

Electrification

Emerging Opportunities for Utility Growth

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EXECUTIVE SUMMARY

This paper presents a counter-narrative to the often-cited utility “death-spiral,” a vicious cycle of declining utility sales and rising electricity rates. Under this prevailing paradigm, weak utility sales growth is exacerbated by increasing distributed generation (DG) penetration.

At the same time, current projections of economy-wide greenhouse gas (GHG) emissions significantly exceed those needed to reach longer-term GHG reduction goals. We present an alternative to this paradigm. In the alternative paradigm, utility sales break out of the death spiral and society achieves desired GHG reductions based on electrification of the transportation and heating sectors, coupled with a significant reduction in the carbon intensity of the power supply mix.

Under technical potential for this alternative scenario, utility sales could nearly double by 2050 while energy sector carbon emissions would decrease by 70 percent. Instead of a future where utilities cede volume to energy efficiency and distributed generation, even partial electrification of the transportation and heating sectors could present a large opportunity for utilities to increase sales and be a major catalyst for reducing economy wide GHG emissions.

However, challenging questions must be confronted in the transition to greater electrification. For instance, who will bear the costs of this transition? How do those costs compare to alternative options for decarbonizing the economy? How will power grid operations be impacted by new, significant sources of load? How will these load impacts depend on parallel developments such as automated driving and the proliferation of car/ride sharing?

The pace and scale at which this transition may be achieved can be directly influenced by utilities. In this paper, we explore a number of initiatives that could be pursued to nudge future industry developments towards electrification. Such activities include retail rate reform, effective engagement with regulators and policymakers, enhanced planning activities, facilitating the deployment of vehicle charging infrastructure, and developing new programs to leverage the grid flexibility benefits that could be provided by more electricity-intensive end uses.



INTRODUCTION

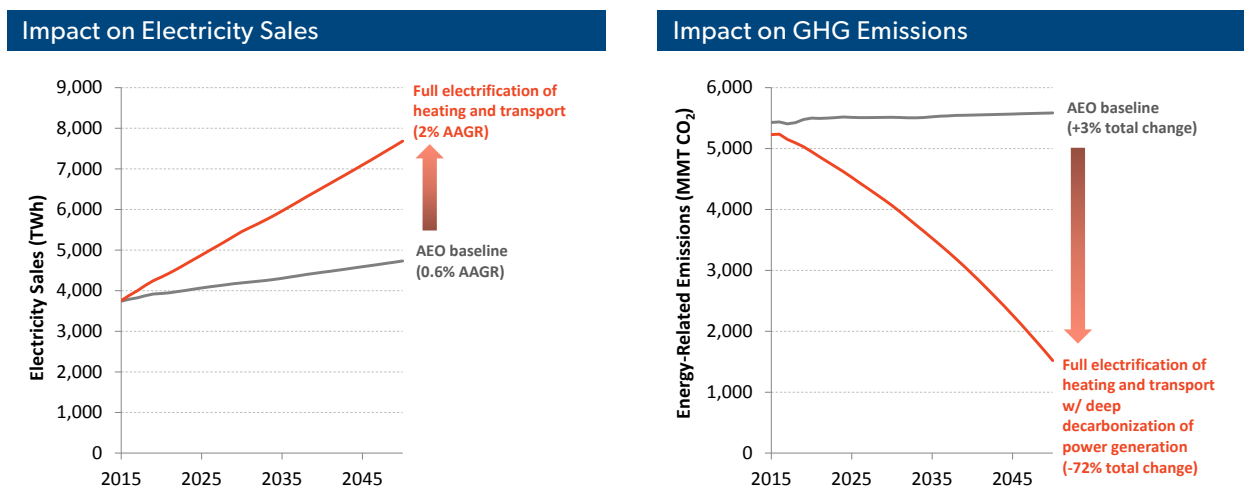
The electricity and broader energy industry is in a period of fundamental transformation. Increasing concerns about climate change risks, advances in cost and performance of alternatives to traditional fossil-fueled technologies, the shale gas revolution, advances in battery storage, and the increasing ability of end-use customers to participate more actively in their energy production and consumption all suggest a profound change in the industry. In addition, advanced economies, such as the United States and Europe, continue to shift away from energy intensive activities and towards installing more efficient devices for providing similar services. The persistence of these trends is leading to a belief by some that the traditional utility model has become untenable.

But what if the prevailing paradigm is wrong and there are other possible visions of the future that would benefit both utilities and society at large?

In this paper we explore an alternative paradigm that is likely attractive for both utilities and society. Specifically, we explore: (1) if there is a compelling prospect for utility sales to reverse the current low/no growth trend and even grow dramatically over the next 35 years, and (2) whether such growth could be essential for achieving the deep economy-wide decarbonization likely needed to minimize the risk of catastrophic climate change. The driver of growth in this alternative evolution would be the nearly complete, and possibly fairly rapid, electrification of transportation and heating, which currently account for about 45 percent of U.S. greenhouse gas (GHG) emissions.

Our modeling of upper-bound growth (i.e., technical potential) in this scenario suggests that sales could double from 2015 levels by 2050 if the heating and transportation sectors were to switch from their current fuel mix to 100 percent electricity. Such a shift would imply annual electricity sales growth rates that significantly exceed recent growth and even growth in the decade prior to the 2009 recession. Coupling electrification of heating and transport with significant decarbonization of the power sector (e.g., through the adoption of clean power generation sources such as renewables, nuclear, or carbon capture) and modest reductions in other energy sectors could lead to more than a 70 percent reduction in U.S. energy-related GHG emissions relative to 2015 levels, and thus represent an important step towards overall economy-wide emissions reductions targets.^{1, 2} These two trajectories are summarized in Figure 1.

FIGURE 1 Impact of Electrification Combined with Deep Decarbonization of Power Sector



Source: The Brattle Group analysis based on EIA AEO 2015 data

In the remainder of this paper, we first briefly lay out the challenges that lie ahead for utilities in the current paradigm of slow sales growth, and we discuss the implications of long-term GHG reduction targets for the generation supply mix. Next, we quantify the impact that full electrification could have on electricity sales levels, load shapes, and system requirements as well as GHG emissions. We also discuss some of the political and technical complexities associated with this transition. Finally, we explain and emphasize that this alternative paradigm is not guaranteed to become a reality but will depend on many factors, including near-term initiatives utilities can develop and implement. We describe several such initiatives.

THE PREVAILING PARADIGM OF ANEMIC UTILITY SALES GROWTH

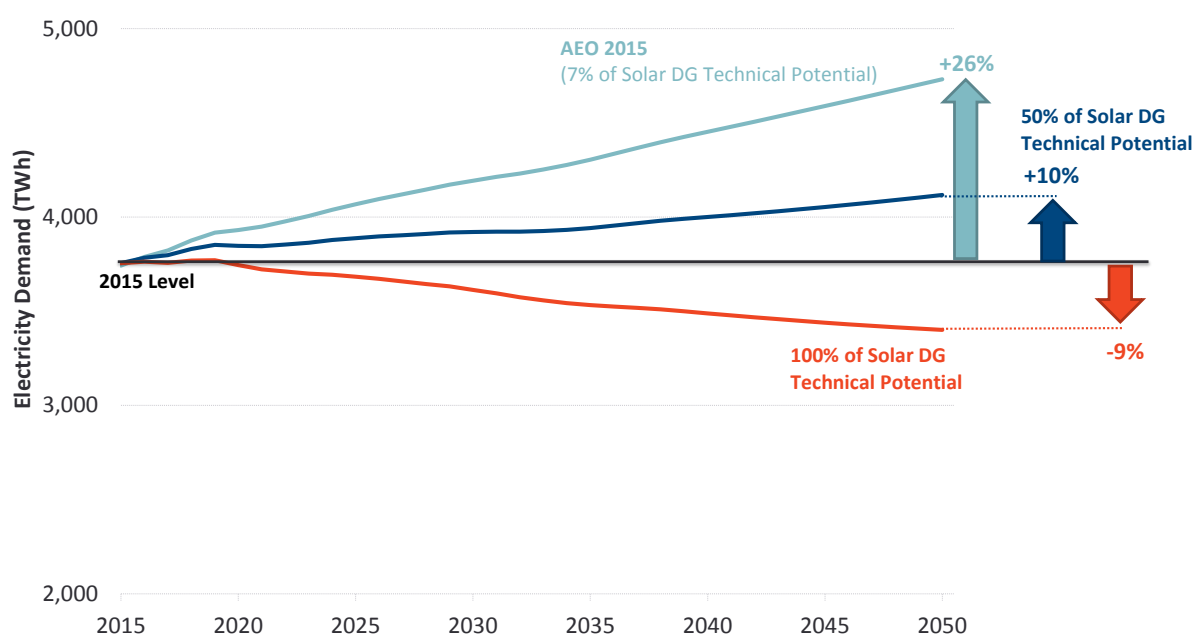
The United States Energy Information Administration (EIA) 2015 Annual Energy Outlook (AEO) projects net electricity sales between 2016 and 2040 will grow at an average annual rate of just 0.6 percent, significantly below the average of 1.3 percent/year over the previous 25 years.^{3, 4} The EIA's projections could well *overstate* sales growth based on their very modest assumptions about the growth of distributed solar PV (increasing from 0.4 percent of total electricity demand today to 2.0 percent by 2040).⁵ For instance, the AEO projects 2022 distributed solar photovoltaic (PV) capacity of 12,700 megawatts (MW), but estimates by Bloomberg New Energy Finance project total non-utility solar PV capacity of almost 50,000 MW by the same year, *four times* the AEO projection.⁶

