ITS AMERICA

Electrification Options and a Transition to a Sustainable Future

ITS America Sustainability Community of Practice

Issue Brief

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Executive Summary

This paper outlines the shift towards an electrified transportation ecosystem, advocating for a balanced and sustainable approach amidst evolving policy landscapes and technological developments. Authored by the Intelligent Transportation Society of America (ITS America) Sustainability Community of Practice, the paper establishes the rationale for advancing electrification in the U.S. and addresses the challenges and opportunities facing the transition to electrified transportation.

While official U.S. policy may shift over time, ITS America's Sustainability Community of Practice expects that global investment in electric vehicles (EVs) and low or zero-emission transportation is likely to continue to grow in the coming years. China and the EU, representing about 50% of global light-duty vehicle sales in 2024, are likely to continue investing heavily in EV infrastructure while incentivizing suppliers and consumers to go electric or zero emissions.[1] The U.S. represents 18% of global light-duty vehicle sales and many U.S. states are likely to maintain their commitments to zero emission transportation, such as California's Advanced Clean Cars II. Moreover, automotive manufacturers have invested heavily in battery production and an electric vehicle supply chain over the past few years and product plans are unlikely to solely prioritize internal combustion engines going forward.

A key facet of planning for an electrified transportation system includes the necessity of a multifaceted approach incorporating electric, hydrogen, hybrid, and traditional fuel options to accommodate diverse transportation needs while minimizing environmental impact and leaving no one behind. While the focus of this paper is on electrification, it emphasizes that there is no single solution: a successful transition will require a combination of technologies, including electrification, hydrogen, hybrid solutions, and synthetic and biogenic fuels. By embracing all viable options, we can ensure that the transition to a decarbonized transportation system is sustainable, attainable, and beneficial for everyone.

Effective planning must recognize the complex dependencies of this transition on the energy grid and grid readiness, infrastructure capacity, supply chain, consumer preferences, access to charging, and cost concerns. Key considerations include the impacts on the grid and energy prices

[1] https://www.spglobal.com/ratings/en/research/articles/240425-global-auto-sales-forecasts-slower-ev-growth-offers-temporary-relief-to-legacy-automakers-13084917

as well as the pervasive and critical nature of transportation to nearly all aspects of modern life. The challenges of establishing a sustainable supply chain, end-of-life circularity, and responsible energy sourcing are also paramount.

Addressing workforce, spatial, and operational challenges, the document calls for a resilient and adaptable system that encompasses smart charging infrastructure, vehicle connectivity, and advanced telematics for grid integration. By promoting standards and interoperability between intelligent transportation systems (ITS) and EV technologies, the paper also highlights the role of technology and new innovations in the transition.

What is vehicle electrification and the energy transition?

Transportation electrification entails a sustainable shift away from the use of fossil fuels towards motive power provided through electricity in the case of electrons stored and then deployed from batteries for Battery Electric Vehicles (BEVs).

Fossil fuel-powered engines are ubiquitous today and employed in a wide variety of vehicle types and across nearly every region on earth. Electrification will need to be tailored to each of these unique cases. There is not one single method to successfully transition vehicles into an electrified future, meaning we need to embrace and foster diversified and use-case specific approaches and technologies. Emerging technologies that eliminate or reduce tailpipe emissions, among them hydrogen low-carbon fuels and hybrid drivetrains, will be an important part of the transition.

A few key electric transportation terms have been summarized below:

Term	**Definition**
Level 1 Charging	Often called L1 or slow charging; 120v charging that typically take 15-20 hours to fully charge a vehicle
Level 2 Charging	Often called L2 or slow charging; 208v charging that typically takes 5-10 hours to fully charge a vehicle
Level 3 Charging	Often called Direct Current Fast Charging (DCFC) or simply fast charging; 480v charging that typically takes 30-90 minutes to fully charge a vehicle

BEV	Battery Electric Vehicle, a vehicle propelled by an electric drivetrain
PHEV	Plug-in Hybrid Electric Vehicle; a dual-drivetrain electric and internal combustion vehicle with the capability to be charged with an external power source, reducing tailpipe emissions
FCEV	Fuel Cell Electric Vehicles; a vehicle propelled by an electric drivetrain that is powered by a hydrogen fuel cell
HEV	Hybrid Electric Vehicle; a dual-drivetrain electric and internal combustion vehicle without the capability to be charged with an external power source

The electrification of transportation is only one part of the broader energy transition, driven by the global desire to combat pollution and reduce our carbon footprint. Many industries have undertaken efforts to identify and implement more sustainable and lower-carbon sources, including construction, agriculture, manufacturing, and of course, transportation.

