To the Editor of IEEE spectrum: August 16, 2013

In the July 2013 IRRR Spectrum cover story "Unclean at any speed" Ozzie Zehner claims to show that electric vehicles do not reduce environmental damage compared to conventional gasoline cars. His primary source is a 2010 National Academy Study that evaluated some of the unpriced "externality" costs of producing and using energy[1]. However, Zehner misrepresents the NAS study results by only reporting the local air pollution costs of manufacturing, maintaining and operating motor vehicles. For example, Zehner only shows the results from Figure S-3b of the NAS report which displays the "health effects and other "nonclimate damages" of motor vehicles in cents/mile in the 2030 time period; The key word is "nonclimate," indicating that these values reported by Zehner do not account for climate change or greenhouse gas implications of building and operating a motor vehicle.

While local air pollution was the motivating factor for the original California Zero Emission Vehicle (ZEV) program that led to the initial development of modern battery electric vehicles (BEVs) such as GM's EV-1, electric vehicles are now seen as a primary mechanism to substantially reduce greenhouse gas (GHG) emissions and oil consumption, which Zehner ignores in his article.

The NAS report does evaluate GHG emissions in their Chapter 5, and reports their results in Figure S-4b (shown on next page) for the 2030 time period in grams of CO_2-equivalent/mile, the figure just after the local air pollution results used by Zehner. While both hydrogen and electric vehicles have greater local air pollution costs than gasoline from tar sands as reported by Zehner, both electric vehicles have lower GHG emissions than gasoline vehicles. The NAS report does not show the GHG costs in cents/mile explicitly, but they do have a long discussion of the likely expected societal costs of GHG emissions and climate change. They do acknowledge the difficulty and inherent uncertainty of modeling the costs of future GHG emissions.

This uncertainty in the estimation of societal costs is reflected in the wide range of GHG costs cited in the NAS report: from $10/ton of CO_2-equivalent to $30/ton to $100/ton of CO_2-eq[2].

[1] *Hidden Cost of Energy: Unpriced consequences of energy production and use*, by the Committee on Health, Environmental and other external costs and benefits of energy production and consumption, National Research Council of the National Academies, The National Academy Press, Washington, D. C. 2010.

[2] In their literature review, the NAS Committee cites one study estimating GHG costs as high as $284/ton.

