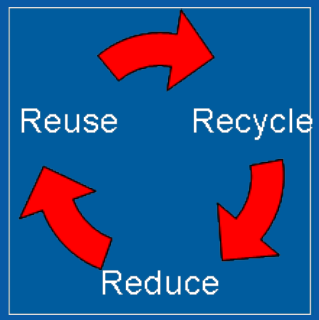
National Renewable Energy Laboratory
Innovation for Our Energy Future

PHEV/EV Li-Ion Battery Second-Use Project

Jeremy Neubauer
Ahmad Pesaran

April 2010

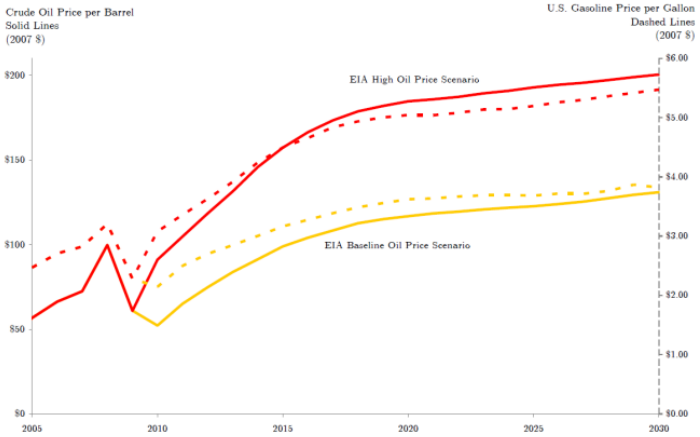
NREL/PR-540-48018

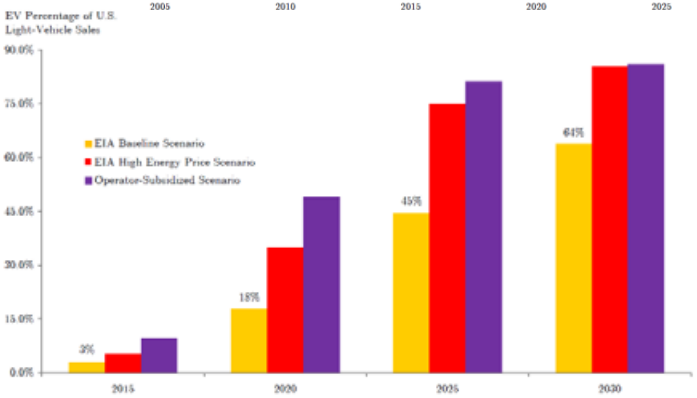


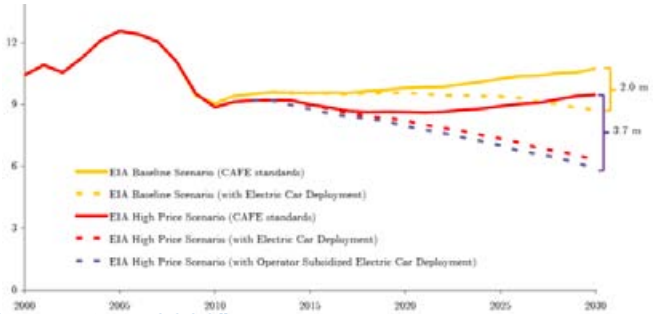
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

PHEV/EV Adoption

- Plug-in hybrid electric vehicles (PHEVs) and full electric vehicles (EVs) have massive potential to reduce U.S. dependence on foreign oil and emissions…
- …but their high initial battery costs inhibit rapid proliferation
  - EV packs can cost more than $30,000!
- **One option to reduce initial battery cost: reuse it in a second application following its retirement from automotive service and obtain a cost credit for its residual value**

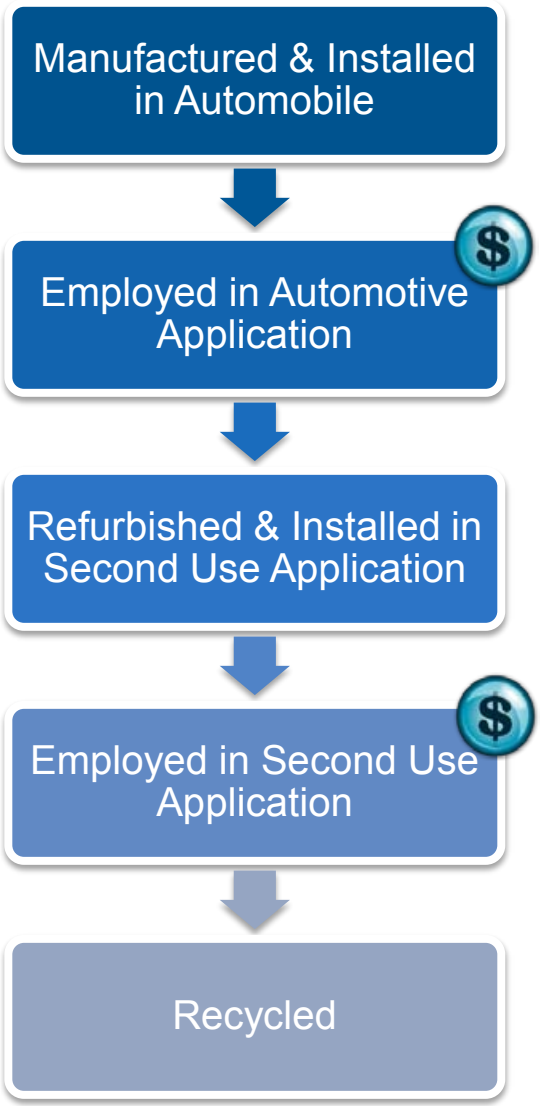






Becker, "Electric Cars in the United States: A New Model with Forecasts to 2030"

