EXECUTIVE SUMMARY

ALUMINUM IN BATTERY ELECTRIC VEHICLES (BEVS) A LIFE CYCLE ASSESSMENT

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Executive Summary

The Aluminum Association (AA) represents aluminum producers in the United States of America and Canada ranging from primary production to value-added products to recycling as well as suppliers to the industry. The association is the industry's leading voice, representing companies that produce the majority of the aluminum ingots and aluminum products shipped and transformed in North America (United States of America and Canada). The Aluminum Association membership plays a crucial role in the shift observed over the recent years in the lightweighting and electrification of vehicle fleets in the North American and worldwide markets.

The demand for battery electric vehicles (BEVs) is expected to grow in the future (Ducker Calisle, 2023). City Vehicles make up the majority of BEVs in the sales fleet today, and Family Crossover vehicle is expected to dominate in 2030 (FEV Group, 2022). To better understand the potential environmental impacts of aluminum in BEVs, the Aluminum Association commissioned Sphera Solutions, Inc. ("Sphera") to perform a cradle-to-grave life cycle assessment (LCA) of two conceptual BEV design scenarios – "Status Quo" and "Aluminum Optimized" for the reference model year of "2025" and "2030". The study focuses on two types of BEVs: a City Vehicle (sedan) and a Family Crossover (SUV).

The conceptual BEV designs are the result of a previously published study known as "Aluminum Value in Battery Electric Vehicles" (refer to as the FEV Study). That study was sponsored by the Aluminum Association and conducted by an automotive engineering service provider FEV Group GmbH. It focused on analysing the economic costs of aggressive aluminum intensive lightweight design concepts (Aluminum Optimized) in comparison to relatively moderate lightweighting design concepts (Status Quo) for BEVs.

Both the Status Quo and the Aluminum Optimized design scenarios involve lightweight design of vehicles with aluminum or other materials to replace heavier steel components or systems. The difference is that the Status Quo, or baseline scenario, refers to the "natural market adoption of lightweight materials and an overall decline in vehicle weight over time," while the Aluminum Optimized scenario focuses on "a more aggressive lightweighting scenario in the future, with aluminum substituting steel at different levels for each BEV segment in 2025 and 2030" – under the condition in which it is engineeringly feasible and cost-benefit to do so (FEV Group, 2022).

The LCA examines and compares the potential environmental impacts of different future design options defined in the FEV study. The future in the FEV study was represented by the "model years" of 2025 and 2030 relative to the "baseline model year" of 2021. From a chronological point of view, the 2030 designs have lower vehicle weights than the 2025 designs. From the design option perspective, the Aluminum Optimized designs reduce vehicle weight by 9% for both the 2025 and 2030 model years for City Vehicles compared to the Status Quo designs. For the Family Crossover, the weight reduction of Aluminum Optimized design is 5% in 2025 and 11% in 2030 compared to the Status Quo.

The LCA covers the potential environmental impacts from raw material extraction through manufacturing, use, and end-of-life stages of the vehicles. The functional unit of the study is the transportation service provided by a BEV of the same vehicle class over a lifetime driving distance of 200,000 miles. The study's primary data is from the vehicle design concepts in the FEV study. Secondary data is largely from the Sphera's MLC databases (2024.1).

The potential environmental impacts are based on the following inventory and impact categories:

Table ES 1: Impact categories and their corresponding acronyms, units and sources

Impact Category	Acronym	Unit	Source
Global Warming Potential (GWP100, excluding biogenic CO_2)	GWP100 fossil	kg CO_2-eq.	IPCC AR6
Ozone Depletion Potential	ODP	kgCFC11-eq.	TRACI 2.1
Primary Non-Renewable Energy Demand	PEDnr	MJ LHV	MLC LCI
Acidification Potential	AP	kg SO_2-eq.	TRACI 2.1
Eutrophication Potential	EP	kg N-eq.	TRACI 2.1
Smog Formation Potential	SFP	kg O_3-eq.	TRACI 2.1
Particulate Matter	PM	kg PM2.5-eq.	TRACI 2.1
Blue Water Consumption	BWC	kg	MLC LCI

