, of EVs to reduce GHG by 20% in the next ten years reached $182 billion, while the cost of NGVs is $61 billion ($120 billion less than EVs). In addition, we explored another three scenarios. If a cap and trade program is implemented, power prices may increase faster than natural gas prices, especially in regions with a large proportion of coal generation.[31] A 20% increase in power prices, holding gas prices constant, will result in EVs having a higher cost to reduce the same amount of GHG emissions.

---

[28] EIA. *Emissions of Greenhouse Gases in the United States 2008*. December 2009.

[29] Bureau of Transportation Statistics. *National Transportation Statistics 2010.* Table 1-11.

[30] This assumption potentially overstates the proportion of emissions from passenger vehicles, as heavy vehicles may emit more per mile, and may be older on average than the passenger fleet.

[31] A number of studies have been released that estimate the impact of cap and trade on electricity prices for US consumers. For example, the American Institute for Economic Research projects electricity price increases of 4.2% to 42% for New England and 10.62% to 106% for the US Midwest (Baumann, David. *Cap and Trade Will Cost Consumers*. American Institute for Economic Research. 24 Jun 2009). PJM Interconnection projects price increases of $7.5-$45/MWh (12% to 70% of average 2008 prices) in 2013 (PJM Interconnection. *Potential Effects of Proposed Climate Change Policies on PJM's Energy Market.* 23 Jan 2009). NARUC forecasts price increases of $20/MWh for price-setting new coal-fired plants (National Regulatory Research Institute. *State Commission Electricity Regulation Under a Federal Greenhouse Gas Cap-and-Trade Policy.* Nov 2008).

Another scenario we examined was a significant reduction in prices for EVs. The high price of EVs is one of the primary reasons that EVs are less cost effective for reducing GHG emissions. If the prices for EVs are reduced by 20%, the total cost of EVs to reduce GHG by 20% will decrease significantly to $96 billion, still higher than that of NGVs. Only when prices for EVs are reduced by 30% or more do we see a cost advantage of EVs to reduce GHG. However, price reductions of this magnitude are not expected in the near term. A report recently released by the National Research Council ("NRC") noted that the premium for EVs is unlikely to narrow significantly in the near future largely because of the cost of their lithium-ion batteries.[32] According to the NRC, "steep declines in cost do not appear likely over the next couple of decades because lithium-ion batteries are already produced in large quantities for cell phones and laptop computers."[33]

The last scenario we considered is a cleaner power generation system, utilizing more renewable energy resources and less coal. According to EPRI's forecast, the unit emission of EVs is expected to be reduced to approximately 400 grams/kWh in 2020, as a result of continuous efforts to control emissions from power generation. Under the reduced emission from generation scenario, the cost of EVs to reduce GHGs by 20% decreases slightly, but is still higher than the cost of using NGVs for the same purpose.

Based on the analyses above, results are most sensitive to a reduction of EV prices. Under most other conditions, NGVs may continue to be more cost effective than EVs in reducing the same amount of GHG emissions. However, if the price of EVs can be reduced significantly in the near future, the cost advantage for EVs may narrow. Our analysis suggests that NGVs should be an important element in any strategy to reduce GHGs from transportation. While EVs appear to have received greater focus from policymakers recently, a more balanced portfolio approach to vehicle fuel sources would be more cost-effective.

6.3 implications for infrastructure financing

The above analysis does not address one key aspect of the transition to alternative transportation fuels, which is the role of the gasoline tax in financing road construction. Presently, at the federal level, a fuel tax of $0.184 is charged per gallon of retail gasoline sold.[34] Proceeds from this tax are directed into the Highway Trust Fund and then earmarked for transportation projects such as interstate highway construction and mass transit. Depending on whether EVs or NGVs are deployed, the above scenarios result in a reduction of demand for gasoline between 19 to 41 billion gallons approximately, and a corresponding loss of approximately $3.5 to $7.5 billion of federal tax revenue for road construction and

[32] Platts. "Electric car use unlikely to cut CO_2 emissions or oil consumption before 2030, says DOE report." *Global Power Report (*17 Dec 2009): 28-29.

[33] *Ibid*.

[34] American Petroleum Institute. *Motor Fuel Taxes*. January 2011. <http://www.api.org/statistics/fueltaxes/>.

maintenance.[35] If state gasoline tax is considered[36], combined state and federal lost tax revenues due to reductions in gasoline sales could be between $9 and $20 billion.

Ultimately, this suggests that alternative revenue sources may need to be found to fund such activities. One source may be greater use of tolls. Use of tolls would have additional potential environmental benefits in potentially reducing driving, and in making more economic use of existing infrastructure if toll pricing encourages off-peak usage. However, tolls may be politically contentious, particularly if imposed on highways where they have not been levied previously. Any ambitious plan to reduce transportation related GHG emissions will need to take the linkage between fuel type and infrastructure financing into account, even if the issue is not initially apparent.

[35] Gasoline tax loss was estimated by determining how many vehicles would need to be eliminated (and the associated reduction in gasoline consumption) in order to achieve a 20% reduction in GHG emissions.

[36] Most US states also levy fuel taxes, which vary depending on the state and are used for a variety of purposes. State fuel taxes range between 8.0 cents per gallon in Alaska to 45.8 cents per gallon in Hawaii, with an average of 29.7 cents per gallon in January 2011; thus, potential lost revenues from a transition to cleaner propulsion sources could be an additional $6 to $12 billion. Source: American Petroleum Institute. *Motor Fuel Taxes*. January 2011. <http://www.api.org/statistics/fueltaxes/>.