Battery Reuse Strategies



- PHEV/EV batteries degraded to 70%-80% of their original power/capacity are insufficient for automotive use
- These “retired” batteries may still be highly useful and could be reused in other applications
- “Second-use” applications could significantly increase the total lifetime value of the battery, **and thus reduce its cost to the automotive user**

Some Second Use Applications

- Grid-Based Stationary
  - Energy Time Shifting
  - Renewables Firming
  - Service Reliability / Quality

- Off-Grid Stationary
  - Backup Power
  - Remote Installations

- Mobile
  - Commercial Idle Off
  - Utility & Rec. Vehicles
  - Public Transportation

Second Use History

- General second use of automotive traction batteries has been studied before:
  - Pinsky, et al., "Electric Vehicle Battery 2nd Use Study"
  - EPRI, "Market Feasibility for Nickel Metal Hydride and Other Advanced Electric Vehicle Batteries in Selected Stationary Applications"
  - Cready, et al. "Technical and Economic Feasibility of Applying Used EV Batteries in Stationary Applications"

- Results showed some promise, but highlighted several barriers:
  - **Sensitivity to uncertain degradation rates in second use**
  - **High cost of battery refurbishment and integration**
  - **Low cost of alternative energy storage solutions**
  - **Lack of market mechanisms and presence of regulation**
  - **Perception of used batteries**

- Due in part to the limited market of PHEV/EVs at the time, no second use programs have been implemented yet

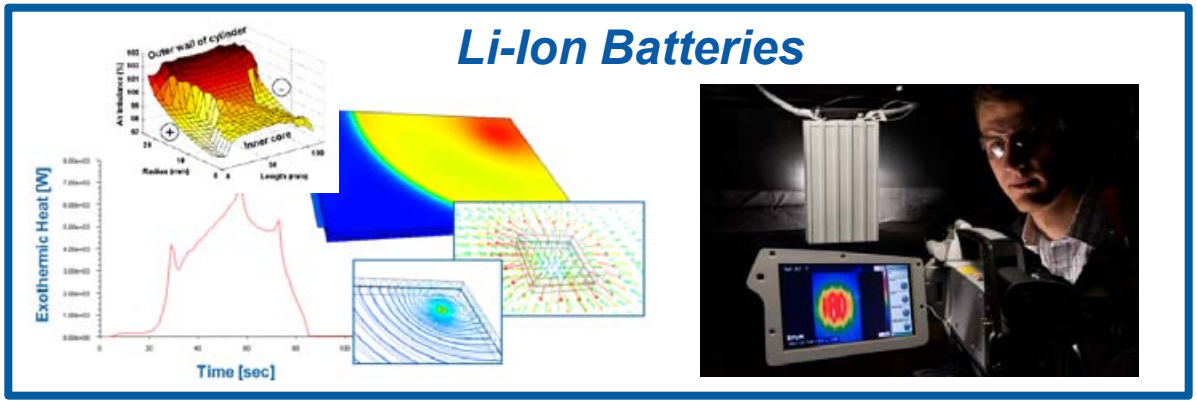
Renewed Interest in Second Use Programs

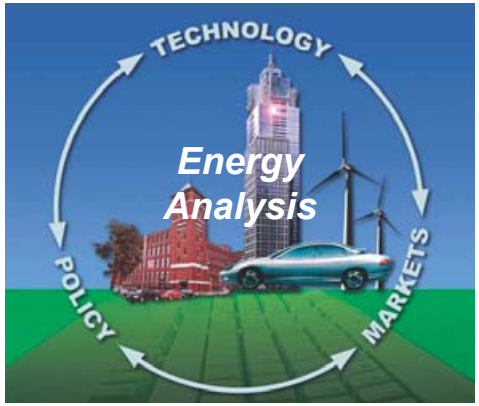
- New opportunities and dynamics for second use of PHEV/EV batteries are driven by…
  - Recent strong interest in PHEV/EVs for reducing emissions and dependence on imported oil
  - Increased need for grid-integrated energy storage to address peak load reduction, grid stabilization / reliability, energy efficiency, etc.
  - Envisioned growth of renewable solar and wind electricity further increasing the value of grid-integrated energy storage
  - Large investment in battery manufacturing for green economy
  - Advances in Li-ion batteries with longer life, but still high cost

Present Second Use & Related Activities

- **AEP & EPRI**… developing a Community Energy Storage (CES) appliance, which they've stated is *"the ideal secondary market we have been seeking for used PHEV batteries"*
- **UC Davis**… has released an RFP titled "*Second Life Applications and Value of Traction Lithium Batteries"* to investigate profitable second use strategies and develop a Home Energy Storage Appliance (HESA)
- **UC Berkeley/CEC**… investigated strategies to overcome the battery cost of plug-in vehicles by the value of integrating post-vehicle battery to grid
- **Rochester Institute of Technology**… funded by NYSERDA to investigate the second use of lithium ion batteries
- **Nissan**… has partnered with Sumitomo to initiate a business plan centered on recovering and reselling used automotive batteries
- **Enerdel** … is working with Itochu to develop energy storage systems for apartment buildings to *"help develop a secondary market"* for used batteries
- **Better Place**… is *"evaluating … second life applications for used batteries"* in partnership with Renault-Nissan
- **DOE / NREL**… funded to investigate reducing initial PHEV/EV battery cost via the second use of automotive lithium ion batteries