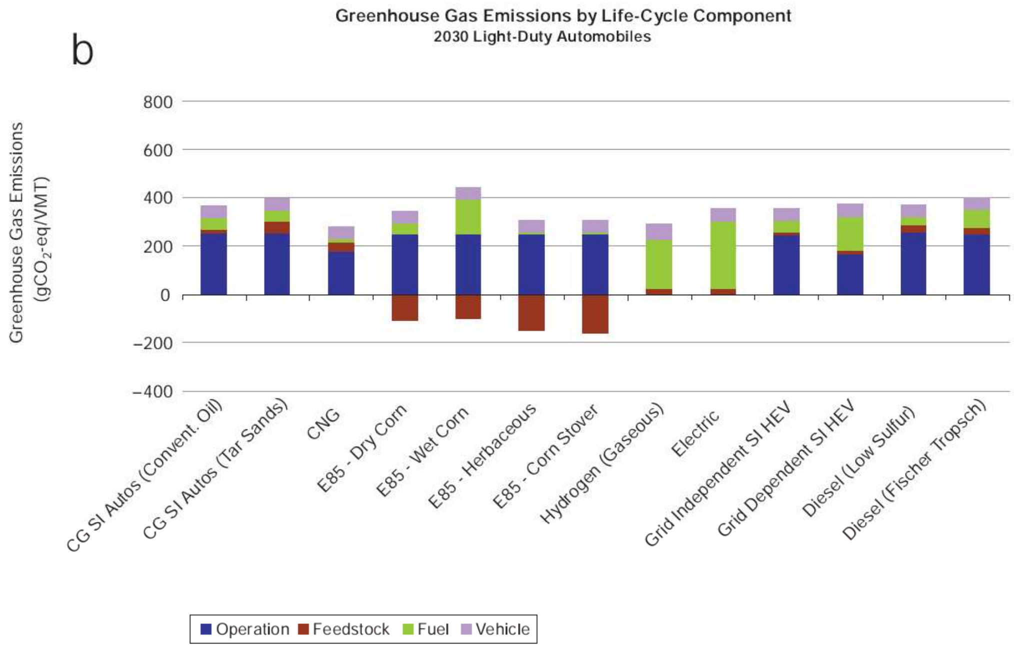

FIGURE S-4 Greenhouse gas emissions (grams CO_2-eq)/VMT by life-cycle component for different combinations of fuels and light-duty automobiles in 2005 (*a*) and 2030 (*b*). Going from bottom to top of each bar, damages are shown for life-cycle stages as follows: vehicle operation, feedstock production, fuel refining or conversion, and vehicle manufacturing. One exception is ethanol fuels for which feedstock production exhibits negative values because of CO_2 uptake. The amount of CO_2 consumed should be subtracted from the positive value to arrive at a net value. ABBREVIATIONS: g CO_2-eq, grams CO_2-equivalent; VMT, vehicle mile traveled; CG SI, conventional gasoline spark ignition; CNG, compressed natural gas; E85, 85% ethanol fuel; HEV, hybrid electric vehicle.

The latest 2012 estimates of GHGs and oil consumption for alternative fueled vehicles from the Argonne National Laboratory[3] are shown in Table 1[4].

In addition to reducing GHG emissions and thereby reducing the potential societal costs due to climate change, BEVs and FCEVs will also reduce the consumption of petroleum. The 2010 NAS report does address energy security in Chapter 6, but they did not assess the societal costs of oil imports, but there are obviously both military costs due to the need to protect our sources of foreign oil,

Table 1 Latest estimates of GHGs and oil consumption from the Argonne GREET1_2012 model

GREET1_2012	CO2-eq. g/mile	Oil use btu/mile
RFG SI autos	449	4820
HEV	322	3443
PHEV40	305	2016
CNG	384	23
BEV	243	49
FCEV	272	21

Externality costs or oil.XLS; Tab 'Dashboard'; D-43 - 8 / 14 / 2013

[3] "The Greenhouse gases, regulated emissions and energy use in transportation" (GREET) model, the Argonne National Laboratory, available at http://greet.es.anl.gov/

[4] RFG = reformulated gasoline; SI = spark ignition (engine); HEV = hybrid electric vehicle; PHEV40= plug-in hybrid electric vehicle with 40 miles all-electric range; CNG = compressed natural gas (vehicle); BEV = battery electric vehicle; FCEV = (hydrogen-powered) fuel cell electric vehicle.

as well as economic costs of importing oil, often from nations that may threaten our nation either directly or through the support of terrorists in the unstable regions of the world. I have previously estimated the societal costs of petroleum dependence as summarized in the next section[5].

Petroleum dependence costs

Consuming gasoline and diesel fuel entails military costs related to protecting our access to Persian Gulf oil and economic costs associated with imported oil. Both costs are difficult to estimate and speculative to some degree. The Department of Defense budget does not break down military costs by mission. What is now the Central Command in Florida that includes the Persian Gulf was originally set up under President Carter in January 1980 with the express intent to use "any means necessary, including military force" to protect our access to oil[8]. With the Iraq war, total US military spending has increased dramatically. Copulos estimated that the portion of military costs that could be associated with defending our sources of oil amounted to $49.1 billion per year in 2003 [9], but revised his estimate up to $137.8 billion in 2007[10]. We averaged the estimates of four sources that scrutinized the military cost of oil protection in some detail, resulting in a range between $80 billion to $150 billion per year (Table 2).

