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Influences on PEV Cost-effectiveness: Powertrain Design; Battery, Infrastructure, and Fuel Costs; and Vehicle Use

Danilo J. Santini, Argonne National Laboratory Senior Scientist

Operating Agent

IEA Hybrid and Electric Vehicle Implementing Agreement

Task 15: Plug-in Hybrid Electric Vehicles

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Sponsor: D. Howell, Energy Storage Program,

Vehicle Technologies Program, U.S. Department of Energy

This presentation draws from several different papers either published or accepted for April publication at the SAE 2013 World Congress. The presentation includes an initial brief synthesis across the various papers written, in preparation for a report (in progress). Most of the work was done during a period when Dan Santini was either a Country Expert or, more recently, Operating Agent for the IEA Hybrid and Electric Vehicle Implementing Agreement Task 15 Study of Plug-in Hybrid Electric Vehicles. The work in the body of this presentation focuses on U.S. results. A version with an appendix will be provided if requested. That more lengthy version puts these results in context with respect to work by Country Experts from Germany who are participating in the study. For most of the slides the vehicle attributes rely on a set of vehicle simulations agreed to jointly by U.S., German, and French Country Experts, with actual simulations jointly conducted by one French (IFP Energies nouvelles) and one U.S. (Argonne) research laboratory.

Adaptation to & acceptance of existing conditions is critical. It is not just batteries!

- 1895-1920 – ICE improved faster than batteries, EVs
  - Jump in ICE kW 1895-1905 (not EVs)
  - Existing refined petroleum products infrastructure
  - Anchored by early adopter niche (doctors)
  - Adaptation of ICE to existing infrastructure
    - Light with high ground clearance
    - Buggy and bicycle parts use
    - Gasoline delivered with modified tank wagons
  - 20 yrs before dedicated stations, gas tax, paved roads, high mph
- 1990-present – Batteries faster improvement than ICE
  - Jump in li-ion power vs. 1990s Ni-MH
  - "Free" excess power with high kWh packs
  - Chargers standardized to now ubiquitous electric plugs
  - First PEVs spun-off (Prius for PHEV, Lotus for EV)
  - Innovator adopters exist – environmentalists, energy security hawks

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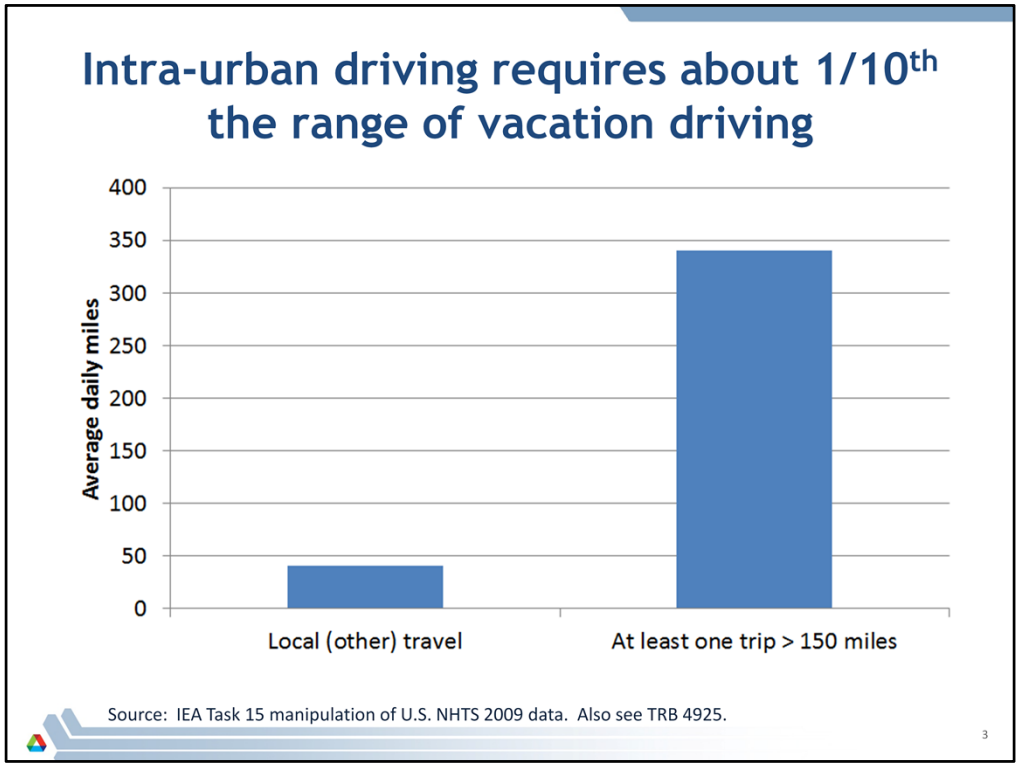
Under the first bullet, see
Santini, D. J. *Electric Vehicle Waves of History: Lessons Learned about Market Deployment of Electric Vehicles* Ch. 3 of Seref Soylu, ed. Electric Vehicles –The Benefits and Barriers, InTech. Rijeka, Croatia (Sept. 2011). http://www.intechopen.com/articles/show/title/plug-in-electric-vehicles-a-century-later-historical-lessons-on-what-is-different-what-is-not-

An overarching point is that the original ICE was able to expand far more rapidly than the EV because it was able to go nearly anywhere and find fuel due to the prior existence of a delivery system focused on refined petroleum products, particularly kerosene. Lighter weight than EVs helped ICEs avoid getting stuck in mud and allowed easier towing of vehicles when they did break down. The EV was then far more confined by infrastructure than today, but this presentation illustrates that infrastructure for driving in the countryside remains a problem for the EV.

In both cases, adaptation of the motive power to existing vehicle component production capabilities seems critical. The li-ion PHEV demonstration was possible because HEVs had been enabled by NiMH and could easily be modified. The Tesla roadster probably tapped into the customer base that had been interested in the most popular type of EV of the 1990s, the GM EV1. It adapted a Lotus roadster body. However, like GM before it for the EV1, Tesla is developing its own unique bodies for its new EVs, now available as the Model S.

In the diffusion of innovation sequence Rogers identifies "innovators" as first, then "early adopters". We see the early 1900s doctors as early adopters choosing ICE "buggy"s to replace horses, which were much slower to get ready to ride in emergencies. They were pragmatic, not "visionary". Today, we see environmentalists and security hawks as visionary innovators. The presentation is looking for an initial early adopter market where ownership for the subgroup would be a pragmatic decision from their point of view.



Details on the breakout of these two categories of vehicle use are found in this year's TRB13 4925 paper "Deploying Plug-in Electric Cars Which are Used for Work: Compatibility of Varying Daily Patterns of Use with Four Electric Powertrain Architectures" by Santini et al.

