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ENERGY AND ENVIRONMENTAL IMPLICATIONS OF A CARBON TAX IN THE UNITED STATES

AN INDEPENDENT REPORT PREPARED BY RHODIUM GROUP FOR COLUMBIA SIPA CENTER ON GLOBAL ENERGY POLICY

BY JOHN LARSEN, SHASHANK MOHAN, PETER MARSTERS, AND WHITNEY HERNDON

JULY 2018

EDITED BY NOAH KAUFMAN, COLUMBIA SIPA CENTER ON GLOBAL ENERGY POLICY

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ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of Vania Fong, Hannah Hess and Trevor Houser at the Rhodium Group for their contributions to the production of this report. We also appreciate the feedback from three anonymous reviewers on an earlier draft of this report. Finally, we are grateful for the input and insights of Noah Kaufman, Ron Minsk, Kate Gordon, Jesse McCormick, Mathew Robinson, Edwin Saliba and Jason Bordoff at the Center for Global Energy Policy throughout the development of this report.

The opinions expressed in this paper are those of the authors and should not be construed as reflecting the views of the Columbia SIPA Center for Global Energy Policy, Rhodium Group, or any other entity.

This work was made possible by support from the Center on Global Energy Policy. More information is available at http://energypolicy. columbia.edu/about/mission.

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EXECUTIVE SUMMARY

A price on carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions has long been a preferred instrument among economists and other academics for addressing the threat of climate change.[1] The idea is simple: putting a price on carbon internalizes the societal costs caused by consumption of fossil fuels and other activities that emit GHGs. The concept sits firmly in the tradition of Pigouvian taxation, which has been applied to address other "externalities"—from the health system costs of tobacco and alcohol use to the environmental cost of substances that deplete Earth's ozone layer. The concept of pricing carbon by way of a tax has been gaining traction among economists as an efficient, market-based strategy for reducing GHG emissions in the United States. More recently, the idea has garnered the attention of prominent Republicans and Democrats within and outside of Congress as well as advocates on the left and right poles of the national political spectrum.

Regardless of the motivation for pursuing a carbon tax, current and future discussions can benefit from an up-to-date and comprehensive assessment of what such a policy would mean for the US energy system and resulting GHG emissions in the future.

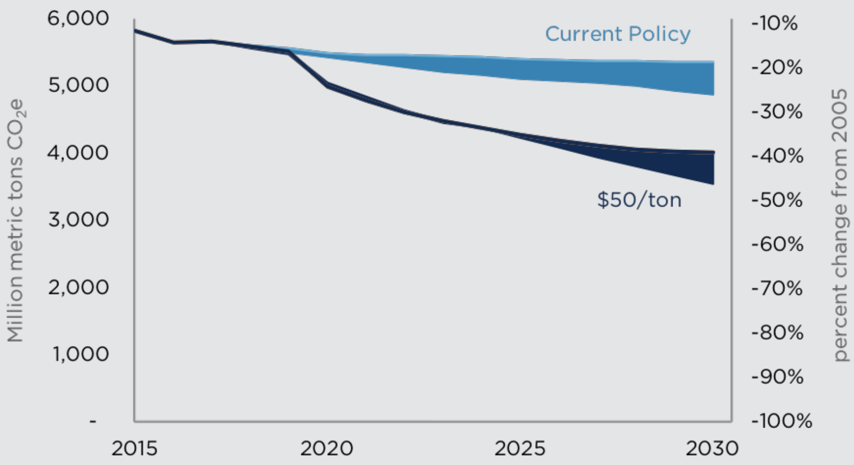
This paper is part of a series under the Columbia University Center on Global Energy Policy's (CGEP's) Carbon Tax Research Initiative. It provides projections of the US energy system and emissions implications of carbon taxes and associated policy choices[2] using RHG-NEMS, which is a version of the National Energy Modeling System (NEMS) maintained by the Rhodium Group.[3] NEMS is developed and used by the Energy Information Administration (EIA) to produce its Annual Energy Outlook and relied on by Congress to assess the impact of past energy and climate legislation.[4]

This paper seeks to answer key questions about the impacts of a carbon tax in the United States. First, how responsive are different sectors of the US economy to a carbon tax at different tax rates? The answer has important policy implications, such as the amount of federal revenue collected under any given tax rate, the likelihood of achieving specified GHG reduction targets, and the potential role of other emission reducing policies. Second, what changes in energy prices, production, and consumption occur under different tax rates? These questions are addressed by assessing three carbon tax rate scenarios.

Based on this analysis, we make the following key findings:

- *A carbon tax can drive substantial reductions in US GHG emissions in the near and medium term.* In our analysis, an economy-wide carbon tax set at $50/ton in 2020 and rising at a real rate of 2 percent achieves emission reductions of 39 to 47 percent below 2005 levels by 2030 (figure ES1).

Figure ES-1: US net GHG emissions, 2015–2030



Source: Rhodium Group analysis.

- *Emission reductions primarily occur in the electric power sector.* The sector is the most responsive to a carbon price, and, in turn, this is where most economy-wide emission reductions occur. The presence of readily available low carbon substitutes drive emission reductions of 23 to 67 percent in the $50/ton scenario relative to emissions under current policy in 2030.

- *A carbon tax drives large increases in renewable energy production and large declines in coal production.* Zero-emitting renewable energy makes up 29 to 41 percent of total US electric power generation in 2030, depending on the tax rate scenario, which represents a two- to threefold increase from 2015 levels. Renewables fill in behind coal generation, which declines substantially in all scenarios. The carbon tax drives a 28 to 84 percent reduction in US coal production by 2030 compared to current policy.

- *Average per capita energy expenditures rise under a carbon tax but do not reach the (inflation adjusted) high levels seen in recent history, even in the highest tax rate scenario.* Increases in energy expenditures per capita due to a carbon tax range from 7 to 27 percent relative to current policy in 2030. Meanwhile, per capita energy expenditures during the commodities boom in the run-up to the great recession were even higher.

- *Carbon tax revenue could potentially be large, ranging from $617 million to as much as $2.5 trillion over the first 10 years, depending on the tax rate and technological innovation in the US economy.* Decisions over revenue of this magnitude could be contentious. Revenue could be directed to a variety of productive uses, including cutting other taxes, deficit reduction or rebates to individuals.

- *Beyond 2030, a carbon tax at the levels considered in this analysis may not be not sufficient for achieving emissions targets.* In the long term, the range of tax rates considered in this analysis will likely be insufficient to reduce US GHG emissions 80 percent below 2005 levels by 2050, absent complementary GHG policies, significant improvements in technologies that can act as direct substitutes for fossil fuels, and/or significantly faster electrification of the transportation, buildings, and industrial sectors than we considered in this analysis.

While this paper focuses on the emissions and energy system impacts of a carbon tax in the United States, the results are used in separate analyses of the potential distributional and macroeconomic impacts of a carbon tax, which are also part of the CGEP Carbon Tax Research Initiative series.

INTRODUCTION

Eighty years ago, British engineer Guy Stewart Callendar provided the first convincing evidence that emissions of carbon dioxide (CO_2) and other greenhouse gases (GHG) from human activity were warming the planet. Today, the body of scientific evidence of human-caused climate change is overwhelming and unequivocal. These changes are imposing a growing economic cost, both in the United States[5] and around the world.[6] These costs are not paid by the individuals and companies responsible for the GHG emissions behind them, but by society as a whole.

One of Guy Stewart Callendar's contemporaries was an economist named Arthur Cecil Pigou, who in 1920 argued in *The Economics of Welfare* that the societal costs of industrial production should be "internalized" through a tax. In the decades since, Pigouvian taxes have been used to address a range of social costs through market forces, from the impact on the public health system of tobacco and alcohol use to the environmental impact of substances that deplete Earth's ozone layer. Economists and other academics have long argued that a similar approach could be taken to address climate change through a tax on CO_2 and other GHG emissions.[7] Such a tax would also raise significant revenues. Over the past few years, a carbon tax has garnered increased attention from elected officials at both the federal and state levels, and from both the Democratic and Republican parties.[8]

The Trump administration has broadly dismissed the threat of climate change and is actively rolling back federal GHG regulations. Despite this, some argued that a congressional push for tax reform could provide an opportunity to pursue a carbon tax.[9] The theory of change is that a carbon tax could provide revenue to cover the costs of such an endeavor. The enactment of a major deficit-funded tax cut package at the end of 2017, however, suggests the window for such a trade (to the extent to which it ever existed) is likely now closed. Meanwhile, the administration and Congress are advancing infrastructure legislation that, if not also deficit financed, will either require cutting current spending on popular programs or a new source of revenue.[10] While some continue to explore how a carbon tax could potentially serve as the source of revenue as part of bipartisan legislative compromise under the current administration, others are considering how a carbon tax could serve as a key component of a Democratic campaign platform in the 2020 presidential elections.

While the likelihood or timing of serious congressional consideration of a carbon tax is unclear, there are important design questions policy makers will need to grapple with if such consideration occurs. The first paper in the Center on Global Energy Policy's (CGEP) Carbon Tax Research Initiative[11] identified and discussed these questions in detail.[12] This paper analyzes the energy and emissions impact of some of the most important carbon tax design choices.

The US energy system is in a state of flux. The shale boom has expanded the role of natural gas, boosted crude oil production to record levels, and put the United States on track to be a net energy exporter. The dramatic reduction in wind and solar costs is transforming the electric power sector. A rapidly growing menu of electric vehicles has the potential to upend transportation and US oil demand. All this makes predicting the future more challenging than ever, let alone predicting how that future will be altered by a carbon tax–driven change in relative prices.

If Congress does consider a carbon tax, it will almost certainly ask the US Energy Information Administration (EIA) to analyze its impact on energy production, consumption, prices, and emissions. EIA has been called upon to analyze most major energy and environmental legislation, including previous carbon pricing legislative proposals like the Waxman-Markey bill, which passed the House of Representatives in 2009.[13] EIA analysis of any future carbon tax legislation will play a central role in the congressional and public debate over the merits of such a proposal.

For its annual long-term forecasts[14] and major energy and environmental policy analysis, EIA uses the National Energy Modeling System (NEMS).[15] NEMS is a highly detailed energy-economic model with individual, interconnected modules for macroeconomic activity; coal, oil and gas, nuclear, and renewable energy production; power generation; petroleum refining and natural gas transmission and distribution; and energy consumption in the residential, commercial, industrial, and transportation sectors.

Like all models, NEMS has its strengths and its limitations. It is one of the few detailed economy-wide models of the US energy system, and the only such model that is publicly available, fully documented, and with completely transparent modeling parameters and input assumptions. For these reasons, combined with the fact that it will almost certainly be the modeling platform EIA will use to assess any future carbon tax proposal, we selected it for this analysis. Doing so also provides an opportunity to identify areas where the leading government energy model may need refinement to better reflect technology deployment and consumer behavior under a carbon tax, and it complements recent carbon tax analysis produced using other modeling platforms.[16]

This paper is structured as follows. In section 2, we review recent US GHG trends and project future emissions under current policy. In section 3, we briefly discuss key carbon tax design elements relevant to this analysis and present the analytical approach used in this study. Section 4 discusses the impact of a carbon tax on GHG emissions in different sectors and for the US economy as a whole. We explore why some sectors are likely to be more responsive to a carbon tax than others, and why additional GHG reduction policies may be necessary in certain sectors to achieve economy-wide emission reduction goals. Section 5 covers the impact of a carbon tax on US energy production, consumption, prices, and expenditures. Section 6 provides 10-year federal budget revenue estimates under different carbon tax rates. We offer some headline conclusions for consideration in section 7.

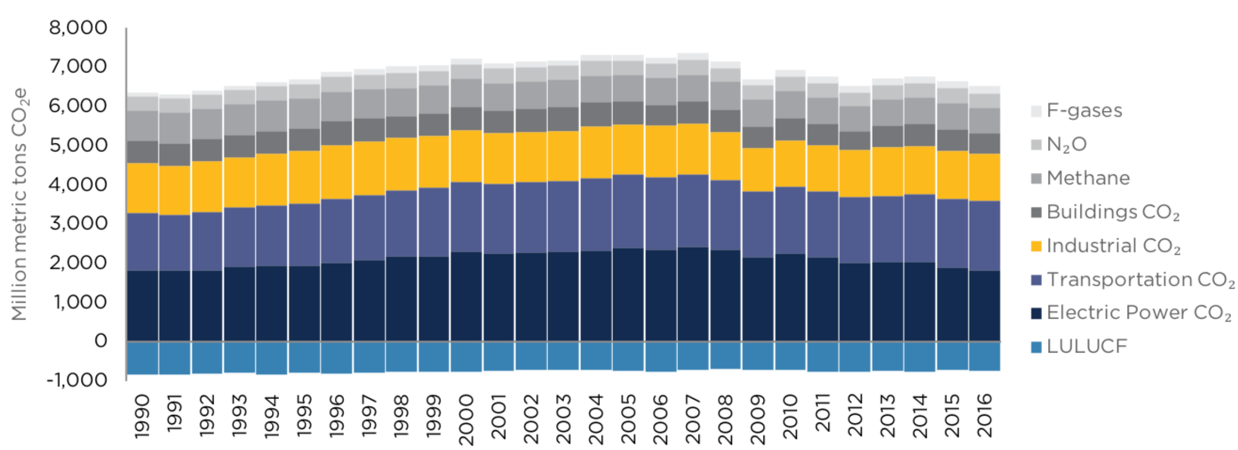
The energy and emissions outputs from this paper have been provided to the Tax Policy Center and the Baker Institute for Public Policy at Rice University, which will be analyzing the distributional and macroeconomic impacts of both a carbon tax and different revenue allocation options, in papers that will also be released as part of CGEP's Carbon Tax Research Initiative.[17]

THE STARTING POINT: US EMISSIONS UNDER CURRENT POLICY

With total gross emissions of 6,511 million metric tons of CO_2e in 2016, the United States is the second-largest GHG emitter in the world on an annual basis.[18] Until the great recession, US emissions were on a steady upward climb driven by growth in population and the economy. Over the past decade, much has changed. Demand for electricity has flattened, while economic growth has recovered, both in the United States and in other developed economies.[19] Transportation demand plateaued until recently due to higher fuel costs and demographic shifts. Increasingly cheap renewable energy technologies and persistently low-cost natural gas due to the shale boom have displaced coal as the leading electricity generation fuel.[20] As of 2016, US net-GHG emissions, inclusive of carbon sequestration in America's forests and rangeland, have dropped 12 percent since 2005 (figure 1).

Most of these recent developments impact emissions of CO_2, the most prevalent GHG in the United States. CO_2 is primarily emitted when fossil fuels are combusted, for example, to generate electricity, propel cars and trucks, fuel factories, and warm buildings. In 2016, CO_2 emissions were estimated to be 5,311 million metric tons, their lowest levels since 1993.[21] Meanwhile, emissions of other more potent but less prevalent GHGs such as methane (largely from agriculture, fossil fuel production, and landfills) and nitrogen dioxide (primarily from agriculture) have stayed mostly flat since 1990. Emissions of "F-gases," man-made GHGs consisting largely of refrigerants used as substitutes for substances that deplete the ozone layer, have grown since 1990, driven by the adoption of the Montreal Protocol. Still, these emissions play a relatively small role in the total US picture. Finally, carbon sequestered in forests and rangelands in the United States represented about three-quarters of a billion tons of CO_2 removed from the atmosphere in 2015, which is a slight increase from 1990 levels.

Figure 1: US GHG emissions by sector from 1990 to 2016 (Million metric tons CO_2e)



Source: EPA Greenhouse Gas Emissions Inventories.

As noted in the introduction, the recent changes in the US energy system make projecting future emissions trends more challenging than ever. We used RHG-NEMS, a version of EIA's NEMS model maintained by the Rhodium Group, to analyze the impact of a carbon tax. We used EIA's 2017 Annual Energy Outlook (AEO) reference case with modifications to construct a projection of the US energy system under current policies without such a tax. The modifications to EIA's AEO2017 reference case include updated policy assumptions to reflect the latest federal and state energy and climate policy developments in place as of June 2017. We also incorporated announced power plant retirements as of June 2017 that are not captured in the 2017 AEO.

Given the recent, rapid changes in clean energy technology development, we constructed two current policy scenarios to capture the uncertainty. One scenario is characterized by relatively modest improvements in clean energy technologies over time. This scenario primarily relies on EIA's AEO2017 technology assumptions, though renewable energy technology costs are updated to reflect projections from the National Renewable Energy Laboratory (NREL). We use this scenario, which produces relatively high future emissions, to assess the price responsiveness of the US economy to different carbon tax rates. The second scenario incorporates NREL's low-cost scenario renewable technology costs, cheaper EV battery costs, cheaper nuclear and low carbon fossil generation costs, faster uptake of high efficiency building technologies, and cheaper EV battery costs than the first scenario.[22] While many of these technologies are commercially available today, some, such as renewable natural gas and industrial CCS, have been deployed in limited applications but would presumably be commercially available in the future.[23] The two scenarios combined are used to consider the emissions and revenue implications of certain carbon tax rates. Please see the technical appendix for more discussion. In order to maintain a reasonable number of scenarios in this analysis, we relied on EIA's AEO2017 fossil fuel resource and cost assumptions. Different assumptions on fossil fuel resource availability and costs could produce results that are significantly different from those we present below.

We estimated emissions of all six major GHGs based on RHG-NEMS output and other sources. To convert non-CO_2 GHGs into CO_2 equivalents, we used the same 100-year global warming potentials (GWPs) used by EPA in its GHG inventory.[24] For methane emissions, we constructed emission rates for coal, oil, and natural gas production based on historical data from EPA's 2017 GHG inventory and adjusted rates downward as appropriate to reflect the effects of federal and state emissions standards. For more details on the assumptions and methods used in the current policy scenario, please see the technical appendix.

