TECHNOLOGY

ELECTRIFIED TRANSPORTATION FOR ALL:
HOW ELECTRIFICATION CAN BENEFIT LOW-INCOME COMMUNITIES

CENTER FOR CLIMATE AND ENERGY SOLUTIONS

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Transportation is responsible for most air pollution in urban areas[1] and produces the most greenhouse gases of any U.S. economic sector.[2] To reduce these emissions, cities and businesses are considering deploying electric vehicles, which produce no tailpipe emissions that would otherwise impact public health in their immediate surroundings and have lower carbon footprints. Increasingly, decision-makers are particularly interested in ensuring that air quality benefits of electric vehicles (EVs) are shared by all, including low-income communities that may be disproportionately exposed to harmful air pollution.[3] Improved adoption and use of electrified transportation in low-income communities could improve air quality impacts on vulnerable populations while reducing greenhouse gas emissions.

Expanding the benefits of electrification to low-income communities may be achieved within and outside of the traditional vehicle ownership model. Individually owned passenger vehicles will improve air quality in local communities and reduce greenhouse gas emissions, but other vehicles or ownership models may also achieve emissions goals. Both transit and school buses may travel through low-income communities, and their diesel-powered engines produce harmful criteria air pollutants and greenhouse gas emissions. Electrifying these vehicles, particularly along routes that travel through low-income communities, would improve emissions and reduce health impacts along their routes without requiring individual EV ownership. Transit and school buses operate in fleets that are closely connected with their city governments, and city planners and fleet managers may consider electric buses as fleet options that benefit broader communities. Passenger EVs may also be deployed in low-income areas by expanding access to EVs without an ownership model through initiatives such as car share programs, taxis, and ride-sharing companies.

This paper encourages planners and fleet managers to consider the potential costs and benefits of different types of electrified transportation on low-income communities. The steps and considerations described in this paper will help planners and fleet managers estimate and explain total cost of ownership (TCO) and the differences in air quality and greenhouse gas emissions of electrified light-duty passenger cars, school buses, and transit buses. This paper provides resources and considerations to compare these vehicles with standard alternatives: gasoline- and diesel-powered cars and buses, and compressed natural gas (CNG) and hybrid-electric buses. Lastly, the paper offers recommended steps for the strategic consideration and deployment of electrified transportation in local communities.

WHY ELECTRIFY?

Criteria air pollutants, defined by the U.S. Environmental Protection Agency's (U.S. EPA) National Ambient Air Quality Standards, negatively impact the health and welfare of U.S. residents. Examples of criteria air pollutants include nitrogen oxides (NOx), volatile organic compounds (VOC), and particulate matter (PM). Transportation sources account for a significant portion of criteria air pollutant emissions; more than half of national NOx emissions, which are a leading contributor to smog, is produced by the transportation sector.[4]

Low-income communities typically experience more severe health effects from vehicle tailpipe emissions because they are often located near major roadways. Minority populations are 50 percent more likely to live near busy roads, and the median income of residents close to such roads is below the national average.[5] Proximity to on-road pollution has been linked to increased risks of persistent and fatal cardio-vascular and lung diseases in neighboring populations.[6]

Strategies to reduce health endangerments for residential and commercial properties near large roads are already recognized by the California Air Resources Board (CARB), which recommends that sensitive land uses such as residences and schools be sited at least 500 feet from major roadways.[7] The deployment of EVs, however, can serve as a new and flexible air quality solution for established communities. The Electric Power Research Institute finds that EVs could significantly reduce ozone in urban areas where low-income communities are often located.[8, 9] In some cases, however, additional EV load could negatively impact the low-income residents that live near electric generation sites (see discussion in section "Understanding Criteria Air Pollutants' Hidden Health Costs").

A recent example shows how neighborhoods that suffer disproportionately from criteria air pollution can benefit from policies promoting clean vehicles. According to the New York City Department of Transportation, approximately 15,000 trucks pass through the city's Hunts Point neighborhood each to transport 60 percent of the city's food. To reduce vehicle emissions impacting the area, the city began a scrappage and replacement program that provides rebates for new low-emission trucks (clean diesel, electric hybrids, CNG, and all-electric vehicles are eligible) to trucking operators in the areas. Monitoring systems that have been installed in nearly 500 trucks indicate that the air quality benefits of reduced-diesel emissions from replacing the older diesel-powered vehicles accrue to the neighborhood.[10]

Additionally, vehicle electrification can reduce greenhouse gas emissions and help cities and businesses meet their climate goals. The exact greenhouse gas reductions that come with replacing a conventional vehicle with an electric one depends on the fuel mix used to generate the electricity. EVs in regions that rely most heavily on coal produce the most greenhouse gas emissions over the life-cycle, and EVs in regions that use higher percentages of renewables and nuclear energy produce fewer greenhouse gas emissions. In the majority of the United States, EVs produce fewer greenhouse gas emissions than equivalent gasoline-powered vehicles achieving 50 mpg. Based on where EVs have been sold, the average EV produces the equivalent greenhouse gas emissions of a vehicle that achieves 73 mpg.[11] EVs' greenhouse gas emissions should continue to improve under the expectation that recent energy trends will be sustained and the electric grid will continue to improve—nationally, electricity produces 20 percent fewer greenhouse gas emissions today than 10 years ago.[12]

This paper focuses on the emissions reduction potential of electrified transportation, but alternative strategies can also reduce criteria air pollutant and greenhouse gas emissions. For examples of low-emission transportation alternatives beyond the scope of electrified vehicles, see **Box 1**.

BOX 1: Beyond Electrification: Alternatives for Improving Air Quality and Greenhouse Gas Emissions

EV adoption can reduce communities' transportation greenhouse gas and criteria air pollutant emissions, but city and regional planners may consider other strategies as well. The "Three-Legged Stool" of emissions is propped up by three components: the fuel efficiency of vehicles, the greenhouse gas content of fuels, and the miles traveled by vehicles (VMT). Switching to EVs is a direct way to improve the emissions performance of two legs (vehicle fuel efficiency and the greenhouse gas content of fuels), but other policy options may also provide emissions improvements.

Notably, promoting EV adoption does not necessarily reduce VMT. However, many other policies and technologies have the potential to do so. A policy such as congestion pricing has the potential to reduce VMT while also promoting improvements on the other two legs of the transportation stool. By placing a fee on vehicles entering areas that are highly trafficked or densely populated, city planners can encourage drivers to consider alternative transit methods, such as carpooling or public transit. Placing more people into fewer vehicles, such as densely-occupied public transit buses, reduces the total number of vehicles traveling over a distance and thereby reduces both greenhouse gas and criteria air pollutant emissions. A congestion pricing program could also incentivize drivers to purchase low- or zero-emission vehicles by reducing or eliminating fees for gas-powered hybrids, EVs, or hydrogen fuel cell vehicles.

