Fueling a Clean Transportation Future

Chapter 4: Electricity

Union of Concerned Scientists

The clean transportation system of the future will be powered significantly by electricity. Major studies have found that a large-scale transition to EVs powered by batteries or fuel cells is required to achieve the deep emissions reductions necessary by mid-century to avoid the worst effects of climate change

(Williams et al. 2014; Yang et al. 2014; NRC 2013). Battery EVs have no tailpipe emissions; instead the emissions associated with using them come primarily from the source of power used to charge the batteries. EVs powered by renewable sources of energy provide major reductions in global warming emissions as well as benefits to air quality and public health. EVs are on the road now, delivering climate benefits today, but moving to cleaner sources of electricity is needed to deliver the full promise of transportation electrification.

In this chapter, we discuss the use of electricity as a transportation fuel, how electricity is produced today around the country, and how the global warming emissions of charging an EV in different parts of the country compare to fueling a car with gasoline. We consider the future of

TIMELINE 3. Changes in the Electricity Industry

2000 2004 2008 2012 2016

2003
The only EVs for sale in the U.S. are "neighborhood" EVs, limited to 25 miles per hour.

2003
The United States produces 50 percent of its electrical power from coal; non-hydro renewables like wind and solar supply just 3 percent.

2010
The first two modern plug-in EV models to be offered by major manufacturers are introduced, the Nissan Leaf and the Chevy Volt.

2013
The Tesla Motors Model S is given the highest grade for any car ever by Consumer Reports.

2014
Coal-powered generation has decreased to 39 percent, as old, inefficient facilities shut down and many more face economic vulnerabilities. Wind and solar power are the fastest-growing sources of new generation, with non-hydro renewables accounting for 5 percent of electricity generation.

2014
More than 20 models of EVs are available.

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Vehicles powered by electricity produce no tailpipe emissions, but many sources of electricity do create global warming pollution at the power plant. Replacing coal-fired electricity generation with renewable energy cuts the emissions associated with charging an EV significantly.

electricity generation, highlighting the importance of renewable energy to maximize the benefits of electric transportation. UCS has published extensively on EVs and electricity generation, and we highlight key conclusions of that work in Boxes 12 (p. 4) and 13 (p. 7), where interested readers can find more in-depth analysis.

The Use of Electricity as a Transportation Fuel

Sales of modern plug-in on-road passenger vehicles only really started at the end of 2010, with the introduction of the 2011 models of the Nissan Leaf and the Chevy Volt (a plug-in hybrid capable of running solely on electricity for 35 miles and then running on gasoline until it can be recharged). Since then, EV sales have been growing rapidly, with more than 340,000 vehicles sold between December 2010 and June 2015, and more than 20 models offered by more than a dozen different brands (InsideEVs.com 2015).

Electricity has been used to power vehicles of various types for a long time in applications where electric power was available (such as subways and some rail lines) or weight and range were not a constraint (such as forklifts and golf carts). But electric passenger vehicles have been held back by the poor performance of available battery technology. Recent technical progress with lithium batteries has allowed the development of plug-in electric automobiles (both battery electric and plug-in hybrids) that compete very favorably against gasoline vehicles, epitomized by the Tesla Model S, which in 2013 received the highest score for a car ever by Consumer Reports, a well-regarded independent consumer testing and rating service that has been testing cars since 1936 (Consumer Reports 2013).

Recent technical progress with lithium batteries has allowed the development of plug-in electric automobiles that compete very favorably against gasoline vehicles.

Lithium batteries are still relatively expensive, and long-range EVs like the Tesla Model S compete only in the luxury segment of the car marketplace. Less expensive vehicles with more limited ranges, like the battery electric Nissan Leaf and BMW i3 and plug-in HEVs like the Chevy Volt, are available across a broad price range, and technical progress and large-scale manufacturing experience with batteries and electronics are bringing costs down quickly. In particular, a 2015 study found that between 2007 and 2014, costs per kilowatt-hour of batteries have fallen from above $1,000 to around $410, with leading automotive battery manufactures producing batteries with costs as low as $300 (a Nissan Leaf has a 24-kilowatt-hour battery) (Nykvist and Nilsson 2015).

The Emissions of Electricity Production

Driving an EV releases no tailpipe emissions and consumes no gasoline, but this does not mean these cars are responsible for zero carbon emissions. To understand the climate impact of EVs, the source of the electricity used to charge the batteries must be considered as well.

[*When the electricity used to power an EV comes from renewable resources such as wind or solar, the vehicle can operate nearly emissions-free.*]

Sources of electricity vary in their global warming emissions. When the electricity used to power an EV comes from renewable resources such as wind or solar power, the vehicle

BOX 12.

