Cost Projections and a Rule of Thumb for both New Plug-in Vehicles and Conversions

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• Slide 4: New Nissan DOD info
• Slide 5: GM’s $/kWh remarks reinterpreted, leading to...
  2012 estimates raised: $400→450/useful-kWh and $700→800/useful-kWh
• Slide 6: Used slide 5’s higher 2012 battery price estimates
• Slide 11: Added ROI & hybridization savings (line in orange and above it)
Costs of PEVs (vs. ICEs) Dominated by Batteries

- In automotive-level mass production, Plug-in Electric Vehicle non-battery costs should soon be lower than for non-PEVs
  - A BEV powertrain is much simpler than an ICE and transmission
    - An electric motor has only one vs. 100s of high-tech precision moving parts
    - The price of high-power electronics is decreasing with increasing automotive volume
  - A PHEV powertrain is nearly the same as an HEV’s

- PEV fuel costs are so much lower (1/4 or less) that battery cost can be looked at as a fuel pre-purchase
EER is Key to Calculating Battery Cost Effectiveness

• EER (Energy Efficiency Ratio) = Ratio of electric vs. ICE ‘tank’-to-wheels efficiencies

• Calculated PHEV EERs, based on Argonne National Labs dynamometer testing of two different plug-in Prius conversions vs. EPA/CAFE data on ICEs (upcoming CalCars paper):
  – EER = 4.7 today, PEVs vs. vehicles meeting 2010 CAFE standards
  – EER = 4.0 est. for 2020
  – EER = 5.2, PEVs vs. older trucks ripe for PEV conversions (4.4 est. for 2020)
  – EER = 3.0, PEVs vs. 2009’s very most efficient hybrid, the Prius

• CA Energy Commission (CEC)’s EER=3.0 is ultra-conservative
  – Estimate for 2020, established before any direct comparisons were available
  – An SAE report projects that just half of CAFE-mandated future fuel efficiency gains will be from increased drivetrain efficiencies
    • The other gains will benefit PEVs as much as conventional vehicles
    • Some of the efficiency gains will be from averaging in plug-in vehicle contributions
Useful-kWh is More Meaningful than Nameplate kWh (kilowatt-hours)

• Usually, only a fraction of battery nameplate capacity is made available to the vehicle
  – Typically 50% to 80%, to meet cycle life requirements
  – Set by cell & vehicle / drivetrain manufacturers, e.g. (two extremes):
    • Chevy **Volt**: 8 kWh (50%) of 16 kWh pack is available
    • Nissan **Leaf**: 80-95% of its 24 kWh pack can be used if (unusually) driven to empty [Prev. info from a Nissan rep. was 100%; latest at http://nissan-leaf.net/2010/08/04/leaf-depth-of-discharge/]
  – Electric range is dependent on available capacity (useful-kWh)
  – All costs and benefits in this paper are relative to **useful-kWh**
Second-guessing Battery Prices

- OEMs & their suppliers guard high-volume battery pricing & projections as competitive, proprietary data, but some recently leaked to the press
  - Analysts have based pessimistic industry outlooks on more available low-volume prices
- Nissan says the Leaf’s 24 useful-kWh battery will cost $9k – ~$425/useful-kWh
  - Believable: a Leaf would sell for ~$23k without the battery; and
  - Nissan is investing billions in facilities to manufacture 200k-500k BEVs/year
  - Another report indicated that initial, before-new-factory-completion cost is double $9k
- GM says the Volt’s (PHEV / EREV) battery cost is [already] “significantly less than $1000/[useful?]kWh”. Est. $800 or $1600/useful-kWh, $6.4 or 12.8k / pack
  - EREV batteries are higher power and cost more than BEV batteries
  - GM has lower production volumes but is already working on next two generations, to be progressively less expensive with higher useful proportion of capacity
- An unnamed major OEM quote: $500/useful-kWh of 2012 battery packs
- Traction Li-ion prices
  - Have been declining by 6-8%/year (>50%/decade)
  - Are still far above their materials costs, indicating room for continued decline
- Our best estimate of 2012 high-volume battery costs:
  - BEV & blended PHEV: $450/useful-kWh
  - EREV: $800/useful-kWh
PEV Rules of Thumb –
Independent of Vehicle Size or Type, motorcycle to 18-wheeler!

• Displacement of oil by electricity:
  – Using today’s EER = 4.7 (est. 2020 EER = 4.0, but battery prices will be lower by then, too)
  – ROI also assumes $3.50/gallon of gasoline (or $3.90/gallon of Diesel), average throughout the ROI period
• PHEV / EREV (based on full use of a single charge per day) and Fleet BEV (based on 140% of range driven each weekday, via 2 charges)
  – **Displacement:** 47 gallons/yr per useful-kWh (10x EER)
  – **ROI:** 4.9 years ($800/useful-kWh => $17 per gallon/yr displaced)
• **Personal BEV** (based on 30% of range – e.g. 30 of 100 miles – driven daily)
  – **Displacement:** 14 gallons/yr per useful-kWh
  – **ROI:** 9.1 years ($450/useful-kWh => $31.90 for each gallon/yr saved)
• The fine print (factors not included, probably overall favoring PEVs)
  – FAVORING PEVs: Improved PHEV charge-sustaining fuel efficiency vs. non-hybrid ICEs, sale of battery for secondary uses, maintenance savings (especially for BEVs), probable government incentives, possible payments for grid services
  – **Other PEV costs:** Electricity (typically <$1.00/gallon equiv.), interest from paying for battery up front
U.S. Oil Consumption is a National Security Issue as Well as a Worldwide Conundrum

• The U.S. imports as much oil as it consumes for transportation, and spends over a billion a day on it! Oil money funds deep water drilling as well as dictatorships.

