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EXPANDING THE REACH OF A CARBON TAX
EMISSIONS IMPACTS OF PRICING COMBINED WITH ADDITIONAL CLIMATE ACTIONS

BY JOHN LARSEN, NOAH KAUFMAN, PETER MARSTERS, WHITNEY HERNDON, HANNAH KOLUS, AND BEN KING

OCTOBER 2020

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Putting a price on carbon dioxide (CO_2) emissions can help governments reduce them rapidly and in a cost-effective manner. While 10 carbon tax bills have been proposed in the 116th US Congress, carbon prices alone are not enough to reach net-zero emissions by midcentury. Additional policies are needed to complement an economy-wide carbon tax and further cut CO_2 from the US energy system.

This study aims to provide a better understanding of such policy combinations. It projects the energy CO_2 emissions impacts of two carbon taxes, starting in 2021, that span the rates in the carbon tax bills in Congress. The "low" tax scenario starts at $30 per ton in 2021 and rises at 5 percent plus inflation per year, reaching $44 by 2030, while the "high" carbon tax starts at $15 per ton and rises $15 per year, reaching $150 by 2030. The paper then describes the barriers inhibiting emissions reductions beyond those achieved by the carbon taxes alone for each major sector: electricity, transportation, buildings, and industry. Finally, it explores the energy system changes needed to overcome those barriers and the policy interventions that could deliver those changes. For certain key energy system changes, it provides quantitative estimates of emissions reductions incremental to the two carbon taxes.

This paper is part of a joint effort by Columbia University's Center on Global Energy Policy (CGEP) and Rhodium Group to help policy makers and other stakeholders understand the important decisions associated with the design of carbon pricing policies and the implications of these decisions. The paper finds the emissions impacts of the low and high carbon taxes alone lead to economy-wide energy CO_2 emissions reductions by 2030 of 33 percent and 41 percent, respectively, below 2005 levels. A carbon tax combined with policy actions that support comprehensive, ambitious energy system changes could lead to emissions reductions in the range of 40 to 45 percent, arguably consistent with US midcentury deep decarbonization goals for the energy system.

In the 2020s, the bulk of these emissions reductions are likely to occur in the power sector, even under a broad decarbonization strategy, due to the significant barriers to large near-term emissions reductions in the transportation, buildings, and industrial sectors.

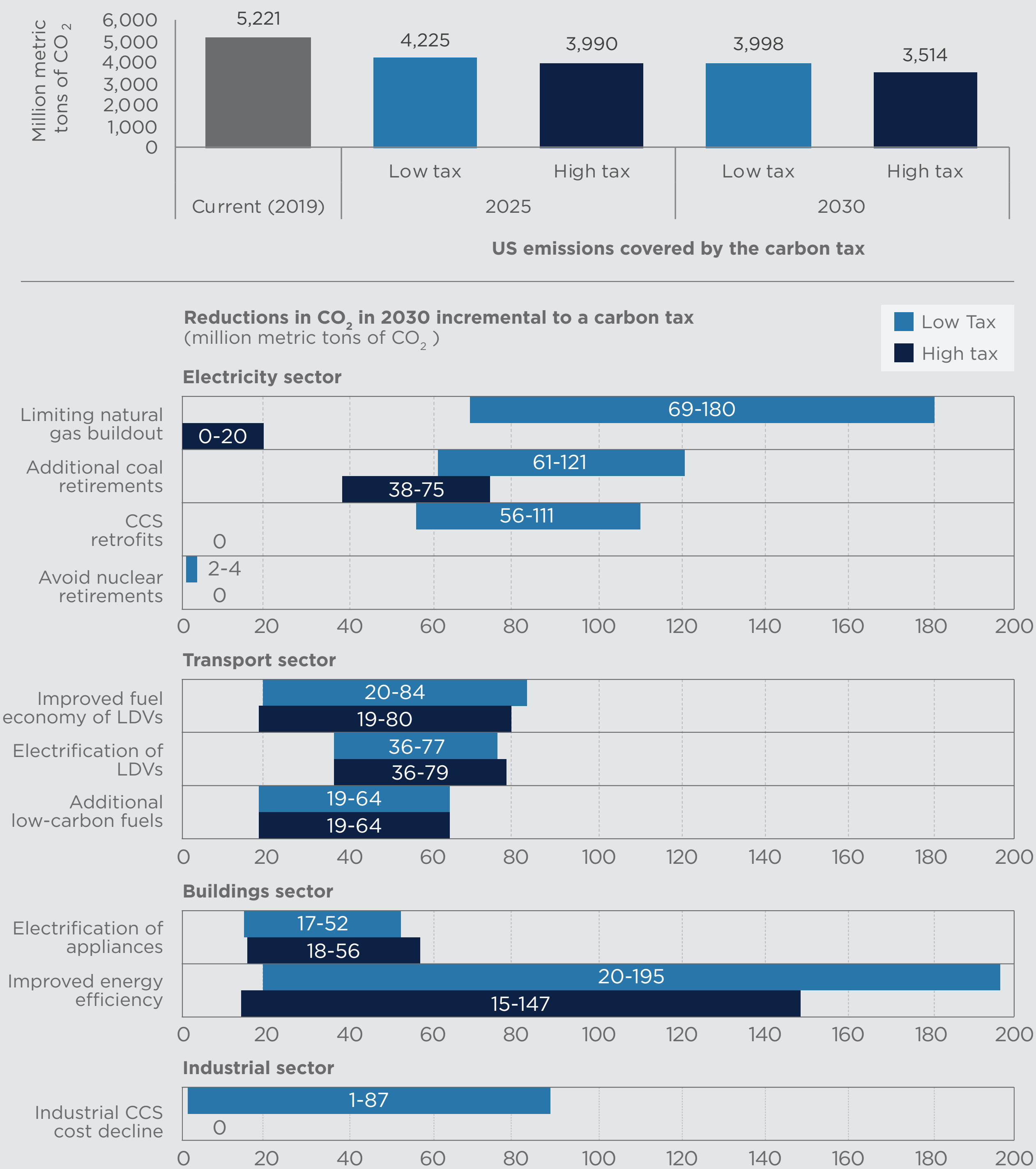
In addition, the paper finds:

- **Barriers to decarbonization prevent carbon prices from driving further reductions.** A carbon price works best when producers and consumers can see and respond to price signals and can easily shift to low-carbon alternatives. Three cross-cutting barriers to additional emissions reductions alongside a carbon tax are: (1) consumer behavior and preferences, (2) lack of substitutes, and (3) slow stock turnover.
- **Encouraging nationwide energy system changes can lead to additional CO_2 emissions reductions beyond the carbon tax in every major sector.** Among the most effective energy system changes at producing emissions reductions by 2030 are limits on new natural gas power plants and improved energy efficiency in buildings. Among

the least effective is additional support to prevent the retirement of existing nuclear plants, because a carbon tax alone is sufficient to keep the vast majority of plants competitive through at least 2030.

- **The carbon tax rates influence the effectiveness of additional energy system changes.** For changes that focus on electrification (e.g., electric vehicle deployments), additional emissions reductions are larger with higher carbon tax rates due to the lower carbon electricity system. For other energy system changes (e.g., limiting new natural gas power plants), emissions reductions are smaller with higher carbon tax rates because the carbon tax by itself achieves some of the same outcomes.
- **The emissions impacts of additional energy system changes are small relative to the impacts of the carbon tax alone.** In combination with market forces and policies already in place, the carbon taxes cause annual emissions to fall 1,223 to 1,707 million metric tons (MMT) between 2019 and 2030. The range of energy system changes explored in this analysis cause emissions to fall an additional 0 to 195 MMT. The small impacts are especially notable outside of the power sector, where carbon taxes and market forces also fail to drive significant emissions reductions by 2030.
- **For certain energy system changes, though, the small emissions reductions by 2030 mask large, longer-term changes that could significantly help the United States achieve its midcentury decarbonization goals.** For example, the analysis shows that a mandate for zero-emissions light duty vehicles of 50–70 percent of new sales by 2030 would only reduce emissions by 36–79 MMT in 2030, largely because only 2 percent of the vehicles on the road turn over each year. However, such mandates are consistent with pathways to achieve 100 percent zero-emissions vehicle sales by around 2040.

Figure ES-1: Summary of results



Source: Rhodium Group analysis
Note: Covered CO_2 emissions include energy CO_2 emissions and a subset of industrial nonenergy CO_2 emissions.

I. INTRODUCTION

Previous studies offer two robust conclusions about the impacts of carbon prices on carbon dioxide emissions in the United States. First, carbon prices are a critical piece of the puzzle: they can reduce emissions rapidly and cost-effectively, and they can serve as the cornerstone of a strategy to achieve domestic emissions targets. Second, carbon pricing policies are insufficient by themselves to reach net-zero emissions this century, a target all countries will need to achieve to stop global warming and avoid the most dangerous impacts of climate change.[1] This is unsurprising, as price signals alone cannot overcome the numerous behavioral and system barriers to emissions reductions, especially outside the power sector.

This raises a natural question: how can policymakers surround a carbon price with complementary policies that combine to create a comprehensive strategy to reduce CO_2 from the US energy system? Previous work has pointed to a framework that policymakers can use to qualitatively evaluate the compatibility of a carbon price and other policies.[2] But little has been done to quantify the impacts of interventions on top of a price on carbon.

This paper starts to fill that gap by combining empirical analyses of carbon prices and alternative interventions in the US energy system to enable a better understanding of where and how quickly emissions reductions can be achieved.

We begin by describing new research, using state-of-the-art modeling, on the impacts of two tax rates reflecting the lowest and highest ambition of the ten carbon pricing plans proposed in the 116th Congress. We review the emissions and energy system changes under each of the carbon tax rates and the drivers of those results.

Then, for each major energy sector, we describe the major barriers inhibiting additional emissions reductions beyond those achieved by the carbon taxes alone. We explore the energy system changes needed to overcome those barriers and policy interventions that have the potential to deliver those changes. For certain key energy system changes, we provide quantitative estimates of their potential to achieve emissions reductions in addition to the two carbon tax policies.

The importance of the impacts of energy system changes driven by complementary climate policies is heightened given the current economic and political environments in the United States. The COVID-19 crisis and associated economic fallout may lead to congressional attention in the near-term primarily on economic stimulus or infrastructure packages, which may include opportunities for clean energy measures. This study will help policymakers understand how such policies may fit into a more comprehensive climate policy strategy that will be needed to achieve any serious climate targets.

Our analysis focuses on emissions in the year 2030 for two reasons. First, the current crisis and expected economic fallout create massive uncertainty in near-term emissions and inhibit useful projections of emissions impacts in the early 2020s. Second, current energy system models have limited ability to project the distant future, including impacts beyond 2030. Still, policymakers must have a longer-term focus. Actions today can enable cheaper and easier emissions reductions in the post-2030 period. Therefore, we also describe whether our projections of the energy system in 2030 are consistent with progress toward longer-term goals.

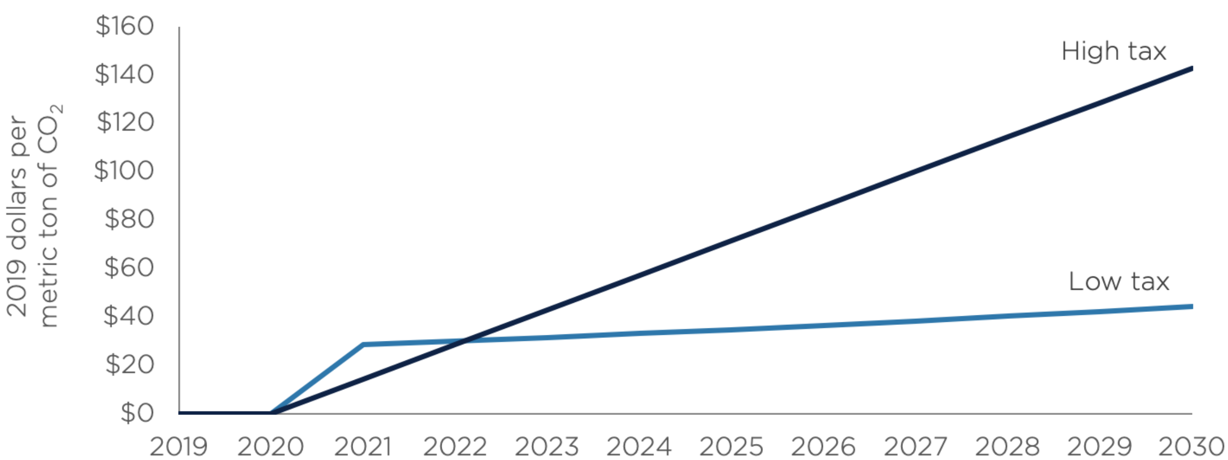
Of course, beyond just emissions, policymakers need to consider the full range of impacts of policy actions on the energy system, economy, public health and environment. Evaluating these additional impacts is beyond the scope of our study.

The Two Carbon Price Pathways

We analyze the energy system and emissions impacts of two carbon tax proposals put forward in the 116th Congress: the Stemming Warming and Augmenting Pay (SWAP) Act of 2019[3] introduced by Congressman Francis Rooney (R-FL) and the Climate Action and Rebate Act[4] introduced by Senator Chris Coons (D-DE). Both proposals establish a per-ton tax on greenhouse gases (GHG) from fossil fuel producers and certain other GHG emitters.

One key difference between the two proposals is the size of the tax. The SWAP Act sets an initial carbon tax rate at $30 per ton in 2021, rising at 5 percent plus inflation per year, whereas the Climate Action and Rebate Act sets an initial rate of $15 per ton in 2021, rising at $15 per year (Figure 1). These proposals represent the bounds of carbon tax rates considered by the 116th Congress; as such, throughout the rest of the paper we refer to them as the "low tax" and "high tax" cases, respectively.

Figure 1: Modeled carbon tax rates



Source: Rhodium Group analysis

Methodology

We use a modified version of the National Energy Modeling System (RHG-NEMS) constructed by the Energy Information Administration (EIA) and maintained by Rhodium Group to analyze the impacts of these carbon tax proposals on US energy CO_2 emissions.

