Fuel Infrastructure Costs: electricity vs. hydrogen

Electricity outlet fuel infrastructure. "Type I" 120 V conventional home outlets would not be sufficient to charge most BEVs or PHEVs. As summarized in Table 1, it will take between 10 to 28 hours[1] to charge car batteries using only a standard 120 V outlet. Most car owners will need access to at least a Type II 240-Volt outlet, if not a Type III fast charging system to refuel their battery electric vehicles (BEVs) or plug-in hybrid electric vehicles (PHEVs) in a reasonable period of time.

Table 1 Estimated charging times for BEVs and PHEVs

			Charging time (hours)		
	Nominal AER range (miles)	EPA rated range (miles)	Type I 120 Volt	Type II 240 Volt	Type III 480+ volt
Nissan Leaf BEV	100	73	16	8	80% in 1/2 hr
Chevy Volt PHEV	40	?	10	4	
Ford Focus BEV	≈100	?	18 to 20	3 to 4	??
Mitsubishi MiEV	83		22.5	6	80% in 1/2 hr
Toyota RAV4 BEV prototype*	100	?	28	12	

*Toyota assures reporters that the production RAV4 will have shorter charging times

BEVsoutlet cost, charging times.XLS; WS 'charging times' F10 5/10/2011

When we first began modeling the costs of installing electrical outlets for BEVs and PHEVs, we used data published by the Idaho National Laboratory[2]. They estimated that a Type II residential outlet would cost between $1,250 and $2,146 each, based on average residential costs for installing a 240-V outlet.

But actual real-world costs were estimated at $8,043 per Type II outlet based on installing 4,600 outlets for $37 million (including $15 million of government funds) by Coulomb Technologies, and $18,400 per Type II outlet for a price of $4.6 million (including $2.6 million government money) to install 250 outlets in Hawaii[3]. But since these "costs" were heavily subsidized by the government, they may not reflect actual costs, but may be the prices that the contractor could charge and still win the job.

In addition, Coulomb Technologies in their annual merit review to the DOE stated that residential customers have to pay for installation of the Type II outlets, so the $37 million project cost does not

[1] The 38-hour estimated is for an early *prototype* of the Toyota RAV4 BEV made in conjunction with Tesla Motors; but Toyota has assured reporters that the production version of the RAV4 will be charged more quickly. See Jana Hartline "Advanced Technology Vehicle Overview," presented at the Toyota Sustainable Mobility Seminar, La Jolla, California, available at: http://www.toyota.com/esq/pdf/2011_SMS_Hartline&Soto.pdf , April 4, 2011.

[2] K. Morrow, D. Karner, & J. Francfort, "The U.S. Department of Energy Vehicle Technologies Program-Advanced Vehicle Testing Activities- Plug-in Electric Vehicle Charging Infrastructure Review," Battelle Energy Alliance Contract No. 5/8517, Report # INL/EXT-08-15058, November 2008. Available at: http://avt.inel.gov/pdf/phev/phevInfrastructureReport08.pdf

[3] See http://www.mauiweekly.com/page/content.detail/id/502980/Federal-funds-used-for-charging-systems.html?nav=17

include all installation charges. If we assume a 50/50 split between residential and public outlets, then this would add another $2.76 million to the price tag[4], raising the average outlet cost to $8643/BEV[5].

ECOtality also reported on their project to install 14,000 Type II outlets to support 8,300 BEVs for a total cost of $230 million, of which $114.8 million came from Federal Recovery (ARRA) funds[6].

This works out to $16,429 per outlet or $27,711 per BEV supported[7].

Table 2 Prices charged by ECOtality for their EV project for Type II BEV charging outlets

The EV project by ECOtality					
	Total Costs	Number of outlets	Cost per outlet	Number of BEVs supported	Cost per BEV
government	$ 114,800,000				
Industry	$ 115,200,000				
Total	$ 230,000,000	14,000	$ 16,429	8,300	$ 27,711

BEVs outlet cost, charging times.XLS; WS 'ECOTALITY' i 11 5/17/2011

Table 3. Summary of estimated BEV & HEV outlet costs

	Voltage	Current	Max Power (kW)	Electrification Coalition	Idaho National Laboratory	Average of Three bids to retrofit 300-car Boulder Parking Garage [1]	Coulommb Technologies [2]	Hawaii Outlets [3]	ECOtality [4]
Type I Residential	120	20	1.9		$833 to $878				
Type II Residentia	240	40	7.7	$500 to $2,500	$1,250 to $2,146		$8,043	$ 8,643	$ 27,711
Type II Public	240	40	7.7			$12,400			$ 27,711
Type III Public	480	??	??	$25,000 to $50,000		$106,000			

[1] Engineering contractor bids to retrofit Boulder, Colorado Parking Garage obtained by Kreider & Associates, LLC

[2] Based on a price of $37 million ($15 million government funds) to install 4,600 Tyoe II outlets

[3] Based on a price of $4.6 million ($2.6 million government funds) to install 250 outlets.

