PHEV and AEVs Power Needs and Benefits

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Introduction

The recent surge in gasoline prices demands that we revisit alternate sources of energy to drive cars and heat homes. Tables 1 and 2 show the attractive and relative low cost of electricity. Furthermore, a look at the average annual load on or utilization of the world's installed electricity generation capacity, see Table 3, shows that it is generally under 60 % and even below 50% in the US. Clearly, such data beg exploration of the viability of battery- or electricity-driven vehicles. Table 4 shows some relevant data for different classes of all-electric or battery-electric vehicles (AEVs, BEVs): battery weight and cost to achieve 33 and 150-mile ranges for electric-mode drives, without detailing the saving from removal of the IC engine, transmission, fuel storage & injection, ignition and exhaust clean-up.

However, reports of the high cost of hybrid vehicles (HEVs), plug-in hybrids (PHEVs) and AEVs and their batteries abound, with contentions of "no-win" trade between tail-pipe and power plant stack emissions, and "better stick to your gas guzzler for now" notions have created more confusion and uncertainty than the AEVs deserve. This write-up intends to shed some light on the above concerns, debunk some misinformation and show why we have a great opportunity to generate a better future and a "win" for every type of stakeholder. Below, we will address concerns such as:

- Will the conversion to Plug-in-Hybrid Electric Vehicles (PHEVs) cause disruptions in the electric power supply in 10, 20 or more years from now?
- Are there measures and plans one can implement to minimize or eliminate such disruptions?
- What are the potential costs and benefits from such conversions to the user, the utility and the government?

ORNL's report (Jan 2008 by Hadley and Tsvetkova)[1] already mentions the possibility of a triple "free lunch," i.e. PHEVs and especially AEVs promise to 1) reduce dependence on foreign oil, 2) reduce emissions, and 3) help to address the "underutilization" of generation and transmission capacity in the US during off-peak hours. However, one of the models used (NEMS) does "not model the transmission system", and the assumptions made in the Oak Ridge Competitive Electricity Dispatch (ORCED) model about vehicle and transmission efficiencies are less than clear (although the model is currently available as spreadsheet on the web[2]). Unfortunately, "The average price calculated by ORCED is found by dividing the total revenues for all plants by the total sales," thus obscuring peak and off-peak price sensitivities. Equally unclear are the assumptions made in another, more recent report[3], so that one may have difficulty understanding its conclusions. Two recent Newsweek articles fail to mention gasoline vs. electricity energy costs and down-play the potential ownership benefits to users and utility power companies[4,5]. It appears that the

- Improved overall efficiency of an electric motor + battery system (80-90%)[6],
- New Li-ion/CoO_2, Li-ion/Mn_2O_4,Li-ion/TiO_4(SCiB) and Li-ion/$FePO_4$ battery performances (short charge/discharge time, safe, wide temperature range and associated >95% charge-discharge efficiency)[6],
- Very low system efficiency (fuel-to-wheel) of present average gasoline-powered, conventional vehicles (CV) (12-18%)[7,8] relative to that of utility power plants including transmission & distribution losses (~30-35%)[10,11],
- Increasing availability of distributed wind- and solar-power sources,
- Ability to incentivise users towards optimal recharging times-and-power profiles, as has been done in Minnesota e.g. for electric water heaters for many years, and in California for PHEVs[9]
- Ability to incentivise users towards local, distributed use of electricity storage e.g. via batteries,

- The contribution to electricity cost of underutilized capacity, which would make electricity cost high both when underutilized and when using high-cost peaking units, rather than calculating electricity costs based on lumped demand and production data[1].
- Overall costs and benefits of AEVs to the user, the power utility and the government

have not fully been taken into account. Neither do the above reports[1,3,10] compare the pros and cons of PHEV or AEVs to other scenarios, notably to one based on fuel-cell and H2-fueled cars. A notable exception is an interview with Paul MacCready (AeroVironment (AVI)[12], who compares battery vs. fuel-cell vehicles(FCVs), and points out the hazard (H2-leaks), complexity & lack of infrastructure for H2-FCVs. Ref.[13] points out that a 1.2 MW fuel cell generator at a bakery only "operates at 47% electrical efficiency, but up to 80% if its waste heat can be used"[13].

To draw out the scenario of a future transportation system based largely on PHEVs and AEVs, we should define and not gloss over the huge scale and magnitude of the total US and world automotive energy consumption, and what an eventually complete conversion to renewable energy would look like. However, some statistics are very encouraging:

- Total global wind-power capacity is 5x larger than the total energy presently consumed by all sources, according to Wikipedia[14], after allowing use only of suitable locations, where wind speeds average 6.9 m/s (15.4 mi/h) at 80 m above ground.
- If that wind-power potential were realized with present 1-2 MW wind-turbines, they would occupy only 13% of total global land area, based on 6 turbines of 1.5 MW(peak) per km2, or 36 kW/acre[14]. Pickens' wind turbine generation density would 20 kW(peak)/acre[15], while older farms were at 10 kW/acre.
- Converting all gasoline-fueled vehicles to AEVs fed solely by wind-power (with suitable storage and transmission lines) would only take 106, 3.4 and 0.16 GW(avg) for USA, Minnesota and Hawaii County (Big Island); with wind-farms covering 0.70, 0.57 and 0.23 % of the land areas (based on 20 kW(peak)/acre); which now support population densities of 0.132, 0.108 and 0.065 persons per acre, respectively.

The total US energy consumption rate is ~100 quadrillion Btu/y[16], $100\text{x}10^{15}$ Btu/y, ~100 hexa Joules/y, 28 trillion kWh/y, which is equivalent to an average of 3,170 GW. Note that our average electricity use of 490 GW (=1089 x 45%, see Table 3) consumes ~ 1600 GW equivalent of fuel feedstock, or about half of our total energy budget. If a carbon tax or carbon-trade is implemented, a $300 per ton (CO2) carbon tax would raise gasoline prices by $1.20 per gallon.