The Inherent Efficiency of Electric Transportation

Comparing electricity to a fuel used in an internal combustion engine (like gasoline or ethanol) on the basis of energy content is potentially misleading. Electric drive is inherently very efficient; therefore, EVs go much farther on a given amount of energy than cars powered by internal combustion engines. For example, a relatively efficient full-sized gasoline-powered vehicle gets about 30 mpg of gasoline. Using the same amount of energy (that of one gallon of gasoline), a Tesla Model S can drive 95 miles and a Nissan Leaf can drive 114 miles (DOE 2015). Based on a comparison of gasoline-powered vehicles and EVs, CARB determined that, on average, EVs can travel more than three times farther using the same amount of energy than a comparable gasoline-powered vehicle, and it adopted an energy-economy ratio of 3.4 for light-duty EVs to allow an appropriate comparison of these different fuels as part of its Low Carbon Fuel Standard (CARB 2015c; CARB 2011; CARB 2009). The same approach and energy-economy ratio of 3.4 has been applied to emissions calculations for various sources of electricity in this report.

The progress of electrification in the U.S. vehicle fleet is more significant than the number of EVs on the road would suggest. Gasoline-powered vehicles are also becoming steadily more electrified—quite visibly in the case of HEVs and in more subtle ways in conventional gasoline-powered vehicles. Even though these vehicles are never plugged in, electrification is bringing significant efficiency gains. Hybrid vehicles like the Toyota Prius use a combination of gasoline and electricity generated on board the vehicle to achieve much greater efficiency than that of conventional vehicles. In the 2015 Honda Accord hybrid, the propulsion system has been largely replaced with a pair of electric motors, one of which propels the car while the other acts as a generator making electricity from a gasoline engine. The hybrid version of the Accord is still powered entirely with gasoline and has no plug to supply electric power from the grid, yet by dispensing with the complex mechanical transmission and relying on electric drive more heavily, the hybrid version goes more than 30 percent farther on a gallon of gas than the non-hybrid versions (DOE 2015).

The improved efficiency of these hybrid systems demonstrates that even when the fuel source is the same gasoline as usual, running the car on electric power dramatically improves efficiency, cuts oil use, and in so doing reduces global warming pollution.

Even within the workings of more conventional gasoline-powered vehicles, functions that were previously provided by mechanical linkages are being replaced by electric motors, reducing associated drivetrain losses and contributing incremental improvements in fuel efficiency. For example, components such as power steering systems and air-conditioning pumps are switching from being mechanically driven to electrically driven. Mild hybrids, which add stop-start function and regenerative braking, improve efficiency by around 10 percent (Bilgin et al. 2015). This inherent efficiency of electric versus mechanical systems is a fundamental reason that clean transportation is increasingly electric. But while greater electrification of gasoline-powered vehicles is reducing gasoline use and pollution, the replacement of the internal combustion engine with an electric motor—especially if powered by clean electricity—offers much larger gains.

can operate nearly emissions free. This potential is demonstrated today by some individuals who are pairing rooftop solar electricity systems with their EV ownership. For most EV owners, however, their cars will be charged using electricity from their region's electricity grid.

In the United States as a whole, coal is the largest source of electricity generation. But its share has been falling steadily from a high of 57 percent in the late 1980s to less than 40 percent in 2014. Coal's share of CO_2 emissions is much higher than its share of generation, because electricity generated with coal produces about twice as much carbon pollution per unit of energy generation as electricity generated with natural gas. Coal is being replaced by natural gas and also renewable energy sources. Emissions from natural gas, while lower than coal, are still significant. Most renewable sources of energy emit no global warming gases at all when producing electricity. Currently, renewables account for a small share of the U.S. power supply (non-hydro renewables accounted for about 5 percent in 2014), but their share is growing rapidly.