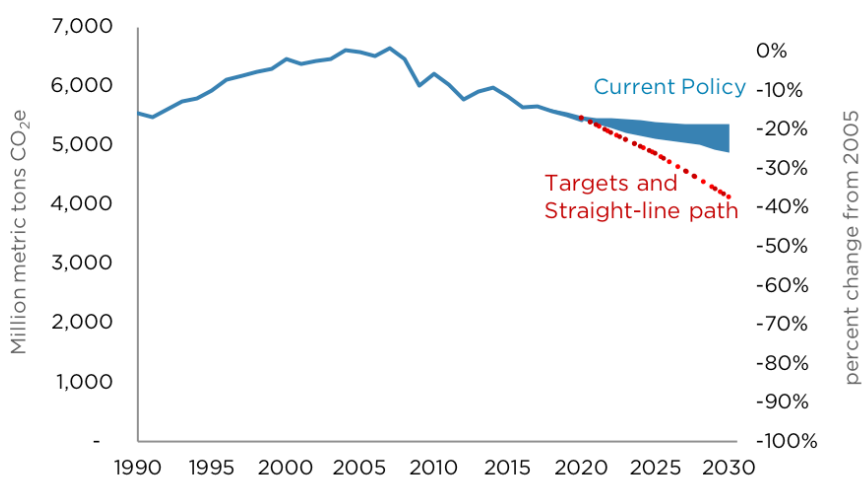
The end result is a US emissions projection range out to 2050 that is consistent with historical GHG data and reflects some technology and behavioral uncertainty within the bounds of overall NEMS model dynamics and AEO 2017 macroeconomic, industrial activity and consumer demand projections. Due to increasing uncertainty of results from further out in our projections, we focus on results through 2030 for the majority of this study.

Finally, in both our current policy and carbon tax scenarios, we assume the rest of the world takes no additional action to address climate change other than what is already underway. While one would expect other countries to take additional action should the United States adopt a carbon tax, the nature, ambition, and geographic distribution of such actions is difficult to project in advance. Should other countries take additional action, global energy and commodities markets would operate differently than assumed in this study. For example, US export markets for fossil fuels could be smaller than assumed in this analysis.

Under the current policy projection, total net-GHG emissions decline slowly over the next 10–15 years, from 5,828 million metric tons in 2015 to a low of 4,872–5,355 million metric tons in 2030. This represents a decline of 19 to 27 percent below 2005 levels (figure 2). The decline is due mostly to a reduction in the carbon intensity of the electric power and transportation sectors and a decline in F-gas emissions through the assumed full implementation of the Kigali Amendment to the Montreal Protocol.[25] In the lower end of the emissions range, additional reductions in energy demand from efficiency improvements in building shells and appliances also play an important role.

Under this current policy scenario, the United States is on track to meet the Copenhagen target of a 17 percent reduction in GHG emissions below 2005 levels by 2020.[26] By 2025, US GHG emissions in the current policy scenario are 18 to 22 percent below 2005 levels—short of the United States' 26 to 28 percent commitment under the Paris Agreement.[27] Maintaining the same emission reduction rate between the US 2020 and 2025 targets out to 2050 establishes one possible long-term pathway to an 83 percent reduction below 2005 levels by 2050. To maintain this straight-line path, US net GHG emissions will need to be 37 percent below those of 2005 in 2030. As noted above, by 2030, emissions in the current policy scenario are 19 to 27 percent below 2005 levels. Given this gap, it is likely that additional policies are needed to enable the United States to achieve deep decarbonization targets by midcentury. An economy-wide carbon tax is one policy option that could be pursued.

Figure 2: US net GHG emissions and reduction targets, 1990–2030



Source: EPA Greenhouse Gas Emissions Inventories; Rhodium Group analysis.

CARBON TAX DESIGN CHOICES

If a window opens for serious congressional consideration of a carbon tax, a quantitative analysis of potential energy system and GHG emissions impacts will be an important component of the process. Such an analysis will depend on the major design decisions that Congress will confront in designing a carbon tax, which are explored in detail in a previous report released by the CGEP Carbon Tax Research Initiative.[28] The key elements that will have considerable influence over the energy and environmental impacts of a carbon tax include the following:

- **Scope and coverage:** Which gases and sectors are covered by the carbon tax? The broader the scope and coverage, the more opportunities for emission reductions.
- **Point of taxation:** Which entities are required to pay the tax? Is the tax applied upstream in the energy system at the point of fuel production or downstream where emissions occur, or is a hybrid approach used? The cost of the tax is likely to get passed through to consumers regardless of approach.
- **Tax rate:** What is the level of the tax set at initially (in dollars per metric ton of carbon dioxide equivalent terms) and in subsequent years? All else being equal, a lower tax rate will result in fewer emission reductions relative to a higher tax rate.
- **Interaction with other policies:** Will other current policies be removed or suspended upon implementation of a carbon tax? Some policies, such as incentives for zero-emitting technologies, may lead to greater emission reductions if a carbon tax is in place. Others may be redundant or irrelevant, adding costs with no environmental benefits.
- **International trade effects:** Will the carbon tax program include a border adjustment to shield domestic manufacturers from international competitors that don't face a similar carbon tax? Without some measures in place to maintain a level playing field, emissions may decline in the United States only to increase elsewhere in the world.
- **Revenue allocation options:** Will carbon tax revenue be used in ways that could accelerate emission reductions? Carbon tax revenue could be used in any number of ways. If some or all of it is directed toward research, development, and deployment of clean energy technologies, emissions reductions may be achieved faster than if the revenue is directed elsewhere.

To assess the environmental and energy system impacts of carbon tax in the United States, all of these design elements were considered in the construction of a set of scenarios used in this analysis. Assumptions around scope and coverage, point of taxation, policy interaction, international trade effects, and revenue allocation are consistent across scenarios.

We assume the tax is applied to all CO_2 emissions that occur from the combustion or consumption of fossil fuels as well as any methane emissions that occur during the production of fossil fuels used in the United States.[29] As noted in the previous chapter, we assume methane emissions rates per unit of fossil fuel production consistent with EPA's 2017 inventory, with adjustments downward to reflect federal and state emissions standards where applicable. 100-year GWPs are used to convert methane to CO_2 equivalents, at which point the carbon tax is calculated. Only methane emissions from mining (for coal) or extraction (for oil and gas) are taxed. Methane emissions from leaks during the transmission and distribution of fossil fuels are not taxed.

In total, emissions covered by this carbon tax represent roughly 81 percent of US gross GHG emissions in 2015. Regarding the point of taxation, we use the default structure in NEMS for modeling carbon tax policies, which applies the tax to each fuel just after wholesale transactions occur or following the importation of fuels into the United States, with tax credits provided to nonemissive uses of CO_2, exports of fossil fuels, and capture and permanent sequestration of CO_2. We also assume there is border adjustment in place on all energy and trade intensive goods and an equivalent credit for exports of those goods by US manufacturers.

Finally, we assume no revenue is recycled back into the US economy.[30] While revenue could be used in ways that can change the emissions and market impacts we report in this study, this approach allows for an assessment of the carbon price independent of any policy choices directing revenues for any purpose. Other papers in this series will explore the distributional and macroeconomic implications of different revenue allocation options based on the results from this analysis.

Analytical Scenarios Based on Tax Rate

We analyze the following three carbon tax rate trajectories, each starting in 2020, based on three estimates of the social cost of carbon dioxide emissions (SC-CO_2) produced by the US government under the Obama administration.[31] These estimates (and a fourth higher SC-CO_2 estimate) were used by federal agencies in cost-benefit analyses of energy and climate regulations. The Trump administration has used lower SC-CO_2 values in its regulatory analyses.[32] Still, the Obama era values are used in this analysis, as they provide a range of carbon tax rates wide enough to conduct a sensitivity analysis of the US energy system to varying tax rates.

- \$14/ton—Starts at \$14/ton[33] CO_2e and rises at an approximately 3 percent real rate annually
- \$50/ton—Starts at \$50/ton CO_2e and rises at an approximately 2 percent real rate annually
- \$73/ton—Starts at \$73/ton CO_2e and rises at approximately a 1.5 percent real rate annually

We modeled the \$50/ton scenario using both sets of assumptions on technology pathways considered for our current policy scenario. This allows us to present an emissions range reflecting uncertainty around the cost, performance, and availability of a variety of clean energy technologies for the \$50/ton scenario. For the \$14/ton and \$73/ton scenarios, we consider only the more conservative of the two technology scenarios. This allows for an assessment of a sector's sensitivity to changes in tax rates while holding technology assumptions constant.

EMISSIONS IMPACT OF A CARBON TAX

The impact of a carbon tax on US GHG emissions is dependent both on the level of the tax and the sector in which the emissions occur. In this section we present the emissions impacts of different tax rates through 2030 by sector, followed by a discussion of the impacts of different carbon tax rates on US emissions overall. We close with a discussion of projected GHG emissions after 2030. Where possible, we highlight areas where modeling assumptions and limitations introduce meaningful uncertainty in the results.

Electric Power Sector

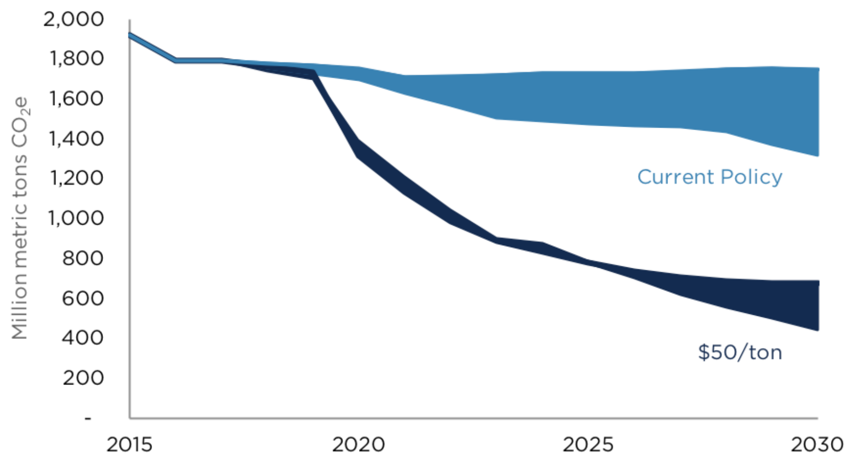
A carbon tax increases the costs of fossil fuels used to generate electricity in proportion to the carbon intensity. NEMS optimizes for least cost system dispatch and capacity expansion over time while meeting all environmental, reliability, and other performance requirements. For dispatch, the generation fleet in any given year will run its low carbon intensity generators, such as natural gas combined cycle (NGCC) units, more than high carbon intensity generators, such as coal steam generators. The magnitude of this shift is determined by the tax rate in that year. NEMS uses foresight when making capacity decisions in each model year to capture long-term market and investment expectations. This means that the carbon tax in each year, as well as in subsequent years, is considered. NEMS considers the economics of existing generators based on their going-forward costs and compares them against the economics of new capacity of all fuels and technologies, taking the carbon tax into account throughout. NEMS then retires existing capacity that is uneconomic under a given carbon tax and builds new replacement capacity as needed while optimizing for least cost. Shifts in dispatch and capacity expansion lead to lower GHG emissions under carbon tax.

The cost of generating electricity is passed on through consumer electricity prices. Consumers can change their consumption of electricity in response to changes in price. This is accomplished by reducing the use of various services (such as light and hot water) and, over time, by the purchase of more efficient electric equipment. The changes in demand for electricity also influence GHG emissions from the sector. Higher carbon taxes lead to lower electric demand and lower electric power GHG emissions, all else being equal.

Emissions Results

Under the $50/ton scenario, we find that electric power sector GHG emissions decline rapidly and deeply following the start of the policy in 2020. Without a carbon tax, emissions are just under 1.8 billion metric tons in 2019 and between 1.3 and 1.75 billion metric tons in 2030, accounting for uncertainty in technological innovation (figure 3). The $50/ton tax rate pathway drives emissions down in the first year by 300 million tons as the generation fleet shifts dispatch toward lower carbon natural gas power plants. By 2025, emissions are one billion tons lower than prior to the start of the policy as coal plants retire, new zero-emitting generation comes online, and low carbon generation continues to be prioritized in dispatch. By 2030, electric power sector emissions range from 445 to 675 million metric tons.

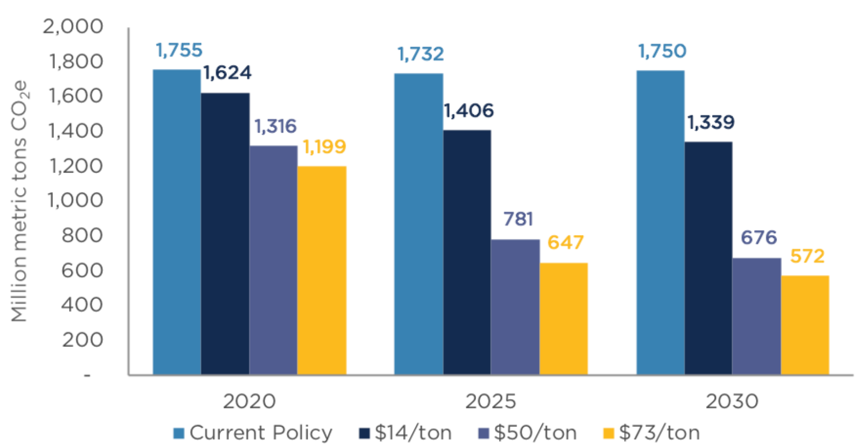
Figure 3: Electric power GHG emissions, central tax scenario, 2015–2030 (Million metric tons CO_2e)



Source: Rhodium Group analysis.

The electric power sector appears to be very responsive to differences in tax rates. Using the conservative technology assumptions for all scenarios, the $14/ton scenario drives emissions down to 1,339 million metric tons, compared with 1,750 under current policy in 2030 (figure 4). The $50/ton scenario cuts emissions to 1,316 million metric tons in 2020 and to 676 million metric tons by 2030. The change in emissions between the $50/ton and $73/ton scenarios is smaller; the $73/ton scenario drives emissions down to 1,199 and 572 million metric tons in 2020 and 2030, respectively, which is just 100 million metric tons lower than the $50/ton scenario (figure 4).

Figure 4: Electric power GHG emissions, 2020–2030 (Million metric tons CO_2e)



Source: Rhodium Group analysis.

There are several reasons why the power sector delivers deep and immediate emission reductions and why emissions are responsive to different tax rates.

First, in NEMS and across most of the United States, the electric power sector operates as a competitive market. This allows for rational economic decision-making in response to the carbon tax. Power plants are dispatched from low to high costs to meet a given level of electric demand. This facilitates the rapid dispatch shift that occurs when a carbon tax is imposed. Market forces respond quickly to the tax, with lower carbon resources expanding their market share. Incumbent carbon intensive generators that are dispatched less face revenue losses that can drive them to exit the market entirely and retire. Power plant developers compete to build new capacity with the carbon tax factored in to their investment decisions.

Second, there is a wide array of relatively low carbon generators currently operating in the United States and a diverse set of low and zero carbon technologies available that can provide new capacity. Rational, competitive markets can respond quickly to a carbon tax only if there are substitutes for carbon intensive generation readily available. The abundance of cheap natural gas and spare NGCC capacity can serve as a substitute for coal generation in the near term. In the medium and long term, renewable energy technologies such as wind and solar photovoltaics (PV), as well as nuclear generation and fossil fuel–fired power plants equipped with carbon capture and storage (CCS) technology, could all play a role. Decarbonizing fuel supply by producing synthetic natural gas derived from sustainable biomass could also lead to lower emissions.

Finally, decision-makers, including electric power utilities and power plant developers, have long investment horizons and low costs of capital. Power plant investments can last as long as 50 years. Utilities have an incentive to pursue technologies that will start out and remain profitable throughout that time frame. Large utilities have access to equity financing or can float relatively low-cost bonds backed by ratepayers, further facilitating large investments.

What Are the Uncertainties?

Our findings are sensitive to the future cost and performance of generation technologies as well as to fuel prices. If, for example, new advanced nuclear reactors can be built more rapidly and cheaply than we have assumed, a carbon tax may drive greater emission reductions earlier than we report here. Uncertainty in fossil fuel prices could also change our results. If natural gas prices are lower than EIA's reference case outlook of roughly $4.25-$5.00/mmbtu (at Henry Hub), then other generating technologies such as coal, renewables, and new nuclear plants will be less competitive, all else being equal. The reverse is also true. The direction of change in emissions from changes in natural gas prices is difficult to estimate a priori.

The lower emissions estimate in our $50/ton tax scenario reflects the potential impact of cheaper zero-emitting generation technologies and lower end-use demand. Still, the consideration of all possible energy system uncertainties is outside the scope of this analysis.

Transportation

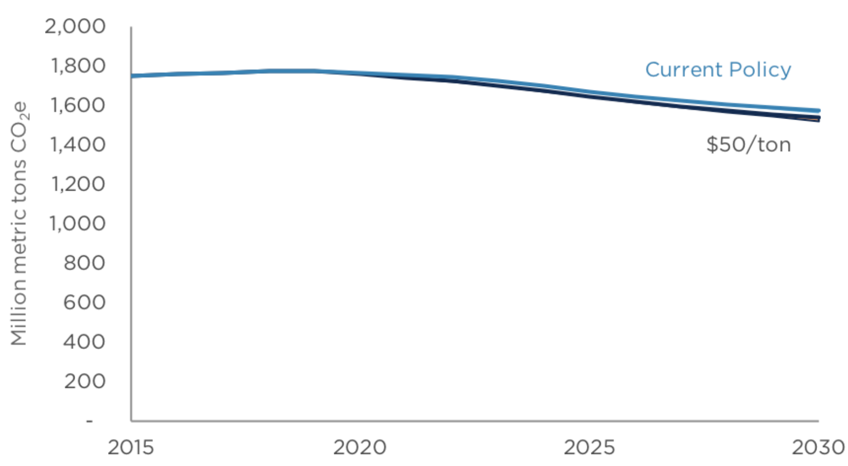
A carbon tax increases the retail price of gasoline, diesel, and jet fuel, as well as natural gas and propane, in proportion to their carbon intensity. As the carbon tax is passed through to consumers, the overall cost of mobility increases. Alternative fuels such as biofuels and electricity also see price increases from the tax, depending on their carbon intensity of production. Consumers and fleet operators can respond to these price increases in the short term by reducing transportation demand and by shifting to more efficient, lower carbon vehicles and transportation modes over the long term.