Why electrify?

At the societal level, transportation electrification has significant impacts on the most harmful "local" emissions – especially the reduction of small particulate matter (PM), which are the fine particulates ($PM_{2.5}$), and nitrogen oxides (NOx) from greenhouse gas emissions. PMs tend to disproportionately impact communities that often included historically marginalized and vulnerable populations. In fact, reduction of harmful particulate matter is often the greatest motivator today for electrification in areas where air quality is exceedingly poor, such as those areas identified as Nonattainment Areas by Federal and state governments.

There are numerous benefits to owners of electric or low-to-zero emission vehicles, including a reduction in vehicle systems complexity, a reduction in the number of components and failure points, and greater efficiency when compared to fossil fueled powered internal combustion engine (ICE) vehicles. This means that energy usage in the use-phase and maintenance needs can be significantly reduced, leading to operational and economic benefits for both public and private users.[2] Additionally, EVs on the road today have high safety ratings from NHTSA, comparable to

[2] https://advocacy.consumerreports.org/press_release/electric-vehicle-owners-spending-half-as-much-on-maintenance-compared-to-gas-powered-vehicle-owners-finds-new-cr-analysis/

traditional ICE vehicles.[3] In surveys, some have said that EVs are more "fun" to drive than other vehicle types, adding to the draw to purchase one.[4]

The overall cost of vehicle ownership, especially post-purchase, could be improved by driving an EV. When properly developed, electrical distribution capacity and charging networks can enable a vastly streamlined yet more dispersed energy supply chain, improving resiliency in the face of natural hazard exposure. The simple convenience of charging at home, or in the workplace, also can provide time savings and efficiency benefits. Up-front costs for EVs are also coming down, becoming more competitive with conventional ICE vehicles and increasingly attractive for buyers with long-run costs in mind.[5]

However, reports have shown that EVs have greater wear on tires than ICE vehicles due to increased vehicle weights from batteries, a cost and safety aspect that buyers will have to keep in mind when purchasing a vehicle.[6] As consumers consider their choices and associated costs, wear-and-tear of vehicles is a key consideration.

While there are alternatives to electric propulsion systems, BEVs are the most prevalent and mature of the zero-tailpipe-emissions technologies available. For this reason, BEVs are already and will likely remain a critical piece of the effort to decarbonize transportation.

Through various smart-charge management strategies, electric vehicles can provide load flexibility which can help ease pressure on the grid. By taking advantage of EV charging flexibility, load curves can be shaped and shifted to level demand. Vehicle-to-grid (V2G) capabilities and on-site energy storage enhance this ability. Charging hardware can be used to provide voltage and frequency regulation and support distributed systems operation. With V2G capabilities and appropriate microgrids, EVs can provide backup during emergencies increasing local resilience to extreme events. EV stakeholders must balance energy production needs with appropriate transportation offtake, fostering development of economically viable and cost-appropriate production of electrified vehicle systems, batteries, hydrogen and other synthetic fuels.

What are the challenges?

The transition to EVs has and will continue to face challenges. A recent working paper from the Massachusetts Institute of Technology Center of Energy and Environmental Policy Research

[3] https://www.nhtsa.gov/press-releases/nhtsa-2025-vehicles-5-star-safety-ratings-testing
[4] https://www.pewresearch.org/short-reads/2024/06/27/about-3-in-10-americans-would-seriously-consider-buying-an-electric-vehicle/#:~:text=EV%20enthusiasts%20tout%20EVs%27%20faster,about%20equally%20fun%20to%20drive.
[5] https://www.washingtonpost.com/climate-solutions/2024/03/18/electric-vehicle-price-drop/
[6] https://www.cars.com/articles/do-evs-wear-through-tires-more-quickly-than-gasoline-cars-481973/

summarized barriers to electrification across three primary axes: higher upfront costs, insufficient EV charging infrastructure, and range anxiety.[7] These barriers have and will continue to drive consumer sentiments and concerns with electrification, but they bely a more complex set of interrelated challenges facing EV manufacturers, charging developers, and vehicle users.