Discussion

Overview: To shed some light on the above points, we will try to clearly state a few simple assumptions, under both mild and extreme scenarios such as total conversion to AEVs in 10-20 years. Under the latter, we will show that the

1. Impact of converting all US gasoline vehicles, now consuming 143 billion gal/y to AEVs, amounts to only 10%, on average (106 GW*), of the total US electricity power generating capacity (1089 GW), which a total energy corresponding to an average load of only ~ 45%[4]
   * Based on assumed 15%[7,8] and 80%[6] energy system efficiencies of gasoline and electric+battery cars, respectively
2. The 143 billion gallons may only represent 60% of the total US imported oil products (assuming a 70% conversion efficiency from crude to gasoline) corresponding to a fraction of the touted $700 billion/year of oil imports, or $420 billion
3. The approx. 250,000,000 total "light-duty" vehicles on the road today in the US amount to a total capital value of 2.5 trillion $, based on an average, half-depreciated value of $10,000/vehicle
4. User fuel cost savings after conversion from gasoline to an all-electric vehicle (AEV) would average out to 4 $/gal x 143 billion gal/y - 106 GW x 8760 h x 0.07 $/kWh/1000 = $ 572 – 65 billion total or 2028 $/year per vehicle owner

5. User cost penalties: If AEVs were to cost even 2x more than new gasoline cars, i.e. $40,000 rather than $20,000, the just extended gov. rebate of $7,500 and the above $20,280 fuel savings over its >10-year service life, would seem to go more than part way towards offsetting the higher purchase cost, although the car-loan cost (interest rate) also needs to be taken into account, especially by AEV manaufacturers and sales organizations. Considering that a 4-year loan at 5%/y interest only adds ~13% to the cost differential of a purchase, or 0.13 x ($40,000 – $20,000)= $2,600, maybe this would not be a difficult hurdle.
6. Utility revenue increase corresponding to a 10% average load increase or 0.07 $/kWh x 1089,000,000 kW x 8760 h x 10%/100 = $ 67 billion/y, which corresponds to an income boost of 100 x 10/45 = 22.2% above the present average load of 45%,
7. Government expense of a one-time rebate of $7,500 per vehicle or ~$1.9 trillion spread over 10-20 years, and loss of gasoline taxes, but compensated by the effect of A) a reduction in oil-product imports for gasoline of $420 billion/year or $4.20 to 8.40 trillion over those 10-20 years, respectively, B) increased tax revenue from a 2-3-fold increase in economic activity spawned by not importing oil at $420 billion/year relative to the "base" case of continuing present gasoline-car use, and C) increased tax from a 22.2% increase in taxable electric power generation.
8. The above attractive scenario would not be complete without mentioning the installation of suitable and smart, radio-controlled energy management systems, which would supervise recharging profiles of the needed energy storage systems (battery, H2-generation via electrolysis, pumped hydro, flywheel, compressed air, etc[17,18])

Details: Let's look at the above points in the same sequence, one at a time, but in greater detail.

1. **Impact of converting all US gasoline vehicles to electric vehicles(EVs)**. The average 106 GW of electric power needed to keep the same number of vehicles on the road as we had in 2007 was derived based on these data:
   -- Annual, 2007 vehicle miles/y traveled = 3 trillion miles/y, at a consumption of 145 billion gal/y, which is equivalent to 21.3 miles/gal.
   -- Average system efficiency of gasoline engine ~15%[7], and of electric drive system ~ 80%
   -- Equivalent average electric power consumption: Based on 120,000 Btu/gal gasoline, we get: 141 billion gal/y x (120,000 Btu/gal) x (1054 Joules/Btu) x (**15/80** efficiency ratio) x 1/(8760*3600 sec/year) = 106 billion W = 106 GW or ~ 10% of total US generating capacity of 1089 GW
   -- The total electric energy generated in the US in 2007 was 4,159,514 GWh/y[16], which is equivalent to an average generation of 4,159,514/(8760 h/y) = 475 GW or 475/1089*100 = 43.6% load
   -- The addition of 10% EV load to the electric grid amounts to an increase of 10/43.6*100 = 23% in load and revenue to the utility power industry.
2. **Cost of oil imports and amount of CO2 emissions associated with gasoline use.** The 145 billion gallons gasoline/year we use[11], only represent a portion of the 339 billion gal /year of total oil product US consumption, of which about 68% make up the touted $700 billion of total US imported oil products. Assuming a 70% conversion efficiency from crude oil to gasoline, the EIA data[16] show that motor gasoline amounts to a fraction of

   145 billion gal gasoline /339 total oil products *100/0.70 = 41.1/0.70 = 61.2%

   of used total oil products of which ~68% are imported. Therefore the cost of oil imports used for gasoline production amount to ~0.612*700 = **$428 billion**. However, the total oil product value avoided annually (domestic and imported) if we were to convert 100% of US vehicles to electric drive would be: ($700 billion/0.68) x 0.612 = $630 billion, while the associated emissions reduction would likely be near **50% of the total oil product CO2 emissions** (between the elimination of the 41.1% actual tail-pipe emissions and the 61.2 %, if all the by-products and processing losses also lead to CO2 emissions)
3. **Capital associated with "light-duty" vehicles.** The approx. 250,000,000 such vehicles on the road today in the US amount to a total capital value of 2.5 trillion $, based on an average,

half-depreciated value of $10,000/vehicle after 5 years, as indicated by charts listing depreciated values of cars costing between $21,000 and $27,000 when new. Seasonally adjusted sales have been declining from 16 million vehicles/y (Sept.'07) to 12 million (Sept.'08) according to http://www.greencarcongress.com/2008/08/us-light-duty-v.html . This is consistent with an average vehicle life of 250/14 = 17-18 years, which is the time one would schedule a normal, market-driven, hypothetical phase-out of CVs (conventional vehicles fueled with gasoline) and phase-in of AEVs or BEVs.