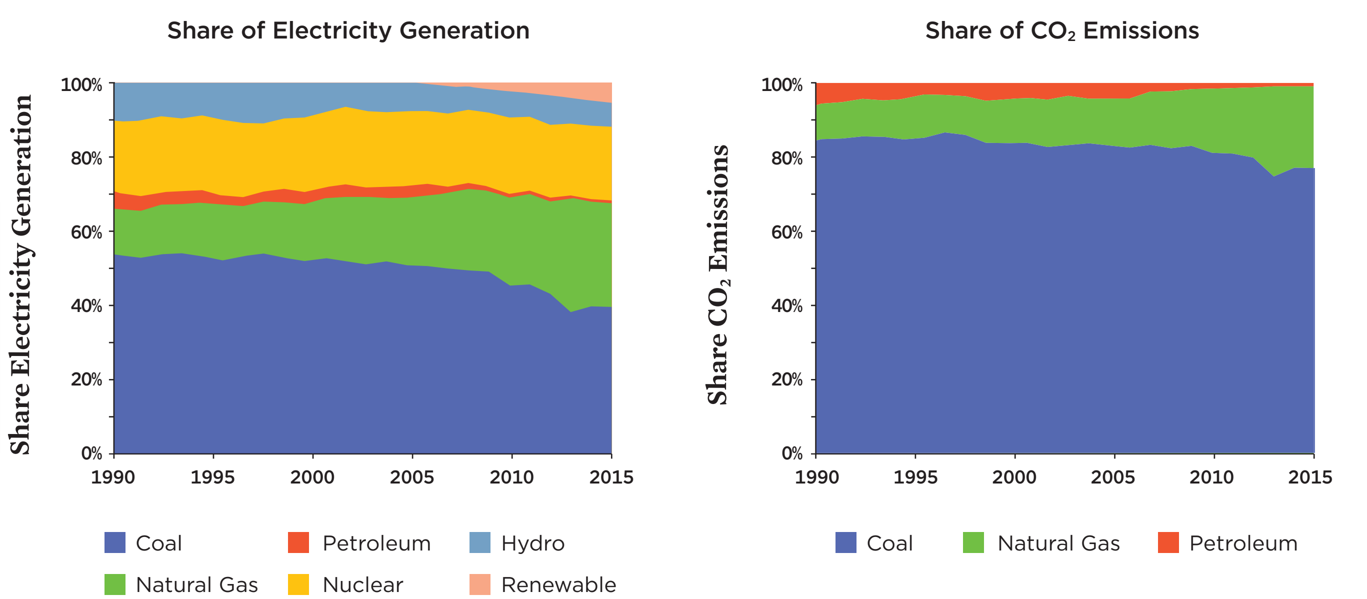
National totals, however, mask regional differences in the mix of fuels used to generate electricity, and these differences result in significant variations in global warming emissions per unit of electricity. Correspondingly, the global warming emissions of driving an EV varies according to the region's power plants' mix of fuels.

Some regions rely on coal for the lion's share of their electricity generation and therefore have higher-than-average emissions per unit of electricity generation. For example, in the grid region called the Western Electricity Coordinating Council (WECC)/Rockies, which covers Colorado and parts of several neighboring states, coal provides 70 percent of the power, 17 percent comes from natural gas, and 13 percent comes from wind and hydropower; as a result, emissions per unit of electricity generation are 60 percent higher than the national average.

Other regions have a cleaner mix and lower emissions. Two western regions have emissions per unit of generation about 40 percent cleaner than the national average, but they achieve these results with very different mix of energy sources. The Pacific Northwest, with its massive dams supplying hydropower, gets more than 60 percent of its power from low-carbon sources, principally hydro at 52 percent, with the remainder coming from coal (25 percent), natural gas (11 percent), wind (7 percent), and other sources. California has similar emissions per unit of energy as the Northwest, but a very different grid mix, with less hydropower but also less coal. Where an EV gets charged makes a big difference (see Figure 18, p. 6).

These different regional grid mixes have a significant impact on the emissions associated with driving an EV. Figure 19 (p. 7) compares the global warming emissions from driving a

FIGURE 17. Coal Dominates Emissions from Electricity



Coal is the largest source of electricity generation, and produces more emissions than any other source, almost twice as much as natural gas per unit of energy generation.

SOURCE: EIA 2015B.

25 mpg car 12,000 miles to driving the same distance in a battery EV that is charged in the different grid regions. Charging an EV on the average U.S. grid has emissions of about half those of a gasoline-powered car, while in regions with relatively cleaner grids, the emissions are just one-third of those of a gasoline-powered car. Even in regions with a relatively dirty grid, like Colorado, charging an electric car is cleaner than fueling a typical gasoline-powered car.

