RAP®

Beneficial Electrification

Ensuring Electrification in the Public Interest

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Abbreviations

BE .... beneficial electrification

BNEF ...... Bloomberg New Energy Finance

Btu .... British thermal unit(s)

CO_2 .... carbon dioxide

EV .... electric vehicle

GWh .... gigawatt-hour

kWh .... kilowatt-hour

MWh....... megawatt-hour

PUC .... public utility commission

TOU .... time-of-use

VER .... variable energy resource

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About This Series

For electrification to be considered beneficial, it must meet one or more of the following conditions without adversely affecting the other two:

1. Saves consumers money over the long run;
2. Enables better grid management; and
3. Reduces negative environmental impacts.

Beneficial Electrification: Ensuring Electrification in the Public Interest explores policy and regulatory decisions that need to be made to accommodate innovations across the power sector that make it possible to electrify many energy uses currently fueled by heating oil, propane, and natural gas. The paper makes the case for what RAP calls beneficial electrification—in other words, electrification in the public interest.

The authors offer six principles that will help policymakers and regulators formulate and evaluate their electrification strategies to broadly secure the benefits. Finally, the paper looks at operational elements that states may want to consider as they move ahead with electrification.

Three other papers in this series feature pathways and no-regrets options for regulators to apply these principles specifically to electric vehicles, space heating, and water heating. Each paper lays out initial steps for regulators to establish programs, including standards and metrics to measure success. More specifically, these papers explore issues such as rate design to enable beneficial electrification; program design and implementation; relationships between beneficial electrification and energy efficiency and demand response programs; screening tests for beneficial electrification; and impacts on wholesale markets and vice versa.

Foreword

Among the wide-ranging changes taking place on the customer side of the power sector, one of the more striking is the opportunity for beneficial electrification—electrifying end uses historically powered by fossil fuels to reduce costs as well as greenhouse gas and other emissions.

At RAP, we are interested in nearly every type of public policy affecting the electric power sector. Beneficial electrification is of particular interest because it provides the opportunity to convert space and water heating—more than half of US home energy consumption in 2015—to electric power. Likewise, electric vehicles have the potential to affect nearly a third of the nation's total energy use and lower the nation's transportation costs.

Such innovative energy conversion opportunities don't come along very often. And in this case, they offer the promise not only of greater efficiency, but also of capitalizing on an electric sector that is getting cleaner every day. Furthermore, some of the end uses being electrified provide storage capacity that, when managed, can actually assist power system operators in accommodating more low-cost, zero-carbon renewable energy resources on the grid.

As a result, beneficial electrification supports policymakers in achieving climate goals and simultaneously utilizes markets to find the best means to achieve them. This is good news for consumers, the nation's economy, and our global environment.

But the potential misuse of these new technologies needs to be considered, too. Will they be deployed in ways that save consumers money, aid in managing the grid, and reduce harmful air emissions, or will they be pursued mainly to build utility load? Will these innovations be pursued equitably, or be available only to the wealthy? The potential for misuse and disruption reinforces the importance of implementing electrification consistent with guiding principles that focus on the public interest.

Beneficial Electrification: Ensuring Electrification in the Public Interest articulates a set of such principles to help policymakers better understand electrification trends and optimize the opportunities they create. Moreover, it formulates first steps for decision-makers to keep in mind in developing beneficial electrification strategies for their states, cities, and companies.

Ken Colburn, principal and director, US Program
Montpelier, Vermont
June 2018

Executive Summary

It's no secret the energy sector is experiencing exponential change. Headlines tout transformative technologies, dynamic changes in costs and how consumers interact with the grid, and societal expectations for a cleaner environment. Three trends in particular are producing effects in the energy industry: the falling costs of variable renewable energy, the declining costs of energy technologies, and the increase in automation and our ability to control electricity demand. These trends are both challenges and opportunities for consumers, utilities, and the environment. Beneficial electrification (BE) provides one of the biggest opportunities in the power sector today to connect consumers with more affordable and cleaner resources and to help utilities better manage the grid and reduce harm to the environment and public health.

Falling costs of generating sources, particularly variable energy such as wind and solar, are causing ripple effects throughout the industry. According to Bloomberg New Energy Finance (BNEF), projects that in 2015 were 5.8 cents per kilowatt-hour (kWh) for solar (in the United Arab Emirates) and 4.5 cents per kWh for wind (in the United States) were, in 2017, 1.8 cents/kWh for solar (in Saudi Arabia) and 2 cents/kWh for wind (in India). As a result, variable energy resources (VERs), also called variable generation, are experiencing explosive growth.

In 2017 the Public Service Company of Colorado reported the results of its all-resource request for proposals (238 projects totaling 60,000 megawatts), including 3 cents per kWh for solar and less than 2 cents per kWh for wind. These prices are much lower than the costs of operating traditional power plants on a national average basis. In 2016 coal cost an average of $37 per megawatt-hour (MWh) just for fuel and operating costs. Gas was a little lower at $30/MWh, and nuclear was even cheaper at $25/MWh. Because these are averages, one has to assume that half of these types of plants cost more than this and are at risk of becoming economically obsolete.

When one compares these resources, wind costs are coming in lower than the fuel costs alone for coal and gas, and solar coming in no higher than the combined fuel and operating cost of coal and gas. This means a utility with plenty of capacity could still buy wind to reduce its fuel costs.

Like renewable resources, other energy technologies are dropping in price and their capabilities improving. In 2016 BNEF estimated that the unsubsidized sticker price of electric vehicles (EVs) would drop below that of internal combustion vehicles sometime between 2025 and 2029, due in large part to the declining cost of lithium-ion batteries, a key component of EVs. BNEF also projected in 2016 that EVs would account for 35 percent of new car sales by 2040. Just one year later, BNEF said EVs' total cost of ownership would reach parity for shared-mobility fleets (e.g., Uber) in 2020 and that EVs would account for 54 percent of 2040 new car sales.[1]

Another point to consider about the pace of change in the power sector: There has been a radical surge in the quantity of information available about energy use and the ease of access to data for consumers, third parties, and utilities. For more than a century we managed energy supply to meet demand, but today, for the first time, we can do the opposite and manage demand to meet supply. In fact, this capability has grown in such ways that much of it can be done automatically. Today buildings and devices have energy-use controls built in so customers can actually be passive but still enjoy the benefits. Cisco Systems projects that, by 2021, more than half of all electrical device connections will be machine to machine, meaning devices will be able to talk to one another without user intervention, enabling even cheaper, cleaner, and more precisely managed energy use.

These factors combined enable us to realize the benefits offered by beneficial electrification. Here we draw a distinction:

1 "Battery electric cars will be more expensive than equivalent internal combustion engine vehicles for the next 7-9 years, depending on segment. By the end of the 2020's, the average [battery electric vehicle] in the US and Europe will be cheaper than a comparable [internal combustion vehicle] in all market segments, though for small cars the gap will be marginal." Soulopoulos, N. (2017). *When will electric vehicles be cheaper than conventional vehicles?* Bloomberg New Energy Finance. Retrieved from https://data.bloomberglp.com/bnef/sites/14/2017/06/BNEF_2017_04_12_EV-Price-Parity-Report.pdf

Electrification is not the same as BE. We assert that for it to be considered beneficial, or in the public interest, electrification must meet one or more of the following conditions, without adversely affecting the other two:

1. Saves consumers money over the long run;
2. Enables better grid management; and
3. Reduces negative environmental impacts.

First, electrification can reduce consumers' long-run costs because many forms of electrification are more efficient than their fossil-fueled counterparts. This decreases overall energy use and operating costs. Moreover, depending on the level of adoption of these end uses, all electricity ratepayers can enjoy these benefits through the associated system benefits, not just those who installed these innovative technologies.

Second, due to the flexibility of many forms of electrification, including water heating, electric vehicles, and some forms of space heating, these end uses can help facilitate and increase grid flexibility. Because these end uses are flexible in when they can be charged and used, they can function like batteries. This enables grid managers to shift load to times when there is less demand for electricity and it is cheaper or when renewable energy generation is being curtailed, and away from times when there is greater demand and the need to draw upon more expensive and often more polluting generation resources. With the electrification of these end uses, electric utilities are in a position to improve their ability to manage loads—that is, to encourage smarter charging practices through rate designs and other means—and realize these benefits that can be shared with their ratepayers.

Third, BE can help reduce environmental impacts by using less energy than fossil-fueled alternatives, providing the ability to reduce reliance on often dirtier resources used to serve electric system peaks, and by adding the flexibility that can make the grid more capable of accommodating variable generation resources like wind and solar. Furthermore, because the carbon intensity of the US power sector has been decreasing since 1990, the increased use of more energy-efficient electric end uses allows consumers to take greater advantage of the greening of the country's generation fleet than in the past.

Principles for Maximizing the Benefits

Electrification is a rapidly occurring phenomenon, simply because it makes sense to many stakeholders in the energy industry. However, to fully realize the benefits that can accrue to consumers as well as grid managers and the environment, it is critical for policymakers and regulators to formulate and evaluate their own electrification strategies. The following principles will help them do so.

1. Put efficiency first.

As long as energy efficiency is the lowest-cost choice among resources, it should be the first choice in policymaking, planning, and utility acquisition. Taking an efficiency-first approach prioritizes investments in customer-side efficiency resources whenever they would cost less or deliver more value than investing in energy infrastructure, fuels, and supply alternatives. It would be an unfortunate result to build a fleet of new renewable resources and then use the output inefficiently. Today, replacing fossil-fueled equipment with efficient electricity-fueled equipment can create opportunities for consumers to control and reduce the cost of their energy use over time. This is due to the improved efficiency of both electricity generation and end-use appliances, as well as the affordability of electricity relative to other fuel options. In other words, due to the efficiency of an EV or heat pump, for example, the quantity of electricity required to produce a certain output (e.g., miles driven or heat delivered) is less energy-intensive and less expensive than the quantity of the fossil fuel currently being used to provide the same output.

2. Recognize the value of flexible load for grid operations.

Unlike traditional electricity load, much of the new electrification load does not need to be taken from the grid at the same time it is being used for water heat, transportation, or even space heating and cooling. As a result, it is inherently more flexible and can serve as either thermal or electrical energy storage. With this advantage, the power system can serve this new load at cleaner and less expensive times of the day. As illustrated by the following examples, space heating, water heating, and EV loads don't need to be entirely served during the morning and evening peaks when power is more constrained, more expensive, and often more polluting.

Space heating: Electrification holds great promise in space heating, where technologies that directly use fossil fuels like oil, propane, and natural gas have historically predominated. Not only are heat pumps far more efficient in most circumstances than combustion alternatives, but when connected with smart thermostats, they can help manage system demand by preheating or precooling a space during the afternoon and running less during the early evening peak, or by making use of thermal energy storage systems. This flexibility can be increased by enabling participation in demand response programs that provide measurable peak load reduction benefits to the grid and avoid unnecessary air emissions.

Water heating: The tank on a water heater is a form of thermal battery, capable of providing significant storage capacity and opportunities for utilities and ratepayers. It does not matter to a consumer if her shower water was heated five minutes or five hours earlier as long as it is hot when she needs it and there is enough. To the extent it is possible to shift water heater energy consumption to lower demand times of the day, it is possible to "charge" water heaters during cheaper and lower-emissions hours. Moreover, this flexibility, especially when aggregated, can deliver capacity, energy, and ancillary services to the grid.

Electric vehicles: EVs constitute a significant source of flexible load because they are battery-powered and, like various types of electric water heaters, can be charged at times that are most beneficial to the grid. This flexibility means EVs can also help reduce loads that would otherwise add to system peaks and drive unnecessary grid investment and costs to ratepayers. As noted above, this flexibility can also help the electric sector accommodate increased amounts of variable renewable generation and further reduce the sector's carbon intensity.

3. Understand the emissions effects of changes in load.

Knowing the generation source of the electricity being used to power devices like heat pumps and EVs is crucial for determining the overall emissions impacts of BE. Nationwide, today's power sector emits the same amount of carbon dioxide (CO_2) as it did a generation ago, in 1993, although it produces nearly 30 percent more electricity annually. This positive trend is due in large part to cleaner generation resources.

Because electrification will add load, knowing a system's marginal emissions is especially important as electrification programs become operational around the country and policymakers try to determine related energy savings. A marginal emissions analysis shows, in aggregate, the emissions from the resource on the margin in a system, meaning the emissions that would be added with the use of one more kWh, or that would be reduced if a kWh is avoided, at each time period during the year.

Although determining marginal emissions will be important as electrification programs get underway, it will also be important to have a sense of the emissions expected as significant amounts of electrification load are added to the nation's grids. If states decide to pursue policies and programs that increase electricity sales, most of that added load may be served by a combination of resources with a very different emissions profile than the marginal unit at each hour of the day in any given power grid. Getting a sense of total emissions is thus likely to require the use of power sector modeling.

4. Use emissions efficiency to measure the air impacts of beneficial electrification.

Beneficial electrification adopts a total-system efficiency viewpoint and seeks to recognize a reduction in the use of primary energy. Despite using more kWhs of electricity, consumers are in a position to use less energy overall, thereby producing fewer pounds of pollution per vehicle mile traveled or per gallon of hot water produced.

The emissions impact of electrification, combined with the wealth of available load, emissions, and consumption data, including system analytics and grid operating data, will enable utilities to ascertain the times of day and months of the year when electrification produces the lowest amount of generation-related emissions on their power systems. Grid managers and regulators can thus develop a more complete picture of the relative emissions efficiency benefits of electrifying certain end uses—and shape load accordingly. Understanding when and where electrification is most emissions-efficient will enable regulators to develop policies, rate structures, and incentives to ensure that electrification minimizes any incremental emissions.

5. Account for the lives of investments.

Energy infrastructure investments—whether made by utilities or homeowners—are long-lived: Generation, transmission, and distribution assets can have expected useful lives of 30 or 40 years or longer, while a home water heater or lighting fixture can last more than a decade. Consequently, opportunities for new investments are necessarily limited and best undertaken when they can avoid other investments. These limitations are especially important because, unless utilities and consumers are positioned to make informed investments when infrastructure replacement time arrives, the opportunity to make lower-cost, cleaner investments may be lost. It is important when these decisions arise to replace infrastructure with least-cost, emissions-efficient resources that will provide years of valuable flexibility to grid managers and cost savings to consumers.

BE investments raise an additional noteworthy factor: As the power sector reduces its environmental footprint over time, the emissions efficiency of electric end uses will improve correspondingly. Consequently, it is important to recognize that the total emissions over the life of an electrification investment may be lower than for the fossil-fueled alternative, even if emissions are higher in the early years of the investment. Thus, in certain jurisdictions where the regional power grid is rapidly decarbonizing, it is worth considering electrification even before end uses are more emissions-efficient than the fossil-fueled alternatives they replace. Note too that fossil-fueled options do not share this advantage. No matter how emissions-efficient they may be today, that will not change over their useful lives.

6. Design rates to encourage beneficial electrification.

Customers are willing to shift their consumption to cheaper hours of the day when the financial incentive to do so is meaningful. Using rates to signal value to consumers is not a new strategy. As noted, many electric technologies can be scheduled to charge when the cost of operating the grid is lower. However, for customers to have incentives to take advantage of that low-cost power—and for them and the utility to reap the economic benefits—time-sensitive pricing will be necessary to communicate to customers the differences in costs at different times of day.

Further, innovation can flow from good rate design. Rates shape the way we use the grid, and grid managers can use rates to make more efficient use of existing grid investments, avoid unnecessary new investments, and motivate customers.

Putting Beneficial Electrification Into Action

Despite being a pathway to significant innovations and opportunities for utilities, consumers, and the environment, BE probably will not occur, nor will related benefits materialize, in the absence of focused action by states. This section outlines the important policy prerequisites, process steps, and other considerations that can contribute to the successful implementation of BE and the realization of its many benefits.

Lay the Foundation in Policy

1. **Develop goals:** The first step in developing any effective policy is to articulate why it is being created. A BE policy should be no different. BE may be a worthy goal in and of itself, but states adopting it will have other policy objectives that may be affected or that may inform how each state implements BE. States will benefit from first defining goals and then prioritizing them before making decisions about specific BE implementation efforts.
2. **Identify barriers:** It is important for policymakers, regulators, and utilities to identify barriers to achievement of their goals. These include, for example, traditional cost-of-service regulation and the incentive it gives utilities to increase sales and resist any measures that might reduce them.
3. **Establish metrics:** Identifying criteria and metrics is essential for states to track progress toward their goals. Metrics could include, for example, the number of EVs sold or heat pumps installed, the quantity of emissions avoided, fossil fuel savings, or peak demand reductions.

Not only can states use metrics for tracking progress, they may also wish to revisit established regulatory practices and use these metrics to develop performance incentives for utilities.

4. **Address timing:** Policymakers will want to recognize that the development and implementation of BE programs represents a long-term effort.
5. **Consider flexibility:** How much flexibility do policymakers want to provide the entities charged with implementing BE? As long as providers are delivering measurable results that meet policy goals and objectives, it could be useful to grant them the leeway to choose the specifics of program design, implementation, and delivery.
6. **Identify affected participants:** States will want to recognize, and perhaps leverage, the many actors that could affect or be affected as BE activity develops.

Ensure an Open Process

Another key to successfully developing policy and creating support for it is to establish a process in which interested parties can participate and engage with one another. Most energy-related proceedings are formally convened before a state public utility commission (PUC) and offer limited opportunities for consumers and other stakeholders to participate. Rules governing interactions vary such that some state utility commissioners may engage in discussions with all interested stakeholders, while other states may strictly limit such interactions. Absent an affirmative step by states, processes for examining BE could become more constrained and less inclusive.

Collaborative efforts can also give regulators the opportunity to convene multiple stakeholders unfamiliar with the commission, its scope, and its rules to discuss a variety of issues in a constructive and less formal environment. Collaboratives can provide a flexible structure to help work through policy questions and resolve conflicts as part of or completely outside a typical quasi-judicial PUC setting. Collaboratives lend themselves to addressing the many broad policy questions electrification raises. They can be set up to address the full suite of issues associated with designing, implementing, monitoring, improving, and even adapting such programs to changing conditions. Over the last several years, state commissions in Maryland, Minnesota, Rhode Island, and Illinois have hosted collaboratives on emerging energy policy issues.

Anticipate Specific Issues

Once states have engaged stakeholders and identified BE-related goals, several specific issues are likely to arise. They include rate design, utility incentives, efficiency resource standards, building codes for new construction, appliance standards, and fossil fuel phaseout.

1. **Rate design:** Adapting electric rate design is a key element of electrification. Electrification depends on independent actions by energy users enabled through sufficient transparency and promise of compensation. For electrification consumers to benefit from the value produced by their flexible electrified loads, the value of their actions must be communicated through the electricity prices they pay or avoid. It is not essential to apply advanced rate design to all customers; that is a separate regulatory decision from making optional time-varying rates available to consumers able to control or shift their usage into low-cost, low-emissions periods.
2. **Utility incentives for participating customers:** Electric utilities have provided ratepayer-funded incentives to enhance the deployment of innovative technologies for many years. It is reasonable to expect that the same rationale will apply at least in part for BE-related equipment.
3. **Energy efficiency resource standards:** BE may result in higher kWh consumption even as the efficient use of energy overall (all fuels) improves. Where existing energy efficiency standards impose obligations only on electricity consumption, states would be wise to modify them to include all fuels. Standards could also consider other metrics, such as avoided CO_2 emissions, Btu savings, or peak reductions.
4. **Building energy codes for new construction and appliance standards:** New construction is the ideal opportunity to deploy new technologies, so states may want to consider building codes that advance BE technologies. The entire cost of an efficient heating and cooling system, as well as a water heating system, is then only an incremental cost.

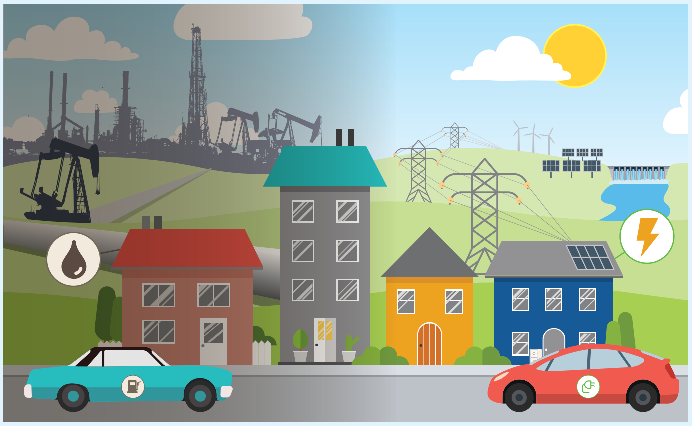
Likewise, appliance standards that explicitly consider the competitiveness of BE appliances will contribute to their adoption.

5. **Fossil fuel phaseout:** We recommend that states consider incorporating equipment investment lifetimes into current planning and analysis. As electric technologies continue to improve and decline in price, the costs of all fossil fuel-based investments over their useful lives may not be as attractive as today, and the risk of creating stranded costs is greater.

This paper is intended to stimulate discussion about how to approach the many opportunities associated with major trends and innovations in the power sector today. BE is a collection of strategies designed to identify and overcome barriers and take advantage of these trends and related opportunities to benefit consumers, electric utilities, and the environment.

Six Principles for Beneficial Electrification

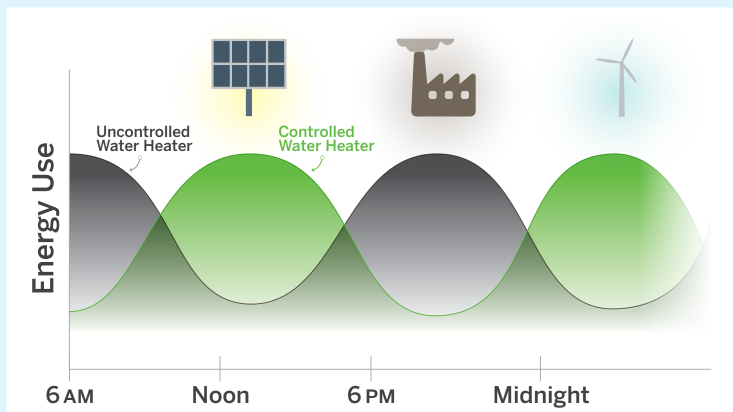
Principle 1: Put Efficiency First



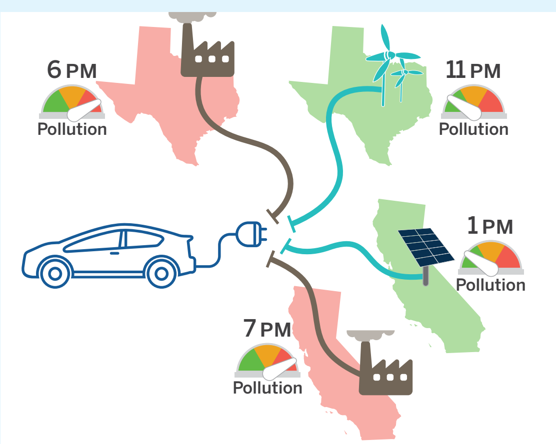
To many, the term "energy efficiency" has historically meant using less electricity. But when switching to electric vehicles or heat pumps for space and water heating, electricity use may go up—even though total energy use declines as less gasoline or home heating fuel is used. Today, energy efficiency calculations should incorporate both the efficiency of the equipment and the fuel used.