4. **Annual vehicle fuel cost savings.** After conversion from gasoline to an all-electric vehicle (AEV) the fuel savings would average out to **4 $/gal** x 143 billion gal/y - 106 GW x 8760 h x **0.07 $/kWh**/1000 = $ 572 – 65 = 507 billion $ total US or 507,000 million $/250 million vehicles = **2028 $/year per vehicle owner**. The above 106 GW are based on:
   - An average IC engine efficiency of 15%[7],
   - An average electric motor + battery efficiency of 80%[6],
   - US annual use of 145 billion gal gasoline[16],
   - An average annual mileage driven of 12,000 miles (32.9 miles/day), consistent with the annual 3 trillion miles of travel[19],
   - The 250 million registered vehicles on US roads[20], and
   - The present average of ~22 miles/gallon CV performance.
5. **Battery- vs. gasoline-car ownership benefits.** Even if AEVs were to cost even 2x more than new gasoline cars, i.e. $40,000 rather than $20,000 (see e.g. Table 5) the just extended gov. rebate of $7,500 (October 2008) and the above $20,280 fuel savings over a 10-year service life, would seem to go more than part way towards offsetting the higher purchase cost, even if financing the $20,000 higher car-loan cost differential is taken into account. Considering that a 4-year loan at 5%/y interest only adds ~13% to the cost of a purchase, or 0.13 x $20,000 = $2,600, the total benefit to an AEV owner would be:

   - $20,000 purchase price differentia - $2,600 financing of price difference = - $22,600 cost
   + $7,500 rebate + $20,280 savings = $27,780 savings, i.e. a total of **$5,180 savings of owning and driving an AEV over a 10-year period, relative to owning and driving a CV**, even without considering the likely higher maintenance costs (carburetion/injection, spark plugs, oil changes, etc) of the latter.

   Figure 1, adapted from ref.[10], illustrates the above with "break-even" lines, the position of which depends on the gas mileage of the CV and the gasoline prices, as shown. For a 0.07 electric rate (close to that of Ohio), 21.5 miles/gal and 4 $/gal, the break-even cost adder for a PHEV or AEV is at about 11 k$, which is commensurate but lower than the above value of 15 k$, and reflects small differences in assumptions on ownership time (our 10 vs. PNNL's 9-year ownership[10]), electric rate (Ohio's 0.085 vs. our 0.07 $/kWh) and possibly higher engine/motor+battery system efficiency ratio than ours of 15/80.
6. **Utility revenue benefits.** The addition to the 106 GW or ~10% average load increase corresponds to a 100 x 10/45 = 22.2% increase in produced electricity above the present level. Assuming an average, discounted electricity rate for off-peak purchases of electricity for AEVs of 0.07 $/kWh, the totally converted AEV fleet would lead to an increased utility industry revenue of 0.07 $/kWh x 1089,000,000 kW x 8760 h/y x 0.10 = **$67 billion/y**. The benefits to utilities are even greater if one considers the possibility of having AEVs serve as part-time and distributed storage media for the "smart" electric grid, whereby parked AEVs may sell electric energy at close to the avoided cost at peak rates and (as an incentive for active BEV participation), and may repurchase such energy later that day during off-peak times and rates.

   Figure 2 illustrates how the real daily high and low electricity demand of Hawaii County (population of 167,000 residents and 28,000 non-residents, consuming 74 Mgal/y, with ~160,000 CVs) on the Big Island of Hawaii[16] was met in 2005 ("old load" via steady output of geothermal and hydroelectric plants (52 MW) and modulating output of oil-fired generators. After an hypothetical switch to AEVs, the first batch of AEVs amounting to a 10% average grid load, the overall load can be balanced to a steady total of 166 MW, via smart battery recharging, filling the demand valleys at night and even shaving off ~ 6 MW during the evening peak near 8 pm. Any additional AEV load, as shown in Fig. 2 via a second BEV load amounting to a total of 18.6% of the generating capacity, can then be evenly distributed over the entire 24 hours of each day. Note too that the increased fuel consumption of the fossil-fired generators (25.1 Mgal/y) is less than the gasoline saved by the eliminating the first batch of CVs equivalent to an average load of 10% (40.1 Mgal/y), so that both fuel consumption and emissions are reduced. The assumed energy system efficiencies of the CDs, (AEVs or) BEVs and electricity generation were 15, 80 and 30%, respectively.

Concerns of utilities, as more generation capacity from intermittent wind and solar-PV generation and additional AEV loads are added to the network are: A) Development and deployment of additional storage, even beyond hydro-pumped storage, such as battery storage[18] and others[17]; B) Installation of sufficient grid transmission to connect distributed clean energy sources (wind, geothermal, solar-PV, biomass) and new demands by AEVs; C) Design and deployment of suitable energy management systems to achieve the attractive load-sharing synergies between utilities and AEVs; and D) Securing the needed funding to finance the above.

At the rates of growth of wind (30-40%/y) and solar (up to 50%/y in 2007), the US would be able to power all AEVs with clean energy before 2018, see Fig.3, if all clean energy was to be dedicated to AEVs, which, although not expected to be the case. However, all US electric generation capacity of 1089 GW(avg) or 3200 GW(peak) could be from wind by 2025, if 1) We continue at the present growth rate and 2) Simultaneously take care of items A) thry D) above.

7. **Government cost and benefits.** How can we quantify the revenue benefits of AEV ownership to the state or country, and thus justify government subsidies and rebates for "clean-energy" AEVs?

