THE FUTURE OF ELECTRIC VEHICLES:
CONFERENCE REPORT

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UNC KENAN-FLAGLER BUSINESS SCHOOL
Energy Center

EXECUTIVE SUMMARY

The UNC Kenan-Flagler Energy Center convened a conference to explore the future adoption of electric vehicles in the U.S. and the associated impacts. Energy Center conferences aim to advance understanding of major Energy Transition frontiers by posing questions '*we don't yet know how to answer*.' Subject area experts and firm executives working in the space are then invited to explore specific topics related to these questions. This allows identification of better answers and more advanced questions. Three questions provided the focal points for this conference:

1. ***What is the 'Life Cycle Carbon Footprint' of Battery Electric Vehicles (BEVs)*** when compared with Plug-in Hybrid Electric Vehicles (PHEVs) and Internal Combustion Engine vehicles (ICEs)?
2. ***What are the implications for the U.S. electric grid,*** both for load and reliability, of the likely adoption of BEVs and PHEVs?
3. ***What is the likely rate of adoption of BEVs*** and PHEVs in the U.S., looking out to 2030 and beyond and what does this imply for adoption rates in other countries?

These questions are considered in this order because the perceived climate advantages of Battery Electric Vehicles (BEV) Plug-in hybrid electric vehicles (PHEVs) vs. Internal Combustion Engines (ICEs) and the implications of their adoption for the grid are factors both incentivizing and impeding the rates of BEV/PHEV adoption.

PHEVs are part of the general movement towards vehicle electrification. However, specific data on PHEV benefits, issues and adoption rates is quite limited compared with BEVs. What follows largely concentrates on BEV findings. This reflects the discussion at the conference. Where PHEV information was available, it will be noted and discussed.

- A ‘clear line of sight’ is difficult to develop on these EV questions. A large number of crosscurrents cloud the picture. This leads to an outlook where adoption will continue to progress but not as fast as EV advocates are hoping. Adoption may also be subject to abrupt slowdowns as specific barriers are encountered and take time to overcome. A wide degree of uncertainty surrounds both forecasts in this area and regulatory “BEV only” deadlines premised on such forecasts. This uncertainty is due to the large number of variables that will impact the outlook. Examples of such variables include supply chain issues, lower than expected consumer demand, competition from China, automaker profitability and uncertain long-term access to lithium and other critical minerals needed for batteries.

- On one side of the question, there is very significant momentum behind EV adoption. Three elements contribute to this:

  1. Intense activism aimed at promoting decarbonization in the transport sector;
  2. Major support from public policy, especially recently passed Federal legislation and tax credits; and
  3. Major commitments from Original Equipment Manufacturers (OEMs) to expand their EV offerings and improve the technologies embedded in these vehicles.

- The strength of this momentum should not be underestimated. Collectively the activism, the passage of supporting laws like the Inflation Reduction Act and the buy-in by both Wall Street and the Original Equipment Manufacturing (OEMs) has produced a sense of inevitability about rapid BEV adoption. Several conference speakers advanced this view of an inevitable conversion to BEV mobility. Evidence of this view can be found in the billions of dollars which OEMs are committing to new EV models. Indeed, virtually every major vehicle OEM has been persuaded or pressured into developing and offering new EV models. TESLA’s market success and transformation from financial life support to cash flow juggernaut has been catalytic for its would-be competitors.

- Another part of this momentum has been the sense that all BEV advertised limitations, such as range, charging time and high prices can be overcome by a combination of more public support, technology advances and consumer education. Several of the conference participants, including OEM representatives, advanced this perspective. As one example, there was optimistic talk about prospects for offering a $25,000 EV to spur mass adoption. Others argued that ‘better education efforts’ by OEMs and dealers would help consumers understand that BEVs are an economic choice and not just a climate strategy.

- On the other side there remain numerous barriers to rapid EV adoption, including ‘over the horizon’ issues. EV’s price points, limited recharging networks, and range anxiety are the issues widely acknowledged and discussed. As noted, considerable work is ongoing to address them and to educate consumers on BEV lifetime economic benefits. The challenge of sourcing the critical minerals needed for rapid adoption is just being recognized. So too is the concentration of metals smelting capacity in China. Mining companies now forecast shortfalls in lithium supply for battery manufacturing by the end of this decade. These supply issues in turn raise questions about the price points attainable for BEVs. Prospects for the $25,000 EV, and whether such a BEV will be attractive to lower income consumers, are thus unclear.

- While the Inflation Reduction Act (IRA)was repeatedly described as a ‘game changer’ and the ‘most aggressive climate bill ever passed in the U.S.’ a close look at the structure of its BEV incentives suggests numerous constraints and contradictions. BEV tax credits are tied to U.S. assembly, meeting U.S sourcing requirements for battery components and critical minerals, a ceiling on consumer incomes and another ceiling on vehicle selling prices. Clearly the allocation of federal subsidies to BEV purchases, charging networks and U.S. manufacturing/assemble capacity will have some effect, but the complexities and limitations make it difficult to depict the IRA as a spur to all-out consumer adoption.

- Other 'over the horizon' issues can evolve in both positive and negative directions; these issues include battery life and efficiency, BEV resale value experience, the profitability of EVs for OEMs as adoption scales up, the potential for major technology improvements in battery performance, and the possibilities for further public policy support or its reversal should political winds shift. There will also be electric grid impacts that will have to be addressed via significant transmission/distribution investments, more utility control over recharging or some combination of the two.

- Another potential headwind concerns who will build, own, operate and maintain the nationwide charging network needed to support mass adoption. Such a network faces the classic early mover dilemma – it needs to be widespread and reliable to attract the usage to make it profitable, but those building the early network will likely lose money for lack of demand. Maintenance of the charging network will need to achieve a high state of reliability which may prove difficult and expensive in low demand locations. Consequently, the charging network likely will need considerable public support to move beyond being concentrated around initial high demand locations.

Photo Credit: Rich Pedroncelli for AP

- To illustrate other uncertainties, BEV carbon lifecycles may not be as favorable as advertised. Existing Carbon Life Cycle Analyses (LCAs) typically assume a 15-year battery life with little efficiency degradation. BEV OEMs, however, offer battery warranties of only 8 years. Moreover, battery performance varies depending on how the vehicle is driven and the climate within which the vehicle operates. Replacing battery packs can cost $15-20 k. Early adopters and leasing companies are now approaching the end of manufacturer's warranties, so first experience on BEV resale value is just coming into view. Early adopters will thus need to distill the net economics of their initial purchase price, their operating savings versus ICEs (which include low EV maintenance costs) and their ultimate resale experience. These results will only crystalize in the second half of this decade.

- Net Scale up effects and technology evolution are the other major uncertainties. Rapid adoption typically permits manufacturing scale-up and economies of scale. In the case of BEVs however, material/metals inputs and the effects of relocating battery manufacturing from China to other countries pose cost inflation risks. Some clue as to their possible impact is provided by OEM efforts now being exerted to source critical materials years in advance and to promote new battery technologies less reliant on critical minerals. The net effects of these trends and their feedback on BEV prices, consumer adoption rates and OEM profitability are unclear.

- The public policy case for supporting BEV adoption rests on studies indicating a greatly reduced carbon footprint versus ICEs. Some of these studies show a net carbon benefit for BEVs after as little as two years of operation, although others suggest 6-7 years is the breakeven. Moreover, the studies foresee little opportunity for ICEs to improve their footprints. Most ICE emissions are related to fuel consumptions, and further improvements in fuel economy are assumed to be 10% at most. This perspective ignores the potential of "clean liquid fuels" which may enable ICE vehicles to operate with significant reduction in carbon emissions.

- The Life-Cycle Assessment (LCA) studies also contain numerous assumptions favorable to BEV findings, e.g., clean power electric grids and long battery lives while ignoring others, such as the emissions associated with sourcing new metals required for rapid BEV adoption. There is also an unstated optimism that current permitting and community opposition challenges impeding the development of infrastructure, transmission and new mines will be quickly and successfully overcome.

- It is reasonable to assume that Organization for Economic Cooperation and Development (OECD) grid conditions and battery capabilities will trend towards the assumptions made in these studies. That said, the LCA advantages attributed to BEVs are still likely overstated; the degree of this overstatement is unclear but will become better defined by the second half of this decade as net scale-up effects will clarify. It is possible that the benefit offered by BEVs relative to PHEVs will erode or disappear. This could lead to more of a 'hybrid' BEV/PHEV approach, as PHEVs offer range and convenience benefits versus BEVs.

- Rapid BEV adoption will also pose grid issues, though not the one widely expected. Continued efficiency gains in electricity use will largely offset the 'load' impacts of EV adoption. Most utilities forecast only a 1-2% annual electricity demand growth even with rapid EV adoption. Reliability issues are however expected due to EV adoption concentrations, i.e., sudden EV adoptions in specific neighborhoods or industrial/commercial areas. Local transmission/distribution systems are not built for the demand surges projected when EV concentrations or fleets all plug in at the same time. Such developments will require considerable substation and wire upgrades, the adoption of time-of-use pricing, utility control over plug-in times or all of the above.

- Considering all the above, one can anticipate continued gains in BEV adoption during the next 3-4 years. Fiscal incentives, OEM marketing and generally supportive media and political environments will drive adoption. For many consumers this will be a first-time experience. Towards the end of this decade however, there will be much better data on vehicle costs, charging networks, battery performance, scale-up effects, resale value, technology improvements and LCA benefits. While it is hard to predict how the net effects of so many variables will play out, it would not be surprising if this results in a slowdown in BEV adoption. The multiple headwinds facing rapid BEV adoption combined with the complexity and limitations of supportive public policy suggest that adoption rates are unlikely to achieve the targets identified by their advocates or the automotive OEMs.

- Current trade wars with China are not helping the cause of BEV adoption. China has built an impressive BEV and PHEV manufacturing industry. Its manufacturing costs are well below those in the U.S., making it possible to envision a Chinese-manufactured $25,000 BEV being offered in the U.S. market.

While this may indeed happen, such vehicles will not be eligible for federal tax credits, and may be subjected to other protectionist measures in the future.

We conclude then that very strong and much better designed public policy support will be needed to enable BEVs to reach even 50% of new car sales by the end of the decade. The better public policy design would incorporate the following:

1. Temporary relaxation of the battery, critical mineral content, personal income and MSRP regulations, allowing BEV tax credits to be available to a much broader range of customers on a much wider range of vehicles.
2. Extension of the 'free trade agreement' provisions to overseas battery suppliers
3. Permitting reforms aimed at enabling much more rapid and extensive mining of critical minerals and development of smelting capacity in the U.S.
4. More public subsidies and financing for buildout and maintenance of urban/suburban Level 2 chargers and fast chargers on interstate highways.
5. Relaxation of trade barriers impacting Chinese BEV/PHEV imports.