City planners can promote multiple mobility options that reduce greenhouse gases and criteria air pollutant emissions. Bicycle share programs have proliferated across most major U.S. cities, often with corporate partnerships that reduce the costs to the cities. Biking and walking can also be encouraged by improving sidewalks or installing dedicated bicycle lanes. These options may help resolve the "last mile" problem of public transit, or the difficulty of transporting passengers from the end of their transit line to their final destination, such as a house or an office. Improving mobility methods will allow residents a greater choice of low-emission travel options.

DEPLOYMENT STRATEGIES MAY BE INFORMED BY DEMOGRAPHICS

Each city has unique attributes and demographics that govern transportation systems. Some cities are densely populated with extensive light rail and transit systems, where others are more sprawling, relying on personal vehicles and large roadways to move people and goods. Understanding how residents commute and what typical travel patterns look like will help city and regional planners develop strategies to extend EV benefits to low-income communities. Demographic information, including the average income of residents, where low-income residents reside, and rates of vehicle ownership, will also inform such strategies.

For example, 94 percent of households in the Kansas City metropolitan area own passenger vehicles,[13] a rate that exceeds the national average (91 percent),[14] and the total number of Kansas City regional commutes in personal vehicles in 2016 was 28 times greater than those made via public transportation. However, public transit provides an enduring value to low-income residents; more than 70 percent of public transit commuters earn less than $25,000 per year. Of the residents that use public transit, the majority are defined here as low-income. Even though the region is heavily invested in light-duty vehicles, further electrification of both light-duty vehicles and transit buses could lessen the health burdens of transportation on low-income communities that are more likely to live near major roads.[15]

Some U.S. transit organizations have already prioritized deploying electrified transportation to benefit low-income and minority communities. The San Joaquin Valley Transit Department established an all-electric bus rapid transit route to low-income communities in August 2017 with the explicit purpose of "providing major improvements in lowering both noise and air pollution" to residents along the bus route.[16] On a larger scale, Seattle's King County Metro developed a feasibility study that led to a decision to purchase more than 100 all-electric buses, and eventually to full electrification[17] — the study recommends improving air quality and public health incomes in low-income and minority communities by prioritizing electrified transportation in these communities.[18] For a case study on King County Metro's process of analyzing and adopting all-electric transit buses, see C2ES's companion fact sheet "Transitioning to

Electrification: Case Studies and Strategies."

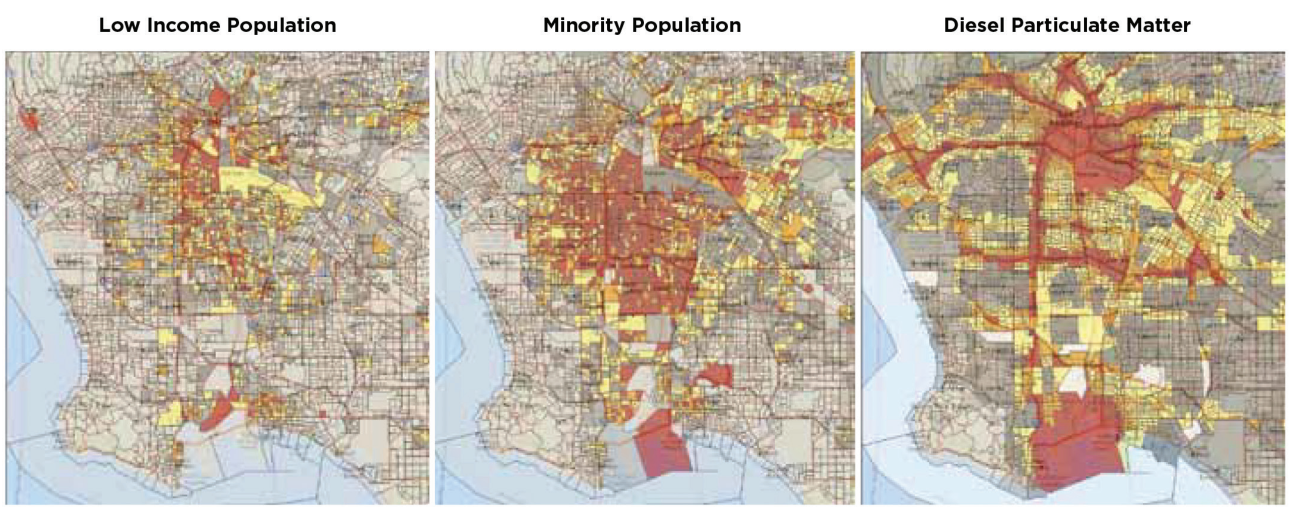
Residential charging station access is important to making EV ownership easy and inexpensive. However, home ownership rates and the housing stock in each city also affect EV deployment strategies. The majority of U.S. residents earning less than the median national income do not own their homes.[19] Renters may not have permission from landlords to install private charging stations, or they may prefer not to make an investment in a property that they do not own. Similarly, residents that live in multi-unit dwellings may not have access to private parking or guaranteed spaces, even if they own their homes. Garage parking spaces may not be guaranteed, and curbside charging is typically not available as of 2017. Planners may consider such critical demographic information when developing strategies to promote EV deployment in low-income communities (see **Box 2** for more on persistent EV barriers for low-income communities).

The City of Los Angeles recently put demographic data into action by cross-referencing census data with areas demonstrating high criteria pollutant emissions from diesel emissions. The resulting images showed a correlation between areas of low-income or high minority populations and low air quality (see **Figure 1**). City planners relied on these data when choosing locations for a new public EV car sharing program in the city's low-income communities with poor air quality that would benefit from an influx of zero emission vehicles. BlueLA, which debuted in June 2017, will deploy 200 vehicles that directly eliminate tailpipe emissions in low-income communities.

BOX 2: EV Ownership Barriers are Heightened for Low-Income Communities

Broad EV adoption has encountered several barriers, including typically higher upfront prices for the vehicles, consumer concerns over finding a charging location, a lack of information about EVs, and more. The EV market has been steadily overcoming these barriers over recent years, but the challenges of adopting EVs are particularly problematic for low-income communities. Price premiums are comparatively higher, residents of multi-unit dwellings may not be able to charge vehicles at their residences, and EVs may not be available through the used vehicle market that would accommodate low-income buyers. Though EV deployment has increased in recent years, low-income buyers are more likely to encounter the traditional barriers to EV adoption.