   Costs would be: The cost of one-time tax credits of $7,500, for the extreme case of 250 million vehicles, totals **~$1.9 trillion,** spread over the average phase-in time of AEVs or over gasoline vehicle service lives of 10-20 years, and the loss of gasoline tax used for road construction and maintenance, which presently amount to 11% x 145 billion gal x 4 $/gal = $64 billion/y. However, this revenue loss averages to less than a quarter of that amount during the first 10 years of a 20-year transition, i.e. **~$16 billion/y**, if one assumes a linear phase-out of all gasoline-powered conventional vehicles. **Total cost: $1.9 + 16x10 = $2.060 trillion.** The rebates would not be needed on the long term because of the projected lower manufacturing cost of AEVs vs. CVs[21,22]

   Benefits: This would: **A)** Eliminate the oil-for-gasoline imports of $428 billion/year or $8.50 trillion over the maximum of those 20 years, and continuing thereafter, and lead to an increased tax revenue from a 2-3-fold increase in economic activity, worth $428 billion x 15% tax x 3 (economic multiplier) = **$193B/y**

   B) Averaged boost in annual sales tax revenues over the first 10 years, from the higher AEV retail price: (1/10y)(0.06 sales tax) x $20,000 price difference x 0.25 billion vehicles = **$30 billion/year**; and

   C) A 22.2% increase in taxable electric energy for AEVs of 6% x (1/4) x $67 billion = **$1.005 billion/year**;. Total A-C benefits for the first 10 years in $ billions:

   $192.5 + $1 + $30 = $223.5 billion/year or **$2.235 trillion over the first 10 years**

   i.e. more than $ 170 billion "net" revenue, despite the $ 1.9 trillion in tax credits, even if only a 10-year time horizon is being considered. If after that time or later the rebates are phased out, the benefits A – D would remain, so that thereafter **permanent, positive government remaining benefits would amount to over $200 billion/y**.

8. **Avoiding supply disruptions and high-cost electricity via energy management controls for BEVs.** The above attractive scenario would not be complete without mentioning the installation of suitable, radio-controlled energy management systems, which would supervise recharging profiles of the needed energy storage systems (battery, H2-generation via electrolysis, pumped hydro, flywheel, compressed air, etc[17]). The possibility of having AEVs

serve for part-time and distributed storage media for the electric grid was already mentioned above under item 6 and Fig.2.

The paragraphs below provide additional illustrations of the increasingly favorable scenario of linking AEVs availability, cost and battery storage with new clean electricity generation and supportive legislation..

As light-duty vehicles get increasingly fueled by electricity, more electricity should be generated by wind, solar-PV and other renewable sources. More than 11,000 Minnesotans of a total of 40,000 had signed up for Xcel's Windsource Program in 2005, choosing to purchase some or all of their electricity from wind turbines[23]. Customers can purchase blocks of energy for as little as $2 per month extra for 100-kWh of Windsource energy (the average home uses about 750 kWh of electricity per month). The premium paid by customers goes directly toward adding wind turbines to supply the amount of wind-generated electricity purchased.[23] Windsource is a voluntary wind program, whereby customers can call 1-800 895-4999 to sign up. Xcel Energy had 2700 MW of installed wind generation capacity early in 2008, or ~2.7/(15.77)*100 = 17.1% of its total electricity generation capacity of 15.77 GW.

The U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) and Xcel Energy announced a first-of-a-kind agreement on Sept. 29, 2005 to develop software to evaluate siting options for off-grid and grid-connected, commercial rooftop solar electricity systems in Colorado. Xcel Energy, Colorado's largest utility, estimates that it will need 18 megawatts of solar power in place by 2007 — at least half of which must come from on-site, customer-owned generation facilities — to meet Colorado's solar component mandate for renewable energy.

Field experience shows that the power of the 26-33 kWh NiMH batteries($225-350 $/kWh for volumes up to 100,000/y in 2000) installed in the different EV types deployed in California by major automobile manufacturers is generally sufficient for acceptable acceleration and speed. Bench tests, and recent technology improvements in charging efficiency and cycle life at elevated temperature, indicate that NiMH batteries have realistic potential to last for 100,000 vehicle miles[24], as further proven with the SUV AEV by Toyota (RAV-4EV), with service over 150,000 miles.

Conclusions

The above discussion provided data and results to demonstrate the 4-fold benefit of BEVs vs. CVs to drivers, utility companies, government and environment. One can summarize the costs and benefits as follows:

1. **Drivers of AEVs or BEVs** (Battery Electric Vehicles): Even with a 2x higher AEV purchase price of $40k vs. $20k for new AEVs, relative to CVs (Conventional IC Vehicle), the $7,500 rebate will result in a net benefit of **$5,180, after driving the BEV for 120,000 miles,** relative to owning and driving a $20,000 CV. The assumed gasoline & electricity costs were 4 $/gal & 0.07 $/kWh, respectively.

   The concerns about AEV availability, high AEV cost; and low-range, batteries' short life and high replacement cost should be largely overcome by A) The many new AEV introductions, see Table 5 by American (GM, Ford, Chrysler, Dodge, Zap[32]), Japanese (Toyota[26], Honda, Nissan[27,28]), Chinese (BYD[30]), Indian and German (BMWs Mini-E, Mercedes and Porsche[29]) automakers, providing 100-200 mile ranges, indicating a surge in competition; and B) Recent advances and improvements in Li-battery life (>5000 cycles, >10 years, >150,000 car miles), recharge time (<10 min), energy density (>100 kWh/kg) and cost (<500 $/kWh), see Tables 4 and 5 and ref.[31].
2. **Utility companies:** After the assumed extreme conversion of all CVs to BEVs, the utility industry would experience an increased revenue of 22.2% in produced electricity above the present level. At 0.07 $/kWh and barring further discounts for off-peak purchases of electricity for BEVs, the added revenue amounts to an average $67 billion/year.

