Technical Appendix: Figure 7, "Private Costs of Transportation Choices," and Figure 9, "External Costs of Transportation Use."

"Energy Policy Opportunities and Continuing Challenges in the Presence of Increased Supplies of Natural Gas and Petroleum"

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Introduction

In figures 7 and 9 from "Energy Policy Opportunities and Continuing Challenges in the Presence of Increased Supplies of Natural Gas and Petroleum," we conduct a transportation life-cycle assessment (LCA) analysis for five vehicle types: conventional gasoline (CVs), ethanol (E85), hybrid electric (HEVs), compressed natural gas (CNGVs), battery electric (BEVs) and hydrogen fuel cell (HFCVs). Included in the LCA are the private costs—the sticker price paid for the car and the "price at the pump" for fuels—as well as the carbon and non-carbon external costs of raw materials extraction and fuel processing, vehicle assembly, and vehicle operation. The analysis ignores taxes, licensing or financing costs; maintenance costs; transportation infrastructure costs; or costs to consumers associated with increased refueling.

Our analysis updates and expands similar studies by the NAS (2010) and Michalek et al. (2011).

Key assumptions Used:

- Vehicle lifetime: 150,000 miles spread evenly over 12 years (follows Michalek et al. 2011)
- Discount rate for fuel and external costs: 4%
- Current prices are assumed: January 2012 fuel prices; 2012 Social cost of carbon; 2012 model year vehicle prices.

I. External Costs

a. Non-Carbon External Costs: Vehicle Lifecycle Emissions

Vehicle Operation Emissions

Sponsored by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), Argonne National Laboratory has developed a full life-cycle model called GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation). It allows researchers to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis. We use the latest GREET fuel-cycle model available, GREET 1 2011, to calculate vehicle emissions in 2015 for 2010 model years. Argonne GREET model default assumptions are used to calculate operation emissions for VOC, CO, NOx, PM10, PM2.5, SOX and Greenhouse Gas CO2-equivalent for light-duty auto vehicles.

We use the latest GREET vehicle-cycle model, GREET 2.7, to calculate the life-cycle energy use and emissions for vehicle assembly.

Valuation of Emissions

In the *Proceedings of the National Academy of Sciences*, Michalek et al. (October 2011) update the NAS (2010) analysis, focusing mainly on electric vehicles. We use Michalek et al.'s updated valuation estimates for vehicle and battery assembly, power plant pollutants, upstream emissions for coal and natural gas, battery upstream emissions, and vehicle upstream emissions valuations. We also follow Michalek et al.'s vehicle production cost estimates for HEVs and BEVs.

Following NAS (2010), E85 vehicles and CNGVs are assumed to have the same vehicle assembly externalities.

Fuel Cycle Emissions
For emissions during the feedstock production and fuel production stages for each vehicle type, we use NAS (2010) unpublished estimates. For ethanol, we assume 100% comes from dry corn production.

b. Carbon External Costs

In valuating carbon emissions, we use the middle estimate of the social cost of carbon by the U.S. Government's Interagency Working Group on the Social Cost of Carbon, which is estimated at $22.36 per ton in 2012 (2007 dollars).

c. Energy Security Externalities

The energy security costs resulting from our reliance on petroleum are difficult to quantify. A literature review for a National Academies of Science article found estimates of oil supply disruptions to range between $0.00 and $0.28 per gallon, with a midpoint estimate of $0.09 from a 2010 study by Brown and Huntington (Michalek et al. 2011). In addition, there are costs associated with increased military spending that are not included in our analysis because of difficulties obtaining precise estimates.

II. Private Costs

a. Vehicle Purchase Price

To determine vehicle costs for conventional vehicles, ethanol vehicles, and electric vehicles, we rely on average vehicle price estimates by Jerram and Gartner (2012) for mid-size fleet vehicles. The report compiles average prices for 2012 model years, for basic-model vehicles of the same engine size. We follow Knittel (2012a) in using the value of $5,500 as the estimated incremental cost difference for a CNG vehicle, calculated by comparing similarly-equipped model year 2012 Honda Civics.

The advantage of this approach is that it reflects current prices and technology widely available. However, not every feature can be held constant using the current-model-year approach because of differences in manufacturing.