Principle 2: Recognize the Value of Flexible Load for Grid Operations

The cost and emissions of power generation vary greatly depending on the time of day. Because electric vehicles and heat pumps are flexible in when they can be charged, their use of electricity can be shifted to times when low-cost, clean resources are available.



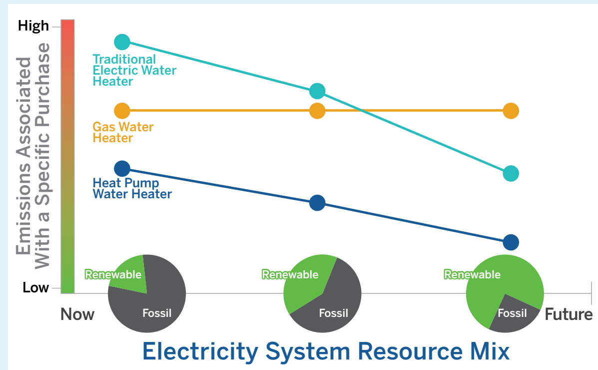
Principle 3: Understand the Emissions Effects of Changes in Load



Knowing a system's marginal emissions—the emissions that will be added with the use of one more kWh, or that will be reduced if a kWh is avoided—is one way of understanding the emissions associated with increased electrification. Marginal emissions vary depending on time and place. Modeling is a useful way to characterize the emissions associated with more significant amounts of electrification load added to the nation's grids.

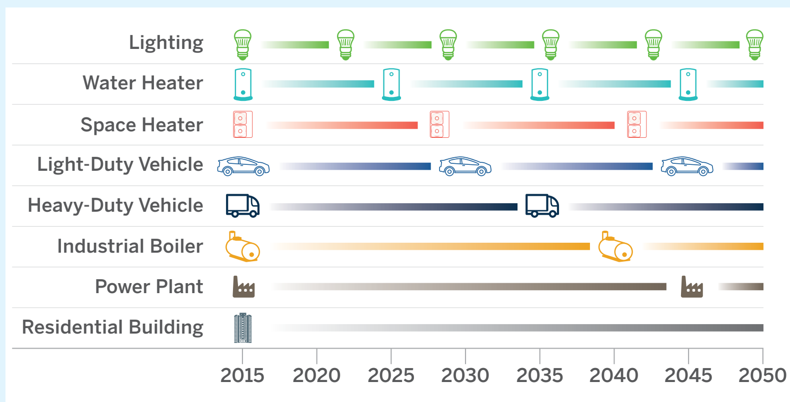
Principle 4: Use Emissions Efficiency to Measure the Air Impacts of Beneficial Electrification

Characterizing the pollution associated with a specific electrification investment requires an understanding of emissions efficiency—the emissions per unit of energy output. By driving an electric vehicle or installing an efficient heat pump water heater, consumers can produce less pollution per vehicle mile traveled or gallon of water heated. Moreover, as the grid becomes cleaner with more renewable generation, the emissions efficiency of that electric vehicle or heat pump will improve further.

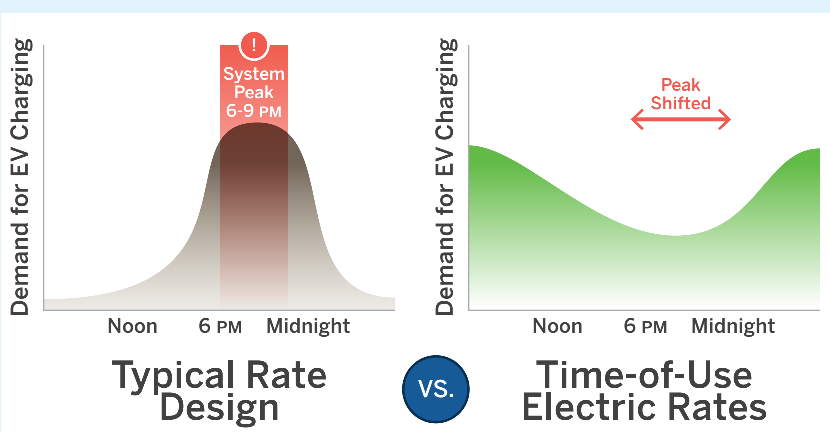


Principle 5: Account for the Lives of Investments

Because energy infrastructure is long-lived, opportunities for new investments are limited. So it is critical to understand the useful lifetimes of investments. Unless utilities and consumers are positioned to make informed investments when infrastructure replacement time arrives, the opportunity to make lower-cost, cleaner investments may be lost.



Principle 6: Design Rates to Encourage Beneficial Electrification



Unlike typical electric rates, time-sensitive rates reflect the different cost of providing electricity at different times of the day, and they signal this price difference to consumers. By using well-designed rates to encourage customers to shift their demand to less expensive times, utilities can make more efficient use of grid resources.

Opportunities in a Changing Energy Sector

Technologies are gaining new capabilities while costs decline, enabling an energy transformation that benefits consumers and the environment.

Beneficial electrification (BE) provides one of the biggest opportunities in the power sector today to connect consumers with far more affordable and cleaner resources and to help utilities better manage the grid and reduce harm to the environment and public health.

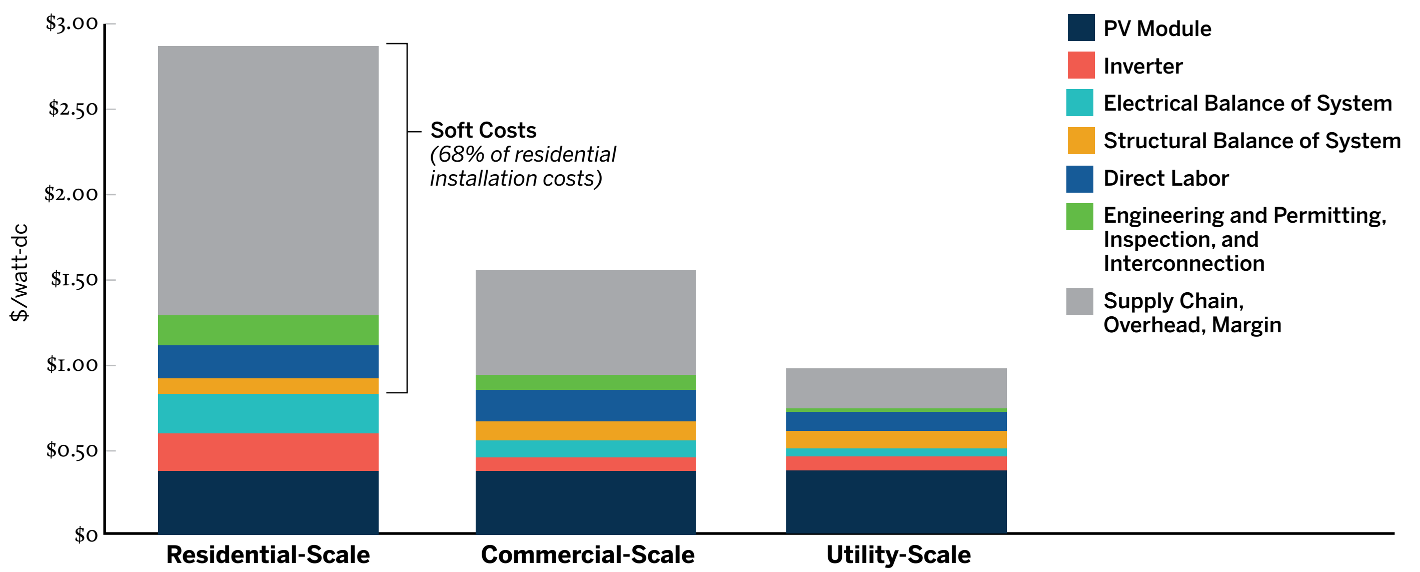
For electrification to be considered beneficial, it must meet one or more of the following conditions, without adversely affecting the other two:
1. Saves consumers money over the long run;
2. Enables better grid management; and
3. Reduces negative environmental impacts.

Although the electric power system was once a centralized structure supplied by remote and largely fossil fuel-fired resources, it is becoming more distributed and interconnected, allowing customers to produce, consume, and save energy in numerous ways. Utility customers are becoming accustomed to the growing availability and convenience of newly electrified end uses in transportation, space heating, and water heating. Because of their greater efficiency, these electric technologies can be significantly less costly to operate than traditional fossil fuel-based alternatives and are poised to bring a new wave of innovation and opportunity for our economy.

The energy sector—specifically the costs and capabilities of energy technologies—is undergoing exponential change. Although that term may be overused, we think of it as illustrated by Moore's law, describing regular doublings of computing power. In the energy sector this translates into doublings in an absolute sense (as in numbers of installations), a capability sense (such as an electric vehicle, or EV, going farther on a charge), or a cost sense (such as halving of the market price for different technologies).

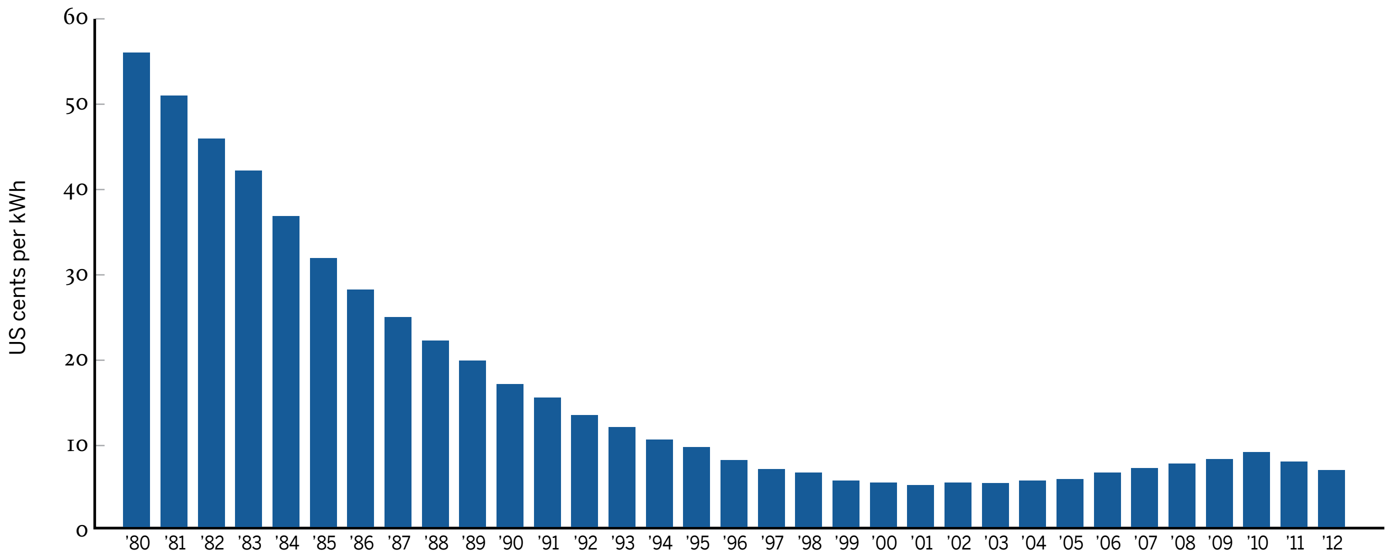
This is happening in many ways. Smart meters and other technologies make data about the grid more available than ever before. Variable energy resources (VERs), also called variable generation, are experiencing explosive growth. And there is rapid advancement in the capabilities of storage and EVs. These forces compound each other, due to the digitization of energy, creating network effects that will enable electricity

Figure 1. Solar Photovoltaic Costs, Third Quarter 2017



Source: Gallagher, S. (2018). *The U.S. Solar Industry: 2018 and Beyond.*

Figure 2. Wind Cost Per kWh (US)



Source: Department of Energy. (2014). *The Clean Energy Economy in Three Charts*.

demand to be managed for the first time in history. This flexibility can make the electric grid more capable of accommodating even greater amounts of low-cost VERs.

Wind and solar costs are falling around the globe. This is occurring for solar systems of all sizes. Figure 1 on Page 17 shows that by the third quarter of 2017, residential solar systems cost less than $3 per watt, and utility-scale systems broke the $1 per watt threshold.[2]

Likewise, US wind power costs declined by an order of magnitude between 1980 and 2012 to about 5 cents per kilowatt-hour (kWh) (see Figure 2).[3] Since then prices have dropped further, to about 2 cents per kWh in 2016.[4]

Bloomberg New Energy Finance (BNEF) recognizes these trends for solar and wind resources. Projects that in 2015 were 5.8 cents per kWh for solar (in the United Arab Emirates) and 4.5 cents per kWh for wind (in the United States) were, in 2017, 1.8 cents/kWh for solar (in Saudi Arabia) and 2 cents/kWh for wind (in India).[5]

Stateside, the all-sources competitive bidding process of the Public Service Company of Colorado reflects similar trends. In 2017 the process yielded 238 projects totaling almost 60,000 megawatts, as illustrated in Figure 3.[6] Solar bids came in at an average of $30 per megawatt-hour (MWh), or 3 cents per kWh. Wind was an average of $18/MWh, or less than 2 cents/kWh.

Comparing those bids to Energy Information Administration data for 2016 is instructive. In 2016, coal-generated

2 Gallagher, S. (2018, January 19). *The U.S. solar industry: 2018 and beyond* [Presentation]. Solar Energy Industries Association. Retrieved from https://www.renewwisconsin.org/wp-content/uploads/2018/01/7.-SeanGallagher-SEIA.pdf

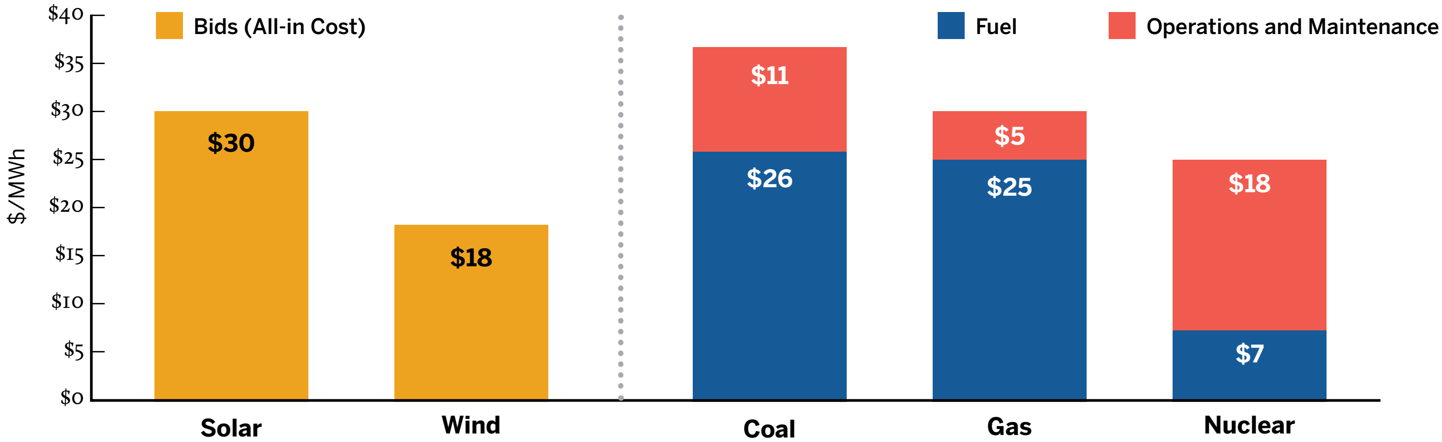
3 US Department of Energy. (2014.) *The clean energy economy in three charts* [Webpage]. Retrieved from https://www.energy.gov/articles/clean-energy-economy-three-charts

4 Wiser, R., and Bolinger, M. (2017). *2016 wind technologies market report.* Washington, DC: US Department of Energy, Office of Energy Efficiency & Renewable Energy. Retrieved from https://energy.gov/sites/prod/files/2017/10/f37/2016_Wind_Technologies_Market_Report_101317.pdf. See also US Department of Energy, Office of Energy Efficiency & Renewable Energy. (2015). *EERE 2014 wind technologies market report finds wind power at record low prices.* Washington, DC: Author. Retrieved from https://www.energy.gov/eere/articles/eere-2014-wind-technologies-market-report-finds-wind-power-record-low-prices

5 Bloomberg New Energy Finance. (2017, October 18). Untitled presentation by Michael Liebreich to California Independent System Operator symposium [Video]. Retrieved from https://www.youtube.com/watch?v=Huy-liZJ49k

6 Public Service Company of Colorado. (2017, December 28). *2016 electric resource plan: 2017 all source solicitation 30-day report.* Denver, CO: Author. Retrieved from https://www.documentcloud.org/documents/4340162-Xcel-Solicitation-Report.html. See also US Energy Information Administration. (2016). *Electric power annual.* Washington, DC: Author. Retrieved from https://www.eia.gov/electricity/annual/

Figure 3. Bids Received by Public Service Company of Colorado vs. Existing Plants



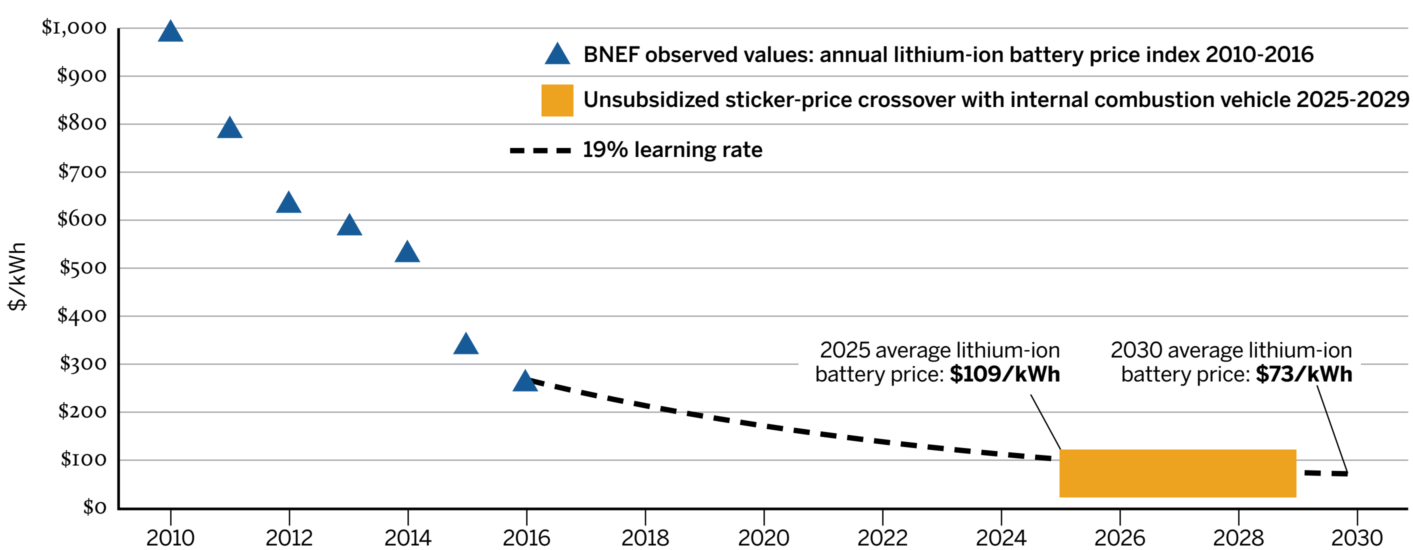
Sources: Public Service Company of Colorado. (2017). *2016 Electric Resource Plan: 2017 All Source Solicitation 30-Day Report.* and US Energy Information Administration. (2016). *Electric Power Annual.*

electricity cost an average of $37 per MWh for fuel and operating costs. Gas was lower at $30/MWh and nuclear even lower at $25/MWh. Because these are averages, roughly half of the generating units are more expensive to fuel and operate.

This raises important questions of economic obsolescence and the reasonableness of ratepayers' paying for the continued operation of resources that may be more expensive to run than currently available alternatives. In the Colorado solicitation, wind costs less to operate than the average fuel costs alone of coal and gas. Solar is less than the operating costs of coal and on par with gas. Under these circumstances, a utility that has adequate capacity could still buy wind or solar to reduce fuel costs and thus customer bills. Utilities may be leaving cost savings for customers on the table if they aren't looking at the relative costs of these renewable resources.

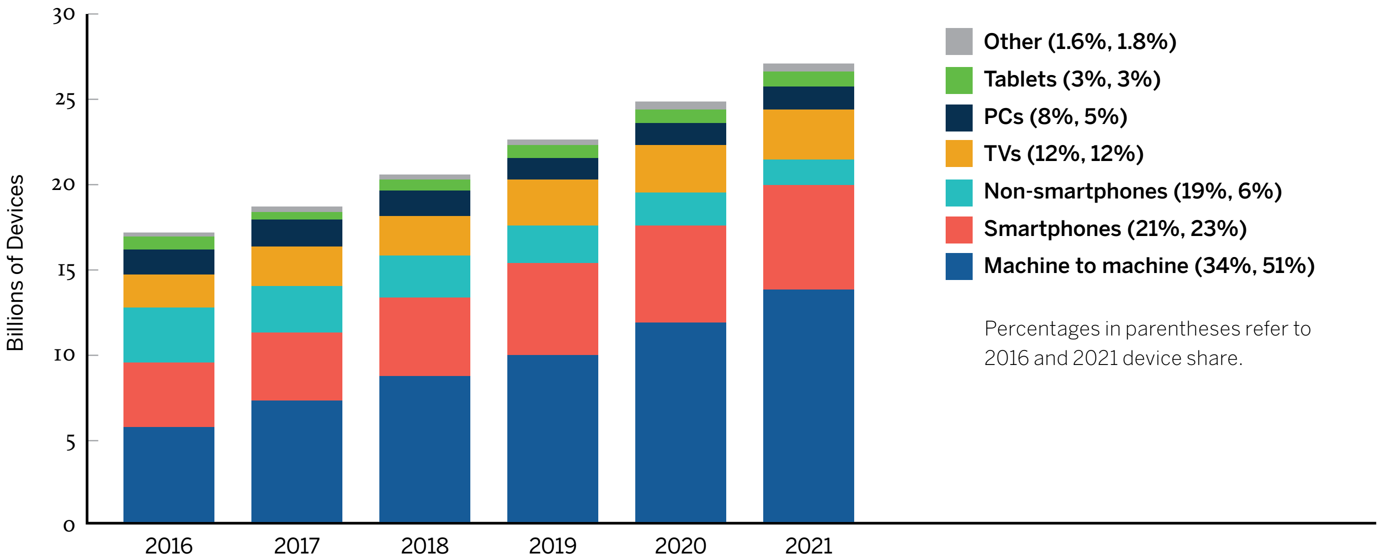
Although the bids to the Public Service Company of Colorado are not unique, it is important to remember that the state does have some of the best wind and solar conditions in the nation. In Oklahoma, American Electric Power has requested approval for the Wind Catcher Energy Connection Project, a 2,000-megawatt wind farm in the Oklahoma Panhandle. That project would deliver wind power at less than 2 cents per kWh.