   However, substantial investments are needed for means to: A) Develop and deploy additional storage, even beyond hydro-pumped storage, such as battery storage[18] and others[17]; B) Install additional grid transmission to connect distributed clean energy sources (wind, geothermal, solar-PV, biomass) and new demands by AEVs; C) Consider the benefits of more extensive deployment of high-voltage DC transmission lines, which feature reduced losses, can uncouple different user AC grid systems[17]; and D) Design and deploy suitable energy management systems to achieve the attractive load-sharing synergies between utilities and AEVs

3. **Government:** Supporting the CV to PHEV or AEV conversion with a one-time $7,500 tax credit for each vehicle to help phase-in a new batch of 250 million AEVs over 10 years will **cost** ~$1.9 trillion. In addition the gradual loss of the ~11% gasoline tax may eventually amounts to $64 billion/y.

   However, this will be offset by **increased tax revenues** from the increased (22.2%) electricity generation ($4 B/y, assuming a 6% sales tax) and increased economic activity from substituting the $428 billion/y oil-for-gasoline imports for domestic clean energy generation work ($193 billion) and increased sales tax for the higher-priced AEVs ($30 B/y) .

   The net result during the hypothetical 1st 10-year transition period was estimated to be a positive balance of $170 billion ($17 B/y) over the 10-year transition period. After the tax credits have been phased out, the **positive balance would be over $200 billion/year**, mostly fueled by the increased 3-fold and taxable economic activity of the eliminated $428 billion/year imported oil products to make gasoline. This assumes that the price of gasoline can be maintained at ≥ 4 $/gal (e.g. via direct taxation or carbon tax), relative to off-peak electricity at ≤ 0.07 $/kWh, so that the market can adjust to and stabilize around this scenario.
4. **Emission reduction:** Elimination of processing and combustion of gasoline fuel was estimated to result in over 50% of CO_2 emission reduction, relative to the emissions presently generated by the total oil products used in the US

The revolutionary shift from gasoline to battery-powered vehicles will disrupt the balance in fabrication and use of many crude-oil-based products, from diesel, aviation fuel, chemical feed-stocks, to road-asphalt and many more, and will need to be given careful consideration. Processing of bio-crude (from pyrolysis), bio-diesel from plant or algae oil and bio-polymers from cellulosic plant material will contribute to the long term sustainable scenario.

Recommendations

- **Future AEV drivers** should have access to information on PHEVs and AEVs staring in high-school, together with basics on clean energy and on sustainability, environmental and cost implications of alternative automotive fuels. Information should be provided about local providers of residential wind and solar-PV generation to charge AEVs, together with purchase and life-cycle cost comparisons via web-based sites.
- **Automobile manufacturers** should be encouraged to:
  - Manufacture AEVs by following the path started in California, with 8 -10-year or 100,000 - 150,000 mile warranties,
  - Incentivise battery recycling initiatives and associated customer support, such as recommendations on home recharging systems via grid, and residential wind- and solar-generators.
  - Partner with electric utilities, as announced by Toyota and EDF[26]; Renault, Nissan and EDF[27]; Renault, Nissan and Tennesee and TVA to provide zero-emission vehicles and optimized AEV infrastructure/service, including charging stations in public places to drivers[28]
- **Government** should diligently and urgently:
  - Enact legislation to either A) stabilize the price of oil products (e.g. via variable taxation, or carbon tax***) at a level that reflects the true cost of oil products (including the >$400 billion cost of the DoD effort in the Middle East), so that clean energy has a fair chance to be competitive with much reduced or eliminated subsidies, or B) subsidize clean energy so that

it remains competitive despite expected fluctuations in the price of oil products, as exemplified by the fluctuation from 148 to 80 $/barrel in just 3 months[25].
*** A $300 per ton (CO2) carbon tax would only raise gasoline prices by $1.20 per gallon.

- Accelerate promotions of energy management (incl. storage[17,18]) systems to help utilities achieve higher average load factors, which also facilitates incorporation of renewable but intermittent electricity generation from wind, solar, biomass, etc systems. The US average electricity load factor is 10-20%-points below that of other countries, see Table 3 below.
- Set super/ultra-low-emission vehicle (ULEV, SULEV and ZEV) performance standards, as California did, to create an even and challenging but defined and attractive playing field for AEV manufacturers. Fairness may dictate a gradual introduction and enforcement of such standards
- Promote deployment of wind, solar-PV, geo and biomass-based renewable electricity via appropriate subsidies for industrial, commercial and residential use, but with built-in, clearly expressed sunset provisions, such as decreasing subsidies at a rate of ~ 5-6% per year, as has been practiced in Europe for some time (for example the subsidized purchase price of electricity in Germany from solar-PV systems decreases ~ 6%/year, under the guideline of socializing the cost yet privatizing the profits).
- Encourage the use of high-voltage DC transmission lines, because of their 5-6x lower losses, greater safety from black-outs; and lower right-of-way requirements than AC lines, as per the Bonneville Power Transmission Roadmap[17]

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    - **Zap Alias** electric car retails at **$32,500** not including shipping, options, dealer prep, taxes, registration or doc fees; 0 – 60 mph : 7.7 sec; Vmax: 100 mph; EV range: **100+ miles** (160.9 km) ; Weight: 1612.6 lbs (733 kg)
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Table 1. Comparison of Transportation Costs vs. Type of Fuel

Energy	Price	$/kWh	Equivalency $/GGE	System Effic'y. %	Transportation Cost 25 miles $	1 mile $	
$/gal gasoline	4.00	0.1139	4.00	15	4.00	0.160	IC-Engine
$/kg H2	4.50	0.1229	4.32	40	1.62	0.065	FC-Vehicle
$/gal E85	2.65	0.1191	4.18	15	4.18	0.167	IC-Engine
$/MBtu NG	12.00	0.0410	1.44	20	1.08	0.043	IC-Engine
c/kWh el.power	7.00	0.0700	2.46	80	0.46	0.018	BEV
$/MBtu coal	1.57	0.0054	0.19	10	0.28	0.011	IC-Engine