We do not consider other greenhouse gases in this analysis. We assume the tax covers energy-related CO_2 emissions (as well as a small amount of emissions from the non-energy use of fossil fuels) but is not applied to any greenhouse gas emissions associated with fossil fuel extraction, such as methane leaks from oil and gas wells. We assume the taxes are implemented starting in 2021, which may be unrealistically soon, but we would not expect 2030 results to differ significantly with a slightly later implementation date (assuming tax rates increase to the same level by 2030).

As a starting point for our analysis, we use inputs from Rhodium Group's *Taking Stock 2019* report, which includes updated federal and state policies in place as of June 2019 (prior to the COVID-19 crisis). We consider the effects of the carbon tax proposals under the central fuel prices and low energy technology cost and performance assumptions from that report. Further detail on these inputs and assumptions is available in the Taking Stock technical appendix.[5]

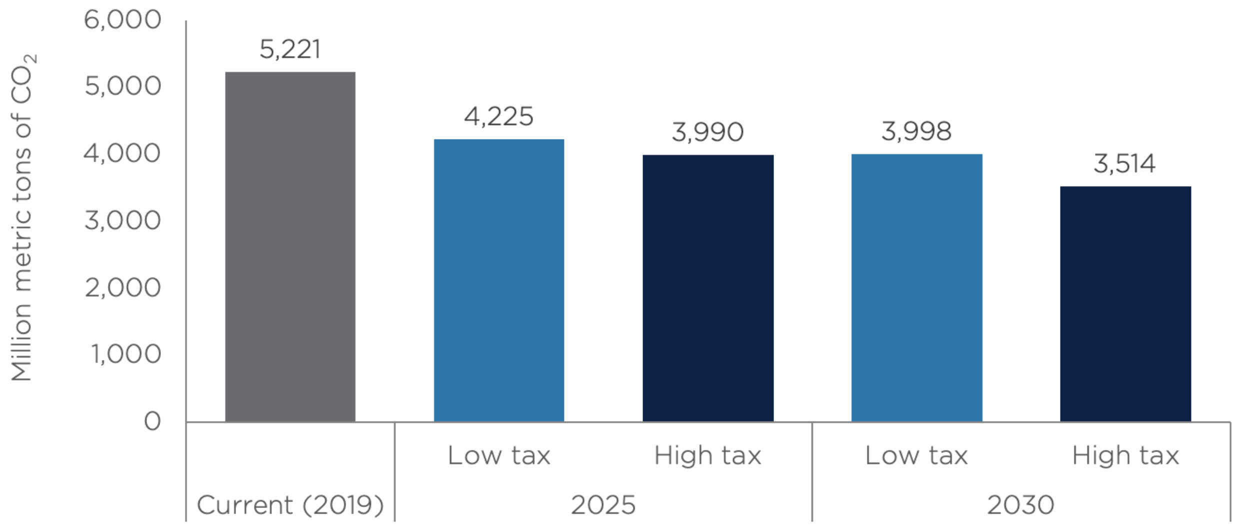
To analyze the impacts of further energy system changes beyond a carbon tax, we consider a range of magnitudes for each system change informed by third-party assessments of technical and economic potential for technology deployment. Where appropriate, we model these further energy systems changes in RHG-NEMS; in other cases, we quantitatively assess the impacts of these changes using alternative analytical approaches. This analysis explicitly represents specific changes in the energy system and is agnostic to the policy used to achieve such changes.

Note that we discuss supply-side impacts on the electricity sector in section III, and we discuss demand-side electricity sector interventions (like electrification and efficiency) and their associated emissions impacts in the context of each end-use sector. We do not consider an exhaustive list of energy system changes in each sector, but instead focus on a representative set of changes expected to yield meaningful carbon dioxide emissions reductions within the next decade.

II. ECONOMY-WIDE IMPACTS OF THE PROPOSALS

The low and high tax rates reduce economy-wide energy CO_2 emissions by 33 percent and 41 percent, respectively, below 2005 emissions levels in 2030.[6] Over the same time period, under the low tax, emissions fall about 2 percent per year on average, whereas emissions fall about 4 percent per year under the high tax—both in excess of the average decline of about 0.4 percent per year from 2010 through 2019.

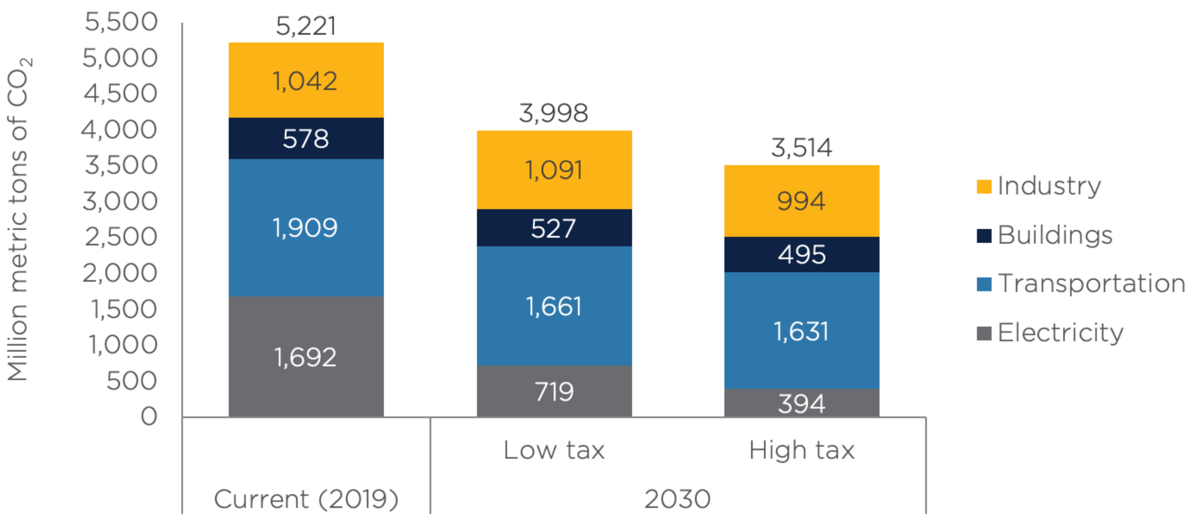
Figure 2: US economy-wide carbon dioxide emissions



Source: Rhodium Group analysis
Note: CO_2 emissions include energy CO_2 emissions and a subset of industrial nonenergy CO_2 emissions.

These reductions are not evenly distributed across all sectors. The power sector is the most impacted by the price signal, accounting for 80 percent and 76 percent of all emissions reductions in the low and high tax cases, respectively (Figure 3). This is in line with previous research done by Rhodium, CGEP, and others.[7] Transportation emissions and emissions from the direct use of fossil fuels in buildings and industry experience much more modest declines. We discuss the impacts of the carbon tax proposals on each sector in greater detail in the following sections.

Figure 3: Direct CO_2 emissions by sector



Source: Rhodium Group analysis
Note: CO_2 emissions include energy CO_2 emissions and a subset of industrial nonenergy CO_2 emissions.

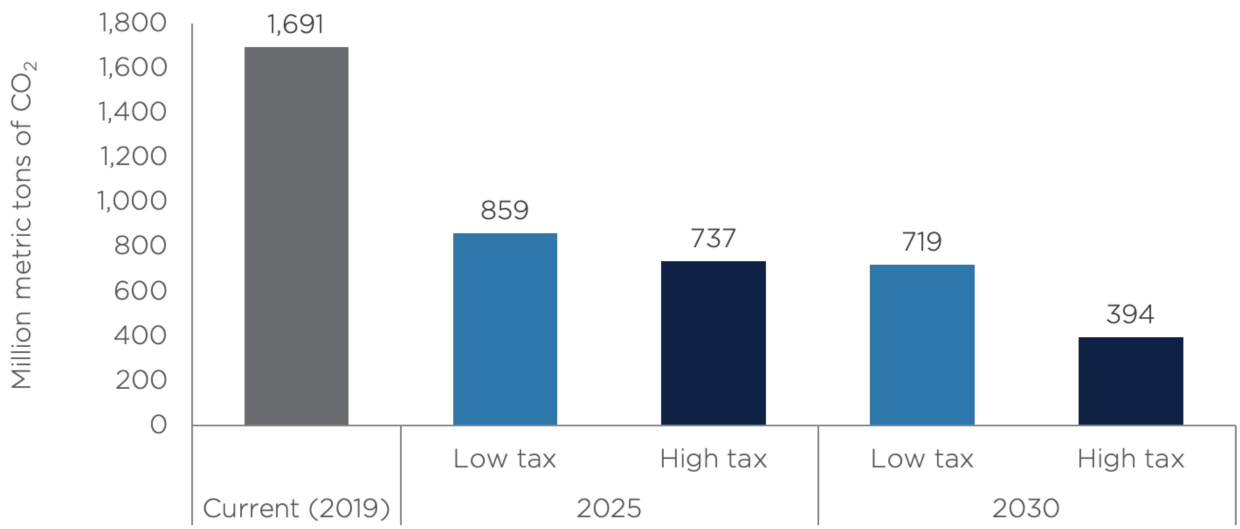
These carbon taxes alone are unlikely to produce emissions pathways in line with net-zero emissions targets by 2050, a common objective for policymakers focused on addressing the risks of climate change. Further progress toward this goal can be achieved through several different policy pathways. One option is to increase the tax levels beyond what is proposed in either of these bills. In theory, a high-enough carbon price would eventually drive emissions reductions in all sectors; however, political constraints may prevent high tax rates, and, for many emissions sources, a higher price signal may not be the most efficient way to overcome the barriers to emissions reductions. An alternative to higher tax rates is for policymakers to enact a suite of complementary policies to address barriers to faster energy system changes aligned with deeper decarbonization.

In the following sections we walk through the impacts of the two carbon taxes on each sector as modeled using RHG-NEMS. We then identify key barriers to decarbonization in each sector and outline energy system changes that can overcome these barriers. Finally, we discuss complementary policies that can potentially achieve those changes in the energy system.

III. ELECTRICITY SECTOR

Under the two carbon tax scenarios, electricity sector CO_2 emissions decrease rapidly by 2030 to 70 percent and 84 percent below 2005 levels. Still, in 2030, electricity sector emissions are between 394 and 719 million metric tons of CO_2 (Figure 4), which is roughly comparable to current direct emissions from the buildings sector.

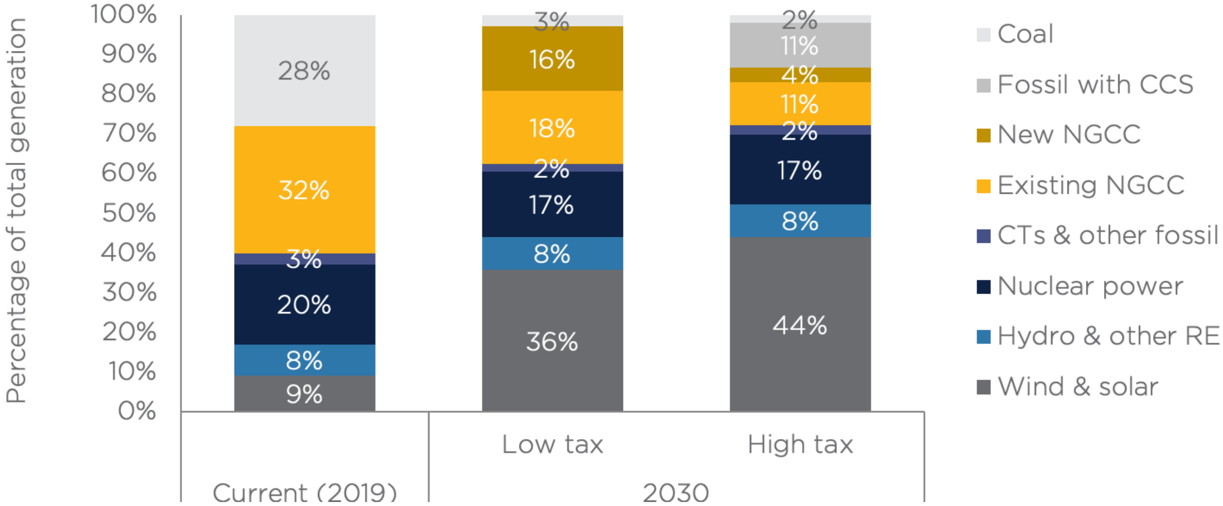
Figure 4: US electricity sector emissions



Source: Rhodium Group analysis

Figure 5 shows total US electricity generation by fuel and select technologies in 2030 under the two carbon tax scenarios. Under both scenarios, solar and wind energy grow to be major contributors to the US power system by 2030 and coal-fired electricity is reduced to very low levels. The major difference between the two scenarios is that a low tax scenario results in an additional 20 percent of generation coming from fossil generation without carbon capture and sequestration (CCS) compared to the high tax scenario.

Figure 5: Electricity by fuel source in 2030



Source: Rhodium Group analysis

Electricity Sector Barriers to Further Decarbonization

In the presence of a carbon tax, the barriers to emissions reductions are lower in the electricity sector than in any other. Electricity producers respond relatively rapidly to price signals and often have numerous available options to shift to less carbon intensive production. Nevertheless, barriers inhibit carbon taxes from driving even deeper reductions in emissions over the next decade, including:

- A lack of infrastructure and market rules to fully value and utilize demand flexibility and storage technologies
- High costs for early-stage zero-emission generating technologies such as 100 percent carbon capture fossil plants, next-generation nuclear, and offshore wind facilities
- Challenges with siting clean energy infrastructure, including generating facilities and long-distance high voltage transmission lines
- Preferences for status quo and familiar technologies among markets participants and operators, which may lead to continued usage and construction of fossil fuel generators when they are no longer the most cost-effective option
- Supply chain and manufacturing limits on the availability of components to meet aggressive clean energy technology projections
- Public opposition to certain carbon-free sources like nuclear power plants or CCS

Electricity Sector Changes and Emissions Impacts

Next, we analyze various potential changes to the US electricity system in the 2020s that could enable additional emissions reductions under the two carbon tax scenarios:[8] limiting the buildout of new uncontrolled natural gas power plants, retrofitting existing natural gas plants with CCS, retiring additional coal plants, and keeping existing nuclear plants online.

