# A Strategy for Overcoming Plug-in-hybrid Battery Cost Hurdles in California: Integrating Post-Vehicle Battery-to-grid (B2G) Use Values

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## California Electric Fuel Implementation Strategies (CEFIS) project

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**PIER Transportation Subject Area**

Energy Generation Research Office
Energy Research and Development Division

California Energy Commission

# Plug-in hybrids are coming

| **Vehicle** | **Li-ion battery** | **e- drive equivalent** | **Status ('09)** | |
|---|---|---|---|---|
| BYD F3DM | 13.2kWh BYD LiFePO4 | 60mi | $22k in China; U.S. in 2011 | |
| Chrysler Town & Country | A123? | 40mi EREV | ?? Up to Fiat now | |
| Fisker Karma | 22.5kWh ALP or EnerDel | 50mi EREV | $87.9k in Sep 2010 | |
| Ford Escape PHEV | 10kWh JCS (doped NiOx?) | 30mi | Making 5k/y in 2012 | |
| GM Chevy Volt | 16kWh CPI (LG Chem) LiMnO2 | 40mi EREV | $40k in Nov 2010; SF&DC | |
| Toyota PHV | 5.2kWh Li-ion Panasonic | ~13mi | Testing 150 in U.S.; retail MY'12 | |

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# Problem

- Battery costs remain high
  - Optimizing cost, life, safety is like squeezing a balloon
  - Batteries alone can cost as much as a competing conventional vehicle
  - Threatens successful, let alone widespread commercialization

## Overview: Strategies for overcoming battery first costs

Several strategies could help, including:

- Battery downsizing, standardization, and leasing
- Shortened initial vehicle deployment
- Down-cycling/repurposing
  - e.g., into stationary use for building and grid-support services
- Third-party or other non-conventional ownership or investment might:
  - Facilitate leasing and align incentives for battery improvements and full and responsible use
  - Allow the NPV of battery services to be brought forward into initial vehicle transaction as "residual value"



## Analytical example (in CA): A strategy for the electric fuel transition

Consider:

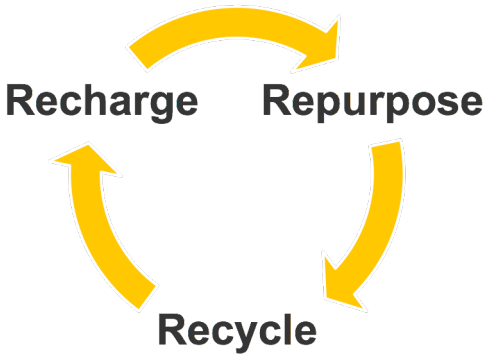
- A 6kWh battery pack
  - Balance of plant: e.g., voltage monitor, throughput meter, minimal intelligence, cooling and electrical (e-) connections
- Initially costing $9k per pack
  - E.g., $1,250/kWh + $1,500 balance of plant
- In mid-sized blended plug-in hybrid:
  - ~10–15mi "EV" range
  - If regularly recharged (ideally with renewables), gasoline ~1/2 of conventional car

# Battery lease—car only

- Battery lease = $130/month over 10y
  - or equiv. if structured per mi
  - e.g., at 7% with $250 setup fee
  - not including recharging infra. or e-
- Better than $9k up front, but still considerable cost hurdle
- Nascent technology forced to compete as commodity
- When no longer up-to-spec in car, still valuable asset…



# Redefining battery pack lifecycle: Getting more




- ***Recharge*** to provide clean power to vehicles.
- ***Repurpose*** for post-vehicle, stationary use with smart home power management and for grid-support services
- ***Recycle*** to reuse battery materials.

## Repurposing pack for stationary use

- After, say, 5 years of degradation in car
- Re-rated at 4.3kWh for 10y of less demanding stationary use
- Repurposed for $7k
  - Re-add dis/charge, inverter, cooling, safety left on car
- I.e., $1k in annualized capital costs
- Can this e- storage device provide net benefit?