A recent study by the National Renewable Energy Laboratory (NREL) estimates the technical potential of residential and commercial rooftop solar PV generation for the entire U.S. to be approximately 1,400 terawatt hours (TWh), or about 30 percent of projected 2050 electricity consumption.⁷ One way to look at the NREL findings is that the potential for rooftop solar PV could easily erase any currently forecasted utility sales growth and possibly even lead to non-trivial reductions in utility sales over the coming decades. As shown in Figure 2 below, assuming a 50



FIGURE 2

Effect of Increasing Levels of Solar DG on Electricity Sales



Sources: AEO 2015, NREL 2016, The Brattle Group analysis

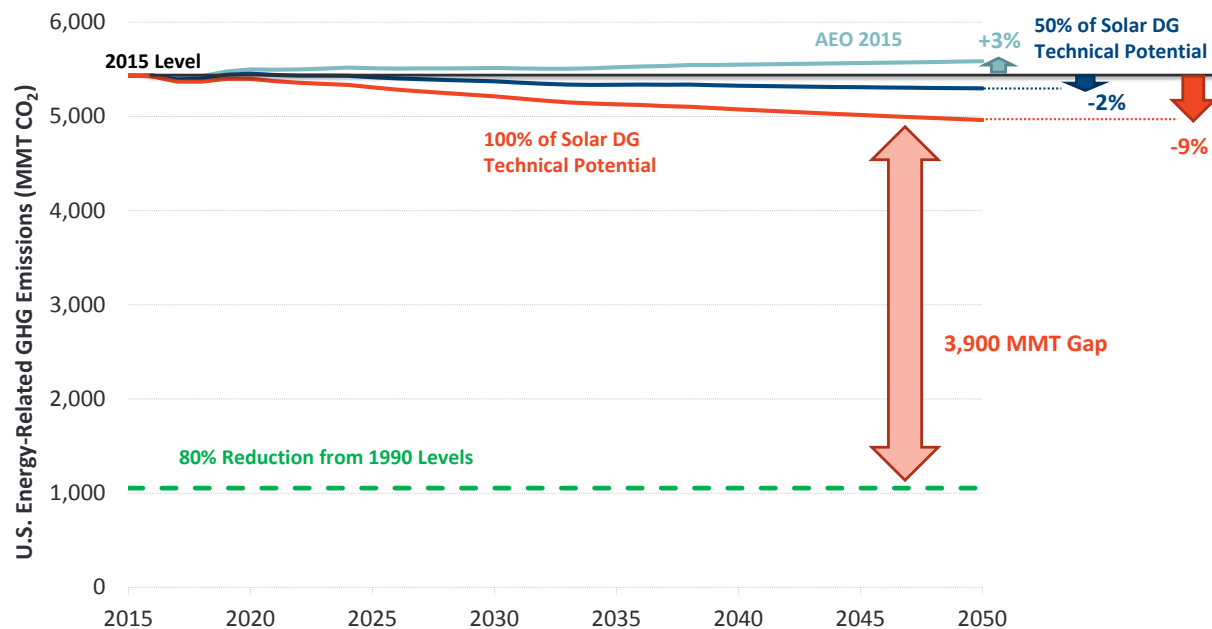
percent realization of the technical potential of rooftop solar PV in 2050 would cut cumulative net growth by 60 percent (from 26 percent to 10 percent). Full realization of NREL's technical potential estimate would cause net negative (-9 percent) cumulative growth through 2050.⁸

On the other hand, 100 percent realization of NREL's technical potential estimate is unlikely, and even if achieved utility sales of electricity would still represent over 60 percent of overall electricity production. A future without utility scale electricity production and, perhaps more importantly, without transmission and distribution networks connecting centralized generation with load, is therefore very unlikely.⁹

Perhaps surprisingly, these high distributed PV cases alone would not be anywhere near sufficient to meet long-term GHG reduction goals. Figure 3 shows that the EIA's Business-as-Usual (BAU) forecast of economy-wide annual GHG emissions, even if adjusted for 100 percent penetration rates of carbon-free rooftop PV generation, industrial emissions remaining mostly flat over the next 30 years and significantly exceeding the levels required to achieve deep economy-wide decarbonization by mid-century.

FIGURE 3

U.S. Energy-Related GHG Emissions with Solar DG Penetration Scenarios



Source: AEO 2015, NREL 2016, The Brattle Group analysis

If this were the end of the story, the future outlook would be unsatisfying and concerning for electric utilities and for society more broadly. Concerns about a substantially reduced role for utilities in generating and delivering electricity (even though perhaps not the “death” of the utility), could well become a reality. At the same time, society would find itself on a carbon emissions path far above what is deemed prudent to insure against the risk of significant and potentially devastating climate change.¹⁰

But the story does not have to end here.

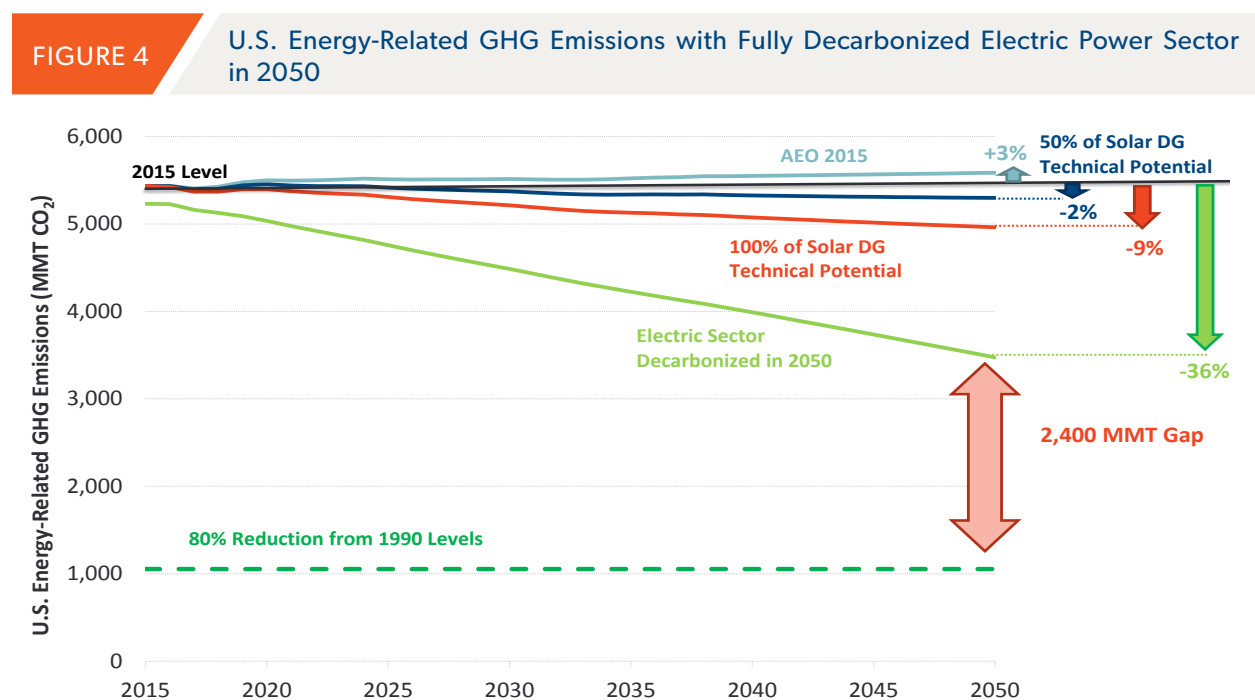
The drive to reduce economy-wide GHG emissions, and ongoing transport developments involving electric vehicles and autonomous shared driving, all provide a pathway to an alternative future paradigm for electric utilities: economy-wide decarbonization through electrification.¹¹