Vehicle Base Purchase Price

	Retail ($2012)	Table 3.11A
Conventional	22,421	Jerram and Gartner (2012)
Flex-Fuel (E85)	25,263	Jerram and Gartner (2012)
Hybrid Electric	26,783	Jerram and Gartner (2012)

Compressed Natural Gas	27,921	$5,500 incremental price quoted in Knittel (2012)
Hydrogen Fuel Cell	50,000	DOE (2011)
Electric	42,730	Jerram and Gartner (2012)

Honda currently has a hydrogen fuel cell vehicle available in California—this vehicle is not for sale, but can be leased at $600 per month, inclusive of maintenance costs, without a purchase option. According to DOE 2011, Toyota plans to introduce a fuel cell sedan in 2015, priced to sell at $50,000, and Hyundai has signaled that it intends to commercialize a fuel cell vehicle at a cost below $50,000 (DOE 2011). While neither vehicle is yet available for retail sale, we assume the hypothetical value of $50,000 for hydrogen fuel cell vehicles for comparison purposes.

The technology surrounding alternative fuel vehicles is new and constantly evolving, particularly in the case of BEVs and HFCVs. Future cost estimates often show large declines in costs by making assumptions about new technological breakthroughs and economies of scale in production. For this reason, cost estimates for many alternative fuel vehicle types are characterized by significant uncertainty (for a discussion of this uncertainty, see Knittel 2012b).

***Private cost assumptions specific to each vehicle*:**

Conventional Gasoline Vehicle

Assumption	**Source**
Fuel Cost: $3.37 per gallon	DOE January 2012
MPG: 24.81 m	GREET 1 2011
Range: 394 miles	Fueleconomy.gov average for model year 2012 non-manual cars with flex fuel capability running on conventional gasoline.

Ethanol (E85) Vehicle

Assumption	**Source**
Fuel Cost: $4.44 per gge	DOE January 2012
MPG: 24.81 m	GREET 1 2011
Range: 286 miles	Fueleconomy.gov average for non-manual cars with flex fuel capability running on E85.

Hybrid Electric Vehicle

Assumption	**Source**
Fuel Cost: $3.37 per gallon	DOE January 2012
MPG: 34.73	GREET 1 2011
Range: 542 miles	Calculated by comparing the difference in range between a 2012 model year Honda civic hybrid

	and sedan, and then inflating the range of the average mid-size conventional vehicle.

Compressed Natural Gas Vehicle

Assumption	Source
Fuel Cost: $2.13 per gge	DOE January 2012
MPG: 25.55	GREET 1 2011
Range: 190 miles	Fueleconomy.gov data

Hydrogen Fuel Cell Vehicle

Assumption	Source
Fuel Cost: $3.49 per gge	DOE January 2012
MPGs: 58.71	GREET 1 2011
Range: 215 miles	Fueleconomy.gov data