Figure 4. Electric Storage Costs



Source: Bloomberg New Energy Finance. (2017). *New Energy Outlook 2017.*

Figure 5. Implications for Information – Global Devices and Connections Growth



Source: Cisco Systems. (2017). *The Zettabyte Era: Trends and Analysis.*

Like renewables, other energy technologies are declining in cost and their capabilities improving. Figure 4 on Page 19 illustrates the cost of lithium-ion batteries—a key component in EVs—and BNEF's estimate of the unsubsidized sticker price crossover point with internal combustion vehicles.[7]

The blue triangles depict the actual observed prices per kWh through 2016. The hatched line illustrates BNEF's projection of how prices are likely to track over the next decade.

One further point to consider about the pace of change occurring in the power sector has to do with the quantity of information about energy use and the ease with which consumers, third parties, and utilities can access it. For more than a century, we have been managing energy supply to meet demand, and the grid we built and maintained to do so has a lot of expensive redundancy.[8]

Today we have a much more precise ability to manage our energy use than ever before. This ability has grown in such ways that much of it can be done automatically. Many devices and buildings have energy-use controls built in, so customers can actually be passive and still get benefits. For example, in Figure 5, Cisco Systems projects that by 2021 more than half of all electrical device connections will be machine to machine, depicted in the bright blue bars.[9] This means energy technologies will be able to talk to one another without intervention by users, which will enable a future of cheaper, cleaner, and more precisely managed energy use.

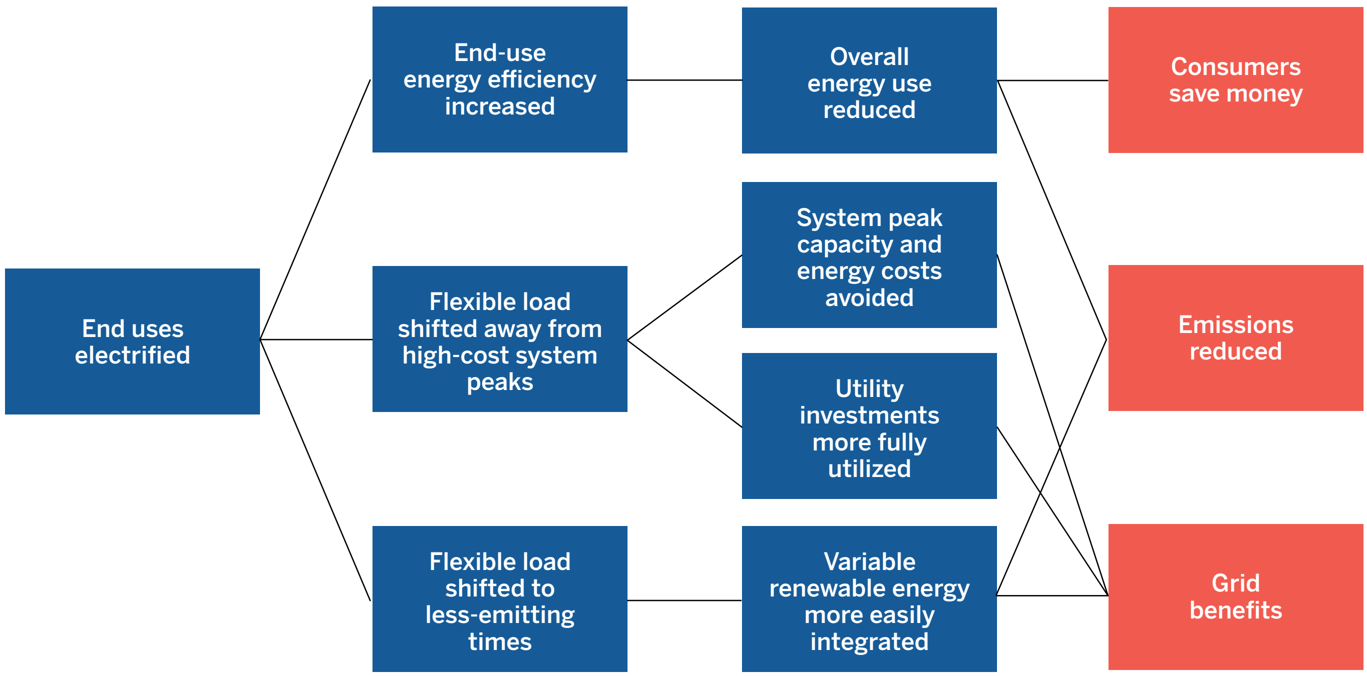
These examples illustrate some of the ways the power sector is changing and some of the qualitative differences we should expect as these technical, economic, environmental, and operational innovations are implemented. These innovations may save consumers money if their electricity suppliers contract for new variable renewable resources. But to accommodate the increase in the supply of inexpensive variable generation, the grid will need more flexibility. Many forms of electrification, including water heating, space heating, and light-duty transportation, can provide grid flexibility. In this

7 Prices are an average of battery electric vehicle and plug-in hybrid electric vehicle batteries and include both cell and pack costs. Historical prices are nominal; future ones are in real 2016 US dollars. Bloomberg New Energy Finance. (2017). *New energy outlook 2017.* Retrieved from https://about.bnef.com/new-energy-outlook/

8 Hogan, M. (2018, February 12). As reliable as your morning coffee: Why do we go overboard on generation resource adequacy? [Blog post]. Regulatory Assistance Project. Retrieved from http://www.raponline.org/blog/as-reliable-as-your-morning-coffee-why-do-we-go-overboard-on-generation-resource-adequacy/

9 Cisco Systems. (2017). *The zettabyte era: Trends and analysis.* Retrieved from https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/vni-hyperconnectivity-wp.html

Figure 6. Relationship of Electrification to Potential Benefits



paper we use three examples of electrical end uses to illustrate their efficiency, flexibility, and potential as power grid resources: air source heat pumps, heat pump water heaters, and EVs.[10]

These electrified end uses are far more efficient than their fossil-fueled counterparts. Heat pumps, for example, are capable of providing 1.5 to 3 times more heat energy than the heat value of the electrical energy they consume, making them ideal for space and water heating. Likewise, EVs are capable of converting 60 percent of the energy they draw from the grid into miles traveled, while comparable gasoline-fueled passenger vehicles convert only about 20 percent of primary energy to the same purpose.[11]

Typically, these end uses are flexible in when they can be charged and used, working like batteries and making them valuable for grid management. This load is flexible because electrically heated water and electrically charged vehicles don't need to be used at the same time that they draw energy from the grid—unlike virtually all other electric end uses[12] (see Figure 6). Due to its flexibility, this load can be shifted to times when there is less demand for electricity and it is cheaper or when renewable energy generation is being curtailed (i.e., discarded or turned off), and away from times when there is

10 We have chosen these three examples for clarity of exposition. We recognize that there are many alternatives to and variations of these three types of technologies, and their effectiveness will depend on a large number of factors including climate and use patterns. See, for example, Deason, J., Wei, M., Leventis, G., Smith, S., and Schwartz, L.C. (2018). *Electrification of buildings and industry in the United States: Drivers, barriers, prospects, and policy approaches* (LBNL-2001133). Berkeley, CA: Lawrence Berkeley National Laboratory. Retrieved from http://eta-publications.lbl.gov/sites/default/files/electrification_of_buildings_and_industry_final_0.pdf. See also Nadel, S. (2016). *Comparative energy use of residential furnaces and heat pumps* (Research report No. A1602). Washington, DC: American Council for an Energy-Efficient Economy. Retrieved from http://aceee.org/comparative-energy-use-residential-furnaces-and

11 "EVs convert about 59%-62% of the electrical energy from the grid to power at the wheels. Conventional gasoline vehicles only convert about 17%–21% of the energy stored in gasoline to power at the wheels." US Department of Energy, Office of Energy Efficiency & Renewable Energy. *All-electric vehicles* [Webpage]. Retrieved from https://www.fueleconomy.gov/feg/evtech.shtml. Heat pump water heaters "can be two to three times more energy efficient than conventional electric resistance water heaters." US Department of Energy, Office of Energy Efficiency & Renewable Energy. *Heat pump water heaters* [Webpage]. Retrieved from https://energy.gov/energysaver/heat-pump-water-heaters. See also Northeast Energy Efficiency Partnerships. *Cold climate air source heat pump.* Retrieved from http://www.neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump

12 For additional examples of this flexibility, see the discussion of ice and chilled water storage applications for commercial air-conditioning applications in Lazar, J. (2016). *Teaching the "duck" to fly* (2nd edition). Montpelier, VT: Regulatory Assistance Project. Retrieved from http://www.raponline.org/document/download/id/7956

greater demand and the need to dispatch more expensive and often more polluting generation resources. Because this load can be shifted, it is valuable to consumers and the utilities that serve them.

The availability of more energy-efficient electric end uses, in combination with the greening of the generation fleet, creates the potential for far greater emissions efficiency.

Because of their flexibility, these end uses have potential as grid resources that can help utilities with load management. BE load can be managed through appropriate rate designs and other smart-charging programs to help balance increasing amounts of variable generation on the grid and the retirement of older, less flexible steam generating units. Using BE load as a grid management tool also positions utilities to provide new and innovative services and programs to customers and to defer or permanently avoid costly generation, transmission, and distribution system upgrades that might otherwise be necessary with new uncontrolled load.

Furthermore, as BE makes the grid more flexible and capable of accommodating VERs by reducing system peaks and enables the grid to accommodate greater amounts of cleaner resources, it also contributes to an even cleaner power sector overall. The availability of more energy-efficient electric end uses, in combination with the greening of the generation fleet, creates the potential for far greater emissions efficiency. In other words, despite consuming more kilowatt-hours of electricity, consumers will produce fewer pounds of pollution per vehicle mile traveled or per gallon of hot water produced.[13]

To some, electrification may simply represent increasing load.[14] But for it to be considered beneficial, electrification must meet one or more of the following conditions, without adversely affecting the other two:

1. Saves consumers money over the long run;
2. Enables better grid management;[15] and
3. Reduces negative environmental impacts.[16]

These three conditions guide our discussion of BE in the following pages.[17] We should emphasize, however, that while fundamental to beneficial electrification, these conditions characterize only *potential* benefits; they won't occur automatically. To help ensure they do occur, the next section of this paper sets out six principles for regulators to observe in developing and evaluating electrification strategies. Observing these principles will make it more likely that electrification will develop in a manner that serves the public good and broadly produces benefits.[18] The final section discusses practical, implementation-related first steps that states can consider as they move ahead with BE or work to position their jurisdictions to do so. These include articulating key policy prerequisites and developing informal collaborative efforts among stakeholders.

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13 This emissions efficiency is a key aspect of BE and raises questions about traditional energy efficiency assumptions. Emissions efficiency is further discussed in the next two sections of this paper.

14 Weiss, J., Hledik, R., Hagerty, M., and Gorman, W. (2017). *Electrification: Emerging opportunities for utility growth.* Cambridge, MA: The Brattle Group. Retrieved from http://www.brattle.com/system/news/pdfs/000/001/174/original/Electrification_Whitepaper_Final_Single_Pages.pdf?1485532518

15 Flexible electrification load can provide various grid management services. See Alstone, P., Potter, J., Piette, M.A., Schwartz, P., Berger, M., Dunn, L.N., et al. (2017). *Final report on Phase 2 results: 2025 California demand response potential study.* Retrieved from http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442452698; see also St. John, J. (2017, January 26). *How California can shape, shift and shimmy to demand response nirvana.* Greentech Media. Retrieved from https://www.greentechmedia.com/articles/read/how-california-can-shape-shift-and-shimmy-to-demand-response#gs.NERYCdk

16 The authors recognize that the environmental footprint of power sector infrastructure including generation is broader than the associated air emissions or, more narrowly, the associated carbon emissions. However, in this paper we focus more narrowly to ensure clarity of exposition and to better illustrate these beneficial electrification principles.

17 We also recognize that electrification will be affected by changes in federal and state energy and environmental policies. See the Appendix.

18 See Table 1 on Page 24.

Principles for Maximizing the Benefits

Six guiding statements will help policymakers and regulators accomplish the objectives of beneficial electrification.

Electrification can achieve a number of outcomes. For example, it can become the means of transitioning fossil-fueled end uses to more efficient and flexible uses of electricity. In doing so, it can also help cut electric sector emissions, reduce costs for consumers, and support grid management through the integration of incremental electric load.[19] To accomplish these objectives, it is important for policymakers and regulators to be able to formulate and evaluate their electrification strategies. The following principles will help them do so:

- Put efficiency first.
- Recognize the value of flexible load for grid operations.
- Understand the emissions effects of changes in load.
- Use emissions efficiency to measure the air impacts of beneficial electrification.
- Account for the lives of investments.
- Design rates to encourage beneficial electrification.

Table 1. Beneficial Electrification Principles Summary

Principle	Saves consumers money over the long run	Enables better grid management	Reduces negative environmental impacts
Put efficiency first	Prioritizes least-cost investment.	Energy efficiency improvements are by their nature shaped like the system load and therefore provide the bulk of savings during high-load hours. Many energy efficiency measures, such as building energy management systems, enable controls that provide additional grid flexibility.	Efficiency by itself reduces kWh use and thus contributes to overall emissions reduction.
Recognize the value of flexible load for grid operations	BE load can be moved to low-cost hours on the grid, saving consumers money and producing net benefits for all grid users.	Flex load can reduce expensive peaks and be moved to times of the day when the grid is less stressed or when variable energy resources (VERs) are being curtailed.	Reducing system peaks typically reduces use of dirtier resources; connecting load with clean VERs increases the system's flexibility and capability to accommodate more VERs.
Understand the marginal emissions impact of changes in load	Reducing energy-related pollution with incremental BE load internalizes environmental costs to society and benefits individual consumers by reducing costs associated with air pollution.	Does so indirectly. An understanding of marginal emissions can help inform grid management.	Understanding marginal emissions provides a basis for reducing emissions associated with incremental load, and time-varying pricing can reflect cost differentials associated with emissions differentials.
Use emissions efficiency to measure the air impacts of beneficial electrification	BE provides a whole-system energy efficiency perspective and opens the door to consumer savings associated with total energy use.	An understanding of the emissions efficiency of certain end uses, in particular those that can be controlled, adds to a utility's ability to determine suitable charging times for BE load.	Determining emissions efficiency helps ensure the ability to analyze environmental impacts associated with fuel switching, the adoption of more efficient end-use equipment, and its management on the grid.
Account for the lives of investments	Understanding investment lives and replacement opportunities can help reduce overly risky investment and clarify the value in taking earlier steps to invest in more efficient end uses.	Does so indirectly. It contributes to understanding the value of various energy infrastructure investments and their ability to be managed.	It contributes to understanding the length of time required before a more efficient investment can be made, and the time that a carbon-intensive investment will take to be paid for before a cleaner alternative can be adopted.
Design rates to encourage beneficial electrification	This is a key tool for moving customer load to less expensive times of the day.	Implemented properly this can reduce system peaks and help the system accommodate greater amounts of VERs through active control of loads at specific congested locations on the grid.	This can move load that already displaces less efficient fossil end uses to cleaner times of the day and to help grids accommodate greater amounts of VERs.

19 See, for example, Vermont Energy Investment Corp. (2018). *Driving the heat pump market: Lessons learned from the Northeast.* Burlington, VT: Author. Retrieved from https://www.veic.org/documents/default-source/resources/reports/veic-heat-pumps-in-the-northeast.pdf

Principle 1: Put Efficiency First

To many, the term "energy efficiency" has historically meant using less electricity. But when switching to electric vehicles or heat pumps for space and water heating, electricity use may go up—even though total energy use declines as less gasoline or home heating fuel is used. Today, energy efficiency calculations should incorporate both the efficiency of the equipment and the fuel used.

Experience shows that energy and economic goals can be met more reliably and at lower cost if their focus includes both supply-side and demand-side solutions.[20] Since the 1980s many states have followed least-cost investment practices, where major supply-side investments are tested against demand-side alternatives before permits for power plants or transmission lines can be issued.[21] In following this practice, states have realized they can meet many reliability challenges just as well or better with demand-side solutions as with supply-side options. Consider several notable examples. Consolidated Edison avoided $1.2 billion in costs to build a substation by instead investing in onsite power generation and basic customer-side energy efficiency.[22] In its Seventh Northwest Conservation and Electric Power Plan (see Figure 7 on Page 26),[23] the Northwest Power and Conservation Council reached the following conclusion:

> Using modeling to test how well different resources would perform under a wide range of future conditions, energy efficiency consistently proved the least expensive and least economically risky resource. In more than 90 percent of future conditions, cost-effective efficiency met all electricity load growth through 2030 and in more than half of the futures all load growth for the next 20 years.[24]

Energy efficiency has multiple benefits, including reduced generation, transmission, and distribution capacity; avoided line losses; avoided variable energy costs; avoided emissions; and a higher reliability index than any other type of resource.[25] As long as efficiency is the lowest-cost choice among resources, it should be the first choice for policymaking, planning, and

20 An added key to enabling beneficial electrification will be to recognize factors that affect performance of demand-side resources. With regard to space heating, for example, there is value in ensuring building envelope efficiency to secure the best results from the use of heat pump technology. Furthermore, to the degree a building functions well with a heat pump and loses less heat or cooling, then that heat pump when controlled can preheat or precool a building and serve as a tool to help grid operators avoid system peaks.

21 Cowart, R. (2014). *Unlocking the promise of the Energy Union: "Efficiency first" is key.* Brussels, Belgium: Regulatory Assistance Project. Retrieved from http://www.raponline.org/wp-content/uploads/2016/05/rap-cowart-efficiencyfirst-2014-dec-04.pdf

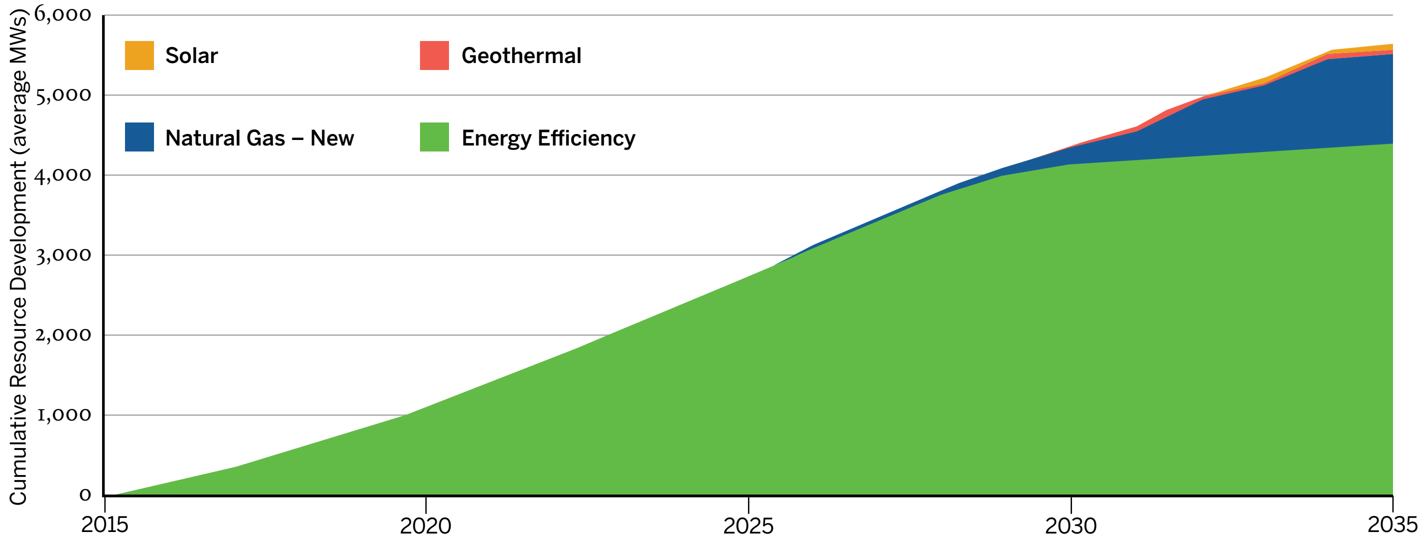
22 New York Public Service Commission. Case 14-E-0302. Order. (December 12, 2014). Order establishing Consolidated Edison Co. of New York Inc.'s Brooklyn/Queens Demand Management Program. Retrieved from http://documents.dps.ny.gov/public/MatterManagement/CaseMaster.aspx?MatterSeq=45800

23 Northwest Power and Conservation Council. (2016). *Seventh Northwest conservation and electric power plan* (Document 2016-02). Portland, OR: Author. Retrieved from https://www.nwcouncil.org/reports/seventh-power-plan. Figure 1.1 in that report "shows the average resource development across all 800 futures tested in the Regional Portfolio Model."