THE DEEP, ECONOMY-WIDE DECARBONIZATION PARADIGM EXPLAINED

There is a worldwide political and technological trend toward decarbonization in the power sector. Even though the debate about climate change continues to some extent in the U.S., significant declines in the cost and increases in the performance of emissions-free technologies (primarily wind and solar) and their complements (battery storage) are leading to a widespread belief that the electricity industry will become increasingly decarbonized.^{12,13}

Even if the electric power sector aggressively pursues full decarbonization by 2050 – removing 36 percent of future energy-related GHG emissions – the U.S. will still be well above its long-term GHG goals as included in the Paris Agreement. Figure 4 below shows that projecting a linear decarbonization trend between 2015 and 2050 still leaves the country 2,400 million metric tons short of a goal of 80 percent reductions relative to 1990 emissions by 2050.

To achieve 80 percent reductions relative to 1990 emissions, further reductions have to come from the non-electric sectors. Attempts to decarbonize transportation (representing 35 percent of total 2015 U.S. energy-related emissions) have so far primarily occurred at the federal level and in California, and include increasing Corporate Average Fuel Economy (CAFE) standards and the blending of conventional fuel with lower emitting fuels such as biofuels and biogas through the Renewable Fuel Standard (RFS).¹⁴ Attempts to reduce emissions related to fossil fuels burned in the residential and commercial sectors mostly related to water and space heating (representing 11 percent of total U.S. GHG emissions in 2014), have largely focused on fuel switching from oil to natural gas, improving the efficiency of water heaters and furnaces and improving insulation.



Sources: AEO 2015, NREL 2016, The Brattle Group analysis

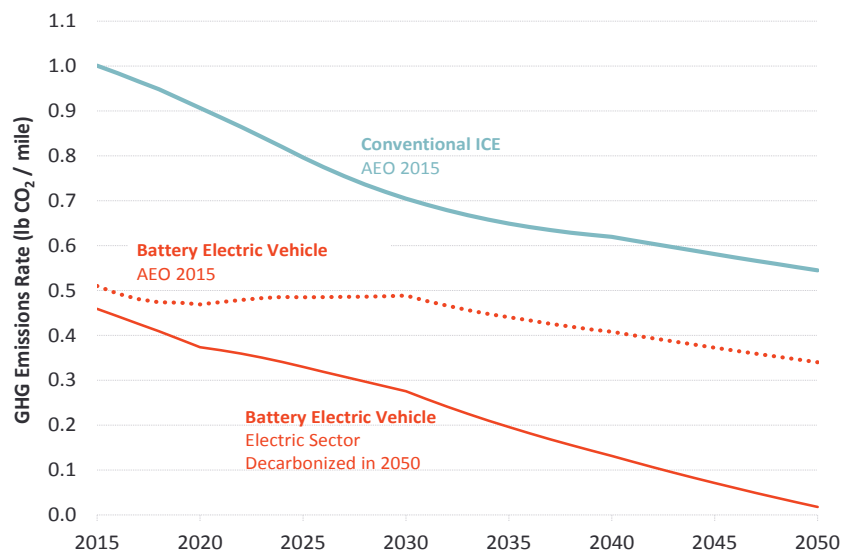
These are beneficial measures which can make a significant contribution to emissions reductions. But conservation and efficiency improvements alone will not eliminate dependence on fossil fuels. Natural gas, while less carbon-intensive than coal or average electric power today, remains a significant source of GHG emissions.

Therefore, an alternative path toward significant decarbonization of these sectors is to aggressively pursue electrification of transportation and heating.¹⁵ While this is certainly not the only possible path to decarbonization, 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.¹⁶

A comparison of the emissions rate of different transportation technologies illustrates how vehicle electrification could lead to significant carbon reductions. Figure 5 shows the vehicle emissions rate from the AEO 2015 assumption for a gasoline-powered light duty vehicle (solid teal) compared to an electric vehicle powered by the AEO-projected electric grid (dotted teal line) and our “greened” electric grid assumptions (solid yellow line).¹⁷ Using reasonable assumptions for future electric vehicle efficiency and carbon rates of the electric sector, battery electric vehicles (BEVs) provide a path for reducing transportation sector GHG emissions.

FIGURE 5

Emissions per Mile for Conventional and Electric Light Duty Vehicles



Source and notes: EIA, AEO 2015. Emissions rate does not account for production emissions of vehicles, which tend to be higher for BEVs than ICE. See: <http://www.ucsusa.org/sites/default/files/attach/2015/11/Cleaner-Cars-from-Cradle-to-Grave-full-report.pdf>

POTENTIAL FOR SIGNIFICANT ELECTRIFICATION AND SALES GROWTH

To demonstrate the potential for electricity sales growth and economy-wide GHG emissions reductions from electrification, we developed a high-level analysis of the gradual electrification of the transportation, residential, and commercial sectors.

We established an upper-bound estimate of the potential for electricity growth under deep decarbonization by assuming a steady conversion of transportation vehicles and residential and commercial heating devices away from burning fossil fuels and towards electric-powered alternatives, such that both sectors are fully electrified by 2050.^{18, 19} In other words, this analysis represents the technical potential for the electrification of heating and vehicle transportation.²⁰ For transportation, we assume that the projected gallons of fuel used by light duty vehicles, commercial light trucks, and freight trucks are replaced by electricity demand for operating an increasing fleet of battery electric vehicles.²¹

For residential and commercial water and space heating, we calculate incremental electricity demand by assuming that appliances fueled by natural gas, propane, and distillate fuel (primarily water heaters and space heaters) are gradually replaced by heat pumps, electric water heaters, and electric ranges.²² For both sectors, the reduction in carbon dioxide (CO₂) emissions results from the decrease in emissions from the burning of fossil fuels, partially offset by power sector carbon emissions, but the latter decline over time as the electric grid is decarbonized as per our assumptions.

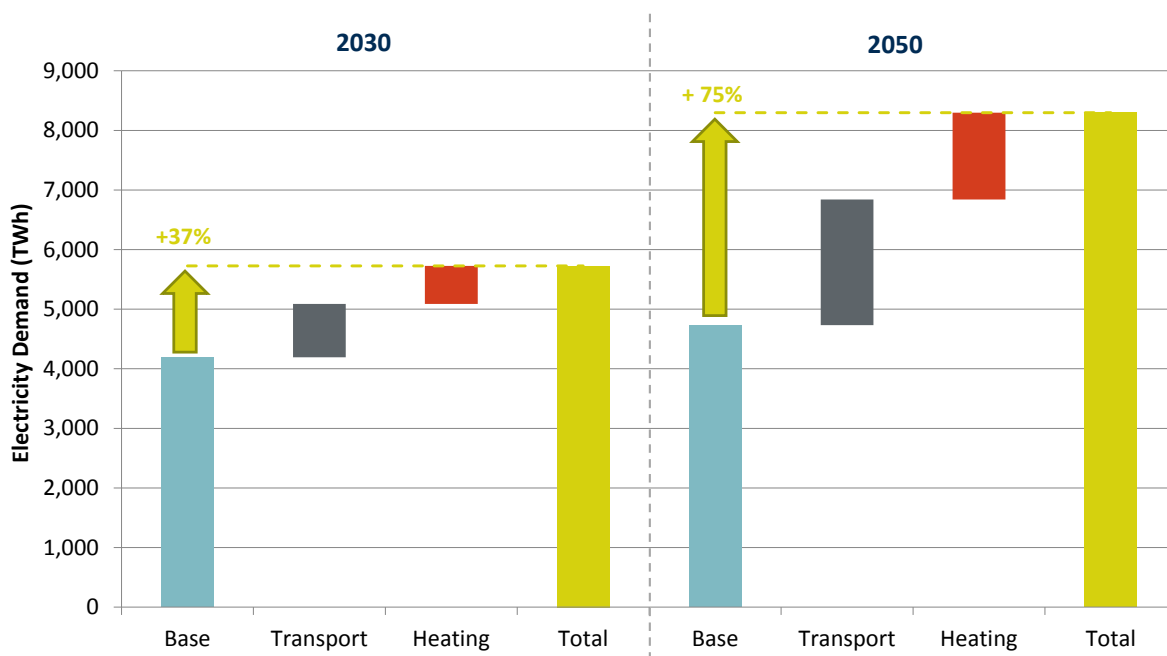
With these assumptions, full electrification of land-based transport (light-duty, commercial, and freight vehicles) in 2050 would increase total electricity demand by 2,100 TWh, or 56 percent of 2015 electricity sales if BEVs were to become the exclusive mode of transportation.²³ The same calculation applied to heating suggests an increase of electricity demand in 2050 of 1,500 TWh, or 40 percent of 2015 electricity sales. Figure 6 below shows how full electrification could lead to an increase of 3,560 TWh of new electricity demand by 2050 relative to the non-electrification BAU.