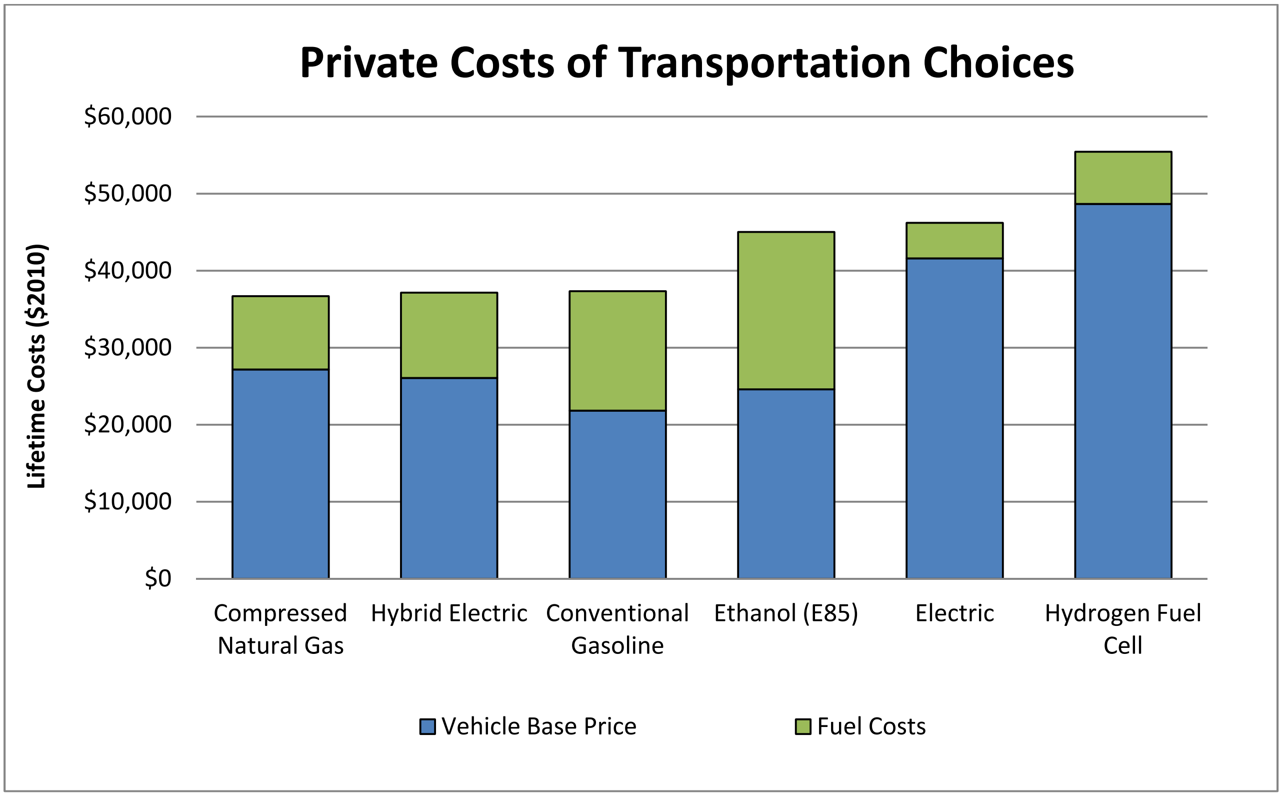
Battery Electric Vehicle

Assumption	Source
Charging efficiency: 88 percent	Michalek et al.
Fuel Cost: $0.0973 / kWh	Electricity use specific to transportation (EIA 2012).
Fuel economy: 2.73 miles/kWh	GREET 1 2011
Range: 75 miles	Fueleconomy.gov data