- If one considers mobility decarbonization through the wider lens of developing countries, the case for a more hybrid approach gets stronger. PHEVs eliminate the range anxiety and recharging network issues making their substitution for ICEs a significant decarbonization step that also allows such countries to concentrate on decarbonizing their carbon-intensive electricity generation.
- As a final comment, the arrival of BEVs and PHEVs in greater numbers is to be welcomed for reasons of national and energy security. Their development constitutes a significant energy diversification that lessens dependence on oil supplies which forecasts project to be increasingly concentrated in a few Persian Gulf countries. This is especially important for Europe and Japan where indigenous oil/gas supplies are either in decline or non-existent.

These summary conclusions will be considered at greater length via a detailed discussion of topics considered at the conference.

Conference Topic No 1 -

WHAT IS THE CARBON FOOTPRINT OF BEVs RELATIVE TO PHEVs AND ICEs?

Much of the enthusiasm and policy support for Electric Vehicles rests on a perception that their adoption is critical to decarbonizing transportation. In theory, decarbonizing electric power generation while adopting a Battery Electric Vehicle fleet (BEV) should eliminate the CO2 emissions currently put out by Internal Combustion Engine (ICE) vehicles. Will that be the case in practice?

To find out, the Energy Center commissioned a student research study examining the **'Life Cycle Carbon Footprints'** of BEVs, ICEs, and Plug-in Hybrid Vehicles (PHEVs). The latter was added because such vehicles were assumed to have a smaller carbon footprint than ICEs while avoiding some of the range and refueling issues that challenge BEVs.

The study examined eight **LCAs**, and selected the study done by the International Council on Clean Transportation (ICCT) as the baseline. The Life Cycle Carbon Footprint encompasses 3 phases for vehicle manufacturing:
1)Raw Material Extraction,
2)Component manufacturing, and
3)Vehicle manufacturing/assembly.
Battery creation for BEVs and PHEVs is incorporated into elements 1 & 2. Next is the fuel manufacturing phase – motor fuel for ICEs and PHEVs. Finally, there is the usage phase when the vehicle is driven, with BEVs and PHEVs consuming electricity produced with some emissions and ICEs combusting motor fuels and releasing emissions. **Attachment 1** outlines this cycle footprint. Grams of CO2 equivalent emitted per kilometer (g-CO2eq/km) was the key metric measured.

Key findings from the study and a host of areas for further examination are then outlined below:

- The eight studies focused only on the U.S. market. **The average result of these studies shows a marked advantage for BEVs with only 111 g-CO2eq/km versus 196 for ICEs. This is a 75% improvement which comes entirely from the vehicle usage phase.** PHEVs are much closer to parity with BEVs, checking in at 135 g-CO2eq/km – only a 22% BEV edge.
- **The International Council on Clean Transportation (ICCT) study show an even more pronounced benefit from BEVs.** Here the ICCT estimates BEVs producing only 83 g-CO2eq/km while the ICE estimate soars to 254 g-CO2eq/km. The PHEV estimate is essentially unchanged. **Attachment 2** summarizes these results and provides further details on the sources of emissions for each.
- **A detailed assessment of the assumptions employed in these LCAs raises several uncertainties as to the extent of BEV carbon benefits.** It seems reasonable to assume that for the U.S. market BEVs will offer some LCA benefit versus ICEs. However, the number and potential impact of these uncertainties is such that more years, better data and more study objectivity will be required to provide an accurate measure of this benefit. The situation will also be dynamic as several factors, e.g., battery technology and raw materials availability, are likely to evolve and the extent of any rapid BEV adoption is yet to be determined.
- **Several study assumptions, e.g., those concerning battery life, grid emissions and battery efficiency, seem unduly favorable to BEV LCAs. Attachment 3** give a hint of this, showing how a 'coal heavy' grid substantially shrinks the gap between BEVs and PHEVs. There appears to be a 'compounding effect' of assumptions in favor of BEVs, i.e., the combined effect of assuming all battery manufacturing is done in the U.S. and that the batteries produced last 15-18 years with no efficiency losses. **It is unclear how much of the cited BEV advantage goes away if the LCAs instead assume Chinese battery and vehicle manufacture backed by a coal-heavy grid, and an 8-year battery life with degradation after year four.**

It then becomes clearer that for BEVs to deliver on their full decarbonization potential, policies and vehicle manufacturing must achieve a set of challenging goals, e.g., very long-life batteries that experience little or no efficiency degradation and be charged on very clean power grids. If BEVs prove unable to achieve these conditions in specific markets or regions, thus offering only marginal advantages over ICEs, the case for a more nuanced vehicle electrification strategy and/or a slower pace of BEV adoption will be stronger.

Photo Credit: Jaun Diego Reyes for the New York Times

- **A second major conclusion is that the net decarbonization benefit of BEVs versus PHEVs may be smaller than current studies suggest.** If such proves true, **PHEVs may prove complementary to BEVs in a mobility de-carbonization strategy** for the following reasons:

  1. PHEVs eliminate much BEV range anxiety, improving prospects for EV adoption.
  2. PHEVs do not require the charging station buildout of BEVs.
  3. PHEVs do not require the same degree of public policy subsidies as do BEVs and appear to be currently profitable for vehicle OEMs.
  4. PHEVs do not require the same degree of new metals as do BEVs, thus putting less pressure on metal mining and smelting. This is visible in **Attachment 2** where PHEVs show lower battery creation emissions versus BEVs.

- **Battery technology emerges as the potential 'game changer'** in this outlook. A breakthrough which would yield that long life, highly efficient, low metals content and low-cost battery would change everything and pave the way for rapid BEV adoption. Extensive efforts and funding are now being directed at these objectives. Conference attendees talked of new prototypes being shipped with the promise of less weight, less liquids, lower metals like cobalt and greater energy density. Advocates continue to forecast major progress over the next decade. **At present, the outlook appears to be one of incremental progress where addressing one feature, e.g., low metals content is privileged at the cost of other dimensions, like energy density.**

- **Finally, none of the LCAs reflects issues associated with the rapid adoption of BEVs. This means, for example, they do not reflect the challenges and emissions associated with opening new mines, smelters or manufacturing plants** and the possibility that these facilities may themselves be located in countries with dirty power grids. Said differently, the scale up of BEV manufacturing may present a front-end emissions issue not reflected in the LCAs.

Photo Credit: Nissan

Detailed Comments:

The comments below provide additional support for the conclusions cited above.

- Battery life and efficiency emerge as the critical variables in these LCAs. As suggested in **Attachment 4**, a 5% improvement in round trip efficiency can improve life-time emissions by 3.4% while **Attachment 5** cites a study where lost battery efficiency increased lifetime vehicle emissions by more than 8%.

- **All eight LCAs referenced in this study assumed no battery degradation during the vehicle life.** This is an important and very favorable assumptions for BEVs. Presently, BEV manufacturers only warranty their batteries for eight years while **vehicles lives are assumed to be 15-18 years** for study purposes.

- The **assumption of no battery degradation eliminates at least two sources of additional BEV emissions.** First, it eliminates the need for battery replacement during the life of the vehicle. This in turn eliminates the need to incorporate a second set of raw material and manufacturing emissions into the LCA. Second, declining battery efficiency increases the electricity charging required per km driven bringing an increment of generation emissions into the LCA.

- **The ICCT study makes further assumptions favorable to BEVs** and unfavorable to ICEs. These are listed just below:

  1. The ICCT study assumes that by 2030 all BEV manufacturing is done in the U.S. allowing it to use the cleaner U.S. grid rather than those operating in Asia. As a result, this study shows 24% lower manufacturing emissions versus the average of the other studies.
  2. The U.S. grid's emissions are assumed to decline in line with IEA' STEPS model (Stated Policies are enacted). This means the 2030 U.S. grid used in the study is materially cleaner than the one which presently exists.
  3. ICCT battery efficiency assumptions lead to BEV electricity consumption of 0.173 kWH/km versus 0.194 for an average of the other studies.
  4. Only a 10% improvement in fuel economy is assumed for ICEs.

- **For these reasons, the ICCT study likely overstates the relative carbon benefits of BEVs** versus alternatives.
  While the study is widely cited, it's clear effort to emphasize the potential benefits of BEVs makes it a questionable baseline for analysis or policy setting.

- There is at present only limited experience and data available around BEV battery life. Aggressive assumptions around battery life, if later proven unfounded, will have various LCA secondary effects which would raise additional questions about BEV adoption:

  1. If as noted, battery lives prove shorter than assumed, BEV battery packs will have to be replaced one or more times during vehicle life, adding additional sets of manufacturing and raw material emissions to the LCA.
  2. More frequent battery replacements for a single BEV would put more pressure on the adequacy of metals as well as smelting capacity in any BEV rapid adoption scenario.
  3. More frequent battery replacements will also impact BEV resale value, car turnover, and the perception of BEV full life costs. Battery pack replacements costing $15-25 k constitute a 'value cliff' once it becomes known where/when such replacements will be needed. Present manufacturer warranties of 8 years will either turn out to be a benchmark beyond which vehicle owners themselves face this cliff, or an expensive liability for OEMs that depresses the profitability of BEV manufacturing.

- **Another area with limited data avails concerns the emissions associated with battery production.** As shown in **Attachment 6,** 81% of battery production emissions derive from the raw materials extraction and processing phase. A limited pool of 'mine-provided data sets' is widely used by LCA studies. The concentration of emissions in the raw materials and processing phases are additional reasons to be cautious about assumptions like the ICCT's view that all battery manufacturing is done in the U.S. in 2030.

- **The limited data around battery production emissions raises additional uncertainties regarding** the BEV decarbonization contribution in a rapid adoption scenario. BEV batteries use copious amounts of metals such as copper, cobalt, and nickel. Obviously, they also require lithium. These raw materials must then be smelted and forged into components. At present, existing mines do not have the capacity to supply these materials for a rapid BEV adoption scenario. Indeed, mining representatives at the conference forecast significant shortages of lithium and copper by decade's end; their forecasts foresee this shortfall even after assuming more materials recycling than currently occurs. **Consequently, a rapid adoption scenario will require new mines to be opened.** These new projects would impact the LCA discussion as follow:

1. Existing LCAs assume batteries are manufactured with materials from existing mines. They contain no emissions associated with creating new mining or smelting capacity.
2. The likely locations of most new mines will be in developing countries like Chile, Peru, Bolivia, Indonesia, and the Democratic Republic of the Congo. Environmental standards and power grids in such locations are more carbon intensive than in the U.S.
3. A similar story applies to raw material smelting, over 90% of which is currently done in China. If the time it takes to permit and construct such facilities in the U.S continues to be markedly longer than in China, BEV LCAs may increasingly have to reflect the Chinese manufacturing carbon intensity and coal-heavy power grid.