Emissions Results

A carbon tax drives transportation emissions below our current policy scenario, but reductions are small and develop slowly relative to what we found in the power sector. In our $50/ton scenario, transportation GHG emissions range from 1,520–1,540 million metric tons in 2030 (figure 5). That represents a decline of 200 million metric tons from 2015 levels, but it is only 30–40 million metric tons lower than in the current policies scenario. We see 10 times as much abatement in the power sector in the first year of the tax alone.

Emissions in both the current policy and $50/ton scenario decline from 2015 levels through 2030. The emissions range reflects different assumptions on the costs of EV batteries. Under current policy, fuel economy and GHG emissions standards on new light-duty vehicles increase in stringency annually until 2025 and then hold constant. The Trump administration has recently announced its intention to scale back the stringency of future vehicle fuel economy and GHG emissions standards, which could increase emissions from the sector in the current policy scenario.[34]

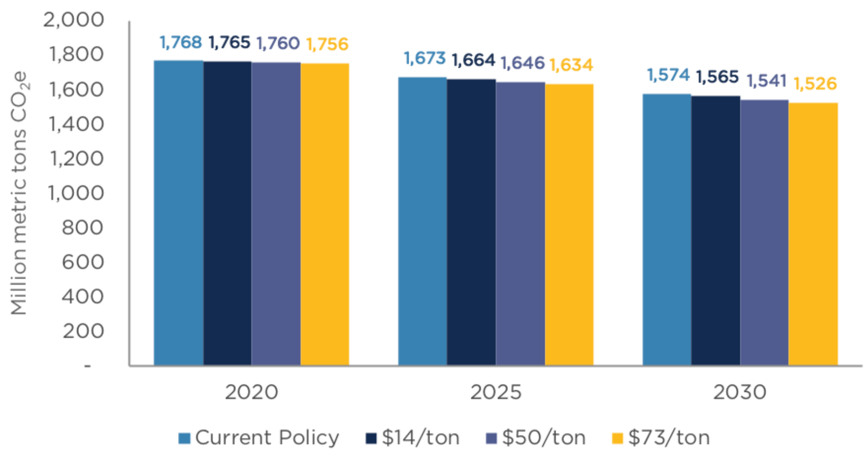
Figure 5: US transportation sector GHG Emissions, 2015–2030 (Million metric tons CO_2e)



Source: Rhodium Group analysis.

The transportation sector appears not to be very responsive to different tax rates. In 2030, emissions range from 1,526 million metric tons in the $73/ton scenario to 1,565 million metric tons in the $14/ton scenario. This range represents a 1–3 percent reduction from current policy in 2030, controlling for technological uncertainty (figure 6). Transportation sector emissions abatement under a carbon tax is an order of magnitude lower than the abatement we find in the electric power sector. Our results are in line with those from other carbon tax modeling efforts.[35]

Figure 6: Transportation emissions 2020–2030 (Million metric tons CO_2e)



Source: Rhodium Group analysis.

Why do our transportation results look so different from those in the electric power sector? There are several factors in play. First, for the existing capital stock, there are more short-term fuel switching opportunities in electric power than in the transportation sector. If a carbon tax raises the effective cost of coal versus natural gas for power generation, existing natural gas–fired power plants can ramp up fairly quickly and push coal generation offline. In transportation, there is still a limited supply of low carbon biofuels that could be quickly and easily substituted for petroleum in existing internal combustion engine vehicles if a carbon tax raised the relative price of gasoline. That means the short-term responsiveness of transportation emissions to a carbon tax is driven primarily through reductions in driving, rather than fuel substitution. In addition, history suggests driving demand is relatively price inelastic.[36]

Second, when it comes to new capital decisions, sectors with high capital costs relative to operating costs are likely to be less responsive to a carbon tax because the tax primarily affects operating costs. The upfront cost of a passenger vehicle is typically an order of magnitude larger than the annual cost of operating the vehicle. Yet a carbon tax primarily increases vehicle operating costs and leaves the sticker price largely unchanged. Contrast this with the electric power sector, where existing capacity dominates, and generators compete almost completely on operating costs (because all of the capital costs are sunk). For that reason, a carbon tax does more to shift generation from coal to gas in the power sector, for example, than from internal combustion engine vehicles to electric vehicles in the transportation sector.

Table 1 shows the increase in the cost of a gallon of gasoline and diesel across our three tax rate scenarios in 2020. Fuel is a key component of vehicle operating costs. In 2016, the average cost of gasoline and diesel were $2.14 and $2.30 per gallon, respectively. In our $73/ton carbon tax rate scenario, the additional tax on gasoline would be 64 cents per gallon in 2020, a 30 percent cost increase over recent prices, but still well within the price range over the past five years.[37] With these cost increases within historical variability, it's unsurprising to see modest reductions in emissions in response to a carbon tax.

Table 1: Cost increase in transportation fuel due solely to a carbon tax, 2020 (dollars/gallon)

	Scenario		
	$14/ton	**$50/ton**	**$73/ton**
Gasoline	$0.12	$0.44	$0.64
Diesel	$0.14	$0.51	$0.75

Source: Rhodium Group analysis.

Even when a carbon tax is high enough to make electric or other zero-emission vehicles more attractive to consumers than an internal combustion engine vehicle, the pace of sector-wide emission reductions is limited by stock turnover rates. The average age of a light-duty vehicle in the United States is nearly 11 years.[38] It takes several years for new, low carbon technologies to diffuse across the national vehicle fleet because each year new cars represent just 2 percent of the total fleet. We see this in the context of current fuel economy and GHG emissions standards, where the full impact of increased stringency does not materialize until a decade after the standards come into effect, because each year's standards only apply to new cars.[39]

These results suggest that if achieving deep economy-wide GHG reductions is one of the policy goals for a carbon tax, then either a much higher carbon tax rate or policy interventions targeting transportation demand, vehicle technology, and decarbonization of fuels may be necessary.

What Are the Uncertainties?

There are a number of future developments that could change our results. The most important involve technology and policy. Regarding technology, new clean energy innovations could change the array of vehicle options available to consumers and, more importantly, could change the operational structure of the sector. Electric vehicle battery costs have dropped by over 80 percent since 2010, and at least one manufacturer offers an EV with over a 200 mile range on a lease for less than $300/month before considering state and federal incentives.[40] Many analysts project that battery costs are on track to decline further to the point where EVs could be competitive with conventional vehicles by the mid-2020s.[41]

We use battery cost projections from EIA (on the high end) and Bloomberg New Energy Finance (on the low end) to capture uncertainty in EV battery costs for our current policy and $50/ton scenarios. Still, even when low EV battery costs are considered, we see little change in transportation emissions, due in large part to slow stock turnover. If EV deployment is greater than projected in the current policy scenario due to factors other than a carbon tax (cheap batteries, better performance, state ZEV policies, etc.), then a carbon tax would have greater emissions impact than we find in this analysis. In addition, more of what is included in "transportation" emissions from fuel combustion in this analysis would end up in the electric power sector.

Autonomous vehicles (AVs) and ride sharing technology could upend the personal vehicle ownership model in ways that could change the responsiveness of driving to a carbon tax.[42] If autonomous taxis can beat the convenience, cost, and safety of personal vehicle ownership, then vehicle and fuel decisions will be concentrated among these fleet operators. The vehicles used in these fleets will lead to much shorter average lives as they will be operated to maximize their utilization, which will accelerate stock turnover. These same factors lower the capital cost to operating cost ratios of these vehicles, leading fleet owners to minimize operating costs. This could make the sector more responsive to a carbon tax. If shared AVs meet a meaningful share of overall transportation demand and run on low carbon fuels, emissions could be lower than what we report here. On the other hand, cheap and convenient transportation may lead to greater demand, putting upward pressure on GHG emissions, all else being equal.[43]

Industry

The industrial sector is highly heterogeneous with a range of different subindustries, each with its own fuel profile, production processes, energy intensity, GHG intensity, and exposure to international trade. In our carbon tax scenarios, the tax is applied to all fossil fuels consumed in the sector both for energy and nonenergy uses (such as chemical and plastic manufacturing). Fossil carbon embedded in products is eligible for a tax credit, because only carbon that is emitted is taxed. Our scenarios also include a border tax adjustment, which provides a tax credit for the export of carbon intensive manufactured goods and applies the same tax on imports. Nonfossil fuel GHGs, which made up 12 percent of total sector emissions in 2015, are not subject to the tax.[44]

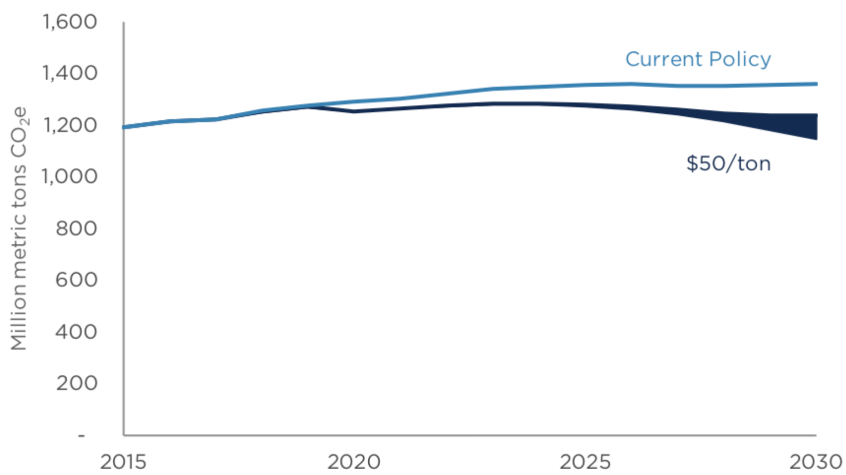
Our modeling also considers abatement technologies not included in the standard NEMS framework. The most consequential are industrial CCS, sustainably produced renewable natural gas, and modular nuclear reactors that could provide high temperature heat and power at large facilities.[45] Since none of these technologies are economic without a carbon price (above relatively limited amounts of RNG produced today), they are not deployed in our current policy scenario but could play an important role in decarbonization of the sector in the long term.

Emissions Results

In our modeling, a carbon tax achieves modest emission reductions relative to 2015 in the industrial sector. Under current policy, emissions increase by 14 percent over 15 years, from 1,194 million metric tons in 2015 to 1,366 million metric tons in 2030 (figure 7). In the $50/ton scenario, carbon tax lowers emissions to a range of 1,148 to 1,239 million metric tons in 2030, which is a reduction of roughly 130 to 220 million metric tons. The border tax provision in our scenarios prevents emissions from "leaking" out of the United States. Firms do not shift production to countries solely to avoid the carbon tax.

In addition, as mentioned earlier, macroeconomic feedbacks in RHG-NEMS are turned off in all of our model runs, because a separate study is examining the macroeconomic effects of the policies. That means the output of industrial subsectors does not change in response to the carbon tax, though energy and carbon intensity can change in response to changes in energy prices.

Figure 7: Industrial sector GHG emissions, 2015–2030 (Million metric tons CO_2e)

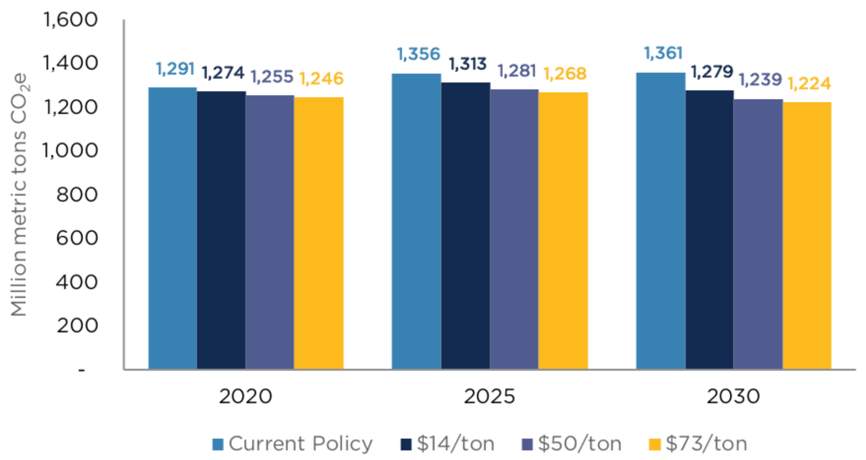


Source: Rhodium Group analysis.

In theory, the industrial sector should be responsive to a carbon tax because it is structured much like the electric power sector. The carbon tax is passed through in the relative costs of fossil fuels. There are rational actors competing for business with a strong incentive to lower costs and maximize profits by taking measures to reduce their emissions and avoid the tax. This competition already drives firms to maximize energy efficiency and explains why the sector is the least carbon intensive in the United States.[46] Most capital costs in the sector are sunk, leading to low capital cost to operating cost ratios, just as in the electric power sector.

Our results show that the industrial sector is more responsive to the carbon tax than the transportation sector, but not nearly as responsive as the electric power sector. Most of these reductions occur later in the study period. In 2030, holding technology uncertainty constant, we find industrial emissions are as low as 1,224 million metric tons in the $73/ton scenario and as high as 1,279 million metric tons in the $14/ton scenario, which is a reduction of 83–137 million metric tons compared to the current policy scenario (figure 8). There are diminishing returns for abatement, as the tax rates shift from the $50/ton pathway to the $73/ton pathway.

Figure 8: Industrial sector emissions, 2020–2030 (Million metric tons CO_2e)



Source: Rhodium Group analysis.

Uncertainties in Our Results

We have the least confidence in the industrial sector projections because the industrial sector module is relatively underdeveloped in NEMS compared to other modules. Technology availability is constrained compared to real-world opportunities, and fuel switching options for the sector in the model are limited. We have attempted to address this issue to some extent through the inclusion of CCS, modular nuclear, and RNG technologies, but data on industrial sector abatement options are limited and, in some cases, outdated.[47]

The low carbon technologies included in our model could become cheaper and more available sooner, driving emissions down faster. Alternatively, the same technologies could end up being more expensive or available later, pushing emissions higher. There are also several technologies not included in our modeling that could change our results if they were, such as electrification of industrial processes, new low carbon production processes for key products such as cement and aluminum, and waste combustion for pulp and paper. More speculative and disruptive technologies, such as three-dimensional printing, could completely reset entire supply chains, thus changing emissions profiles. Further investigation into the price responsiveness of industry to a carbon tax is warranted and, in our view, a priority area for model improvement.

Changes to the design of the carbon tax could also change our results. The legality of carbon border tax adjustments is not a settled matter in international law.[48] If a carbon tax does not contain a border tax adjustment, or if that adjustment is found to be illegal and trading partners do not impose policies of similar stringency, then domestic industrial output could decline due to increased international competition, causing emissions from energy intensive, trade exposed industries to decline faster than our results show. While US emissions would decline in such a situation, emissions in other countries would increase, resulting in no net climate benefit. On the other hand, new research suggests that border tax adjustments could lead to a stronger dollar, which would reduce the competitiveness of US industry and could lead to lower output and lower emissions relative to a policy without a border carbon adjustments.[49] This possible outcome is sensitive to how carbon tax revenue is used, which is a focus of other papers in this series.

Buildings

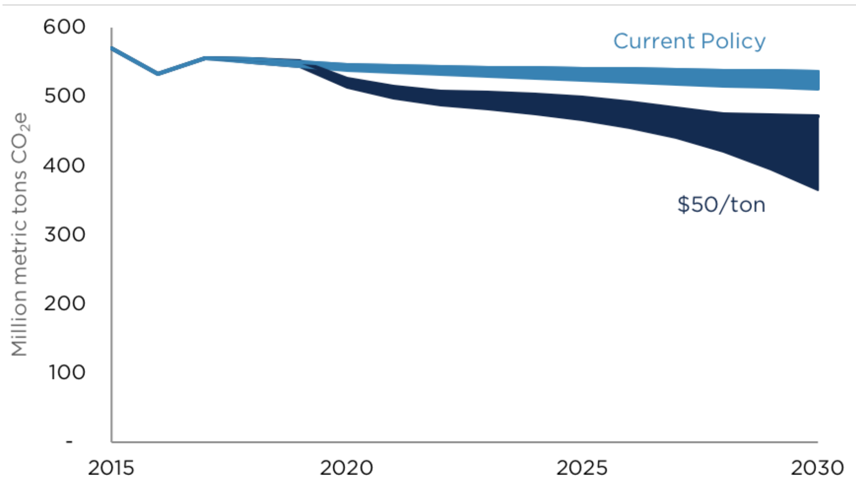
A carbon tax can influence GHG emissions from the combustion of fossil fuels in residential and commercial buildings as the tax is passed through in fuel prices. Like the transportation sector, the building sector consists of millions of consumers all maximizing their utility through their consumption decisions. Consumers predominantly use fossil fuels for space heating and water heating.[50] They can respond to the carbon tax by reducing their consumption of energy services in the near term, and by fuel switching, building shell improvements, energy system management strategies, and replacing existing appliances with more efficient equipment over time. Fuel producers can also decarbonize fuels upstream to avoid the tax. For example, RNG could be "dropped" into the natural gas system. Consumers will have different fuel and technology options depending on where they are located in the United States. For example, more than 10 percent of US homes, mostly in rural areas, are heated with fuel oil or propane.[51]

Buildings are also the largest source of electric demand in the US energy system. In this analysis, the emissions implications of electricity use in building are accounted for in the electric power sector, since that is where GHGs are emitted into the atmosphere.

Emissions Results

Under current policy, we see building emissions slowly decline from 2015 levels of 571 million metric tons to a range of 512 to 536 million metric tons in 2030 (figure 9). The decline is due to efficiency improvements driven by federal appliance standards and building codes as well as state efficiency programs. The range represents uncertainty around the deployment of highly efficient technologies over time.

