Executive Summary

A United States-Based Comprehensive Assessment

Battery electric vehicles (BEVs) do not consume gasoline or produce tailpipe carbon emissions, placing the promise of an environmentally sustainable driving experience within reach of the average consumer. However, the question remains: "Do BEVs truly offer an environmental advantage with respect to global warming potential and secondary environmental impacts – and if so, at what cost?"

To address this question, Arthur D. Little conducted a total lifecycle economic cost and environmental impact analysis of Lithium-ion battery electric vehicles (BEVs) versus internal combustion engine vehicles (ICEVs) to further understand BEVs and their transformative potential. This study models the relative impacts of new BEVs and ICEVs in the United States for the latest full calendar year for which data is available, 2015, and it projects the economic and environmental impacts of BEVs and ICEVs over the entire assumed twenty-year lifetime for a US passenger vehicle. Given that this is a rapidly evolving market, our study also forecasts the economic and environmental impacts that new BEVs and ICEVs will have in 2025, taking into account salient expected developments in battery technology, vehicle range, and fuel economy standards.

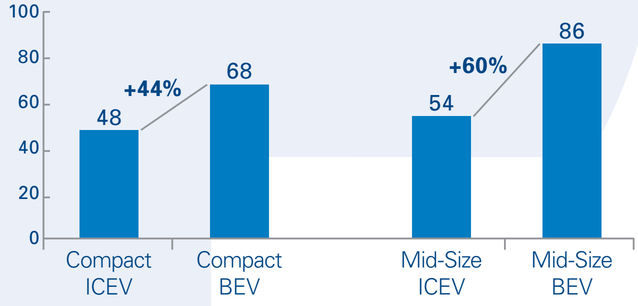
In order to determine the true cost and environmental impacts from BEVs, we performed a comprehensive quantitative analysis excluding any government incentives or subsidies. Our study investigated every stage of the vehicle's lifecycle, from R&D and production, including sourcing of raw materials, through ownership and end-of-life disposal. We evaluated the impacts associated with each component of the vehicle, from the novel technologies and chemistries involved in battery production to the In-Use energy requirements (i.e., gasoline and electricity, from well-to-wheels) necessary to power a vehicle. We constructed models that calculate the 2015 Total Cost of Ownership (TCO), Global Warming Potential (GWP), and Secondary Environmental Impacts (e.g., Human Toxicity Potential characterized as Disability Adjusted Life Years lost) for BEVs and ICEVs. We also forecast how BEV and ICEV technology will evolve over the coming decade and we leveraged this information to model the 2025 TCO, GWP, and Secondary Environmental Impacts for BEVs and ICEVs.

Based on our study, the ultimate environmental and economic reality of electric vehicles is far more complicated than their promise. From an economic perspective, BEVs enjoy some distinct advantages. First, the electricity cost associated with operating a BEV over a distance of one mile is significantly lower than the gasoline cost required to operate a comparable ICEV over the same distance. Second, BEVs cost less to maintain, owing to the relative elegance and simplicity of a battery-electric motor system compared with the frequent maintenance required for operation of an internal combustion system. Third, automotive battery technology has evolved rapidly since the current generation of BEVs came to market, with the price per kilowatt-hour (kWh) of lithium-ion battery packs declining from $1,126 in 2010 to just $300 in 2015 (see Appendix E-1).

These cost advantages, however, are entirely offset by a host of other economic factors. The TCO for a BEV is significantly greater than the TCO for an equivalent ICEV. BEVs in 2015 were, without exception, significantly more expensive to manufacture than comparable ICEVs – due primarily to the cost of battery manufacturing – and they imposed a much higher cost burden on vehicle owners (see Figure 1). Ultimately, this cost burden presents

Figure 1. Total Cost of Ownership over a 20-Year Lifetime for a 2015 ICEV versus an Equivalent BEV