- **Attachment 7** details final areas where further research is needed. The first of these is **battery technology.** Tremendous efforts are currently underway to source batteries with fewer metals, longer lives and lower costs. Accomplishing all three simultaneously is proving difficult, but it is likely that significant progress will be made on some fronts. **This may allow BEV production to become more 'customized,' e.g., cheaper batteries could go into the '$25 k BEV' with the vehicle marketed as an urban, suburban run around for lower income clients. Metals recycling is also an area where great progress could be made,** potentially cutting costs and the need for new mines. Developments to date suggest limited progress, but the prospects of facing resource nationalism in difficult locations is likely to spur recycling efforts.

- **The other area for study concerns the emissions associated with building out and maintaining a recharging network for BEVs.** These also are not reflected in current LCAs. In effect, BEVs require the creation of a nationwide power distribution system that rivals the gasoline/diesel refueling networks that already exist.

- As a final comment, **current LCA studies are clearly inadequate conceptually.** They leave out large factors involved in enabling the rapid adoption of BEVs, which rapid adoption is then embedded in a host of Net Zero plans and commitments being made by companies and political jurisdictions. **Better policy and more prudent forecasts will thus require more complete and `objective LCA work going forward.**

Conference Topic No 2 -

WHAT ARE THE IMPLICATIONS FOR THE U.S. ELECTRIC GRID, BOTH FOR LOAD AND RELIABILITY, OF THE LIKELY ADOPTION OF BEVS AND PHEVS?

The consensus of conference panelists was that the U.S. electric grid would be able to handle electricity demands at the current projected adoption rates. However, conference participants also cautioned that the growth in BEV and PHEV adaption represents a significant change to the operation/management of the electric grid, and it will require careful planning and investment from utilities, policymakers, and regulators to ensure that the grid remains reliable and resilient.

There were several key considerations conference participants considered crucial to maintaining grid reliability as BEV and PHEV adoption ticks upward.

- ***Energy Sources for Generating Electricity*** will need to be expanded to include less carbon intensive fossil fuels, reliable renewables combined with robust energy storage systems, small modular reactor (SMRs) and other distributed energy sources will be required to meet the growing electricity demand over the next 30 years. While renewables are an essential component of current and future energy generation, it will take a flexible ‘all of the above’ sources of energy generation to meet future demand. The ‘all of the above’ approach will also require advanced forms of energy storage and carbon capture technologies.

- ***Increase in the Number of Demand Center Locations*** was considered by the conference participants as a critical consideration in the expansion of the grid infrastructure. Discussion focused on the electricity demand requirements from private and commercial vehicle operators. Examples put forth in some of the discussions put forth demand for meeting home charging station demand for private vehicles while at the same time building capacity to meet the demand of light commercial vehicles (light trucks, box delivery trucks) which depending on the type and size business would require depot charging. For example, large fleet package delivery businesses have depot charging, which is easier for manage charging hours. Vehicles in these fleets tend to have a larger range capability. Smaller businesses – say construction or plumbing companies – may use lighter pickup truck style service vehicles with shorter range capability – and will likely use company installed charging stations for overnight charging. These vehicles can also be charged at public charging stations.

Growth in electricity demand is predicted by some utility companies to be in the range of 5-10% over the next eight years. What is less well known is the location of new demand centers which will be contributing to the growth demand. Building infrastructure to support these new demand centers will require greater coordination between the power companies, government regulatory agencies, local community planning councils and businesses.

- **Electricity Pricing and the Evolving Shifts in Social and Economic Makeup of BEV Owners** - Today the price point of a BEV is tailored for the middle class and the offering is limited primarily to sedans and light utility vehicles. However, as the model types of BEVs manufactured expands to match a broader pricing range (i.e. the $25,000 BEV to the BEV luxury market) to meet a more inclusive socioeconomic access, the physical demographics of BEV owners will necessarily require an expansion of charging stations and equitable electricity pricing.

Further, the conference panelists cited the potentiality of developing BEVs which are equipped for regional considerations such urban vs rural or colder climate regions vs warmer climates regions. The discussion followed that drivers of BEVs or PHEVs in urban areas where shorter distances are the norm may require a less robust a battery system than may be necessary in rural areas. Climate matters as well. BEVs operated in colder regions where snow and ice storms prevail in winter months may benefit from battery composition that is more resilient to cold temperature extremes. Conversely, alternative battery compositions may be needed for BEVs operated in extreme heat during summer months.

- **Building Necessary Transmission Line Infrastructure for Expanding the Grid:** Chief among the new infrastructure components required to support even moderate adoption rates of BEVs is the expansion of transmission lines. Utility companies face several challenges when building new transmission lines, which can make it difficult to construct much-needed infrastructure for the electric grid. Principal difficulties identified were:

1. Permitting and Environmental Regulations: Building new transmission lines can be a lengthy process that requires extensive environmental and regulatory reviews. These reviews can take several years, delaying the construction of new transmission lines and increasing costs. There was a degree of frustration expressed during the grid discussions that environmental activists often use permitting and environmental regulations to slow, or to completely stop, the installation of new transmission lines.
2. Land Use Issues: Transmission lines often require the use of public and private lands, which can lead to conflicts with landowners, local communities, and other stakeholders.
3. Resistance from communities regarding the location of transmission lines can significantly slow down the process of obtaining right-of-way permissions, permits, and approvals.
4. Financing: Transmission lines are expensive to build, and utility companies may face financial challenges in securing the necessary funding. Financing is often complicated by the lengthy permitting process, which introduces uncertainty and delays.
5. Litigation: The construction of transmission lines may be challenged in court by opponents who are concerned about the potential impact on the environment, property values, and other issues. Litigation can be costly and cause extended delays in the construction of new transmission lines.
6. Seeking Public Approval: The construction of new transmission lines may require public approval through the ballot process, which can be challenging and time-consuming. Public support is essential for the construction of transmission lines, and it may require extensive outreach and education efforts to build support.
7. Technical Issues: The construction of new transmission lines may require extensive engineering and design work, as well as coordination with local utility networks. Complex technical problems such a re-engineering aging grid infrastructure while maintaining active power levels will be especially difficult and expensive.
8. Lack of Coordination and Planning: The development of new transmission lines requires coordination and planning among different stakeholders, such as utilities, regulators, and local and state governments. In some cases, the lack of coordination and planning can make it difficult to identify the best locations for new transmission lines and to obtain the necessary permits and approvals.

The combination of these factors, and others not yet identified, make it difficult for utility companies to build new transmission lines. Nevertheless, new transmission infrastructure remains crucial to ensuring a reliable, secure, and resilient electric grid that can meet the increasing energy demand loads and accommodate the growing share of renewable energy sources in the electricity mix.

- Smart Grid Development refers to the evolution of the traditional electrical grid into a more advanced and responsive system that uses digital technology, sensors, and communication networks to better manage the generation, distribution, and consumption of electricity.

Although the conference panelists did not focus on smart grid development as an individual topic, elements of the smart grid technologies were discussed as necessary to improve management of the electric grid.

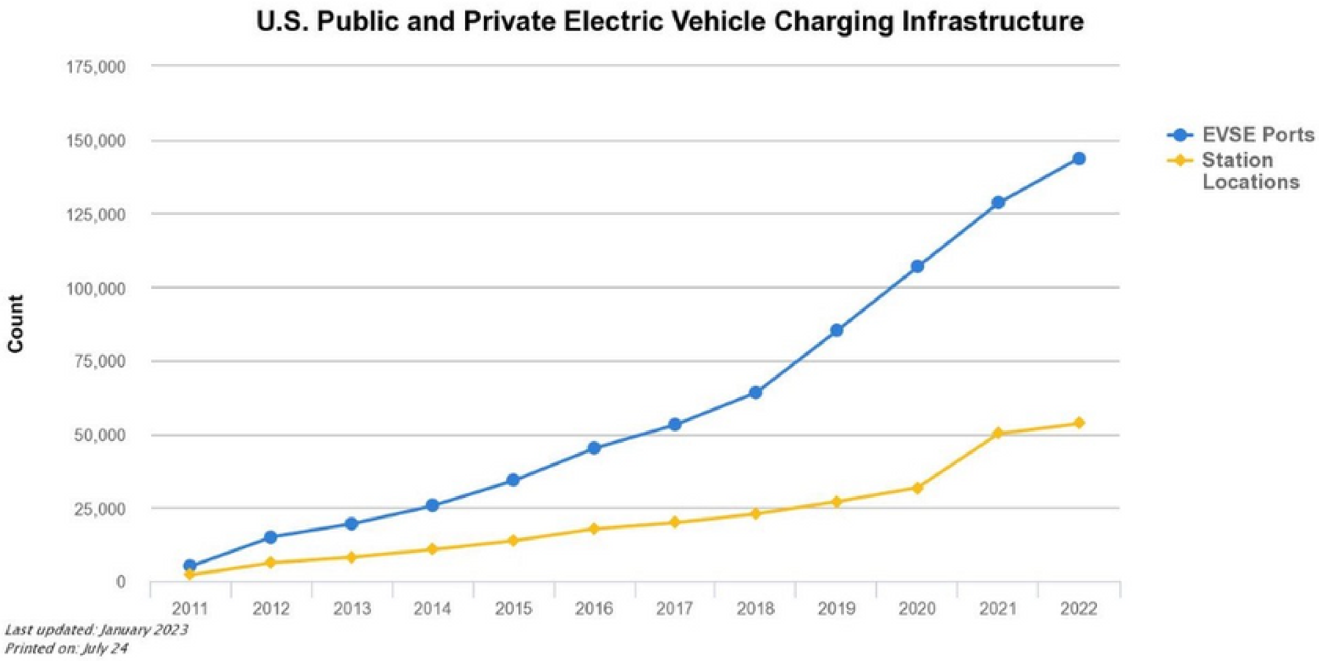
Photo Credit: University of Victoria, Institute for Integrated Energy Systems

Some key areas of smart grid development:

1. **Advanced Metering Infrastructure (AMI):** Advanced metering infrastructure is a key component of the smart grid, allowing utilities to remotely monitor and manage energy use on a more granular level. This can help consumers to better manage their energy use and, in turn, reduce costs and emissions. This metering system also provides the utility company with the ability to determine the optimum times for charging. The panelists generally agreed that as more businesses convert to electric fleets that this type of direct management control will be necessary to properly control load times.
2. **Distribution Automation:** Smart grid technologies can also be used to automate the distribution network, allowing utilities to remotely monitor and control the flow of electricity. This can improve reliability, reduce outages and restoration times, and better manage peak demand.
3. **Time-of-Use Rates:** Variable pricing for electricity, based on the time of use, will become an increasingly necessary load management tool as BEV and PHEV adoption grows. Smart grid systems that provide the utility the ability manage demand through pricing based on the consumer charging during on peak and off-peak hours – pushing EV owners to charge vehicles at off-peak times to avoid high electricity prices.
4. **Energy Storage:** Smart grid development also includes the integration of energy storage technologies, such as batteries, to store excess renewable energy for later use. This can help to smooth out the intermittency issues of renewable energy system.
5. **Microgrids:** Smart grid development also includes the creation of microgrids, which are smaller, self-contained energy systems that can operate independently from the main grid. They can provide backup power during outages or emergencies and can support the integration of renewable energy sources.
6. **Cybersecurity:** As the electric grid becomes more digitized and interconnected, cybersecurity is a crucial aspect of smart grid development.