To understand how such an increase in total electricity demand might impact utility sales, Figure 7 contrasts the evolution of utility sales under the EIA's Reference Case, a scenario where 50 percent of NREL's estimate of technical potential for rooftop solar PV is met, and a case in which the energy sector is fully electrified by 2050. As can be seen, utility sales would double by 2050 even if 50 percent of the technical potential for rooftop solar PV were achieved. This contrasts sharply to only a 10 percent cumulative growth of utility sales between now and 2050 under the same assumption about rooftop solar penetration without electrification. Assuming this transition takes place through 2050 as an increasing number of GHG reduction goals are met would result in an increase of electricity demand of approximately 1.9 percent per year between 2020-2050 compared to 0.6 percent per year under the EIA's Reference Case. Such an annual growth rate would significantly exceed the average rate of electricity sales growth in the decade prior to the 2009 recession.

FIGURE 6

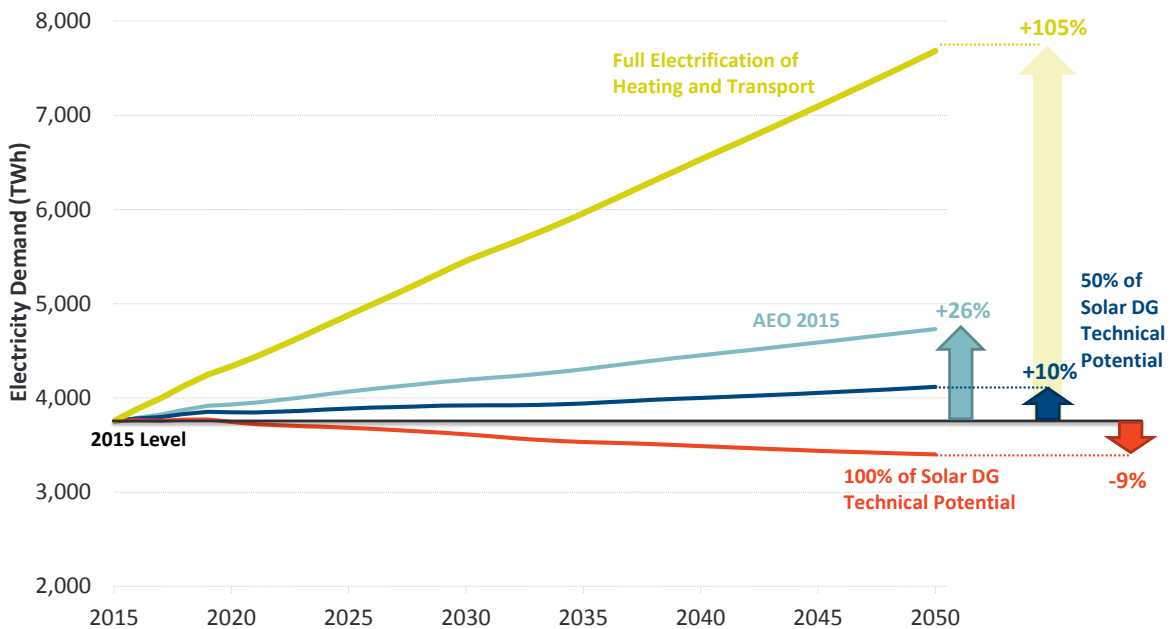
Incremental Electricity Sales due to Electrification of Heating and Transport



Source: AEO 2015, NREL 2016, The Brattle Group analysis

FIGURE 7

Projected Electricity Sales with Full Electrification



Source: AEO 2015, NREL 2016, The Brattle Group analysis

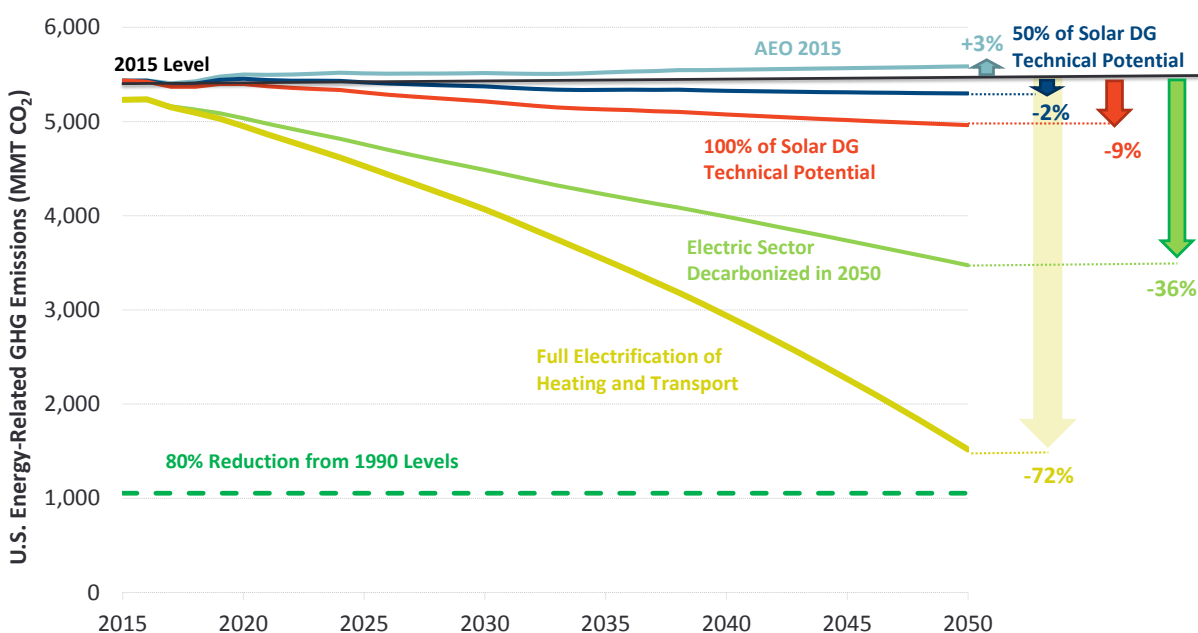
Figure 8 shows how full electrification of the heating and transport sectors, when coupled with 100 percent decarbonization of the electric sector by 2050, would reduce energy-sector related GHG emissions by 75 percent relative to the AEO BAU case and 72 percent relative to 2015 levels. This is close to the 80 percent decarbonization goal often cited as necessary to current global warming to 2 to 3°C by 2050 and beyond. Modest reductions in other sectors not modeled here (around 30 percent) would allow for the U.S. to meet its 2050 GHG emissions targets in this scenario.

Based on the NREL estimate of DG solar technical potential, the individual customer-level total electricity demand (as the sum of current electric demand and new electric demand for heating and transport) significantly exceeds the ability to generate enough electricity in a distributed fashion. Put simply, even with significant increases in solar PV efficiency and deployment of distributed storage systems, the amount of power the typical residential roof can generate will not be sufficient to power all uses of electricity in the home. So even for houses with suitable roofs, a fully autonomous electricity production system is likely infeasible. This is of course truer for non-suitable roofs or for customers without a roof (renters in apartment buildings, etc.). The bottom line though is that there will be a permanent role for the bulk power system.