Figure 9: US GHG emissions from buildings, 2015–2030 (Million metric tons CO_2e)

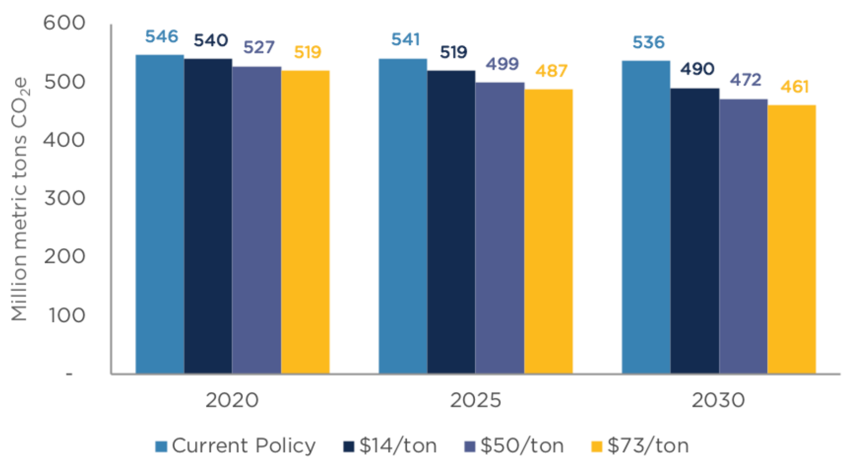


Source: Rhodium Group analysis.

In the $50/tax rate scenario, emissions begin to decline in the first years of the program as consumers reduce demand for energy services in response to higher fuel prices. By 2030 the emissions range under the tax widens to 365–472 million metric tons, reflecting wide uncertainty around the availability of RNG. We assume there is finite supply of sustainable biomass for RNG production, with that supply fully utilized by 2030. The economy-wide limit is 2.5 quads per year in the upper end of our emissions range and 6.8 quads per year on the lower end. These limits were constructed based on multiple sources in the literature.[52] See the technical appendix for more information.

Looking at emissions abatement across the three carbon tax rate scenarios (while holding technology assumptions constant), we find that the buildings sector is modestly responsive to price: more responsive than the transportation sector but less than industry and much less than electric power. In 2030, we find that emissions are as low as 461 million metric tons in the $73/ton scenario and as high as 490 million metric tons in the $14/ton scenario (figure 10). This represents reductions of 9–14 percent relative to current policy in 2030.

Figure 10: Building sector emissions, 2020–2030 (Million metric tons CO_2e)



Source: Rhodium Group analysis.

The modest abatement and stable response to the carbon tax over time in buildings is explained by the fact that the building energy services required, such as space heating and water heating, are difficult for consumers to reduce in large quantities.[53] In the winter, consumers will turn down their thermostats only so far to reduce costs. There are also limits to the attention that energy receives in cost management in commercial buildings, owing to high capital cost to operating cost ratios and the fact that energy costs are less than 1 percent of the total cost of doing business for the average service sector corporation. Another reason consumers may not be responsive to increases in energy costs are principal-agent problems.[54] For example, if a building owner is responsible for heating costs, then tenants will not change their behavior at all in response to a carbon tax.

Just as in the transportation and industrial sectors, stock turnover is also a barrier to deeper emissions abatement in buildings. The average commercial building is 32 years old, and two-thirds of residential homes were built before 1990.[55] Building energy codes can improve the efficiency of new buildings but do not make an appreciable impact on total sector energy consumption for several years due to slow stock turnover. Retrofitting existing buildings to improve efficiency is labor and capital intensive. While space heating and water heating equipment turns over more quickly than a building does, such equipment still lasts 10–20 years.[56]

We find that most abatement achieved in the building sector comes from RNG. Fuel producers have an incentive to avoid the tax when sustainable biomass is available. "Upstream" (at the point of combustion) fuel decarbonization avoids many of the issues discussed above.

If additional abatement beyond what is achieved by the carbon tax is a desirable outcome, additional complementary policies targeting the buildings sector may be necessary. Additional efficiency policies can help, but, due to stock turnover, they have long lead times. Research and development into the expansion of sustainable drop-in fuels could be an option. In addition, policies that require or incentivize the electrification of space heating and water heating in buildings could drive consumption to the more rapidly decarbonizing electric power sector.

What Are the Uncertainties?

New technologies for end users or fuel producers could significantly impact our results. On the production side, as stated above, we found that switching from natural gas to RNG represents the largest share of abatement in the building sector. If there is more RNG available at lower costs than what we assumed in this analysis, emissions reductions could be larger than reported here. If RNG availability is less than what we assumed, or if the costs are higher, then emissions reductions would be lower. Regardless of availability, if RNG production is not sourced from sustainable biomass, then emissions would increase elsewhere in the US or global economy.

On the end-user side, lower costs or improved performance of new low carbon equipment would likely reduce emissions, especially in the long term. If costs are higher or performance is worse, emissions will be higher. Another uncertainty is the role of Internet-connected appliances/equipment and new building management services available to both homeowners and commercial building owners. These new offerings may enable more rapid and deeper cuts in energy consumption, though it is unclear by how much.

Rest of GHGs

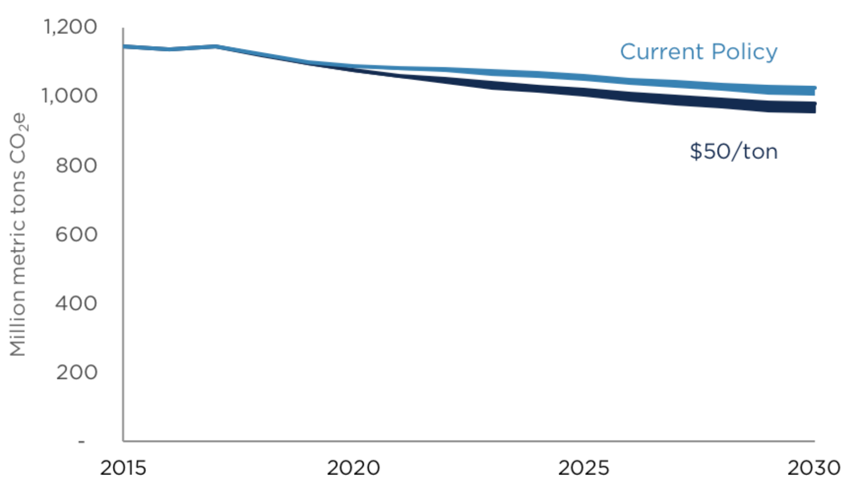
The remaining GHGs across the US economy are not covered by a carbon tax in our analysis, except for methane emissions from the production of coal, oil, and natural gas. We assume fuel producers pass the full costs of methane taxes on to consumers in the form of higher fuel prices and do not take on any mitigation actions in response to the tax. Remaining emissions in this category come from a diverse set of sources and gases across the US economy, including agriculture, waste, and industrial chemicals, such as substitutes for ozone depleting substances (ODS).

Emissions Results

We find that a carbon tax leads to small reductions in GHG emissions from other sources. We find that abatement achieved by a carbon tax is 2 percent, 4 percent, and 5 percent of current policy emissions in 2030 for the $14/ton, $50/ton, and $73/ton tax rate scenarios, respectively.

In the current policy scenario, emissions decline from 1,146 million metric tons CO_2e in 2015 to 1,003–1,029 million metric tons in 2030 (figure 11). The decline is largely due to expected reductions in ODS substitutes as the United States follows through on its commitments under the Kigali Amendment to the Montreal Protocol.[57] In the $50/ton tax rate scenario, emissions decline to a range of 956–982 million metric tons CO_2e in 2030. This is largely a result of lower fossil fuel production, as demand for these fuels (particularly coal) declines in end-use sectors. The next chapter of this report considers the impact of a carbon tax on energy production in detail.

Figure 11: Emissions from all other sources, 2015–2030 (Million metric tons CO_2e)



Source: Rhodium Group analysis.

To achieve larger emissions reductions, one option is to expand coverage of the tax to more emitters. Large, stationary source emitters in the waste sector already report emissions to EPA and represent 2 percent of total US emissions.[58] Covering sources in the agriculture sector may be more challenging due to accounting and monitoring challenges.[59] Given such challenges, these sources may be more amenable to other policy interventions that provide incentives for lower carbon management and production practices.

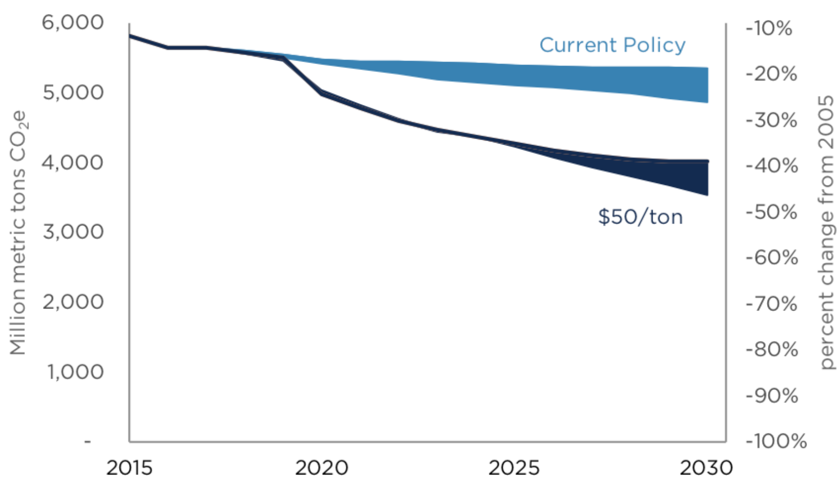
What Are the Uncertainties?

As noted above, we assume that the carbon tax applied to methane from fuel production is fully passed on to consumers and that no methane abatement occurs in response to the tax. There is the possibility that some abatement may occur as producers take measures to avoid the tax, especially if they are unable to completely pass through those costs. We do not include any abatement estimates in this analysis because available methane abatement cost curves are outdated and do not incorporate many technological advances.[60] Total emissions may be lower than what we report here due to this limitation.

Putting It All Together: Economy-Wide Impacts

Here we consider the aggregate results of a carbon tax on total US GHG emissions. We find that a carbon tax can be an effective policy to reduce GHG emissions in the near- and medium-term. Under the $50/ton tax rate scenario, we find that emissions could be 4.2–4.3 billion metric tons in 2025 and between 3.5 and 4 billion metric tons of CO_2e in 2030 (figure 12) with the range reflecting technological uncertainty. Relative to 2005 emissions levels, the range represents a 35–36 percent reduction in 2025 and a 39–46 percent reduction in 2030.

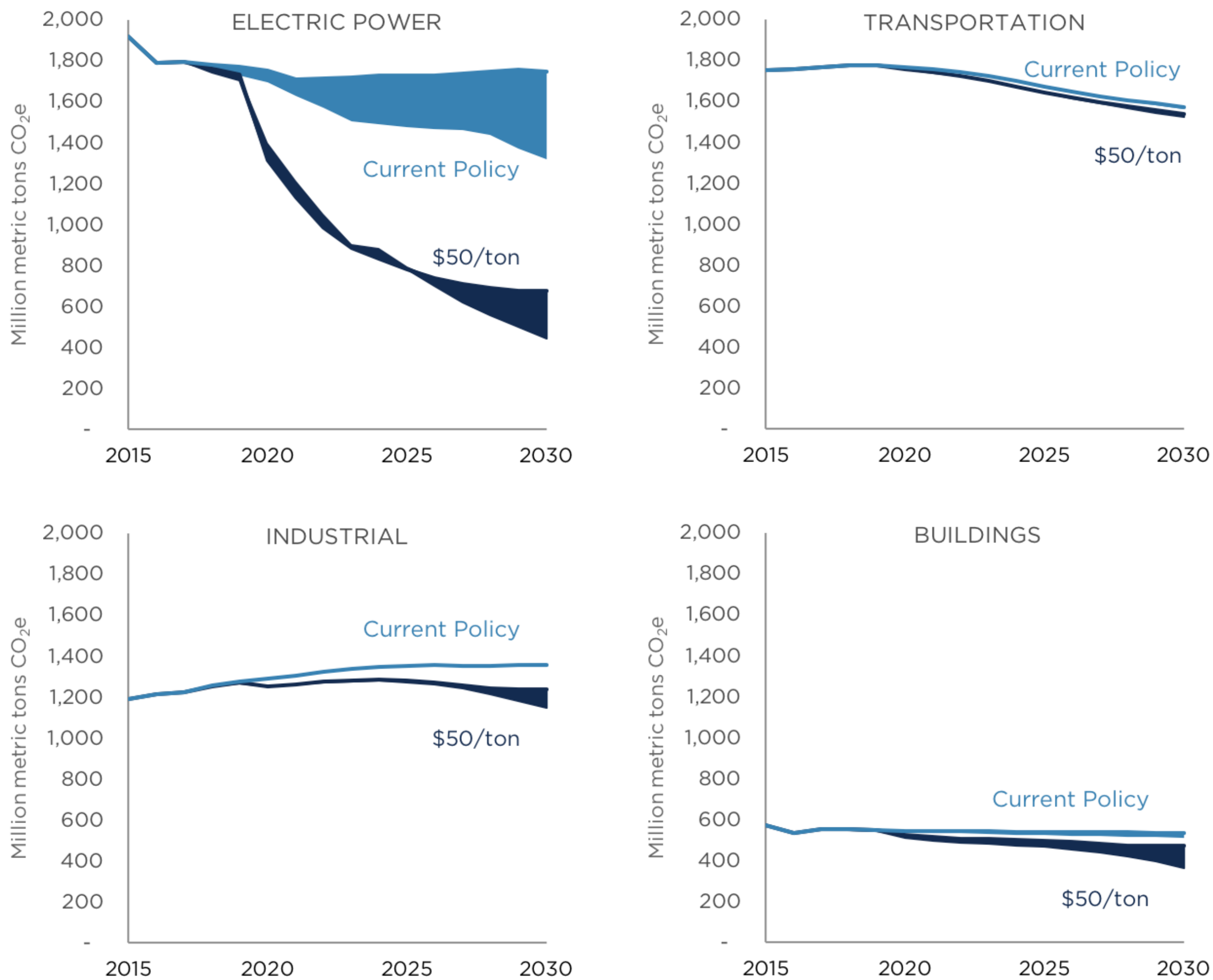
Figure 12: US net GHG emissions, 2015–2030



Source: Rhodium Group analysis.

As mentioned above, most emissions reductions occur in the electric power sector. Competitive markets, low capital cost to operating cost ratios, rational economic decision-making, and an array of near- and long-term abatement options facilitate deep and swift reductions in power sector emissions (figure 13). Due to nonprice barriers, stock turnover constraints, higher capital cost to operating cost ratios, and a smaller set of abatement opportunities, end-use sector emissions see modest declines in emissions. Our results resemble those found in other recent research where similar carbon tax rates were modeled.[61]

Figure 13: US GHG emissions by major sector, 2015–2030 (Million metric tons CO_2e)



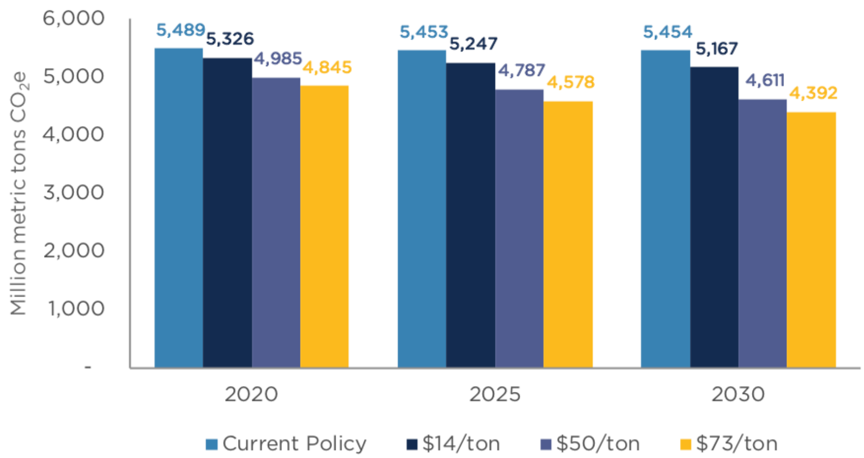
Source: Rhodium Group analysis.
Note: Emissions from all other sources other than these four sectors are not presented in the figure

The Economy-Wide Response to Changes in Tax Rate

The US economy is responsive to changes in the carbon tax rate. When controlling for technology uncertainty, we find that the $14/ton tax rate scenario results in economy-wide net GHG emissions of 5,247 million metric tons in 2025 and 5,167 million metric tons in 2030 (figure 14). This represents a roughly 200 million metric ton and 300 million reduction relative to current policy in 2025 and 2030, respectively. The $50/ton tax rate scenario leads to emissions of 4,787 million metric tons in 2025 and 4,611 million metric tons in 2030, a reduction of roughly 650 million and 840 million metric tons in 2025 and 2030, respectively.

In 2030, reductions are 2.5 times greater in the $50/ton scenario than the $14/ton scenario. In the $73/ton scenario, emissions are 4,392 in 2030, which is just over one billion metric tons lower than current policy in that year. The additional emissions reductions in the $73/ton scenario primarily occur in the electric power sector.

Figure 14: US net-GHG emissions under different tax rates (Million metric tons CO_2e)



Source: Rhodium Group analysis.

GHG Emissions beyond 2030

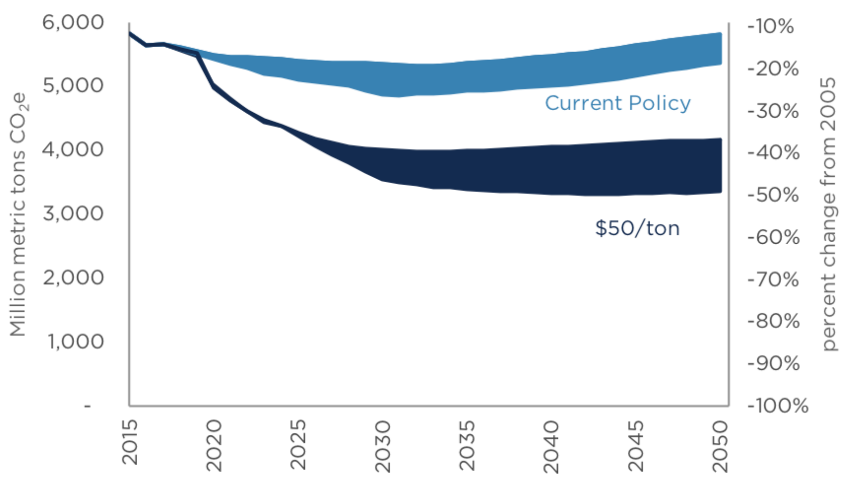
From the mid-2030s onward under current policy, our results show that the growth in population, the economy, and household and business energy demand outpace efficiency improvements and clean energy deployment, causing emissions to rise (figure 15). Under current policy, emissions in 2050 are between 12 and 26 percent below 2005 levels. We have less confidence in the 2030–2050 projections, as technological, economic, and behavioral uncertainties in forecasting only increase over time. That said, given the long-term nature of the problem of climate change, it is worth considering our model results beyond 2030.