24 Northwest Power and Conservation Council, 2016.

25 Lazar, J., and Colburn, K. (2013). *Recognizing the full value of energy efficiency.* Montpelier, VT: Regulatory Assistance Project. Retrieved from http://www.raponline.org/knowledge-center/recognizing-the-full-value-of-energy-efficiency/

Figure 7. Northwest Power and Conservation Council's Seventh Plan Resource Portfolio



Source: Northwest Power and Conservation Council. (2016). *Seventh Northwest Conservation and Electric Power Plan.*

utility acquisition. This conclusion applies to a narrower, more traditional focus on specific commodities like kWhs or therms, but also across all fuel types. Taking an efficiency-first approach prioritizes investments in customer-side efficiency resources whenever they would cost less or deliver more value than investing in energy infrastructure, fuels, and supply alternatives.[26]

Fuel switching, which simply means changing fuel sources to save money and reduce emissions, has been part of utility energy efficiency programs for decades. The American Council for an Energy-Efficient Economy was investigating gas demand-side management and fuel-switching potential in New York state in the early 1990s.[27] In the same time period, the Vermont Public Service Board directed utilities to develop programs to capture all cost-effective demand-side resources, including fuel switching.[28] At that time, efficiency savings came from replacing electric resistance space heating equipment with onsite fossil fuel space heating and water heating technology.[29] Today the opportunity is reversed: Cost-saving fuel switching involves changing customer-side end uses from fossil fuels to more efficient electrical options.[30] But the purpose of fuel switching then was the same as it is now: Replace less efficient fuels and their uses with cleaner, more economical alternatives.

Today, replacing fossil-fueled equipment with electricity-fueled equipment can create opportunities for consumers to control and reduce the cost of their energy use.[31] This is due to

26 Rosenow, J., Bayer, E., Rososinska, B., Genard, Q., and Toporek, M. (2016). *Efficiency first: From principle to practice—real world examples from across Europe.* The Hague, Netherlands: Energy Union Choices. Retrieved from http://www.raponline.org/wp-content/uploads/2016/11/efficiency-first-principle-practice-2016-november.pdf. See also Cowart, 2014.

27 Nadel, S. (2017). *Natural gas energy efficiency: Progress and opportunities* (Report U1708), p. 22. Washington, DC: American Council for an Energy-Efficient Economy. Retrieved from http://www.ourenergypolicy.org/wp-content/uploads/2017/07/u1708.pdf. See also Nadel, S., Eto, J., Kelley, M., and Jordan, J. (1994). *Gas DSM and fuel switching: Opportunities and experiences.* Washington, DC: ACEEE. Retrieved from http://aceee.org/sites/default/files/publications/researchreports/U932.pdf

28 See, for example, Vermont PSB Docket 5270-CV-1, Orders of April 16, 1990, and March 19, 1991. In this investigation the commission ordered "utilities to develop programs to capture all cost-effective demand-side resources, including fuel switching." Hamilton, L.B., Milford, L., Parker, S., and Steinhurst, W. (1992). *Fuel switching programs in Vermont: Issues and experiences*. Washington, DC: ACEEE. Retrieved from http://aceee.org/files/proceedings/1992/data/papers/SS92_Panel8_Paper10.pdf

29 It should be noted that states include combined heat and power in their efficiency program portfolios. Although technically not electrification, these projects could still benefit from an analysis of the relative efficiency of their electrical end uses versus competing technologies.

30 In some circumstances, fuel switching can also imply changing from fuel oil or propane to natural gas service.

31 For example, if a combined cycle gas turbine is at the margin (e.g., in Texas or California), the system is making electricity at 60 percent efficiency. That electricity run to a house would experience 10 percent line losses. The resulting 54 percent efficiency run through a heat pump at 300 percent efficiency would, in turn, result in the delivery of 162 percent efficiency to the house. Even a cold climate heat pump at 200 percent efficiency would deliver 108 percent to the house. No furnace can do that, although some gas heat pumps are capable of greater efficiencies than cold climate heat pumps.

the improved efficiency of both electricity generation and end-use appliances, as well as the affordability of electricity relative to other fuel options.[32] In many cases, due to the efficiency of an EV or heat pump, for example, the quantity of electricity required to produce a certain output (e.g., miles driven or heat delivered) is less energy-intensive and less expensive than the quantity of the fossil fuel currently being used to provide the same output. Savings from electrification can also be maximized by electrifying with the most energy-efficient equipment and using the grid at low-cost hours.[33]

Although the context (i.e., fuel costs and equipment efficiencies) may have changed since the 1990s, the basic rule about reducing net energy costs has not:

> An investment is cost-effective when the net cost of installing and maintaining measures that improve the efficiency of *overall energy usage* is less than the total cost of alternatives to achieve the same end use over the same lifetime.

Given the growing use and increased efficiency of electric technologies like EVs and heat pumps, there appear to be ever more circumstances where electricity usage can increase while total energy use, environmental emissions, and costs decrease. This is confusing to some because an increase in electricity use appears to contradict long-held assumptions underlying energy efficiency, where one endeavors to invest in ways to use less electricity to provide similar or enhanced levels of service and amenities.[34]

The key is to remember that fuel switching involves three elements: the fuel being adopted, the fuel being replaced, and the comparative energy efficiency improvement of the new end-use equipment being installed. In a simple[35] illustration, someone who paid $100 last month for gasoline and $100 for electricity (a total of $200) acquires an EV and this month has no gasoline bill but has a $150 electricity bill. The $50 difference reflects an overall reduction in energy cost despite the increase in kWh consumption. This means electrification can be the more economical investment: The new EV owner's electricity bill increases but is still less than the combination of her prior month's bills for gasoline and electricity.[36] To accurately reflect the costs and benefits in this illustration, a complete fuel switching analysis should account for more than kWh use and include an assessment of the fuels used to generate the electricity. The consumer economics of fuel switching will not be compelling for all applications or every region of the country at current fuel prices and depending on related capital costs. But as electric technologies continue to improve and come down in price, and the grid becomes cleaner with the growth of renewables, the potential benefits for consumers can be expected to expand.[37]

In the absence of regulatory action, one should not automatically expect the adoption of these resources despite

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32 Heat pump technology is not limited to the simple air source examples above. Ground source heat pumps, although expensive, provide higher efficiency, particularly in cold climates. Carbon dioxide-based heat pumps with higher efficiency are being developed. Shared heat pump technology for multifamily dwellings (one water heater serving multiple units, with metering of hot water usage instead of electricity usage) is being tested. Ultimately, a home thermal energy center that combines heating, cooling, water heating, and refrigeration served by a single high-efficiency heat pump unit could become a component of a modern smart home.

33 Various states have programs to support this transition. Connecticut, for example, supports investment in air source heat pumps that can "cost-effectively displace heating supplied by oil, propane, or electric resistance units." Connecticut Department of Energy and Environmental Protection. (2018). *Comprehensive Energy Strategy,* p. 27. Retrieved from http://www.ct.gov/deep/lib/deep/energy/ces/2018_comprehensive_energy_strategy.pdf

34 Baumhefner, M. (2018, March 29). Are efficiency and electrification policies in conflict? [Blog post]. Natural Resources Defense Council. Retrieved from https://www.nrdc.org/experts/max-baumhefner/are-efficiency-and-electrification-policies-conflict

35 This illustration does not consider the incremental cost of an EV versus a comparable gasoline-fueled vehicle. See the discussion of the role of capital costs of fuel switching in Deason et al., 2018.

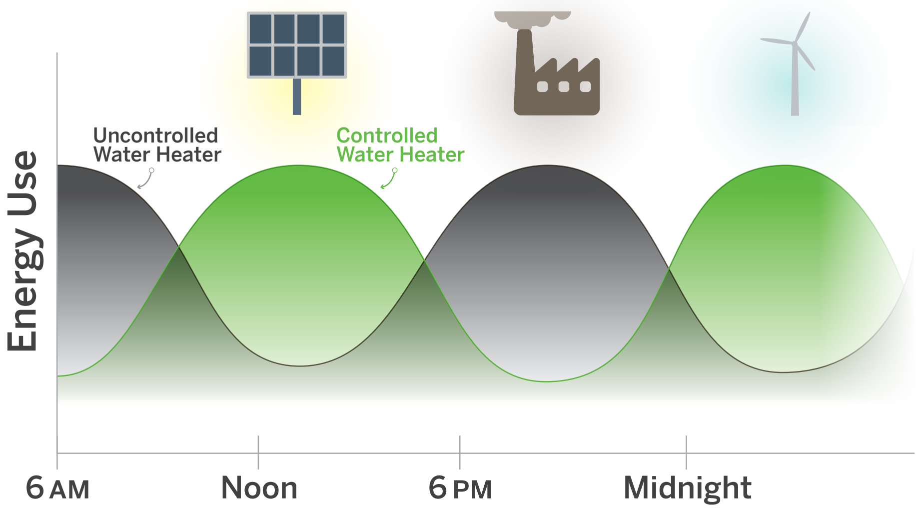
36 Union of Concerned Scientists. (2017). *Going from pump to plug: Adding up the savings from electric vehicles.* Cambridge, MA: Author. Retrieved from https://www.ucsusa.org/sites/default/files/attach/2017/11/cv-report-ev-savings.pdf

37 As discussed later in the paper under Principle 6, paying customers for the value of the flexibility, demand response, and other benefits of BE (or making them pay much less for electricity if they use the flexibility to heat or recharge during low electricity cost times of day) is likely going to be critically important to more quickly enabling BE. See Lazar, J., and Gonzalez, W. (2015). *Smart rate design for a smart future.* Montpelier, VT: Regulatory Assistance Project. Retrieved from http://www.raponline.org/document/download/id/7680

their being more efficient than traditional alternatives and thus offering the potential to save consumers money, lower air emissions, and increase grid flexibility. More meaningful metrics are needed to overcome established barriers in the way we currently measure and account for energy efficiency. On the demand side, investments in efficient solutions have traditionally encountered numerous market barriers to individual action; on the supply side, industry practices, business models, and regulatory practices have tended to favor fossil fuel-based energy infrastructure and sales over energy-saving technologies. Furthermore, even as capital costs decrease, certain vulnerable populations still may not be situated to take full advantage of these innovations. However, as long as energy efficiency—in this example the adoption of an EV and a fuel switch from gasoline to electricity—costs less and delivers more value than investing in alternatives to achieve the same end use over the same lifetime, it should be the resource of choice.

As long as energy efficiency costs less and delivers more value than investing in alternatives to achieve the same end use over the same lifetime, it should be the resource of choice.

Principle 2: Recognize the Value of Flexible Load for Grid Operations



The cost and emissions of power generation vary greatly depending on the time of day. Because electric vehicles and heat pumps are flexible in when they can be charged, their use of electricity can be shifted to times when low-cost, clean resources are available.

Because much of the new electrification load does not need to be charged at the same time it is being used, it is inherently flexible and can serve as energy storage. As a result, the power system can serve this new load at cleaner and less expensive times of the day. For example, water heating and EV loads don't need to charge during the morning and evening peaks when power is more constrained, more expensive, and potentially more polluting. These loads can shift to times of the day when it costs utilities less to meet demand, help avoid overgeneration during the middle of the day, and mitigate the steep ramping needed to serve peak loads.[38]

Shifting the load to less expensive times can produce savings that customers can share in through appropriately designed electricity rates (see Principle 6). With system operator data describing how marginal emissions change over the hours of the year and from year to year, and system load data characterizing peak and off-peak times, utility companies can develop smart charging programs and rate designs to encourage customers to charge their EVs and heat their homes or water at lower-emission and lower-cost times. The following three examples further discuss the ability of BE to increase flexibility and load-shaping capability.

Space Heating

Electrification holds great promise in space heating, where technologies that directly use fossil fuels like oil, propane, and natural gas have historically predominated.[39] Figure 8 on Page 30 shows the percentage of US residential electricity customers who are also natural gas customers.[40] When connected with smart thermostats, for example, heat pumps can help manage system demand by preheating or precooling a space during the afternoon and running less during the early evening peak.[41] Furthermore, smart thermostats enable demand response programs whereby a utility can reduce the electric load of a group of heat pumps by an individually small amount that cumulatively provides a measurable peak load reduction benefit to the grid and avoids unnecessary air emissions.[42] When aggregated, customers who enroll in such programs are compensated for the

38 See Goldenberg, C., Dyson, M., and Masters, H. (2018). *Demand flexibility: The key to enabling a low-cost, low-carbon grid.* Boulder, CO: Rocky Mountain Institute. Retrieved from https://rmi.org/wp-content/uploads/2018/02/Insight_Brief_Demand_Flexibility_2018.pdf

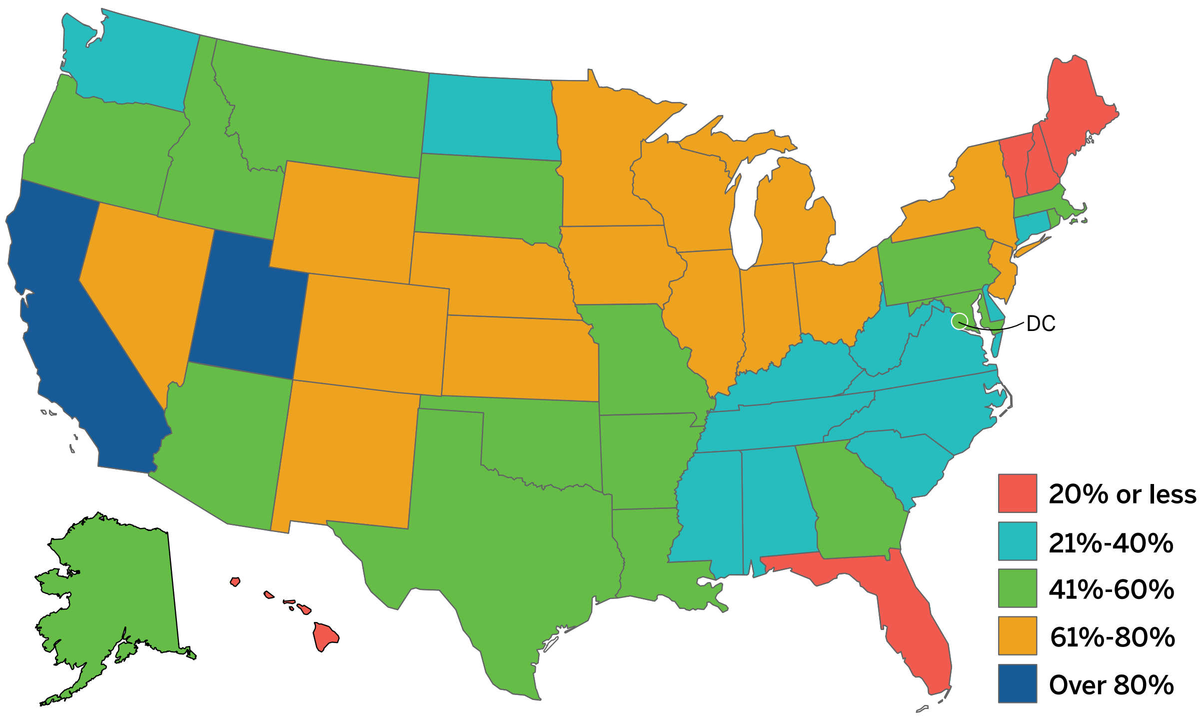
39 See Vermont Energy Investment Corp., 2018.

40 Analysis by Jim Lazar with data from US Energy Information Administration, 2016.

41 "Pre-cooling of buildings refers to shifting the operation of cooling equipment to earlier in the day to make use of more favorable electricity rates and relying on the thermal inertia of the building to provide adequate building comfort in subsequent hours." Deason et al., 2018.

42 "A future grid system with more electrified end uses, coupled with greater control and automation of end-use operation, can provide grid operators and utilities with greater control over load shapes and aggregated end uses." Deason et al., 2018. See also Nadel, 2016.

Figure 8. Percentage of Residential Electricity Customers Who Are Also Natural Gas Customers



Analysis by Jim Lazar with data from US Energy Information Administration, 2016.

energy and capacity benefits they provide to the system in exchange for the utility having the ability to manage their load during the most challenging hours.[43]

Heat pump water heaters can be controlled in a manner that provides benefits to the system by curtailing operation during the hours when the system is most strained and moving that charging to lower-cost hours.

Water Heating

Residential water heating usually peaks in the morning and evening when consumers start and end their days[44] (see Figure 9). From a grid management point of view, this demand trend unfortunately occurs at different times from typical solar production (midday) and the most common wind production (overnight). But water heaters can be controlled, taking advantage of the thermal storage capacity in their tanks. This means it is possible to shift water heater energy consumption (but not hot water use due to its storage in the tank) to other times of the day, making it possible to "charge" water heaters during cheaper and lower-emissions hours. We discuss the capabilities of both electric resistance water heaters and heat pump water heaters below.

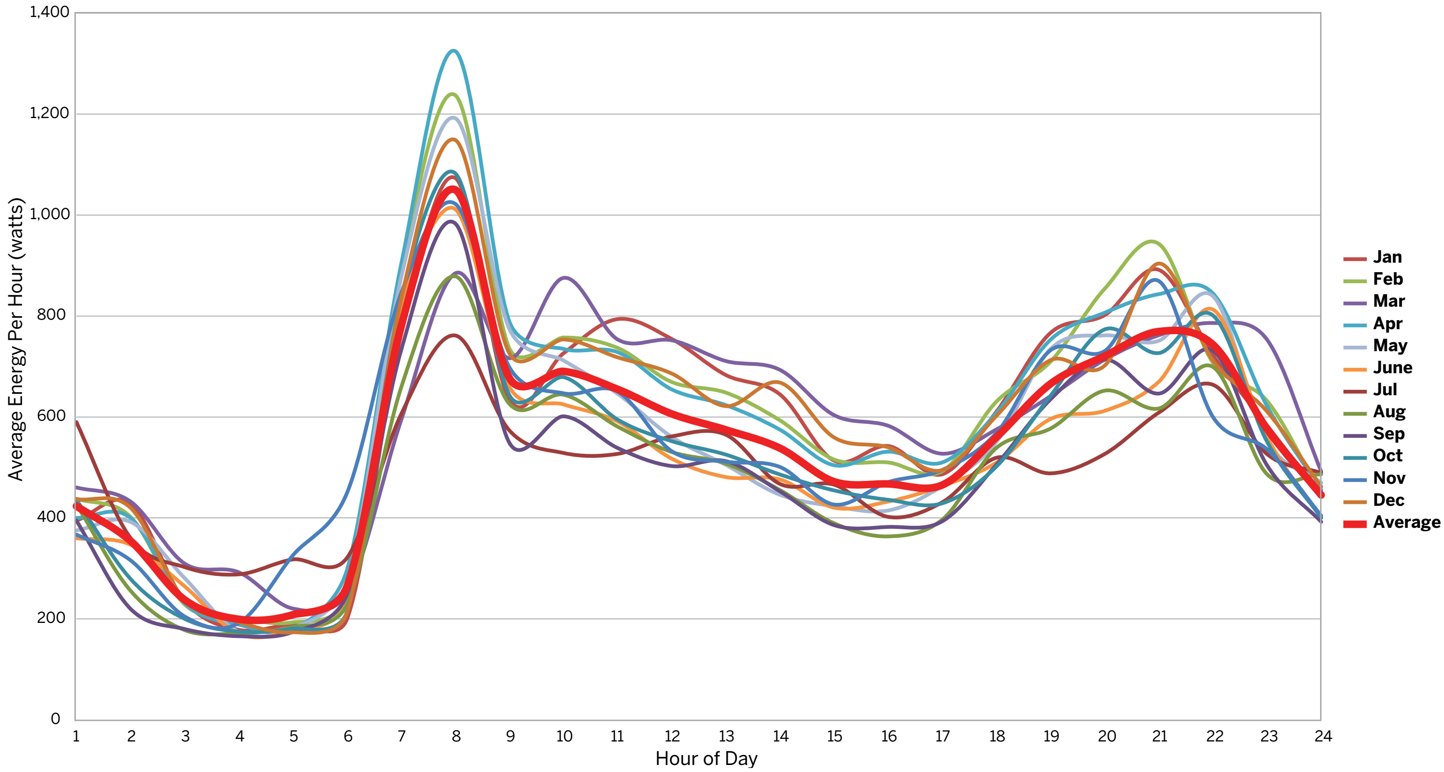
Because the tank of an electric resistance water heater typically can store a full day's supply of hot water (current products are well insulated, and older products can be wrapped), its energy use can be curtailed during peak daytime hours and concentrated into low-cost (and low-emissions) hours, helping companies shave system peaks.[45] Where water heaters are outfitted with the technology to enable fast response control

43 See, for example, the Great River Energy water heater discussion under Principle 6.

44 St. John, J. (2014, September 17). *Aggregating water heaters as grid batteries: Steffes' secret sauce.* Greentech Media. Retrieved from https://www.greentechmedia.com/articles/read/aggregating-water-heaters-as-grid-batteries-steffes-secret-sauce#gs.mUZFfHc

45 Podorson, D. (2016). *Grid interactive water heaters—How water heaters have evolved into a grid scale energy storage medium.* Washington, DC: American Council for an Energy-Efficient Economy. Retrieved from https://aceee.org/files/proceedings/2016/data/papers/6_336.pdf. Sievers, D. (2017, September 28). *New analysis of electric water heaters shows need for cleaner energy mix.* St. Paul, MN: Fresh Energy. Retrieved from https://fresh-energy.org/new-analysis-of-electric-water-heaters-shows-need-for-cleaner-energy-mix/

Figure 9. Water Heater Usage Profile for Upper Midwest



Source: St. John, J. (2014, September 17). *Aggregating Water Heaters as Grid Batteries: Steffes' Secret Sauce.* Greentech Media.

by the grid operator, they can offer frequency regulation and local voltage support by increasing or decreasing load within seconds, depending on system need. However, fairly steep time-of-use (TOU) rate differentials are needed to make electric resistance water heaters competitive with propane or natural gas water heating.

Heat pump water heaters are more efficient than electric resistance models and can deliver a benefit through an overall reduction in customers' water heating load profiles.[46] Because heat pumps cannot be controlled into very short intervals without risking damage to their compressors, they may not be as able to provide the same frequency response benefits as electric resistance water heaters.[47] However, they can be controlled in a manner that provides load-shaping and capacity benefits to the system by curtailing operation during the hours when the system is most strained and moving that charging to lower-cost hours.

Their flexibility means EVs can help reduce system peaks—which drive grid investment and add cost—thereby avoiding the need for additional generation capacity.

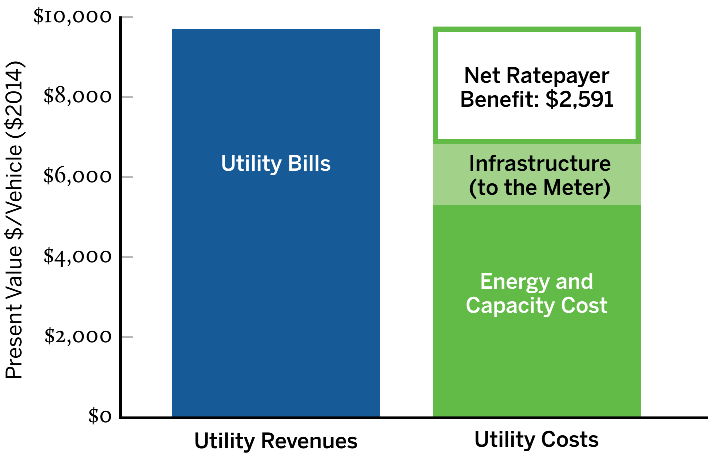
Electric Vehicles

EVs constitute a significant source of flexible load because they are battery-powered and can be charged at times that are most beneficial to the grid. This flexibility means EVs can help reduce system peaks—which drive grid investment and add cost—thereby improving the utilization of the transmission and distribution system and avoiding the need for additional generation capacity. This can be accomplished either through smart charging, TOU pricing, or some combination of both. All these benefits have the effect of lowering the average cost to serve all customers.

