Second Use of PEV Batteries:
A Massive Storage Resource for Revolutionizing the Grid

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Jeremy Neubauer
Ahmad Pesaran
Eric Wood
Kandler Smith

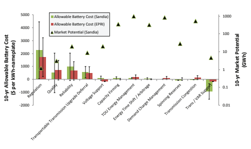
INTRODUCTION

Motivation: Significant interest in re-using batteries after retirement from vehicles to offset initial high battery cost, transfer EOL battery management responsibilities away from automotive owners, and offer low cost battery options to stationary energy storage applications

Objective: Assess the feasibility and impact of PEV battery secondary use

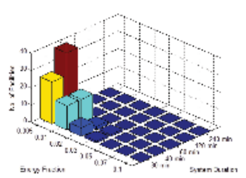
Approach: Predicting battery degradation is critical to both automotive and second use service. We apply an advanced semi-empirical wear model embedded in NREL's Battery Lifetime Analysis and Simulation Tool (**BLAST**), connecting the electrical, thermal, and wear response of the battery to its application. Results feed techno-economic assessments of second-use business strategies.

Download reports and tools at:
http://www.nrel.gov/transportation/energystorage/use.html



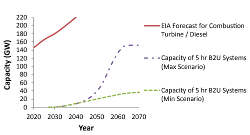
Analysis of grid connected applications using data from Sandia and EPRI shows that high value markets exist, but have small market sizes. Lower value, larger size markets may be better targets to accommodate the large potential supply of second use batteries.

Behind the Meter Storage

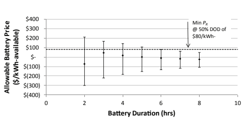


Batteries can be employed in commercial and industrial facilities to reduce demand charges and shift energy usage from high to low cost time periods. While current rate schedules encourage the use of relatively small systems, evolving incentives could drive longer duration systems and a large market in excess of 50 GWh.

Peaker Plant Replacement

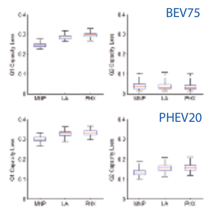


Gas powered combustion turbines typically provide electricity at times of peak demand. Comparing the scale of the market and of second use battery supply suggests that this application could consume all available second use batteries.



Due to geographical and temporal variance in plant operation value, only some fraction of this market appears economically viable. Further investigation is necessary, but is challenged by the need to account for the total systems benefits delivered and the effects of limited storage duration.

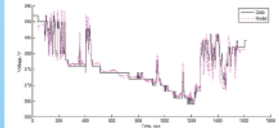
- Calendar effects dominate capacity loss in both vehicles, making the climate of automotive service important
- PHEV batteries see more degradation in both capacity and resistance due to more frequent high DOD cycling
- There is little to no economic incentive for removing batteries from automotive service prior to the end of the vehicle's life



ONBOARD DIAGNOSTICS

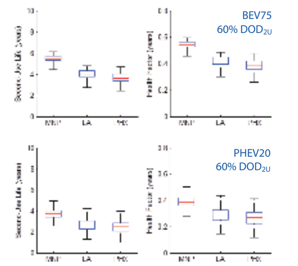
A battery model can be inverted and used to calculate state-of-health battery parameters (like capacity and resistance) from prescribed or arbitrary use data.

This capability can be applied on a vehicle's battery management system to report on the state of health of both individual cells and the pack as a whole and employed to make repurposing decisions.



Example voltage fit of a pack-level battery model and data after optimization of battery capacity, resistance, and diffusion parameters

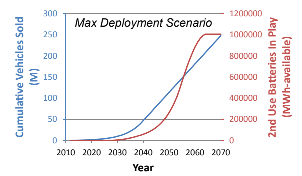
Simulated degradation of used automotive batteries to compute second-use lifetime and health factor across drivers, climates, and vehicle platforms. Predicted 3-10 year second use lifetimes depending on vehicle type, automotive service climate, and second-use DOD.



Projected maximum repurposed battery selling price based on new battery manufacturing cost forecasts and predicted second-use lifetime.