Progress in addressing these challenges has been made at the same time as new challenges arise. For instance, while the vehicle supply chain challenges of 2020-2022 have waned and the availability of public charging has improved, new challenges have emerged such as slow EV growth rates, high insurance rates, and high depreciation costs (compared to ICE vehicles).[8] The potential rollback of EV tax credits in the U.S. may also slow EV growth in certain consumer segments.[9]

Charging and Electricity: Considering the sustainability benefits of electric vehicles, a *sustainable* electric transition first and foremost requires sustainable electricity. While transportation electrification creates a path to decarbonization, electricity supply needs to decarbonize alongside it for the electrified transportation to truly be sustainable in the long-term. This is acutely challenging because an increase in renewable power, which tends to provide "peaky" (irregular) supply, will need to occur while utilities balance and accommodate growing, irregular EV charging loads. Bloomberg has succinctly summarized the challenges and status of this electric transition in the U.S.(see Figure 1).[10] Figure 2 also discusses the gap between where we are today, and what a net-zero 2050 looks like, and if there is room for a diverse range of energy supply.[11]

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7 https://ceepr.mit.edu/wp-content/uploads/2024/10/MIT-CEEPR-WP-2024-16.pdf
8 https://about.bnef.com/blog/are-global-ev-sales-really-slowing-down/
https://www.consumerreports.org/money/car-insurance/electric-vehicles-cost-more-to-insure-than-gasoline-powered-a6372607024/
https://www.wired.com/story/evs-are-losing-up-to-50-percent-of-their-value-in-one-year/
9 https://www.reuters.com/business/autos-transportation/trumps-transition-team-aims-kill-biden-ev-tax-credit-2024-11-14/
10 https://about.bnef.com/new-energy-outlook-series/%23download
11 Slide 108, by Tara Narayanan BloombergNEF: https://assets.bbhub.io/professional/sites/24/BNEF-Global-Energy-Industry-Event-Presentation.pdf