NREL: Uniquely Positioned to Investigate Second Use





DOE - NREL's Second Use Project

- **Objective:** Identify, assess, and verify profitable applications for the second use of PHEV/EV Li-ion traction batteries to reduce the cost and accelerate adoption of PHEV/EVs

- **Strategy:**

Phase 1: Assess the Merit of Second Use Applications and Strategies

Application Identification

- All applications are considered, but high-value / high-impact ones are most desirable
- Accurate use profiles and economic data are needed
- Application value and impact will be estimated before progressing to a detailed investigation

Application Identification

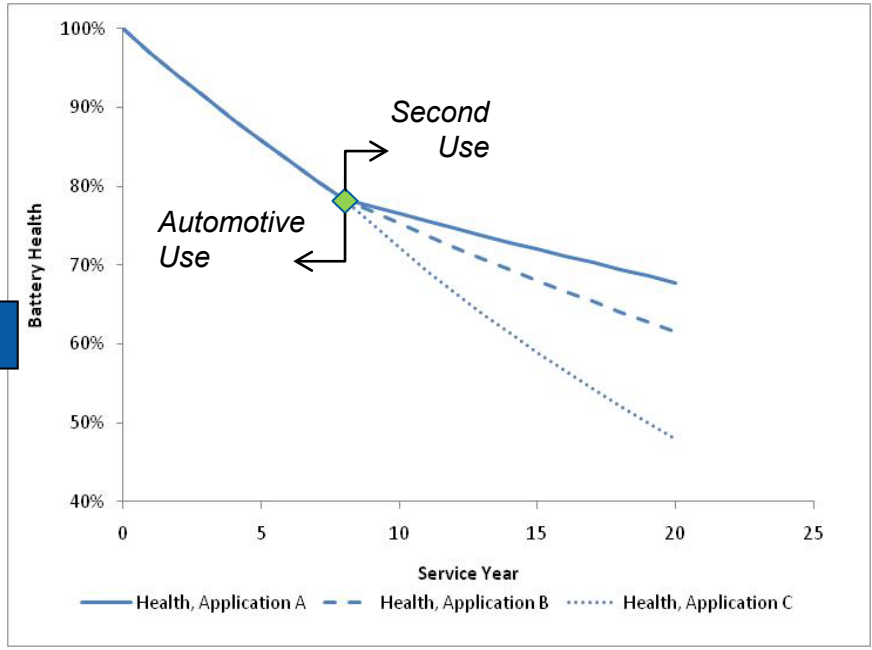
- **For each application, consider…**
  - How does a battery retired from automotive service perform when subjected to the second use profile?
  - What are the projected revenues and costs?
  - What are the safety concerns and liabilities?
  - How do the performance, life, and cost of a second use battery compare with those of competing technologies?
  - What are the regulatory issues or other barriers specific to this application?
  - Is the scale of this application well suited to the expected availability of retired PHEV/EV batteries?

Tool Development & Use

- Must consider *value* and *performance* in both automotive and secondary use environments to calculate total lifetime battery value