[4] Based on a price of $230 million [$114.8 million government funds] to support 8,300 BEVs

BEVs outlet cost, charging times.XLS; WS 'Outlet costs' J 11 5/17/2011

But more recently, Kreider and Associates obtained three firm contractor bids[8] to modify an existing 300-car parking garage in Boulder, Colorado with 10% Type III chargers and 90% Type II outlets[9]. The

[4] 2,300 residential installations at $1,200 each.

[5] $39.76 million/ 4,600.

[6] See: http://www.businesswire.com/news/home/20110516005772/en/ECOtality-Completes-Installation-1000-Blink%C2%AE-Level-2

[7] The Electrification Coalition recommended that two outlets be installed for every BEV initially to overcome "range anxiety;" it appears that ECOtality used a 1.7 ratio of outlets to BEVs in their EV project.

[8] Dr. Jan F.. Kreider, Kreider & Associates, Boulder, Colorado, presented to the *Toyota Sustainable Mobility Seminar*, La Jolla, California, April 6, 2011, Available at: http://www.toyota.com/esq/pdf/11_SMS_Kreider.pdf

average of these three bids to retrofit an existing parking garage were $12,400 for each Type II outlet and $106,000 each for the Type III charger. These are probably the most accurate estimates of electrical infrastructure costs since they are based on competitive bids without any government subsidies.

The Electrification Coalition, a group of organizations supporting the development and deployment of BEVs and PHEVs (which they call "GEVs" for Grid Enabled Vehicles), have recommended that governments and utilities install two Type II outlets initially for each GEV sold to overcome "range anxiety" on the part of prospective GEV buyers[10]. In that case, the cost electricity infrastructure would be at least **$24,800 per BEV** or PHEV, or $27,711 per BEV using the ECOtality prices and 1.7 outlets per BEV.

Hydrogen fueling infrastructure. For comparison, some hydrogen fueling stations for fuel cell electric vehicles (FCEVs) will cost millions of dollars, but, since FCEVs can be refueled in quickly (the average fueling time for 28,000 high pressure hydrogen fueling events for 155 FCEVs that traveled over 3 million miles monitored by DOE was 4.4 minutes)[11] each station can fuel thousands of FCEVs. For example, the Institute for Transportation Studies at the U. of California at Davis[12] based on industry cost data, estimates that the cost for a 1,000 kg/day station is approximately $5.1 million, but this station could support 2,112 FCEVs[13], or a cost of **$2,432 per FCEV**. The DOE's H2A detailed modeling[14] of hydrogen fueling stations estimates that a larger capacity station producing 1,500 kg/day of hydrogen would cost $4.71 million, but this larger station could support 3,169 FCEVs or a cost of **$1,486FCEV**.

The hydrogen infrastructure cost data are summarized in Table 4 for a variety of fueling station options; all data are from UC-Davis[8] unless otherwise specified.

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[9] These are costs to retrofit an existing parking garage, so costs for new facilities should be less. However, most charging outlets will undoubtedly be placed in existing facilities, so these costs may be representative of real-world costs.

[10] *Electrification Roadmap: Revolutionizing Transportation and Achieving Energy Security*, by the Electrification Coalition, released November 15, 2010, available at http://www.electrificationcoalition.org/

[11] Click on "monitoring" link at http://www.cleancaroptions.com/html/ev_fueling_time.html for the report by Keith Wipke, Sam Sprik, Jennifer Kurtz, & Todd Ramsden, "2011 Composite Data Products: National FCEV Learning Demonstration," NREL report presented to the Fuel Cell and Hydrogen Energy Association Conference, Washington, D.C., March 29, 2011.

