# PRELIMINARY FINDINGS OF NATIONAL RENEWABLE ENERGY LABORATORY'S ELECTRIC VEHICLE LITHIUM-ION BATTERY SECONDARY-USE PROJECT

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## ABSTRACT

The high cost of lithium-ion batteries is a major impediment to both the increased market share of electric vehicles (EVs) and the proliferation of energy storage on the grid. The reuse of EV propulsion batteries in grid-connected second-use applications following the end of their automotive service life may have the potential to offset the high cost of these batteries for both markets. In this paper we estimate the financial viability of battery second-use strategies, considering the effects of competitive technology, the costs to repurpose automotive batteries, the value and size of grid-connected energy storage markets, and the deployment rates of EVs.

**Keywords**: energy storage, lithium-ion, EV, second use, battery salvage value

## INTRODUCTION

Accelerated market penetration of electric vehicles (EVs) is presently restricted by the high cost of lithium-ion (Li-ion) batteries. Deployment of grid-connected energy storage, which could increase the reliability, efficiency, and cleanliness of the grid, is similarly inhibited by the cost of batteries. Research, development, and manufacturing are under way to improve the performance and reduce cost by lowering materials cost, enhancing process efficiencies, and increasing production volumes. Another possible path currently under consideration is to recover a fraction of the battery cost via reuse in other applications after it is retired from vehicular service, where it may still have sufficient performance to meet the requirements of other energy storage applications. By extracting additional services and revenue from the battery in a post-vehicle application, the total lifetime value of the battery is increased. Thusly, the overall cost of energy storage solutions for both the primary (automotive) and secondary (grid) customer can be decreased.

The U.S. Department of Energy's Vehicle Technologies Program has funded the National Renewable Energy Laboratory (NREL) to answer these questions and investigate the second use of modern Li-ion EV batteries in grid-related applications. In this paper we estimate the financial viability of battery second-use strategies, considering the effects of competitive technology, the costs to repurpose automotive batteries, the value and size of grid-connected energy storage markets, and the deployment rates of EVs.

## ANALYSIS

We take two approaches to estimating the value of used EV batteries. First is a competitive technology approach, in which a maximum value for the used battery selling price is determined by requiring that used batteries be cost-competitive with equally capable new batteries. Subtracting the cost of repurposing yields the maximum achievable salvage value. Second is a generated revenue approach, in which maximum buying price estimates are determined by the value of applications anticipated to procure used batteries. To provide additional guidance on the viability of second-use strategies, the anticipated supply of used batteries is therefore compared to the financially motivated demand.

### Competitive Technology Approach

Under the competitive supply approach, we assume (1) profitable and willing secondary use applications will be available at the time of the battery's automotive service retirement, and (2) the principal competitor for second-use EV batteries in the selected second-use application is newly produced EV batteries. Under these assumptions, the premise that demand will exist for used batteries priced less than equally capable new batteries is valid. Thus the future selling price of a used EV battery will be proportional to the cost of an equally capable new battery, taking into consideration the health of the used battery and a used product discount factor (equal to the ratio of what a customer is willing to pay for a used product to what that same customer is willing to pay for an equally capable new product). Further details of this methodology are discussed in Reference 1, including means of estimating health factors and new battery costs. Under the assumptions therein, the estimated future selling price for used EV batteries produced today is generally less than $170 per kilowatt hour (kWh), primarily a result of an assumed steep 70% decline in new battery costs.

There are significant costs involved in the processes between retiring a battery from automotive service and selling it to a secondary market (collection, testing, repackaging, etc.). Cready et al. [2] estimated these costs at approximately $72/kWh. Subtracted from a maximum selling price of $170/kWh, this leaves a salvage value of less than $100/kWh to be paid to the automotive battery owner.

### Generated Revenue Approach

Multiple studies on the value of utility-based energy storage applications have recently been released [3, 4]. In this paper, we leverage these works to first calculate the maximum revenue achievable on a dollars-per-kilowatt-hour basis for used EV batteries serving the utility applications reported on therein over a range of feasible discharge durations, rates, and depths of discharge. The results of our analyses on both sources suggest (Figure 1) that regulation, quality and reliability, and transportable transmission and distribution upgrade deferral are the most valuable applications.

Next we select specific discharge durations, rates, and depths of discharge for each of these four down-selected applications, aggregate the quality and reliability applications into one, and subtract the balance of systems costs using the most relevant data available from Reference 2. The resultant revenues and allowable battery costs are shown in Figure 2, showing that the balance of systems costs leave $217/kWh and $175/kWh to cover battery costs on average for area regulation and transportable transmission upgrade deferral, respectively. The average value for the power quality and reliability application has gone to negative $73/kWh, suggesting that the balance of system costs outweigh the potential revenue before the costs of the battery are considered.