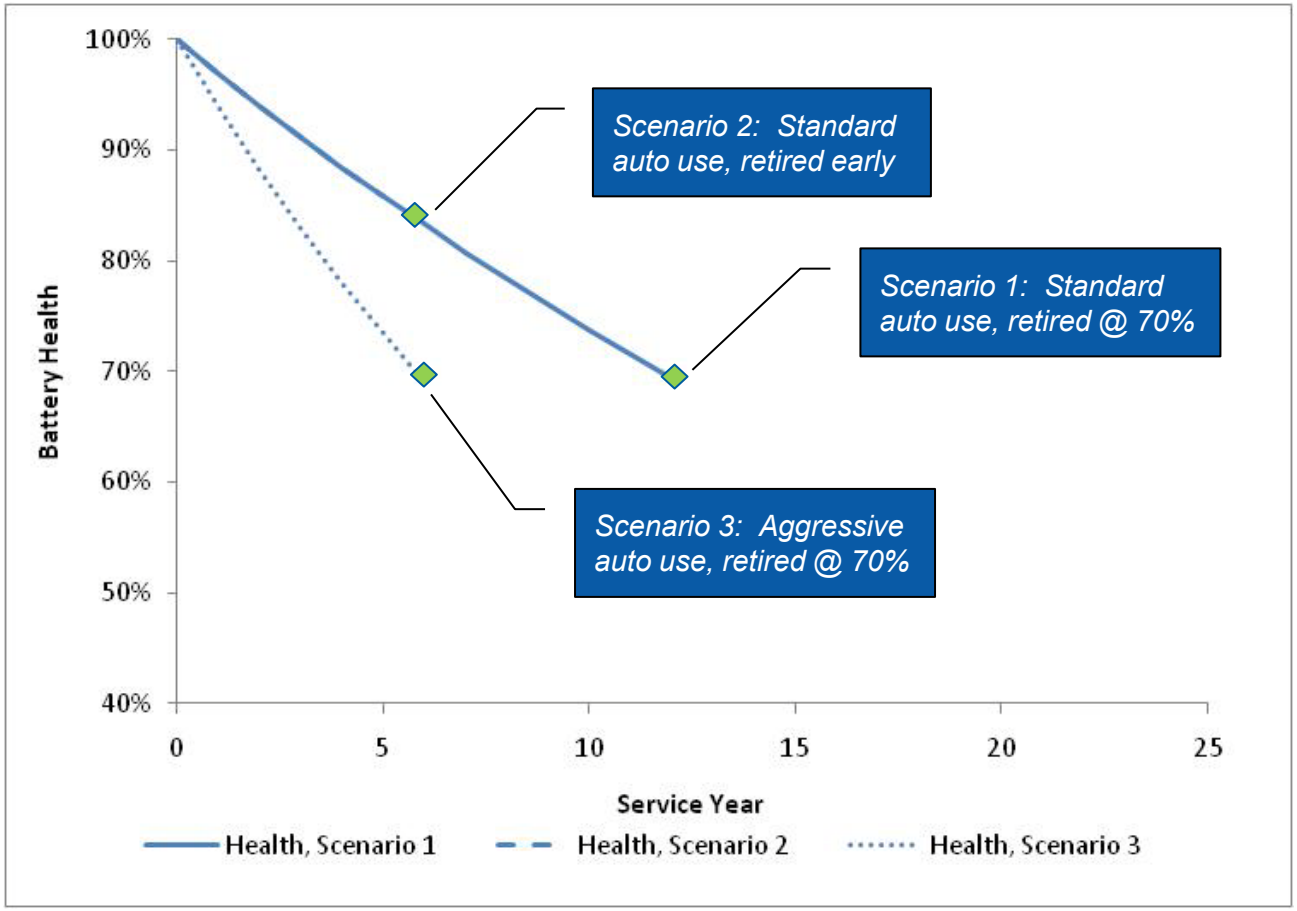
#	Benefit Type	Discharge Duration*		Capacity (Power: kW, MW)		Benefit ($/kW)**		Potential (MW, 10 Years)		Economy ($Million)†	
		Low	High	Low	High	Low	High	CA	U.S.	CA	U.S.
1	Electric Energy Time-shift	2	8	1 MW	500 MW	400	700	1,445	18,417	795	10,129
2	Electric Supply Capacity	4	6	1 MW	500 MW	359	710	1,445	18,417	772	9,838
3	Load Following	2	4	1 MW	500 MW	600	1,000	2,889	36,834	2,312	29,467
4	Area Regulation	15 min.	30 min.	1 MW	40 MW	785	2,010	80	1,012	112	1,415
5	Electric Supply Reserve Capacity	1	2	1 MW	500 MW	57	225	636	5,986	90	844
6	Voltage Support	15 min.	1	1 MW	10 MW	400		722	9,209	433	5,525
7	Transmission Support	2 sec.	5 sec.	10 MW	100 MW	192		1,084	13,813	208	2,646
8	Transmission Congestion Relief	3	6	1 MW	100 MW	31	141	2,889	36,834	248	3,168
9.1	T&D Upgrade Deferral 50th percentile††	3	6	250 kW	5 MW	481	687	386	4,986	226	2,912
9.2	T&D Upgrade Deferral 90th percentile††	3	6	250 kW	2 MW	759	1,079	77	997	71	91
10	Substation On-site Power	8	16	1.5 kW	5 kW	1,800	3,000	20	250	47	60
11	Time-of-use Energy Cost Management	4	6	1 kW	1 MW	1,226		5,038	64,228	6,177	78,743
12	Demand Charge Management	5	11	50 kW	10 MW	582		2,519	32,111	1,466	18,695
13	Electric Service Reliability	5 min.	1	0.2 kW	10 MW	359	978	722	9,209	483	6,154
14	Electric Service Power Quality	10 sec.	1 min.	0.2 kW	10 MW	359	978	722	9,209	483	6,154
15	Renewables Energy Time-shift	3	5	1 kW	500 MW	233	389	2,889	36,834	899	11,455
16	Renewables Capacity Firming	2	4	1 kW	500 MW	709	915	2,889	36,834	2,346	29,909
17.1	Wind Generation Grid Integration, Short Duration	10 sec.	15 min.	0.2 kW	500 MW	500	1,000	181	2,302	135	1,727
17.2	Wind Generation Grid Integration, Long Duration	1	6	0.2 kW	500 MW	100	782	1,445	18,417	637	8,122

Eyer, "Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide"