46 Hledik, R., Chang, J., and Leuken, R. (2016). *The hidden battery: Opportunities in electric water heating.* Cambridge, MA: The Brattle Group. Retrieved from http://www.electric.coop/wp-content/uploads/2016/07/The-Hidden-Battery-01-25-2016.pdf

47 Northwest Energy Efficiency Alliance. (2015). *Heat pump water heater model validation study* (Report No. E15-306). Portland, OR: Author. Retrieved from https://neea.org/img/uploads/heat-pump-water-heater-saving-validation-study.pdf

Figure 10: Utility System Costs and Benefits from Electric Vehicle Charging in California



Source: Ryan, N. & McKenzie, L. (2016). Utilities' Role in Transport Electrification: Capturing Benefits for All Ratepayers. *Fortnightly Magazine.*

An analysis of EV adoption scenarios in California by Energy and Environmental Economics found there can be significant utility system benefits from adding EV charging load to the grid[48] (see Figure 10).[49] The analysis found that utilities' cost to serve EV charging load with substantial EV adoption was lower than the revenue utilities would bring in from those customers, providing a reduction in the cost of electricity to all ratepayers, not just EV drivers.[50]

In addition to helping manage existing grid resources, the flexibility these electric end uses provide can help the electric power system accommodate increased amounts of VERs. In fact, these end uses can become resources themselves if system operators want to use them that way. This flexibility creates value for grid managers, renewables developers, and consumers. As illustrated in Figure 11, increased amounts of renewable energy are being produced across the country but are often curtailed.[51] In 2016 the Electric Reliability Council of Texas curtailed more than 800 gigawatt-hours (GWhs) of wind energy, or about 1.6 percent of its total potential wind generation. In the same year the Midcontinent Independent System Operator curtailed more than 2,000 GWhs of wind power, or about 4.3 percent of its total wind energy potential.[52] Wind is not the only renewable resource affected; in 2016, the California Independent System Operator curtailed more than 308,000 MWhs of wind and solar generation combined.[53]

By moving BE load to times and locations associated with renewable energy curtailment, grid managers could charge EVs and water heaters, helping to reduce the thousands of GWhs of electricity from existing VER investments that are currently being wasted. This doesn't happen today due to limited demand in the overnight or midday hours, but it could. It would exchange the polluting use of petroleum and other fossil fuels for negative- or zero-cost, carbon-free renewable energy from existing resources.

48 They found "a net benefit to all ratepayers, not just EV drivers, in this case an average of $2,591 per vehicle in present value terms over the life of the 2.2 million EVs." Ryan, N., and McKenzie, L. (2016, April). Utilities' role in transport electrification: Capturing benefits for all ratepayers. *Fortnightly Magazine.* Retrieved from https://www.fortnightly.com/fortnightly/2016/04/utilities-role-transport-electrification-capturing-benefits-all-ratepayers

49 Ryan and McKenzie, 2016.

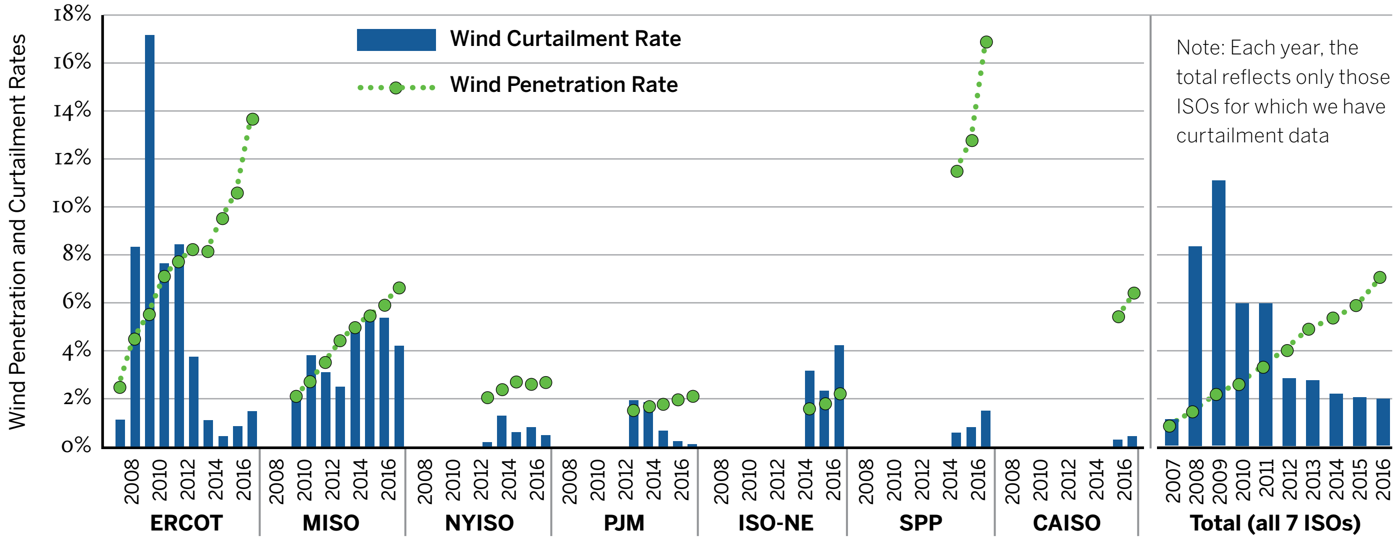
50 "Even with rapid adoption in California (seven million EVs in 2030), the present value of EV-driven upgrades projected through 2030 represents slightly less than one percent of the California utilities' 2012 revenue requirement for their residential distribution systems." Ryan and McKenzie, 2016.

51 "Curtailment of wind project output happens because of transmission inadequacy and other forms of grid and generator inflexibility. For example, over-generation can occur when wind generation is high, but transmission capacity is insufficient to move excess generation to other load centers, or thermal generators cannot feasibly ramp down any further or quickly enough." Wiser and Bolinger, 2017, p. 37.

52 Wiser and Bolinger, 2017.

53 California Independent System Operator. (2017). *Impacts of renewable energy on grid operations.* Folsom, CA: Author. Retrieved from https://www.caiso.com/Documents/CurtailmentFastFacts.pdf

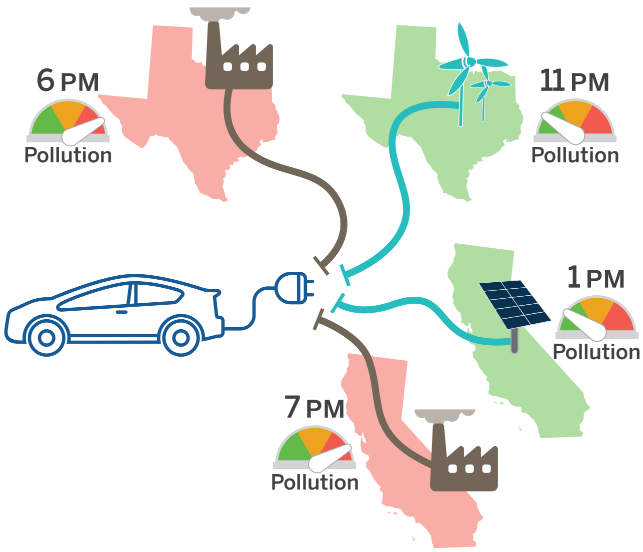
Figure 11. Wind Curtailment



Note: All curtailment percentages shown represent both forced and economic curtailment.
PJM's 2012 curtailment estimate is for June through December only.

Source: Wiser, R., & Bolinger, M. (2017). *2016 Wind Technologies Market Report*.

Principle 3: Understand the Emissions Effects of Changes in Load



Knowing a system's marginal emissions—the emissions that will be added with the use of one more kWh, or that will be reduced if a kWh is avoided—is one way of understanding the emissions associated with increased electrification. Marginal emissions vary depending on time and place. Modeling is a useful way to characterize the emissions associated with more significant amounts of electrification load added to the nation's grids.

Knowing the generation source of the electricity being used to power devices like heat pumps and EVs is crucial for determining the overall emissions efficiency of BE.[54] Nationwide, today's power sector emits the same amount of carbon dioxide (CO_2) as it did a generation ago, in 1993, although it produces nearly 30 percent more electricity annually.[55] This positive trend is due in large part to changes in generation resources.

> Knowing the generation source of the electricity being used to power devices like heat pumps and EVs is crucial for determining the overall emissions efficiency of beneficial electrification.

Between 2007 and 2015 the electric power sector saw a significant switch from coal-fired generation to natural gas, as well as the deployment of large amounts of renewable energy.[56] This caused power sector CO_2 emissions to drop 20 percent, with emissions of other harmful pollutants also dropping significantly.[57] According to the Energy Information Administration, natural gas generation accounted for 34 percent of total electricity generation in 2016, surpassing coal to become the leading generation source.[58] Over the same period (2007-2015), the combined capacity of utility-scale wind, utility-scale solar, and distributed photovoltaic sources increased tenfold from about 10 gigawatts to about 100.[59] Utility-scale and distributed solar power grew to 25 gigawatts in 2015, accounting for 17 percent of total wind and solar generation in 2015.[60]

Although overall US electric sector emissions are declining, this is occurring at different speeds around the country.

54 Emissions efficiency—discussed more thoroughly in Principle 4—means that, despite potentially consuming more kWhs of electricity, consumers have the opportunity to use less energy and to produce fewer pounds of pollution per vehicle mile traveled or per gallon of hot water produced. The authors recognize that the environmental footprint of power generation is larger than the associated air emissions or, more narrowly, the associated carbon emissions. However, for purposes of our discussion, we focus on the narrower topic for clarity of exposition and to better illustrate these BE principles.

55 US Energy Information Administration. (2016, March 1). Solar, natural gas, wind make up most 2016 generation additions. *Today in Energy*. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=25172

56 This increase in natural gas generation since 2005 "is primarily a result of the continued cost-competitiveness of natural gas relative to coal." US Energy Information Administration. (2017, April 20). Natural gas generators make up the largest share of overall U.S. generation capacity. *Today in Energy*. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=30872

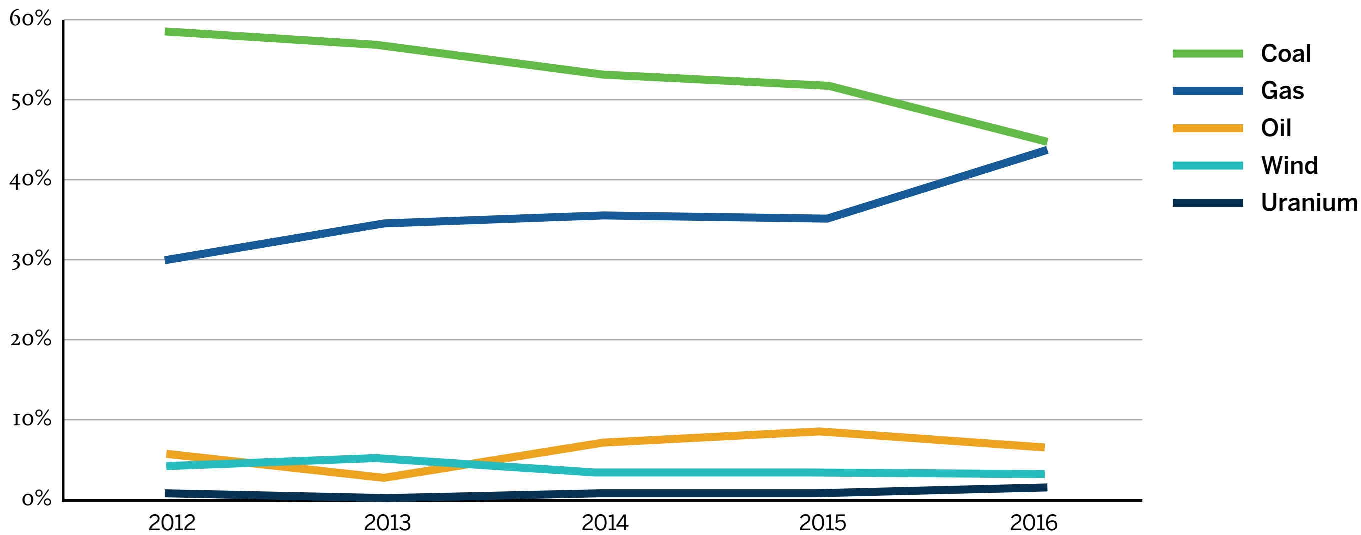
57 Millstein, D., Wiser, R., Bolinger, M., and Barbose, G. (2017, August 14). The climate and air-quality benefits of wind and solar power in the United States (Article No. 17134). *Nature Energy*, 2, 1. Retrieved from https://www.nature.com/articles/nenergy2017134

58 US Energy Information Administration, 2017, April 20.

59 Generation from these sources grew from 35,000 GWh per year in 2007 to 227,000 GWh per year in 2015. Millstein et al., 2017.

60 Millstein et al., 2017.

Figure 12. PJM Marginal Units by Fuel



Municipal waste, demand response, interface, and other fuels are marginal units less than 1% of the time and excluded from the chart above.

Adapted from: PJM Interconnection. (2017). *2012-2016 CO_2, SO_2 and NO_X Emission Rates.*

Consequently, special attention is required to be able to credibly determine the emissions reductions associated with specific electrification efforts.

Electricity supply and demand must be balanced in real time, and the last generating unit added to meet demand at a given time is referred to as the marginal unit. Around the country, marginal units vary over the course of the day and year, depending on fuel availability and operational characteristics, such as the capability to cycle (turn on or off) and ramp (turn up or down) when needed.

Figure 12 illustrates the declining frequency that coal generation has been on the margin in the PJM Interconnection region since 2012 and how natural gas generation has been increasingly filling that role.[61] This figure suggests that, despite the downward trend, coal generation is still on the margin in PJM more than 40 percent of the time. In some areas of the country, renewables can be found on the margin at certain times of the day and year, such as solar at midday in California or wind at night in Texas.

Because electrification will increase load, knowing a system's marginal emissions is especially important as electrification programs start up around the country and policymakers seek to determine related emissions effects. A marginal emissions analysis shows, in aggregate, the emissions from the resource on the margin in a system, meaning the emissions that would be added with the use of one more kWh, or that would be deducted if a kWh is avoided, at each time period during the year.

Also important will be a sense of the emissions to expect when significant amounts of electrification load are added to the nation's grids. It will be necessary to understand what generation will be needed if one expects there to be hundreds of thousands of EVs or if a large percentage of the country's water heating is electrified.[62] This will require the analysis of calculations on the emissions impact of BE load by comparing,

It will be necessary to understand what generation will be needed if one expects there to be hundreds of thousands of EVs or if a large percentage of the country's water heating is electrified.

61 PJM Interconnection. (2017). *2012-2016 CO_2, SO_2 and NO_X emission rates.* Norristown, PA: Author. Retrieved from http://www.pjm.com/~/media/library/reports-notices/special-reports/20170317-2016-emissions-report.ashx

62 According to The Brattle Group, there is the technical potential for US utility sales to "nearly double by 2050 while energy sector carbon emissions would decrease by 70 percent." Weiss et al., 2017.

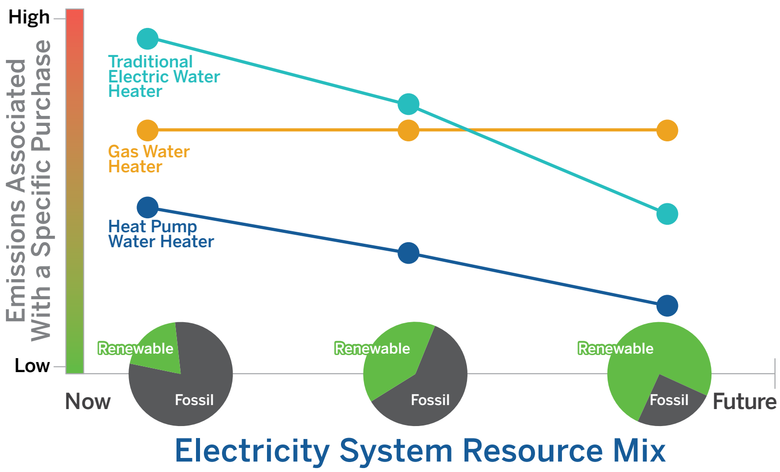
over the long term, business-as-usual generation and expected generation with BE policies in place.

If states pursue policies and programs that increase electric sales, most of that added load may eventually be served by some combination of capacity that has a very different emissions profile than the marginal unit at each hour of the day in any given power grid. Although gas may frequently be on the margin for decades to help balance a system, it may be a relatively small amount and therefore shouldn't necessarily be used as the basis for determining emissions attributed to BE load over the coming decades. Capacity expansion modeling will be a useful way to capture the expected changes to generation resources due to large changes in electricity load from electrification.[63] It will be useful in answering the question: What is the least-cost and highest-value mix of resources over the time horizons chosen?

The average emissions from the US electricity grid have decreased in recent decades, reflecting how successful the nation has been in reducing overall power plant emissions. But because electrification will add load, it is important to be able to account for the emissions from the generating resources that will serve that load. The Appendix looks further at several approaches touched upon here that states can use for determining relevant emissions and ensuring BE.

63 See the Appendix.

Principle 4: Use Emissions Efficiency to Measure the Air Impacts of Beneficial Electrification[64]



Characterizing the pollution associated with a specific electrification investment requires an understanding of emissions efficiency—the emissions per unit of energy output. By driving an electric vehicle or installing an efficient heat pump water heater, consumers can produce less pollution per vehicle mile traveled or gallon of water heated. Moreover, as the grid becomes cleaner with more renewable generation, the emissions efficiency of that electric vehicle or heat pump will improve further.

Based on the ability to assess the fuel efficiency of end uses like EVs and heat pumps and the emissions intensity of the electricity fueling these uses, BE adopts a total-system efficiency viewpoint and seeks to recognize a reduction in the use of primary energy. Despite using more kWhs of electricity, BE consumers will use less energy overall, thereby producing fewer pounds of pollution per vehicle mile traveled or per gallon of hot water produced. This is a significant step beyond energy efficiency business-as-usual and the way energy savings have been separately accounted for—that is, as kWhs of electricity, therms of gas, and gallons of petroleum products.

With the availability of relevant emissions data, utilities will be able to ascertain the months and times when electrification produces the lowest amount of generation-related emissions on their power systems. Considering emissions efficiency, regulators can develop a more complete picture of the relative benefits of electrifying certain end uses. Understanding when and where electrification is most emissions-efficient will enable regulators to develop policies, rate structures, and incentives to ensure that electrification produces the lowest amount of incremental emissions.

Figure 13 on Page 38 illustrates relative energy efficiencies and emissions efficiencies between a standard natural gas water heater and alternatives. The horizontal axis represents more or less carbon-intensive electricity grids, and the vertical axis shows more or less energy-efficient appliances.

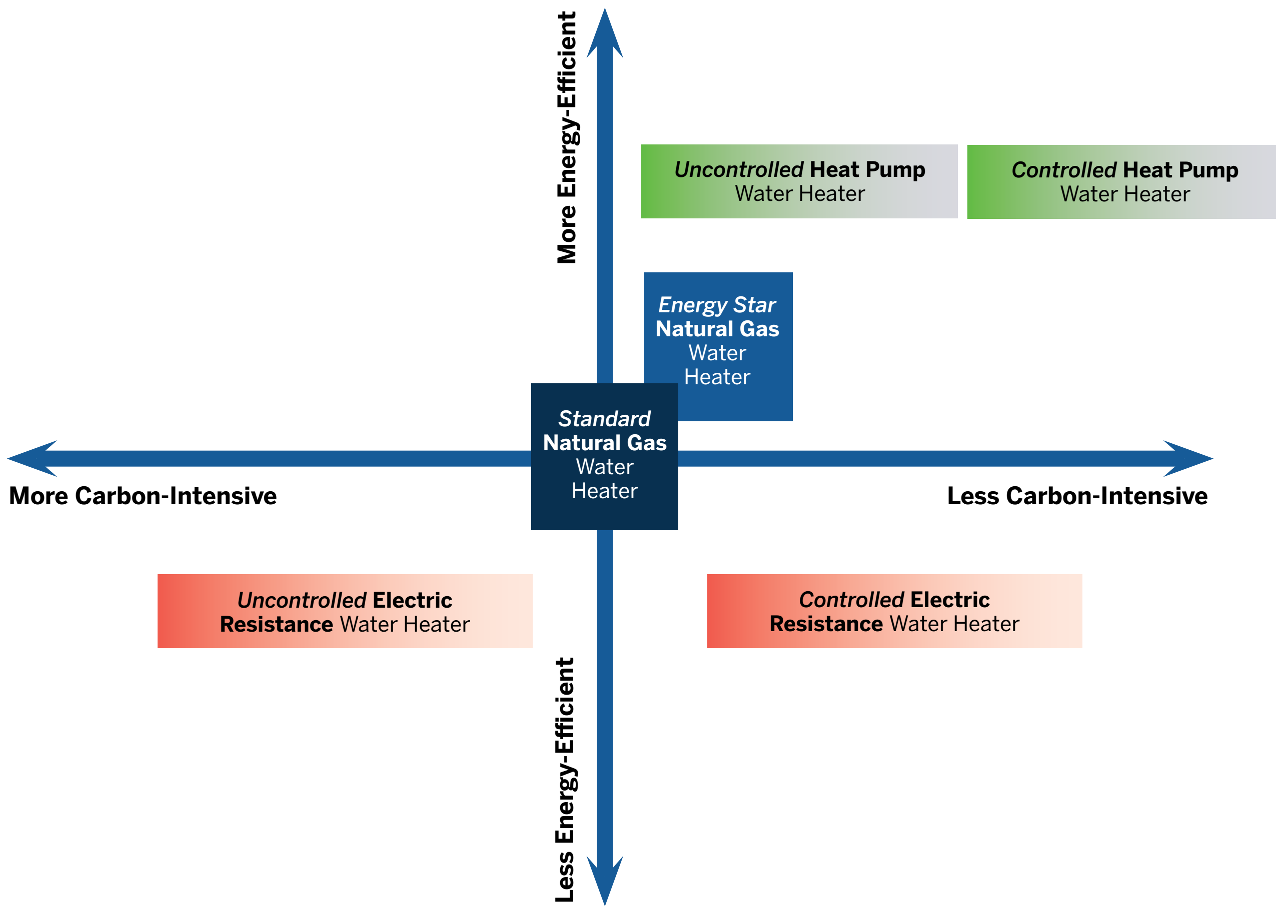
The standard gas water heater is shown at the center of the two axes and is represented as a solidly colored square because its energy efficiency and emissions efficiency are not likely to change. The Energy Star gas water heater is more efficient and thus less carbon-intensive, placing it a little to the right and above the standard gas water heater. Because its energy efficiency and emissions efficiency are also not likely to change, it too is represented as a solidly colored square.

