What is Electrification?

Electrification refers to the process of replacing technologies that use fossil fuels (coal, oil, and natural gas) with technologies that use electricity as a source of energy. Depending on the resources used to generate electricity, electrification can potentially reduce carbon dioxide (CO$_2$) emissions from the transportation, building, and industrial sectors, which account for 63 percent of all US greenhouse gas emissions. Addressing emissions from these sectors is critical to decarbonizing the economy and, ultimately, mitigating the impacts of climate change. This explainer reviews how electrification can reduce emissions; possibilities and potential challenges of electrification in the transportation, building, and industrial sectors; and policy options for encouraging electrification.

How Can Electrification Reduce Emissions?

In the United States, over 70 percent of electricity is currently generated using zero- or low-carbon fuels (36 percent is from nuclear energy and renewables, and 35 percent is from natural gas, which emits the least carbon dioxide of any fossil fuel when burned). Consequently, technologies that use electricity as a fuel source result in lower carbon dioxide emissions on average than those that use fossil fuels directly. Additionally, the electricity grid is expected to become even cleaner over time as many state policies (such as Renewable Portfolio Standards) aim to increase the amount of electricity generated by renewable sources. Thus, the benefits associated with electrification will likely grow in the future as electricity generation becomes less carbon-intensive.

If policymakers seek to decarbonize the transportation, building, and industrial sectors, replacing fossil fuels with electricity may also be one of the only technologically viable options. Several methods are available for decarbonizing the electricity sector, but other sectors have far fewer options available for significantly reducing emissions (read about different options for reducing emissions in each sector here). For example, many alternative transportation fuels (such as biodiesel and ethanol) are cleaner than gasoline, but they still emit carbon dioxide and other conventional air pollutants when burned. Hydrogen, another alternative fuel, does not produce emissions but is very expensive and requires electricity to make. Transitioning from fossil-fuel technologies to electric technologies in non-
power sectors would allow policymakers to focus on decarbonizing the electrical grid—a task that may be far more feasible than attempting to decarbonize each sector separately.

Notably, the benefits of electrification today vary depending on the resources used to generate electricity. Within the United States, emissions from electricity generation vary significantly. Some areas have a higher proportion of zero-carbon resources in their electricity generation portfolios and are much cleaner than regions that rely more on fossil fuels like coal. For example, the state of Washington relies on hydropower for a majority of electricity generation and stands to benefit greatly from electrification. Wyoming, on the other hand, has a resource mix comprised almost entirely of coal with a small amount of renewables and natural gas. Consequently, the benefits from electrification in Wyoming today could be negligible, or even negative for some technologies if generating the electricity to run them creates more emissions than using fossil fuel technologies would. However, these benefits could change in the future as the grid resource mix evolves.

Potential for electrification varies greatly across and within sectors. While some sectors already have commercially-ready technologies, others do not and could struggle both technologically and economically to electrify.

Electrification of the Transportation Sector

Overview

The transportation sector accounts for 29 percent of US greenhouse gas emissions (2017 data). Within the sector, nearly 60 percent of emissions come from light-duty vehicles, 23 percent from medium- and heavy-duty vehicles, and the remaining 18 percent from aircraft, ships, rail, and other sources. Given the limited electrification potential of aircraft and ships, and the small share of rail in the sector, this section will focus exclusively on electrification of light-, medium-, and heavy-duty vehicles.

Benefits of Electrification

Most light-duty vehicles (like cars, SUVs, and small trucks) run on gasoline while heavy-duty vehicles (like buses or large trucks) typically run on diesel fuel. The Corporate Average Fuel Economy (CAFE) Standards have required these vehicles to become more fuel-efficient over time, but substantially reducing emissions from vehicles will ultimately require fuel switching away from carbon-emitting gasoline or diesel to a cleaner fuel like electricity. In addition to decreasing greenhouse gas emissions, transitioning to electric vehicles can benefit the electric grid and improve air quality.

As noted above, the range of benefits of vehicle electrification heavily depends on the types of fuels used for electricity generation. For example, a car that is charged in Washington state primarily with hydroelectric power will have a lower carbon footprint than a car charged in Wyoming using power from coal plants. However, even with these considerations, driving an electric car currently produces fewer carbon dioxide emissions than a gasoline car when charged anywhere in the United States. The reason is that in addition to not producing tailpipe emissions, electric vehicles are also more fuel-efficient relative to gasoline and diesel vehicles.

Electrification of transportation can also improve air quality. Switching to electric cars and trucks can reduce air pollution where the vehicles are operating, since they do not produce tailpipe emissions. Electrification of municipal buses could also be particularly beneficial.
for improving local air quality. While municipal buses account for a small portion of overall transportation CO₂ emissions, they typically run on diesel fuel or compressed natural gas (CNG) and produce tailpipe emissions containing other air pollutants (like nitrogen oxides and sulfur dioxide) that contribute to poor local air quality, while electric buses do not. Switching to electric buses could improve air quality, particularly in low-income neighborhoods that rely heavily on bus lines, and therefore provide health benefits for those communities.

In addition to environmental benefits, electric vehicles could also provide benefits to the electric grid by charging when electricity is abundant and demand is low and discharging to the grid when demand for electricity is high. This capability could be particularly useful for accommodating variations in electricity production from variable renewables.