FIGURE 1: Census tracts comparing low-income and minority populations in Los Angeles with diesel particulate matter emissions



Maps of Los Angeles by low-income and minority populations suggest a correlation with diesel particulate matter.

(Source: Union of Concerned Scientists, "Delivering Opportunity," accessed 6/6/17)

THREE ELECTRIFIED VEHICLE TYPES

Nearly any vehicle can be electrified, but this paper assesses three types: light-duty passenger vehicles, public transit buses, and school buses. Each vehicle type has unique deployment considerations and differing relationships with low-income communities.

- **Light-duty passenger vehicles:** In most of the U.S., light-duty passenger vehicles account for the great majority of highway vehicle miles traveled (89 percent).[20] According to the Federal Highway Administration, EVs can meet greater than 95 percent of drivers' daily commutes (depending upon the availability of workplace charging), which most commonly are between 16 and 30 miles in one direction. EVs are available in two basic configurations—battery electric vehicles (BEVs) that run exclusively on electricity and plug-in hybrid electric vehicles (PHEVs) that have a more limited battery range than BEVs, but can use a gasoline-powered backup engine or generator to extend the vehicle range. BEVs may be more appropriate in locations with extensive charging networks or easy access to charging stations, whereas PHEVs may be better suited to regions that lack sufficient charging or that require driving distances that exceed the typical range of a BEV. Deployment strategies may incorporate efforts to encourage consumers to purchase EVs, or alternately may promote strategies that broaden EV access to specific communities through targeted car-share or ride-hailing programs.
- **Public transit buses:** Transit buses offer a standard alternative to passenger vehicle travel. They are widely deployed, with 1,150 unique bus systems operating in metropolitan and urban areas around the country.[21] Transit buses allow for residents to bypass vehicle ownership or relay less on driving, and consolidating many people into one vehicle can improve air quality.[22] BEV transit buses offer the benefit of zero tailpipe emissions, adding no additional criteria air pollutant emissions to the communities that rely on the vehicles, such as low-income neighborhoods.[23] Electric transit buses are currently available through manufacturers, notably Proterra and BYD, that produce purpose-built electric vehicles rather than converting existing diesel buses to electricity. Battery ranges now extend beyond 200 miles, making these vehicles suitable to most transit systems.
- **School buses:** Children in diesel-powered school buses are particularly vulnerable to low air quality due to their proximity to tailpipe emissions and the concentrated health effects that these emissions have on children. A 2001 study by the Natural Resources Defense Council found that children in the back of diesel-powered school buses could be exposed to toxic pollutants at four times the rate of people driving in the cars behind diesel-powered school buses, and that riding in school buses powered by diesel could pose 46 times the rate of "significant" risk for cancer.[24] A more recent 2015 study performed for CARB found that air pollution in diesel-powered school buses persists in putting children in danger.[25] More than half of all U.S. students, or greater than 25 million children, ride in school buses.[26] As with public transit buses, all-electric school buses' lack of tailpipe emissions could reduce the harmful health impacts of criteria air pollutants, particularly by reducing idling emissions.[27] A 2015 study by the University of Michigan found that reductions in diesel tailpipe emissions had widely positive effects on children, from improved lung functions to reduced absenteeism.[28] Electric school buses are recently available in the North American market, with purpose-built EVs deployed in a few school districts in the U.S. and Canada and preparing for adoption in others.

CONSIDERATIONS AND CALCULATIONS: HOW TO DERIVE LOCAL COST AND EMISSIONS ESTIMATES

City planners and fleet managers must make a compelling case that switching to EVs make sense, environmentally and financially. This section lays out the types of information and the calculations that will help decision-makers take action on EV adoption. For a more detailed example of how to use cost and emissions calculators, see **Box 3** below.

Additional to the factors and information described in the following sections, city planners may benefit from working with fleet managers to gather accurate information about the characteristics of their heavy-duty fleet vehicles. The number and age of vehicles, average lifespan, the fleet's average vehicle miles traveled, and fuel use will help establish a comprehensive description of the fleet's uses and costs. For light-duty vehicles, regional planners may consider the present and future charging needs of residents, such as ensuring a mix of publicly available Level 2 and DC fast chargers, as well as ensuring that lengthy charging gaps along popular travel corridors are filled. Future needs may require higher-power DC fast charging stations, buildings with conduit already laid for charging cables, or simply ensuring enough redundant charging is built that drivers won't face delays or lines for access to public charging stations.

UNDERSTANDING COST OF OWNERSHIP'S MANY COMPONENTS

Calculating the overall costs of a new vehicle enables decision makers to grasp the total investment the vehicle will require. This paper identifies three main cost categories: purchase price, fuel, and operations and maintenance. EVs are often framed as more expensive as a function of focusing on the purchase price of a new vehicle. However, purchase price does not account for the total costs that go into owning a vehicle. The costs of fuel and operations and maintenance can exceed the purchase price of some traditionally-fueled vehicles, whereas EVs are typically less expensive to maintain and operate.

Purchase Price

Planners can estimate the purchase price of a new light-duty vehicle through Kelley Blue Book's online search tool. The tool offers a fair market purchase price range, based on the manufacturer's suggested retail price (MSRP) and regional factors, such as taxes and fees. The search tool does not include incentives and other financial assistance that may also be available through government agencies or electric utilities (see "Funding for Emissions Reductions Projects" for more on incentives).

BOX 3: Using and Refining a Cost Calculator: The AFLEET Tool and Targeted Research

Estimating the total cost of ownership (TCO), air quality, and greenhouse gas emissions impacts of adopting a range of new vehicle types requires a robust cost calculator. The U.S. DOE's Argonne National Laboratory provides the free Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) tool that can be used to quantify the environmental and economic impacts of new fuels and vehicle technologies. The tool combines data from several different models, including the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model to estimate greenhouse gas emissions and the Motor Vehicle Emissions Simulator (MOVES) to estimate other tailpipe emissions, as well as adding some localized information. This tool enables users to easily modify data sources to estimate the potential emissions and costs reductions for an existing fleet adopting alternative fuel vehicles. AFLEET can also be a useful tool that researchers can supplement with targeted research on specific cost and emissions estimates, such as the price of fuel, the costs of criteria air pollutants (based on the health impacts of specific pollutants on regional populations), or regional greenhouse gas emissions. Whenever possible, figures that are specific to a city or region (such as the typical distance driven by a transit bus each year) should be included to make estimates as accurate as possible.