Limiting the Buildout of Natural Gas Combined Cycle Plants

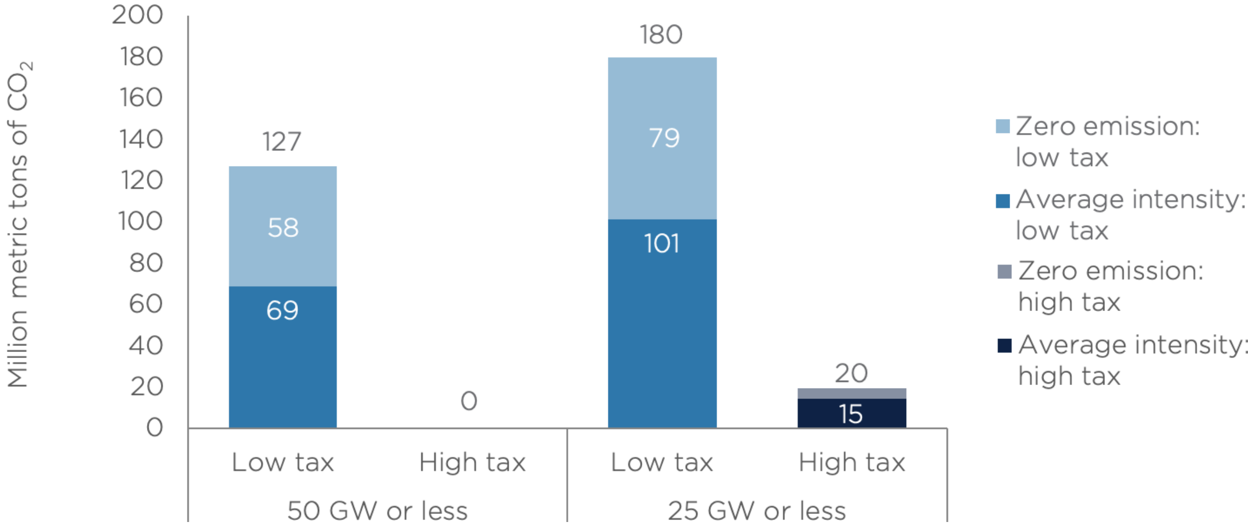
We examine the impacts of limiting the buildout of new uncontrolled (without CCS) natural gas power plants, specifically natural gas combined cycle (NGCC) plants, which provide the vast majority of electricity generation from new natural gas plants in the 2020s. Additions are less than half as large in the high tax scenario because the higher carbon tax rates make natural gas less competitive with alternative fuels and incentivizes significant amounts of carbon capture. In 2030, these new uncontrolled natural gas plants contribute 32 percent and 13 percent of total emissions in the electricity sector in the low and high tax scenarios, respectively.

We analyze limiting the cumulative build of new uncontrolled NGCC capacity in the 2020s to 50 GW and 25 GW. A 50 GW limit on new builds cuts the growth of NGCCs under the low carbon tax roughly in half, but it has no impact on the high tax case (because less than 50 GW are built in that scenario). A 25 GW limit on new builds represents a 77 percent decline in new NGCC capacity under the low tax case and a cut of more than a third under the high tax case.

The emissions impacts of these limits depend on the carbon intensity of the electricity generation that replaces the natural gas plants. We examine two assumptions: (1) replacement with generation that emits carbon dioxide at the fleet-wide average or (2) replacement with zero-carbon generation only.

Figure 6 shows the emissions impacts in 2030, incremental to those achieved with the carbon taxes, of limits on new NGCCs. Assuming the replacement generation is a combination of several technologies with the fleet-wide carbon intensity on average (the darker-colored bars), limits of 50 GW and 25 GW result in 69–101 MMT emissions reduction in the low tax case and a 0–15 MMT reduction in the high tax case in 2030. Replacing the new NGCC capacity with only zero-emitting resources yields further reductions (the lighter colored bars), up to 84 percent higher in the low tax scenario and 33 percent higher in the high tax scenario. This outcome would require additional new variable renewable generation, combined at least in part with batteries and other forms of storage. Deployment of early-stage technologies like the Allam cycle combustion turbine or other 100 percent capture natural gas plants or next-generation nuclear plants also have the potential to play a role, although the limited timeframe may constrain the role of these emerging technologies before 2030.

Figure 6: Limits on cumulative NGCC capacity; 2030 emissions reductions on top of two carbon tax scenarios



Source: Rhodium Group analysis

Increasing Natural Gas CCS Retrofits

A second change in the electricity system that could cut emissions under the carbon tax scenarios is additional retrofits of existing natural gas generation with CCS technologies.

Power sector CCS deployment is quite aggressive under the high carbon tax scenario, with 68 GW of new and retrofitted capacity in place by 2030.[9] The deployment pace between 2026 and 2030 is 12 GW per year, which is large for a technology that has only just begun to be deployed at scale today. Supply and labor constraints could hold back this rapid pace of deployment as could financing and infrastructure challenges. (Of course, another possibility is the technology does not improve as quickly as assumed in our modeling framework.) In contrast, virtually no plants undergo retrofits under the low tax scenario.

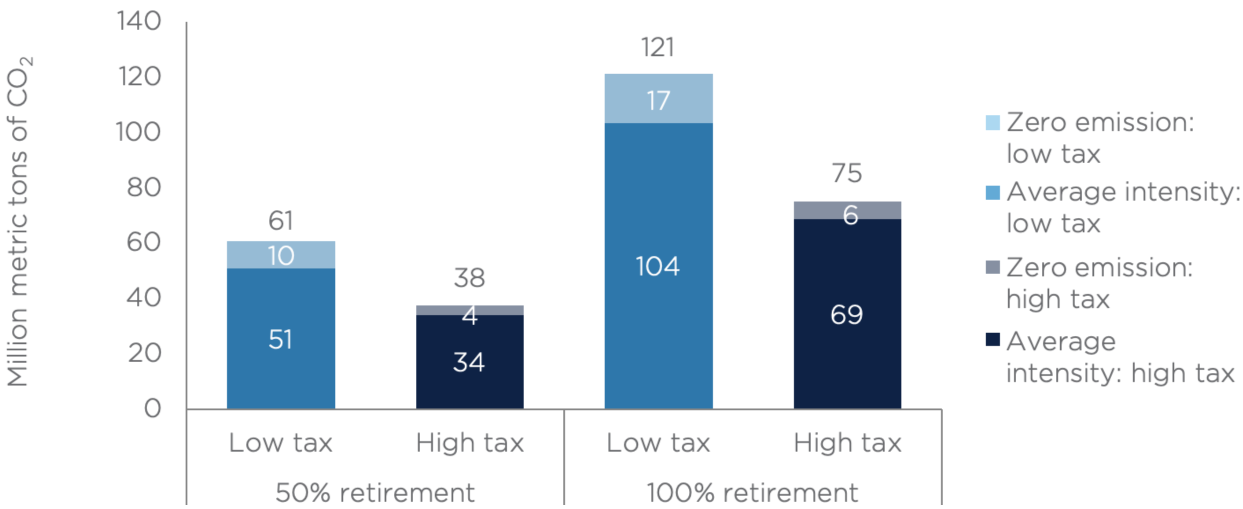
Assuming that deployment of CCS cannot be greater than what we find in our high tax scenario, then no CO_2 reductions can occur with this technology under a high tax. Using the high tax CCS deployment as guide for what maximum deployment might look like in the low tax scenario we consider two cases where 24 GW and 48 GW of existing NGCCs are retrofitted with CCS (i.e., achieving 50 percent and 100 percent of the high carbon tax retrofits). That would lead to an additional 111 million tons of emissions reductions in 2030 in the low tax scenario, assuming all retrofitted generation displaces uncontrolled conventional NGCC generation. Achieving 50 percent of the high tax-level retrofits could reduce emissions by 56 MMT in 2030.[10]

Retiring Additional Coal Power Plants

Another way to reduce carbon dioxide emissions from the power sector is to retire additional coal plants. Coal supplies just 2–3 percent of total generation in 2030 in both the high and low tax scenarios. Still, coal contributes 17–19 percent of emissions from the power sector in 2030 on account of the high carbon intensity of coal compared to all other generation options. We model two coal retirement cases: a low retirement case, in which 50 percent of coal plants slated to still be running in 2030 retire by that year, and a high retirement case, in which all remaining coal plants retire by 2030.

As with the avoided NGCC buildout, we consider the impacts of replacing this retired capacity with generators representing the remaining fleet-wide average carbon intensity as well as with zero emissions generation. Assuming fleet-wide average replacement, retiring 50 percent and 100 percent of remaining coal plans results in 51 MMT and 104 MMT in CO_2 reductions in the low tax scenario and 34 and 69 MMT in the high tax scenario (Figure 7) in 2030. If the coal capacity is replaced with zero-emitting generation, the 50 percent and 100 percent retirement cases yield a total of 61 MMT and 121 MMT of CO_2 reductions in the low carbon tax case and 38 and 75 MMT in the high tax case in 2030.

Figure 7: Additional coal retirements; 2030 emissions reductions compared to carbon tax scenarios



Source: Rhodium Group analysis

Keeping Existing Nuclear Plants Online

Finally, a fourth way to reduce emissions from existing generators under the carbon tax scenarios is to prevent the retirement of nuclear power plants. The fleet of nuclear power plants shrinks under both carbon tax scenarios due to planned retirements. Today, there is 98 GW of nuclear capacity in the US, but about 7.5 GW of that capacity is set to retire. A carbon tax makes zero-emitting nuclear generation more competitive in the electric system, such that only these 7.5 GW of planned retirements occur under the high tax scenario. Under the low tax scenario, an additional 3 GW of nuclear capacity retires due to power-sector economics.

If half or all of those economic retirements in the low tax scenario are instead kept online, the power sector would emit 2 to 4 MMT fewer carbon dioxide emissions in 2030, assuming the retiring capacity is replaced with fleet-wide average generators.

Electricity Sector Policy Discussion

Different policies have the potential to achieve the energy system changes analyzed above, and our analysis is agnostic to which policies are used.

Eliminating all remaining coal by 2030 is likely to require a federal mandate or fiscal incentives to accelerate retirements. A legislative phase out of coal could prohibit the operation of coal plants not equipped with CCS in 2030. Alternatively, Congress could put in place a program to incentivize coal plants to retire with payments or in the case of federally financed assets, loan forgiveness at levels high enough in conjunction with a carbon tax to make it economically attractive to do so. Finally, new air pollution regulations could impose additional costs on remaining coal plants beyond what's currently on the books leading to additional retirements.

These coal plants may be providing reliability services above and beyond the energy they produce, so any replacement generation will also need to provide these services. All necessary reliability services can be provided by non-coal generators and other technologies that can be deployed within this time frame. The coal that remains in our carbon tax scenarios is relatively new and may not be fully paid off or may be located at key balancing points on the grid. Even if this capacity runs infrequently, it can still be economic under a carbon tax in these special situations. A ten year phase out window provides more than enough time for utilities and regional transmission operators to implement mitigation measures to address any local reliability and balancing issues that may be identified.

Coal production is highly geographically concentrated in the United States, so policies would also be needed to support communities that are dependent on the industry for jobs and tax revenues.[11] Quantifying the scale of these policies is outside the scope of this analysis.

Air pollution regulations or fiscal incentives could be used to prevent the buildout of uncontrolled NGCC capacity and to accelerate CCS retrofits of existing plants. Section 111 of the Clean Air Act gives the Environmental Protection Agency (EPA) the authority to set new source performance standards (NSPS) that prevent the construction of new facilities that exceed emission rates associated with a best system of emission reduction. EPA could potentially set NSPS for new NGCCs at a level consistent with 90 percent CO_2 capture or perhaps even higher if it deems the costs to be reasonable and the technology adequately demonstrated.

EPA could also impose existing source performance standards on NGCC and coal plants requiring emissions reductions in line with installation of CCS technology. Where it's economic to do so, plants will retrofit, and, where it is not, plants will retire. Such regulations could potentially be pursued considering only control measures taken on-site at power plants. This "inside the fenceline" approach is in line with current regulations, though, again, EPA will need to determine that CCS retrofits are adequately demonstrated and of reasonable cost.

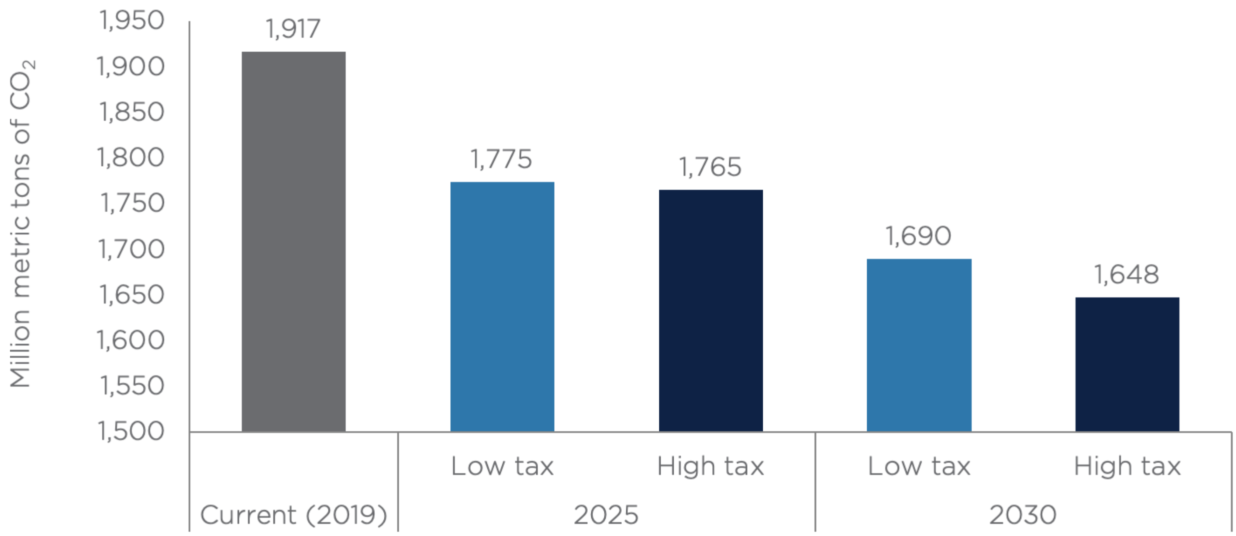
Our modeling finds that a carbon tax alone prevents most nuclear capacity from exiting electric power markets before 2030. Fiscal incentives have the potential to achieve the prevention of the small amount of remaining retirements considered above. Such incentives will need to be carefully targeted. A blanket incentive to the full nuclear fleet will provide support to all generators while only achieving modest additional emissions reductions. A reverse auction where generators compete for the least amount of subsidy needed to stay online or special incentives for the few remaining at-risk generators could be options.