FIGURE 8

U.S. Energy-Related GHG Emissions with Full Electrification in 2050



Source: AEO 2015, NREL 2016, The Brattle Group analysis

OPERATIONAL AND INSTITUTIONAL COMPLEXITIES OF TRANSPORT ELECTRIFICATION

It is important to highlight some of the challenges related to infrastructure investments made to support transport electrification. Our modeling above assumes that many of the factors shaping transport demand and behavior patterns remain unchanged or are consistent with EIA projections. Both electric sales and GHG emissions ultimately depend on the total number of miles driven. But the confluence of electric vehicles (EV), autonomous vehicles (AVs), and shared transport services (such as Zipcar, Uber, Lyft, etc.) could lead to fundamental changes in how transportation will be consumed and thus change the number of total vehicle miles travelled (VMT). For example, it has been suggested that autonomous vehicles could lead to long-term increases in VMT of up to 35 percent,²⁴ which, given the size of electricity demand from EVs, would result in further significant increases in total demand for electricity. However, predictions about the impact of autonomous vehicles are highly uncertain, given the large number of ways in which such vehicles could affect travel demand.²⁵

The implications of rapidly evolving paradigms around electrified and autonomous transport are also significant for both the infrastructure for vehicle charging and the hourly or sub-hourly shape of electricity demand.²⁶ The standard assumption about EV charging still seems to be driven by a vision of transportation largely identical to the current system, based on individual car ownership, stable daily driving patterns, and a gradual and relatively evenly spread increase in EV ownership.²⁷ These assumptions lead to a dominance of home and workplace charging using “Level 1” and “Level 2” charging infrastructure.²⁸ This evolution and resulting charging patterns are relatively inexpensive and lead to only modest and somewhat predictable changes to the shape of overall electricity demand.²⁹ It is further often assumed that efficient pricing of EV charging, for example, through time-of-use (TOU) rates, will lead to “benign” charging that produces a smoother electricity load shape with little or no growth in peak capacity needs. As a result, EV charging is often seen as a non-utility business, interconnection costs are relatively modest, and the effect of charging on peak generation capacity is modest or negligible.

However, the rapid emergence of autonomous driving and both car- and ride-sharing could materially alter this assumption of continued, conventional individualized transport. The following are important considerations that are typically overlooked in studies of the impacts of transport electrification:

- The evolution of both autonomous driving and ride sharing may outpace the evolution of electric vehicles, as evidenced by the fact that several of the major traditional car manufacturers have recently made significant investments in both areas (see Sidebar 1). With the commercial introduction of fully autonomous cars expected around or even before 2020,³⁰ even if VMT remained similar to current levels, in a transportation world dominated by potentially shared autonomous electric vehicles, charging patterns and the infrastructure to support it could be significantly different.
- Today’s individually-owned cars have a very low utilization rate (typically four to eight percent)³¹ and thus sit idle for long periods of time, making low-powered charging over multiple hours possible. Shared autonomous vehicles, on the other hand, could well be used more like taxis or Uber cars, which drive 150 to 250 miles per day,³² or close to ten times as much as the average privately owned car.
- While it is likely that travel demand will still be significantly lower during overnight hours, the more miles driven per day and the need to be available to pick up a ride likely creates the demand for fast, perhaps even for super-fast intra-day charging.
- The location of charging needed for AVs would change, with less charging “at home” or at the workplace, but rather either in centralized locations – autonomous vehicles could return to centralized charging points between rides – or as part of the public road infrastructure, for example, through inductive charging embedded in roads themselves.
- Super-fast charging can currently occur at power levels of 100 kW or more, and inductive charging points could potentially charge at power levels of 200 kW,³³ as compared to Level 1 charging at up to about two kW and Level 2 typically charging at approximately six to eight kW.³⁴ Clearly, charging EVs at power levels 50 to 100 times higher than Level 1 charging over shorter and perhaps less predictable time intervals could create significant challenges to both electric infrastructure and electric system management, at least locally.
- High-power charging likely requires greater involvement of utilities, both because it may require significant upgrades to transmission and distribution infrastructure and controls, and because high-power charging in public spaces could well be considered a “public utility” rather than a private service, with implications for who should own and operate such charging infrastructure.



The rapid developments of autonomous driving technology and shared riding services suggest a potential revolution in the transport system occurring somewhat independent of the utility sales and decarbonization issues on which this paper has focused.³⁵ That is, some of the transformation of transport may happen whether or not the U.S. (and the world) is committed to achieving deep economy-wide decarbonization targets. Put differently, the transformation of transportation may be based solely on the other significant potential benefits of a transport system dominated by (shared) autonomous (electric) vehicles, such as vastly-reduced accident and fatality rates; significantly expanded access to mobility to currently underserved populations such as the young, elderly or handicapped; significantly reduced space use (for parking and potentially road ways) in urban areas; reduced traffic congestion; improved urban air quality; and lower overall transportation costs.

Even though reports on autonomous vehicles often assume that such vehicles will be electric, this may not necessarily be the case. An evolution toward more fleet-based transportation may make it easier to accommodate other fuels as well, such as hydrogen (which is likely also an electric vehicle in the long run unless hydrogen continues to be produced from methane), compressed natural gas (CNG), or various forms of biofuels. Some of these fuels will require new infrastructure, which in turn may be less costly if it does not have to be deployed to parallel the existing gas station infrastructure, but rather in a more concentrated fashion to allow fleet-level refueling. Therefore, to realize the full benefits of transport electrification, utilities will likely benefit from playing a proactive role in identifying possible social and technical systems and transmission processes needed to achieve this development rather than just reacting to the developments of transport.

For example, a greener power supply provides a stronger argument for electrified shared autonomous vehicles, as does the provision of easy and ubiquitous charging. Given the discussion above, it is also possible that utilities can and likely should be an active participant in discussions about supporting infrastructure for a future of shared electric autonomous vehicles, since they may be a natural builder and operator of such infrastructure, and since the spatial distribution and sizing of charging infrastructure will have potentially significant impacts on total investment costs and the costs of reliable electric system operation.

AUTOMOBILE MANUFACTURER INITIATIVES IN AUTOMATION AND RIDE SHARING

Several new trends may define the future of personal transport. For instance, self-driving vehicles have recently begun to emerge as an important technological development. At the same time, companies providing on-demand car sharing services, such as Uber and Lyft, are transforming the taxi industry. Other companies like Car Next Door and Getaround allow car owners to make their cars available for quick errands or weekend trips when not needed.

Taken together, the development of these technologies and services could drive significant change: fewer individuals may own cars, car services could become cheaper if eliminating the need for drivers, and insurance costs could drop in the case that self-driving cars operate more safely than human-driven cars. As costs drop, these services could become a viable alternative to car-ownership. On an individual level, shifting away from car ownership removes burdens like parking fees and vehicle maintenance. On a societal level, a reduction in car ownership would reduce pollution and congestion (to the extent it lowers miles traveled), and would potentially free up parking space for other uses.

Major auto manufacturers have begun investing in self-driving vehicle technology. **Ford** has partnered with **Google** to form a public policy coalition to lobby for regulations that would favor fully-autonomous vehicles. At the same time, Ford is among five investors to collectively invest \$6.6 million in Civil Maps, a startup trying to build three-dimensional maps that would assist self-driving cars. **Nissan** is currently attempting to develop a fully self-driving car by 2020, and **Volvo** has set a goal of putting self-driving cars on the market by 2021.

Large car manufacturers are also investing in car-sharing businesses. **Toyota** and **Uber** have teamed up under a “memorandum of understanding” through which drivers will be offered new leasing options to pay for their Toyota vehicle by working for Uber. Toyota’s \$111 million startup fund, Creation Investment Limited Partnership, is investing in Uber together with Toyota Financial Services Corporation. Uber is investing in driving automation research and development. In May 2016, **Volkswagen** announced a \$300 million investment in Gett, an Israel-based app that connects customers with taxi services. **Daimler** owns mytaxi, which, like Gett, connects customers with taxi drivers. Daimler also owns car2go, a service through which customers can locate and book rental cars for short rental periods. **BMW** has invested in Scoop, a California ridesharing platform designed to match customers for carpools. In early 2016, **General Motors** announced a \$500 million investment in Lyft and a fleet of self-driving vehicles, and secured a seat on Lyft’s board of directors.

According to General Motors President Dan Ammann, “We think our business and personal mobility will change more in the next five years than the last 50.” Thus, while a network of shared, autonomous vehicles may seem like science fiction to some, the degree of investment in these areas suggests that the future may be closer than it appears. These developments are important considerations for studies on transport electrification.





