ALLIANCE FOR INNOVATION AND INFRASTRUCTURE

# Dividing Decarbonization by Sector

*How Strategies for Decarbonizing Heat, Electricity, and Transportation Differ*

## Introduction

To advance the discussion of decarbonization, it is important to differentiate individual sectors because their inputs, operations, and externalities can differ significantly, and in some instances categorically. General discussions about decarbonization can lack precision when they center around or bias towards one solution that is inapplicable to other sectors.

In a prior brief, we surveyed the ways the decarbonization conversation is moving around the country in general. While general in nature, we grouped decarbonization pathways into three groups: energy generation, facilitating assets[1], and direct carbon policies. These groupings included topics together with vastly different decarbonization strategies. To achieve a nuanced understanding and guide policymakers to the most impactful and clearest solutions, we have to discuss decarbonization more precisely.

We start by identifying the top sources of emissions and the industries that produce them. Those are heat, electricity, and transportation. Over 75 percent of U.S. emissions come from these three sources, making them the primary target for decarbonization – and the primary sectors where innovation is most needed.

Separating the issue into these groups will help avoid unnecessary quarrel between strategies. For instance, hydrogen and solar are not truly competitors. One is primarily a fuel for low $CO_2$ energy storage (that can later be converted to electricity or heat or transportation), the other is a source for directly generating electricity.

## Heat

Industrial and commercial enterprises in the United States consume a lot of energy in the form of heat. These may be in furnaces, boilers, forges, or simple space heating, but they all come down to needing heat. This activity is responsible for around one third of all carbon dioxide emissions in the entire economy and nation. When heat to spin a turbine in electricity generation is added, this exceeds 50 percent of all carbon dioxide emissions. In this brief, however, electricity is analyzed separately.

The primary fuels to generate heat are coal and natural gas. Heat can also be generated by burning other gases and fuels, but primarily rely on hydrocarbons for their energy density. In order to move towards decarbonizing heat, there are five primary methods: (1) post-combustion $CO_2$ capture from air (aka direct air capture), (2) post-combustion $CO_2$ capture in exhaust

[1] As defined in our previous brief, these include general economy-wide assets that facilitate or pair with other decarbonization strategies, such as batteries, electric vehicles, and broadly electrified appliances. *See* Dierker, B. (April, 2023). *The Top Paths to Decarbonization: Surveying National Decarbonization Strategies*. Alliance for Innovation and Infrastructure. https://www.aii.org/wp-content/uploads/2023/04/Top-Paths-to-Decarbonization-Brief.pdf.

streams (aka point-source capture), (3) change/replace the fuel, (4) electrify the heating load, and the newest option (5) pre-combustion carbon capture.

**Methods 1 and 2:** Direct-air and point-source $CO_2$ capture are methods by which $CO_2$ is collected from air and from exhaust streams. After the $CO_2$ is captured, it is then compressed and transported for sequestration. $CO_2$ capture is getting a lot of publicity, but few of the demonstrated methods to date are economic at scale. Common sense and physics tell us that these types of carbon capture are costly and relatively inefficient because they pull $CO_2$ from the air where it may not be as concentrated. These methods allow for the continued use of hydrocarbons while still achieving decarbonization. While direct-air capture is currently being privately funded to test at scale, point-source capture is the preferred regulatory requirement by governments to limit industrial emissions.

**Method 3:** Changing the fuel to decarbonize may mean using alternative fuels like ammonia or hydrogen which emit significantly fewer carbon oxides and other pollutants. For comprehensive decarbonization accounting to reach net zero or ultra-low carbon intensity (rather than simply cutting emissions in half moving from coal to natural gas but still directly emitting CO2), these strategies should account for the carbon intensity of production, transportation, and storage like building new pipeline infrastructure. For instance, these fuels must be produced, requiring an energy-intense process and transportation to point of use.

**Method 4:** Replacing the fuel is distinct from changing the heating mechanism. For example, using electricity for heating has certain benefits, but also many drawbacks, including requiring a steady source of electricity. Further, that electricity must also be generated from low-carbon sources to meet decarbonization goals. This puts additional strain on the power grid necessitating further infrastructure buildouts.

**Method 5:** A final pathway to decarbonizing heat is to capture carbon pre-combustion. Such pre-combustion carbon capture is a unique method for limiting carbon dioxide emissions by decarbonizing natural gas before it is burned. This approach removes solid carbon from natural gas and reduces eventual $CO_2$ emissions because there is no carbon available to bond with oxygen. With distributed versions of this technique, natural gas and existing infrastructure can still be used, but new downstream gas processing technology must be installed by the gas user.