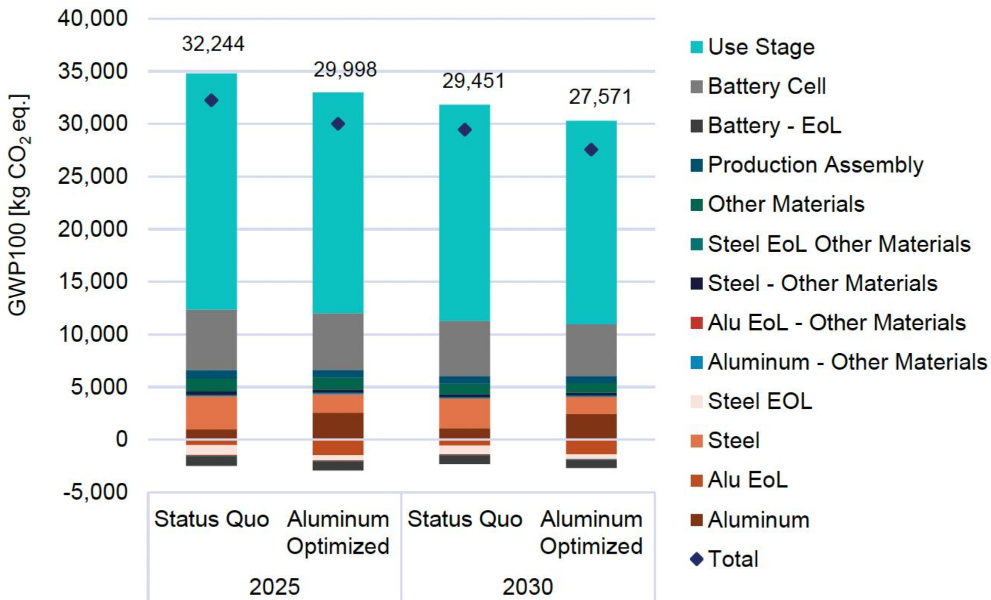
The results of the LCA show that lightweighting BEVs with aluminum contributes to reductions in the life cycle environmental footprint of the vehicles. The most reductions come from Aluminum Optimized designs for both vehicle types and both model years. The overall footprint reduction can be attributed to two major factors: reductions in the footprint of battery manufacturing and reductions in the footprint during the vehicle's use-phase. The study confirms the critical role of aluminum in helping build lighter and cleaner vehicles for the future. It recommends that stakeholders take into consideration the importance of the full life cycle impact when making decisions.

As a snapshot, Figure ES 1 shows the absolute contributions to the cradle-to-grave GWP100 by materials and life cycle stages for City Vehicles. The study findings indicate that:

- Compared to the 2025 designs, the 2030 designs reduce the GWP100 by 9% and 8% for Status Quo and Aluminum Optimization, respectively.
- Compared to the Status Quo, the Aluminum Optimized designs reduce GWP100 by 7% for 2025 and 6% for 2030.
- The reduction in GWP100 due to both lightweight design and battery technology evolution can be as much as 14% between the 2025 Status Quo and the 2030 Aluminum Optimized designs.

Across all scenarios for City Vehicles, the use phase (driving) consistently contributes the most to GWP100, accounting for almost 60% of the total. In the vehicle production phase, the results show that battery cells are the largest absolute GWP100 contributor. When excluding the production of battery cells, the Aluminum Optimized designs increase the cradle-to-gate production phase GWP100 by 2% and 1% for 2025 and 2030, respectively. This underscores the importance of looking beyond the modestly higher carbon intensity of aluminum during the production phase and focusing on the entire life cycle as well as secondary effects such as drivetrain downsizing in lightweighting LCA studies.