Table 2. Comparison of Home Heating Costs vs. Type of Fuel

Energy	Price	$/kWh	Equivalency $/GFOilE	Effic'y. %	Heating Cost 100 MBtu $/year	70 MBtu house $/year	
$/gal fuel oil	4.00	0.1139	4.00	85	3620	2534	Furnace
$/kg H2	4.50	0.1229	4.32	85	3907	2735	Furnace
$/gal E85	2.65	0.1191	4.18	85	3787	2651	Furnace
$/MBtu NG	12.00	0.0410	1.44	90	1231	862	Furnace
c/kWh el.power	7.00	0.0700	2.46	200	946	662	Heat Pump
$/MBtu coal	1.57	0.0054	0.19	60	242	169	Furnace

U.Bonne\TL-07-Plant-Bus.-Mods.\4, 2-Oct-2008

Table 3. Electricity Use and Generation by Country*

Country	Annual Use Wh/y	Installed Ca Wmax	Average Load in %	Trans.%Dist Loss in %
Australia	2.40E+14	4.88E+10	56.14	10.0
China	2.47E+15	5.00E+11	56.50	7.5
India	5.95E+14	1.24E+11	54.73	
Japan	8.77E+14	2.17E+11	46.18	5.2
Korea	3.65E+14	6.33E+10	65.87	4.5
USA	4.00E+15	1.00E+12	**45.66**	6.8
Germany	5.67E+14	1.19E+11	54.43	**
Hawaii	9.66E+12	2.41E+09	45.68	
Hawaii Cty.	1.12E+12	3.00E+08	42.62	***
Iowa	4.01E+13	1.11E+10	41.08	
Minnesota	4.36E+13	1.27E+10	39.32	

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ARITL-07-Plant-Business-Model.xls\2, U.Bonne, 4-Oct-08

Table 4: Specific Energy and Energy Storage Requirements by Vehicle Classes*

Vehicle Class: 33& 150 mi range	Energy miles/kWh	PHEV33 Batt-kWh	PHEV150 Batt-kWh	PHEV150 $**	Li-ion CoO kg**	Li-ion FePO4 kg***
Compact sedan	3.85	8.6	39.1	14,073	244	782
Mid-size sedan	3.33	9.9	45.0	16,200	281	900
Mid-size SUV	2.63	12.5	56.8	20,455	355	1136
Full-size SUV	2.17	15.2	69.1	24,873	432	1382

PEV33 = Plug-in Electric Vehicle with 33 mile-range
* http://www.pnl.gov/energy/eed/etd/pdfs/phev_feasibility_analysis_combined.pdf plus additions
** 360 $/kWh, 160 Wh/kg, 99.9% efficiency; *** 50 Wh/kg

Table 5. HEV, PHEV and BEV Models, Availability, and Performances

Brand	Zap	BMW	Chrysler	Toyota	Toyota	Nissan	BYD	BYD	Chrysler GEM	Chrysler	GM
Model	Alias	Mini-E	Voyager	RAV-4EV	Prius	NuVu	e6	F3e	Peapod	Malibu	Volt
Type: HEV, PHEV, BEV	BEV	BEV	PHEV	BEV	HEV	BEV	BEV	PHEV	BEV-NEV	HEV	HEV
Price in US$ new	32,500			~42,000	21,500		~28,613	~21,460		22,600	
after 5 years					10,800					9,186	
Availability in US, year	2008	2008	2010	1999-2003	2008		2011-13		2008	2008	2010
Top speed, mi/h	100	>95	>100						25		
Motor power HP/kW		204/150									
Battery size, kWh		35	22	?? 46	1.3	4.5	35.6				
Battery power, kW			200								
Range in miles EV/CV	>100	>150	>40/400	85-100	3.5/400		185	62/400	<30		40 / 400
Mileage in mi/kWh		4.29	1.82	2.17	2.69		5.2				