The operation of a standard electric resistance water heater (lower left) is shown as a rectangle with gradient coloring because it has a wider range of potential emissions efficiency depending on the carbon intensity of its source of electricity.[65] As the carbon intensity of the system in which it is located decreases and cleaner resources end up meeting this

64 The concept of emissions efficiency has also been described using the coined term "emiciency." See Dennis, K., Colburn, K., and Lazar J. (2016, July). Environmentally beneficial electrification: The dawn of "emissions efficiency." *The Electricity Journal,* 29(6), 52-58. Retrieved from https://www.sciencedirect.com/science/article/pii/S1040619016301075

65 In Missouri, for example, where the marginal unit could be coal 80 percent of the time (emitting approximately 2,000 pounds of carbon dioxide per MWh), an uncontrolled electric resistance water heater will be more carbon-intensive than that same water heater connected to a less carbon-intensive grid in, say, the Pacific Northwest or California where the marginal generation may be wind, solar, hydro, or natural gas combined cycle.

Figure 13. Illustrative Emissions Efficiency of Water Heater Technologies



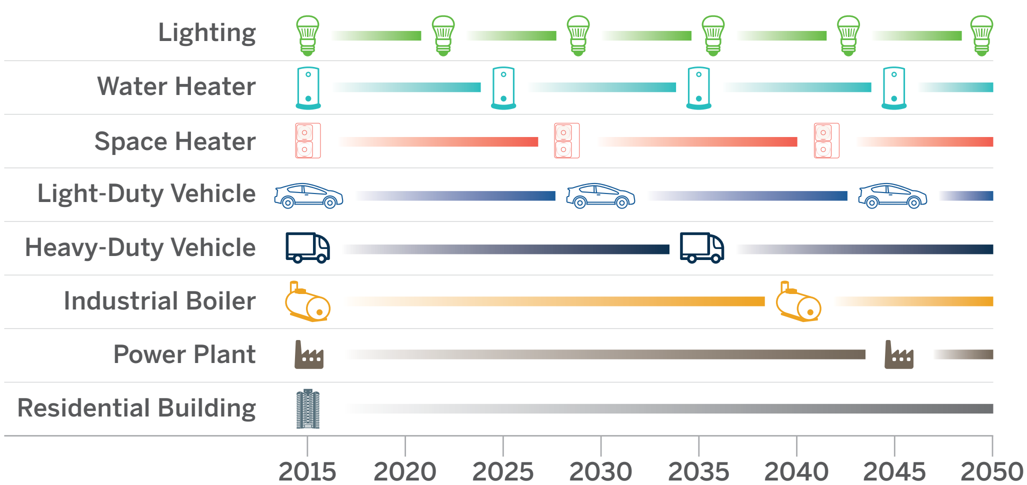
load more often, the emissions efficiency of the electric resistance water heater will improve. To the right, an electric resistance water heater that can be controlled to turn on when emissions are low and paused when emissions are high can be even more emissions-efficient, even though it is less energy-efficient than a heat pump water heater.

The emissions efficiency of various electrical end uses can improve over the lives of those investments due to improvements in the carbon intensity of the fuel (the electricity) they use—a key characteristic not shared by fossil fuel-fired equipment.

Similar conclusions can be drawn regarding the relative energy and emissions efficiency of heat pump water heaters in the upper right-hand side of the figure. Both are characterized as rectangles with gradient coloring because, depending on the emissions associated with the generation serving this load, their emissions efficiency will change, moving them farther to the right or left.

Figure 13 underscores several important points. The context in which these technologies are used will differ, and so will their emissions efficiency. Having information on emissions is thus necessary to evaluate the full benefits of electrification. Further, the emissions efficiency of various electrical end uses can improve over the lives of those investments due to improvements in the carbon intensity of the fuel (the electricity) they use—a key characteristic not shared by fossil fuel-fired equipment.

Principle 5: Account for the Lives of Investments



Because energy infrastructure is long-lived, opportunities for new investments are limited. So it is critical to understand the useful lifetimes of investments. Unless utilities and consumers are positioned to make informed investments when infrastructure replacement time arrives, the opportunity to make lower-cost, cleaner investments may be lost.

When one considers the efficiency of a fossil-fueled water heater or gasoline-fueled car, one looks respectively at gallons of hot water produced per million Btu and miles driven per gallon. We do not expect those efficiencies to change over the lifetime of the investment. We expect the car will get roughly the same mileage in ten years that it gets today. As illustrated in Figure 13, however, electrical end uses work differently. As the carbon intensity of the grid improves, these electrical end uses can be expected to become more emissions-efficient.[66]

At one point in "Practicing Risk-Aware Electricity Regulation,"[67] the authors reflect on the importance of time, a fundamental aspect of utility investment:

> [T]hese infrastructure investments are long lived: generation, transmission and distribution assets can have expected useful lives of 30 or 40 years or longer. This means that many of these assets will likely still be operating in 2050, when electric power producers may be required to reduce greenhouse gas emissions by 80 percent or more to avoid potentially catastrophic impacts from climate change.

Recognizing the opportunities to make lower-cost, cleaner investments is especially important.

Because energy infrastructure investments are long-lived, opportunities for new investment are limited. Figure 14 on Page 40 illustrates the limited occasions for addition or replacement of certain types of energy infrastructure between now and 2050 based on natural stock rollover.[68]

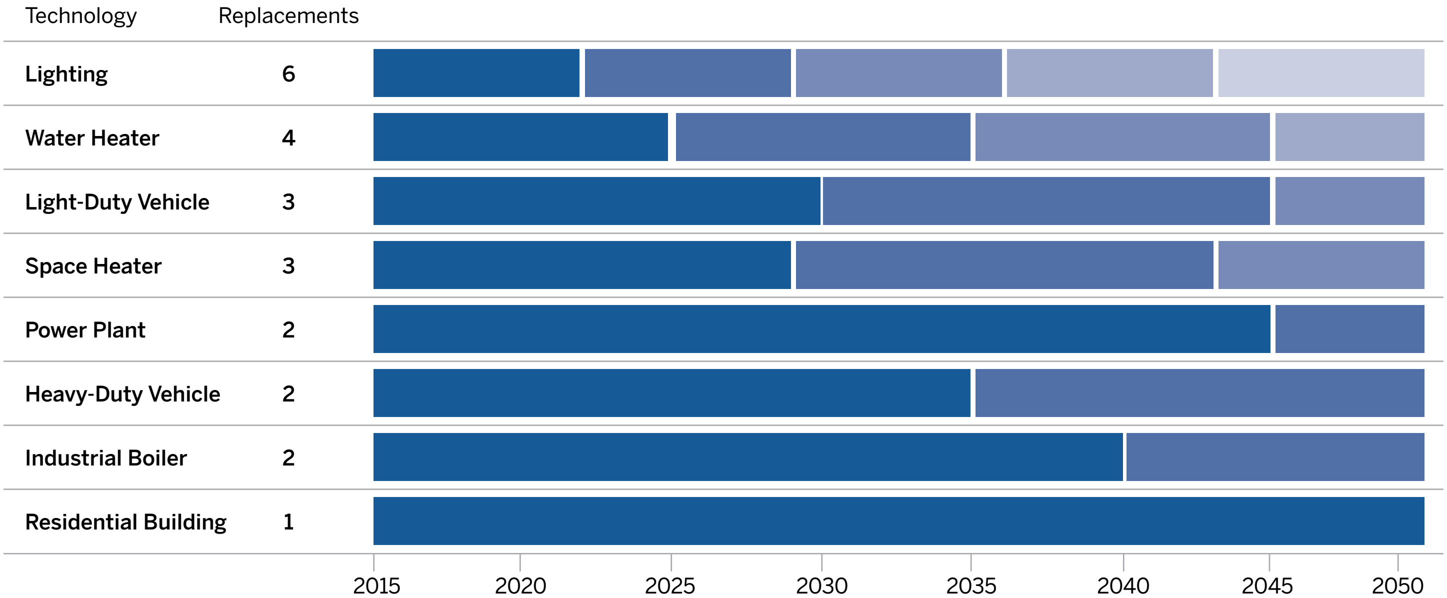
Recognizing these limited opportunities is especially important. Unless utilities and consumers are positioned to make informed investments when infrastructure replacement time arrives, the chance to make lower-cost, cleaner investments could be lost. Depending on the equipment being replaced, the next opportunity may not arise for years—in the case of water heaters, between ten and 14 years—or decades in the case of furnaces. As we noted in the discussion above, as infrastructure and equipment is retired, it is preferable to replace it with least-cost, emissions-efficient resource options that provide valuable flexibility to grid managers and cost savings to consumers.

66 Goldenberg et al., 2018.

67 Binz, R., Sedano, R., Furey, D., and Mullen, D. (2012, April). *Practicing risk-aware electricity regulation: What every state regulator needs to know*, p. 5. Boston, MA: Ceres. Retrieved from http://www.rbinz.com/Binz%20Sedano%20Ceres%20Risk%20Aware%20Regulation.pdf

68 Williams, J.H., Haley, B., and Jones, R. (2015). *Policy implications of deep decarbonization in the United States*. San Francisco, CA: Energy and Environmental Economics. Retrieved from http://deepdecarbonization.org/wp-content/uploads/2015/11/US_Deep_Decarbonization_Policy_Report.pdf

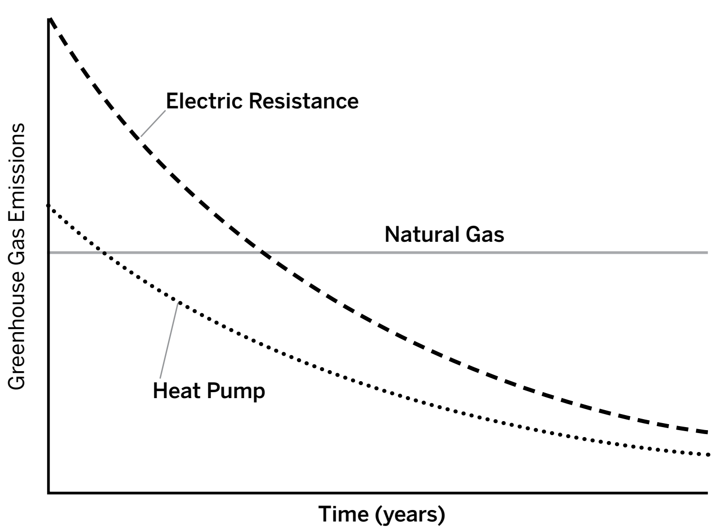
Figure 14. Lifetimes Until Replacement for Key Equipment and Infrastructure



Source: Williams, J.H., Haley, B., & Jones, R. (2015). *Policy Implications of Deep Decarbonization in the United States.*

Furthermore, the emissions efficiency of electric end uses is likely to improve over the lives of many of these investments, as the emissions footprint of the electricity sector continues to shrink. Consequently, it is important to recognize that the total emissions over the life of an investment may be lower than alternatives even if they are higher in the first years after the investment. As illustrated in Figure 15, a gas water heater will have level emissions over time, whereas the emissions associated with electric end uses can be expected to decline.[69] It is thus worth considering electrification options well before end uses are more emissions-efficient than the fossil fuel technologies they replace, especially where the regional power grid is rapidly decarbonizing.

Figure 15: Conceptual Emissions of Individual Water Heaters in a Rapidly Decarbonizing Grid

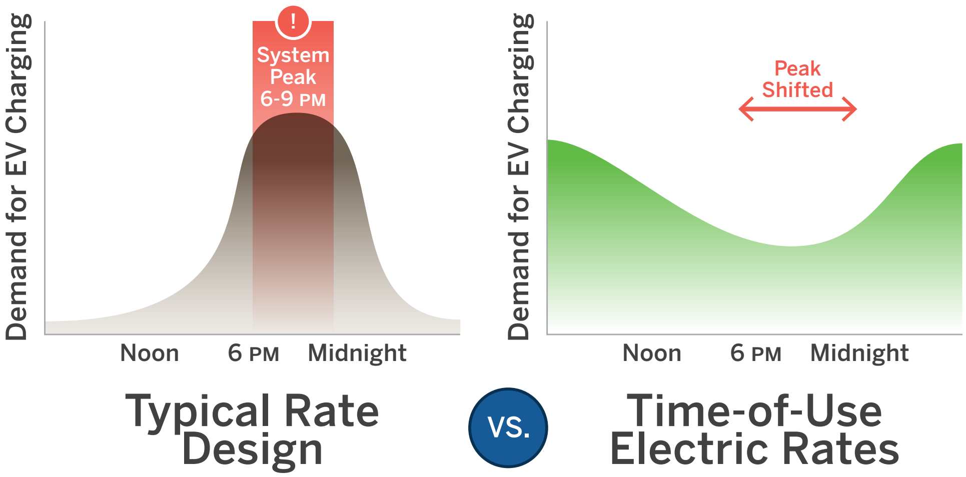


Source: Personal communication with Peter May-Ostendorp and Katherine Dayem, Xergy Consulting, May 12, 2017.

Understanding the useful lifetimes of energy technologies is also important in evaluating other benefits such as consumer cost reductions and grid management services. Many BE investments have upfront incremental costs to consumers, which can be a barrier to adoption, but reduce total cost of ownership over the product's lifetime. State policy and utility programs can help consumers avoid locking themselves in to higher lifetime costs for technology choices through focused consumer education and targeted incentives that mitigate upfront costs. State policy and programs should also recognize and accommodate the challenges confronting the more vulnerable customer segments unable to benefit economically from these innovations.

69 Personal communication with Peter May-Ostendorp and Katherine Dayem, Xergy Consulting, May 12, 2017.

Principle 6: Design Rates to Encourage Beneficial Electrification



Unlike typical electric rates, time-sensitive rates reflect the different cost of providing electricity at different times of the day, and they signal this price difference to consumers. By using well-designed rates to encourage customers to shift their demand to less expensive times, utilities can make more efficient use of grid resources.

Utilities already know that customers are willing to shift their consumption to cheaper hours of the day if the financial incentive is meaningful.[70] Using rates to signal value to consumers is not a new strategy. For example, Great River Energy has been offering its customers lower-cost water heating for more than 30 years by buying energy at a lower rate at night and using it to charge water heaters.[71] Although this storage is thermal rather than electric, about 20 percent of Great River Energy's customers participate in this peak-shaving and valley-filling program. Originally this pricing and control scheme was designed to increase utilization of low-cost coal capacity during nighttime hours. Today it is being used to integrate rapidly increasing wind power supplies, utilizing variable generation that might otherwise be curtailed. To the degree that Great River Energy's generation portfolio decreases in carbon intensity and the company draws upon the increased availability of low-cost renewables, its water heating program will save the company and its customers money and produce fewer emissions.[72]

Timing Should Matter

We know from experience that price can dramatically influence when EV owners charge their vehicles at home. Figure 16 on Page 42 shows the EV charging behavior of drivers who are subject to different rate structures. Standard (flat) rates are shown on the left, while TOU rates are shown on the right.[73]

The Dallas-Fort Worth standard-rate customers lack the financial incentive to shift their demand because the rate they pay doesn't change whether they charge their EVs on peak or off peak. There is no difference. Without any incentive to do otherwise, they are likely to come home, plug in their cars, and start charging right in the heart of the high-cost early evening peak period.

The EV rate design in San Diego is different. It creates an incentive for customers to charge their EVs during less expensive off-peak hours. With the help of smart chargers, customers manage their EV charging to take advantage of

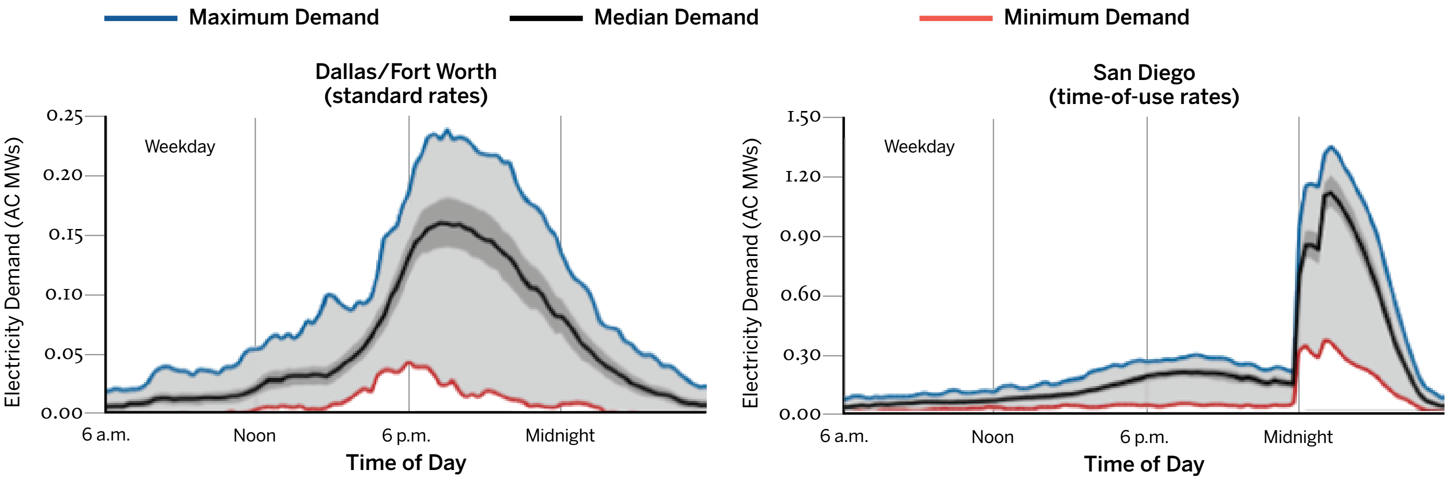
70 Faruqui, A. (2012, August 14). *The future of demand growth: How five forces are creating a new normal* [Presentation before the Goldman Sachs 11th Annual Power and Utility Conference]. The Brattle Group. Retrieved from http://files.brattle.com/files/6597_the_future_of_demand_growth_faruqui_aug_14_2012_goldman_sachs.pdf

71 Great River Energy's service territory has approximately 70,000 large-capacity (85- to 120-gallon) electric water heaters that heat off peak (between 11 p.m. and 7 a.m.) at a lower generation rate than what consumers pay for other electricity usage during daylight hours. For each water heater, the company is moving 14 kWhs from high-usage times of the day to cheaper times when there is little electricity demand.

72 Sievers, 2017.

73 Jones, B., Vermeer, G., Voellmann, K., and Allen, P. (2017). *Accelerating the electric vehicle market*, p. 16. Concord, MA: M.J. Bradley & Associates. Retrieved from https://www.mjbradley.com/sites/default/files/MJBA_Accelerating_the_Electric_Vehicle_Market_FINAL.pdf

Figure 16. A Difference in Rates Can Influence When Customers Charge Vehicles



Source: Jones, B., Vermeer, G., Voellmann, K., & Allen, P. (2017). *Accelerating the Electric Vehicle Market.*

lower rates in the middle of the night, which also helps the utility manage system peak demand. In San Diego, customers set the charge controllers in their vehicles to automatically follow the rate design. Very little charging occurs in the early evening during the peak; most of it occurs after midnight.[74]

Rate design influences whether and how much consumers will benefit from their own flexible load and the cleaner VERs that are becoming available on the grid.[75] Many electric technologies can be scheduled to charge when the cost of operating the grid is lower. However, for customers to have incentives to take advantage of that low-cost power—and for them and the utility to reap the subsequent economic benefits—TOU pricing must be available and must effectively communicate to customers the differences in costs at different times of day.[76]

What's the Differential?

Figure 17 illustrates the summer 2018 residential TOU rate for Sacramento Municipal Utility District customers.[77] There is a strong incentive for customers to shift their usage away from the higher-cost late afternoon summer hours and to take advantage of low-cost electricity from 8 p.m. to noon. Instead of 28 cents per kWh, the rate is 11 cents, a differential of 17 cents/kWh, nearly a 60 percent discount. Utilities across the country could apply similar rate designs to avoid exacerbating system peaks and to save consumers money.

Utilities already know that customers are willing to shift their consumption to cheaper hours of the day if the financial incentive is meaningful.