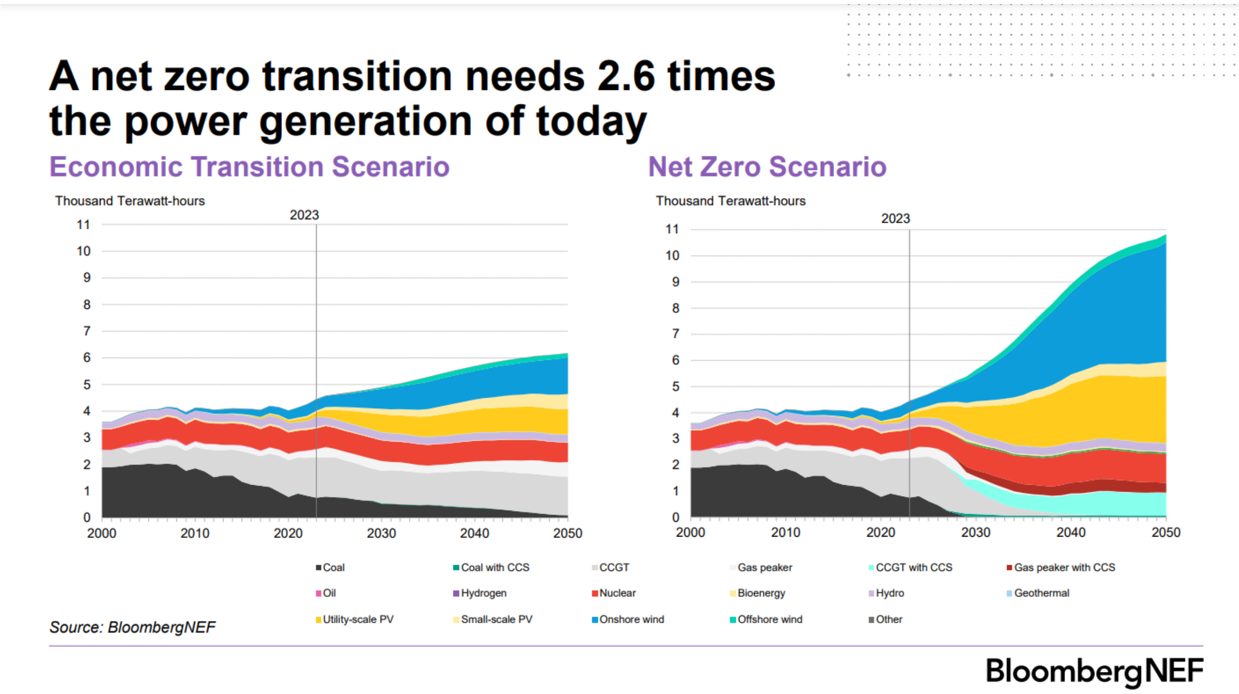

Figure 1

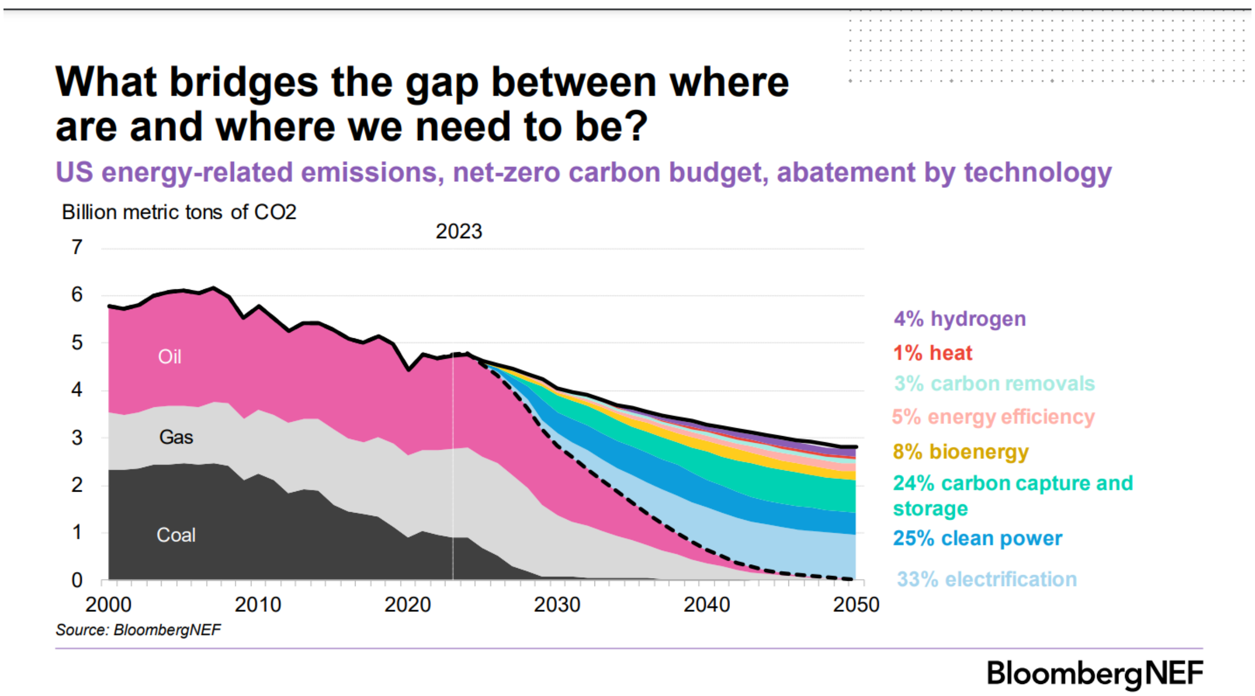

Figure 2

Aside from a supply of sustainable electricity, the U.S. will need a large supply of EV chargers to support the vehicles. According to the National Renewable Energy Lab (NREL), the U.S. will need an estimated 28 million ports by 2030 to support 33 million EVs on the road.[12] Adding chargers in the places that need it most – at airports, along motorways, and near public amenities – will require significant land availability and electrical capacity. Utility upgrades needed to power the chargers can take months or even years to complete. There is also a need for more qualified workers to deploy and maintain EV charging infrastructure. Federal, state, and local laws and regulations require certified electricians to do initial installation and have other certification requirements for service and maintenance.