We find that in the $50/ton tax rate scenario, emissions initially decline after 2030, but at a much slower rate. Depending on technological uncertainty, emissions begin to increase as early as 2034 or as late as 2045. By 2050, emissions in the $50/ton tax rate scenario are 37 to 49 percent below 2005 levels, which is similar to the 39 to 46 percent reductions we found for 2030, but still a large departure from the current policy scenario. We found directionally similar results in our $14/ton and $73/ton tax rate scenarios, and other studies have found similar results as well.[62]

Why does the US emissions pathway flatten out under a carbon tax? Projecting the future is difficult, especially when looking out several decades. While our analysis considers a broad array of clean energy technologies, it is challenging to project how costs and performance will improve over time, especially if a price on carbon catalyzes additional innovation. There is also the potential that new technologies not considered in our modeling, such as low carbon, drop-in biofuels, or electric automated rideshare vehicles, could become cost effective in the future and lead to deeper reductions in emissions.

That said, our modeling shows electric power sector emissions continuing to decline through 2050 while emissions in other sectors rebound. This could be because the model is not capturing potential future innovations. It could also be that the factors that make end-use sectors less responsive to a carbon tax, including stock turnover, high capital cost to operating cost ratios, and principle-agent problems, are such that emissions will not continue to decline absent higher carbon tax rates and/or separate policies that target these barriers to decarbonization.

Figure 15: US net GHG emissions, 2015–2050



Source: Rhodium Group analysis.

Implications

Under a classic Pigouvian approach, as long as "external" (i.e. non-market) costs are accurately priced, the extent to which a carbon tax reduces emissions is not important. For example, if a four-dollar-per-pack tax on cigarettes is sufficient to cover the health system costs of smoking, then people can choose for themselves whether the full costs of smoking are worthwhile. In theory, the cost imposed on the rest of society has been addressed in that scenario.

There are, however, two related challenges in applying a purely Pigouvian approach to carbon, and reasons why the likely emissions responsiveness of a carbon tax matters:

1. There is a much higher level of uncertainty surrounding the social cost of carbon than the social cost of, for example, smoking. That means policy makers will have much less confidence that they have set the tax rate at the right level to fully internalize external costs.

2. Related to the first point, if the world is going to meet international climate change objectives, US emissions will likely need to fall to near zero by the latter half of this century.[63]

> We find that the United States is far from achieving that objective using carbon tax rates derived from current estimates of the social cost of carbon. This suggests that other barriers, such as those identified in this study, may need to be addressed if the United States is to make a substantial contribution to global climate change mitigation

A carbon tax at all the rates evaluated in this report except the $14/ton scenario would be sufficient for the United States to achieve its Paris Agreement pledge for 2025. However, unless there is a dramatic acceleration in the decarbonization of buildings, transportation, and industry, it may fall far short of delivering long-term US emission goals. To the extent to which those goals are important for US policy makers, complementary policies, a higher starting tax rate, and/or a faster escalation of the tax rate over time will likely be required.

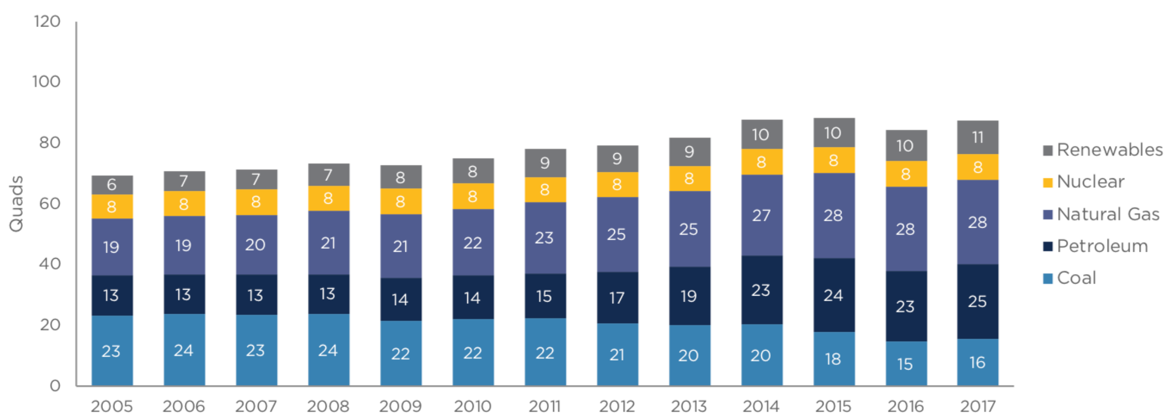
THE ENERGY SYSTEM IMPLICATIONS OF A CARBON TAX

Our GHG emissions results show that different sectors of the economy respond differently to a carbon tax. The results reflect changes in energy production and demand under the carbon tax rate scenarios. In this section we examine these changes in detail. Due to increasing uncertainty in the later years of our projections and the fact that short- and medium-term energy market changes may be most relevant to policy makers considering a carbon tax, results in this chapter are focused on the first decade of a carbon tax policy (from 2020 through 2030). We first review changes in US energy supply and demand by fuel. Then, we consider energy prices and expenditures.

Energy Supply and Demand

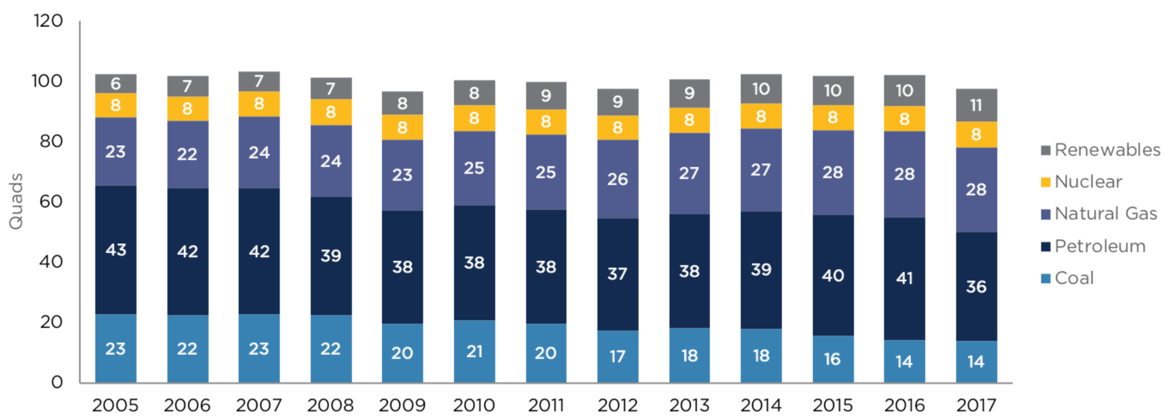
Overall, total primary energy production in the United States increased by 26 percent from 2005 through 2017 (figure 16). Just as they have through recent history, fossil fuels have dominated the boom in energy production. Since 2005, coal production declined 33 percent, in large part due to the surge in natural gas production associated with the ascent of hydraulic fracturing and horizontal drilling technologies.[64] These technologies drove US natural gas and petroleum production up by 50 and 84 percent, respectively, over the same time frame.[65] Zero-emissions energy sources have also increased over the past decade. While nuclear energy production held constant, renewable energy led by wind and solar increased by 80 percent.[66]

Figure 16: US primary energy production, 2005–2017 (Quads)



Source: Energy Information Administration.

Figure 17: US primary energy consumption 2005–2017 (Quads)



Source: Rhodium Group analysis.

While energy production in the United States has increased since 2005, primary energy demand has declined by 2 percent, from 100 quads in 2005 to 98 quads in 2017 (figure 17).[67] Overall, fossil fuels represented 80 percent of total demand in 2017, followed by renewables and then nuclear.[68] Demand for coal largely followed the trends in coal production, because only a small amount of US coal production is exported. Petroleum demand declined by 15 percent due in large part to improvements in vehicle efficiency and slower growth in vehicle miles traveled.[69] Natural gas consumption increased by 24 percent as the fuel took market share from coal in the electric power sector.[70] Finally, renewables consumption has increased in line with production. The surge in US energy production and relatively flat consumption resulted in US net imports dropping from 30 percent of consumption in 2005 to 8 percent in 2017.[71]

Next, we review the impacts of our carbon tax scenarios on energy production and consumption across fuels. All results in this section utilize our more conservative set of assumptions related to technological progress, corresponding to the upper bounds of the ranges of emissions outcomes displayed in the previous section.

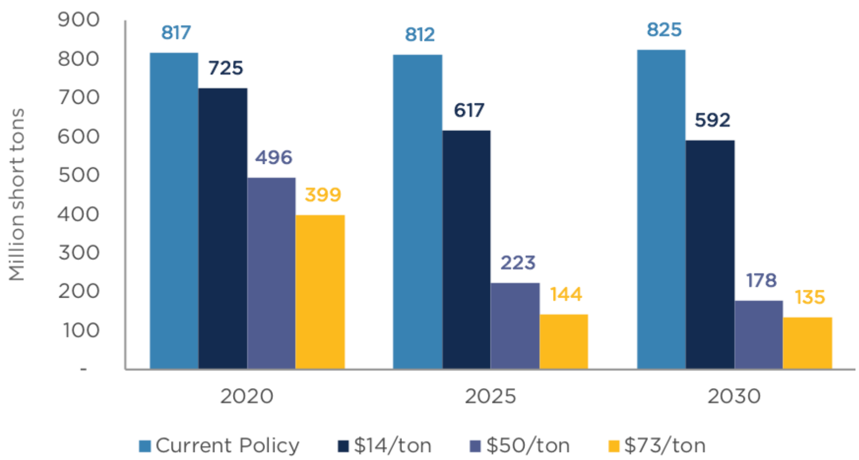
Coal

Coal is the most carbon intensive fossil fuel produced in the United States. In the $50/ton tax rate scenario, US coal production drops by roughly 300 million short tons in the first year of the tax (figure 18). Production continues to decline rapidly after the first year, to 178 million short tons in 2030, or 78 percent below the current policy scenario production levels in that year. The $14/ton tax rate scenario results in an 11 percent reduction in coal production relative to current policy in 2020, or 725 million short tons, and a 28 percent reduction in 2030 (figure 18), or 592 million short tons. Under the $73/ton tax rate scenario, coal production is 399 million short tons in 2020, half the production under current policy in that year. In 2030, coal production in this case is 135 million short tons.

The rapid decline in coal production under a carbon tax is explained by the fact that 93 percent of coal consumed in the United States is used in the electric power sector, with the rest used in the industrial sector.[72] The shift in electric power generation away from coal to lower carbon generation options leaves few domestic market opportunities for coal producers.

Exports of US coal are not covered by the carbon tax and remain roughly constant under the carbon tax and current policy scenarios at roughly 65 million short tons per year between 2020 and 2030. If a US carbon tax spurs more ambitious climate policy abroad, we would expect global coal demand and perhaps US coal exports to decline.

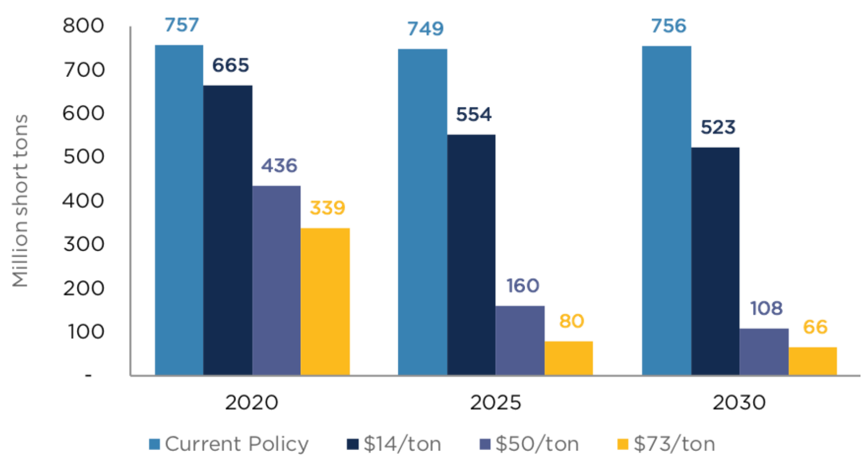
Figure 18: US coal production, 2020–2030 (Million short tons)



Source: Rhodium Group analysis.

Demand for coal follows the decline in coal generation in the electric power sector. US coal demand rebounds from 717 million short tons in 2017 to roughly 757 million short tons in 2020 in our current policy scenario and stays roughly at that level through 2030. In 2020 we find that coal demand drops to 665 million short tons in the $14/ton scenario relative to current policy, or 11 percent (figure 19). In the same year, demand is 436 million short tons (39 percent) and 339 million short tons (51 percent) in our $50/ton and $73/ton tax rate scenarios, respectively. By 2030, coal demand declines to 523, 108, and 65 million short tons in the $14/ton, $50/ton, and $73/ton tax rate scenarios, respectively. This represents as much as an 84 percent decline relative to current policy.

Figure 19: US coal demand, 2020–2030 (Million short tons)



Source: Rhodium Group analysis.

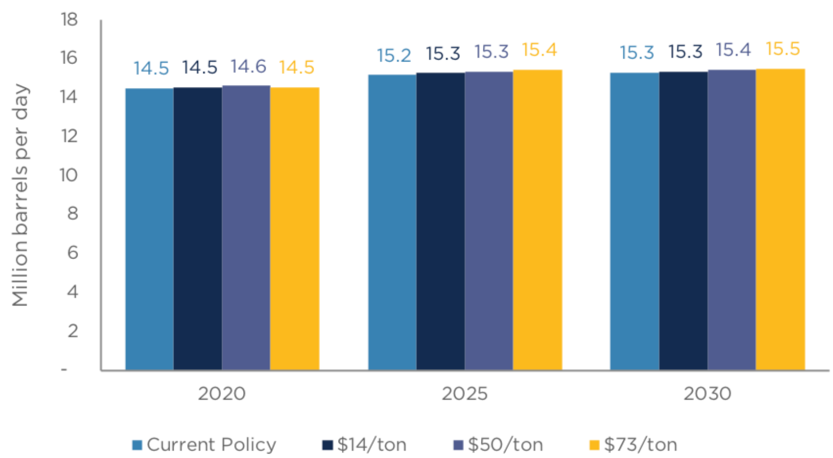
Our results could change depending on the wholesale cost of natural gas relative to coal in the projection period. Higher natural gas prices would lead to higher coal production than what we report here, though it is unlikely that the coal sector would see no decline under a carbon tax. Another important uncertainty is the degree to which electricity consumers respond to increases in electricity prices under a carbon tax. If consumers are more responsive and electric demand is lower than our projections, then coal production and demand may decline faster under a given carbon tax rate. The converse also holds true. If overseas markets for US coal are more favorable than in our projections and additional export capacity is built, then exports and total US coal production could be higher, because our results assume no changes in policies in other parts of the world. Finally, if low-cost CCS technologies become available that enable cost-effective retrofits of existing coal plants, then coal production could be higher than what we report here. Our analysis finds that no coal plants with CCS are built in any of our carbon tax scenarios.

Petroleum

Petroleum production is subject to very different market dynamics relative to coal. First, prices are set in a global market rather than a domestic market. Second, as opposed to the electric power sector, petroleum fuels are primarily used in end-use sectors that are less responsive to a carbon tax. Finally, ever since Congress lifted the ban on crude oil exports in 2015, US producers have had access to markets overseas, and exports are not covered by the carbon tax. This analysis assumes no change in climate policies overseas as a result of the United States adopting a carbon tax.

Under the current policy scenario, US petroleum production increases from 12 million barrels a day in 2016 to 15.3 million barrels a day in 2030 (figure 20). In the $50/ton tax rate scenario, oil production increases above current policy levels in the early 2020s by up to 0.1 million barrels a day and then is little changed from current policy levels by 2030. The increase in production under a carbon tax occurs because marginal oil production is influenced by the price of natural gas. As we will review below, natural gas production increases in the near term under a carbon tax, making oil wells with associated gas more economical. Looking across our three tax rate scenarios, we find that oil production is not sensitive to changes in the carbon tax rate. There is a less than 2 percent increase in US oil production relative to current policy across the three carbon tax rate scenarios considered in this analysis.

Figure 20: US petroleum production, 2020–2030 (Million barrels per day)

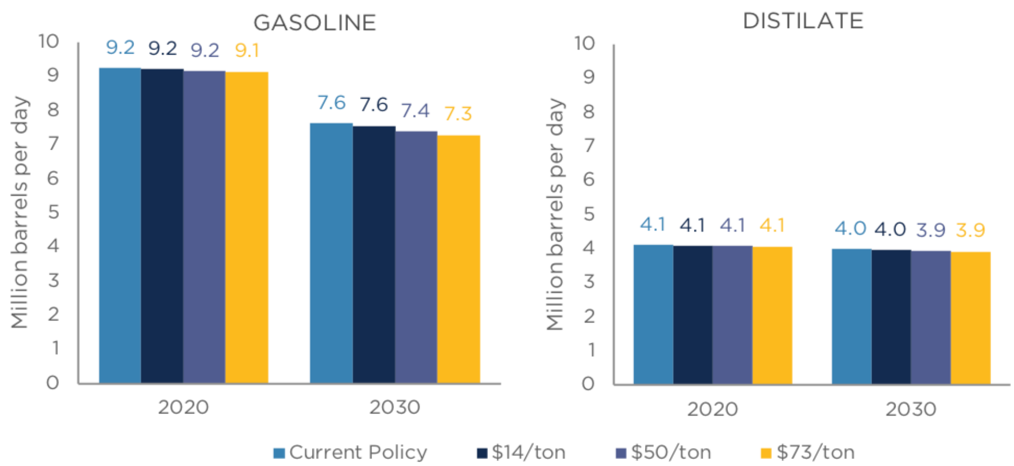


Source: Rhodium Group analysis.

