Electric School Buses and the Grid

Unlocking the power of school transportation to build resilience and a clean energy future

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JAMES HORROX AND SARAH NICK, FRONTIER GROUP

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Executive summary

SCHOOL BUSES are the largest form of public transportation in the United States. Every day, 480,000 of them carry up to half of America's children to school and back.[1]

Currently, fewer than 1% of the nation's school buses are powered by electricity, but with advances in electric bus technology, growing understanding of the benefits of electrification, and now a fresh influx of federal money through the Infrastructure Investment and Jobs Act, electric school buses are becoming an increasingly viable option for school districts.[2] Electric school bus models are now available to meet every use case, and the number of districts that have committed to electric school bus adoption, or have drawn up plans to do so, is growing.

Transitioning to electric school buses would provide numerous benefits to communities and the environment, including improving children's health and reducing air and noise pollution, as well as reducing the disproportionate burden that this pollution places on underserved communities.[3]

Electric school buses have the potential to bring even greater benefits if they are equipped with technology that allows them to deliver power to buildings and back to the grid.

Vehicle-to-grid (V2G) technology enables electric school buses to provide stability, capacity and emergency power to the grid when needed, and potentially to earn revenue for school districts for providing these and other services. **Policy-makers, utilities, school districts and transport operators should work to unlock these benefits through creative public policies and partnerships.**

The unique characteristics of school buses make them ideally suited to serve as a source of energy storage and emergency power. Their use patterns allow them to be available as a source of large volumes of energy storage, especially at the times when the grid is most vulnerable.[4] **If every yellow school bus currently in operation across the United States were replaced with a V2G-capable electric bus of the same type, this would add over 60 gigawatt-hours (GWh) to the country's capacity to store electricity**.

V2G technology can deliver benefits for vehicle owners, utility ratepayers and communities.

Electric school buses with V2G technology can reduce greenhouse gas emissions from both the transportation and power generation sectors – the two sectors of the U.S. economy that contribute most to global warming.[5]

- Replacing all of the country's diesel-powered school buses with electric models would in itself contribute to a sizable reduction in greenhouse emissions, avoiding roughly 8 million metric tons of emissions per year.[6]
- A 2016 study found that the use of V2G in electric school buses could eliminate an average of more than 1,000 metric tons of CO_2-equivalent greenhouse gas emissions over the lifetime of the bus.[7] The same

study found that the use of V2G eliminates enough pollution to completely offset the air pollution damage caused by charging electric school buses from the grid.[8]

- A Columbia University study calculated that a fleet of 1,550 electric school buses providing peak shaving services – managing overall energy demand to eliminate short-term consumption spikes – could reduce CO_2 emissions by 5,500 tons over five years and produce a decrease in electricity-related local air pollution.[9]

- By enabling utilities to draw on distributed sources of energy, large-scale adoption of V2G technology could potentially also lessen the need for new physical power plants, bringing savings for utilities as well as environmental and health benefits – particularly for minority and low-income areas, since peaker power plants are often located in these areas.[10]

The battery storage provided by electric buses could speed the transition to a renewable energy grid, since batteries can absorb renewable energy when it is available in abundance and release it during periods when it isn't, such as at night (in the case of solar).[11]

- A 2017 study calculated that if a significant share of the light-duty motor vehicles currently registered in the territory covered by the PJM Interconnection – the largest power grid operator in the U.S. – were electric and V2G-capable, this could increase renewable energy development by 51 GW.[12] Similar benefits are anticipated with electric school buses.

- A California study found that a mix of V1G (or 'smart charging' – unidirectional controlled charging where EVs or chargers modify their charging rate according to signals from the grid operator) and V2G-equipped EVs can enable "substantial" mitigation of "ramping" (sudden and potentially disruptive changes in power production – a particular issue with solar) equivalent to avoiding construction of 35 600-MW natural gas plants for that purpose.[13]

Energy stored in school bus batteries can also support a range of services to improve the functioning of the grid. These include:

- **Demand response/peak shaving:** V2G allows a vehicle to discharge energy back to the grid as demand peaks, lessening the need for utilities to invest in or buy power from dirty and expensive "peaker" power plants that run on fossil fuels.
    - A 2020 study found that a mix of V2G and G2V (grid-to-vehicle) can reduce the difference between minimum and maximum daily net load enough to lessen utility companies' need for costly capacity expansion and help maintain electricity price stability.[14]

- **Energy arbitrage:** By purchasing and storing energy when demand and cost are low and redistributing it when demand is high, energy arbitrage could enable owners of distributed storage provided by V2G EV fleets to bid on energy markets alongside operators of peaker plants, thus providing storage owners with a source of revenue.[15]
    - A 2019 study assessing the economic viability of inserting V2G systems into energy spot markets for the purpose of energy arbitrage found that, based on the markets in 2019 in Germany, revenues could range from €200 to €1,300 ($235 to $1500) per EV per year.[16]

In addition to V2G capabilities, when equipped with the right technology, electric school buses can bring further benefits, for example providing backup power to support emergency management efforts and critical infrastructure during power outages.[17]

A fleet of V2G-enabled electric school buses could become an important temporary power source during outages – essentially becoming a fleet of mobile batteries that can be deployed at short notice to provide emergency power to homes, businesses, hospitals and shelters.[18]

With the right incentives and effective collaboration between school districts and utilities, electric school buses can be a cost-efficient alternative to their diesel counterparts, producing major savings in lower operating costs from reduced spending on maintenance and fuel, while also providing greater predictability in costs due to the relative stability of electricity prices compared to fossil fuel prices.[19]

When these vehicles are equipped with V2G, the financial benefits can be higher still. **Provided the right mechanisms are put in place, including appropriate rates and tariffs, V2G school buses can potentially benefit school districts by providing services to the grid for which school districts may be compensated in various ways by utilities and system operators.**[20]

- Modelling of a V2G peak shaving program using a fleet of school buses in California found that the savings created outweighed the costs the program incurred, making it beneficial for both utilities and schools.[21]

Replacing every yellow school bus currently in operation across the United States with a V2G-capable electric bus of the same type would create a total of 61.5 GWh of extra stored energy capacity – enough to power more than 200,000 average American homes for a week – and 6.28 gigawatts

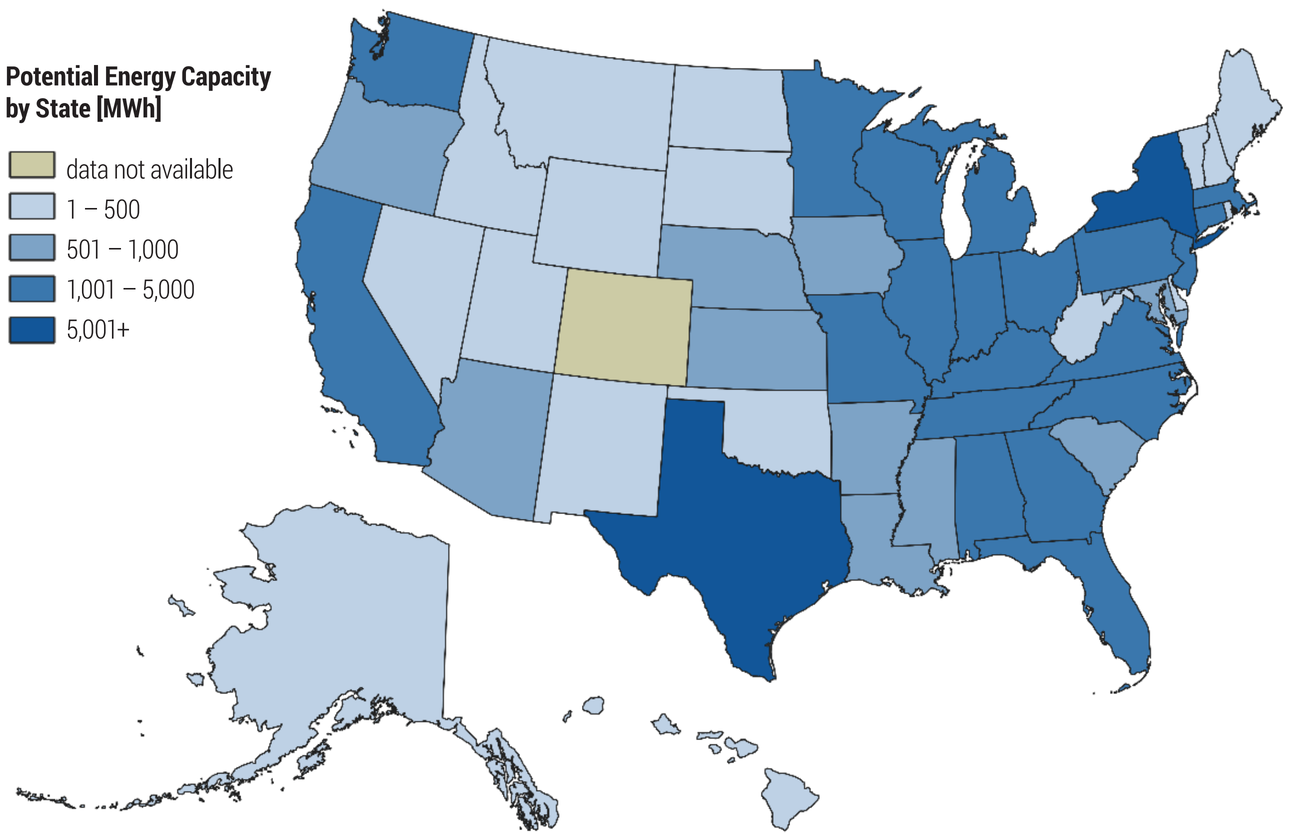

Figure ES-1. Potential electricity storage capacity of school bus fleets by state if states' existing fleets were replaced with electric buses.

(GW) of instantaneous power, providing power output equivalent to over 1.2 million typical residential solar roof installations or 16 average coal power generators.[22]

Electric buses could also provide valuable backup power during emergencies:

- The energy stored in a single Type D bus could power the equivalent of five operating rooms for more than eight hours, and a single operating room for 43 hours.[23]
- Electric school buses could also provide backup power in remote areas that need electricity during outages.