Raw Materials and Production: Achieving a net-zero emissions goal for transportation will necessitate a substantial increase in mineral extraction to support EV production. Estimates indicate that by 2035, at least 384 new mines for graphite, lithium, nickel, and cobalt will be required to meet battery demand.[13] Looking further ahead, projections suggest that over 700 new critical mineral mines will need to be developed by 2050 to support the mass production of batteries essential for decarbonization.[14] These figures underscore the significant expansion needed in the critical mineral sector to facilitate the transition to an electrified transportation system.

Additional challenges arise from the need to develop completely new supply chains for EVs and EV components. Manufacturing capacity for batteries and other components of an EV drivetrain need to be significantly increased to meet stated climate goals. The U.S. Department of Energy has awarded over $3 billion in funding for more than 25 battery projects across 14 states to enhance domestic battery manufacturing and processing capabilities, but many of these battery factories are still in early planning phases.[15] In Europe, companies have faced operational reductions and job cuts due to order delays and market competition, highlighting the difficulties in scaling battery production.[16]

Electric vs. Internal Combustion: The infrastructure and supply chain required for electrification are not a one-to-one swap for internal combustion engines and neither are the

[12] https://www.energy.gov/eere/vehicles/articles/fotw-1334-march-18-2024-2030-us-will-need-28-million-ev-charging-ports#:~:text=National%20Renewable%20Energy%20Laboratory%20estimates,be%20needed%20to%20support%20them.

[13] https://source.benchmarkminerals.com/article/more-than-300-new-mines-required-to-meet-battery-demand-by-2035?utm_source=chatgpt.com

[14] Jackson, L., Meinke, C. & Chandramohan, R. Challenges in the Battery Raw Materials Supply Chain: Achieving Decarbonisation from a Mineral Extraction Perspective. *Mining, Metallurgy & Exploration*, 2683–2692 (2024).

[15] https://www.theverge.com/2024/9/20/24249856/battery-ev-renewable-energy-doe-funding?utm_source=chatgpt.com

[16] https://www.reuters.com/sustainability/struggling-northvolt-stokes-fear-europes-battery-future-2024-09-13/?utm_source=chatgpt.com

vehicles. Electrification will require us to adapt to the functional differences between ICE vehicles and EVs. Many of the challenges associated with transitioning to EVs are driven by three significant differences between EVs and ICEs:

1. **EV battery fires burn longer and are harder to extinguish than ICE fires.** EV battery fires are typically caused by a process called thermal runaway.[17] While EV battery fires are more difficult to extinguish than ICE fires, they are also much less likely. According to an analysis of NTSB data, only 25 out of 100,000 EVs catch fire, compared to 3,475 per 100,000 for hybrids and 1,530 per 100,000 for traditional ICE vehicles, respectively.[18] While much rarer, EV battery fires burn hotter than traditional ICEs and are harder to extinguish. This will require training for first responders and new procedures to address fire risks.

2. **EVs have a longer refueling cycle than ICE vehicles.** These longer charging cycles require operational changes for fleet operators and behavior changes by private vehicle owners. Because electric energy prices fluctuate throughout the day (unlike petroleum or diesel), EV owners also need to maximize off-peak charging when energy is cheaper. Together, these differences require new approaches to fueling. For private vehicles at single family homes, this change may be as simple as plugging-in a car every night. For fleets with high daily duty cycles, charging operations may be more complex.

3. **EVs tend to be heavier than ICEs.** This weight difference is largely driven by the weight of today's batteries. This increased weight, along with the fact that EVs do not contribute to the largest funding source for the Highway Trust Fund (gas taxes) may lead to increased road wear while road maintenance funding decreases if a new funding stream is not identified. This additional weight also poses risks to roadway safety barriers and pedestrians during crashes.

The combination of the longer refueling cycle and heavier weight means that BEVs may not be the best low-carbon option for all applications. These two issues are interrelated: to combat range anxiety rooted in EVs' long refueling cycle, many automakers have sought to maximize vehicle range with large, heavy batteries. Vehicle ranges tend to increase along with battery size to a point, until increased vehicle weight begins to outweigh increased energy capacity. This means the weight of current battery technology limits the feasibility of certain applications, especially large vehicles that cover large daily distances (i.e., long-haul trucking, inter-city buses). These

17 https://www.evfiresafe.com/ev-fire-what-is-thermal-runaway
18 https://www.kbb.com/car-news/study-electric-vehicles-involved-in-fewest-car-fires/

sorts of vehicles may be converted to zero emissions in the future through hydrogen fuel cells or through battery technology advancements such as solid-state batteries.[19]

Finally, EVs and EV charging are fundamentally different technologies requiring a whole new workforce to develop around the maintenance of the vehicles and the installation and maintenance of the infrastructure. This process will take time and will have a learning curve as the workforce prepares for a more electrified future.