Twin Peaks

Rate design will also affect the ability of commercial and industrial customers to take advantage of electrification opportunities like workplace EV charging and commercial heat pump water heating. Utilities typically have tariffs that impose demand charges—a charge per kilowatt rather than per kWh—for these consumers. Most utilities apply these charges

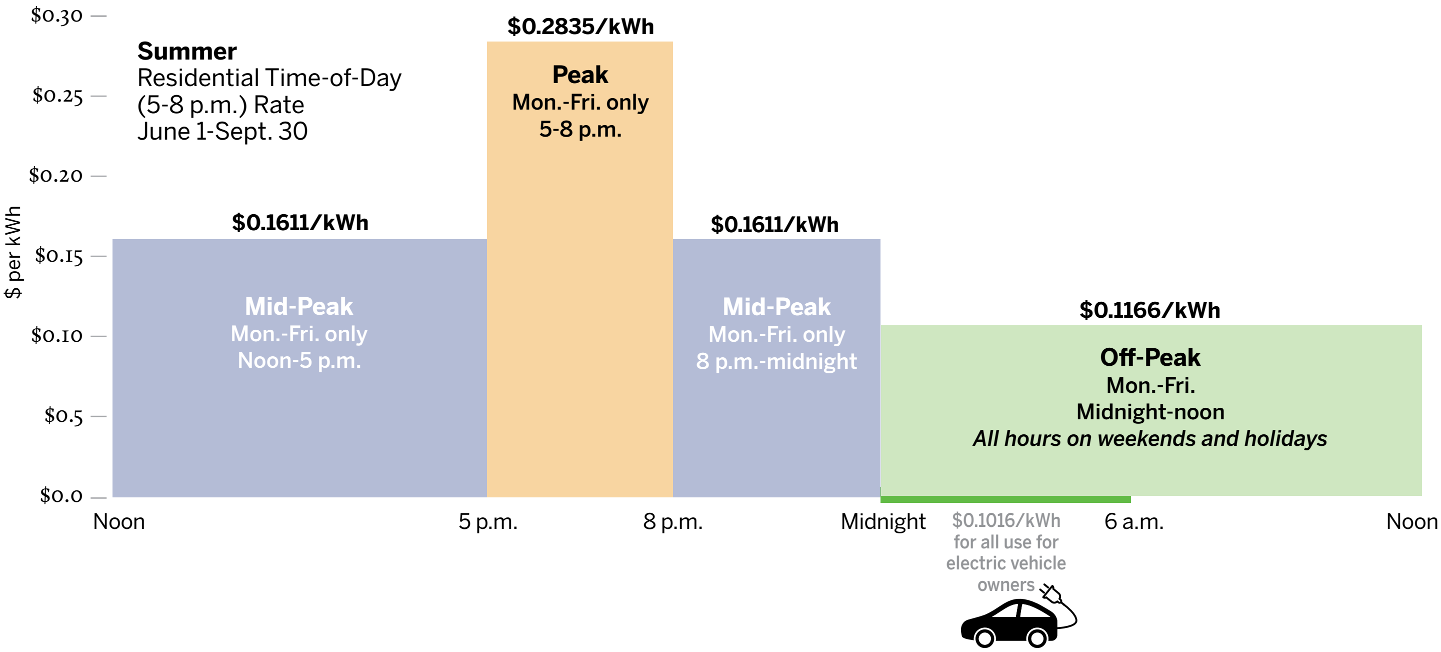
74 Garcia, N. (2017, December 27). Good news: EVs are not crashing the grid [Blog post]. Natural Resources Defense Council. Retrieved from https://www.nrdc.org/experts/noah-garcia/good-news-evs-are-not-crashing-grid

75 Lazar, J. (2018, January 20). Calming Chicken Little: An EV grid tale without the scary ending [Blog post]. Regulatory Assistance Project. Retrieved from http://www.raponline.org/blog/calming-chicken-little-an-ev-grid-tale-without-the-scary-ending/

76 TOU rates have been shown to be effective at saving customers money. One review of the top five cities for EV sales where the utility offers EV TOU rates found that savings ranged from $116 to $237 a year compared with non-TOU rates. McDonald, Z. (2016, July 21). *How much can you save with off-peak charging?* FleetCarma. Retrieved from http://www.fleetcarma.com/electric-vehicle-off-peak-charging-cost/

77 Sacramento Municipal Utility District. *Saving energy when it matters most* [Webpage]. Retrieved from https://www.smud.org/en/Rate-Information/Time-of-Day-Rates/Time-of-Day-5-8pm-Rate

Figure 17. Example Residential Time-of-Use Rate



Source: Sacramento Municipal Utility District. (2018). *Saving Energy When It Matters Most.*

based on the individual peak demand of each customer during the billing period regardless of when it occurs in relation to the system peak. These are known as noncoincident peak demand charges. Figure 18 on Page 44 illustrates how different individual customer demand peaks may occur at times other than system peak.[78]

Demand charges give customers an incentive to improve their individual load factor—that is, to spread out their usage to reduce their individual peak demand.[79] But demand charges do not necessarily provide incentives for customers to adjust their usage in a way that is helpful for managing system peaks.

A more effective rate structure would encourage these customers to move their charging to off-peak times for the grid as a whole, when it is less stressed and less expensive to serve. This would contribute to the management of system peaks rather than individual customers' peaks. It would also better coordinate a customer's electricity pricing with the system costs at the time the customer uses the grid, encouraging customers to concentrate their energy use during less expensive hours. Such rate structures can also reduce the magnitude of demand charges and enable utilities to recover more system costs through volumetric TOU rate designs. Rate design should ensure that the choices customers make to minimize their own bills are consistent with the choices they would make to minimize system costs.[80]

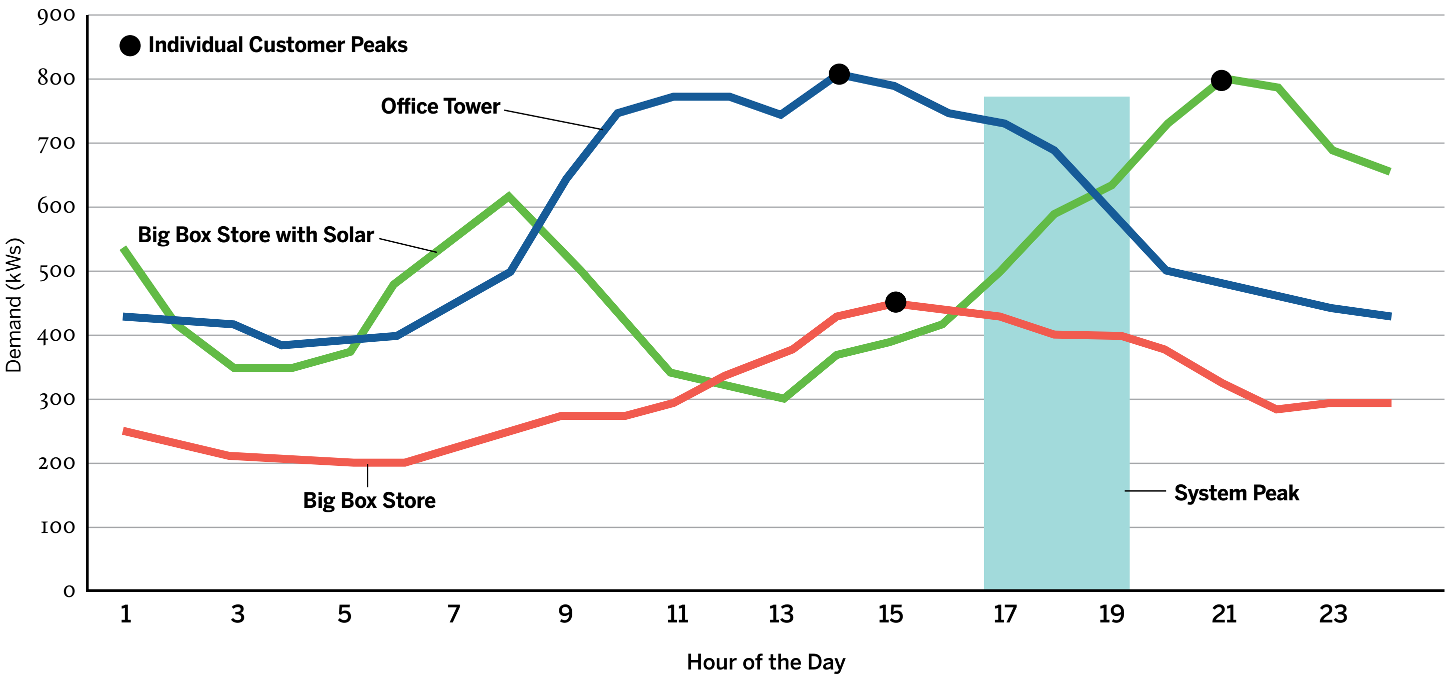
Demand charges that do not coincide with the system peak can also be a disincentive for businesses to provide workplace EV charging to their employees and customers. Even if the system peak occurs later in the day, an increase in demand due to workplace charging of EVs could increase midday demand for an individual business, the demand charges it incurs, and the resulting monthly bills. Workplace charging could target the system's off-peak period, such as during the time when solar arrays are producing energy. This may be a low-cost and

78 Confidential personal conversation, June 23, 2017.

79 See Fitzgerald, G., and Nelder, C. (2017). *From gas to grid: Building charging infrastructure to power electric vehicle demand.* Boulder, CO: Rocky Mountain Institute. Retrieved from https://www.rmi.org/insights/reports/from_gas_to_grid

80 Lazar, J., and Linvill, C. (2018, April 11). *Smart non-residential rate design* [Webinar]. Regulatory Assistance Project. Retrieved from http://www.raponline.org/event/smart-non-residential-rate-design-webinar/. See also Linvill, C., Dupuy, M., Shipley, J., and Brutkoski, D. (2017). *Smart non-residential rate design.* Montpelier, VT: Regulatory Assistance Project. Retrieved from http://www.raponline.org/knowledge-center/smart-non-residential-rate-design/

Figure 18. Customer Peaks vs. System Peak



Source: Confidential personal communication, June 23, 2017.

low-emissions time period for the system as a whole and therefore save money for consumers, employers, and the utility trying to manage its grid.[81]

An effective rate structure would encourage customers to move the charging of their end uses to off-peak times for the grid when it is less stressed and less expensive to serve.

Innovation can flow from good rate design. Rates shape the way we use the grid, and grid managers can use rates to make more efficient use of existing grid investments, avoid unnecessary new investments, and motivate customers. Smart rate design encourages investment in products and services that promote the public interest, such as lower cost, better grid operation, and reduced emissions. Rate designs that are indifferent can motivate products and services that produce the opposite effects.

81 For a more detailed discussion of non-residential rate design, see Linvill et al., 2017.

Putting Beneficial Electrification Into Action

States considering measures to encourage BE will be wise to first lay a solid foundation in policy and set out a process that invites wide participation.

In companion pieces to this paper, RAP will examine in greater detail the operationalizing of BE for specific technologies like EVs, heat pumps, and heat pump water heaters. However, before states undertake actual BE measures—such as an EV charging proposal or a heat pump rebate program—they may wish to consider other important elements, including policy prerequisites and process designs.

States will benefit from first defining and then prioritizing goals before making decisions about specific BE implementation efforts.

Lay the Foundation in Policy

Develop Goals

The first step in developing any effective policy is to articulate why it is being created. A BE policy should be no different. BE may be a worthy goal in and of itself, but states adopting BE steps may have additional policy objectives that could be affected or could inform how the state interprets BE.[82] Related goals might include saving consumers money, avoiding greenhouse gas emissions, ensuring greater equity in access to transportation resources, encouraging innovation and job creation, and making power grids more flexible and capable of accommodating greater amounts of VERs. Different states often have distinctly different goals. States will benefit from first defining and then prioritizing goals before making decisions about specific BE implementation efforts.

Identify Barriers

It is important for policymakers, regulators, and utilities to address how new policy initiatives and legacy frameworks dovetail and create mixed signals, if not perverse incentives, that complicate expeditious and economically efficient utility and private investment.[83] For example, a state's energy efficiency standard may require reductions in kWhs only, rather than recognizing overall energy savings.[84] Without modification, such policies could inhibit the ability to develop and achieve BE energy goals and savings.

Traditional utility regulation could also constitute a barrier to achieving electrification goals. Regulators interested in encouraging utilities to recognize the emissions efficiency of their investments may need to revisit ingrained assumptions behind traditional cost-of-service regulation, where utilities earn a rate of return on rate base. This gives utilities incentives to invest in additional infrastructure to increase their profit, even when less capital-intensive options are available to meet customer needs.

Cost-of-service regulation also motivates utilities to increase sales and resist any measures that might reduce them—a fundamental incentive that is often at odds with the public interest and particularly the acquisition of resources with the lowest social costs.[85] In the absence of measures to mitigate it, this so-called throughput incentive may lead to a real or perceived belief that utility electrification proposals are self-serving and not in the interest of ratepayers.[86] Utility

82 See the Appendix.

83 Correspondence with Noel Crisostomo, California Energy Commission. See also California Energy Commission. (2017). *2017 integrated energy policy report* (Publication No. CEC-100-2017-001-CMF), pp. 78-79. Sacramento, CA: Author. Retrieved from http://www.energy.ca.gov/2017_energypolicy/

84 See, for example, Energy Star. *The difference between source and site energy* [Webpage]. Retrieved from https://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager/understand-metrics/difference

85 Sedano, R. (2014). *Solutions to the throughput incentive*. Montpelier, VT: Regulatory Assistance Project. Retrieved from http://www.raponline.org/knowledge-center/solutions-to-the-throughput-incentive/

86 See, for example, The Utility Reform Network. (2017, July 25). *Prepared testimony of Eric Borden addressing the proposal of Pacific Gas and Electric Company for fast charging infrastructure program* (CPUC Docket: A.17-01-020 et al.). San Francisco, CA: Author. Retrieved from http://www.turn.org/wp-content/uploads/2017/09/A.17-01-020-et-al._TURN_7.25.17_.pdf. See also Massachusetts Attorney General (2017, July). *Initial brief of the Office of the Attorney General re: NSTAR Electric Company and Western Massachusetts Electric Company d/b/a Eversource Energy. D.P.U. 17-05.* Boston, MA. Retrieved from http://www.mass.gov/ago/docs/energy-utilities/ago-initial-brief-dpu-17-05.pdf

regulators could mitigate this concern by addressing the overarching problem of the throughput incentive.[87]

Asking these and related questions can provide greater clarity as states identify and formulate their electrification and other policy goals.

Establish Metrics

Identifying criteria and metrics can help states track progress toward their goals. Metrics could include, for example, the number of EVs sold or heat pumps installed, the quantity of emissions avoided, fossil fuel savings, or peak demand reductions.[88]

Not only can states use metrics for tracking progress, they may wish to revisit established regulatory practices and use these metrics to develop performance incentives for utilities. This can help address the limitations of the traditional regulatory framework discussed above, connecting utilities' compensation and returns to service goals and targets like emissions efficiency. Incentive regulation can encourage utilities to pursue smart rate design; to value flexibility and provide an opportunity for third-party providers to monetize it; to include emissions as a factor in pricing; and to enable customers' access to electrified end uses.[89] This can enhance the grid, give customers more options, and align utility profit incentives with least-cost and higher-value solutions.

Address Timing

Policymakers will also benefit from the recognition that implementing BE programs will be a long-term effort. Where state regulators—such as utility commissions, energy offices, and environmental regulators—are responsible for overseeing programs that legislators, utilities, and other market players will develop, it can require some time to design, develop, and implement a program. So, a willingness to engage in experimentation will be useful.

Consider Flexibility

Policymakers may want to consider how much flexibility to provide the different entities charged with implementing BE.[90] As long as these entities are delivering measurable results that meet policy goals and objectives, it could be useful to grant them the leeway to propose the specifics of program design, implementation, and delivery and to adjust and innovate in response to lessons learned and changing market conditions.

Identify Affected Participants

In addition to developing criteria for success, states could benefit from recognizing the different actors that could affect or be affected as BE activity develops. These groups include:

- Branches of state government beyond the public utility commission (e.g., departments of transportation, energy, and environment) and other substate jurisdictions (e.g., municipal and county governments);
- Natural gas utilities;
- Electric utilities;
- Technology providers;
- Propane and heating oil retailers;
- Third-party charging service providers;
- Consumer and ratepayer advocates;
- Environmental advocates;
- Environmental justice and social justice advocates;
- Transmission system operators;
- Demand aggregators;
- Distributed resource providers;
- Vehicle manufacturers and dealers;

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87 Including the related capital bias that serves as a barrier to accommodating greater amounts of customer resources in their system planning. Sedano, R. (2017, June 8). *Decoupling and the power sector of 2020 and beyond* [Presentation to New Jersey Utilities Association]. Regulatory Assistance Project. Retrieved from https://www.raponline.org/wp-content/uploads/2017/06/rap_sedano_njua_2017_june_8.pdf; and Lazar, J., Weston, F., Shirley, W., Migden-Ostrander, J., Lamont, D., and Watson, E. (2016). *Revenue regulation and decoupling: A guide to theory and application.* Montpelier, VT: Regulatory Assistance Project. Retrieved from http://www.raponline.org/knowledge-center/revenue-regulation-and-decoupling-a-guide-to-theory-and-application-incl-case-studies/

88 Littell, D., Kadoch, C., Baker, P., Bharvirkar, R., Dupuy, M., Hausauer, B., et al. (2017). *Next-generation performance-based regulation* (Technical Report NREL/TP-6A50-68512). Golden, CO: National Renewable Energy Laboratory. Retrieved from https://www.nrel.gov/docs/fy17osti/68512.pdf

89 Littell et al., 2017. See also Lazar et al., 2016.

90 The use of the term "entity" is intentional. Electrification is likely to be delivered by a mix of providers, utilities, and others.

- Commercial building and multi-unit dwelling owners;
- Competitive retail electric suppliers, if applicable; and
- Elected officials.

States will benefit from being as clear as possible at the outset about these actors' possible roles and contributions as states develop a market and programs for BE. Table 2 contains some suggestions to illustrate how this might play out.

Ensure an Open Process

Another key to successfully developing policy proposals and the necessary support for them is to set out a process in which interested parties can participate and engage with one another. Most energy-related proceedings are formally convened before a state public utility commission (PUC) and offer limited opportunities for consumers and other stakeholders to participate. Rules governing interactions with utility commissioners vary such that in some states commissioners may engage in discussions with all interested stakeholders, while in others their interactions may be strictly limited. Absent an affirmative step by states, efforts to examine BE could encounter similar obstacles.[91]

Alternatively, collaborative efforts can provide regulators the opportunity to convene multiple stakeholders unfamiliar with the commission, its scope, and its rules to discuss a variety of issues in a constructive and less formal environment. Collaboratives can provide a flexible structure to help work through policy questions and resolve conflicts as part of or completely outside a typical quasi-judicial PUC setting.[92]

Collaboratives also lend themselves to addressing many broad policy questions that electrification raises. Collaboratives can be set up to address the full suite of issues associated with designing, implementing, monitoring, improving, and even adapting such programs to changing conditions. Covering much of this ground in an informal manner can also help PUCs reduce program costs and improve the quality of decision-making as they explore the development of BE in their jurisdictions.

Over the last several years, state commissions have

Table 2. Roles of Participants in BE Policies

Legislature, energy office, utility commission	• Establish policy goals and criteria for success • Select entities obligated • Identify expected source(s) of funding • Define performance parameters • Develop regulations where necessary
Administrator (governmental or not)	• Develop performance parameters and consequences with obligated entities • Establish consequences for failing to meet BE goals • Ensure verification of achievement of BE goals
Obligated entities	• Develop and refine delivery strategies • Manage implementation of strategies • Develop supply chain relationships • Interact with end users • Develop quality assurance • Track and report budget, expenses, overall energy savings, and avoided emissions
Private sector • *Product and service providers* • *Lenders* • *Local authorities* • *Community organizations* • *Others (e.g., aggregator and retailer handling the power sector parts of the value stream)*	• Train contractors • Manage financing • Oversee infrastructure sales and installation • Develop complementary programs • Provide advice and support

91 For example, the California Legislature identified the need to reduce the barrier to EVs because, as utility sector emissions increase, ratepayers would be responsible for the costs of emissions allowances as purchased under the cap-and-trade regulation.

92 It is important to recognize that informal workshops or a series of workshops can be set up inside formal dockets, between dockets, through sessions directed at the end of one docket explicitly intended to inform a future docket, or, as described above, as purely freestanding sessions hosted by the commission to gather information for indeterminate purposes. Also, in some states it may be the energy office or office of the governor that may be in the best position to host collaborative meetings.

hosted numerous collaboratives on emerging policy issues. For example, the Maryland Public Service Commission has convened a process called Public Conference 44, or PC44, to review the status of state electric distribution systems and issues affecting the deployment of distributed energy resources and EVs.[93] The Illinois Commerce Commission is managing a process called NextGrid, a study looking at issues facing the state's electric utility industry, including topics like innovative technologies, grid improvements, and economic development.[94] In 2017, Rhode Island's Power Sector Transformation Initiative investigated changes to its energy sector to accommodate BE, including new technologies and customer-owned resources. Several Rhode Island Public Utilities Commission-hosted collaboratives focused specifically on buildings and transportation electrification.[95] Another example of a more narrowly focused collaborative is the series of workshops the Washington Utilities and Transportation Commission conducted in 2015 and 2016 that led to its policy statements on EV supply equipment, storage, and integrated resource planning.[96] Rhode Island and Washington have very different power sectors, illustrating that collaborative processes have broad applicability. Washington is dominated by hydro and wind and has low rates, and about half the state is served by public power. By contrast, Rhode Island is a high-cost state served by investor-owned utilities and has a largely thermal power supply base.

In 2015 the State and Local Energy Efficiency Action Network published a useful report titled "Energy Efficiency Collaboratives." It examines how different models of these collaboratives across the United States are created, how they make decisions, how their membership is identified, and their precise relationship with PUCs.[97] As illustrated in Table 3 on Page 50, the report also identifies types of collaboratives whose attributes would lend themselves to state efforts to explore and develop BE policies.

Another key to successfully developing policy proposals and the necessary support for them is to set out a process in which interested parties can participate and engage with one another.

These collaborative models may be informal meetings that are general and introductory or focused more narrowly on specific topics. Initial meetings can explore topics such as other programs around the country or focus on the capability of available technologies. Regardless of the approach, taking these initial steps can help states identify the many issues that are likely to arise and the range of interested individuals and groups that will want to participate as the discourse on electrification develops.

Anticipate Specific Issues

States will want to focus initially on setting goals and developing appropriate venues for having BE-related conversations with stakeholders, but shortly thereafter several derivative issues will arise. They include rate design, utility incentives, efficiency resource standards, building codes for new construction, appliance standards, and fossil fuel phaseout.

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93 The purpose of the proceeding is to "explore issues that will maximize benefits and choice to Maryland electric customers and, in particular, assess how the evolving electric grid impacts low- and moderate-income ratepayers." The process in Case No. 9478 concluded with a package of transportation electrification proposals that were formally supported by utilities, nongovernmental organizations, charging service providers, and many other groups. See Maryland Public Service Commission. *Transforming Maryland's electric grid (PC44)* [Webpage]. Retrieved from http://www.psc.state.md.us/transforming-marylands-electric-grid-pc44/. See also Garcia, N. (2018, March 27). *Maryland on the edge of EV leadership* [Blog post]. Natural Resources Defense Council. Retrieved from https://www.nrdc.org/experts/noah-garcia/maryland-edge-ev-leadership

94 *NextGrid: Illinois utility of the future study* [Website]. Retrieved from https://nextgrid.illinois.gov/

95 See, for example, Rhode Island Public Utilities Commission, Docket No. 4600, Order on July 31, 2017. Retrieved from http://www.ripuc.org/eventsactions/docket/4600-NGrid-Ord22851_7-31-17.pdf. See also Rhode Island Division of Public Utilities & Carriers, Office of Energy Resources, and Public Utilities Commission. (2017). *Rhode Island power sector transformation: Phase One report to Governor Gina M. Raimondo.* Retrieved from http://www.ripuc.org/utilityinfo/electric/PST%20Report_Nov_8.pdf

96 Washington State Utilities and Transportation Commission, Dockets UE-151069 and U-161024, Report and Policy Order on October 11, 2017, paragraphs 1-8, and Docket UE-160799, Policy and Interpretive Statement on June 14, 2017. Retrieved by docket number from https://www.utc.wa.gov/docs/Pages/RecentOrders.aspx

97 Li, M., and Bryson, J. (2015). *Energy efficiency collaboratives.* Washington, DC: State and Local Energy Efficiency Action Network. Retrieved from http://www.raponline.org/wp-content/uploads/2016/05/seeaction-eecollaboratives-2015-sep.pdf

Table 3. Types of Collaboratives

Type	Characteristics
Enhanced collaborative	Possessing a significant operating budget, statutory permanence, and a broad array of specific tasks and responsibilities.
Permanent statewide collaborative	Created to address issues for all electric utilities (including gas utilities) in the state; is permanent as the result of statute, commission order, or track record; has a smaller budget relative to an enhanced collaborative; and could rely more on peer review and input to complete tasks rather than on dedicated staff.
Utility-specific collaborative	Established by the commission to foster stakeholder input for a single utility; operates similarly to a permanent statewide collaborative.
Temporary collaborative	Created to examine a defined set of issues; to be disbanded after completing its mission.