Gasoline has ~10 times the volumetric energy density of Li-ion. Li-ion enables intra-city PHEVs & EVs but Li-ion EVs won't replace CVs for inter-city travel

Energy Source	Nominal Energy Content	
	Wh/kg	Wh/L
Hydrogen	28,000	1310*
Gasoline	12,300	9,200
Natural Gas	9,350	2500**
Coal (bituminous)	8,200	
Ethanol	8,030	6,350
Methanol	6,200	4,930
Li-ion Battery (various types)	110 – 160	85-200***
Nickel Metal Hydride Battery	60 – 120	
Lead-Acid Battery (sealed)	30 – 50	

* at 700 bar, 25°C, ** at 250 bar, 25°C, *** pack volume from "EV Everywhere: Initial Framing Document"

Wh/kg from S. Shaw 2nd Graphite Conf. presentation 12-2013. Wh/L from multiple sources

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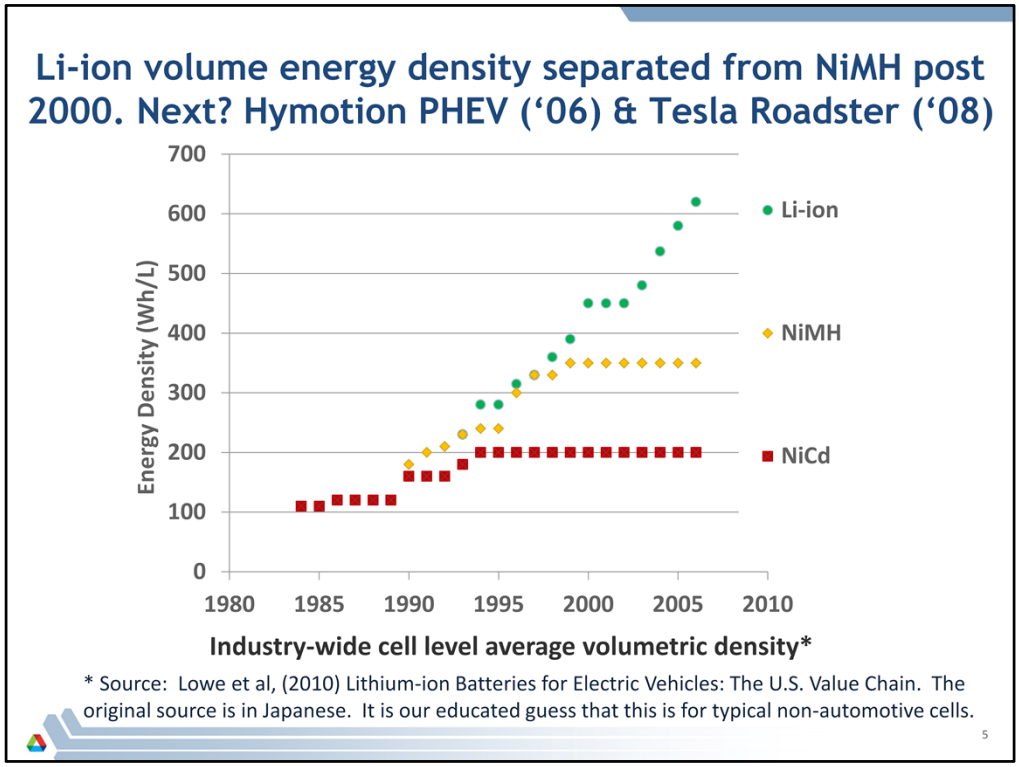
This chart was prepared by using (1) the Argonne GREET model, (2) a presentation from the 2nd Graphite Conference by S. Shaw "Current and future trends in EVs and HEVs", Dec. 5-6 London (Shaw's affiliation is Roskill Information Services), and (3) The DOE EV Everywhere framing document. Mike Duoba of Argonne provided us the compressed energy density values for hydrogen (note the higher pressure) and natural gas. Shaw had numbers for all of the labeled values. We focused on the key comparisons for volumetric energy density, using multiple sources. Obviously, we did not locate numbers we wished to rely on for coal, NiMH, and Lead-Acid. We presume that the EV Everywhere 2012 pack level information is for Li-ion packs. If it is not, we may have understated the volumetric density of li-ion. 2015 values were 85-450. The next slide has a peak of over 600 in 2006, so we judge that those values must be at the cell level.



The original source for this data is

Ikoma, Munehisa. (2006). Present Situation and Trend of Batteries. *Matsushita Technical Journal* Retrieved August 4, 2010, from http://panasonic.co.jp/ptj/v5204/pdf/p0101.pdf.

We found it in: Lithium Ion Batteries for Electric Vehicles: The U.S. Value Chain, by Marcy Lowe et al. It can be downloaded from the web.

Wh/kg (mass energy density) had a similar increase. W/kg (power) increase allows EVs on all roads, including Interstates

Tested Vehicle	Battery Chemistry	~ Wh/kg (energy)	W/kg (power)
1997 EV1	Lead-Acid	11-13	100
1998 RAV4	Ni-MH	50-60	120
1999 EV1	Ni-MH	52-58	220
2009 Mini-E	Li-ion	113-118	580@ 100% SOC 420@ 50% SOC