V2G technology is still in its infancy, and while it potentially opens up a range of opportunities for schools, utilities and communities, there are still a number of barriers that will need to be overcome before those opportunities can be fully accessed.

Realizing the full potential of V2G school buses will require collaboration between school districts, utilities, vendors and other entities, and revising public policies to ensure that investments in electric school buses and V2G make financial sense for school districts and utilities.

To help make this happen, the federal government should:

- **Invest in electric school buses.** The Infrastructure Investment and Jobs Act passed in November 2021 allocates $2.5 billion for new electric school bus purchases and a further $2.5 billion for alternative fuel buses – including electric ones.[24] Maximizing the benefits V2G school buses are able to deliver will require large numbers of buses, which will necessitate further, sustained federal investment over the coming years, with funding particularly targeted at under-resourced school districts.
- **Develop tools and educational materials to enable school districts to better understand the costs and benefits of electric buses and V2G** and thus be able to include V2G benefits in any calculations of return on investment of electric school buses.
- **Provide funding for V2G pilot programs** to enable a fuller understanding of the challenges of V2G and the costs and benefits it can bring to school districts, utilities and other stakeholders, as well as to develop best practices to enable all stakeholders to get the most out of this technology. Funding should be allocated to a diversity of districts, including those serving underserved populations.
- **Support research to develop and standardize hardware, software, regulations and practices** needed for electric school buses to integrate with the grid and participate in energy markets, as well as to determine the value of V2G and the potential benefits it can produce.[25]
- **Increase funding for research on potential business models for public-private partnerships to help school districts with the upfront costs of electric school bus adoption**, including identification of federal, state and local policies that may create barriers or incentives to such models, and develop resources to inform state and school district decision-making.

States should:

- **Develop policies to unlock the various value streams V2G can provide.** Such policies might include exempting bus owners from regulation as public utilities and experimenting with feed-in-tariff (FIT) programs and other forms of compensation that may provide a simple, appealing way of compensating school districts for the V2G services they provide.

- **Provide grant/voucher programs and subsidies for school districts to go electric.** This will ensure school districts and the communities they serve will experience the cleaner air, reduced greenhouse gas emissions and other benefits of electric buses without additional financial burdens.[26] The process of applying for funding should be streamlined to minimize administrative burdens on school districts and ensure that school districts do not have to cover upfront costs for application or the procurement of buses.[27]

- **Prioritize funding for underserved communities.** Communities that suffer the most from the environmental and public health impacts of diesel school buses are often those with the fewest resources available to invest in transitioning to electric ones. Under-resourced school districts, including majority-minority schools and those serving low-income communities and communities facing disproportionate air pollution, should be given priority in the allocation of funds so as to ensure that those with the most to gain from clean transportation have the resources necessary to cover vehicle purchases, infrastructure and operating costs, and the provision of job training programs to address the concerns of mechanics and maintenance staff.

- **Develop a roadmap to enable regulators to support the development of V2G** and facilitate the creation of regulations and policies to minimize the risks for utilities and school districts. This would pave the way for standardization and interoperability of V2G infrastructure, encourage coordination between key stakeholders, and provide greater clarity on regulatory and policy frameworks so as to give utilities the necessary support for getting V2G initiatives approved and implemented.[28]

Regulators and utilities should:

- **Clarify the regulatory status of V2G operations and virtual power plants to allow them access to energy markets.** State public utility commissions should develop a coherent regulatory framework for V2G and ensure that electric vehicles with bidirectional flow are not subject to the same laws and regulations as public utilities.

- **Provide funding for V2G pilot programs**. Utilities should provide financial assistance to enable school districts to participate in V2G pilot programs. This should include assistance covering the upfront cost of buses, as well as charging infrastructure and technical and operational support, and incentives for early adoption, particularly to ensure that under-resourced districts have the opportunity to participate in well-supported V2G pilot programs.

- **Encourage the creation of financing programs** whereby utilities front the initial investment for electric school buses and allow school districts to pay back on utility bills as they save on fuel and maintenance costs. Such programs can help school districts overcome the higher upfront costs of electric buses and deliver monetary savings immediately, opening the door to participation for a wider variety of school districts, including districts with fewer resources.

- **Restructure electricity rates so as to provide discounted off-peak charging**, limit or eliminate demand charges for EV and electric school bus charging, and experiment with policies and practices that allow buses to be used for energy storage and employ vehicle-to-grid technology. Such policies might include premium tariff rates for V2G power similar to current feed-in-tariff programs for renewable energy.[29]

- **Work to establish dialogue and collaborative partnerships with school districts and public officials** in planning and implementing a transition to electric bus fleets which is beneficial to all parties involved, for example including the development of rates for electricity specific to electric school buses.

School districts should:

- **Commit to a full transition to electric buses on a specific timeline.** These commitments will help grow the market, drive technological innovation, and enable school districts to reap the benefits of economies of scale in infrastructure, operational experience, and electricity pricing.
- **Invest in as large a fleet as possible as soon as possible.** Districts should also ensure the availability of additional electrical capacity and build the infrastructure to be able to add more chargers. The larger the fleet, the greater its ability to participate in EV-specific programs.
- **Establish solid collaborative partnerships with utilities from an early stage** and open a dialogue about goals and interests from the outset. School districts should work with public officials and local utilities to enact a transportation rate for electricity and use rate modeling in the planning process for launching electric bus service.

Introduction

IN 1892, A SCHOOL DISTRICT in Ohio commissioned Indiana-based vehicle manufacturer Wayne Works to build a wagon specifically designed for student transportation. Horse-drawn buggies, known as "kid hacks," were already carrying children to and from school in parts of the country, but with Wayne Works' "School Car," as it was known, a vehicle purpose-built for the task began to take shape.[30] In 1910, the company rebuilt the School Car on the chassis of an automobile, strapped an engine to it and launched its first motorized version of the vehicle. In the years that followed, other auto manufacturers keen to get in on the burgeoning school transportation sector began adapting the bodies of kid hacks and school cars to truck frames, adding new features like steel sides and glass windows to create a vehicle akin to what we would now recognize as a school bus. In 1939, the first national conference on school transportation decided on a color scheme, and an American icon was born.

Today, 480,000 school buses carry more than 25 million American children to school every day.[31] But just as the motorized school car replaced the kid hack in the early years of the 20th century, today, a new iteration of this most quintessentially American of vehicles has arrived on the nation's streets: the battery-powered, zero-emission electric school bus.

The electric school bus, like the kid hack and the school car before it, is a creation of its time. When the first motorized school cars came into being it was against the backdrop of an auto industry on the rise and a growing cultural infatuation with, and reliance on, the internal combustion engine – as well as a general lack of understanding of the health and environmental impacts of fossil fuel-powered vehicles. The job those vehicles was designed to do was simple: get children to school and back, safely and efficiently.

A century later, electric school buses (ESBs) have proven themselves capable of doing that same simple but critically important job, and in a way that addresses the priorities and challenges of a 21st century transportation system. Because ESBs produce no tailpipe emissions, they don't emit the air pollutants or greenhouse gas emissions of their diesel counterparts.[32] Since the energy that powers ESBs will increasingly come from renewable sources, greenhouse gas emissions from electricity generation are expected to continually reduce as well. Since ESBs rely on highly efficient electric motors rather than the less efficient complex mechanics of the internal combustion engine, they are cheaper and easier to maintain, bringing substantial savings in maintenance and fuel costs.[33]

But there's another thing that sets these vehicles apart from their predecessors.

A conventional school bus has one main use: it carries children to and from school. For the rest of the day, and throughout school holidays – aside from occasional field trips and summer camps – it sits in a depot doing nothing. In other words, for the vast majority of the calendar year, a diesel school bus delivers no return on investment for the school district that operates it.[34] Electric buses, by contrast, have the potential to provide an array of value streams that can benefit the school districts that own and operate them, and the communities they serve.

The key to unlocking these benefits lies in the fact that as well as drawing power from the grid, electric vehicles can also deliver power *back* to the grid. Equipping school buses with vehicle-to-grid (V2G) technology can bring in revenue for schools and can pay dividends for the grid, providing stability, extra capacity and emergency power when needed, as well as a range of other so-called "grid services" that will become ever more critical as the nation transitions to renewable energy.

The potential environmental, health and financial benefits of electric school buses have already been established both in theory and practice, and school districts that have added them to their fleets have often found that they provide a reliable and cost-effective alternative to their fossil fuel forebears. A growing body of recent research and experience in on-the-ground demonstration and pilot projects indicate that V2G technology may be able to unlock even more benefits. V2G, however, is still very much in its early days. There is much yet to learn, and a great deal more to be done in the way of research and development, as well as real-world deployment of this technology. Smart and bold policy action now can accelerate progress toward unlocking the full potential of electric school buses – and bring the next revolution in school transportation a little bit closer.

Why electric school buses and vehicle-to-grid technologies?

What is V2G, why is it important and why are school buses well-suited to support it?

ELECTRIC SCHOOL BUSES protect the health and safety of children and cut the air pollution and carbon emissions produced by diesel-powered school buses. With vehicle-to-grid (V2G) technologies, the batteries of those buses can also be used to store electricity to support the grid and, in their vehicle-to-building (V2B) applications, provide backup power to buildings and critical facilities during emergencies.

Energy storage is a critical piece of America's future electric grid

Since the U.S. electricity grid was built – much of it more than half a century ago – the way we produce, distribute and use energy has changed dramatically, with new developments bringing new challenges and placing new strains on the grid.[35]

ENERGY STORAGE SUPPORTS THE TRANSITION TO CLEAN ENERGY

The last decade has seen dramatic growth in clean energy that is good for consumers and necessary for the nation's efforts to fight climate change.[36] Wind and solar power, however, differ from the big, centralized power plants for which America's existing power grid was built. Solar and wind power generators only produce power intermittently, and not always at times that coincide with periods of highest demand (solar panels don't generate electricity at night, for example). In order to maintain the proper functioning of the grid, utilities and grid operators have to balance the supply of power with demand for electricity at every second of every day – a task that becomes more complex when it's not just the *demand* for power that's variable, but also its supply.[37]

Energy storage – including in vehicle batteries – is a critical tool that allows utilities to absorb and store renewable energy when it is available in large quantities and deliver it during periods when the renewable resources are not as abundant or available.