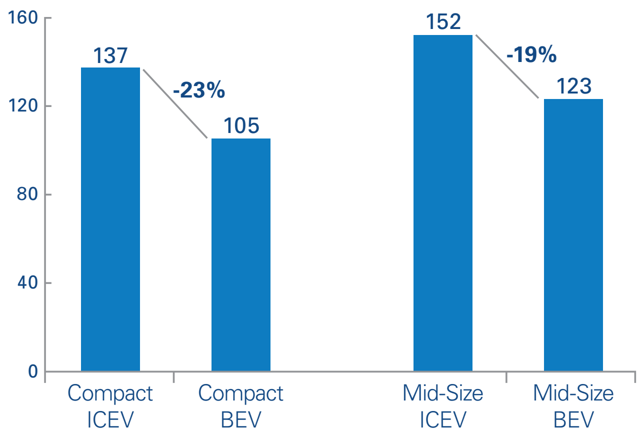
In Thousands of Dollars at Present Value



Source: ADL Analysis

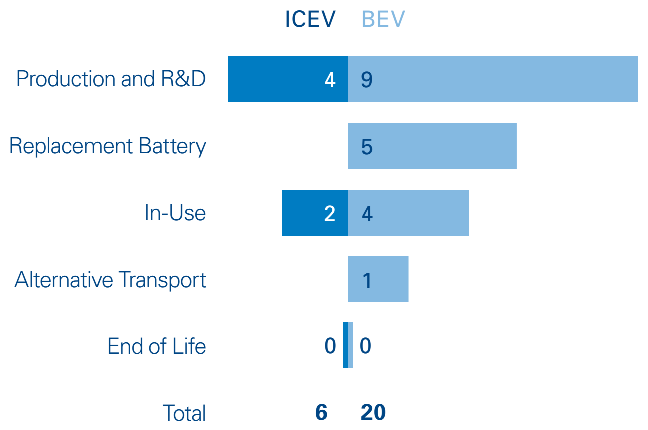
Figure 2. Greenhouse Gas Emissions over a 20-Year Lifetime for a 2015 ICEV versus an Equivalent BEV

In Thousands of Pounds of CO_2e Emissions



Source: ADL Analysis

Figure 3. Days of Life Impact (Death or Disability) for a 2015 Compact Passenger ICEV versus an Equivalent BEV over 20 Years of Ownership



Values do not sum to total due to rounding. Source: ADL Analysis

a significant barrier for wider adoption of BEVs and could explain why their market penetration has been limited to date.

From an environmental perspective, the picture is even more complex. BEVs in 2015 achieve the goal of reducing greenhouse gas emissions relative to comparable ICEVs when considered over a vehicle's lifetime, but this masks an increased human health impact relative to ICEVs and a host of other collateral impacts to the environment (see Figures 2 and 3). While most of the environmental impacts generated by ICEVs are localized to the combustion of gasoline in the vehicle engine, the manufacturing process for BEVs generates a much more widely-dispersed and damaging set of environmental impacts, offsetting a significant portion of their overall advantage with respect to greenhouse gas emissions.

In particular, the usage of heavy metals in the manufacture of lithium-ion battery packs for BEVs combined with pollution generated by the US power grid (e.g. tailings from coal power plants) for the In-Use portion of a BEVs lifecycle generate approximately three times the amount of human toxicity compared to ICEVs (see Figure 3). Given the divergence in where environmental impacts are allocated, it is safe to say that a consumer who chooses to drive a BEV over an ICEV shifts the environmental

Figure 4. Comparison of ADL's Study with Union of Concerned Scientists' and National Bureau of Economic Research's Findings

Impact Area	ADL	UCS	NBER
Total Cost of Ownership	BEV is 44% more expensive than ICEV	Not covered	Not covered
Global Warming Potential	BEV has 23% less GWP impact than ICEV	BEV has 51% less GWP impact than ICEV	BEV has 40% less GWP impact than ICEV
Secondary Environmental Impacts	BEV has 3 times greater Human Toxicity Potential	Not covered	BEV has 3 times greater damages from local pollutants

Source: ADL Analysis, UCS, and NBER