Cost and Price Metrics for Automotive Lithium-Ion Batteries

Values of current energy technology costs and prices, available from a variety of sources, can sometimes vary. While some of this variation can be due to differences in the specific materials or configurations assumed, it can also reflect differences in the definition and context of the terms "cost" and "price". This fact sheet illustrates and explains this latter source of variation in a case study of automotive lithium-ion batteries.

Metrics discussed in this fact sheet

Market Price
The selling prices for commercially available technology

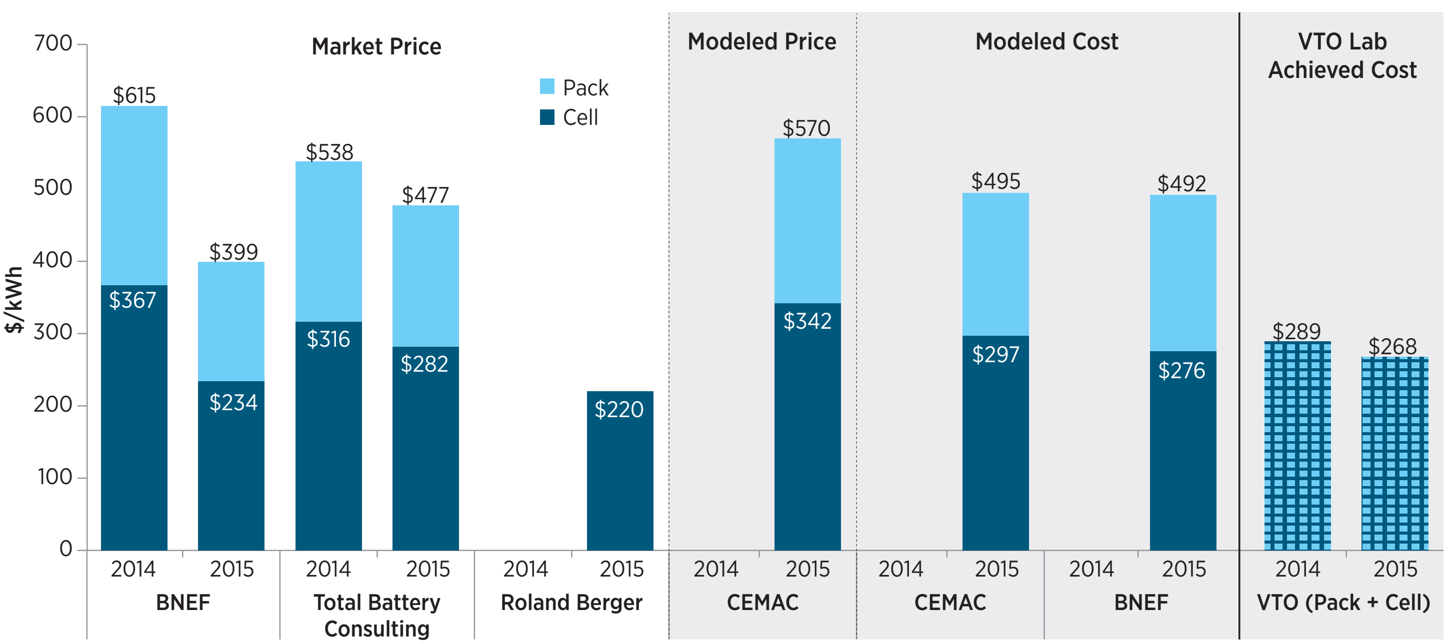
Modeled Price
Estimate of manufacturers' minimum sustainable price for commercially available technology

Modeled Cost
Estimate of manufacturers' cost of production of commercially available technology

Lab Achieved Cost
The projected cost of future high-volume pack production of near- commercial technologies currently in the Vehicle Technologies Office's (VTO's) research and development portfolio

Reported measures of automotive battery costs and prices vary widely. This is in part because the technology is relatively new and the shape, size, chemistry and packaging used for different vehicles vary.[1] However, variation is also introduced because important contextual information around the reported values is often not clearly stated, inviting potentially unsuitable comparison of values from multiple sources. As a simple example, the price a buyer pays for a battery can be referred to as a battery cost (i.e., cost to the buyer), while the cost a manufacturer incurs to produce that battery—a distinct concept—can also be referred to as a battery cost. Further, technology research and development organizations may also define costs and cost targets in specific terms that suit their particular purposes. These definitions can produce values that differ from a commercial

1. The roughly 80,000 light-duty electric vehicles (battery electric vehicles and plug-in hybrid electric vehicles) sold in the United States in 2015 comprised 13 models, each with a unique design. Tesla motors, often cited as a leader in low-cost automotive batteries, currently uses small cylindrical cells, which are typically used in consumer electronics applications. Other auto manufacturers have chosen to focus on larger prismatic cells developed specifically for automotive applications, which may achieve higher energy density and lower costs compared to consumer cells.