What does success look like for a transition to a sustainable electrified system?

To achieve sustainability goals, a transition to an electrified transportation system must be a part of a larger societal decarbonization effort. Success in this aspect means creating a system where the average person feels secure in their access to reliable and sustainable energy, similar to the confidence we have in the availability of gas for cars. In a successful transition, EVs have the potential to support individuals' energy security, offering V2G technologies that that can provide energy resilience to homes or the electric grid when power supply is insufficient.

Much like water, energy and transportation are human necessities in the 21st century. A sustainable electric transition must be a shared transition. Equitable access to charging and affordable electric vehicles are key to sharing the benefits of electrification with all members of society.

Electricity production must be decarbonized at the same time our energy grid faces numerous challenges, including peaky EV charging loads, peaky renewable energy supply, and significant electric load growth, as industrial and construction sectors electrify alongside transportation. Success in this regard will require solutions like grid-scale battery energy storage systems (BESS), microgrids and distributed energy generation. A carbon-free electric system may require a carbon-free baseload of energy generation, potentially nuclear.

In addition to a sustainable energy system, a successful transition to electric mobility will require a multi-pronged approach to charging infrastructure that is reliable and readily available. Charging may not look like the current gas station model, though public fast charging may in some cases be installed in "EV hubs" with convenience stores, similar to present-day gas stations. At the same time, much of the public fast charging installed to date has been in parking lots already constructed for amenities more suited to a 30-minute charge session than a convenience store (i.e., malls and grocery stores). Public fast charging is not and will not be the only charging option. Fast charging in general puts strain on the electric grid and may degrade batteries faster than slow charging. For this reason, most charging will take place overnight with slow chargers, taking

[19] https://itsa.org/advocacy-material/hydrogen-in-transportation-issue-brief/

advantage of vehicle downtime coincident with cheaper off-peak electricity. Charging solutions for those without access to at-home or fleet-depot charging will require particular attention, requiring solutions like curbside charging and urban DC fast charging hubs.

A new supply chain will need to develop around electric vehicles, particularly batteries. Given that there are human rights and environmental concerns with EV batteries, the EU has established a law mandating "Battery Passports" in 2027, which list an EV battery's components and supply chain, in an effort to bring transparency to the battery supply chain.[20] Manufacturers including Volvo and Toyota have already established so-called traceability initiatives to make clear their battery components.[21]

Along with increased transparency and efforts to establish battery chemistries that limit rare earth mineral extraction, battery recycling and broader circularity is key. Significant progress is being made, but mass- market penetration remains to be seen. Battery minerals are being recycled by companies that are developing technologies to extract and refine critical minerals from electronic waste, and other companies are focusing on reclaiming and recycling used EV batteries.[22] Second-life battery applications, in which full EV battery cells are refurbished and put to a new use such as grid-scale Battery Energy Storage Systems (BESS), are also growing.[23]

Advancements in vehicle technology will also be necessary to address the vehicle challenges identified in the previous section, namely refueling cycle, weight, and fire risk. In terms of the potential to significantly diminish all three of these primary challenges, solid-state battery technology arguably holds the greatest potential. Unlike today's vehicle batteries, which have a liquid or gel between the positive anode and the negative cathode, solid-state batteries have a solid electrolyte. While solid-state batteries have been in use for years in small electronics (e.g., pacemakers, wearables) progress on solid-state applications in EVs has lagged. Despite this, progress continues to be made. Toyota has announced solid-state batteries across their production line in 2026.[24]Honda has indicated solid-state batteries will enter their lineup in "the second half" of the 2020s, and Stellantis has announced "demonstration" solid-state battery vehicles in 2026. If solid-state batteries do reach the mass-market, EVs will benefit from higher