Energy storage can deliver other benefits to the grid as well. By injecting power into the grid at the times of greatest demand, energy storage can also reduce the need to tap more expensive generation sources – often powered by fossil fuels – to meet peak demand.[38] Expanding the availability of small-scale battery storage in our communities can reduce the need for new stationary grid storage that brings substantial financial costs for utility companies.[39]

ENERGY STORAGE ENHANCES COMMUNITY RESILIENCE

Energy storage can also help to make the grid and our communities more resilient, enabling the grid to absorb shocks so as to prevent disruptions, manage disruptions as they unfold, and return quickly to normal operation, thus mitigating the scale, length and impact of power outages on communities.[40] Many of the same events that have highlighted the importance of grid resilience over recent years have also underlined the need for back-up power storage. Extreme weather events such as Hurricane Katrina, Hurricane Ida, Hurricane Sandy, Hurricane Sally and the Texas cold snap of 2021 have exposed the vulnerabilities of current emergency power systems to provide backup power in cases of large-scale grid disruption, the consequences of which can be particularly serious for hospitals, nursing homes and other healthcare facilities.

The current emergency power supply systems that provide standby power to these kinds of facilities are known to be susceptible to design, capacity and maintenance issues, and few facilities are able to keep all of their systems running using power from emergency standby generators alone.[41] In addition, many facilities have insufficient generator capacity to provide for their usual power demand in full in the event that one generator fails or is otherwise out of action – and not all have a backup energy source at all, and in emergency situations, the absence of reliable backup power means they often have to scale back their operations or close altogether.[42] Often these vulnerabilities have a disproportionate impact on the very people most likely to be in need of such services. A recent survey of community health centers in California found that only 44% of such facilities had backup generators, and even in those that did, these generators were unable to provide sufficient power to operate all their systems.[43] Seven million Californians, many of them in rural and low-income urban areas, are dependent on nonprofit community health centers for their primary health care.[44]

The consequences of these shortcomings can be severe. After Hurricane Katrina, for example, power outages and inadequate emergency backup power led to the deaths of a number of patients at Memorial Medical Center in New Orleans.[45] During Hurricane Irene, Johnson Memorial Medical Center in Stafford, CT, had to be evacuated when its backup generator failed, and during Hurricane Sandy, the generators at a number of hospitals on the East Coast failed to function properly, including at New York University Langone Medical Center, which was forced to evacuate all of its patients after both of its backup power systems failed.[46]

Recent natural disasters have shown the particular importance of grid resiliency and the availability of backup power for the most vulnerable communities, including low-income and minority populations.[47] Statistics show that Black and Hispanic communities experience more frequent power outages in general than white Americans, and during natural disasters these disparities are magnified.[48] Historically underserved communities often wait longer than more affluent neighborhoods for power to be restored, as was the case, for example, in Puerto Rico, when Hurricane Maria knocked out key electricity transmission and distribution lines leaving the Puerto Rican archipelago without power.[49] Similarly, when rolling blackouts during the February 2021 cold snap left millions of Texas residents without power, marginalized communities were the first to be hit with power outages and expected to have the longest wait to be reconnected.[50] In Austin, for example, the decision to prioritize keeping power on in downtown areas benefited residents of the more affluent neighborhoods nearby, while hundreds of thousands of homes in predominantly Black and Hispanic neighborhoods elsewhere were left without electricity.[51]

The fact that emergency backup generators are often powered by diesel, gasoline or propane brings its own problems – not least of which being that these energy sources may themselves be inaccessible in an emergency situation, either due to fuel scarcity or the inability of some gas stations to run their pumps during power outages. Moreover, reliance on these generators during power shutdowns leads to increased air pollution and other risks to households that use them.[52] Since 2017, at least 39 Americans have died from carbon monoxide poisoning after storms.[53] Of the 28 people who died in the aftermath of Hurricane Laura, which knocked out the electrical grid in southwest Louisiana, leaving communities without power for weeks, 14 died as a result of carbon monoxide poisoning from emergency generators.[54]

Vehicle-to-grid technology – what it is and how it works

Vehicle-to-grid technologies – abbreviated as "V2G" – allow the batteries of electric cars and buses to be used as small-scale forms of energy storage to support the functioning of the grid.

There are various ways that electric vehicles interact with the grid:

- Most electric vehicle owners currently charge their vehicle through **one-way charging**: plugging it into a charging station and drawing electricity from the grid.
- **V1G "smart charging,"** a variant of one-way charging, enables charging to be scheduled for times when grid demand is anticipated to be low, and/or adjust charging according to signals from the grid operator so as to optimize energy consumption and best serve the needs of both the grid and the vehicle at a given time, based on factors such as overall electricity demand and how much energy the vehicle needs.[55]
- **Bidirectional charging** allows electricity to flow both ways, enabling an EV owner to use excess energy stored in an EV battery for other purposes, including in homes (V2H), in buildings in general (V2B), or, in the case of vehicle-to-grid (V2G) systems, returning electricity to the grid itself.[56]

V2G is essentially an advanced form of bidirectional charging which, in areas that have energy markets and/or are controlled by Independent System Operators (ISOs), can give EV owners the ability to access energy markets, thus enabling the vehicle to carry out "grid services," among other benefits. V2G systems can also use software to pull together the combined power of large numbers of vehicles to create a "virtual power plant" (VPP): a decentralized network of flexible power generation and storage.[57] These VPPs take the excess stored energy from each individual EV and treat it as a single energy resource, enabling this virtually aggregated set of resources to perform ancillary services to the grid and also sell energy back to utility companies.[58]

To do this, V2G systems require three main physical elements: 1) electric vehicles fitted with battery-management software and hardware that allows the bidirectional flow of power; 2) electric vehicle supply equipment (EVSE) – i.e., charging stations – which, coupled with the necessary infrastructure to enable bidirectional flow, deliver electrons to and from the grid; and 3) communication technologies mediating between vehicles and grid operators who control the charging and discharging of the vehicle's battery.[59] These mediating technologies sense the status of the grid, and also receive signals from the grid (for example, at times of critical peak demand) to enable a vehicle battery to be charged and discharged to best serve the needs of the grid at a given time. They also track the services provided so that the vehicle owners can receive compensation for the use of their vehicles.[60]

One example of this software is the GIVe (Grid Integrated Vehicle) platform developed by San Diego-based company Nuvve.[61] The platform enables bidirectional V2G charging and grid-connected load management services when connected to a V2G-compatible vehicle via a specific type of charger, enabling EV batteries to store and discharge energy when needed and vehicle owners to sell stored energy back to energy markets.[62] These chargers enable the automated charging and discharging of a vehicle's battery according to instructions received from a cloud-based app that ensures that all vehicles on the platform have sufficient charge for their next trip before ascertaining how much of the stored energy in the battery is available to sell back to the grid.[63] When multiple EVs are plugged into the same system at the same time, the platform can create a virtual power plant from their batteries.[64]

School buses are a promising application of V2G

In theory, any electric vehicle, provided it has the right hardware and software, could be capable of sending power back to the grid. However, there are a number of characteristics unique to school buses – as opposed to other electric vehicles, even including transit buses – that make them particularly well-suited to V2G applications.

Unlike transit buses, which spend most of their time in use, school buses operate for an average of only four to five hours per day and are mostly idle during weekends and school holidays – which together amount to around half of the calendar year.[65] In other words, for roughly 20 hours a day during the school year, and often 24 hours a day on weekends and holidays, many buses – and their batteries – are sitting idle.[66]

These use patterns not only enable school buses to potentially be available as a source of large volumes of energy storage to support the grid, but also to do so at the times when the grid is at its most vulnerable. Such periods include the "shoulder" period in the early evening when electricity demand is high but solar panels are no longer producing electricity, as well as over summer and winter breaks, when peak demand is often at its highest with more families at home and using air conditioning or heating.[67] Whereas most EVs charge at unpredictable times and locations, school bus fleets not only bring the benefit of large numbers of vehicles being available simultaneously, but they also operate on a predictable and limited schedule. This means that the vehicles are available to be charged during the day or at night, and discharged during peak demand hours such as early evening, when demand is highest but renewable energy from certain sources, such as solar, is not being produced.[68] On the other hand, predictable schedules also allow operators more choice over when the vehicles are charged and discharged, meaning that an entire fleet need not be discharged simultaneously but rather at times best suited to serving the needs of the grid.