## Stationary e- storage revenue (subset)

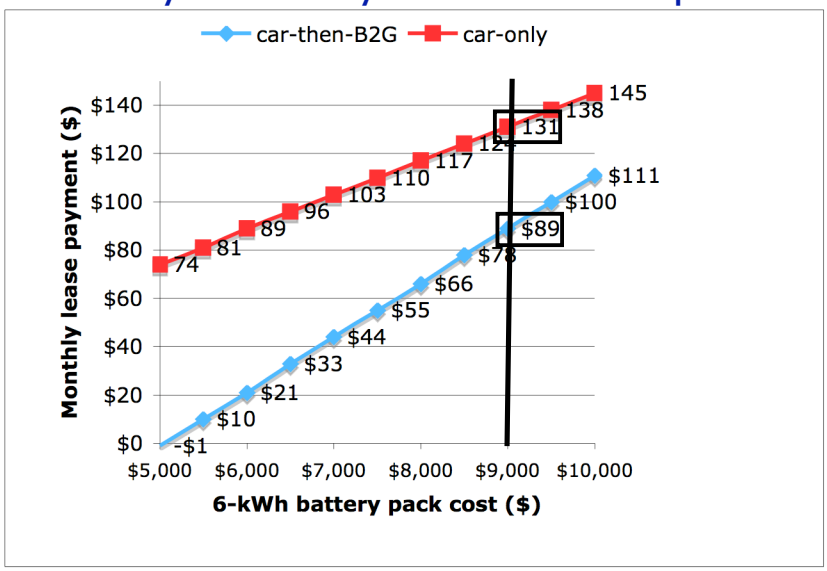
| | **Battery-to-grid (B2G) value (per year)** |
|---|---|
| Grid "Regulation" services | $1,852 |
| Peak-power | $59 |
| Arbitrage | $114 |
| Carbon avoided by wind storage | $12 |
| Annualized infra. capital costs | -$977 |
| Net rev. (covering infra. & energy) | $1,059 |

# Benefits (subset) summary

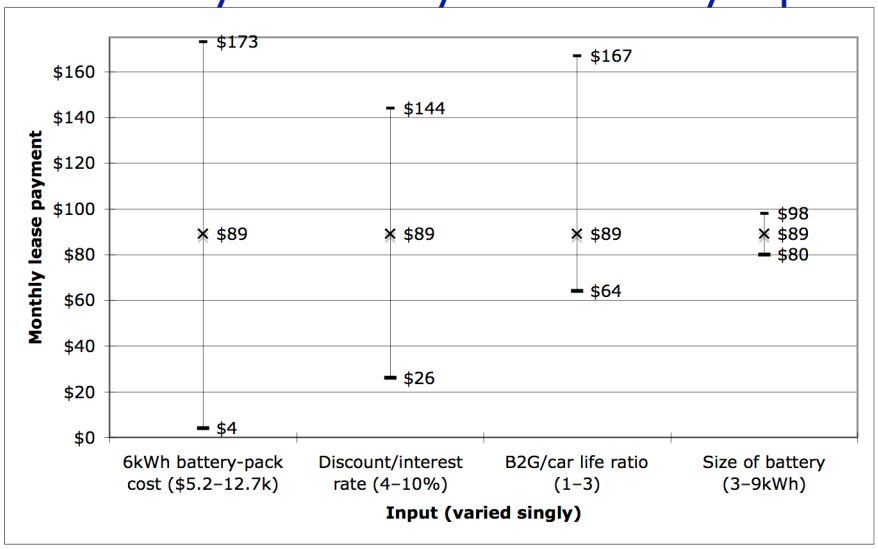
- NPV (B2G revenues) = $5.5k "residual value"
- Lowers $131/mo lease requiring full depreciation over 10y to
- <$90/mo, 5y
  - Assumed high battery costs; $5k battery lease essentially free
  - Reasonable bounding case even better
  - Several unexplored revenue streams
- Get to upgrade car every 5y, with rapidly maturing battery