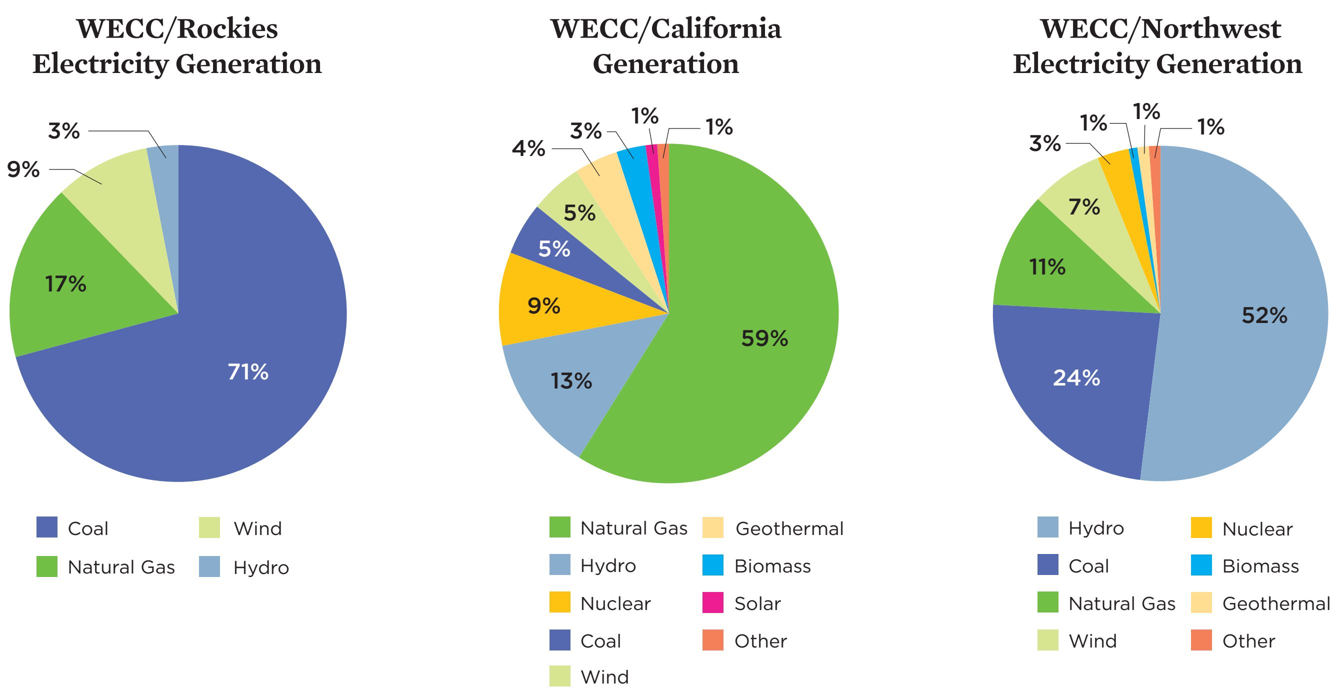
A recent UCS study of the lifecycle emissions of an EV, described in Box 13 (p. 8), highlights the regional variation and also considers the emissions differences associated with the production of battery EVs compared to gasoline-powered cars.

The Future of Electricity

While electricity is overall cleaner than oil, the emissions produced by electricity can be lessened further by shifting electricity generation from fossil fuel sources, such as coal, to renewable sources, such as wind.

[Charging an EV on the average U.S. grid has emissions of about half those of a gasoline-powered car, while in regions with relatively cleaner grids, the emissions are just one-third of those of a gasoline-powered car.]

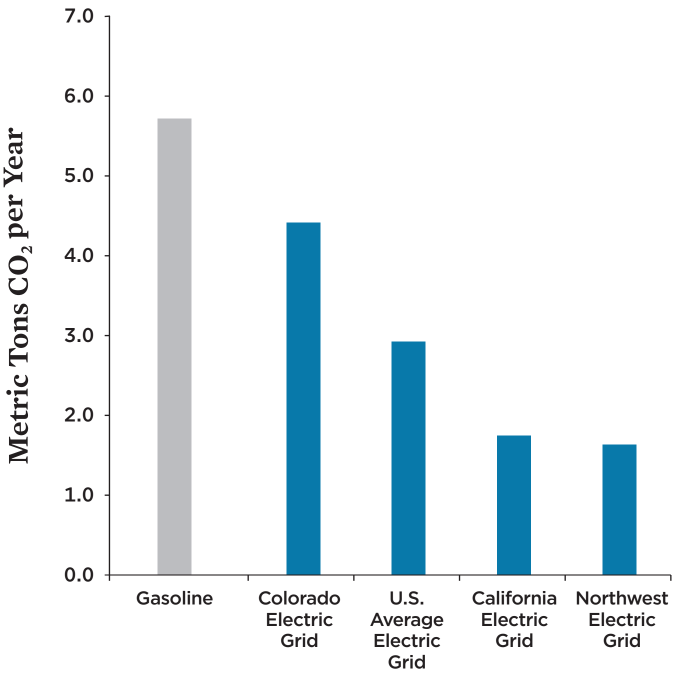
FIGURE 18. Regional Electricity Grid Energy Sources



Electricity is created from a variety of energy sources—including coal, natural gas, and renewable energy—and the mix of sources varies in different regions of the United States. This means that an electric vehicle charged in a region using a greater share of renewable energy to create electricity is cleaner than one charged in a region where the electricity is generated primarily from burning coal.

SOURCE: NEALER, REICHMUTH, AND ANAIR 2015.

FIGURE 19. **Electricity Is Cleaner than Gasoline**



Cars that run on gasoline put out more emissions than even electric cars charged in areas where coal is the biggest source of electricity. When electricity is created from cleaner sources, emissions are reduced further.

