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

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R1, 8/9/2010

- 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)

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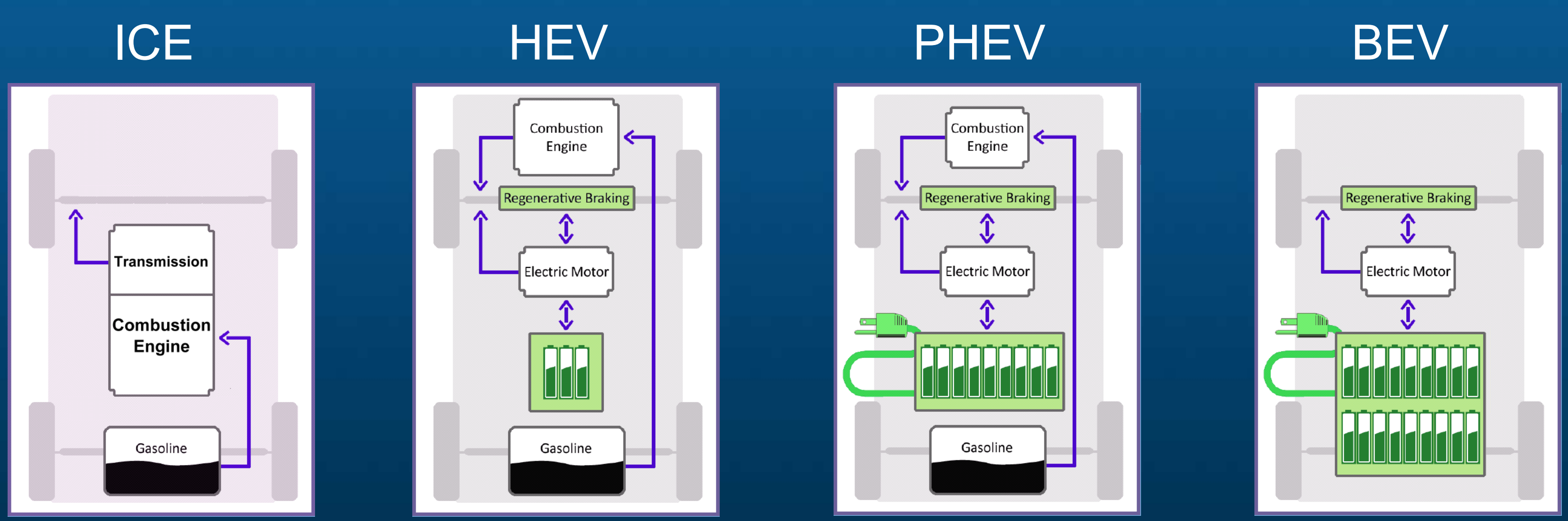
Costs of PEVs (vs. ICEs) Dominated by Batteries

- **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**



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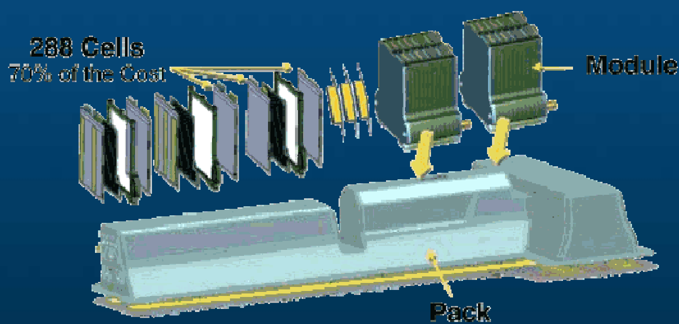
EER is Key to Calculating Battery Cost Effectiveness

- 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*



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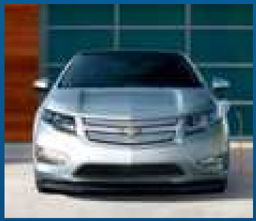
Second-guessing Battery Prices

- 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**

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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