BNEF = Bloomberg New Energy Finance; CEMAC = Clean Energy Manufacturing Analysis Center

Figure 1. Estimated national prices and costs of light-duty plug-in hybrid electric vehicle cells and packs for 2014 and 2015 from several sources. Market prices are observed values. Modeled costs and prices are intended to benchmark the current cost and price, respectively. While lab VTO achieved costs are reported in current year, they are projections of expected costs in 3–5 years for high-volume production. *Sources: Anderman (2016); Attwood (2016); Behl (2015); Curry (2015); VTO (2016); VTO (2015).*

buyer's cost or a manufacturer's cost of production. An additional point of confusion arises from the nature of the technology—automotive *batteries* or *packs* are composed of multiple subcomponents, chief among them being *cells*. Nontechnical media commonly use all three terms interchangeably, creating confusion when a price or cost is reported. Finally, pack and cell costs and prices vary depending upon their intended application (e.g., plug-in hybrid versus full electric vehicle) due to differences in design and performance.

Figure 1 compares 2014 and 2015 price and cost values for light-duty plug-in hybrid electric vehicle (PHEV) cells and packs from two estimation methods—market data surveys (market price) and bottom-up cost models (modeled price, modeled cost)—as well as the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy's Vehicle Technologies Office (VTO) modeled lab achieved costs for pack and cells combined. The market and modeled prices represent the manufacturers' selling prices for the component (cell or pack) for commercial available technology, the modeled costs are intended to estimate manufacturers' costs of production for this same technology, and the VTO modeled costs represent the *projected costs* of future high-volume pack (cells plus pack) production of near- commercial technologies currently in the VTO research and development (R&D) portfolio.

Three observations emerge when inspecting these disparate sets of values together. First, the market price data show a significant price drop between 2014 and 2015 (11% to 35%, depending on source). Second, the 2015 modeled price is higher than market reported prices for that same year. Third, the modeled VTO lab-achieved cost is more than 40% lower than the other modeled costs for the corresponding year.

Drivers of Market Price Reductions

Some portions of the observed 2014–2015 market price reductions reflect improvements in the technology and ongoing maturation of manufacturing processes (i.e., manufacturing cost reductions). Price reductions may also be driven in part by market conditions including global manufacturing overcapacity, supply contract structures, and strategic corporate behavior. Overcapacity may lead to supply-demand imbalances, driving manufacturers to reduce prices in an attempt to support sales volume and minimize losses incurred against fixed capacity investments. Anticipated strong market growth may also incentivize manufacturers to remain in the market and to seek long-term supply agreements with large-volume customers. These agreements, while priced aggressively compared to manufacturing costs today, may deliver attractive profitability on a present value basis over their term given the secured sales volumes combined with an anticipated technology-driven cost reduction roadmap. Finally, most major cell suppliers are diversified corporations that may subsidize their battery manufacturing efforts with profits from other lines of business for strategic reasons. Each of these nontechnical factors can lead to a disproportionate rate of price reduction compared to reductions in the cost of production, and may be responsible for a share of the observed drop in reported prices between 2014 and 2015.

Modeled Price and Cost versus Observed Market Prices

Techno-economic models of manufacturing costs and prices can be used to help illustrate the degree to which nontechnical factors may influence manufacturers' pricing decisions. By focusing on costs and their technical drivers, *cost models* can be used to estimate current manufacturing costs in the absence of publicly available information (as in the automotive lithium-ion battery industry), and to analyze the cost impacts of various technology changes and improvements. The Clean Energy Manufacturing Analysis Center (CEMAC) and Bloomberg New Energy Finance (BNEF) have created manufacturing cost models via independent efforts aimed at benchmarking current costs of production (Chung, Elgqvist, and Santhanagopalan 2016; Attwood 2016). CEMAC has extended its model to estimate price; however, the CEMAC *price model* considers process engineering, cost, and financial factors only, and does not attempt to account for market or economic factors such as supply-demand imbalances. As such, the CEMAC modeled price can be expected to approximate observed pricing when industry conditions are free of major market and commercial factors such as those noted above. Comparing the 2015 modeled price to observed market prices (Figure 1, left) suggests that market factors, not manufacturing cost considerations, currently influence pricing decisions. This is further substantiated by comparing both the CEMAC and BNEF cost modeling results (Figure 1, right) to observed prices, which suggests that manufacturers have sold at or even below their costs of production in recent years.