Overall, smart grid development is a crucial aspect of the transition to a more efficient, and reliable electric grid. It requires collaboration among utilities, technology providers, regulators, and consumers to create an integrated and optimized system.

- **Expanding Charging Station Infrastructure** - To support the growth of electric vehicles, a robust charging infrastructure is necessary. This includes charging stations that are accessible, equitable, reliable and able to charge quickly. The conference panelists identified the necessary characteristics of a national charging station infrastructure. It was generally agreed that building reliable charging station infrastructure at scale and with speed, would require government, commercial, regulatory and financial investment coordination.



Although not presented during the conference, the link below displays the 2022 charging station locations across the United States and gives some insight to where many of the installation gaps still exist.

https://www.visualcapitalist.com/interactive-ev-charging-stations-across-the-u-s-mapped/

Conference Topic no 3 -

WHAT IS THE LIKELY RATE OF ADOPTION OF BEVS AND PHEVS IN THE U.S.?

Conference speakers were split on the likely pace of EV adoption in the U.S. First, when discussing potential adoption rates, **most speakers meant BEVs**. PHEVs did not count in their thinking as a meaningful version of mobility electrification. **Those more optimistic about BEV adoption felt the target of 100% of new light vehicles being BEVs by 2035 was achievable. Other speakers see a variety of headwinds likely to constrain adoption during the second half of this decade.** When one considers the number and magnitude of these headwinds, **the more conservative adoption expectation seems the more realistic. Although not openly acknowledged at the conference, the possibility of a significant disappointment in terms of the pace of U.S. BEV adoption should not be discounted.**

Should this prove the case because of the referenced headwinds (discussed below in more detail), **more consideration should be given to promoting 'BEV + PHEV' adoption.** While not quite as carbon friendly as BEVs on the road, PHEVs ability to meet a variety of other motorist needs without subsidies while also being less carbon intensive than ICEs means that their widespread deployment could provide a large overall decarbonization gain.

BEV adoption is seen as important because transportation is the largest contributor to U.S. GHG emissions. More than half of these emissions come from light duty vehicles. The IRA sets a goal of reducing U.S. emissions by 40% by 2030. Rapid BEV adoption is thus viewed as critical to achieving this objective.

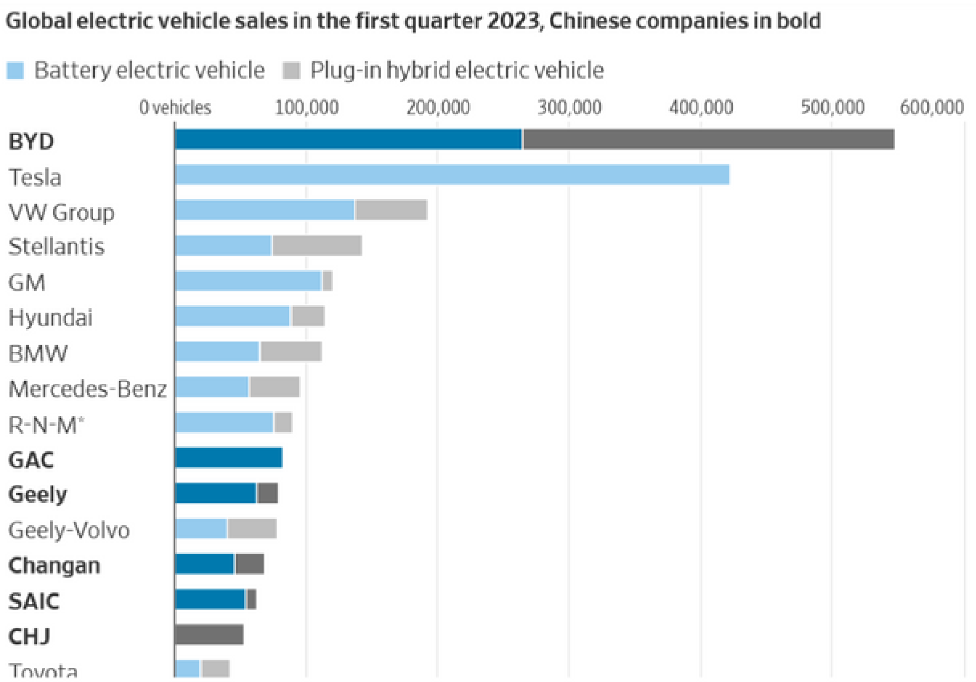
In addition to arguing that it is necessary, those asserting such an adoption rate is feasible make the following arguments. First, they say the minimum threshold of 5% of new vehicle sales has been surpassed – demonstrating initial scale and momentum. Second, they say EVs are or will prove more economical than ICEs when the low costs of driving per mile and the lower costs of maintenance are figured in. They also argue customers will find the EV driving experience superior. They acknowledge that upfront vehicle cost is an issue but assert this is improving with manufacturing economies of scale and improving technology.

Further support comes from the broad and deep commitment of vehicle OEMS to electrify their new vehicle offerings. All major automakers are rolling out numerous electric models and committing billions of dollars of capital to new plant and equipment dedicated to these offerings. Competition and choice are thus expected to encourage consumers to make the switch. OEMs also assume that once the switch is made, consumers will not be switching back.

A good deal of this competitive pressure will come from Chinese manufacturers. China has quietly built a burgeoning EV OEM industry. The industry is heavily subsidized and enjoys a protected market. Chinese consumers also face a variety of disincentives to purchase ICE vehicles. This combination of industrial policies is allowing the Chinese EV industry to reach scale and to innovate rapidly. According to the Wall Street Journal, western visitors to the 2023 Shanghai Auto Show were stunned as to the sophistication and consumer appeal built into the Chinese models on display.

1. The Chinese industry is now positioned to influence the EV competition in other markets. Volvo (Chinese owned) recently announced plans for a new, smaller BEV SUV. With a low end MSRP starting at $35,000, the vehicle is aimed at early career professionals who cannot yet afford the more expensive EV options.
2. This type of competition is going to push BEV innovation across the industry to address the various attributes inhibiting BEV adoption, e.g., range, price, recharging time, interior & cargo space.

The following chart of Sales for QI 2023 reveals the growing presence of these Chinese manufacturers in the global EV market:



SOURCE: WALL STREET JOURNAL, JUNE 3, 2023

Here one should note the relative importance of PHEVs for market leader Build your Dreams (BYD) and the absence of U.S. OEMs other than TESLA from the list of leaders.

Finally, those more optimistic about BEV adoption repeatedly cited the IRA incentives as a 'game changer.' A brief summary of IRA incentives is thus helpful to the discussion:

- The IRA **extends to 2032 a Federal Tax Credit of up to $7500** for the purchase of a new plug-in or fuel cell electric vehicles and **adds a $4000 credit for the purchase of a used EV. The used EV** must be 2 years old or less with a max eligible price of $25,000.

- **To qualify for the full new vehicle tax credit**, the vehicle must meet a number of requirements: 1) **the vehicle must be assembled in the U.S**.; 2) **the vehicle must meet certain minimum requirements for critical minerals and battery components.** If the vehicle meets only one of these requirements, the credit drops to ~$3750.

The battery component requirement calls for **50% of the EV battery to be manufactured in the U.S.** in 2023, with the % then increasing annually thereafter. The critical minerals requirement calls **for 40% of such minerals to be extracted, processed and/or recycled in the U.S. or in a country with whom the U.S.** has a free trade agreement. Subsequent to the IRAs passage, the U.S. Treasury Department issued draft regulations indicating that a qualifying free trade agreement was any agreement of 1 or more years duration calling for free trade in critical minerals. These minerals include lithium, graphite, aluminum, copper, nickel, and cobalt.

- In addition, there are income restrictions on eligibility for the EV tax credits. **Those eligible** must have **modified Adjusted Gross Incomes** reported to the U.S. IRS **less than** the following:

  $300,000 for married couples filing jointly

  $225,000 for heads of households

  $150,000 for all other filers

- Finally, the vehicle manufacturer's **Suggested Retail Price (MSRP) cannot exceed $55,000 for cars and $80,000 for vans, sports utility vehicles and pickup trucks.**

- The IRA also provides for commercial vehicle tax credits based on vehicle weight and an Advanced Manufacturing Production Tax Credit tied to battery kw/h.

While impressive at first glance, the IRA's incentives are sufficiently complicated as to raise questions about their effectiveness in incentivizing BEV adoption. Consider the condition of a potential BEV buyer wondering if they will be eligible for the federal tax credit:

- **First, they must determine if the vehicle they desire qualifies.** Thus, they must check for certification that it **was assembled in the U.S.** If not, the vehicle is not eligible for any tax credit. Second, the vehicle must **meet both the critical minerals and battery sourcing requirements.** If it only meets one, the tax credit is cut in half. It if meets neither, there is no credit.

- Next, they must **certify that the vehicle does not exceed the maximum Manufacturer Suggested Retail Price (MSRPs)** cited in the legislation. If it does, there is no credit. More than a few existing BEV offerings are ineligible.

- Finally, they cannot have modified Adjusted Gross Income above the listed thresholds.

In sum, the IRA's provisions are clearly aimed at boosting middle class BEV adoption of vehicles increasingly sourced and assembled in the U.S. The question is whether these various rules and exclusions will conflict with each other, such that in combination they substantially limit both the pool of eligible customers and the vehicles they can consider. To take one example, the Chinese and Volvo vehicles cited above will not be eligible for the tax credits. However, they may well put downward pressure on the MSRPs of U.S. sourced vehicles.
Facing this competition, will there be much margin left in the U.S. OEM BEVs if they manufacture them to be eligible for credits that would support sales?