The second feature of school buses that makes them ideal candidates for V2G is their large battery sizes. Battery capacity in personal (light-duty) EVs is rarely higher than around 100 kWh, potentially leaving little excess capacity to provide energy back to the grid.[69] While battery size should be matched to a vehicle's duty cycle – no bus operator should oversize their vehicles' batteries beyond the needs of their fleet – electric school buses by nature have greater power needs and larger battery capacity than light-duty vehicles.[70] Larger capacities mean more electricity storage. In addition, while battery degradation is often a concern with V2G due to the increased number of charges and discharges V2G entails, the percentage of loss should be less significant with the larger school bus batteries than with smaller vehicles that have smaller batteries.[71]

With large numbers of large vehicle batteries available simultaneously at regular, prescheduled times, electric school buses would seem uniquely positioned to act as a virtual power plant. Aggregating the vehicles' batteries across an entire fleet, district or region in theory enables them to collectively perform a number of functions, including providing grid stabilization services and facilitating the integration of renewable energy into the energy markets (see p. 17).[72]

Electric school buses and V2G deliver valuable benefits

ROUGHLY 95% of U.S. school buses run on diesel – which produces dangerous pollutants with proven links to numerous health impacts, including cancer, asthma and autism.[73] Research suggests that air pollution inside school buses can be significantly higher than concentrations typically found outdoors.[74] By one analysis, concentrations of particulate matter in school buses are more than double those of roadway concentrations and four times those of average outdoor levels.[75] Moreover, the harmful emissions from diesel school buses disproportionately affect students from low-income communities. Sixty percent of students from low-income backgrounds travel to school by bus, compared to 45% of students from more affluent families.[76] Minority ethnic and racial groups are more likely to bear the brunt of air pollution from road traffic pollution in general, since the historical legacy of discriminatory housing and zoning policies means that these communities tend to be located in closer proximity to highways.[77]

Since ESBs produce no tailpipe emissions, they don't emit the air pollutants or greenhouse gases of diesel buses, and they are likely to become cleaner over time, as more of the electricity used to power them comes from renewable sources. By one estimate, replacing all U.S. diesel-powered school buses with electric models could avoid roughly 8 million metric tons (MMT) of emissions per year.[78] In addition to their health and environmental benefits, since ESBs rely on highly efficient electric motors, they are cheaper to fuel and easier to maintain than internal combustion engine vehicles, thus creating substantial savings in lifetime costs of operation.[79]

Electric school buses can deliver environmental, health and financial benefits – even if they never supply electricity to the grid. But a growing body of recent research indicates that V2G-enabled ESBs may be able to bring additional benefits.

Photo: Theurv via Wikimedia, CC BY 4.0

The first all-electric school bus in California, outside the California capitol building in Sacramento in 2014.

Environmental benefits

Although studies of electric school buses specifically are scant, research has indicated that V2G technology can potentially play a significant role in reducing greenhouse gas emissions from both the transportation and power generation sectors – the two sectors of the U.S. economy that contribute most to the nation's climate emissions.[80]

- A study published in the journal *Energies* in 2016 found that an electric school bus using V2G can potentially eliminate more than 1,000 metric tons of CO_2-equivalent emissions over the lifetime of the bus – roughly equivalent to the lifetime emissions of 19 passenger cars.[81] The same study found that the use of V2G can also eliminate air pollution from fossil-fuel power plants working over typical capacity when accommodating high electricity demand fluctuations, with each bus providing enough energy back to the grid to reduce the mean cost of air pollution by $18,300 over the course of the vehicle's lifetime.[82]

- A recent study by Columbia University concluded that electric school buses using V2G have the potential to mitigate energy production from natural gas "peaking" power plants. The model calculated that a fleet of 1,550 electric school buses providing peak shaving services – managing overall energy demand to eliminate short-term consumption spikes – could reduce CO_2 emissions by 5,500 tons over five years and produce a significant decrease in electricity-related local air pollution.[83] By enabling utilities to tap distributed sources of energy — i.e., a virtual power plant composed of vehicles owned by third parties – V2G technology taken to scale could also lessen the need for new physical power plants.[84] In addition to the environmental benefits, this could ultimately create financial savings for utilities, as well as improving the health and wellbeing of low-income and minority communities, since current peaker power plants are often located in these communities and have negative health impacts.[85]

V2G systems using the battery storage provided by EVs are also one way in which EVs could potentially play a key role in facilitating the large-scale integration of renewable energy sources like solar and wind power. V2G-equipped vehicles are able to absorb renewable energy when it is available in abundance and release it during periods when it isn't, such as in the evening, when large numbers of vehicles are not in use, essentially making them energy storage units and thus mitigating challenges of keeping the grid in balance while relying increasingly on renewable energy.[86] Networked battery storage in the form of large numbers of EVs aggregated in a VPP could enable electricity generators to scale back their contribution to meeting demand and draw from the network of battery storage and generation for the rest, thus lessening the need for costly capacity expansion of generation and transmission capacity and helping to maintain electricity price stability while at the same time easing the process of decarbonizing the nation's electricity grid.[87]

The ability of EVs to facilitate the integration of renewable energy sources including wind and solar into the existing power grid has been the subject of a growing body of research.

- A 2017 study found that if a substantial scare of the light-duty motor vehicles currently registered in the territory covered by the PJM Interconnection – the largest power grid operator in the U.S. – were electric and V2G-capable, this could increase renewable energy development by 51 GW within the PJM Interconnection – an increase of 30% over scenarios without V2G.[88]

- A California study found that a mix of V1G and V2G-equipped EVs can enable "substantial" mitigation of "ramping" (sudden and potentially disruptive changes in power production – a particular issue with solar) equivalent to avoiding construction of 35 600-MW natural gas plants for that purpose.[89] The study highlighted a "substantial synergistic opportunity" if the target of 1.5 million ZEVs on California's roads by 2025 set in the state's 2012 Zero-Emission Vehicle mandate were deployed to provide power storage to support renewables integration.[90]
    - The same study concluded that using EVs instead of stationary storage could save billions of dollars in capital investments needed to enable a successful transition to renewable energy, and could be used as an incentive to accelerate the adoption of EVs.[91]
- Research in Latvia found that V2G-capable EVs could play a substantial role in the integration and use of wind power.[92] The V2G system could provide important "peak shaving" services and reduce CO_2 emissions by around 100 kilograms of CO_2 per EV.[93]
- A 2016 study of the Canary Islands found that V2G in conjunction with pumped hydro storage reduced dependence on fossil fuels while also increasing the share of renewably-generated electricity and reducing carbon emissions. The study calculated that a fleet of 3,361 EVs could potentially increase the share of renewable energy from the current (2015) level of 11% to 49%, leading to a 26% reduction in electric power system CO_2 emissions.[94]

In addition, a number of studies have found that introducing V2G to microgrids – localized, self-sufficient grids able to operate autonomously from the main grid, powering a specific geographical area, such as a college campus or hospital, with energy produced by distributed sources – could reduce operational costs, decrease reliance on the main grid and increase the share of power from renewables.[95]

Benefits for the grid

Energy stored in the batteries of electric school buses can support a range of services and functions necessary for the grid to function properly. These include:

- **Demand response/peak shaving:** Over the past two decades, the ratio of annual peak-hour electricity demand to average hourly demand across the U.S. has risen significantly, meaning that utilities are having to serve an ever-increasing range of demand.[96] Electric vehicles have a valuable part to play in minimizing peak demand on the grid, which can be expensive and environmentally damaging to serve. Whereas one-way charging pulls electricity from the grid at a constant rate until the battery is at maximum capacity, bidirectional charging allows a fully charged vehicle to store energy and discharge it back to a building to reduce that building's demand for power from the grid, or, with the necessary infrastructure in place, to supply power to the grid itself.

  Demand response also has a role to play in mitigating challenges that arise from renewable energy generation – including the fact that electricity generation from renewables does not necessarily coincide with times of highest demand. A 2020 Los Angeles case study evaluating changes in net load in the Los Angeles power grid in a system with solar energy combined with projected numbers of EVs that would be used for distributed storage found that a mix of V2G and grid-to-vehicle (G2V) technologies can effectively flatten out the so-called "duck curve" – the dip in energy demand caused by solar generation during

WHAT IS THE "DUCK CURVE" AND WHY DOES IT MATTER?

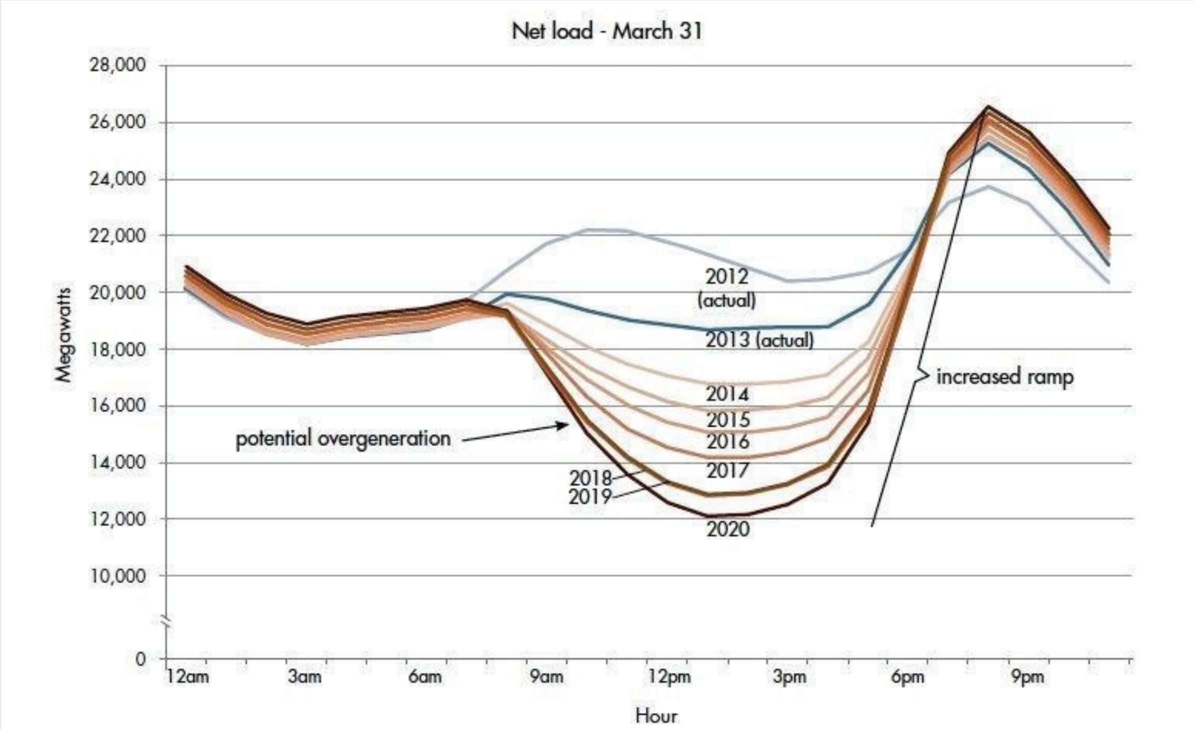

Figure 1. The "duck curve" in California over a typical 24-hour period in the springtime.