A PERMANENT AND ESSENTIAL ROLE FOR UTILITIES THROUGH ELECTRIFICATION

A very possible deep economy-wide decarbonization pathway involves significant electrification of both transport and heating, leading to a central and ongoing role for electric utilities to generate and distribute much more electricity to end users. This role involves the efficient and reliable operation of the power system relying on a mix of centralized and decentralized carbon-free electricity production. Overall, the above paradigm presents a very positive business outlook and opportunity for utilities: continued growth of sales from centralized (i.e., non-distributed) generation as well as a crucial and likely significantly enhanced role for electricity network infrastructure and controls.

In many cases, full electrification, particularly of heating, may not be the most efficient solution since other options (e.g., more insulation, other renewable heating options) could be more cost-effective. But even partial electrification of both sectors would fundamentally change the outlook for centralized production and management of our electric system. And, even though beyond the scope of this paper, electrification could also make a fully decarbonized electric system easier to manage, by adding many layers of flexibility – in the form of thermally storing heat or in the form of charging and discharging millions of batteries in future electric cars (see Sidebar 2 for further discussion).³⁶

More importantly, full or even significant electrification of the transport and heating systems is far from a foregone conclusion. Even if deep decarbonization becomes (or remains) an accepted policy mandate, there are options to decarbonize transportation and heating that do not involve electrification, or at least not the same amount. And since electrification would mean shifting very significant revenues away from conventional fuels (i.e., gasoline, diesel, and natural gas), it would be in the economic interest of those who would lose to develop alternatives to electrification. The most obvious strategy is to count on further improvements of the performance of the internal combustion engine in combination with higher percentages of blended biofuels, leading eventually to a non-carbon emitting biofuel substitute for current transportation fuels. Such a path would leverage existing fueling infrastructure and result in less of an impact on the current delivery infrastructure for transportation fuels. Consequently and unsurprisingly, the transportation fuels industry is proposing a gradual decarbonization along those lines.³⁷

WATER HEATERS AND THE FLEXIBILITY VALUE OF ELECTRIFICATION

The power system will need to become increasingly flexible in order to reliably integrate growing amounts of intermittent renewable generation (largely wind and solar). Electrification of the transport and heating sectors can be complementary in this regard. Both the batteries of grid-connected electric vehicles and the heating elements of electric water (and potentially space) heaters can be controlled and dispatched to respond to fluctuations in generation supply.

Electric resistance water heaters, for instance, can essentially be used as behind-the-meter thermal batteries. The water in the tank can be heated at times when there may be a net excess supply of electricity on the system and low or even negative energy prices, thus fulfilling a need to increase load in order to absorb the excess generation (e.g., during daytime hours for solar-dominated systems or possibly during nighttime hours for wind-dominated systems). The water tank is then fully heated and able to provide the customer with a sufficient supply of hot water during higher net load hours of the day when there may otherwise be a scarcity of power supply on the system. Utilities have successfully offered demand response programs that provide this daily load shifting capability for decades.

A more recent development is the use of electric water heaters to provide ancillary services. Through real-time control of the heating element, the electricity consumption of the water heater can be rapidly increased and decreased in response to fluctuations in power supply in order to provide grid balancing services. Several companies have commercialized the technology necessary to offer these services and it is being proven in the field through a number of demonstration projects and full-scale deployments.

The potential for this resource is large. There are currently more than 50 million electric water heaters in U.S. homes. This represents 40 percent of all household water heaters and nine percent of residential electricity consumption. Assuming each water heater provides two kW of controllable load, this amounts to a 100 GW distributed resource that could be used to provide ancillary services across the U.S. Further electrification of the heating sector will, of course, increase the size of this resource. If heat pumps are adopted rather than electric resistance water heaters, the associated ability to provide demand response may be limited, but there would be additional energy efficiency benefits.

The value of this resource could be significant. A recent Brattle study found that the net benefits of utilizing grid-enabled water heaters in this manner could exceed \$200 per customer per year under certain market conditions (See “The Hidden Battery: Opportunities in Electric Water Heating”). This would pay for the entire cost of the water heater and associated control equipment and program costs in under five years. Given the significant size and value, the potential benefits of behind-the-meter energy storage could become an important cornerstone of electrification strategies.



Given the significant uncertainties related to the costs and implementation challenges of either pathway (biofuels, including biogas, would also present alternative decarbonization pathways for heating, though they involve complex issues related to land use, competition with food production, etc.), there is no obviously preferable pathway from society's perspective.

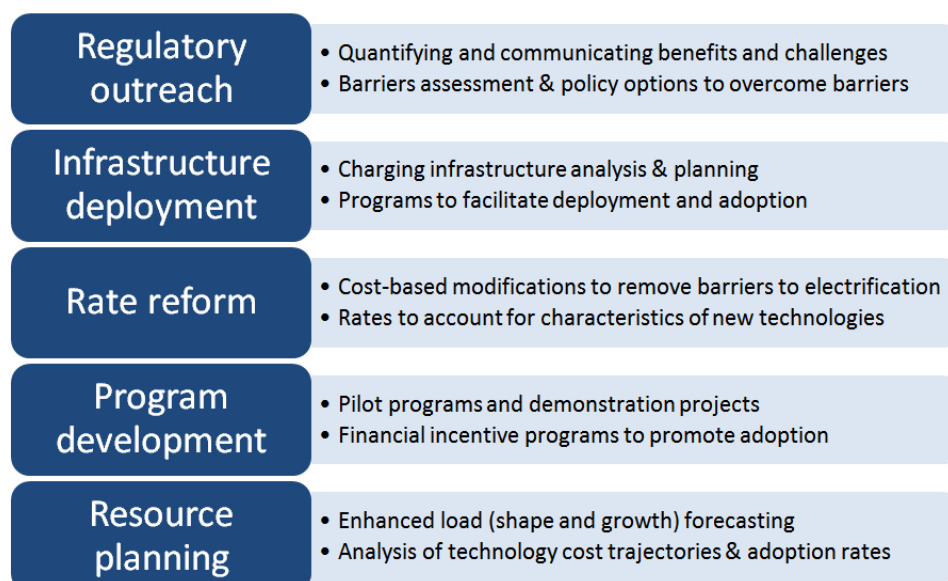
This means that the future becomes “path-dependent” in the sense that the degree and form of electrification will likely significantly depend on facilitative and preparatory actions taken early and along the way, including many actions under the control of the utilities. **The positive outlook outlined in this paper is not likely to occur without utilities playing a leading role to set the path forward in modernizing and decarbonizing sectors in which it has not traditionally been involved, including deploying assets and providing access to electric power infrastructure.**

Electrification of transport in particular is likely to require very significant investments both by consumers (in electric vehicles and home chargers), utilities (in network infrastructure and potentially chargers), and generators (renewable capacity). Perhaps more importantly, deep and rapid electrification would require significant behavioral changes in customers and would fundamentally alter the transportation industry, with negative impacts on traditional fuel suppliers and some car manufacturers. Given that electrification of transport remains a relatively new field, it is also characterized by rapid technological change, which, combined with the need to invest in significant infrastructure, results in complex challenges related to making the right investments at the right time. Many of the behavioral changes are occurring rapidly with the introduction and acceptance of new forms of urban transport, such that the seeds of change required for moving towards electrified transportation are already being planted. Relatedly, political mechanisms to encourage (or require) such electrification are emerging, and utilities should get involved in their specification, including timetables and mechanisms.³⁸

All of this implies that utilities can likely increase the chances of electrification becoming the primary path towards economy-wide decarbonization efforts with actions that lower the barriers to electrification. The options for doing so are many and a detailed discussion is beyond the scope of this article. Figure 9 below lists a few ideas that are likely candidates for near-term activity by utilities, which we discuss briefly in the remainder of this section of the report.

FIGURE 9

Possible Elements of a Utility Electrification Strategy




First, it will be critical to evaluate the benefits and complexities of electrification in a collaborative process with regulators and policymakers.

Electrification will likely create new challenges not only for utilities, but also for their regulators. Conversely, public infrastructure desires of other civic agencies may be complementary to electrification, with the right coordination. As one example, the kinds of utility actions that facilitate electrification would increase electricity use at a time when regulatory incentives are focused on reducing electricity use, primarily through energy efficiency measures. Also, many of the investments needed to facilitate electrification may be beneficial to customers and society only when looking beyond the classic electricity sector. Put simply, electrification would increase customer electricity bills and electricity use, both of which could be viewed critically by the regulatory community if not understood in a broader context. Specifically, customers' overall energy bills might decline as a result, and society would benefit from lower greenhouse gas emissions.³⁹ In addition, widespread adoption of AEV fleets could have urban traffic, safety, and modernization benefits that are very attractive and valuable, but would be positive externalities in any utility-centric assessment and hence not naturally a part of the standard benefit-cost framework. Thus, coordinated planning between urban managers and large industrial transport fleet owners may also be helpful.