Note: The global warming emissions of gasoline represents the metric tons of CO_2e associated with the production and consumption of fuel required to power a typical car (getting 25 mpg) for a year (driving 12,000 miles). For electricity the emissions represent the production of fuel (e.g., coal, natural gas) and consumption by power plants to generate a quantity of electricity needed for a similar vehicle traveling the same distance adjusted for electric drive efficiency.

SOURCE: CARB 2015A; NEALER, REICHMUTH, AND ANAIR 2015.

BOX 13.

Lifetime Global Warming Emissions of Electric Vehicles

UCS recently compared the global warming emissions associated with charging an EV in different regions of the country to driving a gasoline-powered car. We estimated the global warming emissions from electricity consumption in the 26 "grid regions" of the United States—representing the groups of power plants that together serve as each region's primary source of electricity—and we rated each region based on how charging and using an EV there compared with driving a gasoline-powered vehicle. We also estimated, based on recent sales data, the average efficiency of new EVs (battery electric and plug-in EVs combined) sold in the United States in 2015. We found that: 1) driving the average EV in any region of the country produces lower global warming emissions than the average new gasoline car (achieving 29 mpg); 2) our ratings of 20 out of 26 regions have improved since 2009; and 3) more than 66 percent of Americans—up from 45 percent just three years ago—live in regions where powering an EV on the regional electricity grid produces lower global warming emissions than driving a 50 mpg gasoline-powered car.

Comparisons between EVs and gasoline-powered cars look even more attractive when one considers that many EVs are currently being sold and driven in areas where the electricity grid is cleaner than the U.S. average. As a result, based on calculations that weighted where EVs were sold in 2014, driving an EV in the United States produced global warming emissions equal to those of a gasoline vehicle getting 68 mpg.

Our analysis also examined emissions associated with manufacturing different types of cars. We found that, on average, battery EVs representative of those sold today produce less than half the global warming emissions of comparable gasoline-powered vehicles, even when the higher emissions associated with the manufacturing of battery EVs are taken into consideration. Based on modeling of the two most popular battery electric vehicles available today and the regions where they are currently being sold, excess manufacturing emissions are offset within 6 to 16 months of driving (Nealer, Reichmuth, and Anair 2015).

The mix of electricity sources not only varies by region; it is also changing over time. These changes are affecting the entire electricity sector, not just the small share currently used for transportation. After considering how these changes are affecting the grid in general, we will explore the implications for the transportation sector in more detail.

The U.S. electricity sector is in the midst of a major transformation driven by the need to reduce air pollution and reduce the heat-trapping gases responsible for climate change, as well as by the lower price of natural gas and the steadily falling price of wind and solar energy. A complex interplay of policy, technology, and economics are shaping the energy system, and the implications go beyond the future of clean transportation. Taken together, transportation and electricity generation account for more than half of U.S. global warming pollution and a large share of other air pollutants; therefore, the way we generate electricity is critical for public health, climate stability, and our economic well-being. As electricity becomes a more important transportation fuel, the electricity generation and transportation sectors will become increasingly intertwined.

DAVID ILIF/Creative Commons (Wikimedia Commons)

While electricity is overall cleaner than oil, the emissions produced by electricity can be lessened further by shifting electricity generation from fossil fuel sources, such as coal, to renewable sources, such as wind.

CHANGE IS UNDER WAY: COAL'S SHARE IS FALLING, NATURAL GAS AND RENEWABLES ARE GROWING

From 2007 to 2014, coal's share of the U.S. electricity mix declined from almost 50 percent to just 39 percent, while natural gas generation's share grew from 22 percent to 27 percent (EIA 2015b). Utilities are increasingly choosing natural gas over coal for meeting electricity demand because of higher coal prices, standards aimed at limiting harmful pollution from coal-fired power plants, and sharp declines in natural gas prices driven primarily by U.S. shale gas production (Fleischman et al. 2014).

One of the more visible ways that this transition is playing out is in the form of coal plant retirements. Since 2009, plans have been announced to retire—or convert to natural gas—more than 450 coal-powered generators in 39 states, equal to about 20 percent of the total U.S. coal-fired plants. However, there are still many more uncompetitive coal generators that should also be considered for closure. A 2013 UCS analysis of the economic viability of our nation's remaining coal generators found that at least another 360 coal generators are not cost-competitive when compared with natural gas and wind power in the today's power market environment (Fleischman et al. 2014).

This transition away from coal has reduced the emissions associated with operating an EV, which is cleaner today than it was just a few years ago. But there is a lot of room to build on that important progress by reducing the share of coal-fired electricity generation yet further.

One important driver of continued progress in cleaning up electricity generation is the EPA's Clean Power Plan. Finalized in August 2015, the Clean Power Plan is the first-ever national standard for cutting carbon emissions in the power sector. Under the plan, states are collectively required to reduce power plants' carbon emissions to 32 percent below 2005 levels by 2030. The Clean Power Plan provides for a number of options to cut carbon emissions, including increasing energy efficiency, utilizing natural gas and nuclear power, and shifting generation toward renewable energy and away from coal-fired power. States have until September 2016 to submit a final compliance plan, and emission reductions must begin in 2022 (EPA 2015b).