Table 2 – Estimates of the annual military costs of securing petroleum (US$ Billions)

	Low	*High*
Klare [28]	*132*	*150*
Copulos, National Defense Council Foundation	*49*	*138*
Kimbrell, International Center for Technology Assessment[6]	*48*	*113*
Danks, National Priorities Project[7]	*100*	*210*
Average	*82*	*153*
Per barrel military cost based on total oil consumption	*$11.7/bbl*	*$21.8/bbl*
Per barrel military cost based on imported oil	*$17.1/bbl*	*$31.9/bbl*

For the purposes of this model, we need to assign a cost per gallon of gasoline so that we can credit improved fuel economy and the use of non-petroleum fuels with reduced military expenditures. Two obvious choices are to divide the annual military dollar costs by the amount of imported oil (4.8 billion barrels per year), or dividing by the total amount of oil consumed (7 billion barrels per year). Dividing by the total oil consumed might seem too conservative, since if we cut back oil consumption by 40%, we could eliminate most imports and there would be no need for any US military protection of foreign oil. This assumes, however, that all other nations similarly cut their consumption and, further, that they all have sources of domestic oil production to avoid importing oil from the Persian Gulf. Given the growing petroleum demands of China and India and the much greater dependence on foreign sources in countries like Japan, the global economy will most likely depend on the Middle East for many decades. The military oil cost charge would be between $12/barrel and $22/barrel if we use total oil consumption as the denominator.

Dividing the military costs by the amount of imported oil seems reasonable on balance to generate a per barrel cost. This would increase the military protection cost to the range between $17/barrel and $32/barrel, putting a premium on

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[5] C. E. Thomas, "Transportation options in a carbon-constrained world: hybrids, plug-in hybrids, biofuels, fuel cell electric vehicles, battery electric vehicles." *International Journal of Hydrogen Energy* 34 (2009) 9279-9296.

[6] *Kimbrell, A. The real price of gasoline: an analysis of the hidden external costs consumers pay to fuel their automobiles, International Center for Technology Assessment Report #3, Washington D.C., November 1998*

[7] Danks A, Orisich M, Smith S. *The military cost of securing energy*. The National Priorities Project, Northhampton, Massachusetts October 2008.

[8] *Klare MT. Blood and oil: the dangers and consequences of America's growing dependency on imported petroleum, Owl Books, New York 2004*

[9] Copulos MR. *America's Achilles heel: the hidden cost of imported oil; a strategy for energy independence*, The National Defense Council Foundation, Washington D.C. October, 2003

[10] Copulos MR. *The hidden cost of oil: an update*, The National Defense Council Foundation, Washington, D.C. January 8, 2007

reducing oil consumption in the near term when cuts would have a direct impact on reducing our dependence on Persian Gulf petroleum.

The economic costs to society of imported oil are also highly speculative. Greene & Leiby have analyzed these costs in great detail[11]. They list three components of the economic cost of imported petroleum:

- *Transfer of wealth*
- *Loss of potential to produce*
- *Disruption losses*

Based on their 2005 data when oil prices averaged $50/bbl, they estimated an annual wealth transfer between $100 billion and $150 billion. Some analysts minimize the importance of this wealth transfer, noting that some of this money comes back to US firms in the form of purchased equipment. But as Greene and Leiby put it, when oil prices rise well above the cost of production, "the wealth transferred to OPEC producers is therefore pure surplus, i.e. profit. It need not be reinvested in producing more oil. It can be used to fund health care or terrorism, economic development or nuclear weapons, education or repression."
US GDP will also decrease due to the loss of production capacity through higher energy costs for US manufacturers. For 2005, they estimated a range between $10 billion to $50 billion to cover loss of production in the economy.

Disruption due to sudden price fluctuations is difficult to measure. In 2005, Greene and Leiby estimated a range between $50 billion and $170 billion was appropriate as an estimate of economic impact of oil price shocks. They noted that these disruption costs would be directly proportional to the total expenditures on petroleum relative to the size of the GDP. Table 3 summarizes the 2005 data from Greene & Leiby.

Table 3 – Estimates of the economic costs of oil dependence (US 2005$ Billions)

	Low	High
Transfer of wealth	100	150
Loss of production capacity	10	50
Disruption Loses	50	170
Totals	160	370
Per barrel economic cost based on total oil consumption	$22.8/bbl	$52.7/bbl
Per barrel economic cost based on imported oil	$33.4/bbl	$77.1/bbl

Table 4 combines the military cost with the economic cost estimates of our oil dependence. The average combined costs range between $55/barrel and $80/barrel[12] with a high end estimate between $75/bbl and $110/bbl The higher value based on imported oil only is probably justified to represent the likely societal savings by cutting gasoline consumption.