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[20] https://www.autocar.co.uk/car-news/electric-cars/battery-passports?utm_source=chatgpt.com
[21] https://www.wsj.com/articles/volvo-says-users-can-track-source-of-battery-metals-in-its-evs-54f6e4f7?utm_source=chatgpt.com
https://dbp.toyota-europe.com/?utm_source=chatgpt.com
[22] https://time.com/7172584/jb-straubel-2/?utm_source=chatgpt.com
[23] https://www.businessinsider.com/hot-companies-racing-reuse-refurbishment-electric-vehicle-batteries-2022-8
[24] https://electrek.co/2024/09/09/toyotas-all-solid-state-ev-battery-plans-get-green-light-japan/
https://electrek.co/2024/11/20/honda-teases-all-solid-state-ev-batteries-new-demo-line/
https://www.stellantis.com/en/news/press-releases/2024/october/stellantis-and-factorial-take-next-step-to-accelerate-the-future-of-electric-vehicles-with-solid-state-battery-technology

energy density (and corresponding lower weight), faster charging speeds, and significantly lower fire risk.

Of course, the future is unknown and still being shaped. A sustainable electric transportation future is possible, but it will not occur overnight. The transition will require constant re-evaluation and new strategies as the known and unknown implications bear out.

How can ITS advance the transition to electrified systems?

The convergence of ITS and transportation electrification presents numerous opportunities for enhancing the efficiency, resiliency, and safety of modern transportation systems.

An electric transportation system requires a level of connectivity in order to be truly successful. Chargers require integration with the electric grid and with vehicle systems in a manner that fuel tanks and pumps do not. These communications systems between vehicles, chargers, and the grid are amongst the most fragile components of present-day EV fueling, with communications failures being far and away the most common cause of charger downtime.[25] Cybersecurity, likewise, remains a key concern for the resilience of charger networks and the transportation system as a whole.

ITS practitioners not only bring experience with designing and deploying transportation communications networks that will help address communications failures, but they will also be crucial in integrating charger systems with the larger transportation systems as the market matures. In Portugal and Spain, for instance, the Via Verde app used to process and pay tolls, has been expanded by ITS professionals to allow users to locate, reserve and initiate charging sessions at any of the nation's publicly accessible chargers.[26] With charging reliability and accessibility being a core issue in the U.S., ITS can help create a more reliable, connected EV charging ecosystem with consistent communication among infrastructure owner-operators, technology providers, and drivers themselves.

Beyond the chargers, EVs on the market today tend to be more connected, intelligent, and autonomous than their internal combustion counterparts. EVs are just one piece of the more intelligent transportation modes on the road today, including connected and autonomous vehicles (CAV) and vehicle-to-everything (V2X) communications. ITS practitioners will remain at the

[25] https://www.smartcitiesdive.com/spons/investigating-the-uptime-challenges-facing-charge-point-operators/715562/

[26] https://www.a-to-be.com/wp-content/uploads/2022/05/White-Paper_-EV-Charging.pdf

forefront of connected transportation systems, integrating new drivetrains into these systems as they develop.

Most importantly, ITS practitioners design and define the way that our transportation system operates. As electrification progresses, ITS practitioners will need to understand and adapt to the ways that vehicular transportation will change. Driving patterns, along with fueling patterns, may change. Vehicle weights will likely increase as battery weights increase. Safety systems will need to address increased fire risks. ITS practitioners have and will continue to play a role in addressing these challenges.

Conclusion

As discussed in this paper, the transition to an electrified transportation system will bring both opportunities and challenges. If the U.S. is to meet net-zero emission goals, a full suite of electrified or partially electrified transportation options is needed to help ease the transition, gain consumer acceptance, and allow for the integration of full BEVs into the market.

Despite the benefits of reduced tailpipe emissions, significant challenges remain. Supply chains, energy production, grid readiness, consumer acceptance, vehicle costs, and the charging infrastructure buildout still have challenges that need to be worked out by practitioners across both the public and private sector. Across many of these challenges and through this period of change, ITS professionals have the opportunity to help our communities adapt and transition toward a more resilient future. By contributing to the electric and sustainable future of America’s transportation system, we can help ensure that the future of our roads and vehicles is safe, efficient, and resilient for years to come.

This paper was authored by the ITS America Sustainability Community of Practice members.