MOVING FROM COAL TO NATURAL GAS IS NOT ENOUGH

Burning natural gas instead of coal to generate electricity offers important and immediate benefits, including reduced air

[***As electricity is used more and more for transportation, reducing emissions caused by its generation will be critical for public health, climate stability, and our economic well-being.***]

and water pollutants emanating from power plants, fewer smokestack carbon emissions, lower power plant water use, and greater flexibility of the power grid. These advantages, along with the current economic favorability of natural gas, have led some states to rapidly increase their dependence on natural gas. In just five years, Florida has increased the share of its electricity generated from natural gas from 44 percent to 62 percent. Many other states, including Virginia, Delaware, Ohio, and Pennsylvania, are following a similar path (Deyette et al. 2015).

However, despite the important benefits of natural gas compared to coal, a natural gas–dominated electricity generation system would still generate substantial global warming emissions—and fail to effectively address the growing dangers of climate change.

The electric power sector is the largest contributor to U.S. global warming emissions and currently accounts for approximately one-third of the nation's total emissions. Increasing the use of electricity to power transportation will increase the demands on this sector. To limit the worst consequences of climate change, the United States needs to make very deep cuts to emissions from the power sector by 2050. Overreliance on natural gas is risky, both because it fails to adequately mitigate the risks from climate change, but also for other economic and environmental reasons evaluated in detail in a recent UCS analysis, described in Box 14 (Deyette et al. 2015).

Toward a Focus on Renewable Energy

UCS analysis of the electricity sector, like analyses from the National Renewable Energy Laboratory and others, have targeted producing 80 percent of electricity generation from renewable resources as part of overall efforts to avoid the risk of catastrophic climate change. These renewable energy technologies are already ramping up quickly across the country and demonstrating that they can deliver affordable, reliable, and low-carbon power. According to an analysis of the National Renewable Energy Laboratory, an 80-percent reduction of carbon pollution from electricity generation compared to the study's baseline can be achieved in 2050 by relying on renewables for 80 percent of generation (Fields, Luckow, and Vitolo 2015; Rogers et al. 2013; Hand et al. 2012).[4]

Transforming the entire U.S. electricity grid to 80 percent renewable sources will take many years, but some states, regions, and even individuals are moving forward much more quickly, illustrating what is possible. The state of California is already well on its way to meeting a 2020 renewable portfolio standard that requires one-third of retail electricity sales come from renewable energy sources by 2020. In 2015, it increased this target to 50 percent renewable energy by 2030. This transition will build valuable experience that will reduce costs and solve technical challenges, helping to facilitate a national transition to renewable energy by mid-century.

The progress of the electricity sector toward renewables amplifies the benefits of shifting transportation toward electricity. Charging an EV from an 80-percent renewable grid will cut emissions compared to gasoline-powered vehicles by more than 80 percent, to about 0.7 metric ton of CO_2e global warming emissions per year for a typical vehicle. And many drivers of EVs are not waiting until their grid is cleaner to start powering EVs with renewable energy. A survey in 2013 of new EV owners in California, which represents more than 40 percent of the market for EVs, found that 32 percent of

BOX 14.

The Natural Gas Gamble: A Risky Bet on America's Clean Energy Future

The U.S. electricity sector is in the midst of a major change. As power producers retire aging coal plants, they are turning to natural gas to generate electricity at an unprecedented rate.

While this rapid shift is providing important near-term environmental and economic benefits, strong evidence suggests that becoming too reliant on natural gas poses numerous and complex risks, including persistent price volatility and rising global warming emissions.

UCS analysis shows, however, that the dangers of an overreliance on natural gas can be overcome by greatly expanding the use of renewable energy and energy efficiency in our power supply. These technologies are already ramping up quickly across the country, demonstrating that they can deliver affordable, reliable, and low-carbon power. With sensible policies in place, these technologies can flourish, and natural gas would play a useful—though more limited—role in a clean energy system (Deyette et al. 2015).

4 *Many studies of the electricity sector's emissions, including the two referenced in this chapter, are based on combustion emissions from electricity generation rather than full lifecycle emissions that are the focus of this report. They do not consider emissions from mining coal or extracting natural gas, for example. However, the analysis by the National Renewable Energy Laboratory included an appendix that also considered the full lifecycle emissions reductions of their renewable scenario. While these emissions are harder to predict precisely, their analysis found that the level of emissions reductions on a full lifecycle basis were very similar or even slightly higher than emissions from generation (Hand et al. 2012).*

respondents had solar photovoltaic systems in their homes. An additional 16 percent indicated that they planned to install a photovoltaic system in the future (CCSE 2013).