Source: DOE funded field tests: http://avt.inl/fsev.shtml

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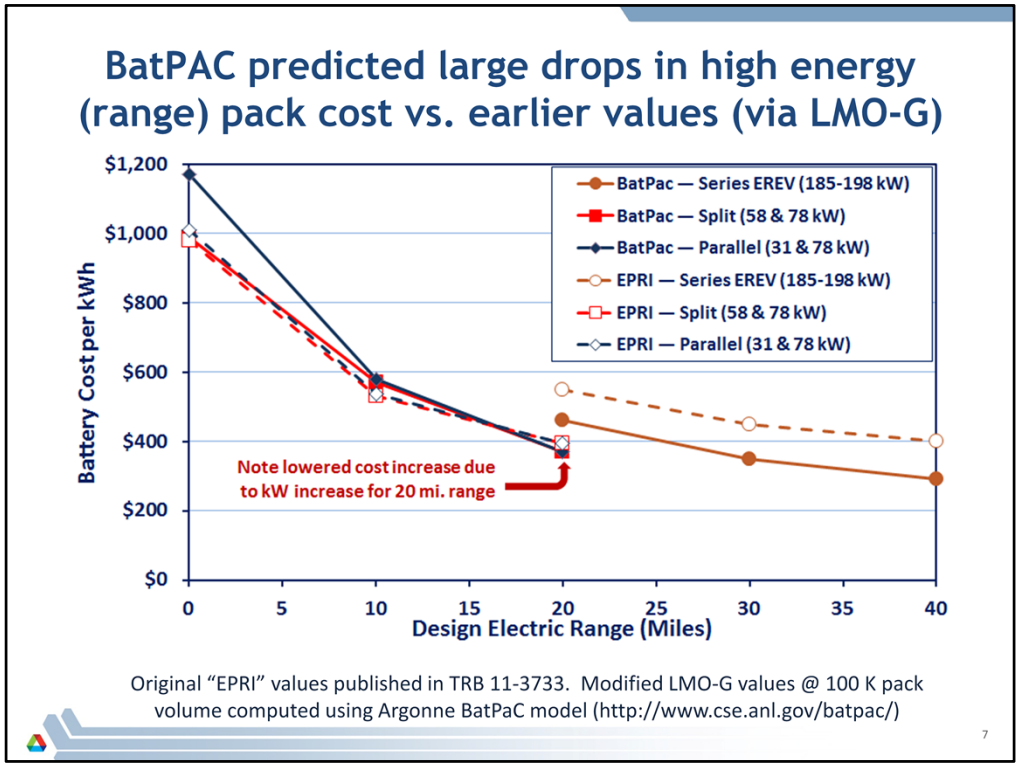
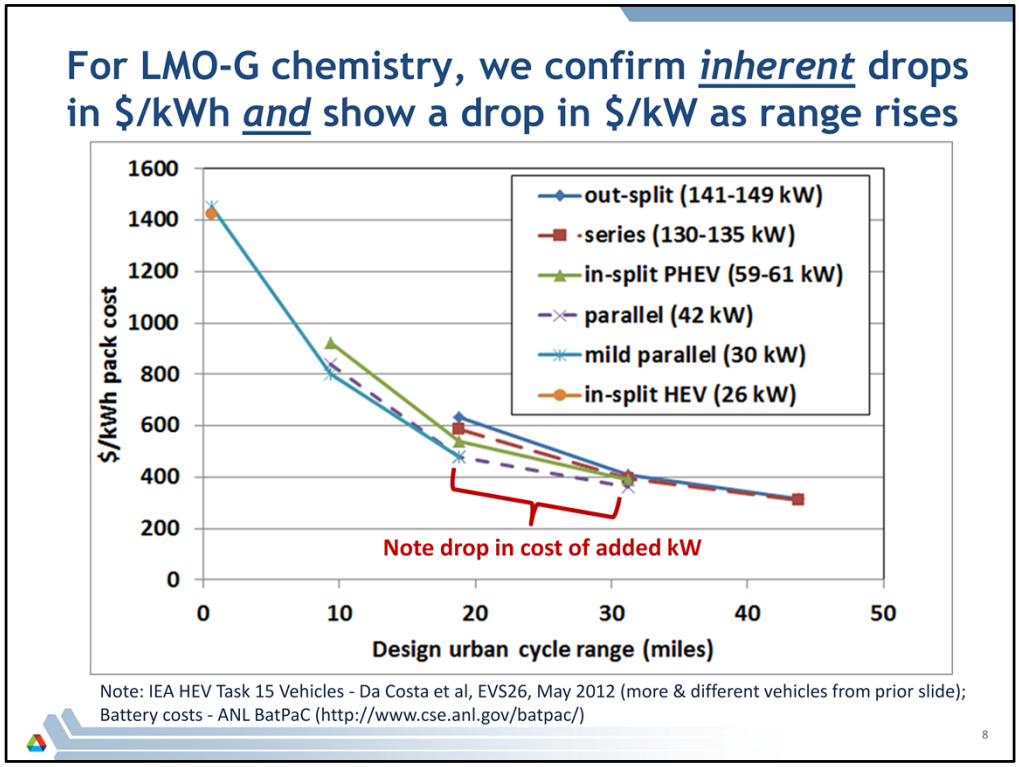
The test results (and many others) can be found at the Idaho National Lab Advanced Vehicle Testing Activity (AVTA) web site. The incremental contribution for this presentation is the last column with the power density numbers. There is a hint at one of the issues with some li-ion battery chemistries/packs, significant variation in power level as a function of state-of-charge. Too much detail for this presentation though.



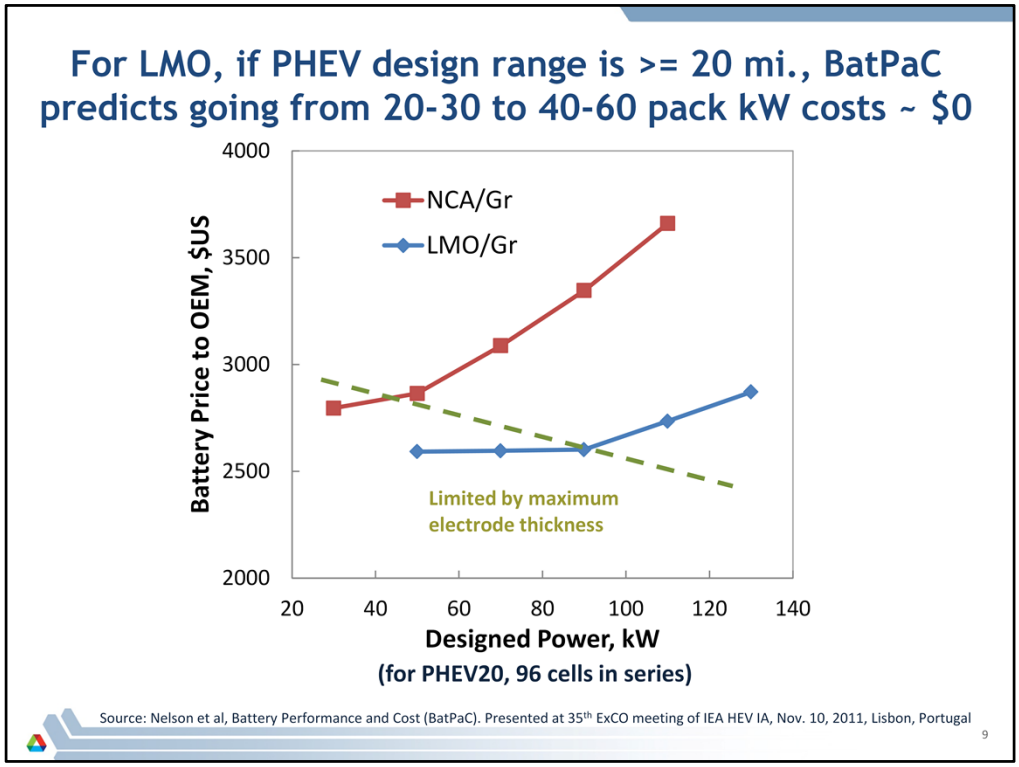
I gratefully acknowledge the past opportunity to work with the Electric Power Research Institute. Under a subcontract, they produced multiple simulations of different PHEV designs, and documented a method of estimating overall cost for the vehicles. Overall results were published in TRB11-3733 "Where Are the Market Niches for Electric Drive Passenger Cars?" by Santini et al. and presentations on methods and results were made at two other conferences. The major drawback was that there was not any documentation of the method of estimating battery cost. Accordingly, Paul Nelson, a veteran semi-retired Argonne battery researcher at the Argonne Chemical Sciences and Engineering division was asked to develop a "transparent" battery cost model. He began that effort and was later joined by Kevin Gallagher. Several publications were spun off of that effort and the model was put in the public domain (http://www.cse.anl.gov/batpac/about.html). The model was thoroughly reviewed and revised and is contributing to better worldwide investigation of battery attributes. Several battery chemistries are included in the model. Anant Vyas, a participant in the earlier study with EPRI, updated the originally submitted battery pack cost estimates with BatPaC (for the EPRI vehicle set) and created this chart, using the LMO chemistry. The LMO chemistry generally leads to the lowest $/kWh estimates of the included chemistries for PHEVs (for the EV the costs of the better of the two included NMC are very close to LMO, and the pack is smaller and lighter). The German Aerospace Institute investigation of PEV costs used an NMC chemistry (details unspecified) for the PEVs. After plotting these results, it was noticed that the increase in cost from the low to the high kW EPRI vehicles with 20 miles of range was greater in EPRI's original submission than for our re-estimates, so that was highlighted (you have to look carefully, it is not the main point of the slide). The next two slides re-iterate the findings on low cost of battery pack power.