Source: U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy.[101]

The so-called "duck curve" is the net electric system load (energy demand minus the supply of distributed renewable energy) over the course of a given day.[102]

As more solar comes online, the demand for electricity from traditional power plants during daylight hours, when solar is plentiful, drops. But peak energy demand often occurs in the morning and early evening when solar is not plentiful. During these periods – in the morning and evening – the electric grid must meet that increased demand from sources other than solar. So, as the nation transitions to renewable energy and the portion of our energy that comes from distributed solar resources during the daytime increases, the dip in the middle of the curve gets lower, and the ramp up to the evening peak gets steeper.

This poses a problem for utilities because it means they will increasingly be forced to ramp up their dispatchable power plants to meet demand during a morning peak (the duck's tail), scale back or shut them down altogether during the day when solar generation is highest (the duck's belly), and then quickly bring them all back online after sunset (the duck's head).

This costly process can be mitigated by using battery storage to absorb renewable energy during the day when it is being generated in abundance and release it during peak periods when it is not, thus lessening the need for utility companies to ramp up their generators during these hours to meet the increased demand – in other words, "flattening" the duck curve.

the day and the steep increase that follows after sunset – concluding that a smart grid V2G and G2V system can reduce the difference between minimum and maximum daily net load from 1.9 GW to just 500 kW and reduce peak load by around 800 MW, from 3,500 MW to 2,700 MW.[97] This is a significant reduction, the study notes, which can lessen utility companies' need for costly capacity expansion and help maintain electricity price stability.[98] The study concludes that even a "moderate" EV adoption plan (assuming 127,000 EVs on the road in the LA area) could give utilities enough battery storage capacity to help "significantly" with peak load shifting and flattening the duck curve.[99]

Another study from California concluded that the peak-shaving services a V2G-enbled school bus fleet can provide can improve grid resiliency, in particular during the summer months when peak conditions can put a strain on electricity infrastructure. By alleviating the pressure on this infrastructure, the study concluded, a V2G-equipped school bus fleet can reduce both the risk of power outages and the need for grid infrastructure maintenance.[100]

- **Energy arbitrage:** Many utilities have rate structures that charge users more for power consumed during peak hours and less for "off peak" power. By purchasing and storing energy when demand and cost are low and redistributing it when demand is high, energy arbitrage enables owners of distributed energy, such as VPPs – provided they are allowed access to the electricity markets – to bid for energy demand alongside operators of peaker plants, and thus provides owners/operators of storage with a source of revenue.[103] A 2019 study assessing the economic viability of inserting V2G systems into energy spot markets for the purpose of energy arbitrage calculated that, based on the markets in 2019 in Germany, revenues could range from €200 to €1,300 ($235 to $1,500) per EV per year, varying by geographic location as well as available energy markets and production structure.[104]

- **Grid resilience and emergency preparedness and response**: For the electrical grid to be resilient, it needs to be able to anticipate, absorb, adapt to and quickly recover from disruptions.[105] V2G could provide grid operators with an on-demand source of power that would, among other uses, enable electric vehicles to provide backup power and mobile power supplies in emergencies. A 2018 study by the U.S. Department of Energy Electricity Advisory Committee found that backup power storage is one of the key ways V2G is suited to enhancing grid resilience.[106]

Benefits to communities

Replacing diesel-powered school buses with electric ones would provide numerous benefits directly to the communities they serve, including improving children's health and reducing air and noise pollution, as well as reducing the disproportionate burden that this pollution places on disadvantaged communities.[107] When equipped with V2G technology, these vehicles can bring a number of further benefits to communities, including playing a role in providing backup power to support emergency management efforts and enhance the resilience of the electrical grid – something that will become ever more of a necessity over the coming years as extreme weather events become more frequent and more destructive as a result of climate change.[108]

A fleet of V2G-enabled electric school buses could become important temporary power sources during outages – essentially providing mobile batteries that can be deployed at short notice to provide emergency power to homes, businesses, shelters and critical infrastructure, while at the same time obviating the need for backup generators and facilitating emergency response efforts in hard-to-reach communities. In some cases, such as with planned powering-down of transmission lines during wildfires, a fleet of buses could be deployed in advance of power shut-offs to minimize disruption caused by power outages before they occur.[109]

The concept of using EVs as back-up power systems has already been demonstrated. In the aftermath of the Tohoku earthquake and Fukushima Daiichi nuclear disaster in 2011, Japanese auto manufacturer Nissan deployed 66 LEAF EVs to provide emergency power to families and relief workers, and in 2019 the company deployed the vehicles to Tokyo following Typhoon Faxai.[110] The LEAF is enabled with V2G and V2X technology allowing owners to supply power back to the grid, and Nissan has recently unveiled a prototype customized version of the vehicle – the RE-LEAF – designed specifically for disaster response.[111] This model is equipped with three 230-volt power sockets and a 62 kWh battery capable of powering energy-intensive emergency equipment for 24 hours before needing to recharge.[112]

In February 2021, when the failure of Texas's power grid left millions without power, electric vehicles became a crucial resource, enabling some Texas residents to power their homes – at least in part – from their car batteries.[113] Automakers are beginning to see the capacity to deliver emergency backup power as a selling point for their vehicles, with Ford and Sunrun recently announcing a partnership to market vehicle-to-home (V2H) technology that could allow homeowners to draw up to three days' worth of power from the batteries of their F150 Lightning electric trucks.[114]

Electric school buses and V2G can make financial sense for school districts

Despite higher upfront costs, electric buses can be a cost-efficient alternative to their diesel counterparts, producing savings over the course of their lifetime in significantly lower operating costs from reduced spending on maintenance and fuel (in places where utility rate policies are favorable), while also

ELECTRIC SCHOOL BUS COST SAVINGS AT TWIN RIVERS UNIFIED SCHOOL DISTRICT

In 2017, Twin Rivers Unified School District in California became one of the first in the country to deploy electric school buses.[117] Twin Rivers added 16 electric school buses to its fleet at an average cost of around $400,000 per vehicle, of which the district paid between $60,000 and $100,000, with the remainder covered by government grants.[118] The district reports these buses produced a 75%-80% savings on fuel costs – $0.16 to $0.19 per mile, versus the $0.82 to $0.86 it cost to fuel its old diesel buses – creating, together with reduced maintenance costs, a total annual savings of roughly $15,000.[119]

Photo: Frontier Group staff

A Twin Rivers USD e-Lion bus.

providing greater predictability in costs due to the relative stability of electricity prices compared to fossil fuel prices.[115] When the societal benefits they deliver by reducing air pollution and global warming emissions are taken into account, those savings are considerably higher.[116]

As well as saving money, school buses with V2G technology can potentially provide further financial benefits for school districts, generating value by providing services to the grid for which school districts can be compensated in various ways by utilities and system operators so as to give fleet owners and energy management companies a share in their profits.[120]

For example, if a school owns an electric bus, that bus's battery can serve as energy storage for the grid when the bus is not in use. The result is that the bus provides stability to the grid and a way to store energy (including renewable energy) at times when it is abundant and cheap and then deliver energy back to the grid at times when electricity is expensive or in high demand. These services generate value for which utilities should compensate school districts.

Examples of this in practice are limited, but a number of simulations have indicated the potential financial benefits.

- Modelling of a V2G peak shaving program using a fleet of school buses in California, whereby participants are paid for the electricity that they offer to the grid for peak shaving at the peak retail price and make a profit by arbitraging these payments against recharging during off-peak periods when the retail price is significantly lower, found that the savings created outweigh the costs of the equipment and administration the program requires, making it beneficial for both utilities (since the system benefits would outweigh any administrative and incentive costs) and schools (since their profits from providing peak shaving services would outweigh their equipment expenses).[121]

Electric school buses and V2G technologies today

AS OF 2021, FEWER THAN 1% of the nation's school buses were electric, with a total of 1,828 vehicles "announced, procured, delivered or in operation."[122] However, advances in electric bus technology, a decline in battery costs and growing understanding of the benefits of electrification have seen increasing numbers of districts committing to electric school bus adoption or drawing up plans to do so. Original equipment manufacturers (OEMs), including Blue Bird Corporation, BYD, Collins Bus Corporation, Endera, GreenPower Motors, Lion Electric Co., Motiv Power Systems, Navistar/IC Bus, Phoenix Motor Cars, SEA Electric, Starcraft, Thomas Built Bus, Trans Tech, and Unique Electric Solutions (UES), are producing increasingly affordable electric school buses, and there are now electric school bus models to meet every conventional diesel use case (Types A-D). Increasingly, these vehicles are equipped with V2G capabilities.[123]

Electric school buses on the rise

While electric school buses have been slow to gain a foothold in the U.S., momentum has built over recent years as more and more school districts have made commitments to electrify their fleets. As of December 2021, 354 districts or private fleet operators have committed to at least one electric school bus.[124] While these commitments span the majority of states, however, this still represents just 2.6% of the roughly 13,500 school districts throughout the country.[125] Twenty-eight districts have committed to 10 or more electric buses, and of those, five are among the largest school bus fleets in the U.S.[126] In 2021, as part of an effort to improve air quality and combat climate change, New York City Council passed a bill requiring the city's school bus fleet be entirely electric by September 2035.[127]

To date, the single largest commitment by a U.S. school district has been Montgomery County Public Schools (MCPS) in Maryland, which in 2021 approved a contract with Highland Electric Transportation to convert its school bus fleet to all-electric, beginning with the procurement of 326 V2G-equipped Thomas Built electric buses.[128] The initiative will involve Highland and its project partners electrifying MCPS' five bus depots and supplying the buses and charging infrastructure, and also includes a V2G component: according to the press release, the buses will "lend their batteries to deliver stored electricity to the local electricity markets, interconnected through [energy provider] Pepco, which helps the community integrate renewable energy and support grid resiliency."[129] This model is also known as transportation-as-a-service (TaaS), where the vehicles are supplied, maintained and managed by a third party rather than the school district.