Looking at petroleum demand, we focus on gasoline and distillate fuel (diesel and home heating oil), which account for roughly two-thirds of total US petroleum demand on a volumetric basis. Gasoline is almost exclusively used to fuel passenger vehicles, while distillate is primarily used in the transportation, industrial, and buildings sectors. In total, both fuels are used in sectors that are relatively less responsive to increases in energy prices due to a carbon tax.

We find that demand for both fuels is largely unchanged under our tax rate scenarios. In the $14/ton scenario, demand is little changed relative to current policy (figure 21) both in 2020 and 2030. By 2030, we find a 0.2 to 0.3 million barrel per day reduction in gasoline demand in the $50/ton and $73/ton scenarios, respectively. In the same year, we find a 0.1 million barrel per day decline in distillate in both scenarios. These small changes in demand are the result of the nonprice barriers discussed in the previous chapter and the relatively small impact of a carbon tax on fuel prices.

Figure 21: US refined product demand in 2020, 2030 (Million barrels per day)



Source: Rhodium Group analysis.

Under a carbon tax, the United States will continue to be a net importer of crude oil even with the small increases in production and decreases in demand we see in the carbon tax rate scenarios. However, we find that net imports of crude oil decline with higher tax rates relative to current policy. By 2030, net petroleum imports decline by 2 to 12 percent relative to 6.8 million barrels per day in the current policy scenario.

Important uncertainties that influence our results include future global oil prices, policy changes in other countries, and technology changes in the transportation sector. Higher oil prices will cause higher exports and production levels. The converse is also true. If US adoption of a carbon tax drives greater global climate policy ambition, then global demand for petroleum and global oil prices will be lower, leading to lower US production. If there are technological breakthroughs allowing commercial scale production of low carbon drop-in biofuels, then production may be lower than what we report here. Finally, if the future vehicle fleet significantly shifts toward EVs, then demand for petroleum may be lower than reported here, though exports could increase in that scenario.

Natural Gas

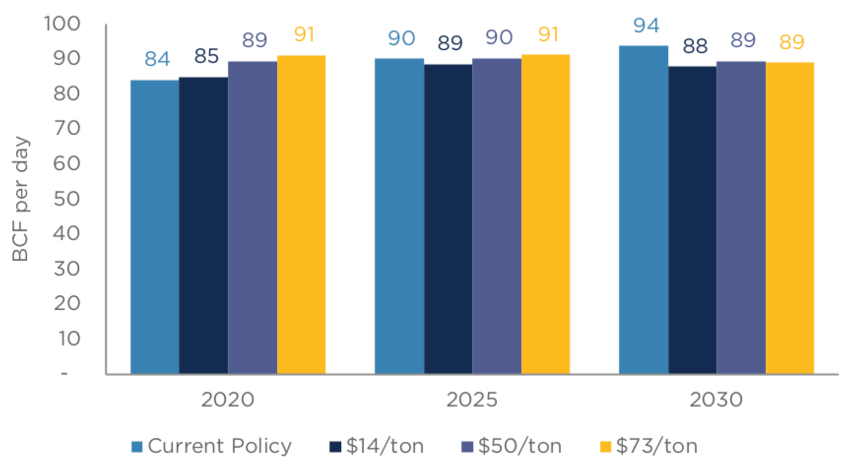
Natural gas is used in every major energy sector of the US economy, and, on net, the United States is an exporter of natural gas. Prices are primarily set in domestic markets, though increasing export capacity will likely make prices more sensitive to global demand in the future. Natural gas is also the least carbon intensive fossil fuel, and the one fuel that competes with a renewable drop-in substitute in our analysis. These attributes make production of this fuel respond differently to a carbon tax relative to coal or petroleum.

On the demand side, natural gas plays a small role in the transportation sector, but it is the dominate fuel in the buildings sector, it currently fuels a third of the electric power sector, and it is an important fuel and feedstock in the industrial sector.

We find that natural gas production increases relative to the current policy scenario in all carbon tax rate scenarios in 2020 (figure 22). This is due to the shift in electric power sector dispatch away from coal and toward natural gas. Natural gas demand (inclusive of RNG) follows a similar path. Total natural gas demand in 2030, inclusive of 6.8 BCF/day of RNG, is roughly similar across tax rate scenarios compared to current policy. Gas demand in the electric power sector declines from the 2020 spike as renewable generation takes on market share. We find that natural gas plants equipped with CCS become economic in the $50/ton and $73/ton tax rate scenarios, with 0.7 GWs and 10.4 GWs of capacity added, respectively, by 2030. Still, this low carbon technology represents no more than 3 percent of all natural gas combined-cycle generating capacity installed in that year.

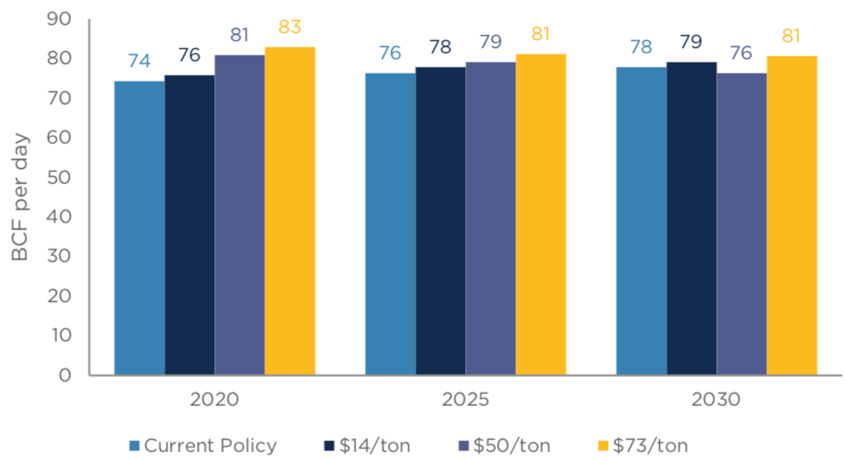
Renewable electricity plus the rise of RNG in the energy system cause natural gas production to decline by 5 to 6 percent across the tax rate scenarios in 2030. In 2030, gas demand is close to current policy levels of 78 BCF per day for the $14/ton and $50/ton scenarios (figure 23). Total gas demand is 3 BCF per day higher in the $73/ton scenario in 2030.

Figure 22: Natural gas production (fossil only), 2020–2030 (BCF per day)



Source: Rhodium Group analysis.

Figure 23: Total natural gas demand (including renewable), 2020–2030 (BCF per day)



Source: Rhodium Group analysis.

Higher demand for natural gas in the early years of the tax leads to a reduction in net exports of natural gas relative to current policy, but the effect is small. By 2030, net exports are as low as 14 BCF/day in the $50/ton scenario, compared to 16 BCF under current policy.

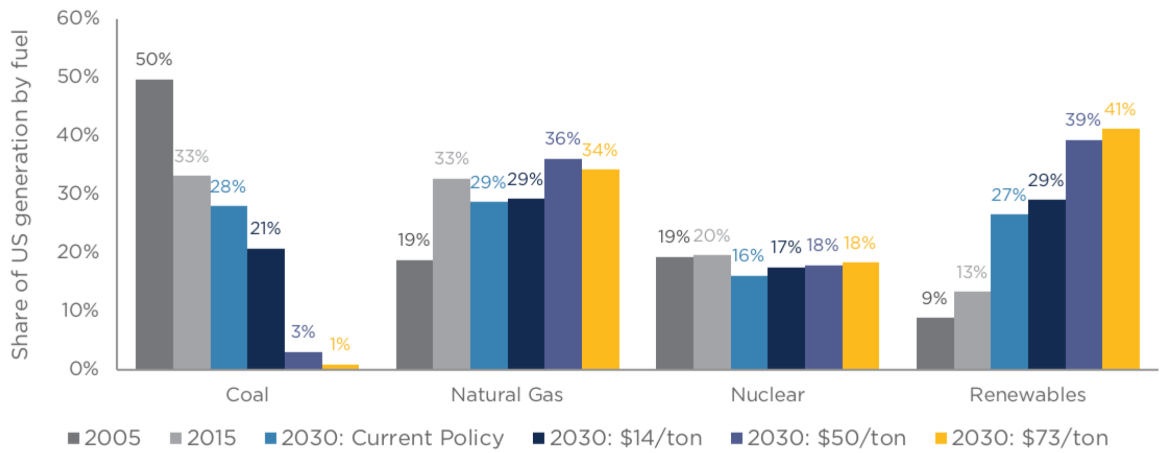
Electricity

We find large and directionally similar changes in the US electric power generation mix across the three tax rate scenarios. In the current policy scenario, electricity generation from coal is 28 percent of total generation. This reflects a continuation of recent market trends, in which cheap natural gas and renewables drove coal's market share down from 50 percent in 2005 to 33 percent in 2015 (figure 24). Meanwhile, in the current policy scenario, renewables provide 27 percent of total generation in 2030, more than double their share in 2015, and natural gas provides 29 percent of total generation in 2030, which is a slight drop from 33 percent in 2015.

We find that a carbon tax accelerates the shift away from coal and toward natural gas and renewables. In the $14/ton scenario, coal generates 21 percent of 2030 electricity (while generation from renewables increases to 29 percent of total generation). Coal's share of generation in 2030 drops to 3 percent and 1 percent of total generation in the $50/ton and $73/ton scenarios, respectively. This decline of coal is the largest driver of emission reductions due to the carbon tax. Renewables' share of generation increases to 39 percent and 41 percent for the $50/ton and $73/ton scenarios, respectively, in 2030. In 2030, natural gas (inclusive of RNG) generation across all three tax scenarios falls close the range of its 2015 share of 33 percent. However, natural gas's share of generation reaches as high as 40 percent in 2024 in the $73/ton scenario before renewables' capacity ramps up by the mid-2020s.

The share of nuclear energy in the generation mix stays roughly the same across the current policy and tax scenarios. The current policy scenario does not include several nuclear retirements announced after May 2017. While a carbon tax could be sufficient to help some of these plants remain economic, such an assessment is outside the scope of this analysis. High costs and long lead times relative to renewables limit the role of new nuclear plants through 2030. The same holds true for fossil generation equipped with CCS. Though not shown in figure 24, natural gas with CCS represents 3 percent of total US generation in our $73/ton scenario and less than 0.1 percent in the lower tax rate scenarios in 2030. Due to the low pretax price of gas relative to coal, no coal fired generation equipped with CCS is deployed in our tax scenarios.

Figure 24: Share of US generation by fuel, 2005, 2015, 2030



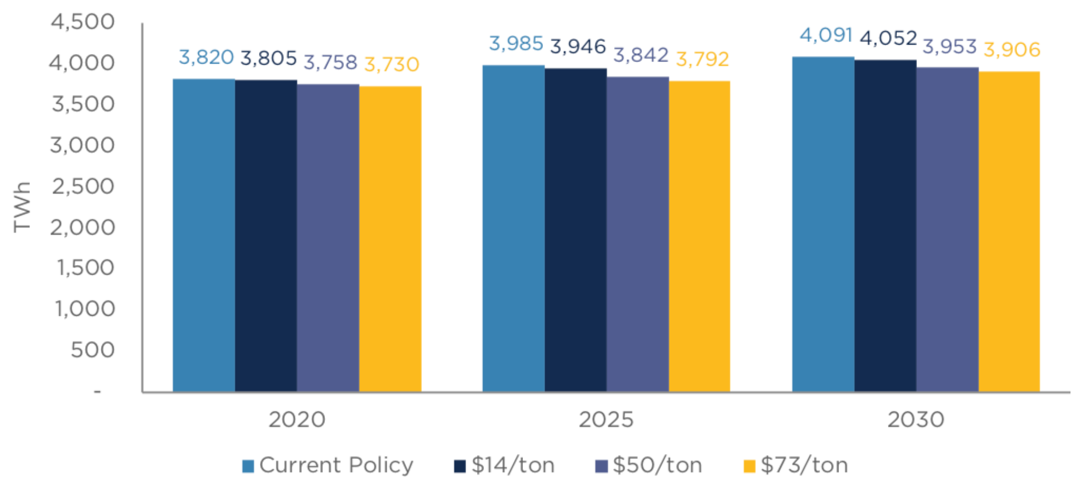
Source: US Energy Information Administration; Rhodium Group analysis. Notes: Shares do not sum to 100 percent because they do not include generation from petroleum or biomass. Natural gas generation includes RNG.

Electric demand responds to the changes in electricity rates caused by the carbon tax. Consumers can reduce their demand for electricity services such as lighting and heating. Over time, they can replace old equipment with more efficient technologies.

In 2020, total US electric demand is 3,820 TWh in our current policy scenario (figure 25), up slightly from 3,726 TWh in 2015. By 2030, demand rises to 4,091 TWh, reflecting a slow increase in demand following relatively flat retail sales in recent years.

We find that electric demand is not highly responsive to a carbon tax. Demand is lower relative to current policy for higher carbon tax rates, but only by a small amount. In the $14/ton tax rate scenario, demand is 3,805 TWh in 2020, a less than 1 percent decline. In the $73/ton tax rate scenario, demand is 3,730 TWh, which is 2.5 percent lower than under current policy. As tax rates increase over time, we find similar relative reductions in demand. In 2030, demand in the $14/ton scenario is 4,052 TWh, which is 1 percent lower than the 4,091 TWh in the current policy scenario. In the same year, demand in the $73/ton carbon tax scenario is 3,906 TWh, which is 4.5 percent lower than in the current policy scenario.

Figure 25: US electric retail sales, 2020, 2025, 2030 (TWh)



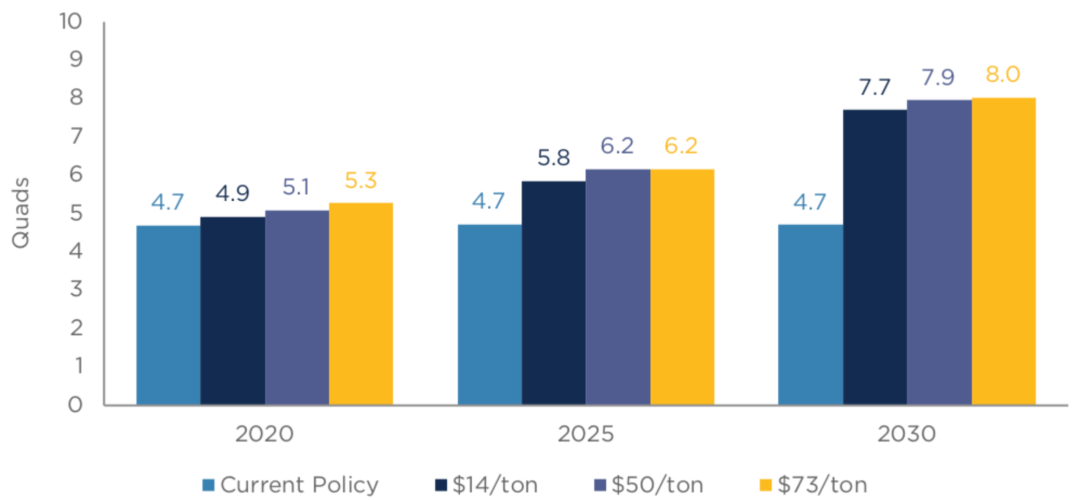
Source: Rhodium Group analysis.

Biomass

The GHG emissions from the combustion of biomass energy are not subject to the carbon tax in this analysis. While some sources of biomass and biofuel production pathways do result in net-GHG emissions to the atmosphere, the exact amount is subject to considerable debate.[73] We estimate that total biomass primary energy supply under our carbon tax scenarios increases from a roughly constant 4.7 quads under current policy from 2020 through 2030 to as much as 8 quads in the $73/ton tax rate scenario in 2030 (figure 26). Our more aggressive technology scenario assumes the supply of sustainable and cost-competitive biomass is 15 quads by 2030.

Taxing GHG emissions associated with biomass could reduce or eliminate the incentive to use biomass as an abatement option and would reduce supply to levels lower than we report here. Taxing biomass emissions (for example, with a tax rate adjusted to reflect the relative life-cycle carbon intensity of the biomass fuel relative to a reference fossil fuel value) would add complexity to the carbon tax program, but it would also increase incentives to use the lowest carbon biomass fuels and feedstocks.

Figure 26: US biomass primary energy supply (Quads)



Source: Rhodium Group analysis.

Prices and Expenditures

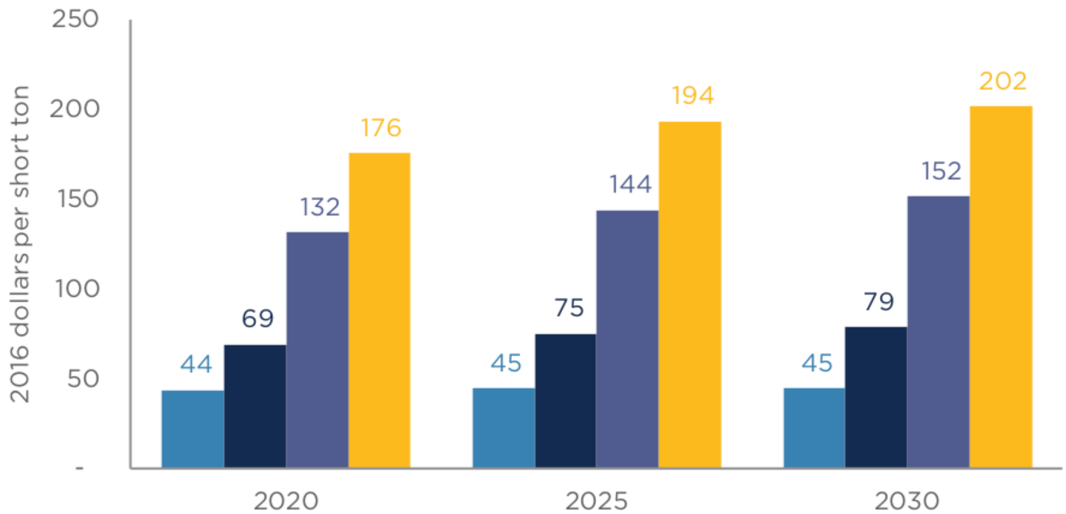
A carbon tax changes energy prices in two ways. First, fuel prices increase to incorporate the tax. The magnitude of these increases depends on the carbon intensity of the fuel. Second, consumers and producers respond to the tax, and a new supply-demand equilibrium is established. In the case of electricity, the operating cost of the marginal generator (i.e., the generator with the highest operating cost that is producing electricity at a given time) sets the wholesale price for power in most markets. For example, if the marginal generator is a natural gas plant, then the increase in wholesale electricity prices will be lower than if the marginal generator is a coal plant (all else equal), given that coal is twice as carbon intensive as natural gas. The cost of a carbon tax can shift which generator sets the price.