This chart presents battery pack costs for the LMO chemistry, using BatPaC, for the group of vehicles jointly simulated by Argonne and IFP Energies nouvelles in the IEA HEV Task 15 study. Though many are similar, this is a different set of vehicles than for the prior slide, using later versions of the vehicle simulation software at the two institutions. A couple of additional vehicles were simulated only with Argonne's Autonomie model, to address emerging questions about the role of peak battery pack power in the cost and fuel consumption behavior of the simulated vehicles. In this case the power levels for any given line (labeled value in the legend) have a more narrow range than in the prior slide, and more vehicles with a relatively constant power level are available. So this slide and our more recent estimates isolatespower considerations more clearly. These simulations include the Voltec "output split" system; the EPRI simulations were done before that was possible.

For any pair of battery pack power levels one can see that there is a reduction in incremental cost of power as range (pack kWh) increases. The last case on the lower right is similar to the Volt, though it has a bit more range. It can be seen that at a range in this area, if a vehicle designer requested LMO battery packs, the cost of having enough power from the battery to assure consistent all electric operation during charge depletion (battery discharge) would be negligible. Of course the electric machines have to be bigger, so this is not free at the vehicle level. But the temptation might be to go for all electric operation capability, all the time and see what the market response would be. The next slide (and this one) shows that for the PHEV with 19 miles of design range, there would be a notable increase in pack cost when going above 100 kW of capability. Still, it is not large.

An important effect enhancing the viability of PEVs is the sharp drop in $/kWh cost as one goes from an HEV to PEV. There is not a narrow range of "automotive battery pack costs" that analysts evaluating PEVs can use. For any single chemistry, the $/kWh costs should drop as power to energy ratio declines. Many analysts have mistakenly assumed (and still do) that HEV pack costs would be representative for PEVs. This phenomenon showed up in prior EPRI studies of PHEVs with NiMH packs. BatPaC investigations have since helped experts realize that this is an inherent trade-off.

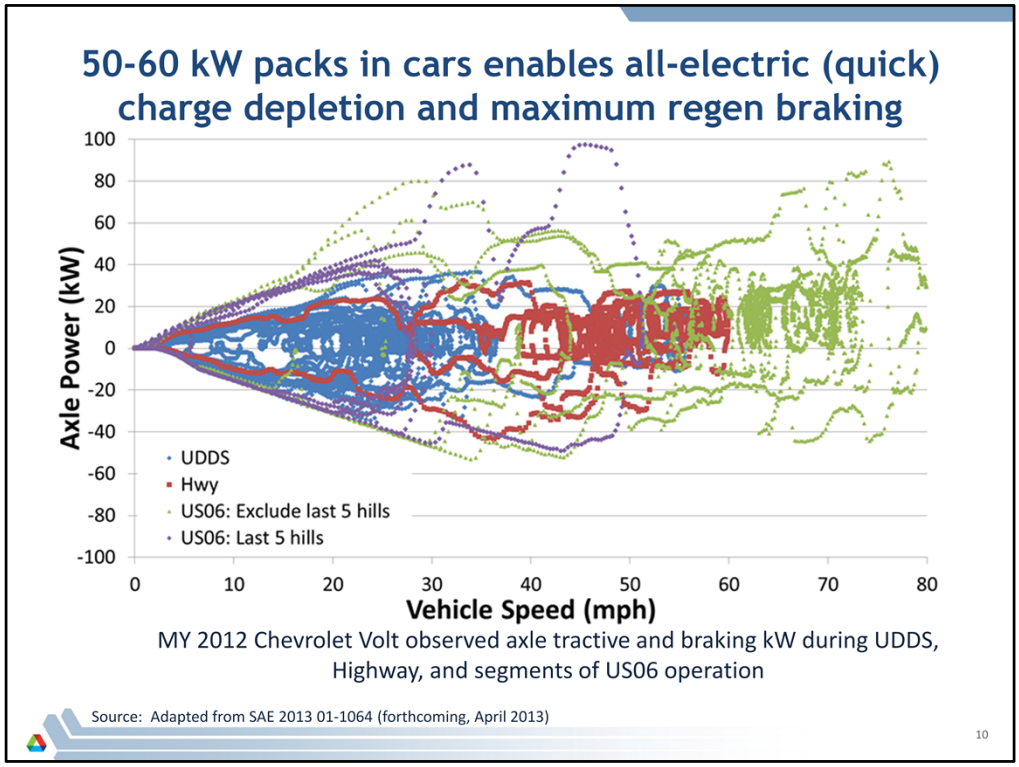


The lines on the prior two charts are (approximately) constant power lines with energy varying. This chart has constant energy lines at the 20 mile point. These are not for exactly the same data and use an earlier version of BatPaC than used in the prior chart.

Kevin Gallagher generated this slide to illustrate the effect of limitation of electrode thickness to 100 microns. For a given amount of energy storage capability (the case in this graph) power in batteries is enabled by adding current collectors (aluminum and copper). More separator material is also required. In effect, the area of surface contact between electrodes and current collectors is increased, allowing faster exit of electrons, and more power. But, as the chart above shows this increases cost. However, what about the flat portion of the cost curve. Since electrode thickness is limited, and structurally there has to be copper and aluminum to hold the electrode material, once the copper, aluminum and separator materials have been reduced to the point where the electrode thickness can no longer increase, then even if the vehicle designer requests less power (by designating smaller, less powerful electric machines) the battery pack must still have enough copper, aluminum, and separator to hold the electrode material, so the power capability of the pack cannot be reduced. For the case above, once one gets to 90 kW for LMO the vehicle designer would be well advised to consider whether there is a good use for the extra power. Our simulations suggested that there are multiple benefits of power in everyday driving that are significant until about 60 kW. After that the only PHEV benefit is to assure that during charge depletion the engine does not come on in a drag race (0-60 run) or very dire emergency requiring all-out acceleration.

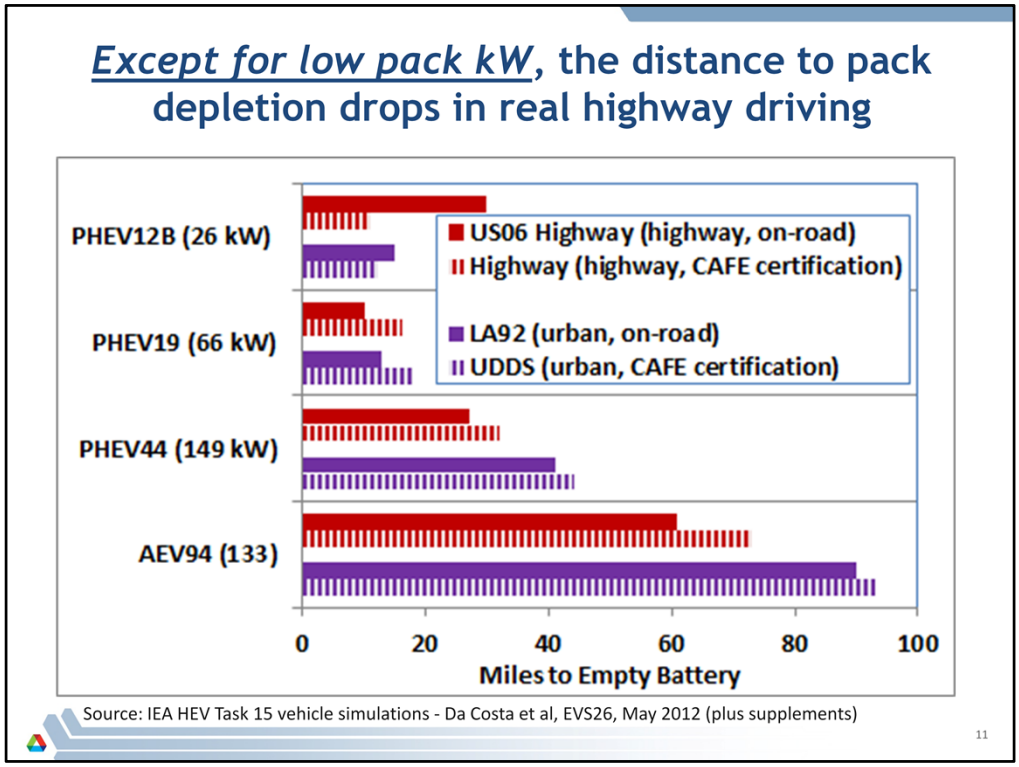
If you study the prior chart (again, not exactly the same data) it appears to show constant cost for the PHEV20 from 30-42 kW, but a slight increase by 59-61 kW.