Electric school buses and V2G technology

As the adoption of electric vehicles has increased across the world, so too has the V2G market. That market is currently concentrated primarily in Europe, but a number of pilots aiming to assess the viability of V2G have been implemented in the U.S.[130]

In 2020, for example, Snohomish County Public Utility District in Washington State installed two V2G chargers at the utility's Arlington microgrid site enabling the company's Nissan LEAFs to send power back to the grid during outages.[131] In Texas, public utility Austin Energy has worked with research organization Pecan Street to assess the viability of EVs for peak shaving and other grid services and since 2020, Vermont power company Green Mountain Power has been using a V2G-enabled 2019 Nissan LEAF at its Colchester, VT, office to reduce energy use on the grid during peak periods.[132] In 2018, Nissan itself launched a pilot with V2G technology company Fermata Energy to use V2G technology to partially power Nissan's North America headquarters and design center, using its LEAF EVs to reduce demand charges by helping power buildings during peak-load times.[133] Elsewhere, in 2017 the University of California San Diego installed 50 V2G chargers around its campus and later added a fleet of five V2G-enabled EVs to the campus's shuttle service Triton Rides.[134]

Pilot programs pairing electric school buses with V2G are scarce. Nevertheless, a number of electric school bus manufacturers have been working to demonstrate the benefits of equipping electric school buses with V2G capability. Several major North American manufacturers now make V2G-capable buses, including Blue Bird Corporation, Endera, GreenPower Motors, IC Bus (Navistar), Lion Electric, and Unique Electric Solutions.[135] Additionally, several OEMs like BYD, Lightning eMotors, Phoenix Motorcars, and Thomas Built Buses, offer V2G as an optional feature.[136] The last few years have seen a number of pilot projects taking place across the country, including in White Plains, New York, and San Diego and Cajon Valley, California.[137] The Sacramento Municipal Utilities District (SMUD) has been "actively looking" at electric school bus V2G technology and partnering with Twin Rivers Unified School District to test the ability of V2G to deliver financial benefits, reduce infrastructure needs, and increase renewable energy penetration, with the aim of eventually expanding to a pilot program for other school districts.[138]

All Blue Bird school buses featuring PowerDrive technology from engine manufacturer Cummins have been V2G capable since July 2020, and Cummins and Nuvve have since collaborated to develop the software required to pair with compatible chargers.[139] As of 2021, all Blue Bird Vision Type C and All American Type D electric school buses will now come enabled with Nuvve's V2G technology, including a standard CCS connector capable of V2G charging and discharging of the buses' 155kWh batteries.[140] Blue Bird's electric school buses equipped with Nuvve's V2G GIVe platform are capable of providing grid services including frequency regulation and demand response.[141]

In Massachusetts in the summer of 2021, in a collaboration between Beverly Public Schools, Highland Electric Fleets and New England regional utility National Grid, a Thomas Built electric school bus successfully delivered roughly 3 MWh of power to the electric grid over the course of 30 occasions totaling more than 50 hours, marking the first time an electric school bus has been used by National Grid in New England to relieve pressure on the grid during periods of peak demand.[142] Highland estimates that the pilot, using a single bus, generated roughly $10,000 for the company over the course of the summer.[143]

Electric school buses could be a major energy storage resource

If V2G were to be taken to scale, the resulting benefits could be significant.

If every yellow bus currently in operation in the U.S. were replaced with a V2G-capable electric bus of the same type, the stored energy capacity of the nation's school bus fleet would be approximately 61.5 GWh – enough to power nearly 200,000 average American homes for a week.[144] The U.S. electric school bus fleet would also have the ability to provide 6.28 GW of instantaneous power until discharged – equivalent to the potential power capacity of more than 1.2 million typical solar roof installations or 16 average utility-scale coal power generators.[145]

An electric bus will not typically be charged to its technical maximum capacity, since consistently charging a battery to its maximum capacity shortens the lifespan of the battery.[146] A study from 2020, for example, found that a BMW i3 electric vehicle charged between 80% and 100% capacity experienced double the amount of energy losses as the same vehicle when charged between 20% and 80% of capacity.[147] To account for the realistic capacity of a nationwide electric school bus fleet, our analysis assumes a maximum usable capacity of 70% of the battery's full capacity.

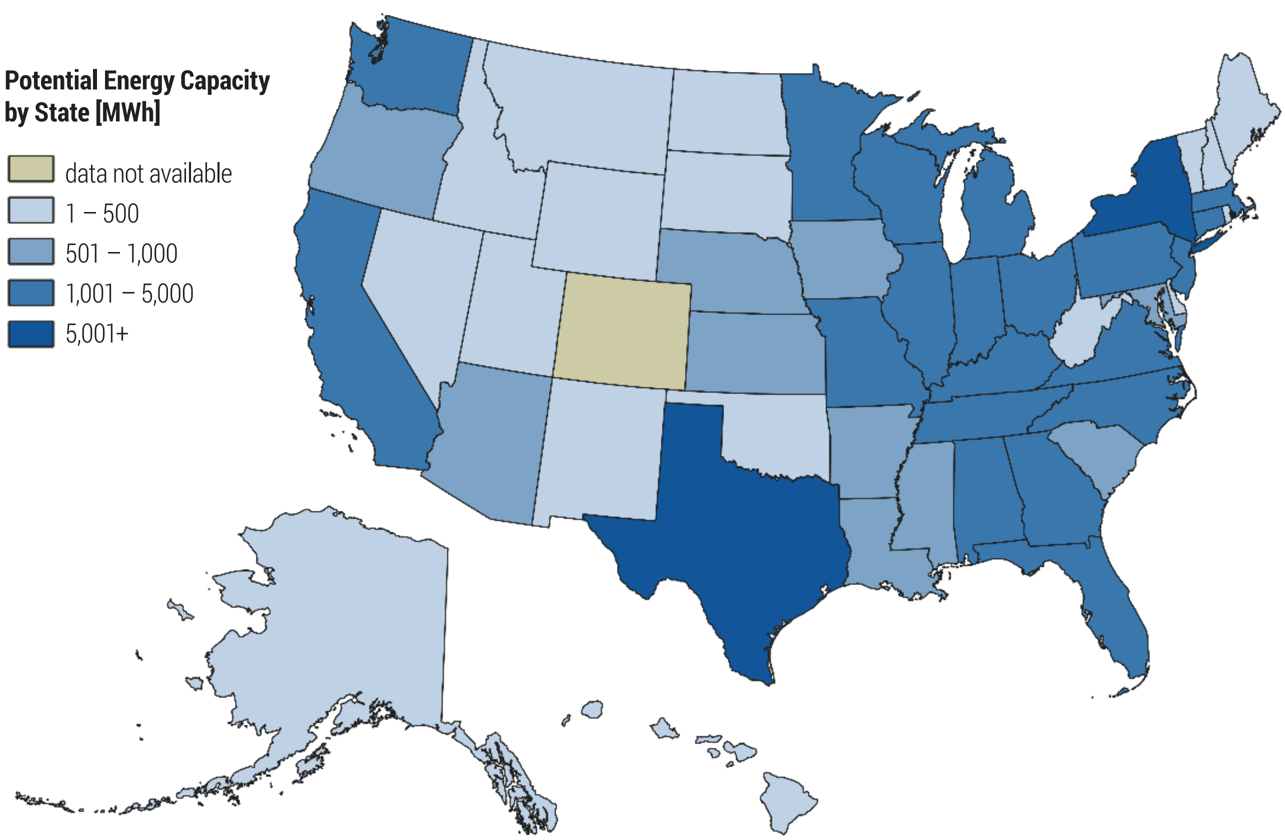

Figure 2. Potential electricity storage capacity of school bus fleets by state if states' existing fleets were replaced with electric buses.

The fact that electric buses are mobile means they provide an invaluable energy source in emergency situations. During "major event days" caused by natural disasters, such as hurricanes or earthquakes, facilities including hospitals and emergency shelters are pushed to their limits.[148] Hospitals are required to be equipped with emergency generators and fuel for 96 hours, but recent history has shown how, in practice, this has often proven insufficient (see p. 13). In a crisis situation, V2G-equipped electric buses can serve as mobile backup generators.[149]

- A single Type D bus could power the equivalent of five operating rooms for more than eight hours, and a single operating room for more than 43 hours.[150]
- If these buses are able to recharge, they could continue to shuttle stored energy to hospitals or other facilities until power can be restored, and in cases where hospital services are needed remotely (such as in a remote shelter), buses can travel to the site.

V2G in Action

VEHICLE-TO-GRID TECHNOLOGY has so far been more widely adopted in Europe and Asia than in the U.S., where a number of pilot projects are underway but still in their early stages.[151] In Europe, where EVs are already playing a role in several countries' grid-balancing markets, a number of projects have shown that V2G technology is a commercially available and workable grid services solution.[152]

For example, in 2016, Danish Technical University initiated a V2G study with Nuvve Corporation to research the potential benefits of V2G and the extent to which V2G can help the grid manage peaks in energy demand.[153] Located at Frederiksberg Forsyning, a municipal utility site near Copenhagen, a fleet of vehicles were made available for the public to rent, and their batteries aggregated to provide frequency regulation services to Danish grid operator Energinet.[154]

The study found that the vehicles were able to function at a high level while stabilizing the grid, and to provide a commercially viable V2G service. V2G savings were used to reduce charging costs for consumers, and each vehicle generated an average revenue of €1,860 Euro ($2,144) per year.[155] The vehicles have since continued to provide grid services and bring in revenue under a commercial agreement with Frederiksberg Forsyning, for which they provide frequency regulation, peak shaving and a range of other services, supporting the grid for 17 hours on average per day, as well as powering Frederiksberg Forsyning buildings.[156]

Challenges limiting the adoption of electric school buses

AS THE NUMBER of electric school buses across the country has grown, so too has the practical experience of school districts in operating those buses. This experience has provided insights into the challenges that will need to be overcome in order to make any large-scale rollout a success, and enabled school districts, utilities, bus manufacturers and local authorities to collaborate to find ways of addressing these issues. Introducing V2G into the equation brings its own set of challenges, especially since the large-scale use of V2G with heavy vehicle fleets is currently largely uncharted territory for the entities involved. While V2G potentially brings a range of opportunities for schools, utilities and communities, several key barriers will need to be overcome before those opportunities can be fully accessed.