Quantitative analyses of various other possible changes to the electricity system that could enable additional emissions reductions alongside the carbon tax include support for specific technologies, including long-distance transmission, energy storage, demand response, or specific renewables generation sources such as wind and solar energy. It could also include a broad-based mandate, like a clean electricity standard (CES), that could in theory be designed to require deeper emissions cuts from the power sector in the 2020s than either of our two carbon tax scenarios.

IV. TRANSPORTATION SECTOR

In the transportation sector, the marginal ability to shift demand to lower-carbon options is much more constrained than in the electric power sector. Because of this, our model shows a much smaller CO_2 emissions response to a carbon tax in the transportation sector. In the low tax scenario, 2030 emissions are 1,689 MMT, or 15 percent lower than 2005 levels, while emissions in the high tax scenario are 1,648 MMT, or 17 percent lower than 2005 levels, as shown in Figure 8.

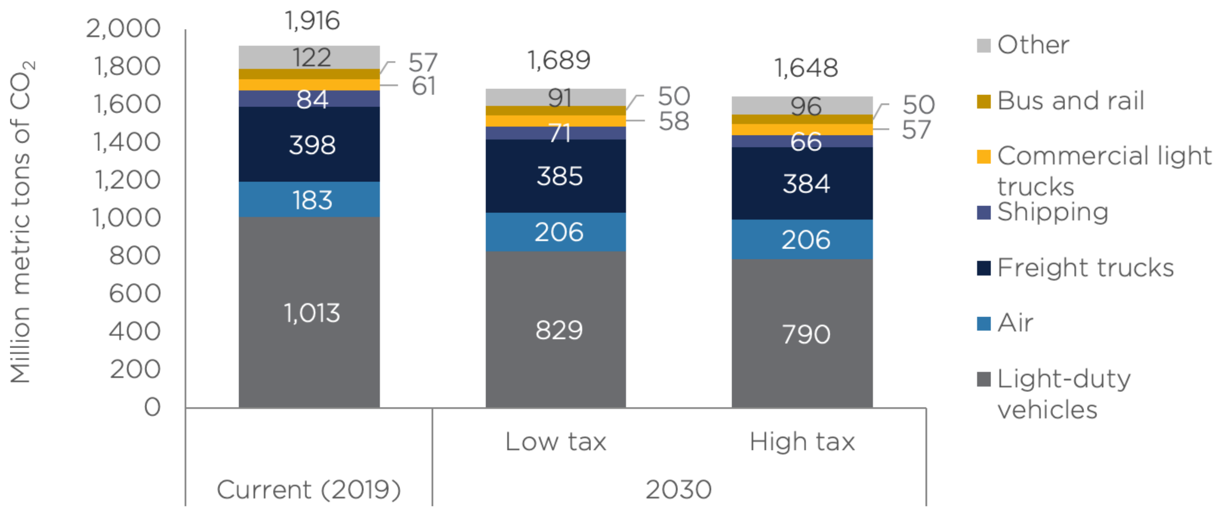
Figure 8: Transportation emissions



Source: Rhodium Group analysis

Emissions from light-duty vehicles (LDVs), which currently make up more than half of all transportation emissions, represent 81–83 percent of the reductions that occur in the sector in 2030 (Figure 9). Outside of LDVs, transportation service demand is relatively inelastic at the carbon tax levels considered in this analysis. In the high tax case, national average diesel fuel costs $4.80 per gallon in 2030, within the range of recent historical variability. This means freight demand and emissions don't change much in the presence of a tax. The same holds true for aviation.

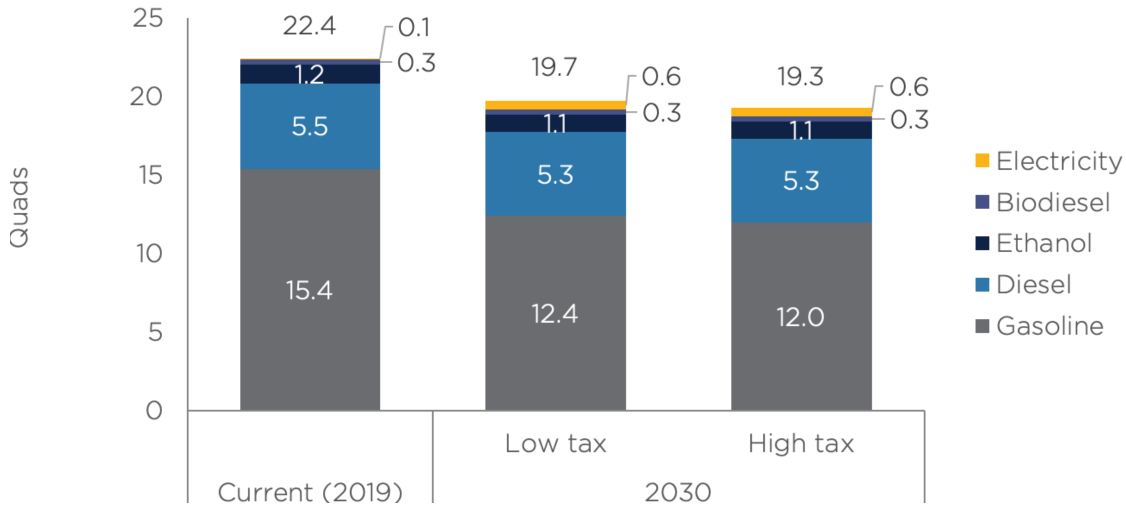
Figure 9: Transportation emissions by subsector



Source: Rhodium Group analysis

Carbon dioxide emissions from transportation on roads (versus air or sea) account for nearly 80 percent of all transportation emissions. We find that total on-road fuel consumption declines due to reductions in vehicle miles traveled (VMT), acceleration of electrification, and improvements in fuel economy driven by the carbon tax in combination with current policies and other trends (Figure 10). Gasoline consumption declines by 19–22 percent in 2030 compared to current 2019 levels, and increased electrification causes electricity to account for just under 3 percent of total on-road transportation energy use. Consumption of diesel, ethanol, and biodiesel remains effectively flat. Since LDVs make up nearly half of all transportation emissions in 2030 under a carbon tax, we focus on barriers to decarbonization for this subsector. Many of these barriers also apply to other transportation subsectors.

Figure 10: On-road fuel consumption, 2019 and 2030



Source: Rhodium Group analysis

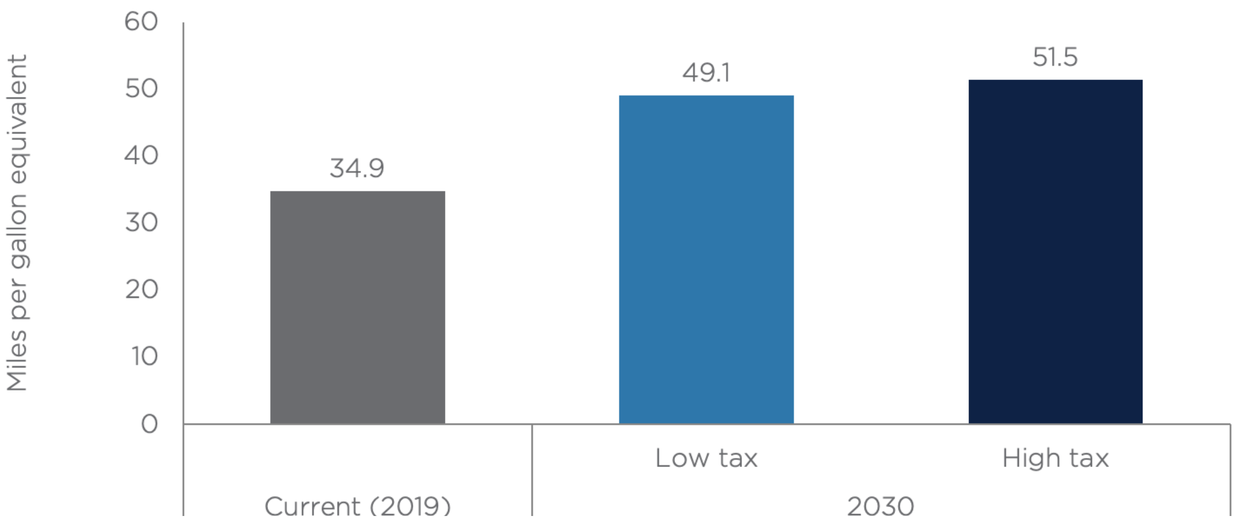
Transportation Sector Barriers to Further Decarbonization

There are several technological and structural barriers to faster decarbonization of emissions from on-road transportation.

Today, low-carbon vehicles and fuels typically cost more than their conventional counterparts. While electric vehicle (EV) models are proliferating in the marketplace, they currently make up 2 percent of all US vehicle sales. The retail price of a consumer model EV can be nearly double the price of a corresponding conventional fossil-fuel model.[12] Lack of consumer familiarity with EV technology and lack of infrastructure (which can contribute to concerns about the ability or speed of recharging EV batteries, or "range anxiety") are also barriers. This lack of familiarity may manifest in a lack of confidence among consumers in EVs compared to more familiar internal combustion engine vehicles. Some analysts project that EVs will decline in cost and become cost-competitive with conventional vehicles in the mid-2020s,[13] and our analysis incorporates projected cost reductions. Still, even with relatively low costs, EVs comprise 41 percent of LDV sales in our high carbon tax scenario in 2030.

The fleet-wide average fuel economy of new conventional internal combustion engine LDVs, which are still projected to be the market leader by sales in 2030, also improves modestly under a carbon tax (Figure 11). However, the costs to buy and operate a vehicle are only two of a wide range of factors buyers consider in their purchase decisions; buyers also consider other car features such as safety, utility, performance, and space.[14]

Figure 11: Average new LDV fuel economy



Source: Rhodium Group analysis

One way to achieve additional decarbonization in the transportation sector is for consumers to replace their current vehicles with new lower or zero-emitting models. The opportunity to shift to zero-emitting vehicles in any given year is small because roughly 2 percent of vehicles on the road are replaced each year. This slow stock turnover limits the opportunities for replacing conventional vehicles with low emitting alternatives. We find that consumers do, on average, choose slightly more efficient vehicles in the presence of carbon tax, but this shift is not transformational.

Technology exists to create low-carbon ethanol, biodiesel, and synthetic hydrocarbon "drop-in" fuels, which can be blended in unlimited amounts with conventional fuels using biomass inputs or a combination of zero-emitting energy, hydrogen, and captured CO_2 from point sources or the atmosphere. The latter class of fuels are sometimes called "electrofuels," as they can be produced using electricity. Regardless of feedstock or production process, drop-in fuels are largely not competitive with fossil fuels today and will need significant policy support to be cost-competitive by 2030.

The primary reasons for the high cost of alternative drop-in fuels are the immaturity of the technologies used to produce them and the low investment in industrial scale production. There are no industrial scale electrofuel facilities currently in operation in the US, no bio-based gasoline production facilities, and roughly 100 biodiesel production facilities.[15] The first few production facilities for any new technology will cost more than future facilities because of novel engineering requirements, unfamiliarity with the technology at scale, and higher financing costs due to technology risk. After the first few plants are built, experience gained from these capacity additions will lead to cost reductions.[16] Beyond early-stage costs, there will be capacity constraints in the first decade or so of deployment of any new fuel production technology as deployment scales up. Long-term cost projections are highly uncertain, but, assuming additional investments in these fuels reduces production costs over time, drop-in fuels have the potential to become competitive with fossil fuels in the coming decades, especially in a high carbon tax scenario.

There are also constraints on the supply of fuel feedstocks for low-carbon fuels. For electrofuels, the primary constraint is the availability of low-cost hydrogen produced with no associated CO_2 emissions. For biofuels, a primary constraint is the availability of sustainable biomass that has low or zero lifecycle carbon intensity.[17]

Additionally, US land-use patterns and transportation systems are largely set up to support personal vehicle travel over other modes. Even if people find that the cost of LDV travel is high under a carbon tax, mass-transit, bicycling, and walking may not be practical alternatives. People living in dense, urban centers may have access to such options, but people in suburban and rural communities with relatively long commutes often do not. Drivers may optimize their travel or reduce the amount of nonessential trips in response to a carbon tax, but we find such reductions in demand to be small: 1–4 percent lower at the tax levels considered in this analysis.