Distinction Between Modeled Cost of Current Technology and VTO Lab Achieved Cost

The CEMAC and BNEF cost modeling results presented in Figure 1 are intended to benchmark the then-current cost of light-duty PHEV cell and pack production of commercially available technology. The VTO modeled costs in the same figure, by contrast, are meant to estimate the projected commercial-scale

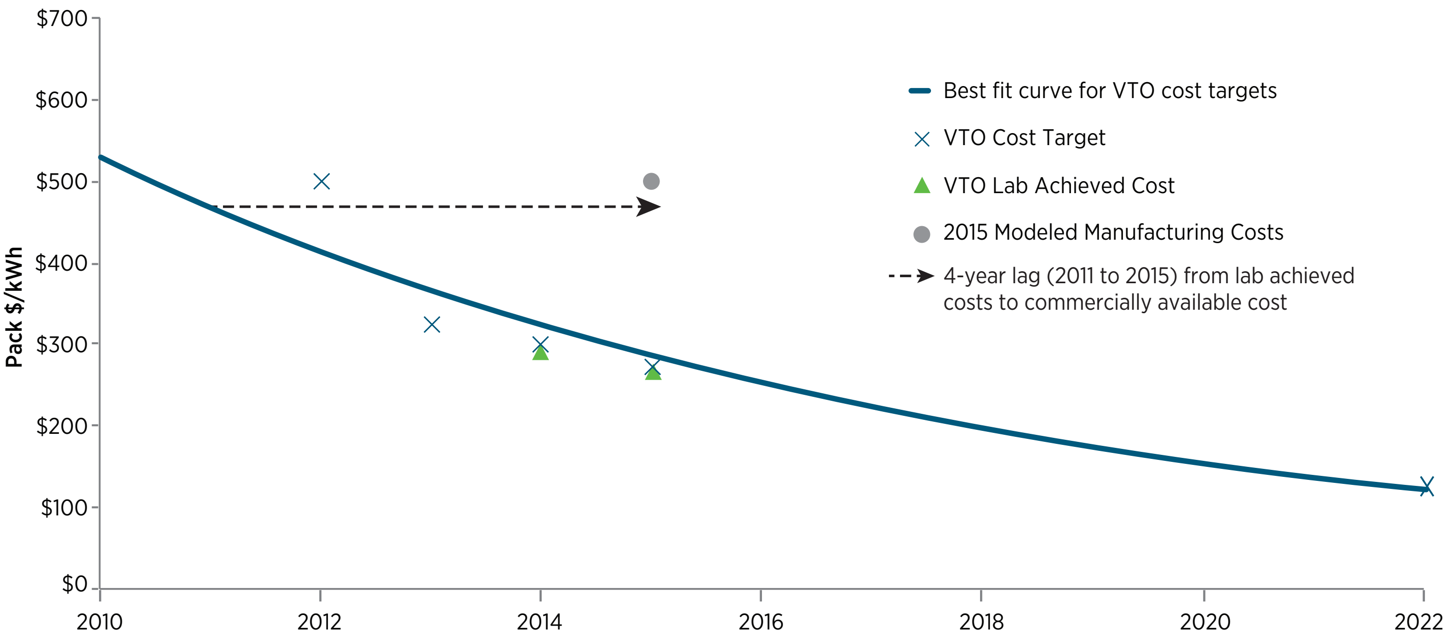


Figure 2. Comparison of VTO modeled cost targets to 2015 modeled manufacturing cost (CEMAC)

production cost of technologies that are currently in R&D. This distinction helps explain why the VTO lab achieved costs are significantly lower than the benchmarked costs.

VTO measures the performance of its R&D portfolio by comparing lab achieved costs to cost targets. VTO's costs targets are set for the current year and also for several years in the future; for example, VTO recently established long-term target for pack cost is $125/kWh by 2022. The cost targets for years 2012–2015 and for 2022 are show in Figure 2.[2] VTO has a track record of meeting its cost targets: in 2014 the cost target was $300/kWh and lab achieved cost was $289/kWh; in 2015, the cost target was $275/kWh, and the lab achieved cost was $264/kWh.

Figure 2 compares VTO cost targets to the 2015 CEMAC modeled cost of commercially available technology ($495/kWh), but with a 4-year lag. The lag is meant to represent the time required to move near-commercial VTO portfolio technologies proven at the lab- or pilot-scale into large-scale commercial production. Figure 2 shows the CEMAC modeled costs closely align with the VTO cost targets from 4 years earlier.