For this reason, utilities likely need to engage regulators early on in ways that allow broadening the tools regulators use to assess investments and programs proposed by utilities to foster electrification.⁴⁰ In the same spirit, a number of actions utilities can take may be considered "pilot projects" even if relatively large scale, or could be larger than what can easily be justified based on current demand. For example, BEV charging technology is evolving rapidly. At present, most studies suggest that the majority of charging will take place overnight at home using Level 1 chargers, with relatively little impact on distribution grid infrastructure. Public charging is also assumed to require relatively low levels of power. However, future charging stations may need to have very significantly higher charging capability, especially if fleets of autonomous EVs operate throughout the day at much higher utilization rates rather than private cars traditionally home operated: while a Level 1 or Level 2 charger requires between three and 10 kW of power, DC Fast Charging and inductive fast charging can require power of up to 100 kW or more. It is thus possible that future DC Fast Charging will require significant upgrades to distribution network infrastructure. Utilities may need to be more proactive when interconnecting new charging stations by upgrading wires to anticipated future higher powered charging devices rather than responding only to current demands. The latter would require finding ways to finance the incremental costs in ways that would not discourage the installation of current technology charging stations.

Second, utilities can play an important role in promoting the deployment of charging infrastructure.

In the near term it is likely that "range anxiety" will remain a major barrier to BEV adoption. Ubiquitous and easy access to charging infrastructure - making BEV charging as easy as possible - will likely be an important precondition for rapid wide-spread adoption of BEVs. Utilities may therefore consider being part of the development of a sufficient charging infrastructure and associated services to lower (perceived) barriers related to lack of charging infrastructure or complexities associated with BEV charging. Where possible, utilities could build, own, and/or operate BEV charging infrastructure, as monopoly or competitive providers. Since even the simplest BEV home chargers will be amongst the more electricity-hungry "appliances", utilities could also play a role in making home charging easier. For example, they could provide financial incentives or installation and maintenance support. To the extent upgrades to electrical service are needed, utilities could provide financial incentives to help defray costs and encourage capabilities upgraded service.



Third, utilities should explore how modified retail rate designs could help remove disincentives for electrification. Some existing rate designs may create an economically inefficient disincentive to pursue electric end-uses. For instance, an inclining-block rate (IBR) structure charges customers an escalating price as their consumption increases over the course of the month. This rate design has largely been used as a policy tool to promote electricity conservation, but, given that both electric heating with heat pumps and home charging of BEVs would significantly increase total electricity consumption, customers under IBR have a financial disincentive to adopt a heat pump water heater, heat pump space heater or BEV charging at home.

In addition to reforming existing rate designs, there may also be a practical need to create a new rate design for a subset of customers who own certain end-uses.⁴¹ For instance, many utilities have created a rate designed specifically for customers with electric vehicles. By offering a lower price during off-peak hours to reflect the lower cost of generating and supplying electricity in those hours, the rate provides BEV owners with an opportunity to manage their charging patterns to save money on their electricity bill while also providing a benefit to the power system.

Fourth, utilities could be proactive in enabling (and incentivizing) the provision of new services that can be provided from behind-the-meter electric devices. For example, grid-enabled water heaters can be controlled to increase or decrease load in real-time to provide balancing services. These balancing services could become increasingly valuable in markets with large adoption of intermittent sources of renewable generation. Electric vehicles could potentially provide similar services when plugged into the grid.

There are many options for promoting the use of electric end-uses in this way.⁴² Customers could be provided with participation incentive payments, akin to conventional demand response (DR) programs. They could be exposed to more time-sensitive retail price signals and adopt automating technologies that allow them to respond to those price signals, or they could participate through a third party aggregator, who would sign up customers and provide these services to the utility or grid operator. In any of these scenarios, customers benefit financially from adopting an electric end-use that displaces other fuels and utilizing it in a way that is beneficial to the power system. To demonstrate that the programs would provide meaningful benefits, it may be desirable to first offer them on a pilot basis.

Finally, the implications of electrification will need to be carefully incorporated into utility planning activities. This study only provides an order-of-magnitude illustration of the broad impacts of a move toward electrification when coupled with decarbonization of the power sector. Utilities, regulators, and stakeholders who are exploring such a transition will need to analyze the impacts of electrification in more detail, taking into account idiosyncratic attributes of the regional market and local utility service territory. At a minimum, this will require a deep understanding of the economics of the “supply side,” such as the cost trajectories of sources of clean generation and incremental costs of incorporating these resources into the power grid. It will also require a more in-depth understanding of “demand side” drivers, including a thorough understanding of customer adoption rates of emerging energy technologies, the benefits that could be achieved by using these technologies to provide around-the-clock demand response, and the potential distribution-level changes in load shapes and associated costs of incorporating large amounts of additional electricity demand into the power grid. Due to the rapid arrival of new transportation modes, such as autonomous driving, shared vehicles, etc., charging patterns based on even large-scale pilots with existing BEV owners may not be sufficient for planning electric infrastructure to support a rapid expansion of electric driving in particular.

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ENDNOTES

1. Energy-related GHG emissions account for about 80 percent of total GHG emissions in the U.S. See: <https://www3.epa.gov/climatechange/science/indicators/ghg/us-ghg-emissions.html>
2. There is relatively strong agreement among climate scientists that near-full decarbonization of the energy sectors in advanced economies will be needed by mid-century to prevent long-term temperature increases beyond two degrees Celsius. See, for example, IPCC, 2014: Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
3. We define net sales as total electricity demand net of self-consumed distributed generation. The EIA made projections to 2040 in its AEO 2015 study. In our analysis below, we extend the projections to 2050 due to the prominence of that date in most GHG reduction targets. We do so by assuming the growth rates of the final 10 years in the EIA analysis are maintained for the period from 2041 to 2050. EIA, AEO 2015, 2015.
4. EIA-826 accessed at <http://www.eia.gov/electricity/data.cfm>
5. Furthermore, EIA has recently been *over-predicting* long-term electricity growth in prior AEO forecasts. See an AEO retrospective on electric sales predictions here: https://www.eia.gov/forecasts/aeo/retrospective/pdf/table_15.pdf
6. Yozwiak, Maddy, "The Impact of the ITC Extension on U.S. Solar," Bloomberg New Energy Finance, 2015
7. Elmore et. al., *Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment*, NREL, January 2016. The technical potential only considers suitable roof space and does not take into account economic factors such as costs and revenues. It is important to note that EIA projects adoption, which depends not only on technical feasibility, but also economic factors. The NREL technical potential show how much higher residential and commercial solar PV adoption could be.
8. We assume the technical potential is achieved in 2050 with a steady increase towards that level of penetration.
9. The economics of grid defection are beginning to be explored. Studies such as RMI's report "The Economics of Grid Defection" tend to focus on the cost of residential solar PV combined with storage at levels that could beat typical residential retail rates. These studies generally don't attempt to estimate limitations on grid defections imposed by absence of suitable roof space, the need to accommodate longer duration deviations of solar PV output from expected averages, and changes of retail rate structures.
10. See: United Nations Intergovernmental Panel on Climate Change, Climate Change 2014: Synthesis Report, Accepted November 1, 2014. Available at: http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf
11. These pathways are the subject of ongoing research. For example, NREL has recently teamed up with EPRI, Evolved Energy Research, Idaho National Lab, Lawrence Berkeley National Lab, and Oak Ridge National Lab in its POWER-UP Study (Potential of Widespread Electrification for Reducing Unwanted Pollution). This initiative explores the pathways toward deep decarbonization through mass electrification of the entire U.S. energy system.
12. For further discussion of U.S. Decarbonization Pathways, see E3, *Pathways to Deep Decarbonization in the United States*, November 2014 and E3, *Policy Implications of Deep Decarbonization in the United States*, November 2015.
13. The DOE released a summary of the cost reductions across five technologies that shows that from 2008 to 2014 costs of utility scale solar PV decreased by 60%, wind decreased by 40%, LED light bulbs by 90%, and battery storage by 70%. DOE, Revolution... Now: The Future Arrives for Five Clean Energy Technologies – 2015 Update, November 2015. <http://energy.gov/sites/prod/files/2015/11/f27/Revolution-Now-11132015.pdf>
14. At the state level, the Low Carbon Fuel Standard (LCFS) policy in California and the Zero Emission Vehicle (ZEV) mandates adopted initially in California and now including nine states have been the most prominent policy for large scale decarbonization. (<http://www.c2es.org/us-states-regions/policy-maps/zev-program>) Other state-level initiatives through the Clean Cities programs have also pursued similar objectives, though at much more modest scales than the LCFS. (See: <https://cleancities.energy.gov/>)
15. We have excluded the electrification of the industrial sector due to the diversity of needs being met in that sector and difficulty in generalizing its fossil fuel consumption to be met by electric rather than combustion engine means. Given that industrial emissions represent approximately 20 percent of total U.S. emissions, achieving an 80 percent reduction in total emissions without reducing industrial emissions would require 100 percent decarbonization of all other emitting sectors.
16. See Wei, M. et. al., "Deep carbon reductions in California require electrification and integration across economic sectors," March 2013.