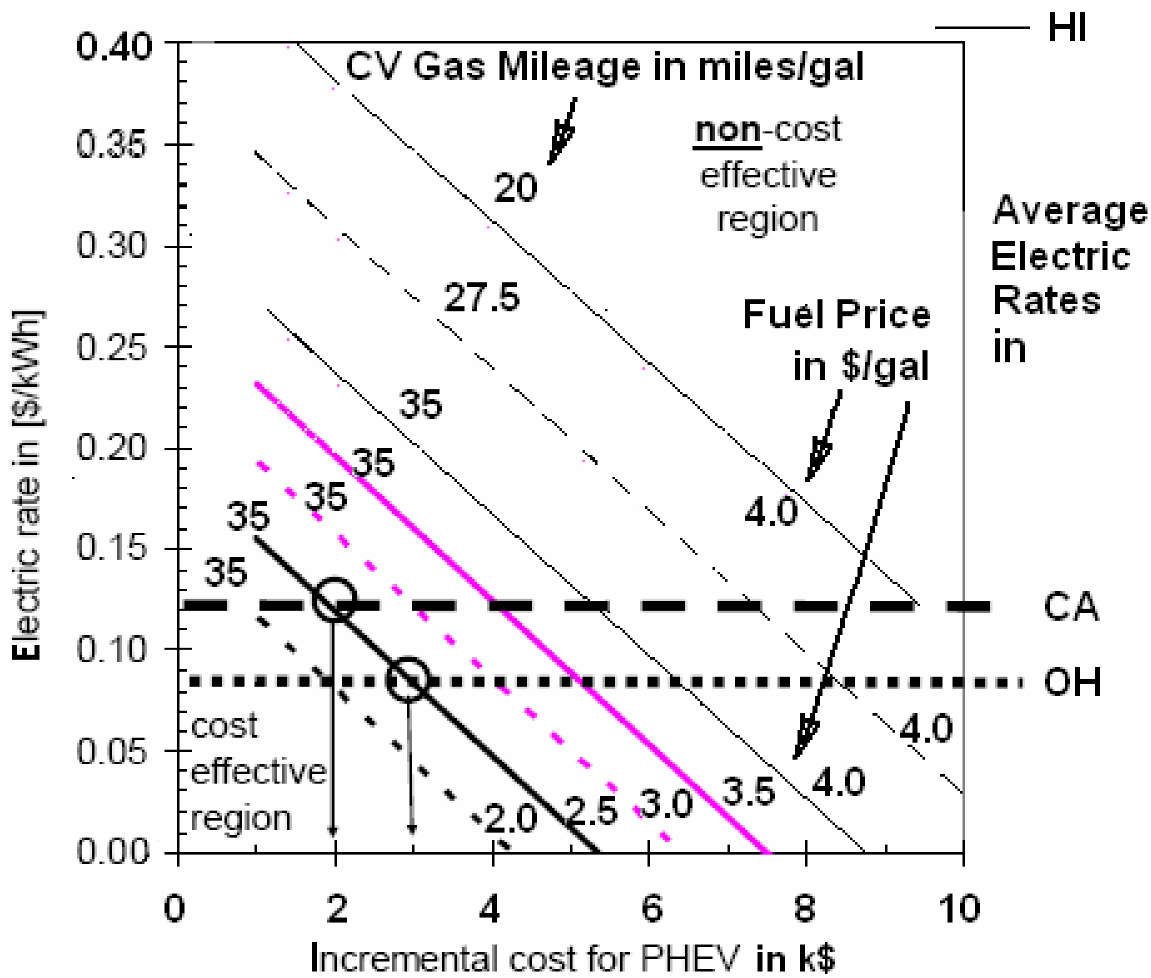

Fig. 1. Life-cycle cost break-even lines for incremental PHEV costs vs. electricity and fuel prices, relative to conventional vehicle(CV) gas mileage. Other assumptions: travel: 33 miles/day, 9-year life, 8% discount, zero resale value. Adapted from a PNNL report by Kintner-Meyer et al [10].

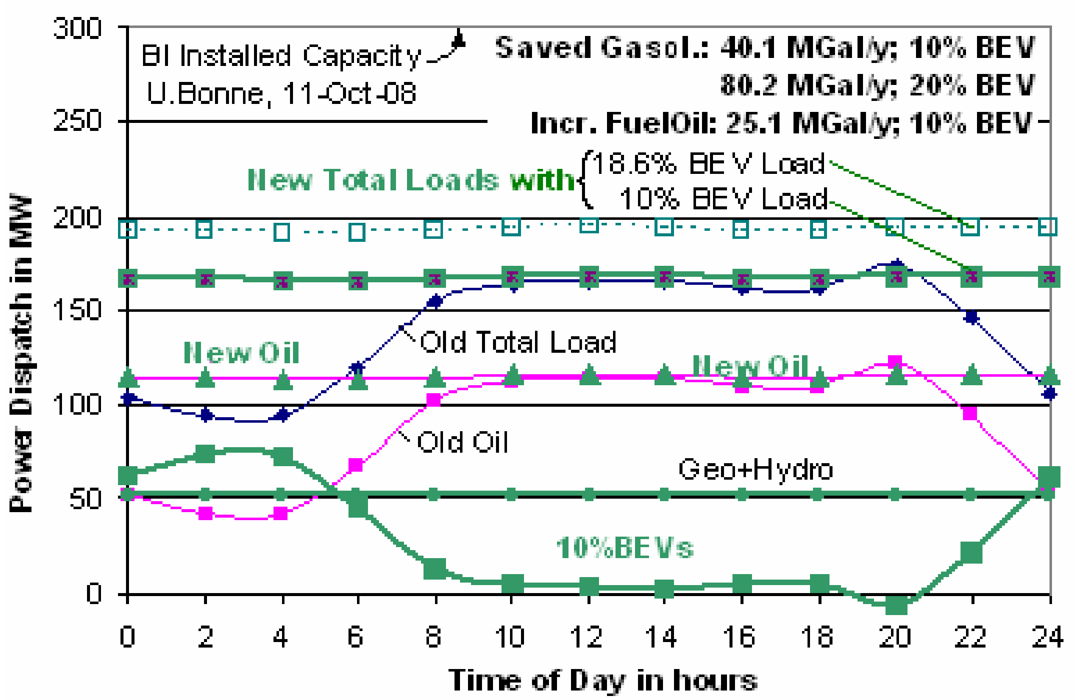

Fig. 2. Typical daily electricity demand in 2005 for the County of Hawaii for two scenarios: 1) Before adding average BEV loads to the electric grid, and 2) After adding average BEV loads of 10% smartly to fill demand valleys and even shave ~ 3-6 MW of the peak load near 8 pm, and then adding up to a total average BEV load of 18.6%, with greater freedom for time of day.