While the amount of effort going into technology improvements is impressive, the inherent challenges presented by BEV technology remain formidable. This can be seen by noting the compromises that vehicle designers are making as the focus on fixing one problem or another. A recent Wall Street Journal article touted a 1000-mile BEV trip with no daytime recharging stops. However, a close read of the article revealed the following:

To expand range, the vehicle received design changes to emphasize aerodynamic body shape, with unspecified consequences for number of passengers, cargo space and hauling capacity.

Stated vehicle range and actual range turn out to be quite different, with the actual over 100 miles less than the promised 500+ mile range. In the experience described in the article, driving over the New Hampshire mountains substantially reduced range, as did running the AC. The author barely made it into Montreal with any charge remaining.

Charging on Level 2 rechargers took more than 12 hours and in Montreal it took 18 hours to fully recharge.

The vehicle's MSRP is $138,000.

This and similar articles provide a view of BEV adoption's challenges on the consumer front. Enormous OEM and technologist effort is going into addressing BEV's limitations. Some progress is visible and is announced with fanfare. **Yet, the 'package' of BEV disadvantages relative to ICEs remains stubborn to overcome.** The smart phone displaced a variety of predecessor technologies because it was better on multiple fronts and affordable. When considering the 'package' of consumer vehicle requirements, BEVs struggle to match up, let alone offer advantages:

- Range: ICEs offer up to 500-mile ranges, but refueling options are everywhere and take only 5-10 minutes to refuel. BEV ranges are less, recharging options limited and time consuming.

- Refueling: 5-10 minutes versus 10+ hours unless attached to Fast Chargers which are far fewer in number and have implications for battery life

- Cargo capacity: plentiful in ICE options, limited in BEVs.

- Hauling capacity: plentiful in ICE options, serious range and/or cargo capacity implications for BEVs

- MSRPs: Generally higher for BEVs versus comparable offering ICEs

- OEM margins: Generally lower for BEVs vs. ICEs; indeed, the perception is Tesla is only profitable because it sells clean energy credits to other OEMs.

It is because of this formidable package of disadvantages that a state such as California has resorted to mandates, in effect forcing OEMs only to offer new EVs for sale in the state after 2035. **If BEVs were confident that they have a winning consumer proposition, such mandates would not be needed.** Europe is similarly resorting to mandates, which action has encountered sufficient German and Italian resistance such that the mandates adoptions was postponed.

Turning to manufacturing and supply chain issues, a different set of concerns arise.

Photo Credit: Pedro J Pacheco, Salinas Grandes, Argentina

Critical minerals supply was cited as a major headwind to rapid BEV adoption. The thing to note here is the number of critical minerals input into Lithium-Ion Batteries (LIBs): lithium, copper, nickel, cobalt, graphite, and certain rare earths. Aluminum and manganese are other metals/compounds employed in some LIBs. The global supply situation for each of these is different, but several are perceived to be challenged in terms of meeting projected BEV demand. In other cases, the country sources raise serious environmental and human rights concerns. Conference speakers added the following comments:

- **An outright 20% shortage in lithium supply is expected towards the end of this decade.** This projection already incorporates growing supplies from recycling. Looking out into the 2030s, lithium supply is expected to alternate between adequate and short.

- **Considerable effort is going into developing new lithium mines, including within the U.S.** The improved supply situation post-2030 reflects an expectation that permitting and project development challenges will eventually be overcome.

- **Copper, cobalt, and nickel face similar issues.** There are sources of expected new supplies from countries like Chile, Peru, and Indonesia. The questions here concern resource nationalism and the extent to which host governments will let foreign companies develop new mines on a schedule that serves rising BEV adoption. Cobalt is a special case with production concentrated in the Democratic Republic of the Congo – abusive child labor practices there raise human rights issues for firms sourcing cobalt supplies there.

- A **collateral issue concerning copper is competing demand from electric grid upgrades needed to support growing load from BEVs.** Copper is relatively abundant and new supply sources are in development. Copper recycling is also progressing. The question is how fast these supplies will come onstream versus growing demand. EV's use 4X the copper as does a conventional ICE light vehicle while an electrified bus uses 16x the copper versus its ICE alternative.

- Given the IRA's requirements for U.S. sourcing of battery inputs, there is a perceived need for new U.S. mines. Here the permitting and local opposition challenges are formidable. New U.S. mines presently take up to 20 years from project conception to first supply.

- Rare Earth Elements (REEs) are a special issue with China currently supplying over 90% of the market. REEs are not critical to Lithium Ion Batteries (LIB) chemistry but are used in certain battery models. REE deposits do exist outside of China, but mining and processing would need to be developed.

Metals smelting and processing is the next part of the LIB supply chain. Over 90% of global capacity for these activities resides in China. Technology is mature for these activities, thus, the barrier to new U.S. capacity is siting environmental approvals and addressing local opposition.

A coalition of certain climate activists and national security experts is coming together to advocate for removing barriers to U.S. production of critical minerals.
This coalition increasingly understands that dependance on China for minerals processing threatens the effectiveness of the IRA in promoting BEV adoption.

Given their prominence within a Democratic presidential administration, this may lead to modifications of current U.S. environmental and permitting laws. **However, environmental activists are still thwarting new U.S. mine development,** and recently persuaded the Biden Administration to withdraw a U.S. Army Corp of Engineers permit granted to a copper/nickel mine in Minnesota.

Conclusions: What is the Likely Pace of BEV Adoption?

Having passed the 5% threshold of new vehicles sales, the questions become how fast this percentage will increase, whether demand will 'flatten out' in the face of various headwinds, and whether those barriers can then be overcome to pave the way for further BEV penetration?

Any prediction is hazardous given the number of variables in play and the potential for U.S. politics to swing dramatically in supportive public policy.

That said, **BEVs have yet to present a compelling value proposition that would induce rapid, voluntary adoption by U.S. consumers.** There various limitations are evident in the intense effort OEMs are devoting to overcome them and in the less than excellent recharging experiences test drivers recount on long cross-country trips.

However, **BEVs purchased with the intent of being used in urban/suburban or fleet settings could see more rapid adoption.** Here a clear line of sight to the IRA tax credits could be important. Continued Democrat control of the Federal government post-2024 could see clarification and liberalization of the IRAs incentives. Additional mandates and regulatory provisions may also come into play. Should a Republican administration come into office, even the IRAs current incentives could be in jeopardy.

Later in this decade, critical minerals supply will become a serious constraint on rapid BEV adoption. Concerns on this front can be seen in the unprecedent efforts OEMs are exerting to lock up critical supplies years into the future.
An underappreciated aspect of this issue is the effect mineral shortages will have on BEV MSRPs. Said differently, it will be difficult for OEMs to offer the low-priced BEVs aimed at the mass market if/when multiple battery inputs are in short supply or are being sourced from expensive providers.

We conclude then that very strong and much better designed public policy support will be needed to enable BEVs to reach even 50% of new car sales by the end of the decade. The better public policy design would incorporate the following:

1. Temporary relaxation of the battery, critical mineral content, personal income and MSRP regulations, allowing BEV tax credits to be available to a much broader range of customers on a much wider range of vehicles
2. Extension of the targeted 'free trade agreement' provisions to overseas battery suppliers
3. Permitting reforms aimed at enabling much more rapid and extensive mining of critical minerals and development of smelting capacity in the U.S.
4. More public subsidies and financing for buildout and maintenance of urban/suburban Level 2 chargers and fast chargers on interstate highways.
5. Some relaxation of trade barriers re: Chinese BEV imports

This kind of support would remove several internal contradictions in the movement to electrify mobility via BEVs. Together with ongoing battery technology efforts, it could lead to scale manufacturing that allowed OEMs to reduce costs, increase margins and replace cash flow from ICEs.

Photo Credit: Ford Motor Company

Because it is not certain that such a program is politically or financially feasible, it makes sense to diversify the efforts going into mobility electrification. Here it is worth considering the recent statements of Toyota's CEO, Akio Toyoda. The executive asserted that 'a silent majority' of automaker agrees with him that BEVs are not the only way forward. Speaking to Toyota's U.S. dealers in Las Vegas, Toyoda went on to say the following:

- **Toyoda reiterated that he does not believe all-electric vehicles will be adopted as quickly as policy regulators and competitors think,** due to a variety of reasons. He cited lack of infrastructure, pricing and how customers' choices vary region to region as examples of possible roadblocks.

- **He believes it will be "difficult" to fulfill recent regulations that call for banning traditional vehicles with internal combustion engines by 2035,** like California and New York have said they will adopt.

- **"Just like the fully autonomous cars that we are all supposed to be driving by now, EVs are just going to take longer to become mainstream than media would like us to believe,"** Toyoda said in a recording of the remarks to dealers shown to reporters. "In the meantime, you have many options for customers."

- Toyoda also believes there will be **"tremendous shortages" of lithium and battery grade nickel** in the next five to 10 years, leading to production and supply chain problems.
- Since the Prius launched in 1997, Toyota says it has sold more than 20 million electrified vehicles worldwide. The company says those sales have avoided 160 million tons of CO_2 emissions, which is the equivalent to the impact of 5.5 million all-electric battery vehicles. **"Toyota can produce eight 40-mile plug-in hybrids for every 320-mile battery electric vehicle and save up to eight times the carbon emitted into the atmosphere,"** according to prepared remarks for Toyoda provided to media.

Toyoda's stance and comments drew immediate criticism from the Sierra Club and Greenpeace. However, he deserves credit for speaking directly to several of the headwinds cited in this report, and for publicly embracing hybrid decarbonization solutions that may be more realistic and achievable.

Photo Credit: Toyota Financial Savings

It may take several more years and direct experience with the headwinds referenced herein to bring about the most feasible version of mobility decarbonization: 1) enhanced public policy support such as outlined above; and 2) acceptance that some combination of BEVs and PHEVs will achieve the fastest aggregate import over the near and medium term.