# Sensitivity of battery lease to 6kWh pack cost



# Sensitivity of battery lease to key inputs

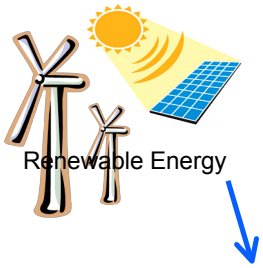





# Illustrative uncertainty range

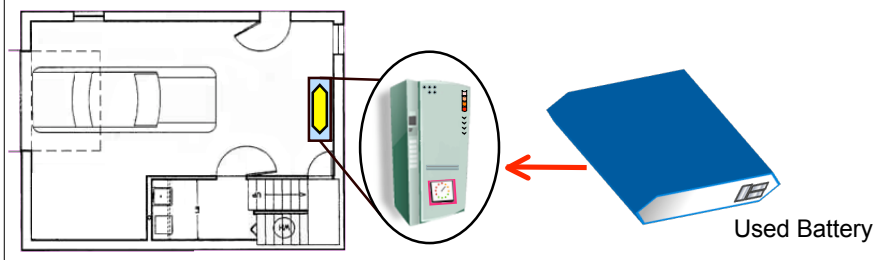
| Battery-to-grid (B2G) value (per year) | "Low" (3kWh system with conserv. inputs) | "Estimate" (6kWh) | "High" (9kWh, favorable inputs) |
|---|---|---|---|
| Regulation revenue covering energy costs | $227 | $1,852 | $7,172 |
| Peak-power rev. covering energy | $6 | $59 | $174 |
| Arbitrage revenue covering energy | $24 | $114 | $323 |
| Carbon avoided by wind storage | $0 | $12 | $198 |
| Annualized infra. capital costs | -$629 | -$977 | -$1,660 |
| Net rev., covering infra. capital | -$373 | $1,059 | $6,207 |

# Repurposed e- storage




As # of units grows:

- 10%+ more wind
- Several % fewer GHGs (including car charging)






# Additional thoughts, recommendations

- Focus shifting to reducing near-term barriers
- Policy focus on reasonably small battery plug-in hybrids, rather than all-battery EVs, as common denominator for public support
  - Less costly, less compromised, require sparser and cheaper infra, less disruptive to consumer, able to benefit from advances in existing fuel and engine systems
    - Overnight, home charging needed most—not opportunity charging
  - Nevertheless, use frameworks broad enough to nurture niche development of ZEVs (battery EVs and FCVs)—don't let swinging pendulum chop down the saplings we'll need soon enough

## Summary: Strategies

Working in concert, several strategies could help the early commercialization picture for electric-fuel, e.g.:

- Battery downsizing, standardization, leasing
- Intentionally short vehicle deployment and down-cycling/repurposing
- Stationary e- storage devices: B2G (and other, perhaps greater) revenues
- Third-party ownership/investment; utility rate basing?



## Directions for future work

- Other values:, deferred grid upgrades, demand response, B2B, customer-side-of-the-meter benefits, sophisticated renewables/carbon benefits, etc. etc.
- Recycling: can you make back more than the costs of shipping heavy spent batteries?
- Smart-grid households vs. battery-pack powerplant aggregation centers?
- Beyond market saturation: evolution of new e-landscapes
- Care to collaborate?

## Thank you for your interest!

Additional slides follow…



## Battery Leasing

- "In Europe this has significantly increased sales of battery EV[65]." (EPRI/HEVWG 2004, p. 4-21)
- Consumer doesn't see upfront cost differential
- Lifecycle costs parity allows for a business case
- EPRI '04 p.4-22: low costs/mi for PHEVs argue to turn batteries into operating, not upfront, cost
- Additional benefits not mentioned:
  - Gives supplier incentive to produce long-lasting, recyclable batteries (to increase profit margin)
  - Gives consumer incentive to use ZEV range (built into lease, whereas gasoline is an additional cost)
  - Any willing takers?

# Key inputs: Battery in bldg.

| **In building** | |
|---|---|
| Time in car | 5 |
| Capacity degradation in car | 0.978/y |
| Capacity remaining after car | 5.37kWh |
| Depth of discharge allowed | 0.8 |
| ***Available capacity in bldg.*** | ***4.29*** |

| **Annualizing costs** | |
|---|---|
| Discount rate | 0.07 |
| Life factor (B2G life / car life) | 2 |



# Grid-support services

| Market | Response Time | Revenues | Dispatch call freq. | Generation Duration |
|---|---|---|---|---|
| Peak Power | Medium | Energy payment [$0.50/kWh generated] | ~40–60/y | 3–5 h [4h] |
| Spinning Reserve | 10 min | Energy ($/kWh) & *Capacity:* per kW available for contract period ($/kW-h) | [20/y] | 10 min – 2 h [1h] |
| Regulation | <1 min Direct control of ISO | | Many short calls per day | Minutes [reg. up/down: 20min reg. up only: 1.4h] |

[K&T05a example values in brackets]

# Key inputs: Energy & regulation

| **Energy** | |
|---|---|
| Cost of "fuel" | $0.115/kWh |
| kWh in / kWh out | 0.85 |
| ***Cost of electricity out*** | ***$0.13/kWh*** |

| **Regulation** | |
|---|---|
| Dispatch/contract ratio | 0.1 |
| Capacity price, reg. up+down | $0.033/kWh |
| Reg. energy price (=fuel price) | $0.115/kWh |
| CA reg. requirement, up+down | 732MW/y |