RENEWABLE ENERGY AND ELECTRIC TRANSPORTATION COMPLEMENT EACH OTHER

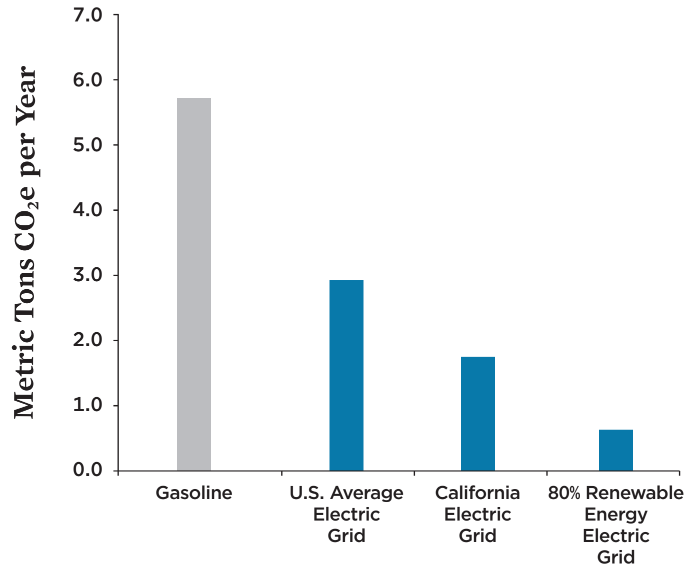
EVs and renewable energy are two critical technologies for making the deep emissions reductions that are required if the United States is to avoid the worst consequences of climate change. While much of this chapter has highlighted the benefits of renewable energy in general and the benefits it offers to EVs in particular, EVs also have unique features that improve electric utilities' ability to integrate high levels of renewable sources of energy into the grid.

Unlike televisions, lights, and many other grid-connected users of electricity, battery EVs have energy storage built in. This provides potential scheduling flexibility for the demand they place on the grid when charging. Using information technology to coordinate the charging of battery EVs at periods when renewable energy generation is abundant, for example, at the mid-day when solar panels are generating at peak capacity, EVs can help balance the load on the grid. This "smart charging" is one of a broader set of "demand flexibility" measures required to facilitate high levels of renewable energy onto the grid (Dyson et al. 2015). Taking this further, future EVs could provide power in a vehicle-to-grid arrangement, compensating for short-term drop-offs in wind or solar power production (CAISO 2014; Kempton and Tomić 2005). Further opportunities for synergy arise from using surplus renewable energy to generate hydrogen to power fuel cell vehicles. This sort of coordination between renewable generation and charging or fueling EVs will not just make things easier for grid managers, but can further reduce the already low cost to power an EV, improving the economics of operating an EV for consumers.

Conclusions and Recommendations

Realizing the full potential of electric transportation to lower emissions from the transportation sector will require large changes in the way electricity is produced and how it is used. An EV charged by a grid with power produced primarily from fossil fuels already offers significant carbon pollution reductions compared to a typical gasoline-powered vehicle. However, EVs charged by a grid powered by 80 percent renewable energy can cut emissions by more than 80 percent compared to today's vehicles—they are one of the core strategies identified by experts to avoid the worst effects of climate change. This calls for investments in a cleaner, more renewable grid and accelerating the deployment of EVs.

FIGURE 20. Renewable Energy Electricity Is Almost 90 Percent Cleaner than Gasoline



Electricity is cleaner than gasoline, but when the electric grid is powered by 80% renewable energy, the reductions in emissions are even more evident. A car charged from an 80% renewable grid produces only 11% of the emissions a gasoline car produces.

Note: The global warming emissions of gasoline represents the metric tons of CO_2e associated with the production and consumption of fuel required to power a typical car (getting 25 mpg) for a year (driving 12,000 miles). For electricity the emissions represent the production of fuel (e.g., coal, natural gas) and consumption by power plants to generate a quantity of electricity needed for a similar vehicle traveling the same distance adjusted for electric drive efficiency.

SOURCE: CARB 2015A; NEALER, REICHMUTH, AND ANAIR 2015; HAND ET AL. 2012.

THE TRANSITION FROM COAL TO CLEAN, RENEWABLE ELECTRICITY MUST BE ACCELERATED

The first step toward cleaning up the grid is to replace coal-fired power plants with cleaner sources of electricity, which is already underway. The next step is for states to implement the Clean Power Plan.

UCS analysis using the Clean Power Plan's rate-based approach for setting emissions goals shows that:

- 31 states are already on track to be more than halfway to meeting their 2022 Clean Power Plan benchmarks, with 21 of them set to surpass them.
- 20 states are already on track to be more than halfway to meeting their 2030 Clean Power Plan target, with 16 set to surpass it (Richardson 2015).