In this section we review how a carbon tax could change key fossil fuel prices as well as electricity prices. We then consider how a carbon tax could change US per capita energy expenditures.

Coal Prices

Since coal is primarily used in the electric power sector, we consider what impact a carbon tax could have on the national average price of coal delivered to generators. We find that a carbon tax will push coal prices up substantially relative to the current policy scenario (figure 27). From 2020 through 2030 under current policy, coal prices stay roughly static around $45/short ton. In our $14/ton scenario, we find that coal prices are $69/short ton in 2020, a 57 percent increase compared to current policy. In the same scenario, coal prices are $79/short ton in 2030, a 76 percent increase.

Figure 27: National average price of coal delivered to the electric power sector, 2020–2030 (2016 dollars per short ton)



Source: Rhodium Group analysis.

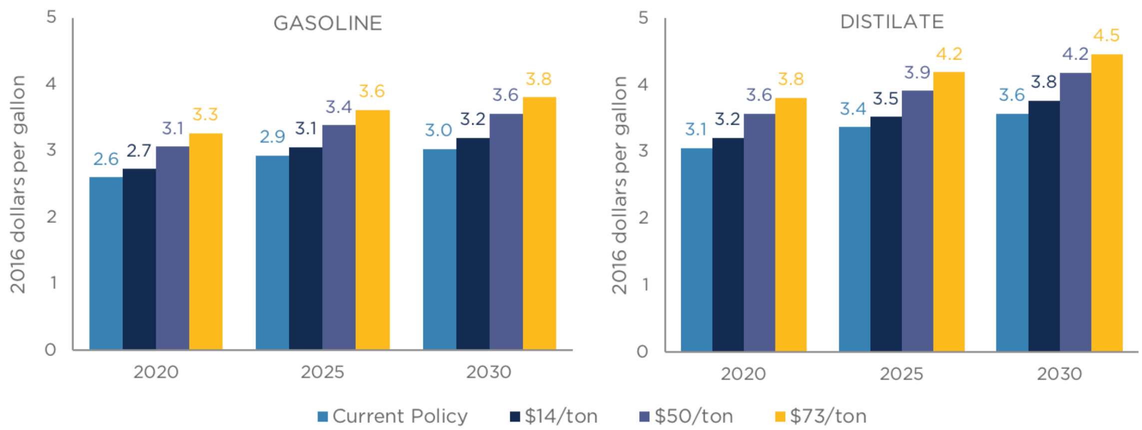
With higher carbon tax rates, we find higher delivered coal prices even as demand for coal falls. Under the $50/ton tax rate scenario, coal prices in 2020 are $132/short ton, three times higher than in the current policy scenario. In 2030 in the same scenario, coal prices are $152/short ton, or 237 percent higher. Finally, in the $73/short ton scenario, coal prices are 300 percent higher in 2020 and 348 percent higher in 2030 than in the current policy scenario.

Increasing coal prices make coal generators uncompetitive in electric power markets, leading to declines in market share, coal demand, and electric power sector GHG emissions, as discussed previously in this paper.

Refined Product Prices

The impacts of a carbon tax on gasoline and diesel prices are much smaller compared to the decline in coal prices, reflecting the relatively lower carbon intensity of these fuels. In the current policy scenario, gasoline prices are $2.60/gallon in 2020 and $3.00/gallon in 2030 (figure 28). A carbon tax would increase gasoline prices in 2020 to $2.70/gallon, $3.10/gallon, or $3.30/gallon in the $14/ton, $50/ton, and $73/ton scenarios, respectively. These price increases are well within the range of historic price variability.[74] The same is true in 2030, when prices are $3.20/gallon, $3.60/gallon, and $3.80/gallon in the $14/ton, $50/ton, and $73/ton scenarios, respectively. We find similar directional results for distillate fuel.

Figure 28: US average gasoline and distillate fuel prices, 2020 and 2030 (2016 dollars per gallon)



Source: Rhodium Group analysis.

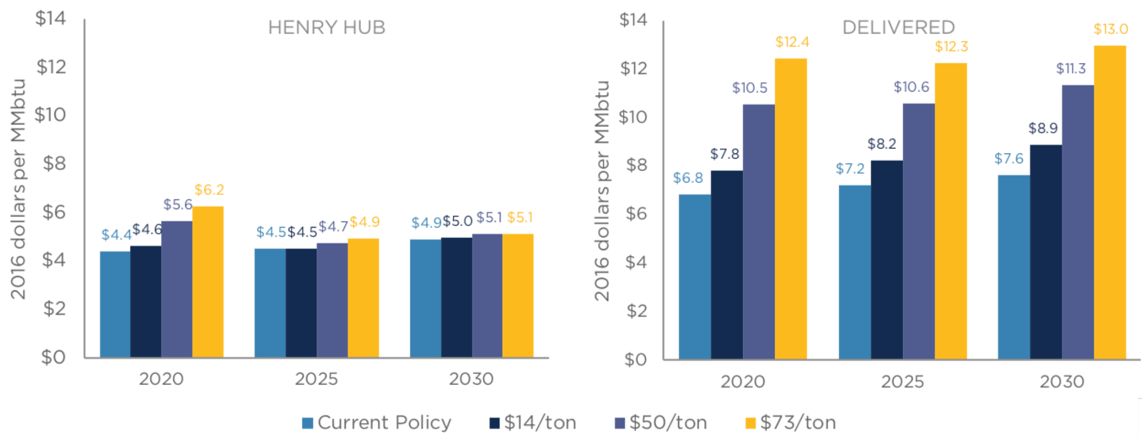
Natural Gas Prices

We find different responses to natural gas prices at the wholesale and retail levels. Wholesale prices reflect the change in supply and demand in the market under a carbon tax but not the cost of the tax itself, since we assume it is applied further downstream. Retail prices reflect both supply and demand dynamics as well as the cost of the tax.

Looking at benchmark Henry Hub wholesale prices, where the tax is not included we find that prices rise substantially in the first years of carbon tax but are roughly unchanged later in the decade. In 2020, we find wholesale natural gas prices of $4.60/MMbtu, $5.60/MMbtu, and $6.20/MMbtu in the $14/ton, $50/ton, and $73/ton tax rate scenarios, respectively (figure 29). While these prices represent an increase of 5 percent, 28 percent, and 42 percent across scenarios relative to $4.40/MMbtu in the current policy scenario, they are still far lower than their recent inflation-adjusted historical peak of $9.86/MMbtu in 2008. The difference is the deep supply of natural gas available as part of the boom in production of shale resources across the United States. The increase in prices caused by the carbon tax in 2020 reflect the surge in gas demand, as the electric power sector responds to the carbon tax through a dispatch shift toward natural gas and away from coal.

By the mid-2020s and onward, natural gas supply catches up with new electric power sector demand, and renewable energy increases its market share relative to fossil generation. At this point, wholesale gas prices under a carbon tax are similar to prices in the current policy scenario. By 2030, we find wholesale prices that are 10 to 20 cents higher than prices in the current policy scenario.

Figure 29: Wholesale and US average delivered natural gas prices, 2020–2030 (2016 dollars per MMbtu)



Source: Rhodium Group analysis.

National average delivered natural gas prices increase much more than wholesale prices because they include the cost of the carbon tax. In 2020, we find prices of $7.80/MMbtu, $10.50/MMbtu, and $12.40/MMbtu in the $14/ton, $50/ton, and $73/ton tax rate scenarios, respectively. These prices represent increases of 15 percent, 54 percent, and 82 percent, respectively, across scenarios relative to $6.80/MMbtu in the current policy scenario in the same year. After 2020, the effects on delivered prices are roughly constant, with the effects of increasing in carbon tax rates offsetting the effects of smaller impacts on wholesale prices.

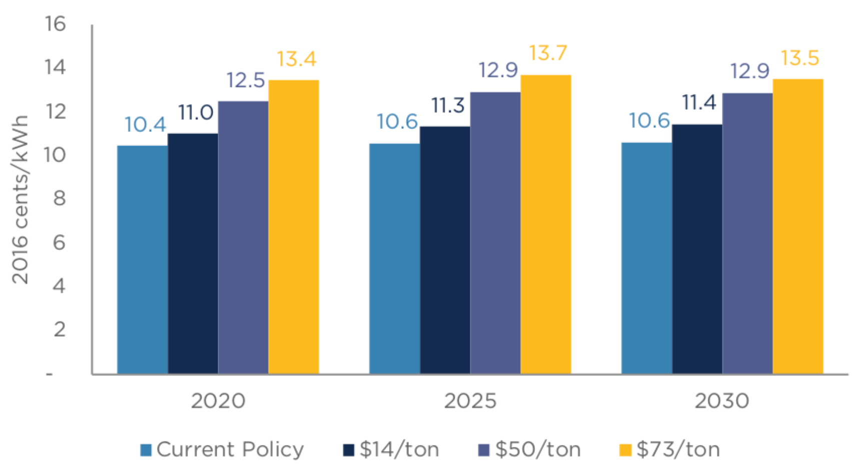
Electric Power Retail Prices

Retail electricity prices reflect the cost of electricity generation, transmission, and delivery to customers. When a carbon tax is in place, prices change in response to dispatch shifts in wholesale markets, retirements of carbon intensive generators, and the addition of new low carbon generation capacity. Prices also change as consumer demand responds to increases in costs, as discussed above.

Electricity prices vary considerably by US state and sometime within states because different electric power markets across the United States have different carbon intensities and different opportunities for new low carbon generation. Markets with relatively low carbon intensities and/or access to cost-effective low carbon generation will experience relatively modest price impacts from a carbon tax compared to markets that currently rely on carbon intensive generation and/or have little access to cost-effective low carbon generation. For example, 95 percent of the electricity in Washington State primarily comes from zero-emitting generation (primarily hydroelectric), whereas 95 percent of all electric generation in West Virginia comes from coal.[75] A carbon tax will have a larger impact on electricity rates in West Virginia than in Washington due to its current reliance on carbon intensive generation. We focus on national average electricity prices to all consumers in this analysis, but state and regional impacts will be important to any potential policy debate.

The impacts to retail electricity prices are similar to what we observed for retail natural gas prices. Electricity prices surge in 2020 in response to the carbon tax, but the impacts are roughly constant through the rest of the decade. In 2020, we find prices are 11 cents/kWh, 12.5 cents/kWh, and 13.4 cents/kWh in the $14/ton, $50/ton, and $73/ton tax rate scenarios, respectively (figure 30). These prices represent an increase of 5 percent, 19 percent, and 29 percent across scenarios relative to 10.4 cents/kWh in the current policy scenario in the same year. The surge reflects the cost of higher delivered natural gas and coal prices and the increased role that natural gas plays in electric power generation in the early years of the carbon tax. After 2020, more zero carbon generation comes online and emissions fall, reducing the influence of the carbon tax on electricity prices even as tax rates increase.

Figure 30: National average retail electricity prices (2016 cents/kWh)



Source: Rhodium Group analysis.

By 2030, we find electricity prices are 11.4 cents/kWh, 12.9 cents/kWh, and 13.5 cents/kWh in the $14/ton, $50/ton, and $73/ton tax rate scenarios, respectively. These prices represent an increase of 8 percent, 21 percent, and 27 percent, respectively, across scenarios relative to 10.6 cents/kWh in the current policy scenario in the same year.

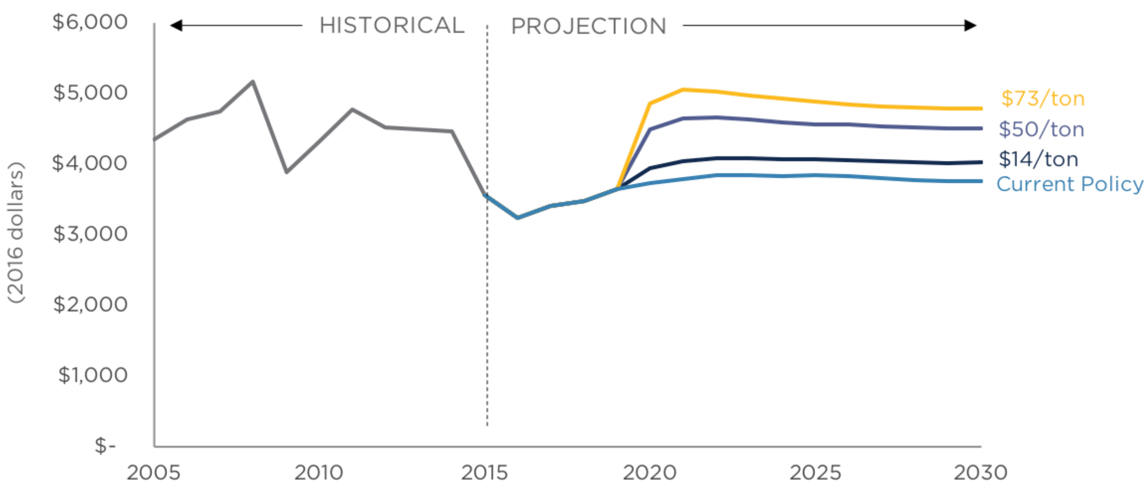
Energy Expenditures

Now that we have considered the potential impacts of a carbon tax on energy supply, demand, and prices, we look at the total combined impact on expenditures. Per capita energy expenditures reflect the total cost of energy consumption across all sectors of the United States divided by population. This provides a broad macroeconomic view of the impact of a carbon tax on national energy costs.

Energy expenditures in 2016 were $3,236 per person. This represents a drop of over $1,900 from a recent historical peak of $5,165 in 2008, at the height of the global commodity boom. In the current policy scenario, per capita expenditures rise to $3,726 in 2020 (figure 31). By 2030, expenditures reach $3,759 per person. This trend reflects increasing natural gas prices and modest oil price increases over the forecast.

With a carbon tax in place, we find that per capita energy expenditures rise relative to the current policy scenario but do not approach 2008 levels in any tax rate scenario through 2030. Reflecting the surge in prices we found in the early years of a carbon tax, expenditures increase in 2020 and peak in 2022 at $4,081 and $4,656 per person in the $14/ton and $50/ton scenarios, respectively, representing an increase of 6 percent and 21 percent, respectively, compared to current policy. Expenditures peak in the $73/ton scenario in 2021 at $5,049 per person, a 34 percent increase compared to current policy.

Figure 31: US annual per capita energy expenditures, 2005–2030 (2016 dollars)



Source: Rhodium Group analysis.

As energy markets and consumers adjust to a carbon tax, the relative impact on expenditures moderates, especially in the $73/ton scenario (figure 31). Consumers reduce demand for fossil fuels, and the electric power sector shifts to low carbon generation, as discussed throughout this chapter. In 2030, expenditures are $4,016, $4,495, and $4,778 per person in the $14/ton, $50/ton, and $73/ton scenarios, respectively. This represents a 7 percent, 20 percent, and 27 percent increase in per capita energy expenditures relative to the current policy scenario in that year.

This indicator masks important variation in cost impacts to consumers across different levels of income. Separate studies in the CGEP Carbon Tax Research Initiative are taking a closer look at the distributional impacts of carbon taxes.

CHANGES IN GOVERNMENT REVENUE

In addition to internalizing the social cost of GHG emissions and enabling emissions goals to be achieved, a carbon tax is promoted as a source of new federal revenue.

What We Did

To estimate potential revenue under each of the tax rate scenarios, we multiplied the applicable tax rate in each year by the total tons of CO_2 subject to the tax that are emitted into the atmosphere according our modeling results. We also added in revenue from the application of the tax to methane emissions from fossil fuel production in CO_2 equivalent terms. We assumed fossil fuel producers do not reduce methane emissions directly in response to the tax and instead pay the tax and pass on the full cost to consumers.[76]

All estimates reflect underlying changes in the US energy system and include a revenue offset of 25 percent to reflect the fact that payments of the carbon tax leave individuals and businesses with less income—and thus lower tax payments on that income.[77] The estimates represent net revenue before consideration of any macroeconomic effects or changes in spending that would likely be a part of a carbon tax legislative effort.

The Result

Table 2 shows revenue estimates for the first 10 years that a tax is in place in our $14/ton, $50/ton, and $73/ton carbon tax rates scenarios. A range is provided for the $50/ton scenario reflecting technological uncertainty. The differences in revenue across tax rate scenarios are a function of the tax rates and the US economy's responsiveness to the tax. Total fossil fuel consumption and the carbon intensity of consumption change in response to the carbon price over time.

We find that regardless of the tax rate, the potential revenue from a carbon tax is large. In the $14/ton tax rate scenario, we estimate that the tax would bring in $57 billion in 2020, rising to $67 billion by 2029. In comparison, the federal excise tax on gasoline and diesel fuel brought in $41 billion in 2016.[78] The $50/ton tax rate scenario would generate $180–$186 billion in 2020, nearly double the revenue from all federal excise taxes in 2016.[79] The $73/ton tax rate scenario would generate $267 billion in 2020, coming close to the $299 billion raised from the corporate income tax in 2016.[80]

Table 2: Changes in net government revenue due to the carbon tax: 5-year and 10-year revenue estimates (billions of 2016 dollars)

											Cumulative	
Scenario	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2020-2024**	**2020-2029**
$14/ton	57	58	59	60	61	62	64	65	65	67	294	617
$50/ton	180-186	176-182	172-179	169-177	170-177	168-176	165-176	162-172	160-176	160-177	868-900	1,682-1,781
$73/ton	267	257	251	250	250	250	250	249	249	250	1,275	2,523

Source: Rhodium Group analysis.