7 List of documents and websites consulted

AAA. "Your Driving Costs." 2010 Edition.

Abuelsamid, Sam. "Another cost of going electric: installing home charging gear." *Autoblog Green.* 23 Mar 2010. <http://green.autoblog.com/2010/03/23/another-cost-of-going-electric-installing-home-charging-gear/>

American Petroleum Institute. *Motor Fuel Taxes*. 5 Apr 2010. <http://www.api.org/statistics/fueltaxes/>

Bankrate. < http://www.bankrate.com/finance/auto/national-auto-loan-rates-for-feb-10-2011.aspx >

Baumann, David. *Cap and Trade Will Cost Consumers.* American Institute for Economic Research. 24 Jun 2009.

Bureau of Transportation Statistics. *National Transportation Statistics 2010.*

Chevrolet. <http://www.chevrolet.com/volt/>.

Clean Car Options. "EV Fuel Infrastructure Cost." 2010. <http://www.cleancaroptions.com/html/ev_fuel_infrastructure_cost.html>

EIA. <http://www.eia.gov/energyexplained/index.cfm?page=environment_where_ghg_come_from>. As of 2009.

EIA. *2011 Annual Energy Outlook Early Release*. 16 Dec 2010.

EIA. *Annual Energy Outlook 2009.*

EPRI. *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options for Compact Sedan and Sport Utility Vehicles*. Palo Alto, CA: 2002.

EIA. *Emissions of Greenhouse Gases in the United States 2008*. Dec 2009.

EPRI. *Plug-In Hybrid Electric Vehicle Environmental Analysis–Electric Sector Modeling of CO_2 Emissions*. Palo Alto, CA: 2006. 1012461.

Honda. *2011 Honda Civic GX Overview.* <http://automobiles.honda.com/civic-gx/>

Honda. *2011 Honda Civic Sedan.* <http://automobiles.honda.com/civic-sedan/specifications.aspx>

Honda. "Honda Begins Production of Civic GX Natural Gas Vehicles." Press Release. 13 May 2009.

Honda. *Honda Cars.* <http://automobiles.honda.com/>

IMPCO Technologies. <http://www.impcotechnologies.com/fuelmaker.asp>

International Association of Natural Gas Vehicles. <http://www.iangv.org/tools-resources/statistics.html>

Kansas Gas Service. <http://www.kansasgasservice.com/saveenergyandmoney/naturalgasvehicles.aspx>

KEMA. *Assessment of Plug-in Electric Vehicle Integration with ISO/RTO Systems.* March 2010.

"Macro Analysts Begin Eyeing Natural Gas Vehicles." *Natural Gas Week* (5 Jul 2010): 12.

National Regulatory Research Institute. *State Commission Electricity Regulation Under a Federal Greenhouse Gas Cap-and-Trade Policy.* Nov 2008.

Natural Gas Vehicles for America. <http://www.ngvc.org/about_ngv/index.html>

NGV Global. "BRC FuelMaker Integration Nears Twelve Month Milestone." 19 Apr 2010 <http://www.ngvglobal.com/brc-fuelmaker-integration-nears-twelve-month-milestone-0419>

Nissan. <http://www.nissanusa.com/leaf-electric-car/index#/leaf-electric-car/>

PJM Interconnection. *Potential Effects of Proposed Climate Change Policies on PJM's Energy Market.* 23 Jan 2009.

PJM Interconnection. Testimony of Kenneth Huber to the United States Senate Energy and Natural Resources Committee. 10 Dec 2009 <http://www.v2g-101.com/images/2009-12-10_S_Senate_testimony_Ken_Huber_-_PJM.pdf>

Platts. "Electric car use unlikely to cut CO_2 emissions or oil consumption before 2030, says DOE report." *Global Power Report (*17 Dec 2009): 28-29.

Randazzo, Ryan. "Massive stimulus grant boosts electric-car charging company, creates jobs." *The Arizona Republic* (14 May 2010). <http://www.azcentral.com/arizonarepublic/business/articles/2010/05/14/20100514biz-ecars0514.html>

Research and Innovative Technology Administration: Bureau of Transportation Statistics. *State Transportation Statistics 2008.* <http://www.bts.gov/publications/state_transportation_statistics/state_transportation_statistics_2008/pdf/entire.pdf>

US Department of Transportation Federal Highway Administration. Highway Statistics.. <http://www.bts.gov/publications/state_transportation_statistics/>

Welch, David. "Chevrolet Volt gets 230 mpg in the city, and only in the city." *Bloomberg Businessweek* 11 Aug 2009. <http://www.businessweek.com/autos/autobeat/archives/2009/08/chevrolet_volt.html>

Woodyard, Chris. "Natural-gas powered cars: who even knows they exist?" *USA Today* (5 Jul 2007). <http://www.usatoday.com/money/autos/2007-05-08-natural-gas-usat_N.htm>

Woodyard, Chris. "Obama stimulus to pay for 15,000 home electric-car charging units." *USA Today* (17 Jun 2010). <http://content.usatoday.com/communities/driveon/post/2010/06/obama-stimulus-to-pay-for-15000-home-electric-car-charging-units/1>