Transport Sector Changes and Emissions Impact

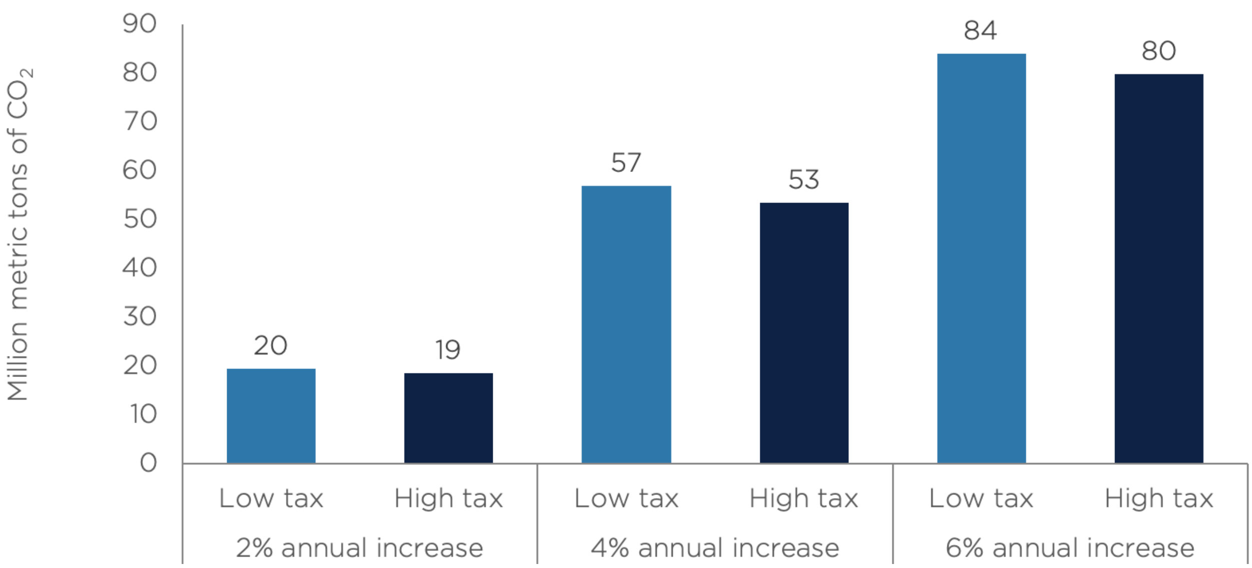
To quantify what additional emissions reductions could occur in on-road transportation alongside a carbon tax, we consider three system changes. First, we consider continuous annual improvement in the fleet-wide average fuel economy of new LDVs. Second, we consider additional annual zero-emission LDV sales above what occurs in the carbon tax scenarios. Third, we consider increased volumes of low-carbon fuel production as a replacement for conventional diesel. We assume these system changes begin in 2021.

Improvement in the Fleet-Wide Average Fuel Economy

We model the impact of increasing fuel economy at three annual improvement rates: 2 percent, 4 percent, and 6 percent per year. In all instances, improvement pathways are higher than what occurs in response to the carbon tax.[18] Annual improvement rates of current and historic US standards generally fall within this range: Obama-era Corporate Average Fuel Economy standards set a 5 percent annual improvement rate for model years 2021–2026, while the recently issued Safer Affordable Fuel-Efficient Vehicles Rule lowers the annual improvement rate to 1.5 percent for the same model years.[19]

We find that increasing the average fuel economy of new vehicles by 6 percent annually can lead to up to 84 million tons of additional CO_2 reductions beyond what a carbon tax delivers in 2030, or 5 percent lower total transportation emissions than with a carbon tax alone (Figure 12). A 2 percent annual improvement leads to 19–20 MMT of CO_2 reductions in 2030 or 1 percent lower total transportation emissions than with a carbon tax alone. Efficiency improvements are achieved through a mix of strategies, including reducing weight, turbocharging engines, high-performance transmissions, hybridization and electrification, as well as shifting sales shares from larger footprint vehicle models to smaller footprint models. By 2030, new LDV vehicles achieve up to 68 miles per gallon on average (Figure 13).

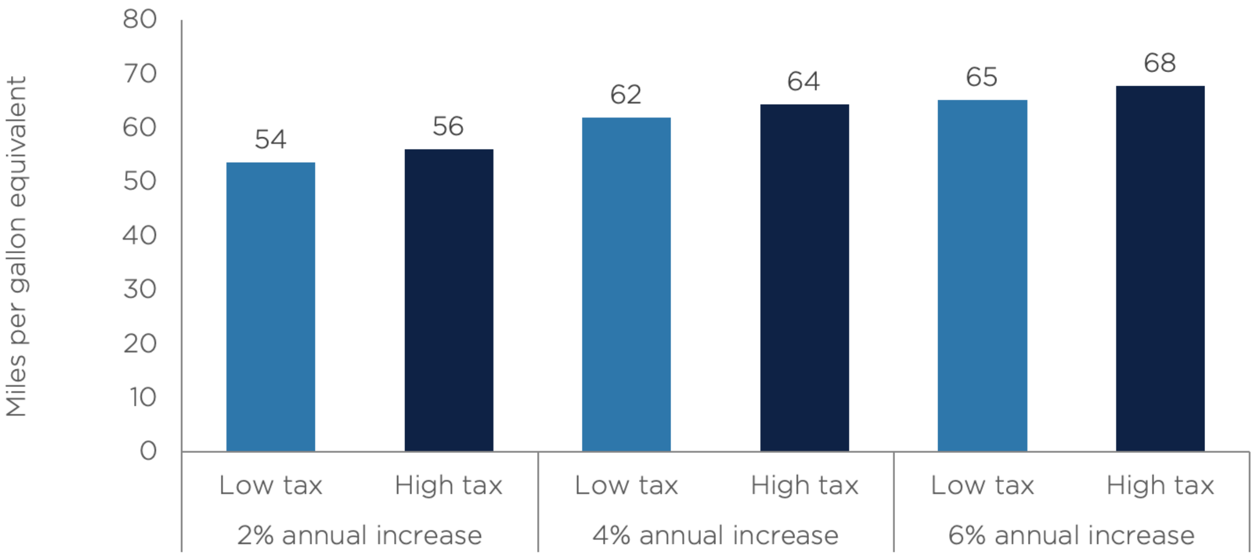
Figure 12: 2030 emissions reductions from increased fuel economy



Source: Rhodium Group analysis

Increasing fuel economy has roughly the same relative emissions benefit in both carbon tax scenarios, but the absolute reduction in tons is slightly lower in the high carbon tax scenario because there are fewer LDV emissions overall. This difference is because of two factors. First, LDV vehicle miles traveled is lower in the high carbon tax scenario in response to higher fuel prices. With fewer miles traveled, the emissions benefit of more efficient vehicles is slightly smaller. Second, the higher carbon tax drives some small vehicle efficiency gains on its own, reducing the incremental benefit of further improvements in efficiency.

Figure 13: 2030 average new LDV fuel economy



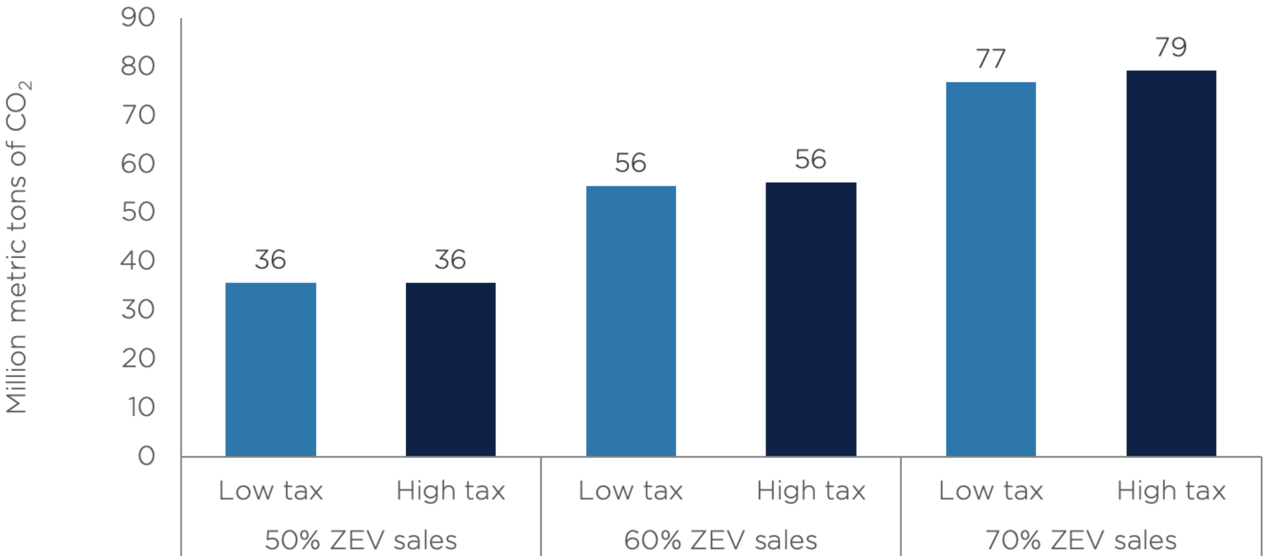
Source: Rhodium Group analysis

Additional Zero-Emission Vehicle Sales

Increasing the amount of ZEVs sold each year also causes additional reductions in CO_2 emissions beyond what a carbon tax alone achieves. ZEVs, including battery electric vehicles and plug-in hybrids, are more efficient than conventional vehicles and can run on electricity, and the electricity grid is rapidly decarbonizing under both carbon taxes.

To test the emissions impact of more ZEVs on the road, we increase ZEV sales shares linearly from 2021 levels to 50 percent, 60 percent and 70 percent of total LDV sales in 2030.[20] For comparison, ZEV sales reach 37 percent and 41 percent under the low and high tax scenarios alone. We find that increasing ZEV sales to 50 percent of LDV sales in 2030 causes an additional 36 million tons of CO_2 reductions, 2 percent lower than with a tax alone. Increasing sales to 70 percent more than doubles the benefit to 77–79 million tons, depending on the tax scenario, or 5 percent lower emissions than with a tax alone (Figure 14).

Figure 14: 2030 emissions reductions from electrification of vehicles



Source: Rhodium Group analysis

Emissions reductions attributable to increased ZEV sales are fairly similar in absolute terms between the two carbon tax scenarios because of three factors that run counter to each other. First, the high tax scenario leads to a lower-carbon electric grid compared to the low tax scenario. All else equal, that should cause the same amount of ZEV deployment to lead to additional emissions reductions in the high tax scenario. At the same time, there are more ZEV sales in the high carbon tax scenario before we consider the additional measures to encourage ZEVs, which reduces the incremental benefits of increased ZEV sales. In addition, just as with fuel economy, the low carbon tax scenario shows slightly higher vehicle miles traveled, so slightly more petroleum is displaced for every mile traveled in a ZEV.

Slow turnover of vehicle stock blunts the impact of changing the efficiency or electrification of new vehicles through 2030, but these energy systems changes in the 2020s will continue to accrue emissions reduction benefits through 2040 and beyond. For example, even if we assume electrification rates return to baseline growth rates after 2030, under our highest ZEV scenario, EVs more than double their share of the LDV fleet in the 2030s, comprising 22 percent of LDV stock in 2030 and 57 percent in 2040. Therefore, even if emissions reductions in the first decade are relatively small, these results demonstrate that near-term interventions can have substantial benefits in the longer term. This is worth keeping in mind when planning for long-term decarbonization of transportation by midcentury.

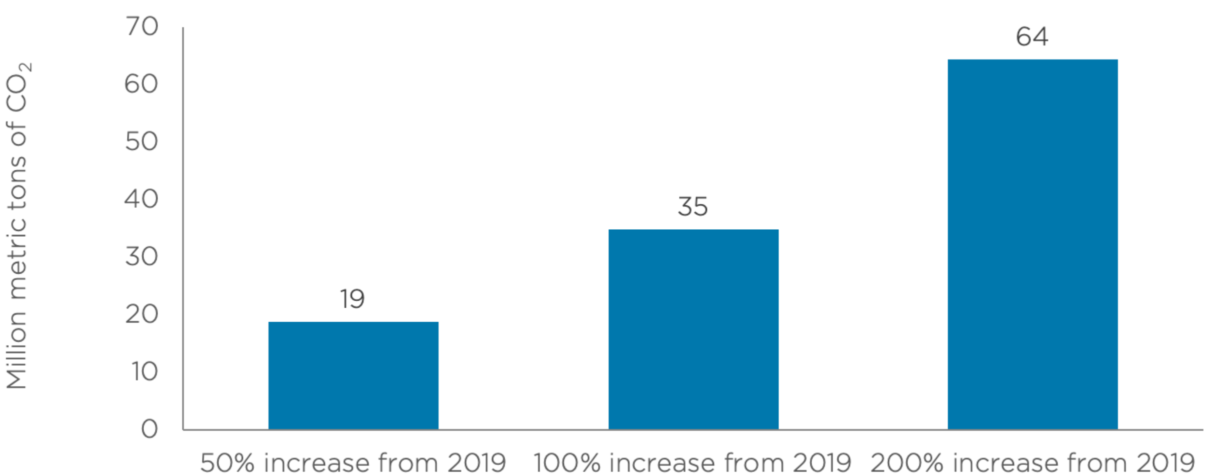
Scale-Up of Low-Carbon Drop-In Fuels

We assess the potential additional emissions reductions of increased consumption of low-carbon drop-in liquid fuels by considering three levels of increased fuel production by 2030.

We focus on replacing diesel fuel in this assessment for two reasons. First, diesel is more carbon intensive at the point of combustion on a per energy unit basis compared to other transportation fuels such as gasoline and jet fuel.[21] Second, low-carbon drop-in fuel production pathways for diesel exist today and are either in commercial production (for biodiesel) or demonstration phases (for electrofuels). For biodiesel, we assume production increases of 50 percent, 100 percent, and 200 percent relative to 2019 levels of 2.2 billion gallons. For electrofuel diesel, we assume the fuel is produced using CO_2 captured by direct air capture (DAC) technologies. We assume both biodiesel and electrofuel diesel come from the lowest possible lifecycle carbon intensity feedstock and production processes. Emissions reductions will be smaller if more carbon intensive pathways are pursued.[22]

We find the scale-up of drop-in fuels can achieve 19 to 64 million tons of additional reductions in 2030 beyond what a carbon tax will achieve alone (Figure 15). Since diesel demand is the same in both carbon tax scenarios, emissions reductions are the same for each scale-up scenario. Given that diesel is used by both LDVs and heavy duty vehicles, CO_2 emissions reductions occur in both end uses. Achieving any of these additional emissions reductions will require new investments in production capacity and, in the case of biodiesel, ready access to sustainable feedstocks. In the case of electrofuels, ready access to additional zero-emitting electricity, beyond what gets deployed under a carbon tax, will also be required. It is worth noting that emissions reductions are estimated on a lifecycle basis. This means that if consumption of these fuels were to increase, some reductions would occur at the point of combustion as fossil fuels are displaced. But some reductions would occur at the point of production of fossil fuels, in the exploration and refining subsectors of the energy system.