17. For our “greened” electric grid path, we assumed a linear decarbonization of the electric grid between 2016 and 2050. We note that this graph is based on an average U.S. view. The local and regional emissions rate could be quite different, driven by diverse electric generation mixes across the U.S.
18. We used projections of future fuel demand from the 2015 Annual Energy Outlook.
19. EPRI has similarly studied the potential for transportation electrification. See *Electrifying Transportation Reduces Greenhouse Gases and Improves Air Quality*, September 2015 and *Plug-in electric Vehicle Projections: Scenarios and Impacts*, December 2015.
20. We note that other developments in transportation such as autonomous driving, ride sharing, etc. described in some detail later in this paper, could lead to an increase in total vehicle miles traveled and, if fully provided by electric vehicles, provide even additional sources of electricity sales growth.
21. Based on the California Transportation Electrification Assessment (TEA) Phase II study, we found that 9-11 kilowatt hours (kWh) of electricity are consumed for every gallon of gasoline equivalent that is displaced. We assumed that the relationship between kWh consumed and gallons of gasoline displaced remains constant through 2050. By assuming a fixed ratio for each vehicle class, we are assuming that the efficiency of each vehicle type improves at essentially the same rate. We did not assume any changes to the projected trajectory of Vehicle Miles Travelled (VMT) by the EIA. In addition, we have not assumed a significant growth in fuel cell vehicles (FCV) that require more electricity to operate per mile than BEVs, but provide other benefits (including an extended range and fast fueling) that may result in significant penetrations in a full electrified scenario.
22. We assume the heat pump coefficient of performance (COP) starts at 2.25 and steadily increases to 5.0 in 2050 for space heating, primarily based on the MIT Future of Natural Gas Study, Appendix 5D. For water heating, we assume the COP begins at 1 and grows to 1.5 in 2050. The COP is greater than 1 because heat pumps act on a refrigeration cycle that is able to transfer more energy for heating or cooling purposes than is consumed to circulate the refrigerant.
23. We did not make additional assumption concerning the decarbonization of air travel or other modes of transportation (including rail, buses, or shipping) beyond the EIA projections. An alternative approach to transportation decarbonization is development of hydrogen fuel cell vehicles (FCV) and the infrastructure to produce, transport, and store the hydrogen. Several car manufacturers are embracing this approach over the BEV alternative. Projections for electricity demand under this approach are three to four times higher. For example, see Bossel, Does a Hydrogen Economy Make Sense?, Proceedings of the IEEE, October 2006, Figure 9, which shows that 100 kWh of renewable AC electricity would result in 69 kWh of electricity available to power an EV, but only between 19 and 23 kWh to power a hydrogen fuel cell vehicle.
24. See Bierstedt et al., Effects of next-generation vehicles on travel demand and highway capacity, January 2014, p.4
25. For a discussion of the various factors impacting VMT, see Todd Litman, Autonomous Vehicle Implementation Predictions, Victoria Transport Policy Institute, December 2015.
26. See Faruqui, A. et al., “Smart Pricing, Smart Charging: Can time-of-use rates drive the behavior of electric vehicle owners?” October 2011.
27. See Nexant report by Cook et. al., *Final Evaluation for San Diego Gas & Electric’s Plug-in Electric Vehicle TOU Pricing and Technology Study*, February 2014.
28. Level 1 refers to slow (5-8 hour) charging with a 230V supply mostly overnight, i.e., off peak. Level 2 refers to relatively-quicker (3-4 hour) charging with a 230V supply. Both these levels tend to be easy to install at the household level.
29. See NREL’s “California Statewide Plug-in Electric Vehicle Infrastructure Assessment,” May 2014 where they outline how 97-92 percent of charging will be done at home or at work. See also E3’s “California Transportation Electrification assessment: Phase 2,” October 2014 where they assume load profiles based on L1 or L2 charging at homes or work.
30. See GM Executive Credits Silicon Valley for Accelerating Development of Self-Driving Cars, Wall Street Journal, May 10, 2016 (<http://www.wsj.com/articles/gm-executive-credits-silicon-valley-for-accelerating-development-of-self-driving-cars-1462910491>). See also Die Zukunft nach dem Abgas-Skandal, FOCUS Magazin Nr. 17 (2016), April 2016 (German) (http://www.focus.de/finanzen/news/wirtschaft-und-geld-die-zukunft-nach-dem-abgas-skandal_id_5457885.html), citing senior VW officials, who predict commercially available fully autonomous vehicles by 2019.
31. See <http://www.reinventingparking.org/2013/02/cars-are-parked-95-of-time-lets-check.html> (accessed 11/24/2011) for an overview of methodologies to estimate the utilization rate of passenger vehicles.
32. Average daily miles driven by Uber cars and taxis vary significantly. See <http://www.statisticbrain.com/taxi-cab-statistics/> (accessed 11/24/2016) and <https://www.quora.com/What-is-the-average-mileage-an-Uber-black-or-Uber-X-car-drives-in-a-day-in-San-Francisco> (accessed 11/23/2016) for some anecdotal evidence.
33. See <http://cleantechnica.com/2016/04/20/200-kw-wireless-ev-charging-momentum-dynamics-says/>
34. See Understanding Electric Vehicle Charging (<http://www.pluginamerica.org/drivers-seat/understanding-electric-vehicle-charging>) for a description of different charging levels.

35. An article on the potential utility impacts of SAEVs is forthcoming.
36. Electric water heaters are a particularly attractive source of “flexible load” in the residential sector. For more information, see Ryan Hledik, Judy Chang, and Roger Lueken, “The Hidden Battery: Opportunities in Electric Water Heating,” prepared for NRECA, NRDC, and PLMA, January 2016.
37. See for example Roland Berger, Integrated Fuels and Vehicle Roadmap to 2030+, April 26, 2016, a study commissioned by a coalition of automotive companies and fuel suppliers that proposes such a largely fuel- and internal combustion engine based decarbonization pathway.
38. Examples include New York’s 80x50 GHG reduction policy, AB32 in California, and laws under consideration in China, Germany, and elsewhere, which would mandate battery vehicles under certain conditions within the next decade.
39. In general, it is possible that decarbonization will be costly relative to business-as-usual. In that sense, customer bills may need to go up, even without considering shifting energy use in transport and heating towards electricity. But it could be that electrification is cost-effective relative to other decarbonization approaches.
40. For valuable discussion of policies that unintentionally discourage beneficial electrification, see Keith Dennis, “Environmentally Beneficial Electrification: Electricity as the End-use Option,” *The Electricity Journal*, November 2015. See also Keith Dennis, Ken Colburn, and Jim Lazar, “Environmentally Beneficial Electrification: The Dawn of Emissions Efficiency,” *The Electricity Journal*, 2016.
41. While such rates should be cost-based and therefore could be applicable to any customer – with or without a particular end-use – in some cases there may be advantages to designing a rate that is specifically aligned with the operational characteristics of the target end-use technology, in order to incentivize the optimal utilization of that technology.
42. Ryan Hledik and Jim Lazar, “Distribution Pricing with Distributed Energy Resources,” prepared for Lawrence Berkeley National Laboratory’s Future Electric Utility Regulation series, May 2016. <https://emp.lbl.gov/future-electric-utility-regulation-series>

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