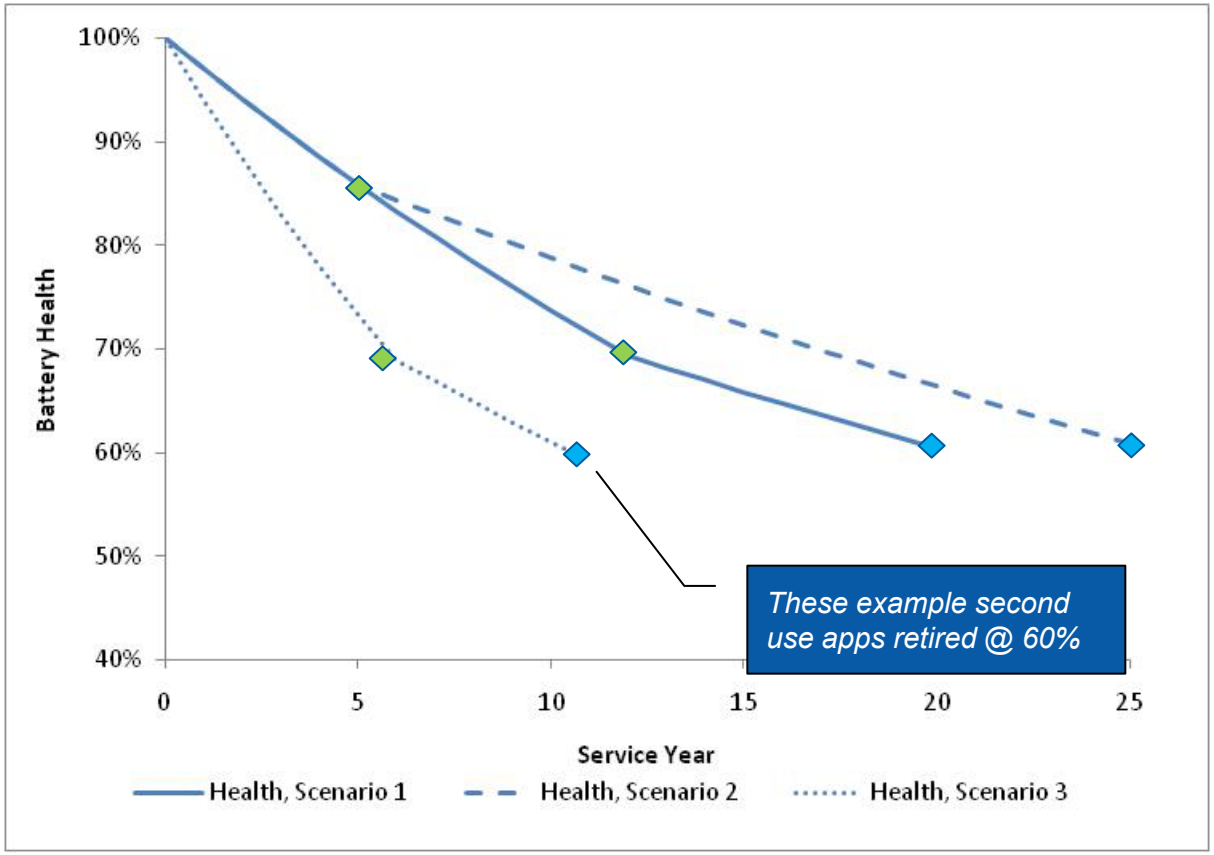
Tool Development & Use

- **First, model performance through automotive use**
  - Consider multiple automotive scenarios, such as various climates, use profiles, initial sizing strategies, retirement dates, etc.



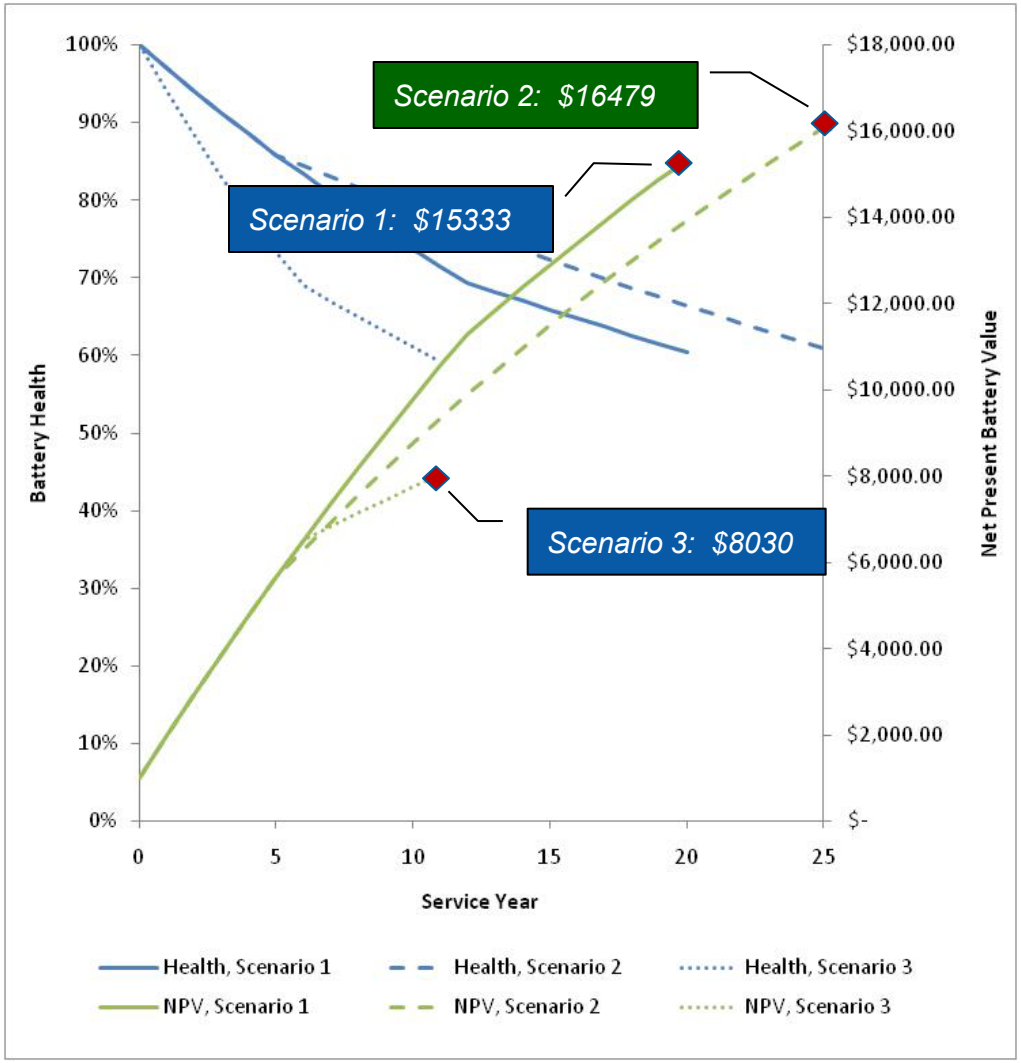
Tool Development & Use

- **Next, select a second use application (or aggregation thereof) and model performance in the second life**
  - Consider appropriate second use application variables