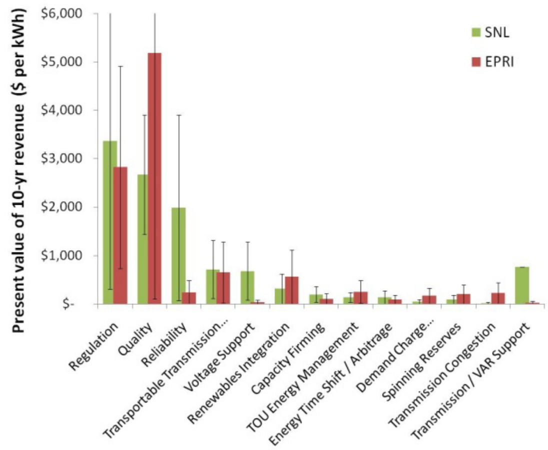


**Fig. 1. Grid energy storage application revenue.**

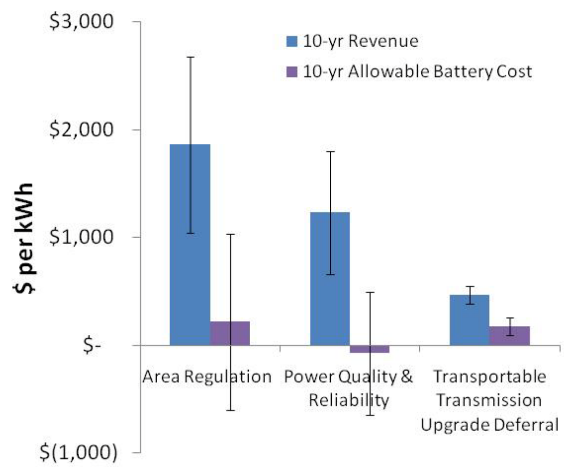


**Fig. 2. Revenue and allowable battery cost for three down-selected grid energy storage applications.**

### Supply and Demand

It is additionally worth considering the relative supply and demand of used batteries. Accurately estimating available supply is challenging, as it depends upon the adoption rate of EVs, the type of EVs deployed, automotive battery life, etc. Our conservative forecast of used battery supply predicts approximately 2.5 gigawatt hours (GWh) could be deployed by 2030. Aggressive EV deployments and more optimistic assumptions about the number and state of batteries available for second use could increase this number to more than 30 GWh by that time.

For comparison, our methods applied to the data in Reference 3 predict a total ten-year grid demand of 15.8 GWh for the down-selected applications. The fact that our allowable battery cost calculations show only subsets of the regulation and power quality and reliability markets to be cost-effective, and that there is growing competition from other technologies in each of these markets, means the actual achievable markets are likely smaller. On the other hand, the basis market projections in Reference 3 may need to be amplified to treat our principal period of interest (2020 to 2030). Thus there is too much uncertainty in our estimates to precisely contrast the supply of used batteries with the demand from the grid. However, it is observed that the supply has the potential to considerably overrun the demand, which would suppress battery salvage values if new, higher value markets are not identified.

## CONCLUSIONS

The analysis herein estimates a maximum salvage value of ~$100/kWh and a maximum used battery sale price of ~$170/kWh, based upon the availability of competitive technology and the costs of repurposing. Having considered the value and market size of many grid-connected applications, as well as the balance of systems costs, it appears that area regulation, power quality and reliability, and transportable transmission and distribution upgrade deferral can supply a sufficient market at this price point under conservative EV deployment scenarios. Aggressive EV deployments could change things considerably by providing a surplus of used batteries, which would reduce the selling price and thus presumably open up additional markets. It is important to note, however, that there are many assumptions and uncertainties involved in making these estimates.

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## BIOGRAPHICAL NOTE

**Conference presenter:** Dr. Jeremy Neubauer is a Senior Engineer with the National Renewable Energy Laboratory’s Center for Transportation Technologies and Systems. His primary responsibility lies in researching the reuse of retired automotive traction batteries to ultimately reduce the cost and accelerate the adoption of plug-in hybrid electric vehicles and electric vehicles. Before coming to NREL, Dr. Neubauer was Chief Engineer at ABSL Space Products, a leading manufacturer of lithium-ion batteries for the space industry. There he developed energy storage solutions for long-duration, high-reliability, and manned space missions. Dr. Neubauer has a B.S., M.S., and Ph.D. in Mechanical Engineering from Washington University in St. Louis.