Challenges and Barriers

Widespread electrification of light- and heavy-duty vehicles faces many economic and technological challenges. Many car manufacturers already sell electric cars, but these vehicles face barriers to widespread adoption, mainly due to limited charging infrastructure and the high price tag (largely attributable to battery costs). As the number of electric vehicles grow, they could also put pressure on the local power lines by substantially increasing the amount of electricity being used.

Heavy-duty vehicles face even more obstacles to electrification relative to light-duty vehicles. Heavy-duty trucks require large batteries that take up a lot of space, limiting the space available for carrying goods. Also, trucks often travel very long distances and may require frequent charging, which adds to travel time and makes limited charging infrastructure a significant barrier. These features could limit the ability for electric trucks to substitute for fossil fuel-burning trucks unless other measures are taken to reduce charging times, such as advances in fast charging technology or battery exchange (see ICCT for more).

Electrification of Buildings

Overview

Residential and commercial buildings contribute about 12 percent of all US greenhouse gas emissions. A majority of commercial and residential buildings rely on fossil fuels—such as natural gas or oil—for space heating, water heating, and cooking.

Benefits of Electrification

As with vehicles, carbon emissions from buildings can be reduced through fuel switching from fossil fuels to electricity for residential or commercial building energy needs. Additionally, switching to electric heating and cooking technologies can have substantial air quality benefits. Some electric appliances can be better for indoor air quality than their fossil fuel-based counterparts—natural gas cooking stoves, for example, release carbon monoxide, nitrogen dioxide, and other harmful pollutants when in use.

Challenges and Barriers

Electrification of buildings is quite feasible from a technological standpoint. Commercially available electric technologies for heating and cooking currently exist, including electric heat pumps, electric hot water heaters, and electric stoves. A recent study done by the Lawrence Berkeley National Laboratory (LBNL) estimates that nearly the entire sector could be electrified using existing technologies; however, electrification faces economic constraints.
Economic feasibility varies geographically and by building type. For example, electric heaters (for heating both space and water) are economically competitive with existing fossil-fuel technologies in some areas of the US (particularly the South and California). However, they struggle to achieve economic parity in other areas. LBNL claims that electric heat pumps make the most sense economically in areas with mild climates and low electricity prices. Additionally, they are also more economically competitive when installed in new buildings than when they replace existing technologies in older buildings.

Benefits of Electrification

Electricity can theoretically substitute for fossil fuels as an energy source in processes for the production of some materials, such as heating required in the production of glass, paper, steel, and cement. For example, replacing natural gas furnaces with electrolytic reduction technology has the potential to significantly reduce CO₂ emissions in several industries, including textile, wood, paper, and chemicals.

Challenges and Barriers

Electrification of industrial processes faces more technological challenges than other sectors. Electrification could alter many existing processes, which could create complications, especially if the processes are intricate. Additionally, reducing emissions by replacing feedstock with non-fossil alternatives is challenging for many industries (particularly steel and cement production). Alternative feedstocks in these industries are still in early-stage research and development without commercial application.

In addition to technological challenges, electrification of industry faces economic challenges. Electrified industrial processes are currently more expensive than existing technologies to operate, as electricity is more expensive than natural gas per unit of energy.

Given these technical and economic barriers, the industrial sector may be the most difficult sector to fully electrify. In some cases, other alternatives for decarbonization might be more feasible and less expensive (such as implementing carbon capture and storage for existing processes).

Implications for Policy

Electrification is technologically feasible in many sectors, but it faces implementation challenges due to the high costs for replacing existing technologies and processes. If policymakers and electric utilities wish to reduce greenhouse gas emissions by encouraging electrification, policies and incentives that will help overcome these barriers may be needed.

Some policy incentives already exist to promote electrification, such as tax credits and rebates for the purchase of electric cars and heat pumps. While these policies can encourage a transition to electric technologies, a more economically efficient approach would be an economy-wide carbon pricing policy, such as a carbon tax or emissions cap-and-trade program,
that affects all sectors rather than addressing each sector individually. If carbon dioxide emissions were priced across the entire economy, then fossil-fuel based technologies would become more expensive to operate, thus encouraging electrification of these technologies. A carbon price would also encourage fuel switching to cleaner energy sources within the electric sector, further improving the overall benefits of electrification.

If electric utilities wish to encourage electrification, they can also offer price incentives for the use of new electric technologies like cars or water heaters. For example, San Diego Gas & Electric (SDG&E) offers customers a low electricity rate specific for electric vehicle charging during off-peak hours.

Policymakers or utilities may also have to intervene to prevent potentially negative consequences from electrification. As more sectors become electrified, electric utilities may face challenges in meeting higher electricity demand, which might require upgrades to infrastructure in order to accommodate the additional load. Alternatively, these impacts could be mitigated through other methods, such as managed charging of cars or water heating. Similarly, as the economy becomes more dependent on the electricity system rather than fossil fuel-burning technologies, policymakers and grid operators may need to take precautions to ensure that the power grid is able to maintain reliability and resilience in the face of possible power disruptions. Despite these challenges, electrification could be an effective tool for reducing carbon emissions, especially if it is encouraged through efficient policy design.

Resources for the Future (RFF) is an independent, nonprofit research institution in Washington, DC. Its mission is to improve environmental, energy, and natural resource decisions through impartial economic research and policy engagement.

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