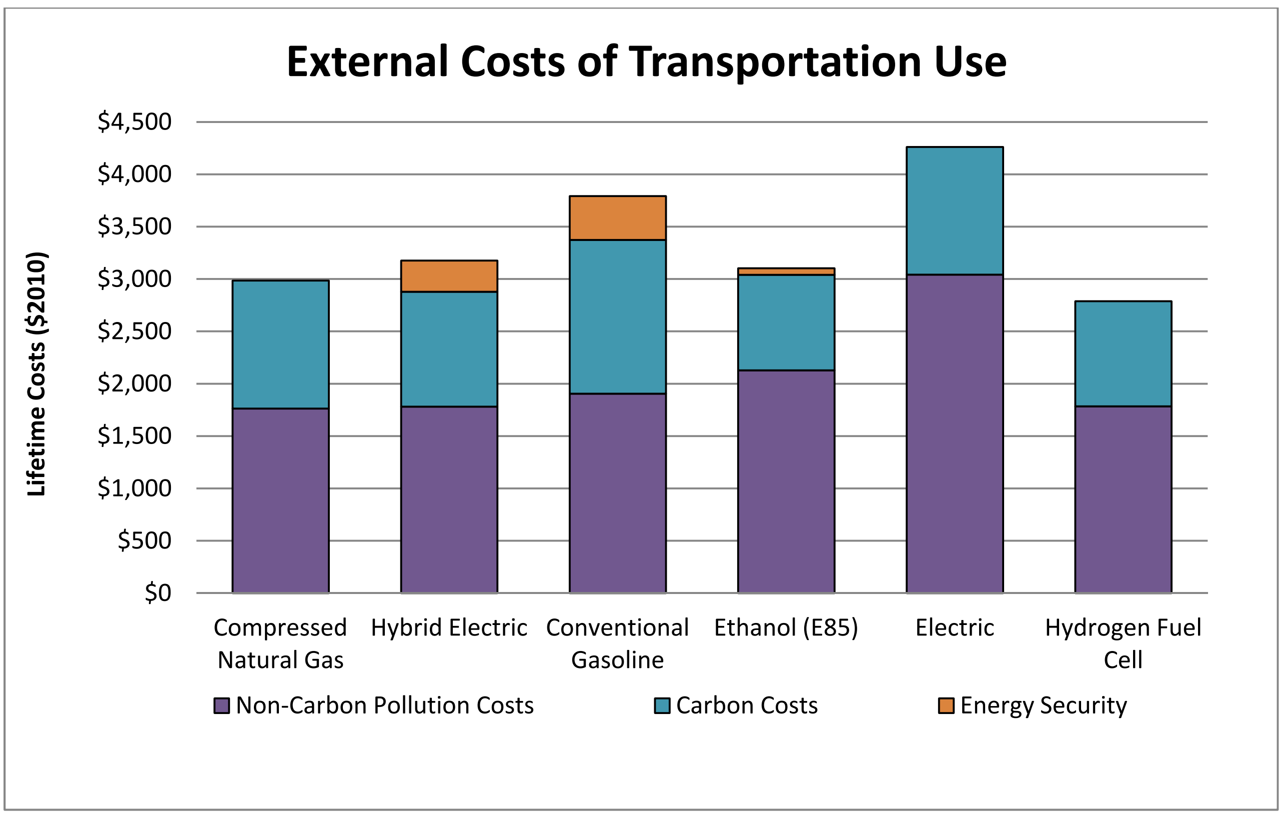
Other Assumptions

- Monetary values are converted to year 2010 dollars using the GDP Price Deflator used by the Energy Information Administration.

III. Results:



Private Costs of Transportation Choices
Lifetime Costs ($2010)
$60,000
$50,000
$40,000
$30,000
$20,000
$10,000
$0
Compressed Natural Gas
Hybrid Electric
Conventional Gasoline
Ethanol (E85)
Electric
Hydrogen Fuel Cell
Vehicle Base Price
Fuel Costs



External Costs of Transportation Use
Lifetime Costs ($2010)
$4,500
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Compressed Natural Gas
Hybrid Electric
Conventional Gasoline
Ethanol (E85)
Electric
Hydrogen Fuel Cell
Non-Carbon Pollution Costs
Carbon Costs
Energy Security