# Key inputs: Peak power & arbitrage

| **Peak power** | |
|---|---|
| Demand | 150h/y |
| Price | $0.50/kWh |

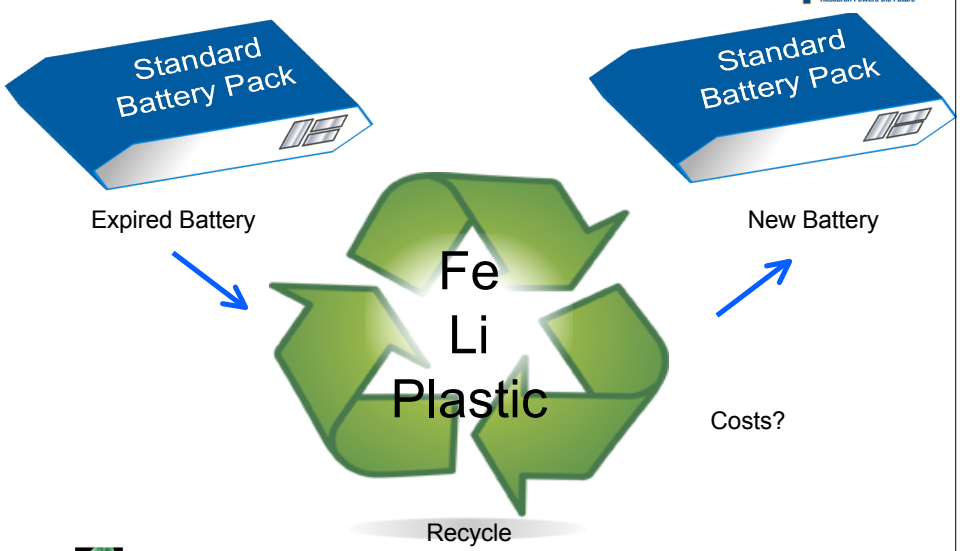
| **Arbitrage** | |
|---|---|
| Spark spread, incl. transmission & losses | 0.1 |

# Additional revenue streams analyzed

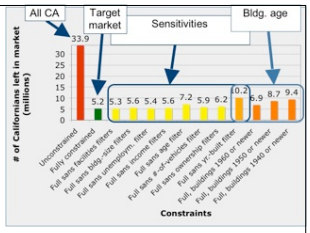
- Electricity arbitrage (buy low, sell high)
  - Assume $0.10/kWh spark spread
  - Interpolate, scale, build upon Lamont 2004 analysis for 1kW hypothetical storage using real CA e- prices
- Carbon reduction (simple case)
  - Starting point: assume each device saves two fills per day of otherwise wasted wind energy
  - Save average CA C intensity of ~0.3 $TCO_2e$/MWh
  - Assume $15/$TCO_2$ value (low end of 2008 Deutsche Bank predictions for CA)



# Recycle



# Charging: target market
## (Williams & Kurani 2006)




Early market potential of home "refueling":

- Up to 10M of 34M Californians in 2000 Census appear "pre-adapted" to home recharging (e.g., own residence not connected to too many units, have an income, etc.) (Williams & Kurani 2006)
- More (about half) may have a plug near to where they park (Axsen & Kurani 2008)
- But sufficiency of electrical facilities (e.g., plugs and wires), and thus recharging infrastructure installation costs and level of service, are less well understood (e.g., 5M of 10M live in newer residences)
  - Electrical facilities could be several $100s (low-power to serve, e.g., small-battery plug-in hybrids) to several $1,000s (for necessary upgrades and/or higher power to serve bigger batteries)



# Infrastructure capital costs
## (Williams 2007)

- 10 guage cord and wall outlet…$50
- Large appliance/Level 2AC plug…$650
- Electrical service upgrades…pricey

**Residential plugs and wires**

| Voltage (V) | Amperage (A) | Pline (kW) |
|---|---|---|
| **120** | **15** | **1.8** |
| | | $50 |
| **240** | **40** | **9.6** |
| | | $655 |
| **240** | **60** | **14.4** |
| | | **24.0** |
| | | $1,500 |
| **240** | **80** | **19.2** |
| | | $1,800 |
| **240** | **400** | **96.0** |
| | | $5,000 |