For more information on available modeling tools, see the Glossary of Modeling Tools, and for more information on the uses of AFLEET, see: https://www.afdc.energy.gov/uploads/publication/afleet_measures_impacts.pdf

Light-duty vehicles used for estimates should have similar traits, and they should be broadly available at dealerships. The Nissan Leaf and Tesla Model S are two of the best-selling BEV models since 2009, and the Chevy Volt is the best-selling PHEV model in the same timeframe. However, the Leaf purchase price (and driving range) is approximately half that of a Model S, so the Leaf may be more applicable to low-income communities' needs. A gasoline-powered vehicle that has the size and features similar to the desired EV may provide the best comparison. For example, Ford and Chevy both offer PHEV versions of their Focus and Cruze, making these models easily comparable. Because all of these vehicle models are widely sold, excluding Tesla models (which cannot be sold directly to consumers in numerous states), they are likely widely available on the used vehicle market, which may allow additional low-income buyers to purchase them. Using the Kelley Blue Book vehicle locator, the purchase price of a used vehicle can be determined for specific regions in the same way new vehicles are estimated. Discounts and incentives for new and, in rare instances, used EV purchases and charging infrastructure differ by state and utility service territory. To assess what EV discounts and incentives may be available in a particular location, city and regional planners can visit the U.S. Department of Energy's Alternative Fuels Data Center (AFDC). The AFDC lists state incentives that apply to EVs, such as rebates for the purchase or lease of an EV offered by a state or utility.

The purchase prices for new heavy-duty vehicles can be found through varied resources. Argonne's AFLEET tool provides generalized cost estimates that are typically accurate for a range of established vehicles, such as CNG transit and school buses. Because purpose-built electric buses are relatively new and costs are partially tied to rapidly falling battery prices, the actual prices may differ from AFLEET's estimates. Estimated purchase prices can be derived through manufacturers' promotional materials or by contacting the manufacturer directly. To estimate how costs will apply and compare them with other vehicle types, case studies and feasibility studies can help determine the costs of heavy-duty EVs. For example, feasibility studies from Washington state's King County Metro compare their estimated electric transit bus purchase costs with their business-as-usual diesel and diesel-hybrid buses, and a feasibility study by the Vermont Energy Investment Corporation does the same for electric school buses in New England.[29]

Fuel Costs

Fuel accounts for a significant cost over the lifetime of a vehicle. According to calculations by C2ES, a diesel-fueled school bus can spend more than $70,000 over the lifetime of the vehicle, or approximately 78 percent of the bus's average purchase price.[30] Electrification can provide considerably less expensive fuel for light- and heavy-duty vehicles. A study by transportation consultancy CalStart estimates that electricity for transit buses may cost less than 75 percent of the cost of diesel and less than half the cost of CNG.[31] Prices can vary by region, but the regions with the largest price differences between diesel or CNG and electricity will financially favor EV adoption the most.[32]

Fossil fuel prices can vary greatly over time. Though both oil and natural gas prices are at near historic lows, however, their volatility has in the past left fleet managers relatively exposed to market fluctuations. According to the U.S. Energy Information Administration (EIA), gasoline prices fell by nearly 70 percent from September 2012 to February 2016, and have since risen back up to approximately 50 percent of September 2012 prices.[33] By contrast, electricity prices are relatively stable, with residential prices remaining nearly constant in real dollars over the past two decades.[34] City planners must make assumptions about the cost of fuel in the future, either by forecasting prices or simply accepting a current price as a default.

Fuel prices for each type of vehicle are available as default values through Argonne's AFLEET tool. For more specific results, researchers can turn to companies that specialize in collecting energy price data:

- Current gasoline and diesel prices can be determined in each state by using the American Auto Association's price locator.
- CNG prices in each state are available through natural gas vehicle advocates CNG Now, or by converting spot prices from the EIA's Henry Hub index.
- Electricity prices are determined through public rate filings and are posted at utilities' websites. Many utilities offer discounted rates for EVs and time-of-use rates that encourage overnight charging. Larger energy consumers, such as EV transit and school bus operators, may subscribe to larger non-residential plans.

Calculating costs also requires accounting for the infrastructure needed to fuel the vehicles. The costs of fuels may depend upon whether the fueling stations are public or private, such as at a fleet facility. For gasoline-powered vehicles owned by individual residents, gasoline stations are readily available and do not add any costs to their TCO. However, EV owners often choose to install a \$500-\$1,000 Level 2 charging station at their residences, but this investment is not required. A combination of public and workplace charging and lower-powered Level 1 charging could suffice at no additional installation cost to drivers. Public and workplace charging is typically costlier than residential charging due to trenching (digging and hardening conduit for wires), interconnection with utilities, and more expensive equipment (total equipment and installation costs for Level 2 charging stations typically start at \$3,000[35] and can exceed \$10,000).[36]

Fleet operators may be more likely to need specialized fueling infrastructure to meet the large fueling demands of a vehicle fleet. Diesel-powered bus fleet operators may already own fueling infrastructure because diesel is an incumbent fuel. By contrast, CNG bus operators may need to install expensive fueling infrastructure, which may add at least \$400,000 to a project, which may include labor, equipment, and capital costs for vehicles and fueling infrastructure.[37] Electric school buses will likely be able to use less expensive Level 2 charging stations because their idle time allows for longer charging sessions, but transit buses may require fast charging. The costs of installing DC fast charging may range significantly, from approximately \$10,000 to more than \$100,000 per station for light-duty vehicles and more than \$300,000 for heavy-duty vehicles, though notably each of these stations can serve multiple vehicles. City planners should consider using publicly available guidebooks to site and install charging stations effectively and at the lowest costs, such as guidebooks produced by C2ES for EV charging and CNG fleets.[38]

Heavy-duty vehicles that need to recharge their large batteries quickly, such as transit buses that charge on route, will likely incur demand charges, or fees levied by utilities based on the largest amount of electricity used within a defined period. Demand charges can significantly increase the cost of electricity, in some cases making fueling EVs more expensive per mile than diesel-powered buses.[39] Planners may be able to reduce demand charges by spreading charging times throughout the day between buses or by charging overnight, which may be possible depending upon the number of available buses, the rate of recharging, the length of bus routes, and the capacity of the buses' batteries.

The U.S. DOE offers a tool to help estimate the cost of installing and operating alternative-fuel vehicle fleets and the associated infrastructure. The Vehicle and Infrastructure Cash-flow Evaluation (VICE) model allows users to input data specific to their needs to estimate break-even costs of switching to CNG compared to gasoline- and diesel-powered vehicles.