A note on the effect of the electrode thickness limit for constant power (the graph above is for constant energy). In past years we prepared two EVS papers with aggregate results from BatPaC. In the first, we limited electrode thickness to 100 microns and noticed a cost kink that arises in a different fashion. At constant power, electrode thickness and energy can only be added up to the point where the electrode thickness limit becomes binding. The cost kink did not seem an overwhelming effect in overall cost, but it does nevertheless seem to be important “at the margins”. In the next paper we allowed the model to generate 300 microns, but got a lot of negative comment on the impracticality of assuming such a thickness is possible by 2020. BatPaC reviews led us to use 100 microns as a default limit in our present simulations. 100 microns is a limit, not a result. The HEV packs end up with less than 100 microns. Adding electrode thickness with the amount of copper, aluminum and separator constant only causes modest cost increases. The sharp $/kWh plunge from HEV to initial PHEV is partly related to this effect. However, once the limit is hit, more current collector material (aluminum and copper foil) and separator material has to be added, driving up the cost of just adding energy. The decline in the cost curve then slows as kWh and range increase on the other side of the kink.



This plot has been developed by Eric Rask of Argonne, using Argonne test data for a Chevrolet Volt. The Chevrolet Volt has well over 100 kW of battery pack power. The plot above examines how much of that power (actually, axle power – there are losses from the battery to the axle) is required in three different driving cycles. The UDDS (blue) and Highway (red) cycles are CAFE certification cycles. It can be seen that these two cycles cluster in certain speed ranges. For example the Highway does not include free flow Interstate driving, even though such driving is common in urban areas today (despite 55 mph speed limits). For these two cycles it has been well known for years that in actual driving cars accelerate and decelerate more rapidly. The cycles were originally "clipped" because the dynamometers available could not handle acceleration and deceleration beyond a certain point. Excessive in-use emissions led to a new dynamometer design that enabled testing at much higher rates of acceleration. That was followed by development of new cycles to conduct such testing. The US06 was one of those cycles. Cycle designers pushed the peak acceleration rates up specifically to cause measurement of criteria pollutant emissions for cars pushed hard. Criteria pollutant emission rates in these conditions were orders of magnitude higher than at UDDS or Highway peaks. One question is whether the rates were pushed so hard that they are atypical. The EPA OTAQ Report EPA420-R-06-017 shows that real world driving acceleration and deceleration rates are higher than for the UDDS and Highway, but less than for the US06. Thus, the power required for real world driving is not as great as implied by the two US06 segment plots. Taking this into account and using an educated guess, we assume that about 60 kW of battery pack power is likely to cover the vast majority of real world driving in future mid-size PHEV cars. The simulation results imply that this is enough for our lighter weight midsize car simulations. The engine does not come on during any drive cycle simulated (<u>including US06</u>) in charge depletion in our input split PHEV 19 and PHEV31, which have just over 60 kW of pack power. The Volt, however, is heavier than these simulated 2020 vehicles, thus the higher (than 60 kW) peak kW ratings needed to have it match the US06. Remember though that power to meet the US06 is not needed in real world driving.

Regenerative braking is limited by traction, though we cannot say whether the deceleration rates in the Volt tests approached this limit, just that the cycle was met with less than 60 kW at the wheels. EPA420-R-06-017 showed some real world deceleration rates outside of (but adjacent to) US06 limits, perhaps picking up some panic decelerations.

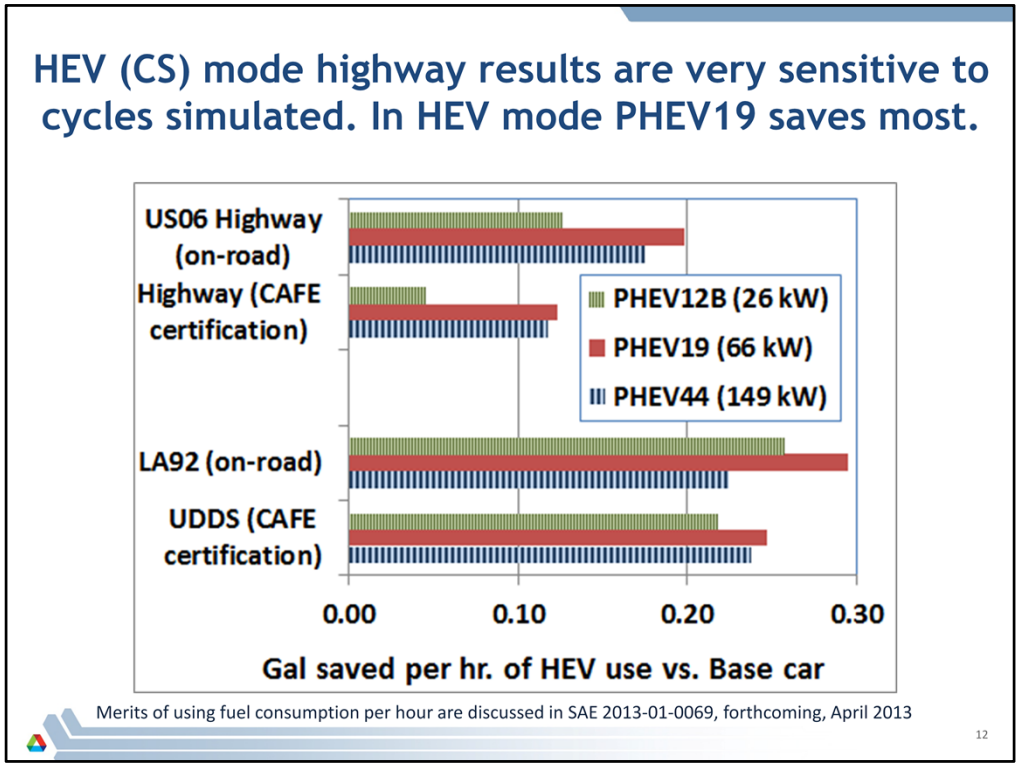


These results are based on IEA HEV Task 15 simulations. A subset of four vehicles was selected for use in TRB 4925, due to their similarity to PEVs available in the U.S. Top to bottom, the similar vehicles are Prius PHEV, C-Max Energi, Volt, and Leaf.
Tests of the Plug-in Prius at Argonne have yet to be completed. However, my colleague who drove one from home to work on Interstates for a distance well beyond the charge depletion design distance observed to me that he arrived at work with charge left. This is consistent with the simulation prediction for the 26 kW case.