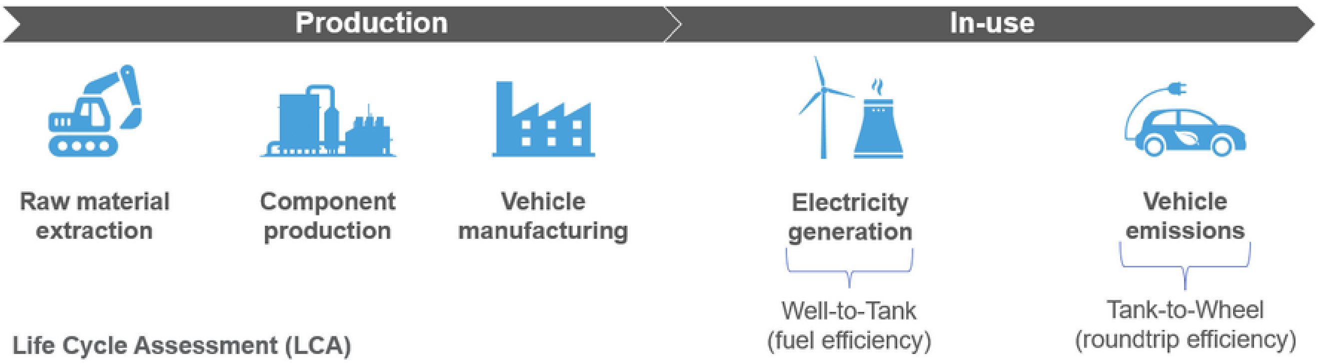
NOTES

1. https://www.wsj.com/articles/chinas-ev-juggernaut-is-a-warning-for-the-west-1389f718?page=1, June 7, 2023
2. Ibid.,
3. https://www.irs.gov/credits-deductions/credits-for-new-clean-vehicles-purchased-in-2023
4. https://www.wsj.com/articles/ultralong-range-electric-cars-are-arriving; June 2, 2023

ATTACHMENTS

Attachment 1

The Emissions Lifecycle of a Passenger Vehicle



Life Cycle Assessment (LCA)

- Common method for calculating the cumulative emissions generated by a product throughout its life
- Emissions are estimated at each phase by calculating the total energy consumption by source and applying relevant emissions factors
  - Emissions factors are specific to fuel type and/or grid mix, meaning there is variability between reports

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Attachment 2

Emissions Estimates Across Vehicle Types

The in-use phase contributes the highest proportion of lifetime emissions for all three vehicle types. Manufacturing emissions are not insignificant, but in-use energy reduction offers the greatest opportunity for emissions reduction

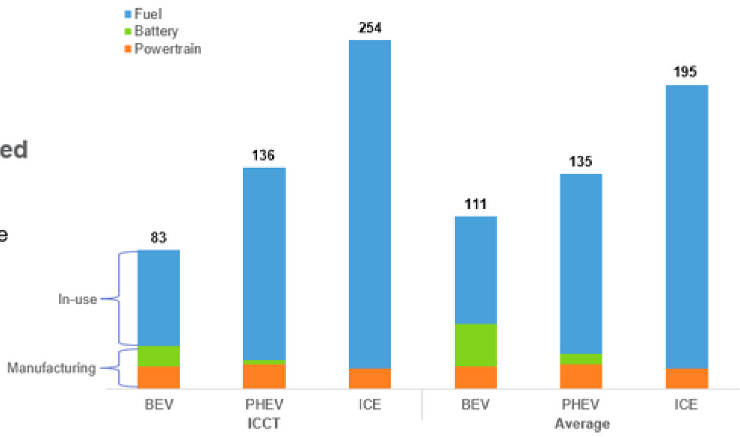
The ICCT report assumes more drastic reductions in electricity generation emissions by 2030 compared to similar LCAs

- 24% lower forecasted BEV fuel emissions
- 20% reduction in manufacturing emissions

Grams of CO2 equivalent (g-CO2eq) is the standardized unit for quantifying emissions

- The ICCT report (and many others) divides the total lifetime emissions by an estimated lifetime distance driven to determine emissions emitted per kilometer driven (g-CO2eq/km)

Lifetime Emissions of Vehicles Manufactured in 2020 (g-CO2eq/km)



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Attachment 3

Sources of Vehicle Emissions

Battery Efficiency is the Primary Factor Affecting BEV Emissions

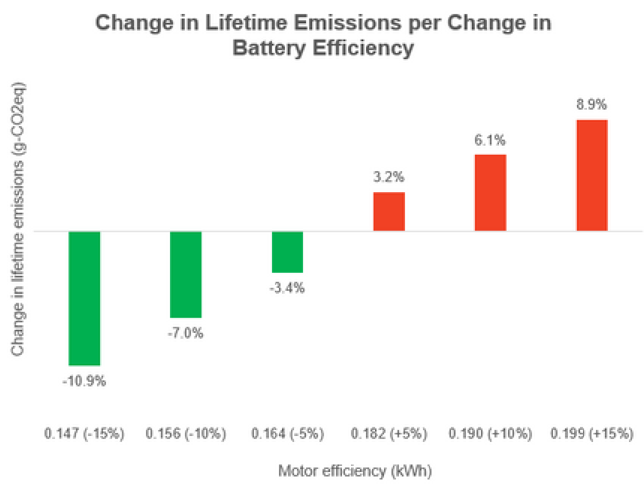
Roundtrip efficiency (kWh or L / km) and fuel efficiency (g-CO2eq / kWh or L) are the two primary factors that affect lifetime emissions

A 5% improvement in roundtrip efficiency reduces lifetime emissions by approximately 3.4%

- The ICCT average of 0.173 kWh/km is used as the starting point in our calculations
- The average roundtrip efficiency from the comparable reports was 0.194 kWh/km, again showing the variability in emissions reporting

Estimates vary on potential roundtrip efficiency improvements for both BEVs and ICEs

- The ICCT report predicts a 10% improvement in ICE fuel efficiency
- At this rate, ICEs would need to achieve a roundtrip efficiency of 0.027 L/km (~87 mpg) to be competitive with BEVs



Attachment 4

Sources of Vehicle Emissions

Losses in Battery Capacity and Roundtrip Efficiency

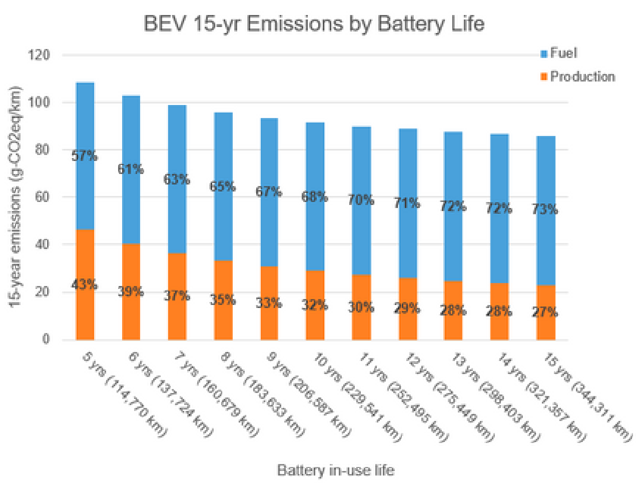
Battery capacity (total kWh stored per charge) and roundtrip efficiency (kWh/km) degrade with use, incentivizing more frequent vehicle purchases or battery replacements, and potentially reducing BEV and PHEV resale value

Battery roundtrip efficiency losses are estimated to increase lifetime fuel emissions by 8.1%[1]

- Decreasing roundtrip efficiency increases long-term emissions output from BEV ownership by increasing average kWh/km
- These losses are not factored into existing LCAs

Shorter vehicle lifetimes could lead to more frequent vehicle purchases and limit the used BEV market

- Typical battery warranty is 8 years or 161k km (100k mi)[2]; however, DOE battery life estimates are 12-15 years[3]
  - This wide discrepancy is a result of the lack of comparable historic lifetime performance data for modern battery technology
- Forecasts on the size and value of the BEV resale market are highly speculative



Source: 1) Implications of future electricity mix and different battery end-of-life management; 2) Well-to-wheel greenhouse gas emissions of electric versus combustion vehicles from 2018 to 2030 in the US 3) DOE Alternative Fuels Data Center: Electric Vehicle Benefits and Considerations

Attachment 5

Sources of Vehicle Emissions

Effects of grid mix on BEV and PHEV in-use emissions

The key to BEV's carbon success is their low average emissions per kilometer, even when charged on a grid with predominately fossil fuel generation

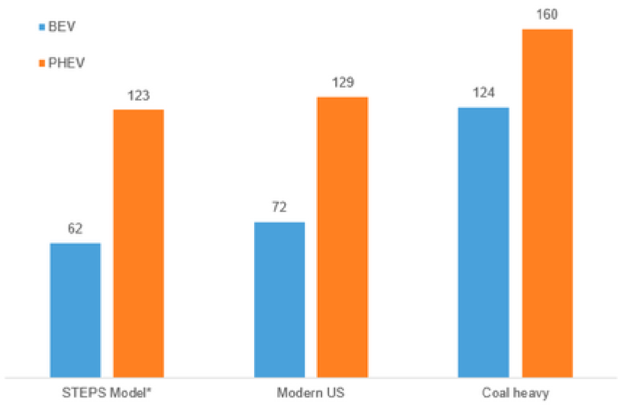
The high emissions from gasoline limit the impact of grid decarbonization on reducing PHEV emissions

- Electricity supplies approximately 59%[2] of the energy for PHEVs, making them less carbon intensive than ICEs, but not able to compete on a km/km basis with BEVs

Grid decarbonization will help maximize the emissions reduction from transportation electrification

- IEA's STEPS model is designed to represent where regional energy systems might go based on current policy direction
  - This is the model we used as the basis for all other calculations
- The Modern US model assumes no additional decarbonization before 2030
- We used data from India's modern grid mix to estimate the generation profile of a coal-reliant grid

Fuel Emissions (g-CO2eq/km) by Grid Mix[1]



UNC KENAN-FLAGLER BUSINESS SCHOOL   Source: 1) ICCT report, EIA 2021 World Energy Outlook; 2) ICCT Report

Attachment 6

Sources of Vehicle Emissions

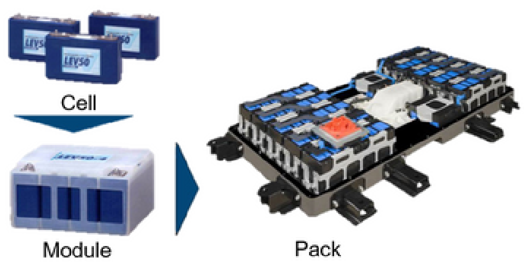
Battery Production Emissions are the Largest Source of Uncertainty

Raw material extraction and refining accounts for 81% of emissions incurred during battery manufacturing; however, estimates vary widely based on energy input

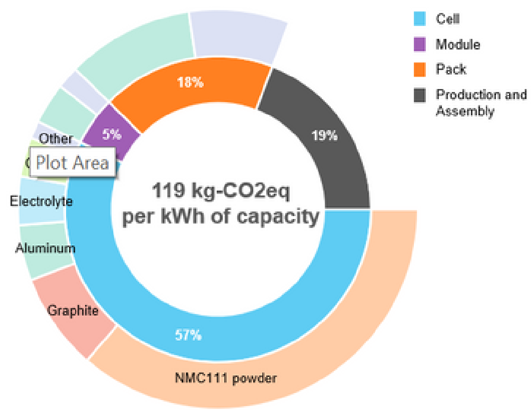
Calculating accurate emissions estimates is challenging due to the lack of publicly available data

- Frequently cited LCAs typically rely on a limited pool of mine-provided data sets to estimate sourcing emissions
- Natural gas heating contributes the largest portion of battery production emissions, followed by electricity