Figure ES 1: Contributions of materials and life cycle stages to GWP100 per City Vehicle with a lifetime mileage of 200,000 miles

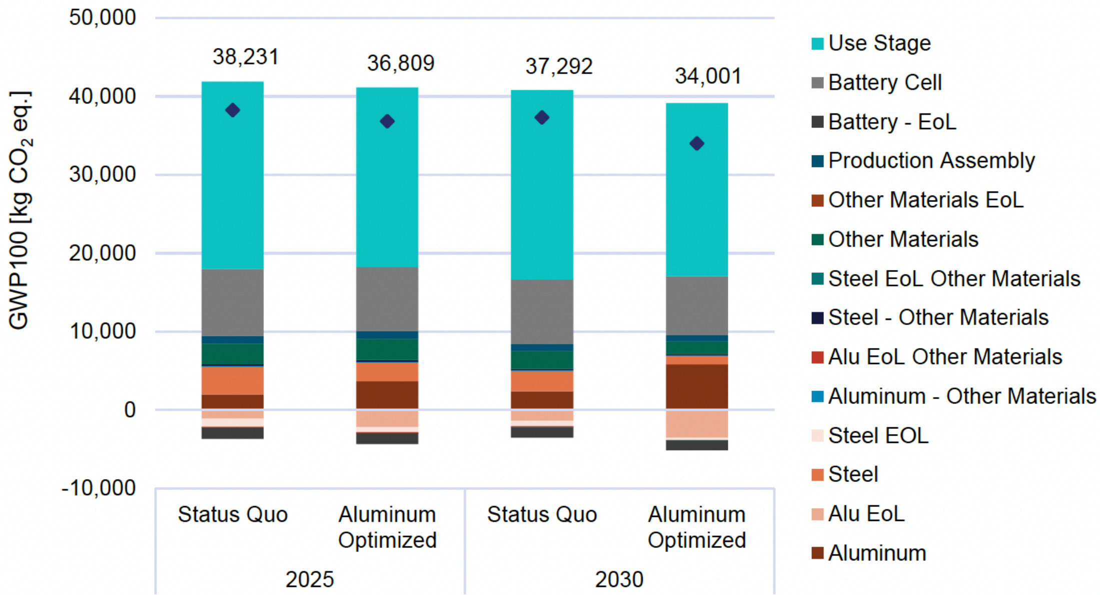


Similarly, Figure ES 2 shows the absolute contributions to the cradle-to-grave GWP100 by materials and life cycle stages for the Family Crossover vehicles. The study findings indicate that:

- Compared to 2025, the 2030 designs reduce GWP100 by 2% and 8% for Status Quo and Aluminum Optimization, respectively.
- Compared to the Status Quo, the Aluminum Optimized designs reduce GWP100 by 4% and 9% for 2025 and 2030, respectively.
- The reduction in GWP100 due to both lightweight design and battery technology evolution can be as much as 11% between the 2025 Status Quo and the 2030 Aluminum Optimized designs.

Across all scenarios for Family Crossover vehicles, the use stage contributes 50% to 55% to GWP100 across all model years and designs. In the production phase, the results show that battery cells are again the largest contributor, despite moderate battery downsizing due to lightweighting. Excluding the production of battery cells, Aluminum Optimized designs increase the cradle-to-gate production phase GWP100 results by 8% and 17% for 2025 and 2030, respectively. This again underscores the importance of looking beyond the carbon intensity of a material's production phase and focusing on the full life cycle impact of the vehicle in lightweighting LCA studies.

Figure ES 2: Contributions of materials and life cycle stages to GWP100 per Family Crossover with a lifetime mileage of 200,000 miles



Overall, the contribution analysis shows a similar pattern of hotspots for both vehicle types and model years. Aluminum Optimized vehicles offer advantages in reducing the overall GWP100 through vehicle weight reduction that leads to a reduced battery size and fuel efficiency gains. In other impact categories, the Aluminum Optimized vehicles reduce PEDnr, AP, PM, and BWC compared to Status Quo vehicles. Further analysis shows that the break-even point for Aluminum Optimized Family Crossover vehicles compared to the Status Quo occurs at around 40,000 miles. For City Vehicles, the break-even point is already achieved during the production phase itself, i.e. the cradle-to-gate GWP100 is lower for the Aluminum Optimized designs than for the Status Quo designs. This is the result of a modest increase in the footprint of the vehicle's construction materials offset by a reduction in the footprint of the production of battery cells due to smaller battery sizes.

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