Basically, one needs enough pack power to keep the engine from coming on during charge depletion. One can see from the prior chart that 26 kW would generally not be enough to keep this from happening.

EPA420-R-06-017 shows that real world driving involves more energy use per mile than for the UDDS or Highway at similar speeds. The added road load means that more kWh will be needed per mile during all-electric charge depletion in real world driving, so the distance to battery pack depletion will drop, as shown above for all vehicles simulated with more than 60 kW of pack power.

The dramatic differences in highway driving cycle results for the PHEV12B (12 miles of blended charge depletion distance in urban driving) with 26 kW of pack power imply that management of driving style could have a very significant effect for such vehicles. Reducing rates of acceleration should be very effective in assuring maximum use of electricity per mile in charge depletion.



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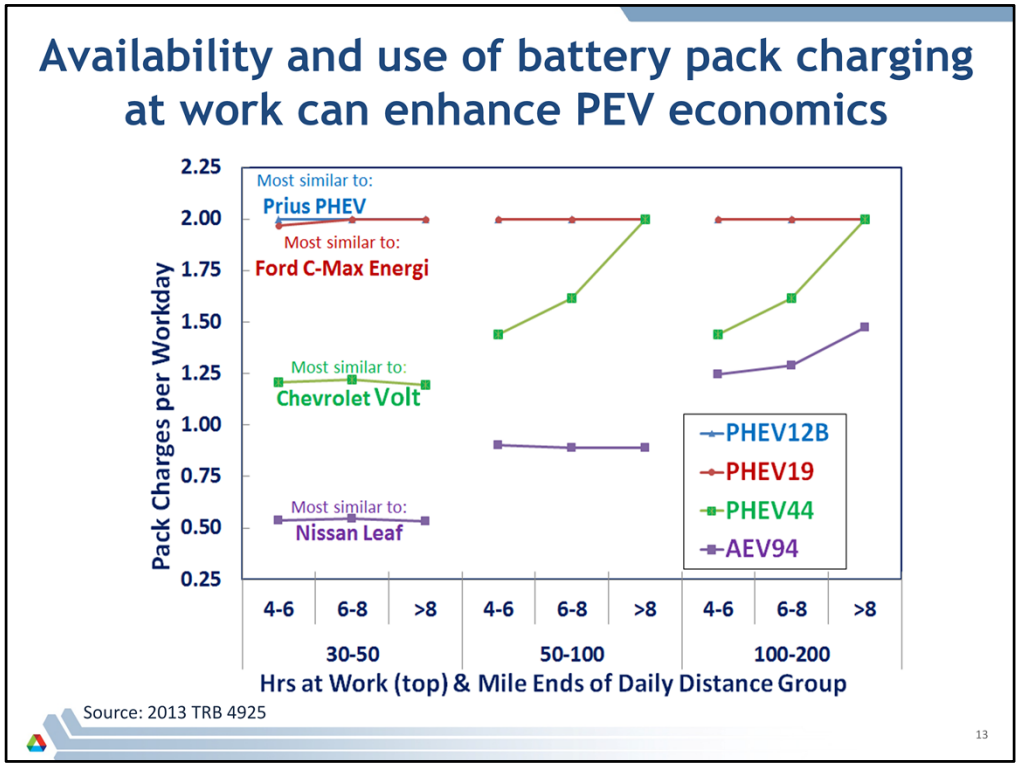
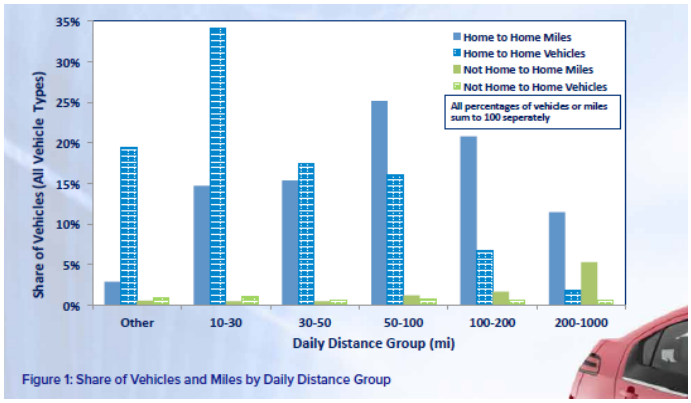
A result that was initially surprising was greater HEV mode (charge sustaining) efficiency for the PHEV19 with 60 kW of pack power, relative to the lighter PHEV12B with 26 kW. The hypothesis is that the added regenerative braking energy recovery enabled by a more powerful pack more than offsets the weight penalty of the larger pack. While the drop off of the PHEV44 *might* be due in part to the switch from an input-output split powertrain to input-output split, examination of the details suggests not because the fuel economy penalty is much less for Highway driving relative to UDDS driving for the output split. Note that the PHEV44 is closer to the PHEV19 in real world highway driving (US06 Highway) than real world urban driving (LA92) , which implies a very well chosen powertrain design for the probable use patterns of the PHEV44. The problem is simply the added mass that the PHEV44 has to carry relative to the PHEV19. As the average speed of the driving cycle increased, the CS mode % difference between the two vehicles generally declined, suggesting that the output split was designed to maximize highway efficiency, which is the logical thing to do if this vehicle would operate all electrically around town and only operate in CS mode on long trips, which tend to be high speed. In any case, the results show that CS mode fuel consumption is least for the PHEV19. These results also imply that the vehicles become more sensitive to style of driving when operated at higher average speeds.