[11] Greene DL, Leiby PN. *Oil independence: realistic goal or empty slogan?* Oak Ridge National Laboratory, March 2007

[12] *This societal cost can be lower or higher than the price of oil, both of which were demonstrated in 2008 as oil prices oscillated between a peak of $147/barrel in the summer and then dipped below $40/barrel by December 2008.*

Table 5 shows the results of combining the 2010 NAS societal cost estimates of between $30/ton and $100/ton of CO2-eq. GHG emission societal costs with the estimates of the energy security societal costs of Table 4, all converted to cents/mile societal costs for the various types of vehicles[13].

The average societal cost data are shown graphically in Figure 2, and the maximum cost data in Figure 3. This information demonstrates that if you only count the local air pollution costs, then both BEVs and FCEVs have greater cost than either gasoline cars or natural gas vehicles (NGV's). But if you include the full societal costs including the cost of greenhouse gases and oil imports, then the electric vehicles (powered by either electricity or hydrogen) have lower societal costs than either gasoline vehicles (conventional, HEVs or PHEVs) or NGV's.

Table 4 – Summary of the estimated societal costs of US petroleum dependence

	Low	High	Average
Average annual military oil supply protection costs ($US billions/yr)	82	153	118
Average annual economic costs of oil dependence ($US billions/yr)	160	370	265
Total annual costs of oil dependence ($US billions/yr)	242	523	383
Per barrel oil dependence cost based on total oil consumption	$34.5/bbl	$74.5/bbl	$55/bbl
Per barrel economic cost based on imported oil	$50.5/bbl	$109/bbl	$80/bbl

Table 5. Estimated societal costs of various vehicles.

		Average Costs			MAX costs		
	Local Air Pollution Costs	Average GHG costs	Average Oil Costs	Total Average costs	Max GHG costs	Max Oil Costs	Total Max costs
RFG SI autos	1.36	1.49c/mile	5.49c/mile	8.33c/mile	4.95c/mile	7.43c/mile	13.74c/mile
HEV	1.49	1.07c/mile	3.92c/mile	6.47c/mile	3.55c/mile	5.31c/mile	10.35c/mile
PHEV40	1.63	1.01c/mile	2.30c/mile	4.93c/mile	3.36c/mile	3.11c/mile	8.10c/mile
CNG	1.18	1.27c/mile	0.03c/mile	2.47c/mile	4.23c/mile	0.04c/mile	5.45c/mile
BEV	1.50	0.80c/mile	0.06c/mile	2.36c/mile	2.68c/mile	0.08c/mile	4.26c/mile
FCEV	1.63	0.90c/mile	0.02c/mile	2.55c/mile	3.00c/mile	0.03c/mile	4.66c/mile

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[13] The energy security costs are calculated by using the oil consumption estimates from the GREET model (third column of Table 1), assuming that each gallon of gasoline has a higher heating value of 115,000 btus and each barrel of oil yields 42 gallons of gasoline.