The difference between the VTO lab achieved cost of $264/kWh and the 2015 modeled cost estimated for commercially available technology (BNEF: $492/kWh; CEMAC: $495/kWh) is explained by the superior performance of the technologies currently in the R&D stage compared to those available in the market today. The exact performance and cost improvements modeled are business-sensitive to the technology developers (and thus are not publicly available). However, the CEMAC cost model can be used to generically demonstrate a possible roadmap to this target level, as presented in Figure 3. Compared to the CEMAC 2015 modeled cost of commercially available technology, two technology performance improvement assumptions and one manufacturing efficiency assumption were modeled to reach the VTO target: (1) electrode (cathode and anode) capacity is increased by 20% over currently mass-produced technologies; (2) cell voltage is increased by 6% over currently mass-produced technologies; (3) cell production yields are increased to 96% from the current benchmark estimate of 86% for large-scale cell producers.

Summary

The explanations and examples presented in this fact sheet demonstrate the importance of understanding the full context of various cost and price metrics that are reported in technical papers, market research reports, and the general media—especially with respect to relatively immature technologies and markets where a standard paradigm has yet to develop. Without this knowledge, it is not possible to reasonably compare or analyze cost and price values from multiple sources. Appropriate analysis and insights can be developed once this context of cost and price values is clear.

2. VTO cost benchmarks are only reported since 2012; an exponential extrapolation for 2010 and 2011 is used.

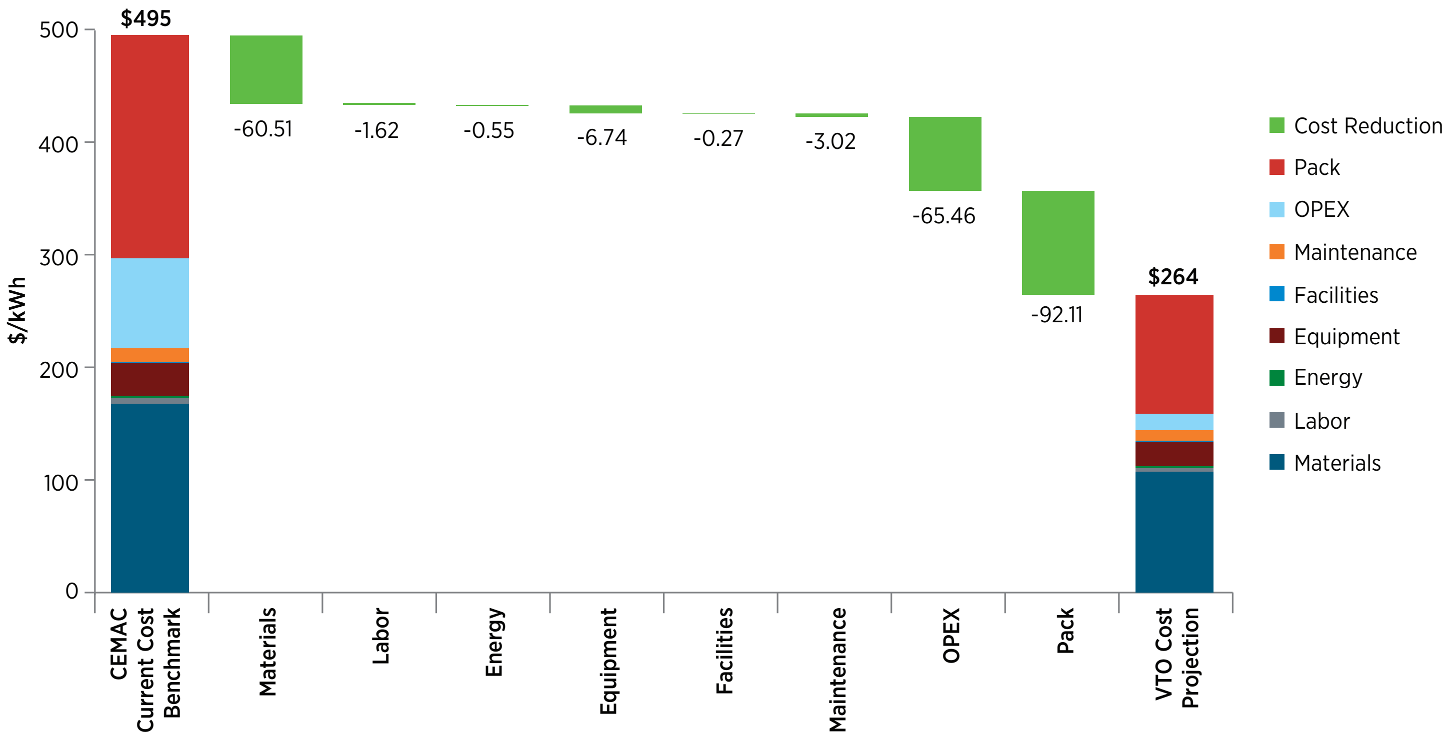


Figure 3. Comparison of 2015 modeled cost of commercially available technology (CEMAC) and current modeled cost projection for innovative technologies in development (VTO). Illustrative cost reductions are driven by potential improvements in energy density and manufacturing yield.

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