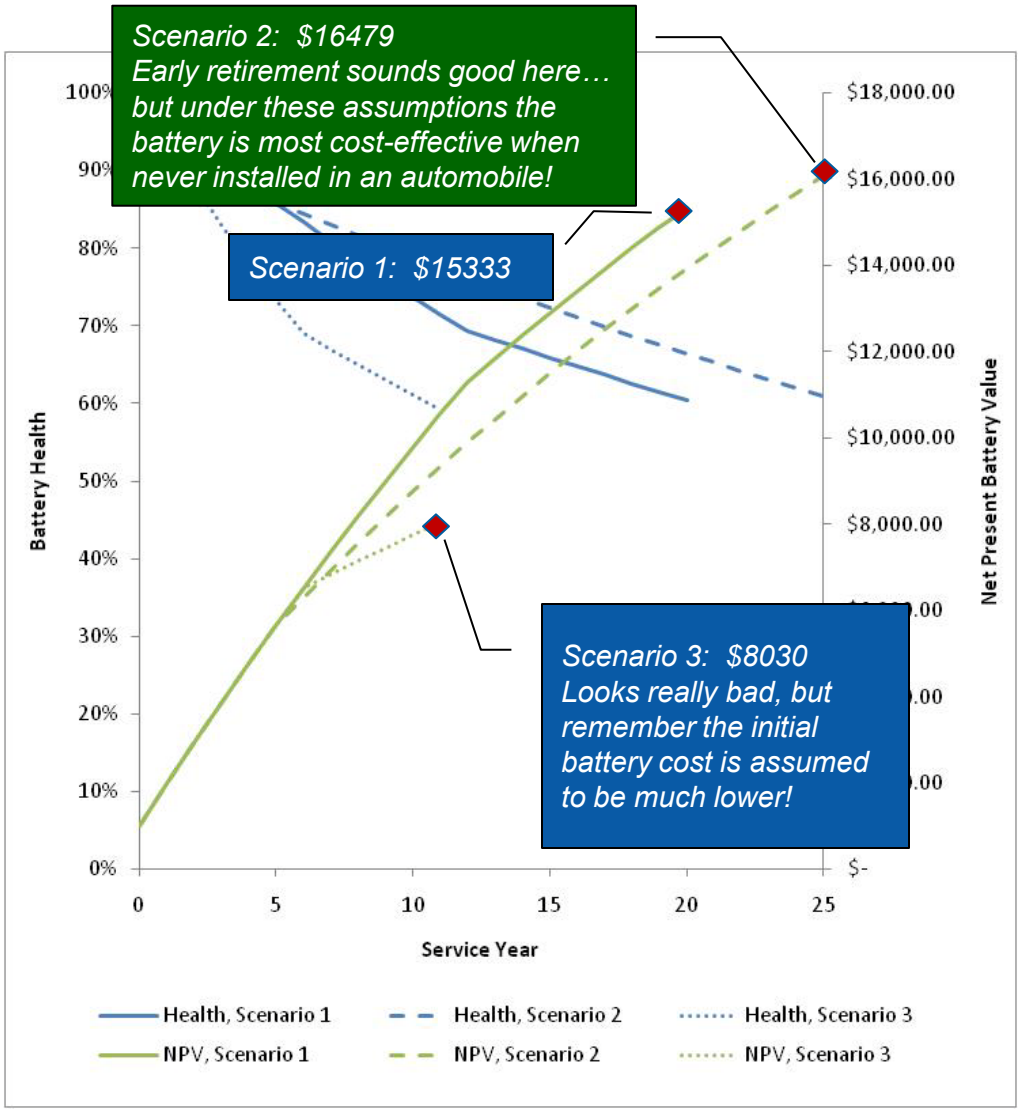
Tool Development & Use

- **Third, calculate the net present value of each scenario and select the optimum use strategy**
  - Apply a $/mile valuation to automotive life?
  - Include both a discount rate for future revenue and anticipated increase / decrease in future second use revenue
  - Account for costs, including reconfiguration, shipping, maintenance, etc.



Tool Development & Use

- **Some things to consider in a proper analysis…**
  - Every time a battery is replaced in a car, a cost is incurred to the owner
  - Linear battery degradation may not be a good assumption
  - If the second use application is too valuable, operators may choose new batteries over used ones