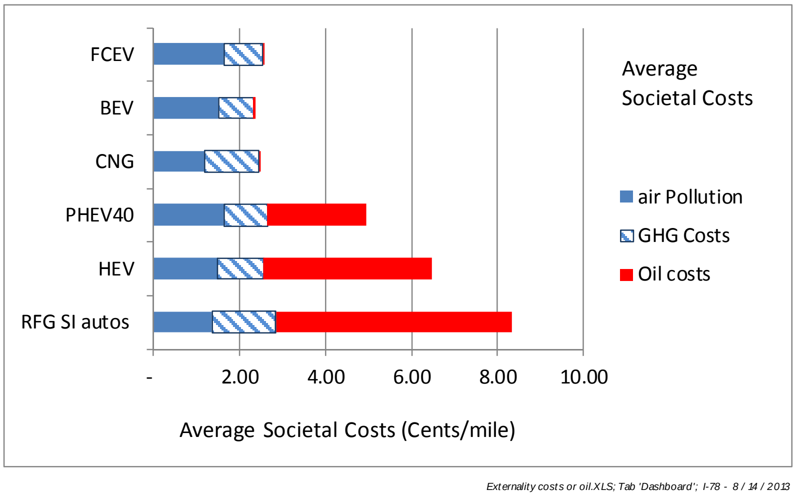

Figure 2. Average Societal Costs for motor vehicles

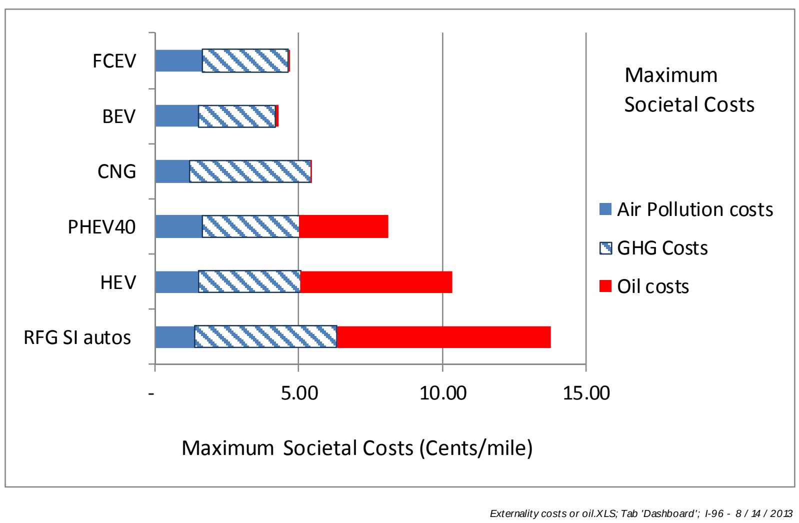

Figure 3. Maximum Estimated Societal Costs for motor vehicles

Finally, Figure 4 illustrates the distribution of societal costs for a conventional (non-hybrid) gasoline car, showing that local air pollution, the only figure of merit used by Zehner in his Spectrum article, accounts for only 9.9% of the estimated high societal cost to at most 16.3% of the estimated average societal costs due to driving light duty gasoline vehicles.

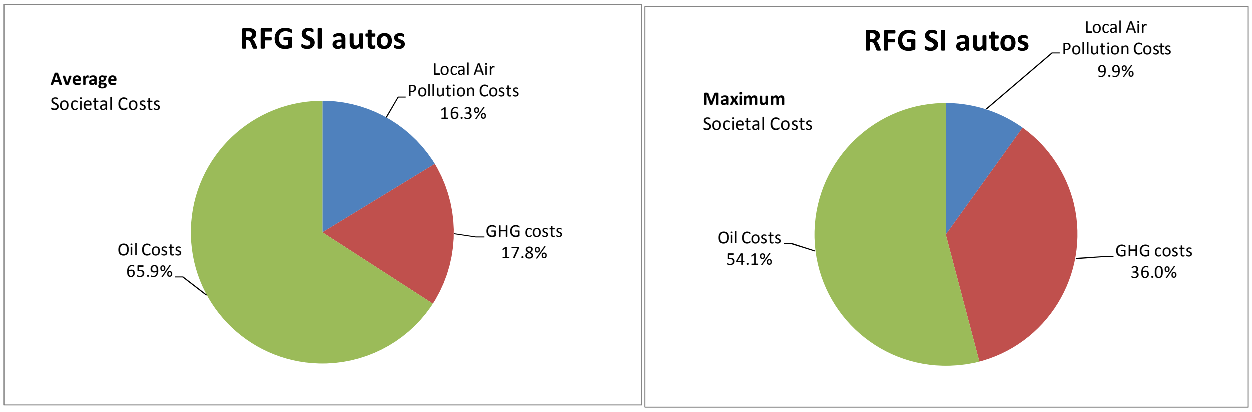

Figure 4. Distribution of Societal Costs based on Average costs (left side) and maximum estimated costs (right side)

As a member of the IEEE, I am disappointed that the editors of the IEEE Spectrum would publish such a biased article on transportation, ignoring the significant climate change and energy security incentives for moving to electric vehicles powered either by electricity or by hydrogen.

Sincerely,

C.E. Thomas, Ph.D.