Figure 15: Emissions reductions from increased drop-in road transportation fuels for both carbon tax scenarios, 2030



Source: Rhodium Group analysis

While we do not consider the impacts of combinations of energy system changes on top of a carbon tax, the emissions reductions estimated from drop-in fuels have the potential to be largely additive to emissions reductions from the other transportation sector changes considered above. For example, if ZEV deployments only displace gasoline vehicles, then emissions reductions from drop-in diesel fuels would be entirely additive.

Looking past 2030, it is worth reiterating that access to low lifecycle CO_2 biomass feedstocks may limit biofuel production in the long run. Electrofuels are not subject to this constraint. Instead, the only constraints on electrofuels are access to water and affordable zero-emitting energy.[23] This suggests that emissions reductions from drop-in fuels could increase as scale-up constraints for electrofuels are overcome.

Transport Policy Discussion

There are a number of policy levers that could be considered to spur the deployment of more lower-carbon on-road vehicles and fuels. We consider policies in the following categories: mandatory requirements, retail cost and production incentives, infrastructure investments, and other mechanisms.

Mandatory Requirements

Existing examples of mandatory measures fall into two categories: fuel economy standards and sales mandates for vehicles or fuels. Federal fuel economy standards (and associated GHG emissions standards) set a corporate average fleet-wide performance requirement on all vehicles sold by car manufacturers in the United States. To achieve emissions reductions associated with the system changes presented above, Congress could mandate or executive agencies could revise existing rules to require annual increases in fuel economy. Current rules require a 1.5 mpg annual improvement through 2025. Meanwhile, recent congressional proposals have called for at least a 6 percent annual improvement for all years into the future.[24]

There is currently no federal ZEV sales requirement nor is there existing executive authority to implement one. A federal ZEV mandate will require an act of Congress. Several states have ZEV requirements that are consistent with California's regulations requiring 1.5 million ZEVs in that state by 2025. As discussed above, ZEV sales in our carbon tax runs incorporate low battery cost assumptions and achieve up to 41 percent of sales in 2030 under a high carbon tax. If a federal ZEV mandate were pursued, it may need to be set higher than 41 percent in 2030 to achieve any reductions beyond what a carbon tax alone will achieve.

In terms of fuel sales mandates, the federal Renewable Fuels Standard (RFS) already acts as a deployment incentive for specific biofuels but does not focus on drop-in fuel deployment, and electrofuels currently are not eligible under the standard. Another example of a fuel mandate is California's Low Carbon Fuel Standard (LCFS). The LCFS requires a steady reduction in road transport life cycle carbon intensity over time and allows electrofuels, drop-in biofuels, and conventional biofuels to contribute to compliance, depending on their carbon intensity relative to diesel or gasoline.

A federal clean fuels standard that works to credit a broad range of fuels could be pursued in a number of ways. Congress could pass legislation creating a new program or revise the RFS to incentivize fuels beyond what is currently covered in that program, or the EPA may have authority under section 211 of the Clean Air Act to regulate the carbon intensity of on-road fuels.

Retail Cost and Production Incentives

Policies can also directly target the relatively higher cost of lower-carbon vehicles and fuels on both consumer and producer sides. Retail cost incentives can be used to lower the cost of ZEVs and high efficiency vehicles with the goal of increasing deployment. An assessment of the incentive values needed to achieve the system changes discussed above is outside the scope of this analysis. Currently, the federal government provides a tax credit of up to $7,500 for the purchase of eligible electric vehicles with a cap of 200,000 vehicles per manufacturer. Increasing the cap and/or increasing the value of the credit can increase ZEV deployment.

Additional retail incentives to accelerate deployment of high efficiency and ZEV vehicles include feebates, where a tax is imposed on low efficiency or conventional vehicles and a tax credit is provided for high efficiency and ZEV vehicles. This approach reduces the cost of clean vehicles relative to conventional vehicles while also providing a revenue stream (from the fee) to pay for incentives.

Another possible retail incentive are tax credits for the purchase of eligible new vehicles in exchange for the trade-in of a low efficiency conventional vehicle. This “cash for clunkers” policy was used as part of a package of economic recovery efforts during the Great Recession.[25] A cash for clunkers policy that incentivizes ZEVs and high efficiency vehicles has the potential to accelerate deployment of such vehicles. It also has the potential to accelerate stock turnover because it provides an incentive for drivers to turn in their old vehicles.

Meanwhile, production incentives can be used to accelerate drop-in fuel deployment. First, incentives in the form of tax credits or other mechanisms can be used to subsidize the production and procurement of low lifecycle GHG feedstocks, such as waste biomass. Second, deployment grants, loan guarantees, or tax credits can be used to subsidize the construction of fuel production capacity. For example, an investment tax credit could be used to reduce the capital cost of building out production capacity to meet a given level of fuel deployment. Finally, incentives can be used to subsidize volumetric production of drop-in fuels. Tax credits already exist to support biofuel production, and they could be increased and expanded to incentivize any low-carbon fuel production.

Infrastructure Investment and Other Mechanisms

Investments in infrastructure can reduce CO_2 emissions from the transportation sector. There are two major approaches. One is to invest in alternative modes of transport and expand trip options. This reduces LDV VMT and emissions so long as the alternative modes, such as walking, biking, scooters, and transit, are lower emitting on a person-mile basis. The other approach is to invest in infrastructure to support a greater amount of new ZEV vehicles on the nation’s roadways. Investments in electricity distribution systems, home charging, public charging, and hydrogen fuel production and distribution have the potential to increase consumer adoption of these vehicles.

Information-sharing is another mechanism that can facilitate the system changes described above. Currently, all new vehicles sold in the US have a label displaying average annual relative GHG emissions intensity and five-year savings or costs relative to an average vehicle.[26] Under a future carbon tax, these labels could incorporate the costs associated with CO_2 emissions. Additional information could potentially increase consumer purchases of ZEVs and high efficiency vehicles. For example, widespread public information on public charging locations may reduce range anxiety. Information on operating costs for ZEVs that charge in non-peak hours may also inform consumers of lower costs of ownership beyond what is currently captured in labeling programs.

Finally, charging drivers for other externalities beyond CO_2 emissions can reduce LDV VMT and emissions. For example, charging for congestion associated with traveling during peak times and in congested zones can reduce trips and incentivize mode shifting.[27] Such a charge would reduce emissions across the LDV fleet through reduced transportation demand and may incentivize the types of system changes we consider in this analysis. For example, if congestion charge rates were reduced or waived for high efficiency vehicles or ZEVs (similar to high occupancy lane access privileges available to ZEV drivers in some states), that could accelerate deployment of such vehicles.

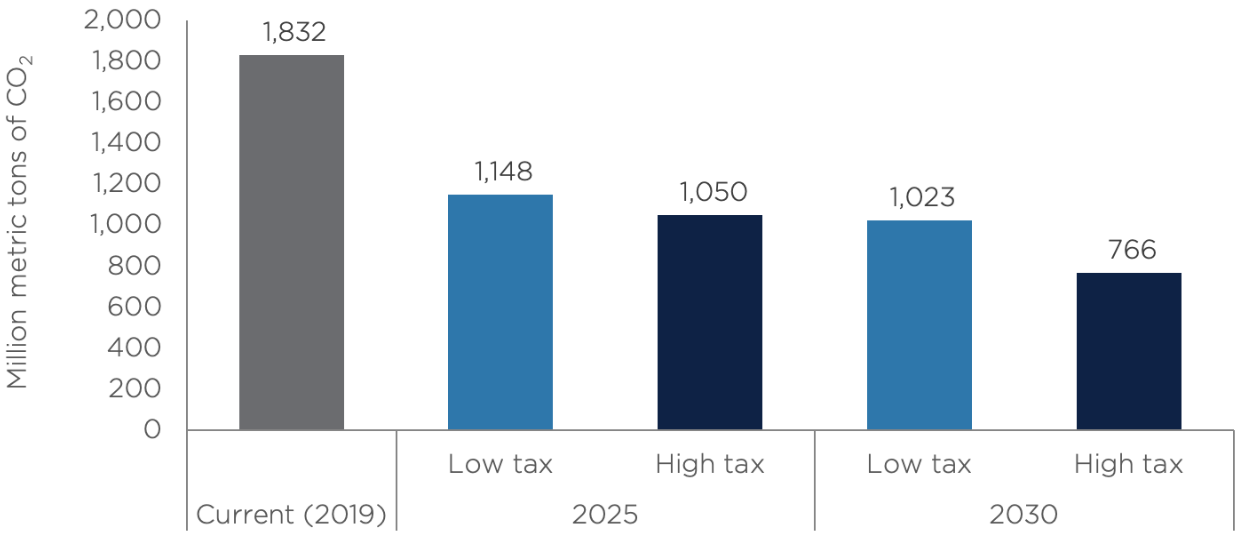
V. BUILDINGS SECTOR

The impacts of carbon taxes on emissions in the residential and commercial buildings sector are larger than the impacts in the transportation sector, though this result is largely driven by a cleaner electricity sector.

Overall, emissions from the use of energy in buildings in 2030, both from direct combustion of fossil fuels and emissions associated with electricity consumption, declines to 1,023 MMT of CO_2 in the low tax case and 766 MMT in the high tax case—representing a 56 percent and 67 percent decline in building emissions compared to 2005 (Figure 16).

Compared to 2019 levels, energy use in buildings declines by 10–12 percent through 2030, while total residential and commercial square footage both increase by 11 percent over the same time period. These results reflect consumer reactions to the price increases caused by the carbon taxes as well as adoption of more efficient technologies.

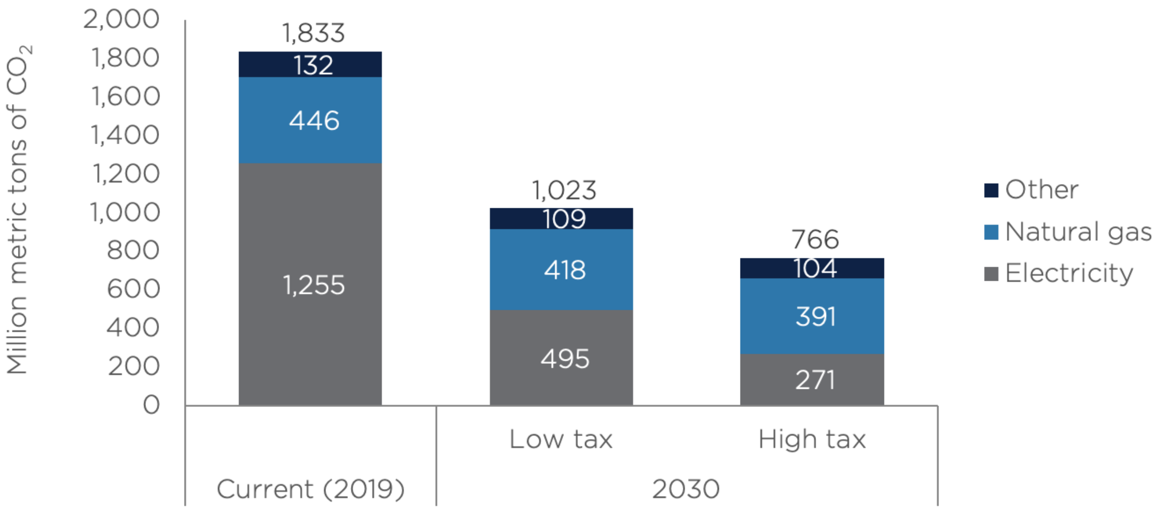
Figure 16: Building emissions



Source: Rhodium Group analysis

Under both the low and high tax rates, more than 90 percent of the change in building emissions comes from reduced emissions from electricity (Figure 17). While electricity consumption declines very slightly, the cleaner grid caused by the carbon taxes is the primary cause of emissions reductions. Meanwhile, demand for natural gas for direct use in buildings declines by 8 percent and 12 percent from 2019 through 2030 under the low and high tax cases, respectively.

Figure 17: Building emissions by fuel type



Source: Rhodium Group analysis

There are two main pathways to achieve greater levels of decarbonization in the buildings sector. First, by improving energy efficiency: for example, by installing more efficient heating, ventilation, and air conditioning (HVAC) systems, water heaters, and appliances; by tightening the building envelope through greater use of insulation and more efficient windows and doors; and by using smart thermostats, energy management systems, and other connected devices to optimize energy use.

Second, decarbonization can be achieved by switching to lower-carbon fuels. One promising pathway for this switch in the next decade is electrifying end uses that currently rely on natural gas, heating oil, or propane, such as water heaters and furnaces.[28] Under the two carbon tax scenarios, electricity is much less carbon intensive on a total energy basis than natural gas and petroleum. Moreover, most electrified end uses are more efficient than the fossil fuel-fired alternatives, yielding lower overall energy demand for the same level of service demand. Switching to drop-in fuels, such as renewable natural gas, is another possible pathway to lower-carbon fuels in buildings.

Buildings Sector Barriers to Further Decarbonization

Several types of barriers impede deeper levels of decarbonization in the buildings sector, including the speed of replacing the building stock and its components, the capital cost of lower-carbon options, and split incentives and other behavioral barriers.

Stock Turnover

As is the case in the transportation sector, buildings and their major energy-consuming equipment have long lifetimes, leading to slow stock turnover rates. The most effective time to opt for efficiency and electrification measures is often during the construction of new homes and buildings. However, more than half of American homes are at least 40 years old, as are 45 percent of commercial buildings.[29] Moreover, half of all home heating equipment is at least 10 years old,[30] while commercial boilers last an average of 25 years.[31] Even when efficiency or electrification measures are cost-competitive with existing technologies, it takes a long time for the less carbon intensive technologies to proliferate across the building stock because there are few opportunities for replacement each year.