Many states are exceeding the requirements of the Clean Power Plan, supporting more renewable energy and setting a

BOX 15.

Hydrogen Fuel Cell Vehicles

While battery EVs are the focus of this chapter, hydrogen fuel cell EVs are also an important technology to cut carbon emissions and oil use from transportation. Hydrogen fuel cells produce electricity on board the vehicle from hydrogen rather than relying on energy stored in batteries. This gives them unique attributes, producing only water vapor, benefiting from the attractive properties of electric drive, and resembling battery EVs in that they release no carbon pollution from their tailpipes. Hydrogen fuel cell EVs, like battery EVs, see increased climate benefits when renewable sources of hydrogen or electricity are used.

Vehicles using hydrogen fuel cells also have some key differences from battery EVs. While EVs offer the convenience of home recharging and allow the use of existing electricity infrastructure, hydrogen fuel cell EVs allow fast central refueling similar to that of current gasoline-powered vehicles, once the necessary infrastructure is in place. Fuel cell vehicles are much more efficient than internal combustion engines, but not quite as efficient as battery EVs. CARB computed an energy economy ratio for hydrogen fuel cell powered passenger cars as 2.5, which means they can go 2.5 times as far as gasoline-powered cars on the same amount of energy, while battery EVs have an energy economy ratio of 3.4. However, hydrogen fuel cells offer the highest energy storage capacity for electric drive, facilitating scalability to larger and heavier vehicles. Hydrogen fuel cell technology complements batteries, rather than competing with them, and both technologies can help to cut the United States' oil use and global warming emissions from transportation (NRC 2013; CARB 2012).

A series of three UCS fact sheets describes in more detail how these two EV technologies complement one another (UCS 2014c), how clean they are based on the source of the hydrogen available today (UCS 2014b), and the importance of low-carbon hydrogen production to fulfilling their potential (UCS 2015c).

course for even deeper reductions in emissions. California passed legislation in 2015 requiring 50 percent renewable electricity generation by 2030. Other states have formed regional partnerships, such as the Northeast Regional Greenhouse Gas Initiative, to collectively cap carbon emissions from power plants. Together, the nine northeastern states in this partnership have cut emissions by 40 percent since 2005 and have used auction proceeds of $1.4 billion to invest in energy efficiency, renewable energy, and other measures that will support continued emissions reductions over time (Cleetus 2015).

THE DEPLOYMENT OF EVS NEEDS TO RAMP UP

While EV technology has proven its ability to produce great vehicles, car makers are still developing experience with the large-scale manufacturing needed to bring down costs. As a result, tax credits and other types of support are vital to bring EVs within reach of drivers at all income levels. In addition to direct sales support, a variety of policies are needed to help build out the charging infrastructure in homes, apartment buildings, workplaces, and other locations that will make EVs an even more attractive choice for car-buyers.

Delivering clean power and clean transportation will require transformative changes in both sectors, but thoughtful coordination of the two sectors can deliver synergistic benefits for both. As new technologies are deployed to coordinate battery charging and hydrogen fuel production with periods of high availability of renewable sources of energy, EVs can increase the reliability of the grid while reducing the cost of power for their owners and the global warming emissions of the country's transportation sector overall.

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A NOTE ON THE FEBRUARY 2017 CORRECTED VERSION

The original release of this report made an incorrect inference based on preliminary research. The error became apparent upon subsequent publication of the final analysis, so we have removed the specific claim and the reference to the preliminary analysis. The revised report reflects the literature available at the beginning of 2016, when this report was originally published. Subsequent analysis will be reflected in future publications.

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Fueling a Clean Transportation Future

Smart Fuel Choices for a Warming World

> ***Cutting oil use dramatically is essential to avoiding the worst impacts of climate change, but to achieve a clean transportation future, we must ensure that all of our fuels are as clean as possible.***

The clean transportation system of the future will be powered increasingly by electricity. Electric vehicles (EVs) cut oil use by getting their power from the grid rather than a gasoline pump. How much they cut global warming pollution, therefore, depends on the grid used to charge them. A battery EV charged on the average U.S. grid produces about 50 percent of the global warming pollution produced by a gasoline-powered vehicle. But in many parts of the country the grid is much cleaner. In California, which has more EVs than any other state, charging the same vehicle produces just 35 percent of the emissions of a conventional vehicle.

As the use of coal to produce electricity falls, the grid gets steadily cleaner. However, to avoid risky overreliance on natural gas, it is important to invest in expanding the use of clean renewable energy from wind and solar power. EVs can facilitate utilities' efforts to integrate more wind and solar resources, leading to a synergy between two crucial elements of a comprehensive approach to reaching the deep emissions reductions required to stabilize the climate.

Union of Concerned Scientists

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