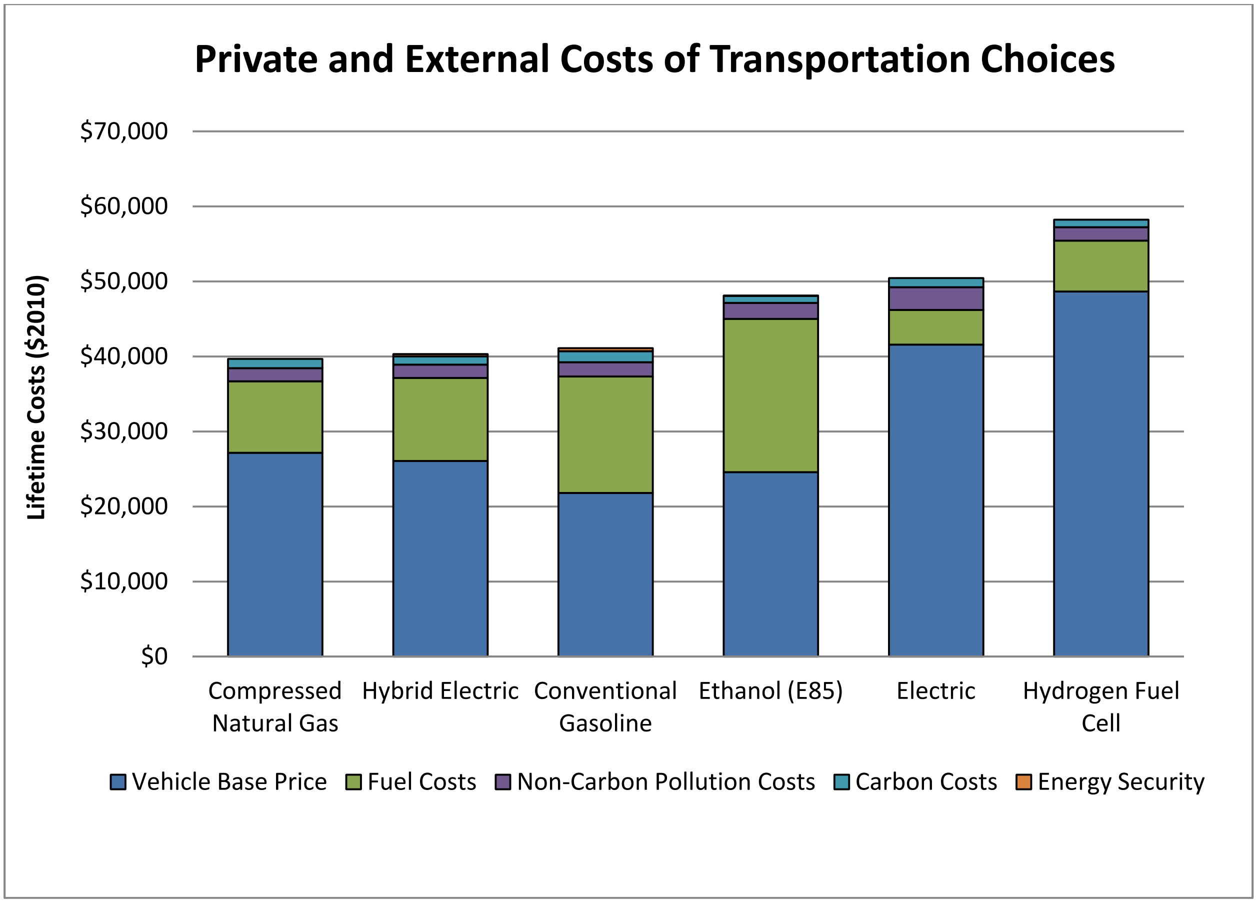


Table 1. Private and External Costs ($2010) of Transportation Choices

Vehicle Type			Private Costs		External Costs		
	Share of Alternative Fuel Vehicles in 2009	Range without refueling, 2012 Model Years	Vehicle Base Price	Fuel Costs	Non-Carbon Pollution Costs	Carbon Costs	Energy Security
Conventional Gasoline	n.a.	394	21,821	15,508	1,904	1,470	417
Ethanol (E85)	75.03%	286	24,586	20,432	2,127	914	63
Hybrid Electric	24.70%	581	26,066	11,077	1,781	1,098	298
Compressed Natural Gas	0.00%	190	27,173	9,516	1,763	1,222	0
Hydrogen Fuel Cell	0.00%	215	48,661	6,785	1,784	1,004	0
Electric	0.21%	75	41,586	4,617	3,042	1,219	0

Table 2. Net Present Value ($2010) of the External Pollution Costs of Transportation Use

	Non-Carbon External Costs From				Carbon External Costs From			
	Fuel Production	Vehicle Assembly	Vehicle Operation	**Total**	Fuel Production	Vehicle Assembly	Vehicle Operation	**Total**
Conventional Gasoline	561	637	707	1,904	286	187	997	1,470
Ethanol (E85)	803	637	687	2,127	(253)	187	979	914
Hybrid Electric	400	720	661	1,781	204	179	715	1,098
Compressed Natural Gas	457	637	669	1,763	278	187	757	1,222
Hydrogen Fuel Cell	729	962	93	1,784	765	240	0	1,004
Electric	947	2,001	93	3,042	704	516	0	1,219

IV. Excel Description

The assumptions and calculations described above can be found in the spreadsheet THP_tranportationsocialcosts.xlsx. The first sheet provides a table of contents. The summary of output is provided in Table 1. Table 2 summarizes key assumptions used in other tables. Tables 3 and 4 provide additional information on market share and range of vehicles, used in Table 1. Tables 5 and 6 are used to estimate private costs—the vehicle purchase price and fuel costs over the vehicle lifetime. Table 7 is a summary of external costs calculations made in later sheets. Table 8 calculates the external costs of feedstock and fuel production. Table 9 is the calculation of external costs of vehicle assembly. Table 10a-10f are the GREET 1 2011 model outputs for vehicle operation emissions for each vehicle type in this analysis. Table 11 calculates the external costs of oil supply disruptions per gallon of gas. Table 12a and 12b are assumptions from the NAS (2010). Finally, Table 13+ show the default GREET input assumptions.

Key Sources:

Fuel Costs:

Department of Energy. 2012b (January). "Clean Cities: Alternative Fuel Price Report. http://www.afdc.energy.gov/afdc/pdfs/afpr_jan_12.pdf

Energy Information Administration (EIA). 2012. "Electric Power Monthly." Table 5.3. Average Retail Price of Electricity to Ultimate Customers: Total by End-Use Sector, 1998 through February 2012 http://205.254.135.7/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_3

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Michalek, Jeremy, Mikhail Chester, Paulina Jaramillo, Constantine Samaras, Ching-Shin Norman Shiau and Lester Lave. 2011 (October). "Valuation of plug-in vehicle life-cycle air emissions and oil displacement benefits." Proceedings of the National Academy of Sciences of the United States of America. 108(4) 16554-16558.
Excel file with calculations available here: http://www.cmu.edu/me/ddl/publications.html

Jerram, Lisa and John Gartner. 2012. "Executive Summary: Total Cost of Ownership of Alternative Fuel Vehicles for Fleet Operators." Pike Research: Boulder, CO.