Ultra-low $CO_2$ versions of this methane pyrolysis approach can feed the "decarbonized natural gas" directly into a combustion chamber, boiler, or furnace. This avoids the carbon-intense buildout of new transmission infrastructure, pipelines, or storage tanks associated with centralized production of green hydrogen as well as the potential pitfalls of straining the electrical grid. It also most efficiently removes carbon because it does so at the most concentrated point – removing it directly from methane ($CH_4$) rather than pulling $CO_2$ out of the ambient atmosphere or exhaust streams.

Overall, the methods of decarbonizing heat focus primarily on the combustion process. Zooming out of the heat sector more broadly, other strategies may require new infrastructure or add additional demand to the electricity grid. Importantly, the solutions in this space differ considerably from the demands for electricity itself or transportation.

## Electricity

Historically, producing electricity usually requires heat. For the practical overlap, solutions from the industrial and commercial heat section apply to this sector, such as a form of carbon capture. But some heat applications do not fit well with electricity, and not all electricity solutions require heat. Accordingly, when it comes to decarbonization, strategies for reducing the carbon intensity of electricity generation must be evaluated as its own sector.

Electricity is generated from three methods, which each have their own decarbonization strategy: (1) heat-turbine, (2) direct-turbine, and (3) direct-electric. While many methods use heat and steam to spin a turbine that turns a generator, some turbine spin directly from kinetic energy in wind or water. Finally, a direct method is photovoltaics in solar panels that directly collect electrons into circuits to generate electricity. From these three methods, it is clear that decarbonization must be discussed differently in electricity than from heat and transportation.

**Method 1:** The predominant form of electricity generation relies on heat, often in conjunction with steam, to spin a turbine. Combustion of coal and natural gas together account for around 60 percent of electricity generation in the United States as of 2022.[2] While relying on natural gas to displace coal results in half the emissions, many are not content to view this as a decarbonization tactic. Incorporating renewable natural gas into the mix does further reduce the carbon intensity because this form of biogas is comprised of previously captured methane. Other approaches to decarbonizing the heat-turbine methods of power generation align with the tactics from commercial and industrial heat above, namely forms of carbon capture and use of alternative fuels.

Perhaps the most promising way to decarbonize electricity is to utilize nuclear power. Nuclear fission relies on splitting uranium atoms to release heat, which is then used alongside steam to spin turbines. The reaction emits no carbon dioxide or pollution and can operate at high capacity around the clock. While currently only responsible for generating 18 percent of utility scale electricity in the United States, advancement of small modular reactors may make the process more economical. Worth noting, geothermal power is also an ultra-low carbon form of power generation that relies on heat and steam, but at less than one percent of the energy mix, it is not presently a widespread viable form of decarbonizing electricity.

**Method 2:** Similar in form to heat-turbine power generation, are the direct-turbine options, which are naturally ultra-low carbon[3] because they require no combustion. The two key power generation options are hydropower and wind power. In each case, the natural movement of water or wind spins a turbine to generate electricity without generating carbon at the source. A shared drawback is the need for transmission infrastructure to connect these to the energy grid. Hydropower is regionally favorable where water resources are abundant, while wind has similar geographic zones that make it more effective. For wind, the intermittency of natural air flow can create a serious disconnect between the theoretical capacity and the actual output. For decarbonizing electricity, these methods must be placed strategically and tied to storage devices.

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[2] Energy Information Administration. (2023). https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.

[3] As with all other techniques in this and other sections, nothing is ultimately carbon-free on a life-cycle basis. *For example*, hydropower requires infrastructure that uses carbon-intense concrete to build, solar panels rely on mining for critical elements overseas, and nuclear material must similarly be mined, milled, converted, and transported.

**Method 3:** While other power sources spin a turbine to generate electricity, solar power has two differences. First, it converts solar energy into electricity directly, where photons from the sun hit the photovoltaic cells and lead to electrons running through circuitry. The second difference is that solar power can be centralized like all other energy sources or distributed/at-source. Utility-scale solar power comes from a solar farm of arrayed solar panels, which must be connected with transmission infrastructure to connect to the grid. Rooftop solar, which functions with the same technology can be set atop many structures and locations.

With decarbonization in mind, solar can provide a portion of utility-scale electricity to power the national grid, although it currently only provides around three percent of the energy mix. It can also decrease the ultimate demand on the grid by providing flexible rooftop options to directly power certain pieces of infrastructure, homes, or businesses, thereby reducing the amount of electricity they must pull from the grid itself.