[12] *Jonathan S. Weinert & Timothy E. Lipman, "An Assessment of the Near-Term Costs of Hydrogen refueling stations and station components," Institute for Transportation Studies, U. of California at Davis, Final Report # UCD-ITS-RR-06-03, January 13, 2006; available at: http://hydrogen.its.ucdavis.edu/research/track2/tr2pr1

[13] Assuming 11,800 miles per year and a FCEV fuel economy of 68.3 miles/kg of hydrogen (Toyota FCHV-adv.)

[14] See this link for the DOE's H2A cost model case studies: http://www.hydrogen.energy.gov/h2a_prod_studies.html

Table 4. Estimated cost of hydrogen fueling infrastructure per FCEV supported and average cost of hydrogen in $/gallon of gasoline on a range-equivalent basis

Hydrogen infrastructure cost per car

VMT/year 11800
FCEV f.e. ########## 0.47kg/day
Today-UC-davis

Hydrogen fuel cost ($/gge:gallon of gasoline on a range-equivalent basis)

Average f.e. gain: 1.93
HEV f.e./ICV f.e. 1.45
FCEV f.e./ICV f.e. 2.4
HEV % 50%

Station Type	kg/day	FCEVs supported	Installed Cost($M)	Cost per FCEV & total cost for 1 M FCEVs ($M)	Average $/FCEV		Hydrogen Cost ($/kg)	Hydrogen range-equivalent Cost ($/gge)	Average Hydrogen Cost ($/gge)	
Mobile refueler	10	21	0.243	$ 11,571			$31.0/kg	$16.3/gge		
SMR	100	211	1.048	$ 4,967			$13.0/kg	$6.8/gge		
SMR	113	238	1.078	$ 4,529			$12.3/kg	$6.5/gge		
SMR	480	1,014	2.740	$ 2,702			$4.5/kg	$2.4/gge	Average:	Average:
SMR	565	1,193	3.088	$ 2,588	$ 3,201	$ 4,038	$7.0/kg	$3.7/gge	$3.64/gge	$4.91/gge
SMR	1000	2,112	5.137	$ 2,432			$6.5/kg	$3.4/gge		
LH2 station	1000	2,112	2.697	$ 1,277			$7.2/kg	$3.8/gge		
HTFC energy station	91	192	1.345	$ 7,005			$4.9/kg	$2.6/gge		
DOE-H2A-SMR	1500	3,169	4.71	$ 1,486			$3.39/kg	$1.8/gge		
Current-NRC/NAS-SMR	480	1,014	1.848	$ 1,822			$3.5/kg	$1.8/gge		
Future-UC-Davis SMR	480	1,014	1.458	$ 1,438	$ 1,191		$4.3/kg	$2.3/gge	$1.74/gge	
Future-NRC/NAS	480	1,014	0.957	$ 944			$2.3/kg	$1.2/gge		

BEVs outlet cost, charging times.XLS; WS 'H2 cost per car' N 22 5/1 /2011

SMR = steam methane reforming (Making hydrogen from natural gas and water); LH2 = liquid hydrogen supplied to the station by tanker truck; HTFC = high temperature fuel cell, such as a molten carbonate fuel cell (MCFC) used to convert digester gas from a waste water treatment plant to electricity, heat and hydrogen for fueling vehicles) H2A = the DOE's cost model for hydrogen systems. NRC/NAS = the National Research Council of the National Academies of Science)[15]

Conclusion: the infrastructure to support one million BEVs will cost on the order of $24.8 Billion (assuming the Electrification Coalition's recommendation of two Type II 20-Volt outlets per BEV), or $12.4 Billion if one public outlet per BEV is deemed adequate)

The average cost of a hydrogen infrastructure for one million FCEVs would be approximately $3.2 billion initially (ignoring the initial mobile refueler option), dropping to $1.19 Billion in the future according to the UC-Davis and NRC estimates. Note that the estimated average cost of hydrogen would be $3.64/gge initially, falling to $1.74/gge in the future[16].

Conclusion: the electrical outlet infrastructure for BEVs may cost between 4 and 20 times more than the cost of a hydrogen infrastructure!

[15] "Transitions to Alternative Transportation Technologies – A Focus on Hydrogen," by the Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies, by the National Research council of the National Academies, National Academy Press, Washington, D.C., 2008, available at: http://books.nap.edu/openbook.php?record_id=12222&page=R1

[16] These costs in $/gge represent the cost of hydrogen such that the owner of a FCEV would pay the same fuel cost per mile as the owner of a gasoline vehicle[assuming a 50/50 mix of HEVs and non-hybrid gasoline cars] with gasoline at the stated price.