High upfront costs

Electric school buses cost significantly more upfront than traditional diesel buses. The average diesel school bus costs around $90,000, while a comparable electric school bus costs between $290,000 and around $400,000, before necessary additions, including charging infrastructure and installation, and training of staff to maintain the fleet and supervise V2G operations.[157] Electric buses cost less to maintain over time (see p. 21), even before taking into account revenue-generation from V2G, but high upfront costs will be an obstacle for school districts. This is likely particularly true of districts in low-income or otherwise underserved areas, which in many cases already struggle to fund school transportation but which are often also those that would also stand to benefit the most from decreased air pollution and more modern buses.[158] No school district, however, is in a position to spend these kinds of sums without guarantees of return on investment.

Government funding, such as the California Energy Commission's School Bus Replacement Program, which provides financial support for disadvantaged communities to replace diesel buses with electric alternatives, can help make electric school buses an affordable option for school districts that may otherwise struggle to cover the upfront costs.[159] However, for electric school buses and V2G to gain widespread acceptance as a financially viable option for school districts, it will be necessary for the various actors involved to work together to tap the benefits of this technology.

Partnerships between school districts and utilities will be an essential area of collaboration – especially since the negotiation of favorable energy rates has been a key factor in the return on investment reported by those school districts that have pioneered electric school buses to date.[160] The fact that school buses can be owned by school districts, city or county agencies, or contractors, however, opens up possibilities for a variety of public-private partnerships to offset upfront and ongoing costs and enable all of the entities involved to access the full value of a V2G program.[161]

- One model is that proposed by Dominion Energy in Virginia, one of the first U.S. energy suppliers to integrate V2G into its commercial operations.[162] As part of an initiative aiming to use batteries in electric school buses as a grid flexibility asset to mitigate the need to build additional capacity to the grid to support the integration of a new 2.6-gigawatt offshore wind farm, Dominion's pilot program will supply 50 V2G-equipped electric school buses to a number of communities across Virginia, using the batteries to store energy while the buses are not in use and discharging it back to the grid during peak periods.[163] The school districts pay $100,000 for each bus – roughly equal to the upfront cost of a diesel school bus – while Dominion pays the difference and owns and manages the charging equipment.[164]
- Another model, proposed by school bus electrification company Highland Electric Transportation, is to replace the initial and ongoing costs of electric school buses and chargers with an annual per-bus, mileage-based fee, equal to or lower than a given school district's budget for its existing diesel bus fleet.[165] That fee includes the bus, all of the infrastructure, the electricity that goes into the bus, training, and reimbursement for maintenance.[166] Highland then recoups its investment through revenues generated from the grid services the buses provide.[167] This type of arrangement, similar in some respects to existing solar leasing programs, was piloted in a 2021 collaboration in Massachusetts between Highland, Beverly Public Schools and energy provider National Grid, in which a Thomas Built electric school bus provided V2G services for Massachusetts' electric grid over the summer. Highland covered the cost of the bus, chargers and electricity, charged the school district a fixed-price subscription and compensated the district for the services the bus provided by way of a lower subscription price, while allowing National Grid to use the energy stored in the bus battery to ease demand on the grid during peak periods.[168]

Knowledge and data gaps

The initial investment in a fleet of electric buses requires big decisions on the part of school districts. Electric buses alone operate differently than their diesel counterparts, but bidirectional connection to the grid brings additional layers of complexity in terms of communicating with utilities and bidding into energy markets. While knowledge regarding how to implement V2G buses exists, the absence of long-running examples that demonstrate success, both in a logistical and financial sense, may make schools considering adding electric buses to their fleets wary of bidirectional grid integration.[169] A shortage of concrete examples will slow the adoption of V2G technologies, in turn keeping demand low and prices high.

One major challenge in this regard is a lack of conclusive research on how best to maximize the value of electric school buses as distributed energy resources. In theory, a fleet of V2G-capable school buses opens up multiple potential value streams – for example, customer bill management, peak shaving, demand charge management, Volt/VAR optimization, frequency regulation and so on. Recent simulations, however, have suggested that under the current market structure, annual profits from one stream alone may not be sufficient to incentivize widespread adoption.[170] And each potential source of revenue may come with its own uncertainty.

Realizing the revenue-generating potential of an electric school bus fleet necessitates "stacking" the value streams and services the fleet can provide for all of the various entities involved so that they provide an adequate incentive for adoption.[171] School districts may lack the time or expertise to understand the various potential revenue streams or to coordinate with the various entities whose involvement would be required to unlock those streams.

Making V2G an economically attractive proposition for school districts will also likely require changes to utility policies such that they provide more attractive compensation for energy storage and other grid services. For example, elimination of costly demand charges and/or the creation of a premium tariff rate for V2G power similar to current feed-in-tariff (FIT) programs for renewable energy may make V2G for bulk storage more economically attractive, providing a simpler or more appealing way of compensating districts for the services they provide than enabling them to participate in volatile energy markets.[172]

Regulatory complications

In the U.S., retail sale of electricity is regulated by state public utility commissions, and rules vary from state to state. While an electric vehicle does not produce electricity, flow of energy to the grid can be considered energy sales, meaning that electric vehicles with bidirectional flow could be subject to the same laws and regulations as utilities.[173] States handle this issue in a number of ways. Ownership of charging sites by utilities varies heavily, with some states allowing utilities to own charging stations without regulation and others preventing any utility ownership of charging stations at all.[174] Some states have made charging station operators exempt from public utility regulations. Others have done nothing to address the issue.[175] The absence of a coherent regulatory framework for V2G and limited understanding among regulators regarding V2G is a significant hurdle to widespread adoption. Research by the Smart Electric Power Alliance has found that utilities identified the lack of regulatory knowledge regarding V2G as one of the main obstacles to V2G program development, and the lack of regulatory support as the "number one internal barrier" to getting V2G programs approved and implemented.[176]

Lack of coordination between entities

Implementing V2G in a project on the scale of an entire school bus fleet will require school districts to partner with utilities from the planning stage. Utilities will play an important role in ensuring schools have sufficient infrastructure to charge their bus fleets, for example. As electrification efforts continue to grow, new demands are placed on the grid that require larger upgrades. An increased load of one MW to the grid typically requires upsized cables or a similar fix, while a 20 MW load can require the construction of new substations.[177] Moreover, direct collaboration with utilities will often be necessary in order for schools to be able to bid for energy within the electricity market, although regulations already complicate this issue.

Policy recommendations

EARLY DEPLOYMENTS SHOW that electric school buses can deliver clean, efficient, cost-effective transportation to the millions of American children who rely on buses to get to school. Unlocking the further opportunities presented by pairing school buses with vehicle-to-grid technology will require collaboration between school districts, utilities, emergency management agencies and other entities, and revising public policies to ensure that investments in electric school buses and V2G make financial sense for school districts and utilities. The following policies and actions can help make this happen.

Recommendations for the federal government

- **Invest in electric school buses.** Put simply, maximizing the benefits V2G school buses are able to deliver to school districts and ratepayers will require large numbers of buses. The larger the fleet, the greater the benefits. The $2.5 billion allocated for electric school buses and $2.5 billion for clean alternative fuel buses – including electric ones – in the recently adopted bipartisan $1.2 trillion Infrastructure Investment and Jobs Act is a start, but it is only a fraction of what is necessary to transition the nation's school bus fleet to zero-emission electric models.[178] For this to happen, school districts across the country will require sustained federal investment, although with developments in electric bus technology and sustained high-volume orders from school districts, the upfront costs of electrification will almost certainly fall over the coming years.[179]
- **Develop tools and educational materials to enable school districts to better understand the costs and benefits of electric buses and V2G**. School districts need to be able to quantify the potential benefits of V2G and develop projections of revenues that can be derived from it in order to be able to include V2G benefits in any calculations of return on investment for electric buses.
- **Provide funding for V2G pilot programs** to enable a fuller understanding of the challenges of V2G and the costs and benefits it can bring to school districts, utilities and other stakeholders, as well as to develop best practices to enable all stakeholders to get the most out of this technology. Funding should be allocated to a diversity of districts, including those serving underserved populations, since disseminating best practices that work for such districts will necessitate prioritizing these districts in the pilot phase.
- **Support research to develop and standardize hardware, software, regulations and practices** needed for electric school buses to integrate with the grid and participate in energy markets, as well as research to determine the value of V2G and the potential revenue streams it can produce. This will help increase access and transparency to utilities and provide a framework for investment decisions.

Support for V2G R&D can include empowering utilities to use "innovation funds" for programs to test new technology, and developing standards that support V2G aggregation, communication and control requirements.

- **Increase funding for research on potential business models for public-private partnerships to help school districts with the upfront costs of electric school bus adoption**, including identification of federal, state and local policies that may create barriers or incentives to each model, and develop resources to inform state and school district decision-making.