Thinking about decarbonizing electricity necessarily requires thinking about existing energy infrastructure, new demand forecasts, and new requirements for new infrastructure. It also relies upon supply chains and transportation methods for critical materials needed to capture or harness energy. The cost and benefit of decarbonizing the electricity-generating sector must be carefully evaluated.

## Transportation

In the transportation sector, there are a number of strategies to decarbonize and reduce emissions. While some “last mile” options include incentivizing bikes or scooters or making cities more walkable, other approaches focus on passenger vehicles, middle distances (e.g., regional delivery fleets), and long-haul transportation (e.g., traditional long haul and Class-8 type trucks). These would each have effects on emission reduction, but the common thread between advocates is to reduce emissions by cutting the consumption of hydrocarbons as fuel. The methods include: (1) improve fuel efficiency, (2) hybrid and alternate fuel sources, and (3) electrifying the fleets.

**Method 1:** The overwhelming majority of the private and commercial vehicle fleets in the United States, and indeed the world, run on gasoline or diesel. These rely on internal combustion and compression engines burning fuel to power the engine and result in carbon dioxide alongside other exhaust and pollutants. Before departing from hydrocarbons – and creating an entirely new transportation system – there are prominent options to limit the carbon intensity of the existing fleet.

Fuel efficiency standards are at the forefront. For decades, the federal government has required improved efficiency through the Corporate Average Fuel Economy (CAFE) standards. Alongside industry innovation, this has greatly improved fuel efficiency, allowing vehicles to travel farther on the same quantity of fuel. Both private sector and public policy favor increased fuel efficiency, which means this method for reducing the carbon intensity of vehicle fleets is advancing on its own, but slowly and marginally.

**Method 2:** Hybrid vehicles improve efficiency considerably, utilizing stored power in batteries to extend the range of the vehicle. This provides even greater opportunity for emissions reduction by only partially relying on combustion for the same or greater driving range. Another alternative to traditional gasoline-powered vehicles is to utilize natural gas as a combustible fuel. Natural gas has been used in passenger and commercial vehicles and burns with a lower quantity of emissions relative to gasoline or diesel fuel. It functions similarly, but despite the lower emissions rate and similar driving range, there is little to no systemic infrastructure to support this type of fleet.

A final alternative fuel is hydrogen. While it is functionally more similar to an electric vehicle, hydrogen-powered vehicles fill their tank with hydrogen that then utilizes fuel cells to power an electric motor. Similar to natural gas, there is a lack of nationwide infrastructure like gas stations to support hydrogen vehicles.

**Methods 3:** Outside of hydrocarbons and alternative fuel options are electric vehicles. While the concept of electric vehicles is over a century old, there has been a resurgence in recent decades, and EVs are largely considered the primary strategy for decarbonization and end goal for all roadway travel among advocates. Within the EV category are battery-electric and fuel-cell electric vehicles.

Battery-electric vehicles require electricity from an external source to charge a battery that runs an electric motor. This electricity must come directly from the power grid (or indirectly from a home power wall or generated onsite via rooftop solar). Regardless of the approach, any true method of decarbonization will require EVs to be powered by low-carbon electricity. Presently, coal and natural gas provide the majority of electricity to the national power grid, meaning many electric vehicles are indirectly powered by hydrocarbons. To ensure low-carbon electricity means greatly increasing the overall capacity of the electric grid with nuclear and other sources, because charging electric vehicles will add new demand to the already strained grid if the majority of vehicles in the United States switch to battery electric over gasoline. Battery-electric vehicles are also material-intensive, so while they do not produce carbon dioxide emissions while operating in the same way gasoline-powered vehicles do, they do have lifecycle emissions to factor in from the mining and manufacturing stage through retirement and disposal of waste.

Overall, the transportation sector has both overlapping and distinct decarbonization needs and strategies from other sectors. Unlike heat, there is no focus on high-intensity combustion, while using electric vehicles may require greater dependence on the electrical grid. Like other sectors, careful and precise cost and benefit analysis is essential for policymakers to undertake that includes broad and nuanced factors.

## Conclusion

Discussions of decarbonization strategies should clearly articulate the sector to which they apply. Next, the analysis should be broad enough to capture multiple scopes of emissions and understand the additional demand on the energy grid and what additional infrastructure will be needed. Often, the discussion around decarbonization defaults to the same solutions (very often "wind and solar") despite those not being applicable or most effective in certain sectors. By dividing decarbonization into sectors, we can best understand the options for what is feasible and economical.

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# Recommended Citation for this report

Dierker, B. (April, 2023). *Dividing Decarbonization by Sector: How Strategies for Decarbonizing Heat, Electricity, and Transportation Differ.* Alliance for Innovation and Infrastructure.

# About Aii

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