New Battery Price	Second Use DOD	Vehicle	Health Factor	Max Repurposed Battery Selling Price
$250/kWh	60%	BEV75	0.33	$83/kWh
		PHEV20	0.29	$73/kWh
	50%	BEV75	0.72	**$180/kWh**
		PHEV20	0.65	$163/kWh
$150/kWh	60%	BEV75	0.33	$50/kWh
		PHEV20	0.29	**$44/kWh**
	50%	BEV75	0.72	$108/kWh
		PHEV20	0.65	$98/kWh

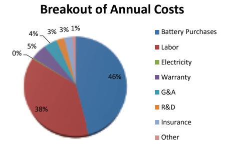
Applied calculated battery lifetimes, second-use DODs, etc. to PEV deployment scenarios; found that rolling supplies of available second-use battery capacity could exceed 1 TWh.



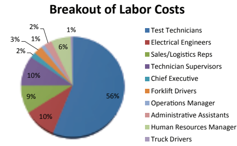
A detailed economic model of a repurposing business was created that includes:

- Local, regional, and national battery collection options
- Floor plan that scales with module size and requested facility throughput
- Capital equipment purchases (battery cyclers, work stations, fork lifts, etc.)
- Labor expenses (technicians, supervisors, human resources, etc.)
- Cell fault rate and its effect on facility yield
- Return on investment requirements

Breakout of Annual Costs



Breakout of Labor Costs

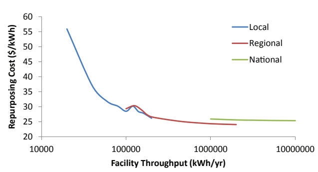


After the cost of buying batteries, technician labor constitutes the majority of remaining repurposing costs – even when repurposing modules without disassembly to the cell level.

Reducing handling time to minimize technician labor is thereby key to minimizing repurposing costs.

Our minimum cost scenario suggests that $20/kWh-nameplate repurposing costs and $40/kWh-nameplate selling prices are possible when processes are streamlined.

Facility throughput can greatly affect repurposing costs. A regional facility operating at ~1 GWh/yr of retired automotive batteries (~45,000 BEVs per year) is near-optimal, and is well suited to repurposing a single design of battery.



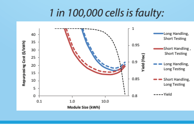
CELLS, MODULES, OR PACKS?

Technician labor dominates repurposing costs, and many battery modules are built using methods that are not easily reversible (e.g. welding, adhesive bonding). Thus, extraction and/or replacement of individual cells is economically infeasible for most second-use applications.

Modules or packs are thus the only repurposing options. Due to the high cost of cell replacement, an individual faulty cell can spoil its entire module/pack. The likelihood of bad cells (cell fault rate) and the size of the module being repurposed thereby drive a facility's yield and overall cost of operations.

Accordingly, the ability to identify faulty cells prior to purchase (e.g. via use of onboard diagnostics data) will be of great value to future battery repurposers.

1 in 100,000 cells is faulty:



QUESTIONS ANSWERED

- **When will used automotive batteries become available, and how healthy will they be?** We expect PEV batteries to be available only at the end of the original vehicle's service life with ~70% of its initial capacity.
- **What is required to repurpose used automotive batteries, and how much will it cost?** Cost-optimal repurposing facilities will likely service modules from a single model of PEV and operate on a regional level to minimize repurposing costs, which could fall below $20/kWh-nameplate.
- **How will repurposed automotive batteries be used and how long will they last?** Peaker plant replacement service appears best matched to the cost and availability of 2U batteries. When optimized for this service, 2U battery life could exceed 10 years, cycling less than once per day with discharge durations greater than one hour.
- **What is their value?** The value to the original owner is restricted to eliminating end of service costs, but the value to the broader community could be significant: reduction of greenhouse gas emissions and fossil fuel consumption, decreased cost and increased reliability of electricity service, and deferral of battery recycling.

ACKNOWLEDGEMENTS

This activity is funded by the **DOE Vehicle Technologies Office**, Energy Storage Technology.

We appreciate the support provided by DOE program managers **David Howell** and **Brian Cunningham**.

Special thanks to our subcontract team led by **Mike Ferry** at the **California Center for Sustainable Energy.**