Capital Cost of Alternatives

Upgrading to more efficient appliances or installing new electric equipment can be expensive. Though the total lifetime cost of ownership of the less carbon intensive equipment may be lower, homeowners and building owners may not have ready access to the additional capital necessary for the lower-carbon intensive options, or they may undervalue future energy savings in favor of spending less up front. Homeowners and building owners may also simply lack information about lower-carbon options. Switching from fossil fuels to electricity may require more time, planning, and coordination with multiple contractors compared to simply replacing broken equipment with incumbent fuel technology.

Split Incentives and Other Behavioral Barriers

If the building is not occupied by its owner, there may be a split incentive problem in which building owners do not want to pay for efficiency or electrification upgrades because they do not see the benefits of such an expense in the form of lower utility bills paid by renters.

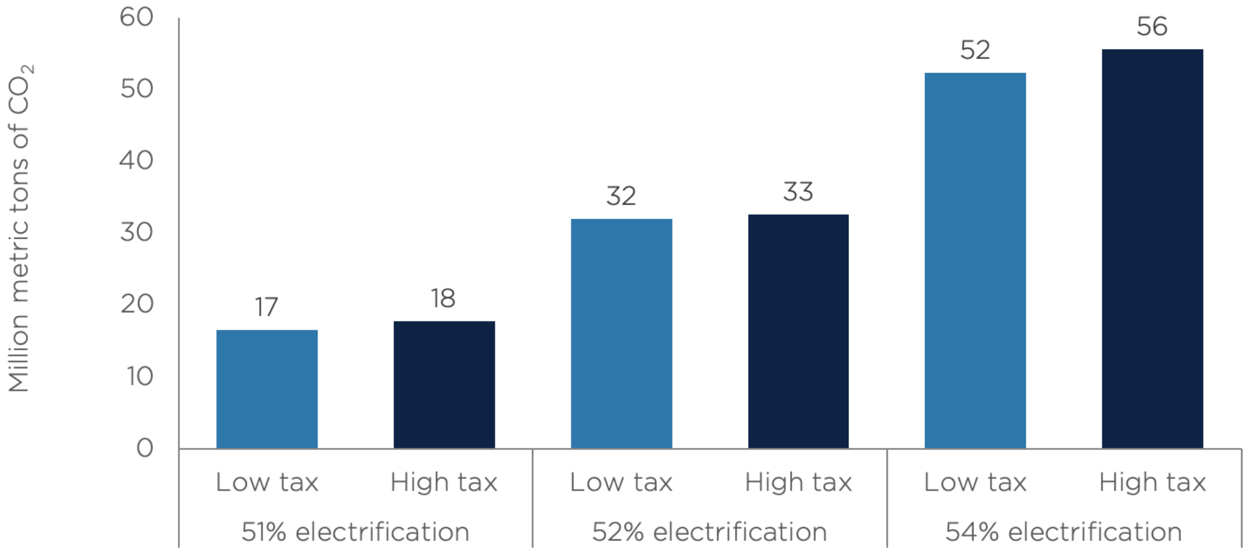
Buildings Sector Changes and Emissions Impacts

We analyze the impacts of two energy systems changes beyond the application of a carbon tax to demonstrate the potential for further decarbonization in the buildings sector. First, we consider several levels of electrification of building end uses compared to what occurs under the carbon tax scenarios, then we examine achieving deeper efficiency gains in the buildings sector.

Electricity represents 49 percent and 50 percent of building energy use in 2030 under the low and high tax cases, respectively—up from 47 percent of building energy use today. To consider further advances in electrification, we model the effects of achieving 51 percent, 52 percent, and 54 percent electrification rates in 2030. These levels are derived from the National Renewable Energy Laboratory's Electrification Futures Study (EFS) and represent the medium and high electrification scenarios in 2030 (in the case of the 51 percent and 52 percent cases), plus a three-year acceleration of the high electrification scenario (in the 54 percent case).[32] The medium EFS scenario represents electrification among the most cost-effective opportunities, while the high EFS scenario represents a "transformational change" to the energy sector from additional technology improvements, policy supports, and consumer uptake.

We find that the electrification of building energy uses contribute emissions reductions of 17 MMT to 56 MMT beyond what the carbon taxes deliver on their own in 2030 (Figure 18). These reductions are driven chiefly by lower levels of on-site natural gas and, to a lesser extent, petroleum demand and the greater levels of efficiency of electrified substitutes. Because of this improved efficiency, there are modest increases in electricity demand in each scenario, which mute the difference in carbon intensity between the two carbon tax cases.

Figure 18: 2030 emissions changes from increased building electrification



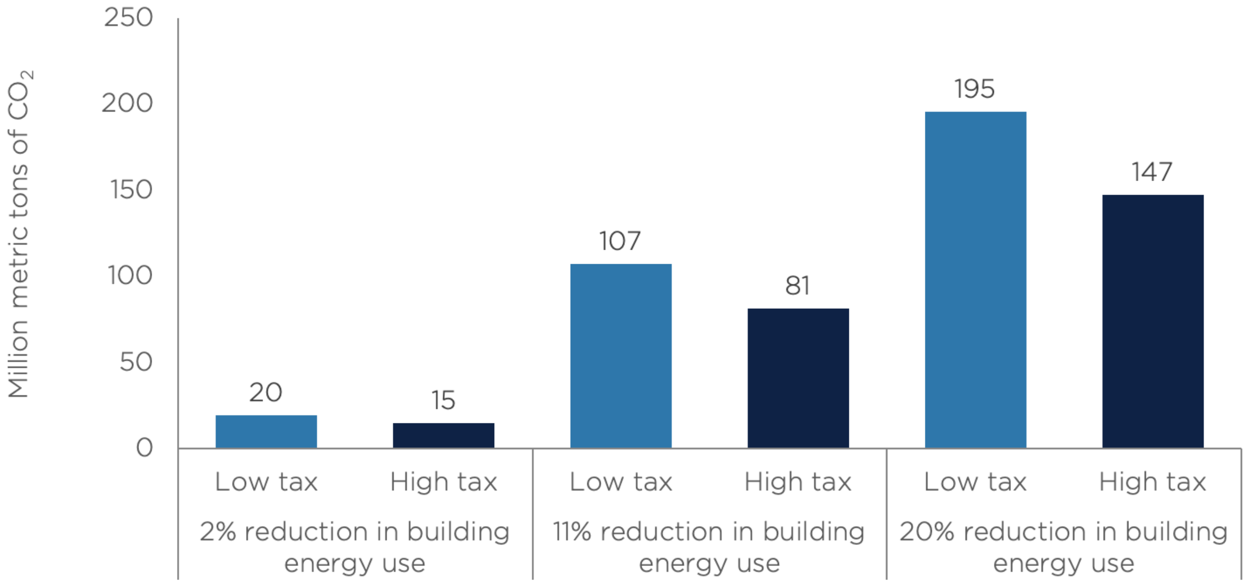
Source: Rhodium Group analysis

In the EFS scenarios, sales of new appliances are increasingly electric by 2030: residential space heater sales are 61 percent electric (up more than a third from 46 percent in 2019), residential water heater sales are 44 percent electric (up from 36 percent in 2019), and commercial space heating sales are 38 percent electric (nearly double the 21 percent rate in 2019).[33] Despite these large changes in sales, the electrification rate is only slightly higher in 2030 because of slow stock turnover. However, over a longer time horizon, these higher sales rates of electric technologies, combined with a further decarbonized grid, will drive greater levels of emissions reductions.

Turning to improvements in the energy efficiency of the building stock, we model three efficiency scenarios that result in a 2 percent, 11 percent, and 20 percent reduction in total building energy use in 2030. The 2 percent scenario represents a plausible lower bound of additional efficiency improvements achievable through 2030 without substantial additional policy interventions, while the 20 percent scenario is roughly equivalent to national achievement of the most aggressive state efficiency goals.[34,35] The 11 percent scenario provides a midpoint between these two scenarios. We assume these efficiency improvements accrue chiefly in reduced electricity use, though we include some efficiency improvements in natural gas as well.

We find up to an additional 195 MMT of CO_2 in 2030 can be reduced by increasing energy efficiency beyond what occurs as a result of the carbon tax (Figure 19). Just over 45 percent of these reductions occur from reduced on-site natural gas use; the remaining 55 percent of reductions come from reduced power sector emissions. The magnitude of the emissions reductions is greater in the low tax case because of the relatively more carbon intensive electricity grid.

Figure 19: 2030 emissions changes from increased building efficiency



Source: Rhodium Group analysis

Buildings Sector Policy Discussion

There is a range of building decarbonization policies that can help achieve the electrification and efficiency system changes discussed above. These policies can be classified under the following general approaches: regulatory policy, fiscal incentives and other government spending, as well as labeling and disclosure.

Historically, two of the most impactful policies in reducing emissions in the buildings sector have been regulatory policy approaches: minimum equipment performance standards (frequently called appliance standards) and building energy codes. Appliance standards are requirements that certain equipment meet minimum efficiency levels to be sold in the United States. Congress could act to expand the breadth of equipment covered under these standards, and the Department of Energy could pursue more aggressive energy savings through this program.

Whereas appliance standards set efficiency levels for individual pieces of equipment, building energy codes establish minimum efficiency requirements for the building itself, and can be prescriptive (e.g., stipulating what type of insulation or windows to install) or performance-based (e.g., stipulating a maximum allowable level of energy use for the building).[36] To achieve deeper decarbonization, building codes could pursue a path of net-zero energy or net-zero emissions buildings.[37] Extending the notion of building codes even further, some localities are also banning the use of fossil fuels in new homes and buildings.[38]

The policies discussed above address new appliances and buildings. Regulatory policy can also address emissions from the buildings sector as a whole. Today, 22 states have some form of energy efficiency standard or target, which typically requires a regulated entity like a utility to achieve some level of reduction in retail energy sales.[39]

Fiscal incentives can also help advance building decarbonization by mitigating the monetary barriers to deployment of the low-carbon building solutions discussed above. Such incentives can take the form of tax credits and deductions to home and building owners for installing electrified or more efficient equipment and building materials. To contend with slow stock turnover, the federal government could offer grants or tax incentives for retiring older, more emitting equipment and replacing it with new, less carbon intensive versions—a "Cash for Clunkers" for the buildings sector, as was tried during the American Reinvestment and Recovery Act of 2009.[40] Direct federal spending can also bolster decarbonization through grants to the municipal, university, schools, and hospitals (MUSH) buildings market, increased federal funding for low-income weatherization programs, and federal spending, including on the provision of concessionary finance mechanisms, for public housing.

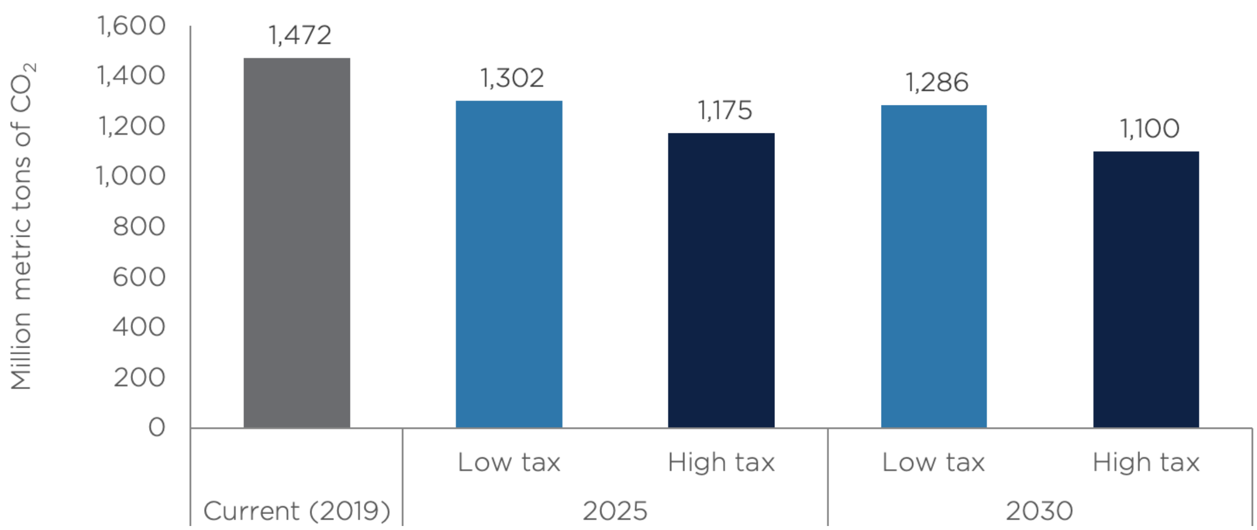
A third category of building decarbonization policy is labeling and disclosure. These policies seek to mitigate the information barriers to the adoption of electrified and more efficient technologies. Several dozen cities across the country require owners and operators of some or all commercial buildings to measure (or benchmark) their buildings' energy use; some of these cities also require the public disclosure of that data.[41] The European Union has similarly required building labeling for residential buildings.[42] These data can help buyers or tenants choose buildings that will have lower energy bills and may also "name and shame" poor performing buildings. For appliances, the EPA's "ENERGY STAR" has been successful in promoting adoption of more efficient equipment, and it could be expanded to cover more products, to achieve deeper energy reductions for covered products, and to put an emphasis on emissions reductions as opposed to energy savings.[43]

VI. INDUSTRIAL SECTOR

While the industrial sector as a whole is composed of vastly different manufacturing processes, methods, and firms, these sub-sectors can be linked by several key themes: firms in the sector are large energy users, very sensitive to prices and business cycles, and usually have equipment and plants that last multiple decades.[44] The largest industrial emitters include refining, chemicals, cement and lime, aluminum, glass, iron and steel, and pulp and paper. Industry is among the toughest sectors to decarbonize, in part because of the high temperature heat needed to produce many goods.

We find that by 2030, industrial emissions fall to 1,286 MMT in the low tax scenario and 1,100 MMT in the high tax scenario (Figure 20), declining to 76 percent and 65 percent of 2005 levels. Much of this decline is a result of a cleaner electricity system (81 percent and 69 percent in the low and high tax cases). We also project 31 MMT and 118 MMT of CO_2 being captured through industrial CCS facilities in 2030. There are only modest declines in petroleum and coal use in 2030, and natural gas use increases in both tax scenarios through 2030.