Tool Development & Use

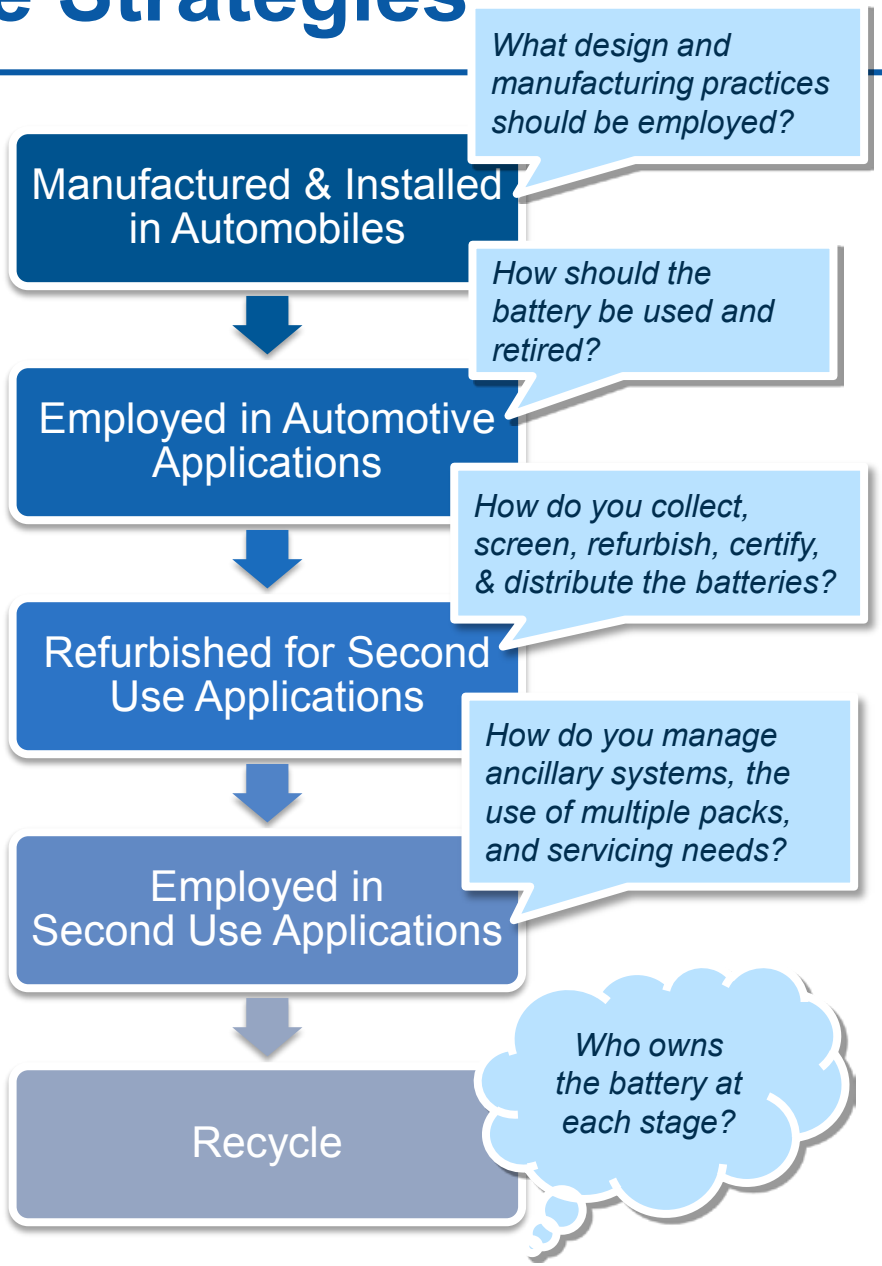
- **Repeat for multiple (aggregations of) second use applications, identify the best ones, and calculate an initial battery price discount**

Tool Development & Use

- **Questions the tool will be asked to answer…**
  - How do different automotive use profiles, environmental conditions, and lifetimes affect performance in the second use application?
  - What is the total lifetime value of the battery, in both its automotive and second use applications?
  - What is the sensitivity of total lifetime value to use history and other parameters?
  - What is the uncertainty in the complete analysis?