Operating Costs

Operating costs are highly variable and consist of many components, typically including maintenance, depreciation, insurance, taxes and fees, and sometimes the cost of fuel (listed separately here). The costs of operating and maintaining a vehicle can account for a significant percentage of a vehicle's TCO. For example, a 2013 Ford Focus may cost approximately \$10,000 to purchase, but according to auto analyst Edmunds' "True Cost to Own" calculator, the vehicle will cost approximately \$20,000 to operate and maintain over five years, excluding fuel costs.[40] EV maintenance costs are typically significantly lower than gasoline- and diesel-powered vehicles because there are fewer components that need replacement and lubrication, and air filters are not needed. The American Automobile Association confirmed the low costs of maintaining EVs in its evaluation of 2016 vehicles' TCO, though noted the higher-than-average rate of depreciation in the EVs' values.[41]

EV batteries do represent a large investment, and replacing a new light-duty battery can be expensive for vehicle owners. Continuing to use the Nissan Leaf as an example, a battery pack costs approximately \$6,000 to replace. Conservative estimates for BEV operations and maintenance costs typically include the cost of replacing a battery once in the lifetime of a car. This assumption is built into the AFLEET model's operating and maintenance costs for EVs. Many automakers provide warranties for EV batteries, though the warranty may not last the full lifetime of the vehicle. Heavy-duty EV fleet operators, such as school districts and county transit agencies, also build in a one-time battery replacement into their vehicles' TCO. If an EV does not need a battery replacement, the TCO would improve substantially relative to conventionally-fueled vehicles.

Specialized heavy-duty buses require additional operation and maintenance costs. Trained drivers, mechanics, and first responders for CNG and EV buses may add costs beyond the typical operating and maintenance costs required for diesel bus fleets. City planners can contact local Clean Cities coalitions, the implementation program of the U.S. DOE's Vehicle Technologies Office, for more information about regional operations costs. Estimated operating costs are also included in Argonne's AFLEET tool for each fuel type and vehicle class.

UNDERSTANDING CRITERIA AIR POLLUTANTS' HIDDEN HEALTH COSTS

The EPA has identified six pollutants, commonly called "criteria air pollutants" that degrade air quality: carbon monoxide, lead, ozone, nitrogen dioxide, particulate matter, and sulfur dioxide. These pollutants are emitted from many sources, including tailpipes, and they create health burdens that are borne by the general population that breathe the degraded air.

Analysts and planners can determine the hidden health costs that vehicles are creating by designating financial costs for each air pollutant. Each pollutant has been assigned a dollar amount per gram to place a cost on their health effects. The National Highway Traffic Safety Administration (NHTSA) supplies figures for many of these pollutants in its federal fuel economy regulations. For example, carbon monoxide is considered less dangerous when emitted in open air than particulate matter, so carbon monoxide is assigned no health cost per gram emitted, whereas a gram of fine particulate matter produces 40 cents of detrimental health consequences to nearby populations.

Determining the costs and quantity of criteria pollutants emitted by different vehicles requires assumptions and detailed information about the age, location, miles driven, vehicle class, and fuel for each vehicle. For example, ground-level ozone is created by chemical reactions between NOx and VOC in the presence of sunlight. The chemical reaction is affected by temperature, so warmer, sunnier locations are more impacted by the same NOx and VOC emissions than cooler locations. CNG buses may produce fewer ozone emissions than diesel-powered buses, but they emit far greater quantities of carbon monoxide. The lack of any price on carbon monoxide emissions, however, may make CNG buses a more cost-effective solution when accounting for health costs. The timing of vehicle purchases also impacts air pollutant emissions as light-duty gasoline-powered vehicles will improve considerably due to the implementation of Tier 3 emission standards that are being implemented beginning in 2017.[42]

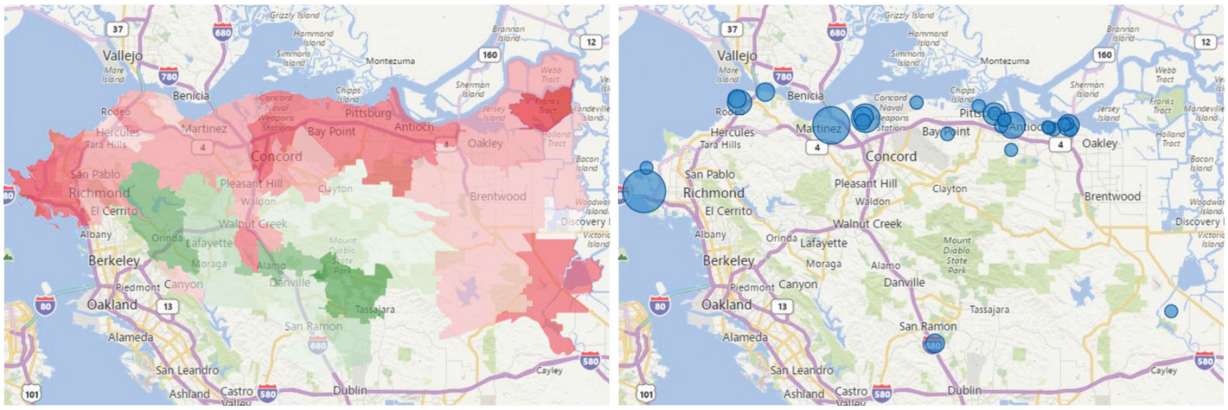
Sorting out the quantity of tailpipe emissions and health costs can be complex and requires localized information. The AFLEET tool uses the U.S. EPA's Motor Vehicle Emission Simulator (MOVES) model to estimate criteria air pollutant, greenhouse gas, and air toxics emissions for mobile sources at the national, county, and project level.[43] AFLEET also provides information about the costs of each criteria air pollutant by county for each vehicle type. However, the tool only measures strict tailpipe emissions, not accounting for the "long tailpipe" that BEVs (and PHEVs operating only on electricity) have considering the related emissions from power generating facilities.

The impact of power plant emissions on local populations can be highly variable, depending upon the generation mix, location of generating facilities relative to population centers, and prevailing wind patterns. General quantities of criteria air pollutants and health costs from power plant emissions can be calculated by combining several pieces of information that pertain to electric power generation in a region, and wherever possible local information can be added. For instance,

- The U.S. EPA's state electricity profiles provide nitrogen oxides (NOx) emissions produced per megawatt-hour while generating electricity for public consumption. Similar information based on individual electric grids can be found through the U.S. EPA's eGrid and Power Profiler tools.
- The Electric Power Research Institute's Regional Economy, Greenhouse Gas, and Energy Model for the United States (US-REGEN) provides criteria air pollutant emissions rates for each fuel type relative to the NOx produced.
- Once criteria air pollutant emissions have been quantified, prices can be applied. NHTSA provides criteria tailpipe costs for each criteria air pollutant. Since power plant emissions' impacts on public health are highly variable, using tailpipe emissions costs can be seen as a "worst case," in which emissions directly impact nearby populations as they would from a vehicle's tailpipe.

