Steve Fecht for General Motors

Lithium is a key ingredient in General Motors' Ultium battery packs, like this one being tested by GM Validation Engineer Andre Brown at the GM Global Battery Systems Lab on the campus of the GM Tech Center in Warren, Mich.

Electrifying our vehicles and improving mobility

ABOUT THE AUTHOR

This article was written for *Update* by Chris Atkinson, Sc.D, who is the Director of Smart Mobility and Professor of Mechanical and Aerospace Engineering at the Ohio State University. In that capacity, he is responsible for developing research, development, education and innovation in mobility, or "transportation with a conscience," as he describes it. He is an SAE international Fellow (2018) and has been involved with SAE in a number of ways over his 31 years of membership, including serving on standards committees, judging student competitions, as a reviewer, and as an author and presenter of over 30 SAE technical papers.

Transportation is now the largest contributor to GHG emissions in the U.S. at 29% of all 2019 emissions, having overtaken electric power generation (25%) in recent years (EPA, 2020). Over 90% of the fuel used in transportation in the U.S. is petroleum-based, primarily gasoline and diesel (DOE, 2020). Electrification of the automotive vehicle fleet (light-, medium- and heavy-duty) has the potential to achieve U.S. decarbonization goals once renewable power generation reaches higher levels nationwide (12.4% of all electrical power generation in 2020, mainly hydroelectricity and wind, EIA).

The industry transition to battery electric vehicles (BEVs) is proceeding at an accelerating pace, albeit from low levels of penetration (roughly 3% of new LD vehicle sales in 2020). However, an emerging issue that has the potential to significantly disrupt this progress is the sourcing and supply of a range of critical materials and minerals, used primarily for batteries, power electronics, and motors. The US has a limited domestic supply of a wide range of these materials, including lithium, cobalt, nickel, germanium, manganese, silicon, graphite, the platinum group metals, and rare earth elements (REEs)—all essential for EV manufacturing. While many of these materials are mined and can be sourced from a wide range of locations worldwide, practically all routes for their beneficiation and upgrading lie abroad. Essentially, the US is now reliant on foreign sources and supplies of critical materials and components that it does not control in order to meet its own promised GHG emissions reduction and decarbonization goals. The current US administration is well aware of these commodity sourcing issues and has started to respond accordingly (see, for example, the Department of Interior's List of Critical Minerals from 2018, and the National Blueprint for Lithium Batteries 2021-2030 of the Department of Energy). While reusing and recycling used battery packs will be an essential industry practice, only after a decade or so of appreciable EV sales will recycling volumes have a significant impact on raw materials availability.

New LD vehicle sales in the US are currently around 17 million per year, and assuming an average 90 kWh battery pack per vehicle implies a total domestic battery (cell) production requirement of 1,530 GWh per year. Currently, cell production facilities are each of the order of 30-35 GWh/yr, which implies that roughly 45-50 such battery production facilities will be required to meet future US LD vehicle production targets. There are currently 4 such facilities in operation in the US today, and thus a 10x increase in cell production volume is required before all LD vehicle sales can be fully electric—not including the use of batteries in MD or HD BEVs or in stationary energy storage to ensure grid resiliency, for example.

The transition to a substantial BEV fleet will also require a significant build-out of the electrical grid, at both the high-voltage transmission and local low-voltage distribution levels—but the sheer number of charge points (EVSEs), public or private, required to adequately recharge the fleet on a daily basis is a matter of uncertainty. This issue is best considered in terms of miles of range provided per EVSE unit per day. Level 2 recharging in private homes allows about 40 miles of vehicle range added per hour of charging (at ~300 Wh/mile vehicle energy consumption at the wall plug), without improving the average domestic electrical service. This daily available range of 80 miles per 2-hour recharging event is greater than the 53.8 miles of daily driving undertaken by the average US household (according to the 2017 National Household Travel Survey conducted by the Federal Highway Administration of the US DOT); however, the availability of suitable higher-power home-based recharging is clearly problematic for those drivers dependent on street or communal parking. Fast charging is clearly required to support longer-distance trips (bear in mind that vehicle owners typically buy their vehicles for the "99th percentile" of utility and most are intolerant of compromised performance and range).

The entire US vehicle fleet traveled a total of 3.26 trillion miles in 2019 (Bureau of Transportation Statistics, 2021), of which 90.2% of VMT was driven by LD vehicles, 3.8% MD, and 6.0% HD. Assuming an average 300 Wh/mile required for LD vehicles (at the generation facility), 1.0 kWh/mile for MD (such as delivery vans) and 2.0 to

Chris Atkinson and the Mazda 787B, the 1991 Le Mans winning vehicle, at the Mazda Museum in Hiroshima, Japan, 2019.

4.0 kWh/mile for HD (long haul tractor trailers or transit buses), implies a total electrical energy requirement of 1.363 T kWh if all 2019 miles were fully electrified. This represents an additional 34% or so required over and above the total 4.01 T kWh electricity generated by all sources in the US in 2019—a significant, yet achievable required increase.

Essentially, the US has traded an historical dependence on foreign oil for a growing dependence on foreign-sourced critical materials (even though the US has been a net petroleum exporter since 2020). As an industry, we need to address the R&D aspects of these emerging supply constraint issues from a multiplicity of angles, including basic materials research, vehicle and component design, manufacturing, systems integration, mobility system optimization, supply chain management, recycling, and alternative sourcing options.

The constraints to be considered in the system optimization include materials and components supplies, ideal deployment scenarios for BEVs, recharging access and convenience, and system costs,

VEHICLE ELECTRIFICATION BY THE NUMBERS	
Transportation Sector's Contribution to US GHG Emissions (2020)	29%
Power Generation Sector's Contribution to US GHG Emissions (2020)	25%
Current Renewable Electrical Energy Production (2020)	12.4%
New US LD Vehicle Sales (2019)	17.0M
EV Sales as Percentage of US LD Sales (2020)	~3%
Number of Commodities on US Federal Government's List of Critical Minerals (2018)	35
Number of Battery Cell Production Facilities Required to Fully Electrify all New LD Vehicles (at 30-35 GWh/year each)	45-50
Total Fleet VMT in the US (2020)	3.26 T miles
Additional Electrical Energy Generation Required to Electrify all VMT – LD, MD, and HD (2020)	1.36 T kWh
Future Increase in Electrical Energy Generation Capacity Required to Electrify all VMT (at 2020 levels)	~34%

among many others. A full mobility system optimization is required, but this is not something that we are used to performing. We are typically accustomed to operating within a system in which a large number of economically selfish decisions are made by OEMs, purchasers, and operators alike. Optimizing the full automotive and mobility system for a particular singular goal—in this case decarbonization—that is not central to the decision-making of any one sub-agent, presents an interesting problem. OEMs wish to maximize profits for their shareholders, owners seek to minimize their total cost of ownership for the given utility of their vehicle, drivers wish to minimize their time spent driving while maximizing convenience and utility, while society requires beneficial environmental, accessibility, economic, and social mobility outcomes.

Materials availability, recharging convenience, the stranded cost and longevity of the existing fleet, and the availability of renewable energy remain problematic issues. Long haul trucking (and separately marine and aviation) remain recalcitrant to full electrification.

We are early into a multi-decadal smart mobility system transition, although transportation based on zero-carbon, renewably based energy is within our reach. Beyond decarbonization, much more remains to be done in the automotive realm on vehicle and traffic safety, vehicle automation, connectivity, and integration with emerging modes of smart mobility. Only then can we achieve the goal of low environmental impact, full social and economic mobility, and improved equity and access for all. The automotive industry has much to contribute in this battle, and a bright future ahead. ■