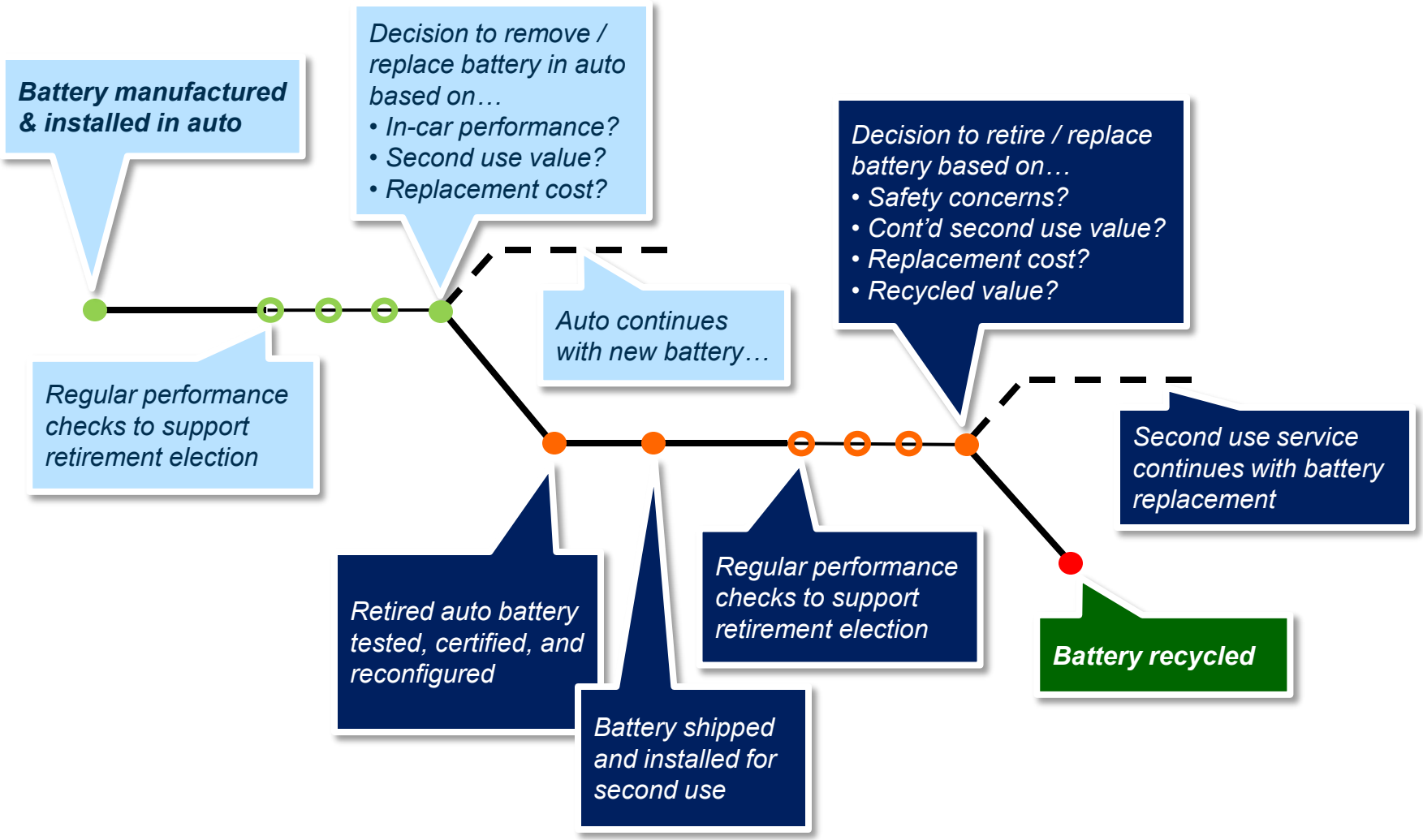
Optimizing Use Strategies

- For a given second use application, there can be many different ways to implement it
- Changing these variables can have a significant impact on total lifetime value and general feasibility
- In this segment, the use strategy of the battery is optimized via the developed tools and practical considerations



Optimizing Use Strategies

- **Example timeline …**



Selecting the Best Applications & Strategies

- Maximum total lifetime value of the battery (biggest initial cost reduction)
- High feasibility of implementation
- Matched well to the size of the PHEV/EV market

Phase 2: Verify Performance In Second Use Applications

Acquire Aged Li-Ion Batteries

- Prefer field-tested batteries from (pre) production PHEV/EVs
- Accelerated aging via lab testing is also an option, but may not ensure correlation with actual field use
- Mass-produced cell and pack designs are required


Courtesy chevrolet.com


Courtesy fiskerautomotive.com


Courtesy nissanusa.com

Courtesy thinkev.com


Courtesy teslamotors.com

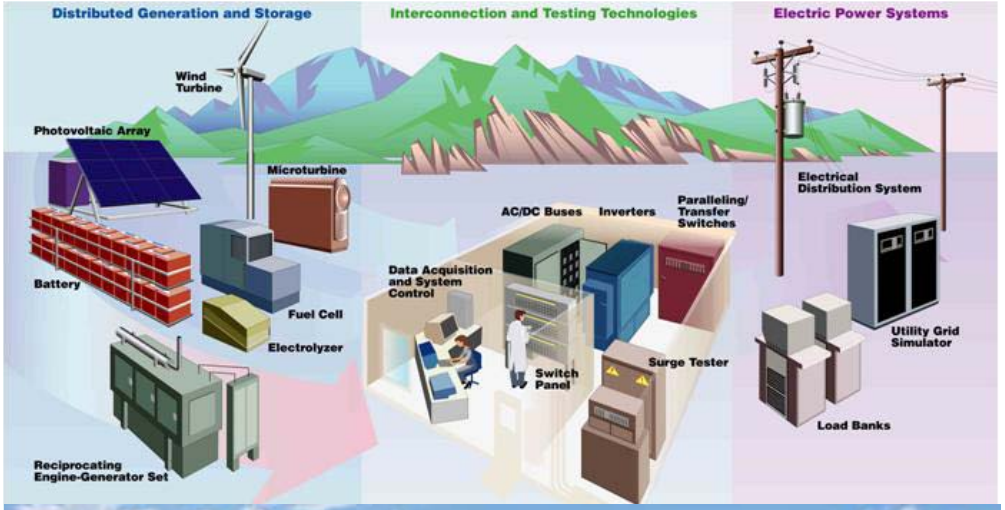

Courtesy miniusa.com

Conduct Long-Term Testing

- Subject the aged batteries to the expected use profile and conditions of the second use application to verify performance and degradation predictions and lifetime valuations

- Lab testing for precise control of conditions

- Field testing for final demonstration



NREL's Distributed Energy Resources Test Facility could serve as a venue for this phase

Phase 3: Facilitate Implementation of Second Use Programs

- **Disseminate study findings** to inform the market of the potential profitability of the second use of traction batteries
- **Provide validated tools and data** to industry
- **Develop design and manufacture standards** for PHEV/EV batteries that facilitate their reuse
- **Propose regulatory changes** to encourage the reuse of retired traction batteries in other applications

DOE-NREL's Second Use Program Status

- High-level objectives and strategies have been formulated
- Work has begun on researching possible second use applications and on tools to forecast performance / degradation
- Discussions with possible partners are under way

What's Next?

- NREL is currently seeking partners to investigate the reuse of retired PHEV/EV traction batteries to reduce vehicle cost and emissions as well as our dependence on foreign oil
- A Request for Proposal (RFP) will be issued in April 2010 seeking subcontractors to support all aspects of this effort
- A workshop to solicit industry feedback on the entire process is also being planned

Acknowledgements

- This activity is funded by the DOE Vehicle Technologies Program, Energy Storage Technology
- We appreciate the support provided by DOE program managers
  - David Howell
  - Steve Goguen

- Technical questions regarding Battery Second Use should be directed to Jeremy Neubauer at 303-275-3084 or jeremy.neubauer@nrel.gov
- Questions regarding the request for proposals should be directed to Kathee Roque at kathee.roque@nrel.gov