The types of criteria air pollutants emitted by tailpipes may differ considerably from power plant air quality emissions, but the health impacts for electrified transportation are lower than for diesel, CNG, or diesel hybrid vehicles. Electrifying transportation may yield significant reductions in pollutants that create ground-level ozone

FIGURE 2: Comparison of Income and Greenhouse Gas Emissions in Northern California



Map on left shows income by county (green is high, red is low), the map on the right shows greenhouse gas emissions (larger bubbles are higher levels of emissions).

(sSource: Atlas Public Policy, July 2017)

or in particulates, even factoring in Tier 3 emissions that will improve the criteria air pollutant performance of light-duty vehicles. The electrification of non-road vehicles could also produce significant improvements in regional air quality.[44]

For low-income communities to benefit from electrified transportation, planners must ensure that the power for new EVs is not produced disproportionately in low-income neighborhoods and does not create local health impacts. If the marginal health costs of increased power production in low-income neighborhoods are greater than the estimated benefits that accrue to the neighborhoods, EVs may not be a valuable investment to reduce air quality health impacts. For example, a comparison of low-income counties across from San Francisco Bay and greenhouse gas emissions produced in those counties suggests a correlation between low-income communities and proximity to power plant emissions (see **Figure 2**).

The scenario shown above is not necessarily representative of most regions in the United States, but rather illustrates the concept that low-income communities may still suffer from high levels of air pollution due to EV deployment if power generation is disproportionately sited in low-income communities and is produced by fossil fuel sources.

GREENHOUSE GAS EMISSIONS VARY BY REGION

Greenhouse gas emissions from transportation can vary depending upon the system of calculation. Tailpipe emissions simply measure the average greenhouse gas content of gasoline, diesel, or natural gas and apply the figure to the fuel economy of the vehicle. Lifecycle emissions take many more factors into account, including upstream fugitive, refining, and shipping emissions. The latter may provide more accurate information, but also requires significantly more data inputs. For the purposes of simplicity, this section will address tailpipe emissions.

When measuring tailpipe emissions, location does not impact the greenhouse gas performance of gasoline, diesel-, or natural gas-powered vehicles. However, the electricity that powers EVs is critical to deriving greenhouse gas output, and electricity mixes can vary significantly by location. The Union of Concerned Scientists used U.S. EPA data to show the equivalent greenhouse gas emissions of a typical EV compared to a similar gasoline-powered car, and the range of outcomes can be quickly understood (see **Figure 3**). EVs in regions that rely more prominently on fossil fuels, particularly coal, have lower fuel economy greenhouse gas equivalents than EVs in regions that use more nuclear and renewable energy.

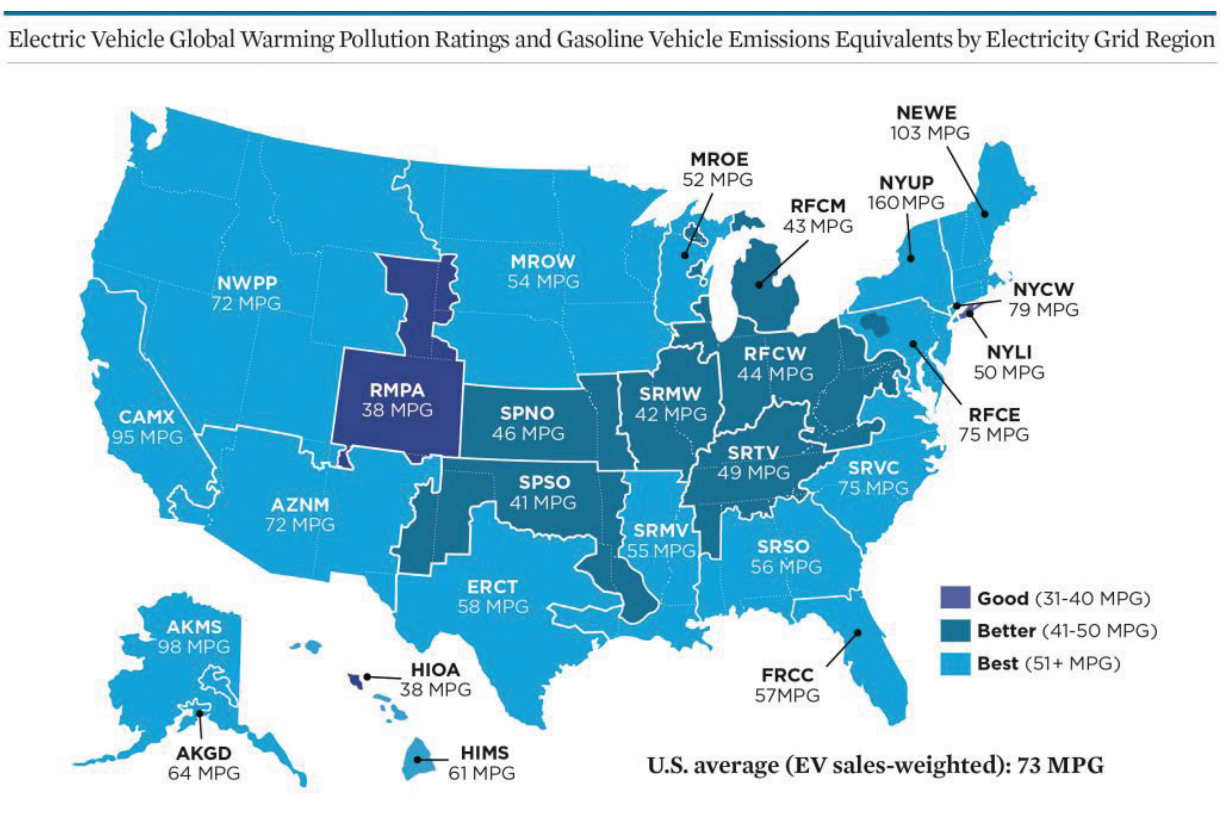
There are several tools that help determine the greenhouse gas emissions for EVs and for gasoline-, diesel-, and natural-gas powered vehicles. The simplest method for light-duty vehicles is to use the U.S. Department of Energy fuel economy website, fueleconomy.gov. The website permits users to estimate the greenhouse gas emissions in grams per mile for all light-duty vehicle models. The greenhouse gas estimator also uses the U.S. EPA's Power Profiler to provide location-specific emissions information.[45]

Heavy-duty vehicle emissions data can be estimated using several different tools. Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) model assesses the full lifecycle of transportation emissions, from vehicle recovery to disposal. The U.S. EPA's Motor Vehicle Emissions Simulator (MOVES) model allows users to input on-road and off-road information, such as location and vehicle operating characteristics. Both models are used in the AFLEET tool.