Rate Design

As discussed in Principle 6, electricity rate design is a key element of electrification. Electrification depends on independent actions by energy users. For consumers to benefit from the value produced by their flexible electrification load, the system or societal value of their actions must be communicated through the electricity prices they pay or avoid. The penetration of more emissions-efficient energy end uses will depend on time-varying pricing to make them sufficiently attractive to consumers. Utilities can provide economic incentives to adopt these cleaner resources through different rate designs. Lower off-peak rates will make electric end uses cost-competitive with fossil-fueled heating and transportation alternatives in many areas, expanding the innovative options available to consumers.

Utility Incentives for Participating Customers

Electric utilities have provided incentives to encourage innovative technology deployment for many years. This is the case, for example, with smart thermostats, window replacements, and appliances like refrigerators. These programs tend to move the market over time so that continuing incentives are rarely required. It is reasonable to expect that the same rationale may apply for BE-related devices.

Energy Efficiency Resource Standards and Financing

Where existing efficiency standards require reductions in kWhs only, states would be wise to modify them to reflect all fuels. It would be useful to apply standards that consider other metrics as well, such as avoided CO_2 emissions, Btu savings, or peak reductions.[98]

If BE measures are cost-effective for consumers, then financing methods should be available that work for consumers, using such approaches as on-bill financing. If a customer can have a lower monthly energy bill, that would be desirable. For certain vulnerable populations that don't have access to credit, other kinds of programs will be necessary to meet their needs in an equitable manner.

Energy Standards for New Construction and Appliances

The economics of installing efficient equipment for space heating and cooling and for water heating will favor new construction over existing housing. New construction is an

98 Although not dispositive in their approaches, there are numerous examples of mechanisms that have been adopted to recognize the connection between the sources and end uses of energy. See, for example, Lees, E. (2014). *French white certificates and energy savings in the transport sector.* Brussels, Belgium: Regulatory Assistance Project. Retrieved from http://www.raponline.org/wp-content/uploads/2016/05/rap-lees-frenchwcstransport-2014-may-19.pdf. In the European Union's Energy Efficiency Directive, for example, a primary energy factor connects "primary" and "final" energy. See Council Directive 2012/27/EU on Energy Efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. 2012 O.J. (L 315/1). Retrieved from https://eur-lex.europa.eu/eli/dir/2012/27/oj. It indicates how much primary energy—including fossil fuels like gas, oil and coal, nuclear energy, and renewable energy like wind and solar—is used to generate a unit of electricity or a unit of usable thermal energy. Esser, A., and Sensfuss, F. (2016). *Evaluation of primary energy factor calculation options for electricity—final report.* Karlsruhe, Germany: Fraunhofer-Institut für System und Innovationsforschung. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/final_report_pef_eed.pdf

ideal opportunity to deploy new technology, because the entire cost of a heating and cooling system is being considered.

Appliance standards set out minimum energy standards, and they are typically adopted separately for gas-fired and electric technologies.[99] In light of the competitiveness of air source heat pumps and air source heat pump water heating systems, it would be worthwhile to consider including these requirements in new building codes and appliance standards and ensuring their effective adoption.[100]

Fossil Fuel Phaseout

The economics for phasing out end uses employing fuel oil, petroleum, and propane are currently more compelling than for end uses relying on natural gas.[101] It is still advisable, however, for states to explicitly consider incorporating equipment investment lifetimes into their planning and analysis. As electric technologies continue to improve and decline in price, the economics of all fossil fuel-based investments over their useful lives are likely to face competitiveness challenges.

For new natural gas system expansions, regulators may need to require life-cycle cost analysis recognizing whatever state carbon goals apply. For example, in states with a commitment to very low carbon emissions by 2050, newly expanded natural gas service may not be viable unless, for example, natural gas industry "green gas" efforts produce adequate results.[102]

99 See discussion of codes and standards at Section 3.6 of Deason et al., 2018.

100 The redesign of buildings to include electrified end uses can be expected to increase efficiency and contribute to greater system resiliency. See Wei, M., Nelson, J.H., Greenblatt, J.B., Mileva, A., Johnston, J., Ting, M., et al. (2013). Deep carbon reductions in California require electrification and integration across economic sectors. *Environmental Research Letters*, 8(1). Retrieved from http://iopscience.iop.org/article/10.1088/1748-9326/8/1/014038

101 Although this may be true for buildings that already have access to natural gas, it may not be the case when considering the costs of gas pipeline expansion (see Principle 5). This is especially so if one remembers that gas pipeline expansion would never occur if the plan weren't to use that infrastructure for many decades.

102 See, for example, Nemec, R. (2018, January 25). RNG, electrification pushed by California utilities. *NGI's Daily Gas Price Index*. Retrieved from http://www.naturalgasintel.com/articles/113158-rng-electrification-pushed-by-california-utilities

Conclusion

This paper is intended to stimulate discussion about how to characterize and implement BE, one of the major innovation opportunities in the power sector. Recent technological advances and increases in the efficiency of end-use equipment are for the first time making possible the economic electrification of uses that have traditionally been powered by fossil fuels like natural gas, propane, fuel oil, gasoline, and diesel.

BE reflects a collection of strategies designed to identify and overcome barriers; take advantage of technology trends and related power sector opportunities; connect consumers with more affordable and cleaner resources; help utilities better manage the grid; and reduce the environmental impacts of powering energy end uses.

For electrification to be considered beneficial, it must meet one or more of the following conditions, without adversely affecting the other two:

1. Saves consumers money over the long run;
2. Enables better grid management; and
3. Reduces negative environmental impacts.

By establishing BE principles and suggesting goals and models for organizing effective public engagement processes, we offer regulators an analytical framework to improve energy productivity in their own states through BE. This principles paper is the first in a series of four reports; three companion pieces will examine the implementation of BE for specific applications in transportation, space heating, and water heating.

Appendix: Beneficial Electrification and Carbon Management

> "We focus on electrification here because we view it as the current, most obvious feasible pathway, requiring fewer technological/cost developments and potentially less infrastructure development than other options."
>
> *Electrification: Emerging Opportunities for Utility Growth,* The Brattle Group (2017)

More than 30 US states have adopted climate action plans, greenhouse gas reduction targets, or carbon markets. The goals of beneficial electrification (BE) are consistent with these extensive and long-standing state- and regional-level efforts to use energy more efficiently and reduce the carbon intensity of the economy.[103] In support of climate goals, policymakers have conducted studies to identify critical levers for managing the transition to a low-carbon economy. Two approaches these studies consistently identify are electrification and the achievement of energy savings through investment in energy efficiency. For example, the European Climate Foundation, in a 2010 study outlining a pathway for reducing the EU's greenhouse gas emissions at least 80 percent from 1990 levels by 2050, recognizes:

> The most cost-effective pathways to achieve this objective depend critically in the shorter term on the deployment of more aggressive energy efficiency measures and, particularly post 2020, on a large-scale switch of heat and transport sectors to the use of decarbonised electricity.[104]

In 2015, California's Air Resources Board, Independent System Operator, Public Utilities Commission, and Energy Commission sought to evaluate the feasibility and cost of a range of greenhouse gas reduction scenarios to meet their goals.[105] Looking economywide and across the state, the PATHWAYS project concluded that certain actions are critical to meeting greenhouse gas reduction goals, including a significant increase in energy efficiency and conservation in buildings, vehicles and industry, and switching away from fossil fuels in buildings and vehicles.[106]

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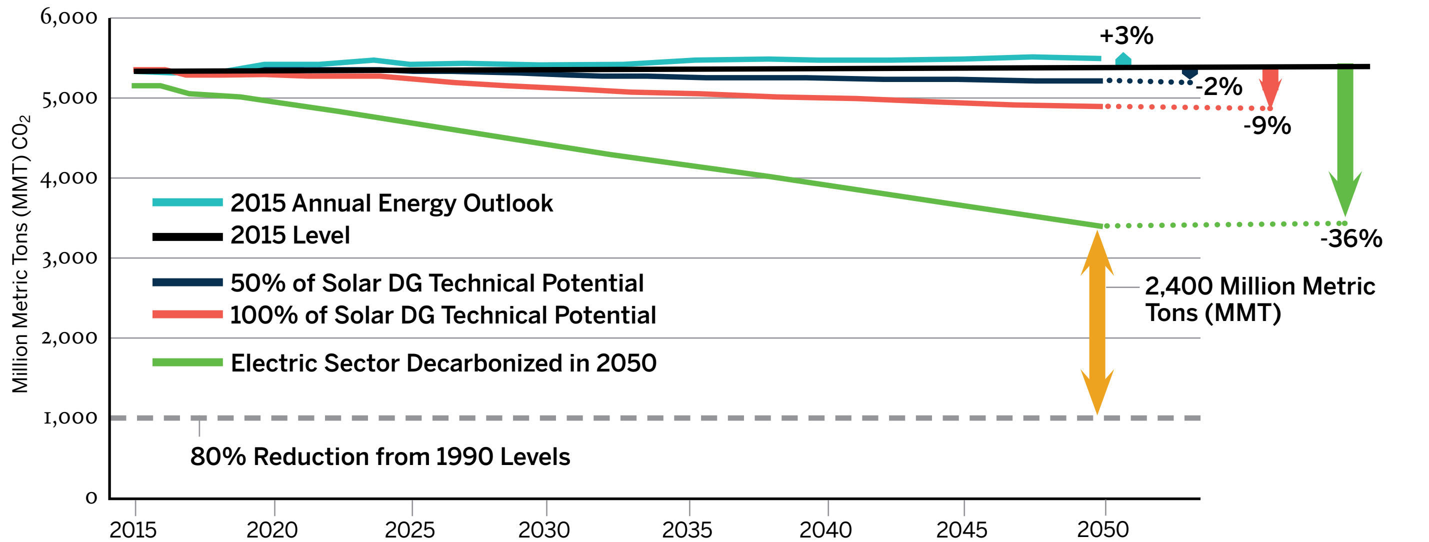
103 Center for Climate and Energy Solutions. *Climate action plans* [Webpage]. Retrieved from https://www.c2es.org/us-states-regions/policy-maps/climate-action-plans; see also https://www.c2es.org/us-states-regions. Mason, M., and Megerian, C. (2017, July 17). California Legislature extends state's cap-and-trade program in rare bipartisan effort to address climate change. *Los Angeles Times*. Retrieved from http://www.latimes.com/politics/la-pol-ca-california-climate-change-vote-republicans-20170717-story.html; and Gusting, G. (2017, August 23). 9 Eastern states agree to cut power plant emissions an extra 30%. *Inside Climate News*. Retrieved from https://insideclimatenews.org/news/23082017/rggi-northeast-states-tighten-power-plant-emissions

104 European Climate Foundation. (2010). *Roadmap 2050: A practical guide to a prosperous, low-carbon Europe*, p. 6. Retrieved from http://www.roadmap2050.eu/attachments/files/Volume2_Policy.pdf. See also Wei, M., Greenblatt, J.B., Nelson, J.H., Mileva, A., Johnston, J., et al. (2013). *Scenarios for meeting California's 2050 climate goals*. Berkeley, CA: University of California and Lawrence Berkeley National Laboratory. Retrieved from http://www.energy.ca.gov/2014publications/CEC-500-2014-108/CEC-500-2014-108.pdf; and Wei, M., et al. (2013). *Scenarios for deep carbon emission reductions from electricity by 2025 in western North America using the SWITCH electric power sector planning model*. Berkeley, CA: University of California. Retrieved from http://www.energy.ca.gov/2014publications/CEC-500-2014-109/CEC-500-2014-109.pdf. The authors identify elements critical to the achievement of the 2050 goal of 80 percent greenhouse gas reductions from 1990 levels, including "widespread electrification of passenger vehicles, building heating and industry heating." They also write that "moving away from oil and natural gas and towards electricity is a key decarbonization strategy." In 2015 the World Bank reached similar conclusions. Meeting climate goals will require "transforming how the world uses energy"; "the work starts with a shift from relying on fossil fuels for electricity to using clean energy that decarbonizes electricity"; and "with increasing amounts of clean energy following, a massive shift to electrification can then increase access to clean energy and displace polluting fuels." World Bank. (2015). *3 steps to decarbonizing development for a zero-carbon future*. Retrieved from http://www.worldbank.org/en/news/feature/2015/05/11/decarbonizing-development-zero-carbon-future

105 Mahone, A., Hart, E., Haley, B., Williams, J., Borgeson, S., et al. (2015). *California PATHWAYS: GHG scenario results*. San Francisco, CA: Energy and Environmental Economics. Retrieved from http://www.ethree.com/wp-content/uploads/2017/02/E3_PATHWAYS_GHG_Scenarios_Updated_April2015.pdf

106 Mahone et al., 2015. These actions include significantly increasing energy efficiency and conservation in buildings, vehicles, and industry; switching away from fossil fuels in buildings and vehicles; sustaining the pace of low-carbon electricity development (i.e., about 50 percent renewables in 2030 in California); decarbonizing liquid or gas fossil fuels with sustainable biofuels or synthetic decarbonized fuels; and reducing non-energy greenhouse gases (methane and fluorinated gases).

Figure 19. US Energy-Related Greenhouse Gas Emissions with Fully Decarbonized Electric Power Sector in 2050



Source: Weiss, J., et al. (2017). *Electrification: Emerging Opportunities for Utility Growth.*

Using what we know about energy investment lifetimes will also be critical for meeting the deep reductions in greenhouse gas emissions by midcentury to which many states and countries have committed. Figure 19 illustrates how achieving a 2050 goal of an 80 percent reduction is not possible by reducing power sector emissions alone but will require additional sectors like transportation and heating.[107]

BE is obviously an essential connection between the power sector and the decarbonization of these other sectors. BE end uses, such as electric vehicles and heat pumps, have the potential to become more emissions-efficient over time. However, given the long lifetimes and the infrequent opportunities for natural replacement of current fossil-fueled automobiles and heating sources, efforts need to begin soon to facilitate those transitions. This will require an explicit effort to evaluate the useful lifetimes of energy investments consistent with available BE opportunities to avoid locking in the use of higher-emitting technologies. A fully decarbonized economy will require a sustained transition from our existing energy supply and demand infrastructure to more efficient, low-carbon equipment.

The rationale for electrification based on a decarbonized power sector, as opposed to other approaches to reaching significant carbon targets, is that the continued use of fossil fuels—no matter how efficiently—cannot achieve emissions reduction goals and do so in the shortest time.[108] Reaching an 80 percent goal requires additional reductions from other sectors, such as transportation and residential and commercial water and space heating.

Adding to that conclusion a greater understanding of the lives of investments and the limited opportunities to replace energy infrastructure, it becomes clear that while fuel switching from oil to natural gas, for example, will contribute to greenhouse gas reductions, these efficiencies alone, when compared with BE, will not eliminate the need to step further away from fossil fuels.[109]

So, despite the dramatic improvement in the carbon intensity of electricity generation when coal is replaced by natural gas, there appear to be no pathways available where fossil fuel use becomes free of carbon emissions.[110] Despite power plant emissions from natural gas being about half of coal's emissions

107 Weiss et al., 2017.

108 Weiss et al., 2017, p. 5. The authors cite a 2016 study in the EU, noting that, for certain sectors, electrification may not be the only path for significant decarbonization. One path might seek to improve performance of internal combustion engines and increase the level of fossil fuels and biofuels to the point of complete adoption of some sort of "non-carbon emitting biofuel substitute for current transportation fuels." See Roland Berger GmbH. (2016, April 27). *Integrated fuels and vehicle roadmap to 2030+*. Munich, Germany: Author. Retrieved from https://www.asktheeu.org/en/request/4108/response/13332/attach/10/doc%206.pdf

109 Weiss et al., 2017, p. 5.

110 Research and development efforts are underway to develop carbon capture and storage technologies for carbon reduction purposes, but these technologies are still cumbersome and expensive, and none is close to commercialization. They have been shown to be neither effective nor cost-effective.

footprint on a per-energy-unit basis, the Achilles' heel in the bridge-fuel hypothesis may be that overinvestment in natural gas infrastructure could actually undercut the transition to even lower-emitting and more cost-effective technologies.[111]

Assessing Emissions Effects of Electrification

As noted earlier, although overall power sector emissions are declining, this is occurring at different speeds around the country.[112] Consequently, it is important for decision-makers to be able to credibly determine the emissions reductions associated with incremental electrification activities in their specific regions.

Identifying Marginal Emissions

Hourly data, available in some regional transmission organizations, would provide reasonable granularity and could be used to assess how emissions are changing over the hours of a year and from year to year. This won't reflect the emissions of the specific unit used for frequency regulation, often a very flexible unit on automatic generation control, but rather the emissions of the unit that would be started up or shut down in response to a large step change in load. Here we consider three methods for obtaining marginal carbon dioxide emissions rates, listed in descending order of accuracy:

1. **Marginal emissions analysis:** This shows, in aggregate, the emissions from the generation resource on the margin in a specific balancing area, meaning the emissions that would be produced to meet an additional increment of load. This should be hourly data, available from the system operator, that can be used to assess how emissions will vary over all the hours of the year and from year to year in response to permanent load changes.[113] This approach provides the most accurate and useful information for policymakers to determine a system's marginal emissions and the impacts of electrification.
2. **Deemed savings model:** In the absence of an accurate resource load shape and a marginal emissions analysis, something analogous to a deemed savings approach (commonly used in evaluating energy efficiency programs) could support a reasonable characterization of marginal emissions for each power system. With this approach, electrification measures of all kinds could be listed and characterized with a reasonable estimate of annual carbon and other emissions reductions they would provide, ideally in at least quarterly increments. Accumulating all known electrification measures in a utility's service territory or a power system during a year would quickly produce a "deemed emissions reduction database." This approach is applicable in the context of BE, reflecting emissions reductions typical of converting fossil-fueled end uses to electricity-powered ones.
3. **Emissions estimation:** A system operator or state agency could review available historic data to identify the likely marginal unit at different times in a year and use emissions information from that facility, or generic emissions factors, to estimate the marginal emissions at various times.[114] This approach provides a way to at least offer some information to regulators and the public. Generic system data that help characterize hours and seasons when electrification is likely to be beneficial for vehicles or other end uses can aid utilities in developing smart charging programs that minimize emissions. Regulators could require additional data tracking to improve the programs' accuracy.

Other approaches for characterizing marginal emissions are being developed. For example, WattTime, a subsidiary of the Rocky Mountain Institute, has developed an approach that applies various algorithms to continuous emissions monitoring data from generating facilities and from Open

111 Littell, D. (2016). Natural gas: Bridge or wall in transition to low-carbon economy? *Natural Gas & Electricity*, 33(6). Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/gas.21953/full

112 Millstein et al., 2017.

113 Over the life of electrification, utilities will retire today's power plants and build new capacity. It is the emissions of those replacement units—likely to be a mix of wind, solar, natural gas, nuclear, and other resources—that will supply the incremental electricity in the future. The short-term impacts are relevant but unlikely to control the analysis.

114 For example, if a natural gas-fired combined cycle turbine is the marginal unit at most peak evening periods (approximately 5 to 8 p.m.) then the marginal rate might be 700 to 1,200 pounds per MWh for those hours.

Access Same-Time Information Transmission System data from independent system operators to characterize marginal emissions associated with electricity use.[115]

Modeling

As noted in the discussion of Principle 3, modeling is another way to ascertain the emissions potential of electrification. We briefly consider two categories of energy sector models. First, a dispatch model can simulate operation of a specified power system over a relatively short period and help illustrate what would be the least-cost dispatch of a complex system of interconnected generators to reliably meet load.[116] Second, a utility-scale or national-scale capacity expansion model generally has higher spatial and temporal resolution and, for example, is used in integrated resource planning.[117] Table 4 illustrates various features of each approach.

Table 4. What the Types of Energy Sector Models Do Well [118]

Type and capabilities	Questions they can ask
Dispatch models	
• Simulate detailed (hourly to subhourly) operation of a given system. • Assess resource adequacy and other aspects of system reliability. • Analyze the impact of system changes (e.g., capacity retirements and additions) on system operation. • Assess transmission congestion and locational marginal prices. • Describe the daily pattern of generator emissions.	• What are the operations, emissions, and resource adequacy effects in a given region of coal or nuclear unit retirements? • What is the maximum potential for redispatch from coal steam units to natural gas combined cycle? • What is the value of storage, demand response, and solar power to the power system?
Capacity expansion models	
• Examine the impacts of power sector policies (or alternative technology and fuel trajectories) on the generation and capacity mix in the midterm to long term.	• What effects on generation and capacity will result from environmental policies? • What are the cost implications of alternative pathways to a future of low greenhouse gas emissions? • How will future prices of natural gas affect capacity investment? • What changes in consumption and expenditures will result? • What are the efficiency and distributional effects of various policy designs?

115 See http://watttime.org/.

116 Examples of production cost models include PROMOD, GE-Maps, PLEXOS, and GridView. Boyd, E. (2016). *Power sector modeling 101*. Washington, DC: US Department of Energy, Office of Energy Policy and Systems Analysis. Retrieved from https://www.energy.gov/sites/prod/files/2016/02/f30/EPSA_Power_Sector_Modeling_FINAL_021816_0.pdf

117 Boyd, 2016. National scale models include National Energy Modeling System, Regional Energy Deployment System (ReEDS), Integrated Planning Model, Haiku, and MARKAL (MARKet Allocation). Utility-scale examples include UtiliResource Planning Model, Aurora, System Optimizer, Strategist, and PLEXOS.

118 This table is adapted from several parts of Boyd, 2016.

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