BEV Battery Assembly Components[2]



NCM111 Battery Emissions by Manufacturing Phase[1]



UNC KENAN-FLAGLER BUSINESS SCHOOL   Source: 1) Dai et. All 2019; 2) X-Engineer.com

Attachment 7

Conclusions and Areas Requiring Additional Research

Areas Requiring Additional Research

Carbon analysis uses historical data to provide a reliable guide for short-term decision-making. However, several external factors with potentially significant impacts on emissions do not fall within the scope of LCAs

The carbon cost of expanding BEV production capacity is not fully accounted for

- If the adoption rate of BEVs keeps pace with the predictions made in the STEPS model, the global capacity for rare earth mineral mining will need to increase
- Current emissions calculations account for the variable emissions cost per vehicle at current production levels but do not factor in the capital expansion required to meet rapidly increasing demand

The impact of building the charging infrastructure required for high levels of BEV adoption is understudied and not included in most emissions studies

- Understanding this impact is critical for effective systems-level policy-making because it provides a more accurate estimate of the emissions reductions required in other sectors to achieve high-level carbon reduction goals
- It is unlikely that adding this cost into emissions calculations will increase BEV emissions enough to make a competitor technology less emissions-intensive

There are transportation and storage technologies under development that could further reduce emissions

- Emergence of Na-ion batteries with lower environmental impact and widely available raw material
- Battery recycling promises up to 95% material recovery for batteries; however widespread adoption of recycling technology has yet to take off

AGENDA

THURSDAY, FEBRUARY 23

11:00 a.m. **CHECK-IN: Kenan Center Lobby**

Bag check for overnight guests, boxed lunch for speakers and other guests available

12:30 p.m. **WELCOME AND OPENING COMMENTS**

Stephen Arbogast, Director, UNC Kenan-Flagler Energy Center

12:40 p.m. **MEETING GUIDELINES AND KEYNOTE AND SPEAKER INTRODUCTIONS**

Dan Domeracki, Associate Director, UNC Kenan-Flagler Energy Center

12:50 p.m. **KEYNOTE ADDRESS 1: Hurdles to EV Consumer and Commercial Adoption**

Albert Gore, CEO, Zero Emission Transportation Association (ZETA)

1:10 p.m. **KEYNOTE ADDRESS 2: Geopolitics and the Beginning of the Supply Chain for Electric Vehicles**

Jonathan G. Price, PhD, CPG, State Geologist Emeritus, Nevada Bureau of Mines and Geology, University of Nevada and President of the American Geosciences Institute

[What will be the pace of adoption and market penetration of EV's in developed economies and in developing countries?]

1:30 p.m. **OPENING PANEL DISCUSSION: What do we need for Consumer and Fleet Uptake at Scale? What are the Key Challenges?**

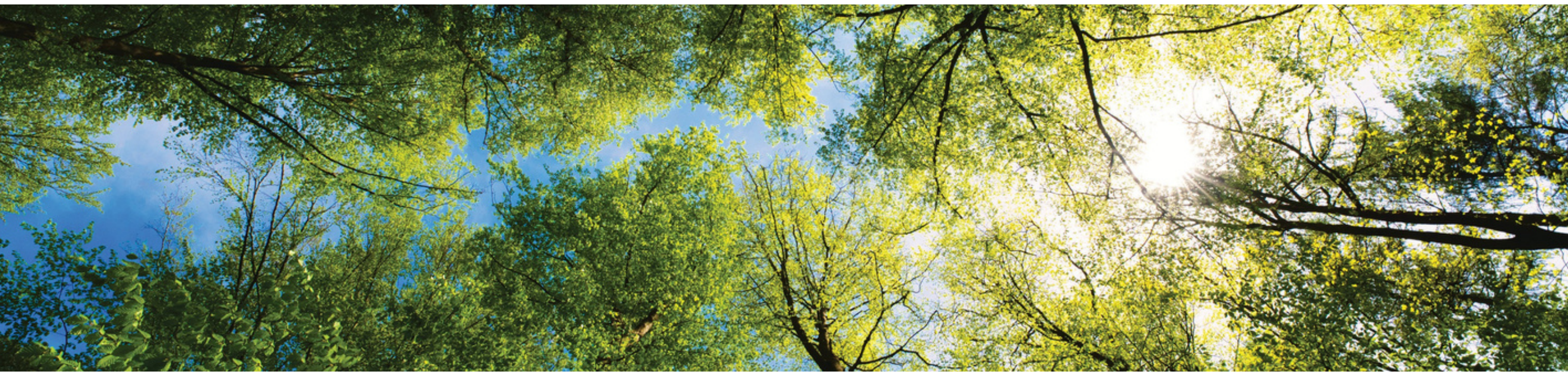
Moderator: Mike Flint, Manager, ScottMadden Management Consultants
Panelists:
Ben Prochazka, Executive Director, Electrification Coalition
Andre Welch, Director of Federal Affairs, Ford Motor Company
Dr. Shelley Francis, Co-Founder & Managing Partner, EVNoire

2:45 p.m. **COFFEE BREAK**

[What is the de-carbonization effect, all-in, of EV penetration?]

3:00 p.m. **STUDENT RESEARCH PRESENTATION: Total Carbon Footprint – Comparing EV, Hybrids and Liquid Fuels**

UNC Kenan-Flagler MBAs:
Parker Bly
Patrick Wheeler
Blessing Ezealigo



3:30 p.m. **PANEL DISCUSSION: What are the Full Life Cycle Impacts of Electric Vehicles on Decarbonization?**

Moderator: Darby Casey, UNC Kenan-Flagler MBA
Panelists:
Andrew Dillon, Innovation Fellow, Energy & Utilities, West Monroe Partners
David Nenon, Manager, EV Battery Supply Chain Strategy and Analytics, Ford Motor Company
Devin Horn, Manager, Battery Public Policy, Panasonic Corporation of North America

4:45 p.m. **SUMMARY**

Stephen Arbogast
Dan Domeracki

5:00 p.m. **ADJOURN**

Vans take speakers and luggage to Rizzo Center

6:30 p.m. **SPEAKERS RECEPTION AT RIZZO CENTER**

ENERGY CLUB, UNC KENAN-FLAGLER ALUMNI RECEPTION, SPONSORED BY WEST MONROE
CAROLINA BREWERY, 460 W. FRANKLIN STREET, CHAPEL HILL

7:30 p.m. **SPEAKERS DINNER AT THE RIZZO CENTER**

FRIDAY, FEBRUARY 24

6:30 a.m. **BREAKFAST at the Rizzo Center**

7:30 a.m. **Vans take speakers and luggage to the Kenan Center**

8:00 a.m. **Coffee and light refreshments**

8:20 a.m. **OPENING COMMENTS**

Dan Domeracki

8:30 a.m. **PANEL DISCUSSION: Bolstering the Critical Minerals Supply Chain**

Moderator: Christine Barchick, Manager, Global Communications & Sustainability, Livent Corporation
Panelists:
Meredith Bandy, Vice President Investor Relations, Albemarle
Danielle Woodring, Manager, Center for Critical Minerals, SAFE
David Nenon, Manager, EV Battery Supply Chain Strategy and Analytics, Ford Motor Company
Jackson Switzer, Senior Director of Business Management & Market Strategy, Redwood Materials
Austin Devaney, EVP & Chief Commercial Officer, Piedmont Lithium

9:45 a.m. **PANEL DISCUSSION: How do the IIJA and Investment Reduction Act Change the EV Landscape? How will State Governments Support Implementation and Other Enabling Policies?**

Moderator: Eliza Henderson, UNC Kenan-Flagler MBA
Panelists:
Leilani Gonzalez, Policy Director, Zero Emissions Transportation Association (ZETA)
Zack Pierce, Policy Advisor, State of NC
Jay Robertson, Manager, West Monroe Partners
Terry Travis, Co-Founder and Director, EVNoire

[Electric Vehicles, Policy, Infrastructure, Utilities, and the Grid]

11:00 a.m. **PANEL DISCUSSION: What are the implications for Electricity Demand and Grid Integrity for a Range of EV Scenarios?**

Moderator: Rae Michos, Manager, West Monroe Partners and UNC Kenan-Flagler MBA
Panelists:
Jay Oliver, Duke Energy
Beia Spiller, Resources for the Future (RFF)
Philip Tucker, Panasonic Corporation North America
Aravind Kailas, Advanced Technology Policy Director, Volvo Group North America

12:15 p.m. **LUNCH**

1:00 p.m. **PANEL DISCUSSION: Making Charging Accessible and Equitable – Who Builds it? Who Maintains it? Who Pays for it?**

Moderator: Brandon Colman, Electrify America
Panelists:
Josh Kmiec, ScottMadden Management Consultants
Jennifer Weiss, Clean Transportation for North Carolina, North Carolina Department of Transportation
Aravind Kailas, Advanced Technology Policy Director, Volvo Group North America

2:15 p.m. **CONFERENCE WRAP-UP / INVITATION TO GET INVOLVED**

Stephen Arbogast
Dan Domeracki

2:30 p.m. **CONFERENCE ADJOURNS**

FEATURED SPEAKERS

STEPHEN ARBOGAST

UNC Kenan-Flagler Energy Center

Stephen Arbogast serves as the Director of UNC Kenan-Flagler Energy Center. He is the author of "Resisting Corporate Corruption: Cases in Practical Ethics from Enron through the Financial Crisis" (Wiley, 2017). His Exxon career spanned 32 years and included assignments as Finance Manager of Esso Brasileira, Treasurer of Exxon Capital Corporation and Finance Director of Esso Standard Thailand. He received a master's degree in public affairs from the Woodrow Wilson School of Public and International Affairs at Princeton University, a BA in government from Cornell University and a master's degree in theological studies from the University of St. Thomas, Houston.

DAN DOMERACKI

UNC Kenan-Flagler Energy Center

Dan Domeracki serves as the Associate Director of UNC Kenan-Flagler Energy Center. He retired from Schlumberger with 41 years of global industry experience. As a member of Schlumberger's corporate team, he was responsible for their government affairs program, managing the non-lobbying, non-political, interactive working relationships with governments in North America, Europe and Asia Pacific. He was also responsible for building Schlumberger Global Stewardship.

TINA JEFFRESS

Panasonic Corporation for North America

Tina Jeffress is a Senior Manager with Panasonic North America's Corporate and Government Affairs team, covering energy and sustainability. A member of the UNC Kenan-Flagler Class of 2018, Tina served as President of the MBA Energy Club and received the Core Value Award for Leadership. Tina holds an MBA from UNC Kenan-Flagler and a BA in International Development from UCLA. Tina also served as Co-Chair for this conference.