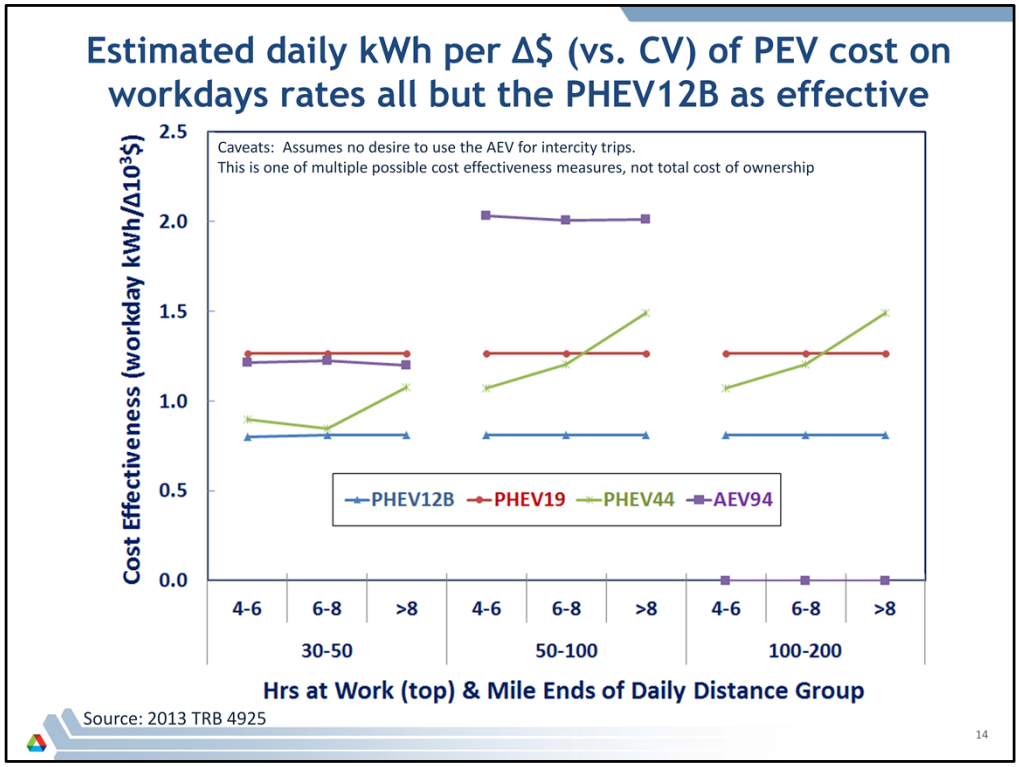


These results are based on selected IEA HEV Task 15 simulations. The chart from the TRB13 4925 paper "Deploying Plug-in Electric Cars Which are Used for Work: Compatibility of Varying Daily Patterns of Use with Four Electric Powertrain Architectures" by Santini et al.

This paper looks only at workday operation of vehicles driven to work. An interesting nuance not shown is that the groups above account for a lot of miles of travel, but not a large fraction of vehicles (see the paper).



The point of the chart (not the "figure") is that a battery pack must be "just right" in size. If it is small and can be charged in two points, then one can always get two charges in per day. This will still hold true until the battery gets too big to fully deplete by arrival at work. With the "level 1 chargers" at 1.4 kW per hour if a pack is too big and the vehicle does not stay parked long enough, the pack cannot be refilled. If it does get refilled, if it did not arrive empty then two charges will not be achieved. More charges of the pack is equivalent to increased utilization, which spreads costs over more kWh of daily charging. The AEV is most difficult to discharge twice a day and if the owner can, that means often driving near empty (empty on a cold day in a snowstorm), so range anxiety will be extreme.



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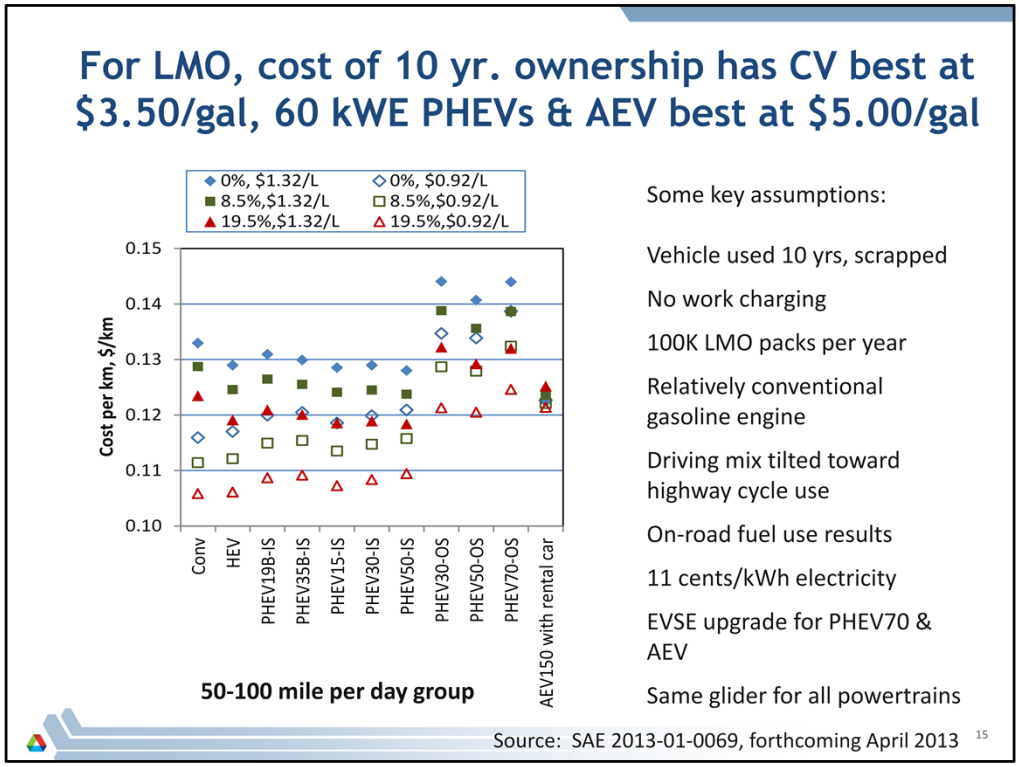
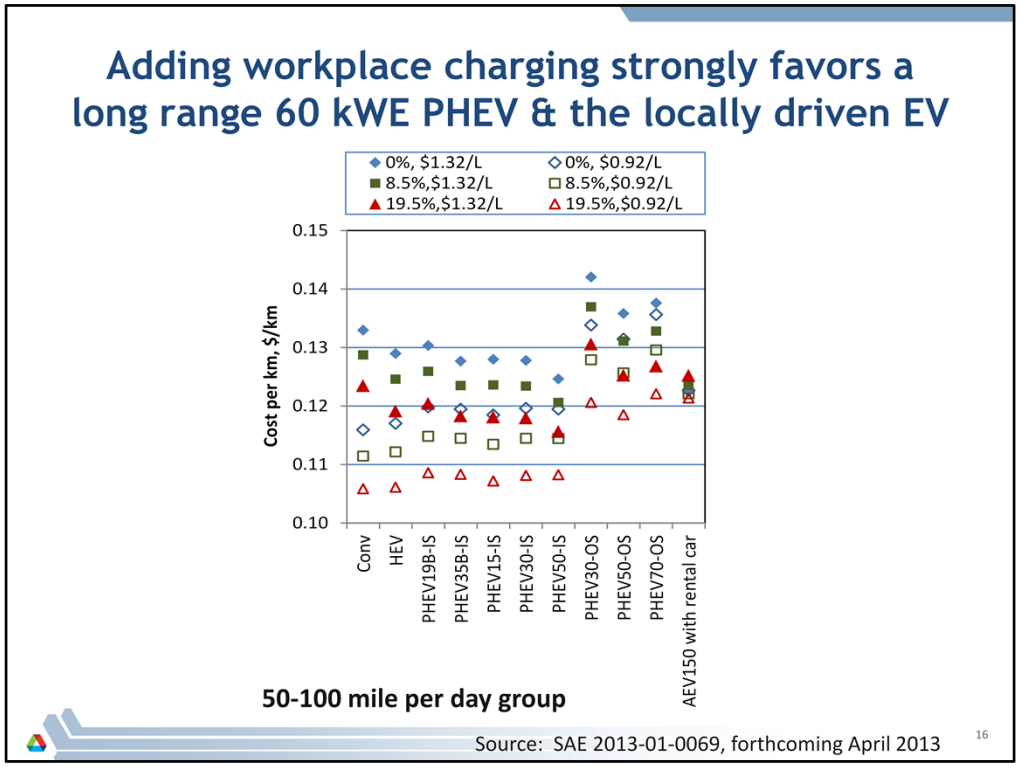
This is a cost effectiveness measure that totally ignores charge sustaining operation. It only addresses effectiveness on the workday, not on other days of the year. The daily kWh used is divided by the thousands of dollars of cost of the PHEV or AEV in excess of the conventional vehicle. The problem with the PHEV12B is that it does not have a big enough battery pack. The problem in slide 11 does not apply in these cases, since the distance to work exceeds even extended depletion distances. It is simply a matter of an HEV being an expensive vehicle. Adding only a few kWh to enable plugging in makes it expensive in terms of the kWh used for travel that one can accomplish per dollar of investment. In these distance groups the PHEV19 empties its pack before arrival at work and fully recharges itself at work even with only 4 hours, so it always achieves two charges per day. Its percent increase in kWh per day is much more than the percent increase in cost, and it always beats the PHEV12B. It usually beats the PHEV44 also, except in the two longer distance groups when the PHEV44 is emptied by arrival at work and can refill before departure from work, in 8 hours.