• To stabilize at 450 ppm, which many believe may still cause a tipping point, the IPCC recommends 20% GHG reductions vs. 1990 by 2020 (80% by 2050)

• Transportation must shoulder its share of GHG reductions, as it accounts for the following percentages of GHG emissions

  – 20% worldwide
  – 30% in the U.S.
  – 40% in California
  – 50% in metro CA

• Even at 10x the HEV new-vehicle penetration rate, by 2020, PEVs will only:

  – (the numbers in orange are for 2030, but are needed for 2020)
  – Total 21% (100%) of new vehicles
    79% will still be new ICEs, each guzzling gas for another 15+ years!
  – Total 3% (37%) of the fleet
  – Reduce oil consumption by 2% (27%) and carbon emissions by 1% (19%)
Reasons for the ‘Big Fix’ Strategy: Mass-produced ICE->PEV Conversions

• Biofuels can help, but, besides the necessary refineries, there are enough cellulosic raw materials for only 30% of transportation energy

• We can’t retire existing vehicles fast enough to accelerate reductions by many years
  – Worldwide new-vehicle production capacity would have to double to save a decade
  – Manufacturing new vehicles (even with recycled materials) contributes the following ‘embedded energy’ to lifetime energy consumption:
    • Today’s ICE vehicles: ~15% as much as their lifetime fuel consumption
    • Efficient BEVs: up to 80% as much as their lifetime fuel consumption! (PHEVs in between)

• At any stage in an existing vehicle’s life:
  – A replacement PEV would need to be twice as fuel efficient to save as much as the manufacturing energy lost by crushing its predecessor early.
  – After only 9000 mi, energy savings ensue from converting a vehicle into a PEV

• Rapid conversion of many of the 100M large light, medium, and heavy-duty ICE vehicles in the U.S. into BEVs and PHEVs can accelerate our overall oil consumption and GHG reductions by a decade!

• Therefore, we must fix millions of the 250M (900M worldwide) existing vehicles, plus those non-plug-in vehicles still being produced
Mass-produced Conversions Can Accelerate Oil & GHG Reductions by the Decade We Need!

U.S. PEV Fleet Penetration from OEM PEV Penetration of New Vehicle Sales 10x as Fast as Happened for HEVs

Gasoline and GHG Reductions from OEM PEVs vs. also from Mass-produced Conversions
The Low-hanging Fruit: Pickups, Vans, Larger Vehicles, and Those with Defined Drive Cycles

- They use 50% of transportation fuel; generally have room for batteries
- Due to scale, conversion cost is lowest per gallon of fuel saved
- Vehicles with known, limited routes can become BEVs; others, PHEVs
- Custom conversions can be cost-effectively designed, tested, and certified for each of the many vehicle models like the F-150 that have sold in the millions
- Conversions can be:
  - Custom designed, tested, and certified for each of the most popular vehicle models like the F-150
  - Built in recently closed auto assembly plants, using batteries from new recently-stimulus-funded factories
  - Installed by local dealers and repair shops, providing local jobs across the country
- Additional battery manufacturing capacity investment is just waiting for demand
The Economics of Gas Guzzler Conversions

- Mass production costs for pickups, with 3 conversion alternatives:
  - Can extend the life of vehicles in good shape with aging/gluttonous drivetrains
  - Battery cost figured separately as a pre-payment of otherwise-future fuel costs
    - Energy Service Company battery financing and/or government incentives until prices decline
    - Battery ROI is better than for new PEVs, as existing fuel economy of older vehicles is worse
      - Est. EER = 5.2, est. 52 gal/yr displacement per useful-kWh => 4.4 years battery ROI
      - Est. 30% hybridization fuel efficiency increase may reduce overall ROI to 2-3 years!
  - Add PHEV components to the existing drivetrain: ~$5k + battery
    - Cheapest but only 1/2 - 2/3 as effective as a new PHEV
    - 1/2 - 2/3 new-vehicle savings at 10-20% (+ battery) the price of a new vehicle
  - Replace the drivetrain with a PHEV version: ~$10k + battery
    - Except for vehicle drag, can be as effective as a new vehicle, for 20-40% of the price (+ battery)
  - Replace the drivetrain with a BEV drivetrain: ~$5k + a larger battery
    - Limited range, but, at 10-20% (+ battery) the price of a new vehicle, effective e.g. for fleet vehicles with known routes
    - Not having an ICE means the lowest fuel and maintenance costs
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Plug-In Hybrids Use Cheaper, Cleaner, Domestic Energy

Quick Takes
How to Get a PHEV
Where PHEV Conversions Are

9/20/09 DRAFT: The Big Fix: 16 Founding Points for the Campaign to Upgrade Gas Guzzlers

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