Figure 20: Industrial emissions



Source: Rhodium Group analysis

Industrial Sector Barriers to Further Decarbonization

The following are barriers to greater emissions reductions in the industrial sector under a carbon tax, several of which are similar to the barriers in other sectors.

- *Lack of substitution options.* The industrial sector lacks commercially available, cost-effective options to switch to lower-carbon fuels. Many industrial processes require high temperatures that fossil fuels are currently best-suited to provide. In addition, in some cases, the fossil fuels themselves serve as the feedstock for the manufacture of industrial goods.

- *Energy efficiency rebound effects.* While there may be large potential for the industrial sector to become more energy efficient, some of the benefits (from an emissions perspective) will be outweighed by increased production due to the energy savings. This "rebound effect" can be observed in empirical studies.[45]
- *Behavioral momentum.* In a space as competitive as the industrial sector, plant managers and operators are reluctant to try low-carbon alternatives. This could be due to high internal hurdle rates for efficiency measures or aversion to implementing risky new processes. Even a high carbon tax rate may not make it worthwhile for plant owners to take on such risks.
- *Long stock turnover times.* Finally, stock turnover times can be particularly long in the industrial sector. Steel plants, for example, can last up to 100 years, and have extremely high upfront capital costs. Without outside capital, it is very unlikely that they would switch to a lower-carbon production method under a tax regime. The operational price increases resulting from the carbon tax do not outweigh the capital costs of switching to a cleaner production method such as making steel using an electric arc furnace with direct reduced iron.[46]

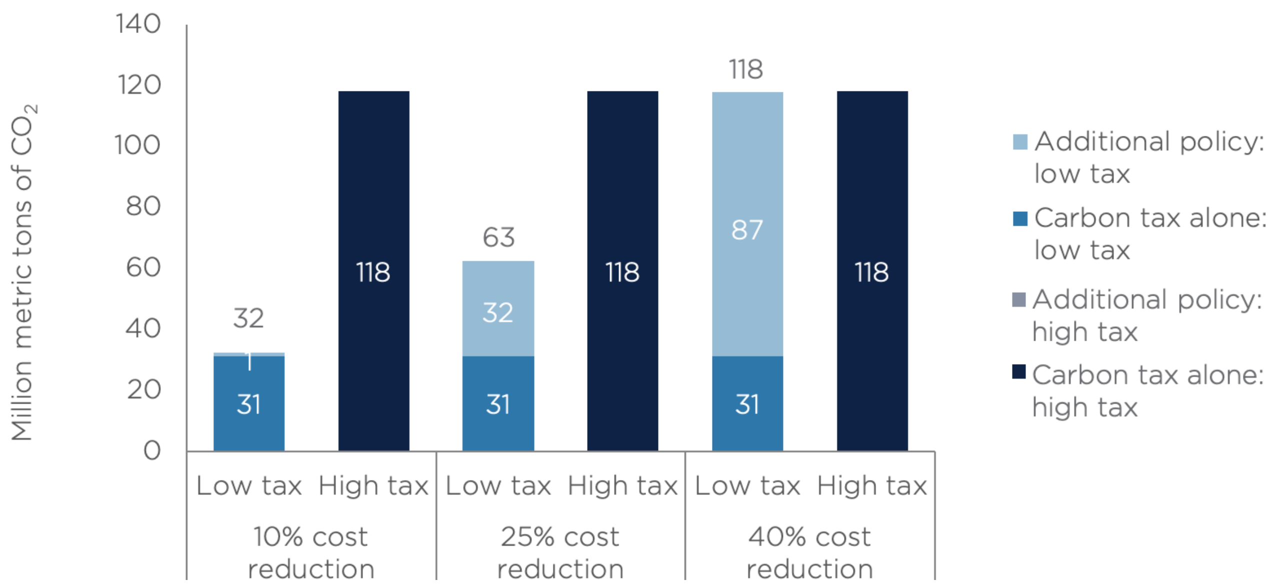
Industrial Sector Changes and Emissions Impact

Our quantitative analysis for the industrial sector focuses on CCS. In general, CCS requires capturing emissions at one or more points in an industrial process, concentrating and compressing the CO_2, and then transporting that CO_2 to a location where it can be injected underground for long-term storage or used for enhanced oil recovery or other purposes. The benefits of CCS include its applications across many industries, from chemicals to cement making. CCS can be used at both existing and new plants, and has some proven success in pilot projects. Finally, CCS retrofits enable the current capital stock to continue to exist. While there are several other options for decarbonizing industrial sector energy uses, such as replacing fossil fuels with lower-carbon options like biomass, synthetic fuels, and low-carbon electricity, these alternatives are outside the scope of our report.

Costs are a large factor in CCS deployment, and a carbon tax makes some CCS economic in the industrial sector. In 2030 in the high tax scenario, 118 MMT of capture capacity is deployed, whereas 31 MMT of capture capacity is deployed in the low tax scenario. To approximate a significant investment program into CCS research, development, and deployment, we reduce the total costs for industrial CCS by 10 percent, 25 percent, and 40 percent and estimate the emissions impacts of doing so. Limited cost reductions in the 10 percent case are representative of learning rates from other gas capture technologies over ten years of deployment, mid-range reductions are in line with projections for direct air capture over its early scale-up period (roughly through the first 10 MMT of capture capacity), and the aggressive cost reduction case assumes relatively similar cost declines as were seen in the early phases of utility-scale solar and wind deployment.[47]

Under the high tax rate, decreasing the cost of CCS does not result in additional CCS capacity because the tax itself deploys CCS to the limit of what is assumed to be available through 2030. As Figure 21 shows, reducing the cost of CCS by 10 percent increases the total carbon sequestered in the industrial sector by an additional 1 MMT in the low tax rate; reducing the cost by 25 percent reduces emissions by an additional 32 MMT; and, a 40 percent reduction results in an additional 87 MMT emissions reductions relative to the low carbon tax scenario in 2030.

Figure 21: Industrial CCS emissions reductions in 2030



Source: Rhodium Group analysis

Industrial Sector Policy Discussion

To achieve these lower CCS costs, policies that facilitate deployment of actual CCS projects are likely the most fruitful avenue. For industries like solar and wind, it has been shown that one of the biggest factors in reducing capital costs has been "learning by doing." The experience gained from putting steel in the ground reduces costs, creates supply chains, and creates efficiencies, all of which translate to lower potential CCS costs. Key policy interventions include loan guarantees for pilot projects, tax credits or subsidies per ton of carbon sequestered, or direct investments into CO_2 infrastructure like pipelines. These programs could be part of a potential stimulus package; the 2009 Recovery Act, for example, included $3.4 billion in funds for CCS-related programs.[48] Another possible approach is for governments to purchase lower-carbon products through procurement (such as "buy clean" programs, which could also incentivize a range of emission reduction options beyond CCS).

In general, costs will vary widely within the industrial sector, and each plant will require a unique solution to adapt to local infrastructure and production needs. Firms that emit purer streams of CO_2, that is, higher concentrations of carbon dioxide relative to other gases, will have more attractive CCS opportunities. As such, policies that focus on carbon sequestered rather than on specific industries may lead to better outcomes. Policy actions that address other constraints on deployment such as pipeline infrastructure could also contribute to the accelerated buildout of carbon capture.

SUMMARY AND DISCUSSION

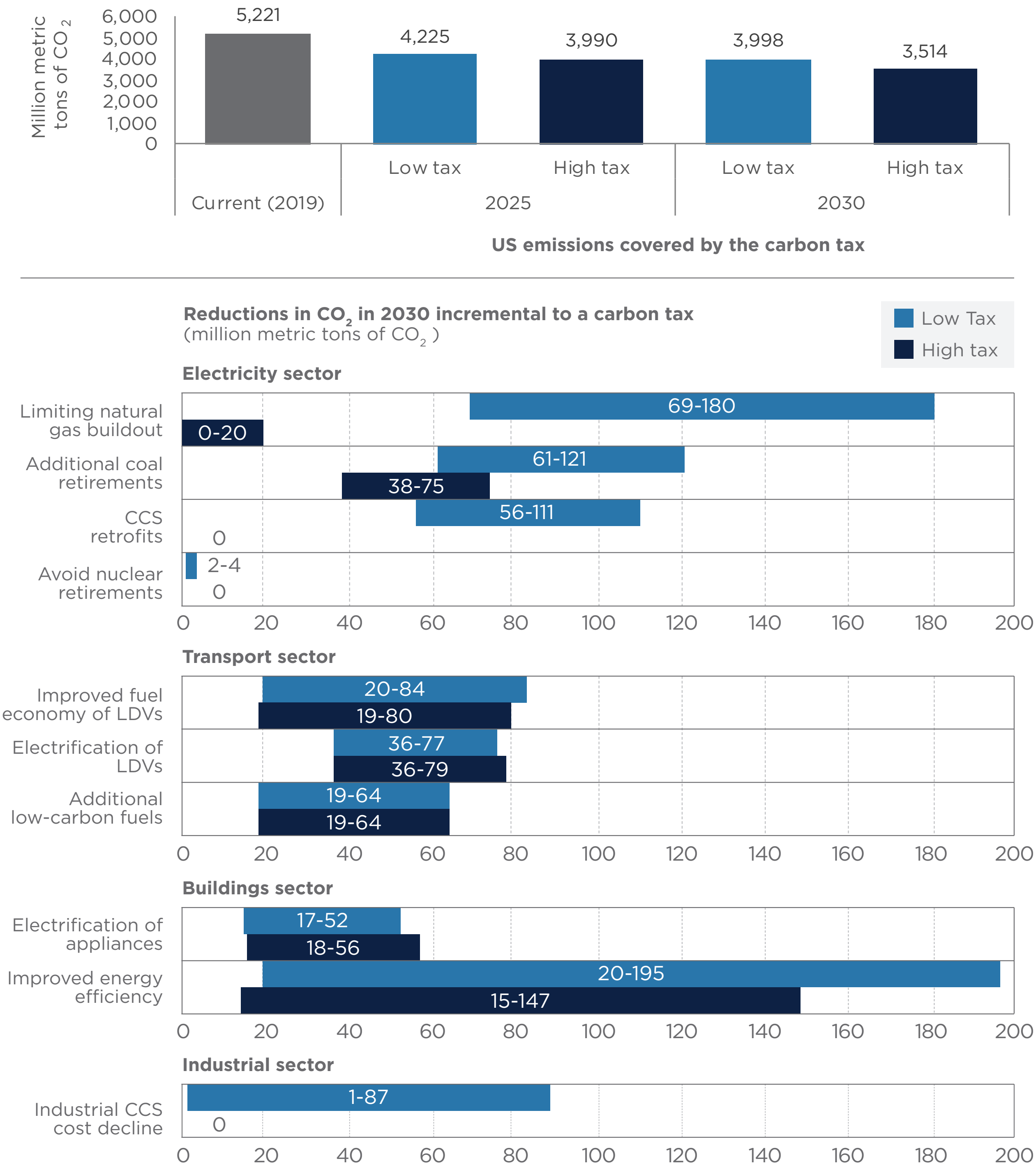
Carbon prices are widely considered a critical piece of a broader strategy to achieve domestic emissions targets, but carbon pricing policies are likely insufficient by themselves to achieve midcentury decarbonization goals.

This study has explored the impacts of two carbon tax pathways that span the range of rates proposed to the 116th US Congress, the energy system changes needed to overcome the major barriers inhibiting emissions reductions beyond what the proposed carbon tax policies are likely to achieve in the 2020s, and policy interventions that can help deliver those changes.

For certain key energy system changes, we provided quantitative estimates of the potential to achieve emissions reductions incremental to the two carbon tax policies. Figure 22 summarizes the results. The results are contingent on the assumptions described throughout the paper and in supporting documentation and subject to considerable uncertainty based on the evolution of energy markets, consumer behavior, technologies, and the economy. Nevertheless, the following takeaways are directionally robust across a broad range of assumptions:

- Encouraging a range of additional energy system changes can lead to additional emissions reductions in every major sector.
- The incremental emissions reductions from the individual additional energy system changes are small compared to the emissions reductions achieved in either of the scenarios that examine a carbon tax policy alone. (However, this result is dependent on the energy system changes we elected to analyze—more aggressive assumptions would have led to larger emissions reductions).
- For energy system changes that focus on the electrification of end uses, additional emissions reductions are larger under the high carbon tax scenario due to the cleaner electricity system. For other energy system changes, incremental emissions reductions are larger under the low carbon tax scenario because there is more “low hanging fruit” remaining compared to the high carbon tax scenario.

Figure 22: Summary of results



Source: Rhodium Group analysis
Note: Covered CO_2 emissions include energy CO_2 emissions and a subset of industrial nonenergy CO_2 emissions.

The small emissions reductions relative and incremental to what a carbon tax acheives are especially notable outside of the power sector. Our results indicate that the small impacts on near-term emissions in the buildings, transportation, and industrial sectors are not unique to carbon taxes. Instead, the significant barriers to large near-term emissions reductions in these sectors could persist even under a much broader decarbonization strategy. This does not imply that large near-term emissions reductions are impossible in these sectors, but that they may require more ambitious actions than we explored in this study, such as bans on fossil fuel usage or performance standards that far surpass the stringency of most proposals. Moreover, as we discuss, some energy system changes with small near-term impacts can result in more meaningful emissions reductions in the long-term owing to factors like slow stock turnover of cars and buildings. Lastly, while this study focused on energy CO_2, additional emissions reductions could be pursued through large scale changes in land management and deployment of direct air capture combined with storage. Increasing deployment of these natural and technological carbon removal options can complement energy system interventions and will be needed at scale by midcentury to meet ambitious climate goals.[49]

Importantly, the results are not necessarily additive across the analyses (i.e., the emissions reductions of combining two energy system changes may not equal the sum of the two). Still, the results suggest a carbon tax combined with policy actions that support comprehensive, ambitious energy system changes beyond what a carbon tax alone produces could lead to energy CO_2 emissions reductions in the range of 40 to 45 percent below 2005 by 2030, which is an emissions pathway that is arguably consistent with midcentury deep decarbonization goals for the energy system.

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