This is consistent with the McKinsey & Company analysis of alternative vehicles for the EU[17], where they concluded that electrical infrastructure would cost 5.3 times more than hydrogen infrastructure, as shown in Figure 1.

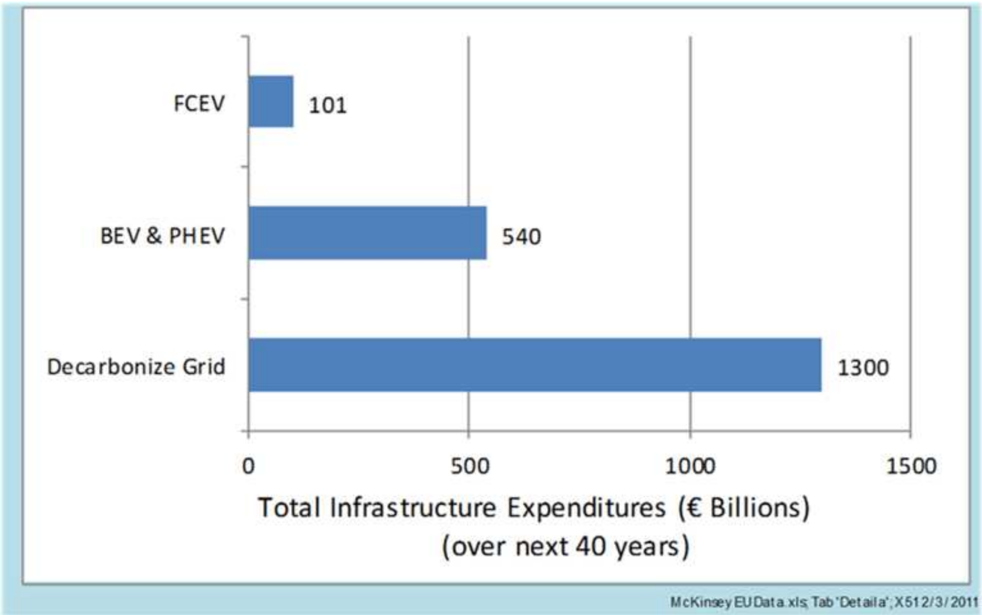

Figure 1. Estimated cumulative costs over 40 years for electrical infrastructure for PHEVs and BEVs and hydrogen infrastructure for FCEVs estimated by McKinsey & Company for the EU.

[17] For a summary of the McKinsey report, see: http://www.cleancaroptions.com/McKinsey_EU_Report_key_points.pdf
The full Mckinsey report "A Portfolio of power-trains for Europe: a fact-based analysis- the Role of battery electric vehicles, plug-in hybrid electric vehicles and fuel cell electric vehicles" can be downloaded from http://www.now-gmbh.de/die-now/publikationen/studie-entkarbonisierung-individualverkehrs.html

From another perspective, consider how many hydrogen fueling stations could be built with the $230 million spent on the EV infrastructure project:

Station Type	kg/day	FCEVs supported	Installed Cost($M)	Number of H2 Stations for $230M	Number of FCEVs supported by $230M
Mobile refueler	10	21	0.243	947	19,996
SMR	100	211	1.048	219	46,366
SMR	113	239	1.078	213	50,935
SMR	480	1,014	2.740	84	85,124
SMR	565	1,194	3.088	74	88,906
SMR	1000	2,113	5.137	45	94,591
LH2 station	1000	2,113	2.697	85	180,168
HTFC energy station	91	192	1.345	171	32,876
DOE H2A SMR	1500	3,169	4.71	49	154,750
Current-NAS SMR	480	1,014	1.848	124	126,211
Future-UC-Davis SMR	480	1,014	1.458	158	159,972
Future-NAS	480	1,014	0.957	240	243,719

BEVsoutlet cost, charging times.XLS; WS H2 for $230M; F18 5/17/2011

Thus for $230 million we could install between 49 to 171 regular hydrogen fueling stations, or up to 947 of the hydrogen mobile refuelers. These stations could support between 33,000 and 180,000 FCEVs, with an average of 95,000 FCEVs supported with $230 million in infrastructure funding (excluding the mobile refuelers), compared to only 8,300 BEVs or PHEVs supported by this same expenditure. In other words, $230 million would support an average of 11.5 times more FCEVs than BEVs!