The AEV has a bigger pack than it needs in the middle group, but its cost is less than the PHEV44 because it does not have an engine. It benefits from the lowered cost increment and beats the PHEV44. While the AEV costs more than the PHEV19, its added pack size relative to the PHEV19 and ability to use it outweighs the added cost. In the longer distance group (100-200 miles) it cannot make the distance with two charges per day. At the short end of the 100-200 mile group it might have enough range, except on very cold or very hot days.



The forthcoming SAE 2013-01-0069 will present cost of ownership for all vehicles simulated for the IEA Task 15 study. The data are in metric terms for SAE. The PHEV ranges are in kilometers and costs are per kilometer. The four discussed in prior slides related to the TRB 4925 paper are included, but so are several more. At $5.00 per gallon, if the consumer wants to use the vehicle for significant vacation travel the added cost of an engine is worthwhile relative to an AEV. If the vehicle is only going to be used for intra-urban travel, then get an AEV and drop the engine. In the group illustrated, the PHEV31 with 62 kW battery pack is the least cost if the vehicle is used for vacation travel. At $5.00 gallon in this distance group the PHEVs with 60 kW or less and 31 miles of range or less, as well as the AEV, are a better buy than a conventional. The PHEV designed with a very high power battery pack (> 100 kW) and electric machines to assure all electric charge depletion, plus an engine, leads to too costly a vehicle in every case. Charging cost upgrades to allow second charges in less than 8 hours hurt the PHEV44 (PHEV70-OS). This paper focuses on average group conditions for a given vehicle, while TRB4925 allowed more variation of vehicle circumstances in the group for the same vehicle.



The forthcoming SAE 2013-01-0069 will present cost of ownership for all vehicles simulated for the IEA Task 15 study. The four discussed in prior slides related to the TRB 4925 paper are included, but so are several more. This case allows for work charging, which benefits the PHEVs with ~ 60 kW of pack power. At $5.00 per gallon, if the consumer wants to use the vehicle for significant vacation travel the added cost of an engine is worthwhile relative to an AEV. If the vehicle is only going to be used for intra-urban travel, get an AEV and drop the engine. In the group illustrated, the PHEV31 with 62 kW battery pack is the best all-purpose vehicle. At $5.00 gallon in this distance group the PHEVs with ~ 60 kW and 31 miles of range or less (PHEV50-IS), as well as the AEV, are a significantly better buy than a conventional. The PHEV designed with a very high power battery pack (>100 kW) and electric machines to assure all electric charge depletion, plus an engine, leads to too costly a vehicle in every case. Charging cost upgrades to allow second charges in less than 8 hours hurt the PHEV44 (PHEV70-OS). There may be cases where we could find a small niche for the PHEV44 in this group if we considered the case where workplace charging allows full recharges on workdays. This paper focuses on average group conditions for a given vehicle, while TRB4925 allowed more variation of vehicle circumstances in the group for the same vehicle.

Implications

PHEV cost effectiveness will vary by market segment, is favored by:

- **Longer average driving distances**
- **Inexpensive supplemental daytime charges, e.g., at workplaces**
- **Lower battery costs and/or high gasoline prices**
- **Appropriate CD range and battery power (5-10 kWh, ~ 60 kW)**
  - **Lower-power battery extends CD time & distance**
- **Efficient CS operation associated with right battery kW (~60)**
  - **Lower-power battery gives less benefit in hybrid mode (CS)**
  - **Larger, high-power battery packs can hurt CS efficiency**

Unable to use energy density & infrastructure of gasoline for the long-trip tail of travel patterns, EVs are "boxed in" to a small market

- **Using a 20+ kWh pack to meet typical driver tail travel is too costly**
- **For the few customers driving enough, range anxiety is real, severe**
- **Charging frequency for vacation use is generally unacceptable**

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The implications draw a bit from other research that could not be included in the space requested for this presentation. However, they should largely be evident from the information here. Uncertainty about how important the statement in any line above is addressed in the following slide, which taps into even more project research outside of that presented here.

Many unknowns lie ahead, such as:

- How many vehicles are not intended for inter-city use?
- Which vehicles are used frequently and in a consistent daily use pattern (work commuting seems a leading candidate)
- How much does new intra-urban vs. inter-city infrastructure cost, how many kW are needed?
- What is the trade-off between high charge power, battery life and battery cost?
- Accounting for vehicle marketability, what PEV design(s) will best accomplish the most gasoline use reduction?
- Will shale gas hurt or help intermittent renewables (solar & wind).
- Will environmentalists pay more for plug-in vehicle systems that can exceed HEV GHG performance (not just CV GHGs) … i.e. will they purchase RECs for their PEVs and/or install solar?
- Will the smart grid movement (needed for solar & wind integration) increase or decrease PEV popularity and sales?

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First bullet – the NHTS cannot accurately answer this, leading to our use of two sensitivity cases in SAE 2013-01-0064.
Second bullet. NHTS can provide some insight here, but is still limited. The weekly survey in Germany makes it clear that daily variability of use must be studied to predict the "right" battery sizes and most cost-effective PEV market segments.
Third bullet: The answer is probably that rural fast charge points are just too expensive. To the best of my knowledge it remains to be documented.
Fifth bullet: Most predictions assume that a large share of vehicles must be electrified. Most research results and targets are presented in terms of share of vehicles sold. This has to stop. The proper metric is total fuel saved and/or miles electrified.
Sixth bullet: Low cost natural gas undercuts more expensive wind and solar but … low cost natural gas reduces the net cost of backing up wind and solar.
Seventh bullet: Environmentalists probably will pay more and will invest longer term. EVs are already clustering in areas where solar is installed on a lot of rooftops.
Eighth bullet: The management literature on the diffusion of innovation "chasm" (G. Moore) highlights big differences between innovators, early adopters, and the early majority. Success with one does not automatically lead to success with the next. His term is "the Chasm", where the business must restructure as it switches from serving one group to another. Can alliances between energy hawks and environmentalists have legs? Will the mass market consumer be impressed with advice from either group? There is presently a backlash against the smart grid movement. There is a logical tie between integration of solar and wind and the smart grid, and this match will be tied to environmentalism. A lot of information is needed to understand the system. Will this complexity turn off normal new car buyers (who have higher income than the general population, and probably higher knowledge). Or will they enthusiastically embrace opportunities to be more engaged with an interesting vehicle-customer interface?