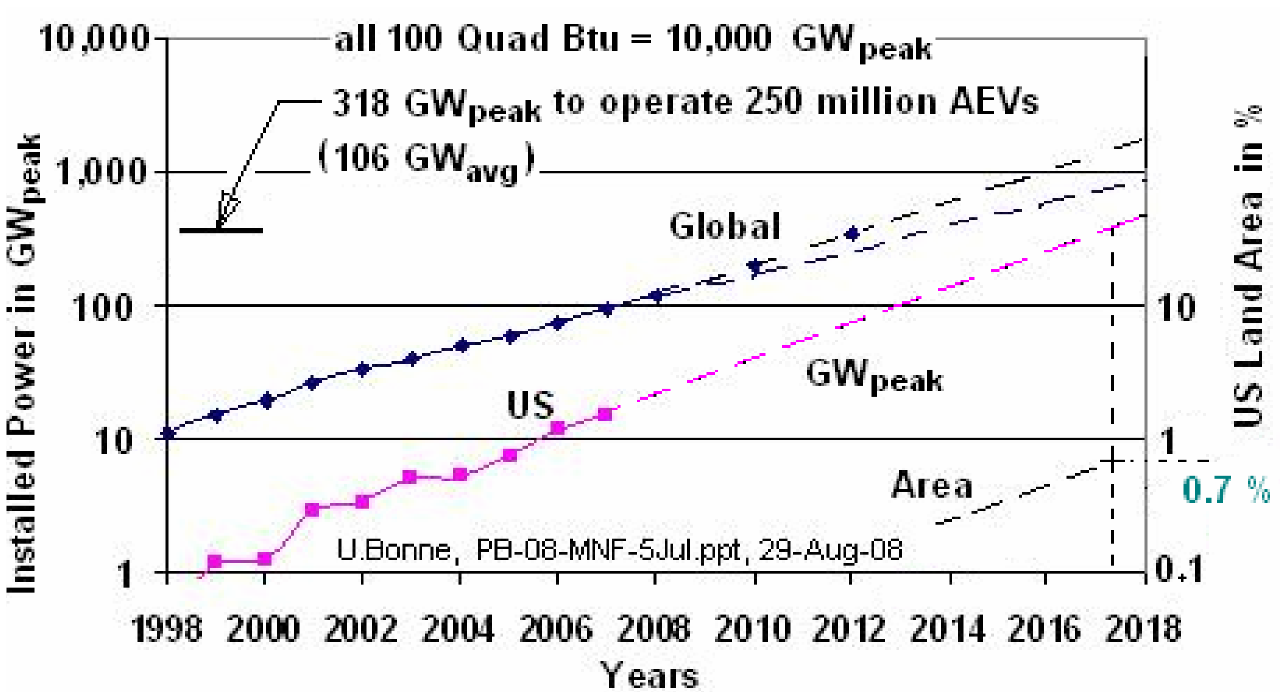

Fig. 3. Growth in wind-power generation, both globally and in the US. Also shown at lower right is the real estate in % of total area, to host wind farms. At 0.7% the AEV needs will be met. ~3,000 GW$_{peak}$ wind-power (at 33% capacity factor) would be needed to replace all of ~1,000 GW$_{avg}$ US 2008 installed electric power generation capacity. Present installed power cost: 1.5 \$/W$_{peak}$; energy cost: 4 c/kWh. At present growth rates, all AEVs all US electricity could be powered by wind before 2018 and 2025, respectively.

Appendix

A) Additional References3

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12. http://blocksindicator.com/2008/09/wind-energy-is-leading-the-renewable-energy-race/
13. An all-electric car is expected to be available for purchase next year (2009) in the U.S.; it is called "Think City" from **Think** North America, a Norwegian-California joint venture startup. The car runs on sodium or lithium batteries with a **110-mile** range
14. Mini goes electric: BMW to test battery-powered "Mini-E" in the US. Green Energy News - October 18, 2008 – Vol.13 No.30, BMW will build 500 or so (AEVs) MINI Es for real people testing in CA, NY and NJ for 1-year leases with an extension option. Cars will change hands when the lease expires and drivers are willing to let go of the keys. BMW will take the cars back to the shop at the end of the pilot project for a detailed evaluation. http://www.green-energy-news.com/arch/nrgs2008/20080087.html The MINI E is a stock 2-door MINI with lithium-ion battery of 35 kWh at 380 volts. The MINI E weighs 3230 lbs (1,465 kilograms) or ~700 lbs (318 kilograms) more than a gasoline-powered version. Under the hood, of the now 2-seat MINI, is a 204 hp (150 kW) electric motor that will, with 162 ft-lbs of torque (220 Nm), accelerate the car to 62 mph (100 km/h) in 8.5 seconds. Top speed: limited to 95 mph (152 km/h). Max range: ≥150 miles or 240 kilometers. Car includes a charging station (wall box), to recharge car's battery in 2.5 hours from fully drained. Regeneration breaking: ~ 75%, which extends the car's range by ≤20 percent. The cars are in production now in Oxford, England and Munich, Germany.
15. Matra distributes in France NEVs (Neighborhood El.Vehicles) by **GEM-Chrysler**. http://www.invest-in-france.org/uploads/files-en/08-06-25_155311_PR_New_Motorisations_June2008.pdf see also http://www.gemcar.com GEM=Global Electric Motorcars. GEM-Peapod NEV: Max speed 25 mi/h, <30 mile-range, 6-8 hours battery charge time; max./cont. power 12/5 HP. Net weight 1290 lbs. Max.payload 900 lbs; 4-passengers. 12 x 6 = 72 V battery w/charger
16. Joseph J.Romm (jromm@getf.org) is Exec.Dir. of the Center for Energy and Climate Solutions in Arlington, VA. He served as Acting Assistant Secr.of Energy for Energy Efficiency and Renewable Energy under the Clinton admin. Also authored the book: "Hype about H2: Fact and Fiction in the Race to Save the Climate," Island Press, 2004), "The Hype about Hydrogen," http://l.b5z.net/i/u/6096111/i/hydrogenhype.pdf "...burning a gallon of gasoline releases about 20 lbs of CO2. Producing 1 kg of H2 (with a heating value equivalent 1 gal gasoline) by electrolysis would generate about 70 lbs. of CO2."
17. Shai Agassi's Better Place Inc. business plan features a network of electric charge stations, where customers can swap discharged for charged batteries. www.BetterPlace.com
18. **Mercedes-Benz** will have invested in clean-technology research and zero-emission technology by 2010. 1,900 watts per liter (W/L).Li-ion battery temperatures of between 15 and 35°C Duvall, M. 2002. Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options for Compact Sedan and Sport Utility Vehicles. Final Report 1006892. Electric Power Research Institute. Palo Alto, CA.
19. Duvall, M. 2003. Electricity as an Alternative Fuel: Rethinking Off-Peak Charging. Plug-in HEV workshop. Electric Power Research Institute. Palo Alto, CA.