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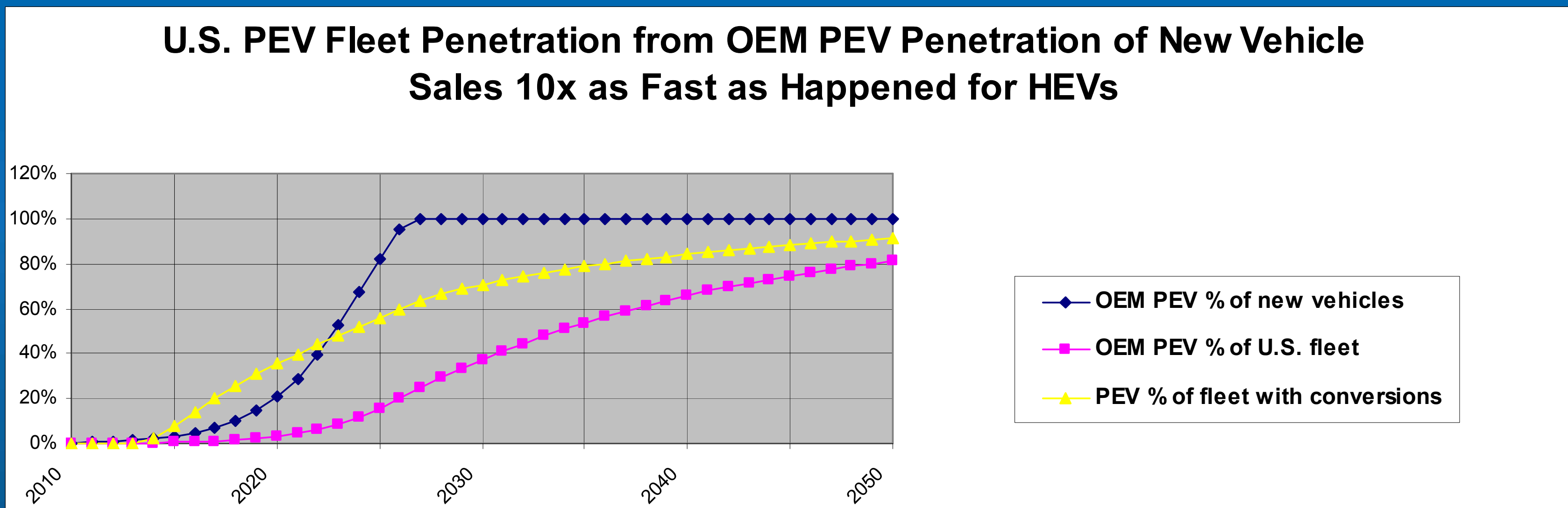
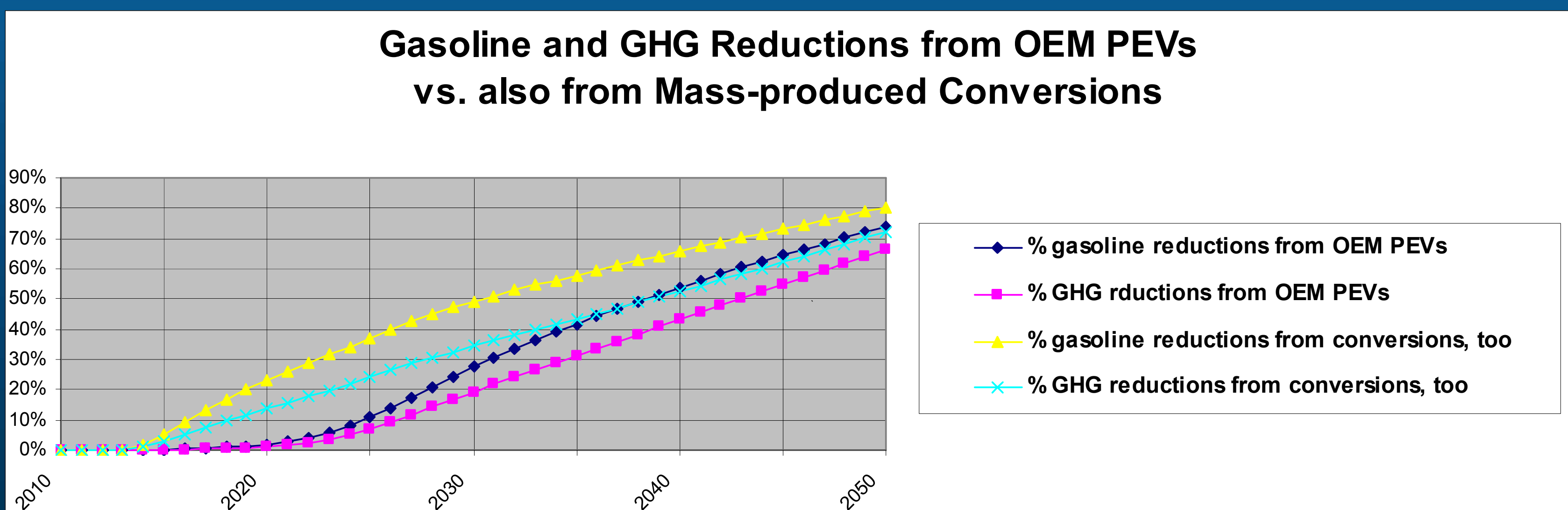
Mass-produced Conversions Can Accelerate Oil & GHG Reductions by the Decade We Need!





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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

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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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