Recommendations for states

- **Develop policies and regulations conducive to unlocking the various value streams V2G can provide.** Such policies might include exempting bus owners/aggregators from regulation as public utilities and experimenting with feed-in-tariff (FIT) programs and other forms of compensation that may provide a simple, appealing way of compensating school districts for the grid services they provide.
- **Provide grant/voucher programs, and subsidies for school districts to go electric.** This will ensure school districts and the communities they serve will experience the benefits of electric buses without additional financial burdens. The process of applying for funding should be streamlined to minimize administrative burdens on school districts and ensure that school districts do not have to cover upfront costs for application or the procurement of buses.[180]
- **Prioritize funding for underserved communities.** Excluding California, where generous state funding programs have led to relatively high numbers of electric school buses, only a small percentage of the electric school buses currently operational in the U.S. are in school districts serving the most vulnerable and socio-economically disadvantaged areas of the country.[181] Under-resourced school districts, including majority-minority schools and those serving low-income communities and communities facing disproportionate air pollution burdens, should be given priority in the allocation of funds so as to ensure that those with the most to gain from clean transportation have the resources necessary to cover vehicle purchases, infrastructure and operating costs, and the provision of job training programs for mechanics and maintenance staff.
- **Develop a roadmap to enable regulators to support the development of V2G** and facilitate the creation of regulations and policies to minimize the risks for utilities and school districts. This would pave the way for standardization and interoperability of V2G infrastructure, encourage coordination between key stakeholders and provide greater clarity on regulatory and policy frameworks so as to give utilities the necessary support for getting V2G initiatives approved and implemented.[182]

Recommendations for regulators and utilities

- **Clarify the regulatory status of V2G operations and virtual power plants to allow them access to energy markets.** State public utility commissions should develop a coherent regulatory framework for V2G and ensure that electric vehicles with bidirectional flow are not subject to the same laws and regulations as public utilities. Utilities and grid operators should work to effectively implement FERC rule 2222, opening up wholesale power markets to distributed energy resources.
- **Provide funding for V2G pilot programs** to enable a fuller understanding of V2G and the costs and benefits it can bring, as well as to develop best practices to enable

all stakeholders to get the most out of the technology. The technical viability of V2G technology has been demonstrated, but school districts and utilities still face many unknowns. Financial assistance, both in the form of funding for operational support and incentives for early adoption, should prioritize pilot programs in low-income school districts, with funds set aside to help cover the upfront cost of buses as well as other costs, such as charging infrastructure and technical support. Federal and state officials should support those pilots and ensure that the lessons are shared broadly so that other school districts may benefit from their experience.

- **Encourage the creation of financing programs** whereby utilities front the initial investment for electric school buses and allow school districts to pay back on utility bills as they save on fuel and maintenance costs, as well as leasing models whereby utilities or third parties own the buses and lease them to school districts. Regulators should ensure that utility regulations allow utilities to develop and implement such programs, such as the pilot currently underway in Virginia led by Dominion Energy, which can help school districts overcome the higher upfront costs of electric buses and deliver monetary savings immediately – something particularly important in under-resourced communities and school districts that predominantly serve children of color.

- **Restructure electricity rates so as to provide discounted off-peak charging**, limit excessive demand charges, and experiment with policies and practices that allow the buses to be used for energy storage and employ vehicle-to-grid technology while ensuring that there is a fair and adequate mechanism for compensating the bus owners. Such policies might include premium tariff rates for V2G power similar to current feed-in-tariff programs for renewable energy, with special rate treatment for the storage services provided, or a demand response model, whereby the excess power/load reduction is offered up for auction. State regulators should authorize rate treatments that enable these changes.

- **Work to establish dialogue and collaborative partnerships with school districts and public officials** in planning and implementing a transition to electric bus fleets that is beneficial to all parties involved, for example including the development of ESB-specific transportation rates for electricity.

Recommendations for school districts

- **Commit to a full transition to electric buses on a specific timeline.** These commitments will help grow the market, drive technological innovation and enable school districts to reap the benefits of economies of scale in maintenance facilities and other infrastructure, operational experience, and electricity pricing. Sustained, higher-volume purchase orders would enable bus manufacturers to reduce the cost of V2G electric school buses and thereby accelerate the switch to electric fleets.

- **Invest in as large a fleet as possible as soon as possible**. Ensure the availability of additional electrical capacity and build the infrastructure to be able to add more chargers. The larger the fleet, the greater its V2G revenue-generating potential.

- **Establish solid collaborative partnerships with utilities from an early stage** and open a dialogue about goals and interests from the outset. School districts should work with public officials and local utilities to enact a transportation rate for electricity and use rate modeling in the planning process for launching electric bus service.

Methodology

U.S. SCHOOL BUS SALES DATA were taken from *School Bus Fleet Magazine*'s 2020 Fact Book ("School Bus Sales Report – 2019"), which outlines U.S. bus sales by bus type from 2010 through 2019.[183] The number of buses owned by state was taken from *School Bus Fleet Magazine*'s 2021 Fact Book ("School Transportation: 2018-19 School Year").[184] The analysis used values for total yellow school buses by state, combining district-, contractor- and state-owned buses.

Specifications of electric buses on the market by type were taken from Vermont Energy Investment Corporation's (VEIC's) 2019 Electric School Bus Resources report.[185] This analysis used data for standard battery size/capacity and charge system voltage and power for buses that were listed as V2G capable. The average value was used for power and capacity in all bus types, except in the case of Type A bus storage capacity, in which the median value was used. This analysis assumes all buses are Type A, C and D buses, which are the predominant types of buses used in the United States. It also does not account for electric school buses introduced to the market since the publication of the VEIC report.

For some brands, battery capacity was listed as a range rather than a single operating value, which may have referred to different battery options for the same vehicle. For each range, the average value was used.

The data on bus sales – representing sales from the previous 10 years – were adjusted to arrive at an estimate of the composition of the active school bus fleet. The lifespan of a Type A bus on average is 13.9 years, and the lifespan of Type C and D buses on average is 15.2 years.[186] Knowing this, Type A buses would be purchased about 9% more frequently than other types of buses. Sales numbers for Type A buses were adjusted to reflect their faster retirement relative to other bus types. The adjusted sales figures for the three bus types were then summed over the 10-year period and divided by total bus sales to arrive at the proportion of each type of bus in the active fleet. These percentages were then multiplied by the size of the total yellow bus fleet in each state to arrive at an estimate of the number of buses of each type on the road in each state. This method produced a fleet composition of 18% Type A buses, 71% Type C buses and 11% Type D buses. (Figures for the size of the total yellow bus fleet were not available for Colorado.)

To evaluate whether bus sales by type (and, by extension, the composition of the bus fleet) may have changed over the previous decade (or more), we plotted a trendline for the 2010 through 2019 bus sales data, which indicated no significant trend.

The market share of buses by type was assumed to be the same across all states.

In reality, the composition of the bus fleet may vary due to factors such as population density, public school spending, state program financial support, weather, etc. There is, however, no known source of publicly available data on the composition of school bus fleets by type and by state.

Next, potential instantaneous power (measured in megawatts) and battery capacity (in megawatt-hours) across all buses in the U.S. were calculated. The average (or median where necessary) charging power and battery capacity by bus type were calculated using their respective columns on the VEIC fact sheet. All brands and models were weighted equally.

The number of buses by type within each state was multiplied by the average capacity and average power of buses of that type to find the total capacity and instantaneous power available by state if all buses were replaced with electric versions. The total U.S. capacity and power values are the sum of capacity and power values by state.

As a practical matter, the full storage capacity of electric school buses is unlikely to be available as a source of energy storage, as full charging and discharging of batteries can accelerate battery degradation. We assume that 70% of the capacity of school bus batteries is potentially available to support the grid (though the amount of power actually available at any given point in time will depend on the battery's state of charge and the duty cycle of the bus).

In addition, the process of discharging a battery and delivering stored electricity to the grid can involve significant energy losses. These losses vary depending on a number of factors, such as parasitic loads and equipment connections. We estimate those losses here at 29.78%, which are applied to all estimates of the number of homes that could be powered with electricity delivered via the grid from electric bus batteries.[187] This value is the experimental rate of energy losses when discharging at a current of 40 A. An average Type D electric bus discharges at 80 A.[188] Losses would likely be lower if the batteries are used in vehicle-to-building applications (such as emergency response) as opposed to vehicle-to-grid applications. This estimate of losses is also applied to the estimates of instantaneous power available from electric bus batteries nationwide, though this is likely a very conservative estimate.

Appendix 1: School bus fleet potential storage capacity by state

AVERAGE HOMES THAT COULD BE POWERED IF EXISTING SCHOOL BUS FLEETS WERE REPLACED WITH ELECTRIC BUSES. DATA WAS UNAVAILABLE FOR COLORADO.

State	Power capacity [MWh]	Instantaneous power [MW]	Average homes powered for a day
Alabama	1,030	105	19,219
Alaska	95	10	3,680
Arizona	935	96	17,923
Arkansas	661	68	13,326
California	3,085	315	115,199
Colorado	-	-	-
Connecticut	1,122	115	33,701
Delaware	230	23	6,977
Florida	1,838	188	34,374
Georgia	1,931	197	38,143
Hawaii	86	9	3,404
Idaho	367	38	8,213
Illinois	3,305	338	97,911
Indiana	2,106	215	47,966
Iowa	587	60	14,495
Kansas	525	54	12,704
Kentucky	1,036	106	20,623
Louisiana	892	91	15,870
Maine	412	42	15,427
Maryland	945	97	21,102
Massachusetts	1,174	120	41,654

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State	Power capacity [MWh]	Instantaneous power [MW]	Average homes powered for a day
Michigan	2,152	220	67,982
Minnesota	2,382	243	65,643
Mississippi	700	71	13,039
Missouri	1,552	159	32,250
Montana	453	46	11,271
Nebraska	744	76	15,694
Nevada	325	33	7,124
New Hampshire	417	43	14,152
New Jersey	2,179	223	68,142
New Mexico	262	27	8,346
New York	5,948	608	211,048
North Carolina	1,693	173	34,727
North Dakota	235	24	4,627
Ohio	1,894	194	46,347
Oklahoma	73	7	1,453
Oregon	633	65	14,768
Pennsylvania	2,817	288	71,124
Rhode Island	221	23	7,932
South Carolina	662	68	13,080
South Dakota	261	27	5,374
Tennessee	1,204	123	22,025
Texas	6,471	661	122,101
Utah	413	42	11,478
Vermont	157	16	5,897
Virginia	2,055	210	40,081
Washington	1,393	142	30,703
West Virginia	378	39	7,688
Wisconsin	1,281	131	39,432
Wyoming	175	18	4,306

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