The U.S. EPA's Diesel Emissions Quantifier (DEQ) tool, which is often used to estimate potential emissions reductions for proposed projects under the Diesel Emissions Reductions Act (DERA), can be used to estimate heavy-duty diesel and CNG transit and school bus greenhouse gas emissions. Similar to the MOVES model, users can input on-road and off-road information, such as location and vehicle operating characteristics. The DEQ tool has a unique consideration, however—its estimates of CNG emissions are notable outliers from other estimates, including the GREET model's outputs and a 2013 study[46] by MJ Bradley and Associates.

Deriving the greenhouse gas emissions of BEV buses can be accomplished directly by using the tailpipe calculation method, combining the greenhouse gas emissions profile of a region with the electric motor efficiency of electric buses. The U.S. EPA's Power Profiler tracks carbon dioxide emissions for grids around the United States, providing local emissions profiles (1.67 pounds per kilowatt-hour in Washington, D.C., for instance). The motor efficiency of a BEV can be estimated by calculating the energy required to travel a certain distance. For example, a transit bus that needs 440 kilowatt-hours to travel 250 miles uses 1.76 kilowatts per mile. With these figures, city planners can definitively calculate heavy-duty EV greenhouse gas emissions on a local level. In this example, an all-electric bus would produce 1.54 pounds of carbon dioxide per mile in the nation's capital, or approximately half the greenhouse gas emissions of a diesel-powered bus.

FIGURE 3: Equivalent Greenhouse Gas Emissions of an EV to a Gasoline-Powered Car in MPG



EVs' greenhouse gas emissions range by electric grid, but most of the nation lives in an area where the average EV emits greenhouse gas at an equivalent of better than 50 miles per gallon.

(Source: Union of Concerned Scientists, "New Numbers are in and EVs are Cleaner than Ever," accessed 6/7/17)

AVAILABLE FUNDING FOR PROJECTS THAT REDUCE OR ELIMINATE TAILPIPE EMISSIONS

The greatest concern that some fleet managers and city planners have expressed is the upfront cost of purchasing EVs. Price premiums are one of the greatest barriers to EV adoption. Research from the International Council on Clean Transportation shows that cities that have the greatest financial incentives for reducing consumers' EV purchase costs typically experience the highest levels of EV adoption (though the financial incentives are nearly always attributable to states). Reducing the purchase costs of EVs will make electrified transportation more financially competitive with traditionally-fueled vehicles and encourage uptake by city planners, fleet managers, and residents (see **Box 4**). Funding resources are available to help offset the purchase costs of new vehicles or the purchase and installation costs of EV charging infrastructure for light- and heavy-duty vehicles.

For light-duty vehicles, the federal government offers the most noteworthy incentive, a tax credit worth up to $7,500 for the purchase or lease of a new EV. The tax incentive may not always fully apply, however. Taxpayers must accrue enough tax liability to be able to apply the credits, which may not benefit low-income residents. The incentive also applies only to new vehicles, which does not benefit buyers of used vehicles. The credits are also limited by manufacturer; once an automaker has sold 200,000 vehicles, the credits sunset after a year. Several automakers have already passed the 100,000-vehicle threshold.

Several states and utilities offer EV purchase incentives, as well as incentives for installing residential and public charging infrastructure. Some vehicle purchase incentives approach or exceed the funding level of the federal incentive, such as Colorado's rebate worth up to $6,000 or short-term rebates worth up to $10,000 from utilities in Missouri and Ohio that partnered with Nissan. California offers a rebate that varies based on income, with low-income families eligible for higher incentives and high-income families' rebates capped. Electric utility Southern California Edison offers an innovative $450 credit for used EV buyers, the first entity to make EV purchase incentives available to the used vehicle market.[47] For a full list of incentives, the U.S. DOE provides a regularly updated list at the Alternative Fuel Data Center. The list includes information on where residents, businesses, and city and state agencies can find incentives for the purchase of EV charging equipment and any restrictions on the funding, such as a requirement to make the charging station publicly available.

Funding for heavy-duty EVs is available largely through federal programs. Some funding is specific to reducing heavy-duty diesel emissions, such as money from the federal Diesel Emissions Reduction Program (DERA), but does not specify which low-emission technologies are required. Some funds require low- or no-emission technologies, such as the Federal Transit

BOX 4: Putting Funding into Action: Case Studies on EV Deployment Projects

Pilot projects and early adopters are using publicly available funding resources to reduce the upfront costs of deploying EVs. A pilot project in California used DERA funding and the revenue from the state's cap-and-trade program to help finance the conversion of six diesel school buses into EVs. The project is exploring new revenue streams to improve the buses' total cost of ownership (TCO), including vehicle-to-grid and vehicle-to-building services that transmit stored energy out of the buses. King County Metro in Washington state used federal "Low No" funding to finance most of a $4.7 million pilot project to test EV transit buses. The test was successful, initiating a review of the entire transit bus system that led to King County Metro committing to purchase more than 100 BEV transit buses in the near term and a complete switch to all-electric buses by 2025. These sources of funding, as well as billions of dollars administered through two separate Volkswagen settlement funds, may be available for deploying EVs and charging infrastructure.

For more information on these case studies and on innovative strategies to advance consumer EV uptake, see the C2ES companion brief *Transitioning to Electrification: Case Studies and Strategies*. To learn more about the funding sources that helped enable these projects, see the C2ES companion brief, *Transitioning to Electrification: Funding Resources*.

Authority's suitably named "Low No" grant program for transit buses. The Congestion Mitigation and Air Quality (CMAQ) program provides funding to areas in nonattainment, or areas that have been identified as exceeding limits for at least one criteria air pollutant defined by National Ambient Air Quality Standards. States without nonattainment or maintenance areas may use a minimum apportionment of CMAQ's $2.4 billion annual budget to spend on transit capital expenditures that have an air quality benefit.

Federal funding can be generally applied through block grants, or can be specific to:

- Transit — Low No grants from the FTA;
- School buses — The DERA program allocates funding specific to school buses; or
- Infrastructure — EV charging infrastructure is eligible for U.S. Department of Transportation TIGER grants.

The U.S. EPA's settlement with Volkswagen also established $2.7 billion for diesel engine or vehicle replacement, divided between states and territories where the faulty vehicles were on roads. The automaker also established a subsidiary, Electrify America, that will be investing $2 billion over the next decade to extend EV charging infrastructure, expand access to electrified transportation, and promote the benefits of EVs. For a full description of the VW Settlement, see C2ES' fact sheet linked in **Box 5**.