ALBERT GORE

Zero Emission Transportation Association (ZETA)

Albert Gore is the Executive Director of the Zero Emission Transportation Association. A veteran in the clean technology space, he spent seven years at Tesla Inc., most recently as the lead for Public Policy and Business Development in the Eastern and Midwestern U.S. Previously, he was the Deputy Director of Policy and Electricity Markets at SolarCity.

JONATHAN G. PRICE, PHD

American Geosciences Institute

Dr. Jonathan G. Price is the Nevada State Geologist Emeritus. He is the President of the American Geosciences Institute and a past President of several geological organizations. Jon was the 2013 recipient of the Gold Medal of the Mining and Metallurgical Society of America.

MIKE FLINT

ScottMadden Management Consultants

Mike Flint is a Manager at ScottMadden where he consults for utilities, independent power producers, and other companies in the electric power business. His work focuses on strategic and business planning, electrification, decarbonization, and grid transformation. He received his MBA from UNC Kenan-Flagler Business School.

BEN PROCHAZKA

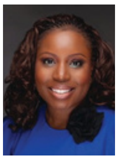
Electrification Coalition

Ben Prochazka is the Executive Director of the Electrification Coalition and has spent a decade accelerating transportation electrification, working on community and corporate engagement programs with EV industry partners, federal/state agencies, and policymakers to promote the actions needed to accelerate transportation electrification across the country.

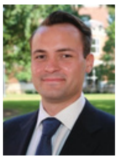
ANDRE WELCH

Ford Motor Company

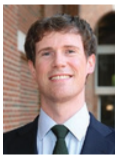
Andre Welch is a Director of Federal Affairs at the Ford Motor Company. In this Washington D.C., based role, he is responsible for advocating Ford's positions on federal legislative and regulatory matters related to the connected, automated and electric vehicle transition.



DR. SHELLEY FRANCIS
EVNoire
Dr. Shelley Francis is Co-Founder and Managing Partner with EVNoire, an award-winning, tech consultancy working on electric, connected, shared and autonomous vehicle solutions. She utilizes her years of expertise to integrate E-Mobility best practices, diversity, equity, inclusion and public health into the transportation sector.

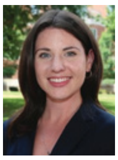


PARKER BLY
UNC Kenan-Flagler MBA
Parker Bly is a member of the MBA Class of 2023 and has a BS in civil engineering from CU Boulder. Before business school, Parker was an engineer at Kiewit, working on power plant construction projects. After graduation, Parker will work at ScottMadden as a consultant.



PATRICK WHEELER
UNC Kenan-Flagler MBA
Pat Wheeler is a member of the MBA Class of 2024, focusing on energy and real estate. Before pursuing his MBA, he worked in consulting for CGI Federal, implementing finance and procurement IT systems for government clients. He plans to pursue a career in energy storage development.

BLESSING EZEALIGO
UNC Kenan-Flagler MBA
Blessing Ezealigo is a first year MBA student. Originally from Nigeria, she has a B.Tech and M.Sc in physics with a PhD in innovation sciences and technologies. She has worked with an energy startup as a project manager and an operation manager.



DARBY CASEY
UNC Kenan-Flagler MBA
Darby Casey is a Class of 2023 MBA student at UNC Kenan-Flagler Business School concentrating in energy and real estate. Prior to business school, she worked for a midstream energy company. Darby earned her BBA from Hofstra University. After graduation, she will return to Duke Energy.

ANDREW DILLON
West Monroe Partners
Andrew Dillon is a leader of transportation electrification services for West Monroe, with 20 years of experience in transportation electrification strategy, EV total cost of ownership tools, fleet advisory programs, EV make ready programs, carbon credit tracking for EV charging and DER integration.

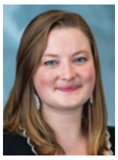
DAVID NENON
Ford Motor Company
David Nenon is the Manager for EV Battery Supply Chain Strategy and Analytics at Ford Motor Company. He received BS degrees in chemistry and environmental science from the University of North Carolina at Chapel Hill and a PhD in chemistry from the University of California Berkeley and began his professional career at Tesla in the battery supply chain group.

CHRISTINE BARCHICK
Livent Corporation
Christine Barchick is Manager, Global Communications & Sustainability at Livent Corporation (NYSE: LTHM), a fully integrated lithium technology company headquartered in Philadelphia, PA. Christine holds a BA from Harvard University and an MBA from UNC Kenan-Flagler Business School.

MEREDITH BANDY

Albermarle

Meredith Bandy serves as Albemarle's Vice President, Investor Relations and Sustainability. She is a Chartered Financial Analyst. She earned an MBA from UNC Kenan-Flagler Business School and a bachelor's degree in business administration from Georgetown University.



DANIELLE WOODRING

SAFE

Danielle Woodring is the Manager of the Ambassador Alfred Hoffman Jr. Center for Critical Minerals Strategy at SAFE. Danielle brings real-world geological and science policy expertise to the Center. After obtaining her Master of Science in structural geology and geological mapping, Danielle worked as a geologist for the Washington Department of Natural Resources, Washington Geological Survey and the U.S. Geological Survey.

DEVIN HORN

Panasonic Corporation of North America

Devin Horn manages Panasonic's battery public policy. He previously served at the U.S. Department of Commerce, where he helped develop the *National Blueprint for Lithium Batteries,* the White House's report on battery supply chains, and led Department-wide efforts to promote U.S. clean tech companies.

JACKSON SWITZER

Redwood Materials

Jackson Switzer is the Senior Director of Business Management and Market Strategy at Redwood Materials. Redwood is a battery materials company creating a closed-loop, domestic supply chain. He oversees commercial activities and growth of Redwood's recycling, anode, and cathode materials businesses.

AUSTIN DEVANEY

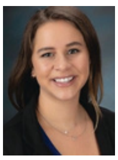
Piedmont Lithium

Austin Devaney serves as Executive Vice President and Chief Commercial Officer. From 2015 to 2019 he served in increasingly senior sales and marketing roles with Albemarle Corporation, the world's #1 lithium producer, ultimately serving as Vice President Strategic Marketing and Customer Excellence. For Albemarle's predecessor, Rockwood Lithium, Mr. Devaney served as Global Product Manager – Lithium Hydroxide, and National Sales Manager – Battery Products.

ELIZA HENDERSON

UNC Kenan-Flagler MBA

Eliza Henderson worked in solar origination, most recently at Cypress Creek Renewables, prior to pursuing her MBA at UNC Kenan-Flagler Business School and Master in Environmental Management at Duke. She interns for storage developer Broad Reach Power and will be joining Piper Sandler's energy investment banking team upon graduating.



LEILANI GONZALEZ

Zero Emissions Transportation Association (ZETA)

Before joining ZETA, Leilani Gonzalez spent several years handling energy and environmental issues within each government jurisdiction. She began her public service career in the Florida State Legislature. Afterward, she continued her environmental policy work in the U.S. House of Representatives and the U.S. Senate.

ZACK PIERCE

Office of Governor Roy Cooper

Zach Pierce is a public policy professional with over 10 years of experience working on climate change, clean energy, and environmental justice issues across the U.S. He currently serves as Governor Roy Cooper's Senior Advisor for Climate Change Policy, responsible for policy development, project management, stakeholder engagement, strategic planning, and other duties to execute the Governor's climate agenda.

JAY ROBERTSON

West Monroe Partners

Jay Robertson is a consultant experienced in developing electric vehicle strategy, programs, and infrastructure for electric utilities. In recent months, he has helped numerous clients unpack IIJA and IRA legislation and pursue funding opportunities that change the energy industry landscape.

TERRY TRAVIS

EVNoire

Terry Travis is the Managing Partner and Co-Founder of EVNoire. He utilizes his expertise to integrate E-Mobility best practices and E-Mobility diversity, equity and inclusion in the transportation sector. His work focuses on electrification with organizations ranging from auto manufacturers, utilities, government agencies, charging network companies, rideshare/delivery network companies, fleets, transit agencies, and other key stakeholders.

RAE MICHOS

West Monroe Partners

Rae Michos is a Manager in West Monroe's Energy & Utilities Practice with 10 years of professional experience in energy, science, engineering and education. She is skilled in providing strategy and solutions for electric and gas distribution, energy generation, organizational change, talent and regulatory affairs.

JAY OLIVER

Duke Energy

Jay Oliver is the Managing Director of Grid Systems Integration at Duke Energy. He leads battery storage development, transportation electrification, grid connectivity strategy, demand side management, and clean energy customer programs. He is a licensed professional engineer.

BEIA SPILLER

Resoures for the Future (RFF)

Dr. Beia Spiller is a fellow and the Director for the Transportation Program at Resources for the Future. She is an energy economist, who focuses much of her work on identifying environmental, economic and community impacts of renewable energy resources, energy policies and vehicle electrification.

PHILIP TUCKER

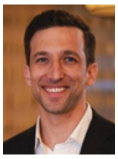
Panasonic Corporation North America

Philip Tucker is a Manager of Business Operations and Strategy with Panasonic's Smart Mobility Office. He is focused on developing new technologies at the nexus of energy and mobility. Prior to joining Panasonic, Philip worked inside utilities developing and managing novel demand management and EV programs.

ARAVIND KAILAS

Volvo Group North America

Dr. Aravind Kailas is the Advanced Technology Policy Director at Volvo Group, where he oversees policy development and public affairs campaigns to further Volvo's interests in automation, connectivity and electromobility. He also manages the Group's engagement in California, and has been pivotal in launching numerous high-visibility initiatives in the state.



BRANDON COLMAN

Electrify America

After receiving his degree from UNC Kenan-Flagler Business School in 2018, Brandon Colman spent four years as an EV Solution Developer at Duke Energy, supporting enterprise strategy and commercial EV charging product development. He joined Electrify America in early 2022, where he seeks to provide public DCFC solutions to utilities across the country.

JOSH KMIEC

ScottMadden Management Consultants

Josh Kmiec is a Director at ScottMadden Management Consultants. His engagement experience includes work in grid transformation, regulatory reform, energy efficiency, and electric vehicles. Prior to working at ScottMadden, Josh served as an intelligence officer in the U.S. Air Force.

JENNIFER WEISS

North Carolina Department of Transportation (NCDOT)

Jennifer Weiss is the Senior Advisor for Climate Change Policy at NCDOT where she coordinates climate-related transportation activities across NCDOT and works closely with the state's experts to help inform North Carolina's climate policies and programs, including the North Carolina Clean Transportation Plan.

The Energy Center at UNC Kenan-Flagler Business School strives to advance sound, conscientious and innovative leadership in the energy space through comprehensive programming for our students.

www.energyatkenanflagler.unc.edu

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