CONCLUSION AND RECOMMENDATIONS

Low-income communities experience disproportionately high health costs from vehicle tailpipe emissions. These communities could benefit from the deployment of EVs, a versatile new technology that produce no tailpipe emissions. For light-duty vehicles, school buses, and transit buses, EVs produce lower criteria air pollutant costs and fewer greenhouse gas emissions. Even though the price of EV batteries is falling rapidly, the purchase price of an EV is nearly always more expensive than a gasoline-, diesel-, or natural gas-powered equivalent. Though fuel costs and operations and maintenance costs are less expensive for EVs, the savings do not typically make up the difference for the upfront price premium of the vehicles' batteries. However, monetizing the hidden improvement in health costs helps reduce the difference in TCO between EVs and their fossil fuel-powered equivalents.[48]

Reducing the upfront costs of vehicles, finding innovative revenue streams, or developing new strategies to encourage consumer uptake will help make EVs more financially competitive. Once total cost of ownership parity is achieved, EVs will provide a much more compelling solution for expanding the triple benefit of cost-effectiveness, fewer greenhouse gas emissions, and reduced air quality pollutants to low-income communities.

However, city planners can facilitate the transition to electrified transportation by considering the following steps:

- Define the targeted low-income communities and how electrified transportation would impact the communities (taking into account where electricity is generated and the emissions consequences of marginal increases in electricity output);
- Quantify the air quality and greenhouse gas emissions reductions goals that they could achieve by deploying EVs;
- Determine the feasibility and costs of meeting those goals;
- Locate and secure funding for new vehicles or vehicle programs;
- Connect stakeholders, including but not limited to departments of transportation, community groups, and private investors; and
- Implement and monitor projects to meet emissions goals.

Putting these ideas into action will require coordination of transportation planners, city managers, community coordinators, and private enterprise. The recently launched BlueLA program in Los Angeles provides an excellent example of coordination among stakeholders.[49] Following Mayor Eric Garcetti's expressed interest in reducing greenhouse gas emissions and improving air quality in low-income communities, laid out in the city's "Sustainable City pLAn," planners secured a $1.7 million grant from the statewide California Climate Investment. Bolloré, a French company that runs car share programs in European cities and in Indianapolis, will invest approximately $10 million in BlueLA. The Los Angeles Department of Transportation has helped develop proposed locations and interest in low-income communities through partnerships with community organizations representing low-income residents and the ethnic groups residing in low-income neighborhoods. The BlueLA program will provide 200 all-electric vehicles and charging access at 100 charging locations in low-income communities across the city.

With the proper alignment of planning, technology, and funding, electrified transportation can benefit all community residents. For additional resources that will help inform and drive decision-making processes, city planners can consult **Box 5** below.

BOX 5: Additional Resources

Transitioning to Electrification: Case Studies and Strategies: https://www.c2es.org/document/transitioning-to-electrification-case-studies-and-strategies/

Transitioning to Electrification: Funding Resources https://www.c2es.org/document/transitioning-to-electrification-funding-resources/

Volkswagen Settlement Funding: What Cities Should Know: https://www.c2es.org/publications/volkswagen-settlement-funding-what-cities-should-know

2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards: https://www.gpo.gov/fdsys/pkg/FR-2012-10-15/pdf/2012-21972.pdf

Strategic Planning to Implement Publicly Availably EV Charging Stations: A Guide for Businesses and Policymakers: https://www.c2es.org/publications/strategic-planning-implement-publicly-available-ev-charging-stations-guide-businesses

Strategic Planning to Enable ESCOs to Accelerate NGV Fleet Deployment: A Guide for Businesses and Policymakers: https://www.c2es.org/publications/strategic-planning-enable-escos-accelerate-ngv-fleet-deployment-guide-businesses-policy

King County Equity Impact Review Tool: http://www.kingcounty.gov/elected/executive/equity-social-justice/tools-resources.aspx

What's afoot in DOE's Clean Cities: AFLEET: http://www.afdc.energy.gov/uploads/publication/afleet_measures_impacts.pdf

Peak Demand Charges and Electric Transit Buses: http://www.calstart.org/Libraries/Publications/Peak_Demand_Charges_and_Electric_Transit_Buses_White_Paper.sflb.ashx

Foothills Transit Battery Electric Bus Demonstration Results: http://www.afdc.energy.gov/uploads/publication/foothill_transit_beb_demo_results.pdf

Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet: http://kingcounty.gov/~/media/elected/executive/constantine/news/documents/Zero_Emission_Fleet.ashx?la=en

Electric School Buses: Feasibility in Vermont: https://www.veic.org/docs/resourcelibrary/veic-electric-school-bus-feasibility-study.pdf

GLOSSARY OF MODELING TOOLS

AFLEET: The Alternative Fuel Lifecycle Environment and Economic Transportation Tool was developed by Argonne National Laboratory for the U.S. DOE's Clean Cities program and its stakeholders. The tool allows users to combine local and national inputs to estimate fleet expenses, criteria air pollutant emissions, and greenhouse gas emissions.

GREET: The Greenhouse gases, Regulated Emissions, and Energy use in Transportation tool is a lifecycle assessment model developed by Argonne National Laboratory to evaluate greenhouse gas emissions outputs and energy consumption for advanced vehicle technologies and alternative fuels.

MOVES: The Motor Vehicle Emissions Simulator is the U.S. EPA's emission modeling system for estimating mobile source emissions at the national, county, and project level for criteria air pollutants, greenhouse gases, and air toxics.

VICE: The Vehicle and Infrastructure Cash-Flow Evaluation was developed by the National Renewable Energy Laboratory for fleet managers to assess the financial soundness of converting their fleets to run on CNG. The model allows users to choose among several financial and vehicle options to estimate project payback, petroleum displacement, and annual greenhouse gas savings.

DEQ: The Diesel Emissions Quantifier is a tool that the U.S. EPA offers to help fleet managers estimate the emissions outputs for medium- and heavy-duty vehicles. The tool uses a baseline fleet for diesel and alternative fuel vehicles to estimate greenhouse gas and air quality benefits of reducing diesel emissions and is often used to assess emissions reductions for DERA projects.

Power Profiler: The U.S. EPA's Power Profiler draws location-specific data from its eGrid database to provide the feedstocks for regional energy production. The eGrid database is divided into more than a dozen distinct regions with distinct energy and emissions profiles, including greenhouse gas and criteria pollutant emissions profiles.

US-REGEN: The U.S. Regional Economy, Greenhouse Gas, and Energy model developed by the Electric Power Research Institute combines models that track U.S. electric production and U.S. economic factors. The REGEN can model a wide range of environmental and energy policies in both the electric and non-electric sectors.

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