In the $14/ton tax rate scenario, revenue increases gradually over time; in the higher tax rate scenarios, revenue declines gradually over time. This reflects the fact that responses to the carbon tax push GHG emissions down at a rate similar to the annual increase in the tax rate. The actual annual change in revenue at a given tax rate will depend on how responsive the economy ends up being to a carbon tax. For example, in the $50/ton tax rate scenario, revenue declines by 5 to 11 percent between 2020 and 2030, depending on technological uncertainty. This illustrates the importance of the tax escalation rate as a key element of carbon tax design if one of the desired goals is to generate new government revenue that is steady or increasing over time. An escalation rate faster than 2 percent could generate more revenue and further reduce emissions, all else being equal.

Over 10 years, the cumulative increase in federal carbon tax revenue could range from $617 million to $2.5 billion, which is roughly 3 to 12 percent of total on-budget federal revenue between 2008 and 2017. There are a number of ways this revenue could be used, including reductions in the federal deficit, reductions in other taxes, lump-sum payments to citizens, assistance to those that are adversely impacted by a carbon tax, and other options.[81] Other papers in this series will explore the macroeconomic and distributional effects of different revenue use options based on the energy and revenue results reported here.

Here Are the Uncertainties

The revenue estimates reported here could change due to several factors. Our uncertainty range presented in the $50/ton tax scenario shows how differences in technological progress could lead to higher or lower revenue. This same uncertainty could lead to higher or lower revenue estimates for the $14/ton and $73/ton tax rate scenarios.

Our modeling demonstrates one possible way different economic sectors may respond to energy prices under a carbon tax. If these sectors are less responsive to a carbon tax, revenue estimates would be higher. If these sectors are more responsive to a carbon tax, then revenue estimates would be lower.

Policy uncertainty could also change our revenue results. If complementary policies aimed at overcoming barriers to price responsiveness in end-use sectors are implemented, then the carbon tax may lead to more abatement and lower revenue. Decisions over how to use revenue from a carbon tax may also change future revenue estimates because, for example, different revenue uses will have different macroeconomic impacts.

Policy makers should consider these uncertainties carefully if a steady source of federal revenue is a desired outcome of a carbon tax. Congress could set the tax rates conservatively (i.e. higher) to deliver revenue that exceeds the desired targets to avoid the possibility of a revenue gap. Alternatively, Congress could choose to enable the automatic adjustment of tax rates to meet specified revenue targets.

SUMMARY OF FINDINGS AND CONCLUSIONS

In this report, we considered the potential impacts of an economy-wide carbon tax on all fossil fuel CO_2 emissions and methane emissions from fossil fuel production. Using a consistent set of design elements, we modeled three carbon tax rate scenarios and quantified the impact of each on US GHG emissions, energy markets, and federal tax revenue. We conducted the analysis using RHG-NEMS, a version of EIA's US energy system model. Given that NEMS is the primary federal energy system model used for government energy market and policy analysis, the results presented in this report provide insights on what could be expected in a possible future legislative carbon tax debate. The results also highlight possible shortcomings in the model and areas where improvement could be considered. The results presented in this report lead to the following findings:

Emissions Impacts

- *A carbon tax drives substantial reductions in US GHG emissions in the near and medium term.* Economy-wide carbon taxes at the rates considered in this analysis achieve net GHG reductions of 13 to 29 percent relative to emissions under current policy in 2030. This is equivalent to 27 to 46 percent reductions from 2005 levels.
- *Emission reductions primarily occur in the electric power sector.* The electric power sector is the most responsive to a carbon price, and, in turn, this is where most emissions reductions occur. The presence of competitive markets and readily available low carbon substitutes drives emissions reductions of 23 to 67 percent relative to current policy in 2030.
- *A carbon tax at the levels considered in this analysis is necessary but potentially not sufficient for achieving long-term emissions reduction goals.* While the long-term results from our analysis have a higher level of uncertainty, policy relevant insights can still be identified. If the desired outcome of a carbon tax policy is to reduce US GHG emissions to over 80 percent below 2005 levels by 2050, the range of tax rates considered in this analysis may be insufficient absent complementary GHG policies or significantly faster decarbonization of the transportation, buildings, and industrial sectors than currently expected.

Energy Market Impacts

- *A carbon tax drives an increase in renewable energy production matched with a decline in coal production.* Zero-emitting renewable energy makes up 29 to 41 percent of total US electric power generation in 2030, depending on the tax rate scenario, which represents a two- to threefold increase from 2015 levels. Renewables fill in behind coal generation, which declines substantially in all scenarios; the carbon tax drives a 28 to 84 percent reduction in US coal production by 2030 compared to the current policy scenario.
- *US consumption of natural gas and petroleum products are less affected.* In the initial years of the carbon tax, natural gas demand increases as electric power generation shifts from coal to gas. However, by 2030 gas demand is no more than 1.4 Bcf/day higher than

under current policy due in large part to the emergence of renewable energy. Demand for gasoline and diesel fuel is little changed because the transportation sector is the least responsive to a carbon tax.

- *Average per capita energy expenditures rise under a carbon tax but do not reach the (inflation adjusted) high levels seen in recent history, even in the highest tax rate scenario.* Increases in per-capita expenditures due to a carbon tax range from 7 to 27 percent relative to current policy in 2030. Per capita expenditures during the commodities boom in the run-up to the great recession were even higher.

Federal Revenue Impacts

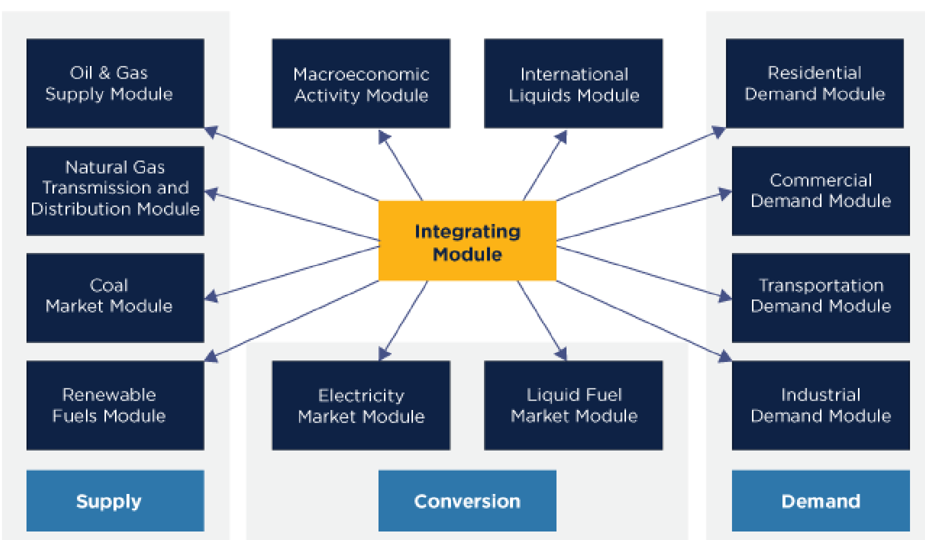
- *The increase in government revenue due to the carbon tax could be large, ranging from $617 million to $2.5 trillion over the first 10 years.* Decisions over revenue of this magnitude could be contentious.
- *If steady or increasing revenue is a goal of a carbon tax, an escalation rate higher than the 1.5 to 3 percent used in this analysis may be necessary.* We found that in all but the $14/ton tax rate scenario, revenue gradually declines as emissions are reduced at a rate that is faster than the tax escalator. If steady or rising revenue from a carbon tax is desired, a higher escalation rate should be considered.

TECHNICAL APPENDIX

Our analysis uses the NEMS model, a version of the Energy Information Administration (EIA)'s National Energy Modeling System (NEMS) maintained by the Rhodium Group (RHG). EIA uses NEMS to produce its Annual Energy Outlook (AEO), which projects the production, conversion, consumption, trade, and prices of energy in the United States through 2050. NEMS is an energy-economic model that combines a detailed representation of the US energy sector with a macroeconomic model provided by IHS Global Insight. The version of NEMS used for this analysis is keyed to the 2017 version of the AEO. Complete NEMS documentation is available on the EIA's web site at https://www.eia.gov/outlooks/aeo/nems/documentation. Documentation of the energy sector assumptions used in the AEO 2017 version of NEMS is available here: https://www.eia.gov/outlooks/aeo/assumptions.

NEMS is a modular system with a module for each primary source of energy supply, conversion activity, and demand sector, as well as the international energy market and the US economy (figure A1). The integrating module acts as a control panel, executing other NEMS modules to ensure energy market equilibrium in each projection year. The solution methodology of the modeling system is based on the Gauss-Seidel algorithm. Under this approach, the model starts with an initial solution, energy quantities, and prices, and then iteratively goes through each of the activated modules to arrive at a new solution. That solution becomes the starting point, and the above process repeats itself. The cycle repeats until the new solution is within the user-defined range of the previous solution. Then the model has 'converged,' producing the final output.

Figure A1: NEMS Architecture



Source: https://www.eia.gov/outlooks/aeo/nems/documentation/integrating/pdf/m057(2017).pdf

To model carbon taxes for this report, we made the following revisions to EIA's standard AEO2017 NEMS reference case scenario.

1. ***Macroeconomic activity module was turned off for all scenarios:*** Through the macroeconomic activity module (MAM), NEMS can capture the macroeconomic impact of a carbon tax via the effects of increased energy prices as well as additional government revenues collected from the carbon tax. This report, however, was designed to capture just the energy system and environmental impacts of a carbon tax. A detailed assessment of macroeconomic and economic distributional implications of higher energy prices and revenues using output from this report was conducted by partners in the CGEP Carbon Tax Research Initiative. We turned off the MAM to avoid double counting of macroeconomic effects with modeling done by partners. The energy and environmental impact insights derived in this report should be considered to be slightly conservative (emissions are higher) in response to the carbon tax alone due to turning off the MAM. Accordingly, without the macroeconomic response of carbon tax, the carbon tax revenue estimates in this report are higher than if RHG-NEMS was run with the MAM turned on. Revenue recycling decisions could also influence energy and emissions results if the MAM were turned on. Revenue recycling was out of scope for this analysis.

2. ***Restrictions on fuel choices for replacement of appliances are relaxed:*** NEMS restricts fuel choice when certain appliances are due for replacement (for example, moving to an electricity-based heating system from natural gas) in both residential and commercial buildings under the current policy scenario. The restriction accounts for consumer bias and capital costs for replacing underlying infrastructure (for example, venting and ducting), coupled with the uncertainty of future fuel prices. However, under a pre-defined carbon tax, some of the uncertainty of future fuel prices is reduced, and consumers could be more flexible in switching fuels when making appliance replacement choices. In our carbon tax runs, we increased the share of buildings that can switch fuels when replacing appliances (their decision is based on comparing lifecycle costs across fuels instead of picking an appliance which uses the same fuel as the current equipment). This share increases with the increase in carbon price.

3. ***Increased options for combined heat and power in industry:*** In this report, we allowed nuclear power, via small modular reactors (SMRs) to be an option for combined heat and power (CHP) plants in industry. The technology becomes available in 2026 (based on current plans of installing first small modular reactor (SMR) in Idaho in 2026 by NuScale Power). We assume the subsequent technology penetration rate does not exceed the penetration rate of nuclear in the power sector, with the penetration rate defined as a share of total generation. Levelized cost estimates were taken from NuScale Power[82].

4. ***Carbon capture and storage (CCS) in industry:*** In addition to advanced nuclear technologies, we allowed for the use of CCS. We used levelized costs of capture and storage estimates available from Leeson et. al 2017 and adjusted them by industry and sequestration rate assumptions[83]. When the levelized cost of abatement exceeds the carbon tax, we assume industries install CCS at the rate of the nuclear penetration curves outlined above. We also assume an electric penalty of 0.194 kwh per ton of carbon sequestered. The penetration of CCS and emission and revenue impact was exogenously determined.

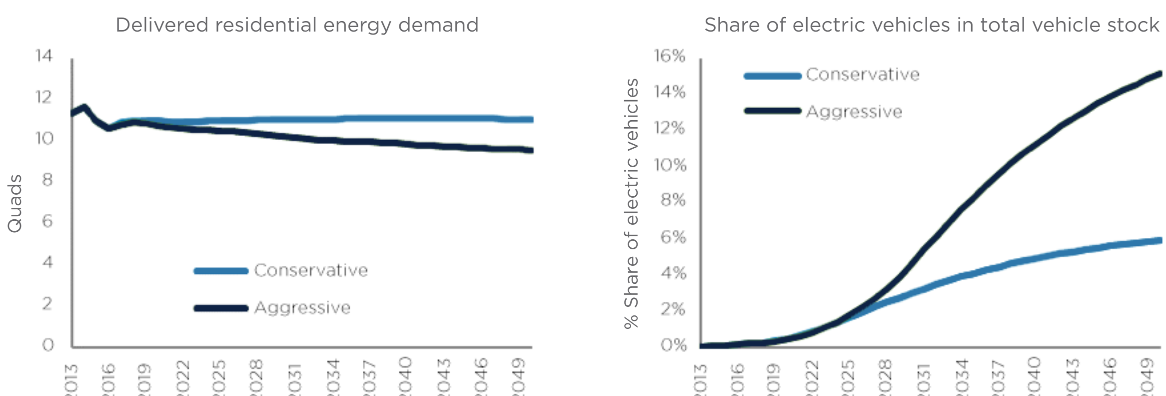
5. ***Availability of renewable natural gas (RNG):*** Though limited to select pilot projects today, renewable natural gas produced from a wide variety of biomass feedstock has the potential

to become an important zero-emission fuel source in future. Currently, NEMS doesn't model the production and consumption of RNG, so we accounted for the impact of RNG exogenous to NEMS. We assume that because RNG is not a fossil fuel and because biomass fuels are exempt from the tax in our scenarios, RNG is also exempt from the tax. That said, we limit RNG supply to sustainable sources defined as landfill gas, wastewater treatment plants, manure, and crop residues. We do not account for any likely reductions in methane emissions from these sources associated with production of RNG in our 6-gas projections. We allowed for the availability of renewable natural gas (RNG) to all sectors under a carbon tax starting in 2020. Penetration is based on production cost estimates[84,85,86] and carbon tax level but not allowed to exceed 2.5 quads in any given year (fossil-based natural gas equivalent) under the AEO2017 based scenario assumptions. Available RNG displaces fossil-based natural gas so that the total natural gas consumption is unchanged.[87] Some studies[88] estimate higher RNG potential due to different assumptions on technological advances and feedstock. Our more aggressive technology scenario assumes a maximum penetration of 7.5 quads.

6. ***Lower cost of renewable technology:*** Technology costs for utility scale and distributed wind and solar electricity generation were updated. Our conservative technology scenario uses costs from the 2016 National Renewable Energy Laboratory (NREL) Annual Technology Baseline (ATB) Mid case. Our more aggressive technology scenario uses costs from the 2016 NREL ATB Low Case.

7. ***End-use low carbon technology penetration:*** Our conservative technology scenario uses AEO2017 assumptions for building equipment efficiency and EV battery costs, aside from the consumer choice adjustments discussed above. Our more aggressive technology scenario assumes faster adoption and penetration of energy efficient equipment in the residential and commercial sectors relative to AEO2017 assumptions by assuming consumers choose the most efficiency technologies available when purchasing new equipment. Battery costs are assumed to follow Bloomberg New Energy Finance's EV battery cost forecast and lead to much higher penetration of electric vehicles compared to the adjusted reference case (Figure A2). Also, NREL's 2016 ATB Low case was used for utility-scale and distributed wind and solar electricity generation costs.

Figure A2: Difference between conservative and aggressive technology assumptions



Source: Rhodium Group analysis.

Projecting all GHGs using RHG-NEMS

All historical greenhouse gas (GHG) emissions and removal estimates (1990-2015) come directly from the 2017 Environmental Protection Agency (EPA) Greenhouse Gas Inventory. Like the EPA inventory, all gases are reported in carbon dioxide (CO_2)-equivalent emissions based on the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4) 100-year global warming potential (GWP) values.

Carbon Dioxide emissions

Projected CO_2 emissions from all energy use in RHG-NEMS is inconsistent with EPA's accounting conventions for CO_2 from fossil-fuel combustion in its GHG inventory. To address this inconsistency, we make the following adjustments to RHG-NEMS output to generate a forecast for CO_2 from fossil-fuel combustion:

- **International bunker fuels—** Emissions from fuel combustion by ships and airplanes that depart from or arrive in the US from international destinations are not included in EPA's inventory of total US emissions nor are they counted in US climate targets. However, they are included in RHG-NEMS CO_2 output. We subtract these emissions from our projections.

- **Industrial non-energy use of fuels—** Fossil fuels are used as feedstocks in the manufacture of a variety of products such as steel and chemicals. Generally, EPA accounts for CO_2 emissions generated by consumption of these feedstocks in the industrial processes categories of the GHG inventory, not under fossil-fuel combustion CO_2. We subtract CO_2 emissions from non-energy uses of CO_2 from our fossil-fuel combustion projections and account for non-energy use of fuels and feedstocks elsewhere based on applicable RHG-NEMS output.

- **Transportation non-energy use of fuels—** A small amount of petroleum fuel used in the transportation sector (largely for lubricants) is not combusted but generates CO_2 emissions through its usage. We subtract this amount from projections of petroleum CO_2 emissions in the transportation sector and account for them elsewhere as non-energy use of fuels.

RHG-NEMS does not provide an Intergovernmental Panel on Climate Change (IPCC) consistent projection output for non-fossil fuel consumption CO_2 emissions from activities such as non-energy use of fuels and industrial processes. We applied the following methods to project non-fossil fuel combustion CO_2 emissions:

- **Inventory categories with emissions below 25 million metric tons (MMt)—** We extrapolate historical trends from EPA's latest GHG inventory in line with EPA's latest GHG projection guidance.

- **Inventory categories with emissions above 25 MMt—** We follow EPA's latest guidance, scaling inventory data based on category-appropriate RHG-NEMS output. For example, recent historical CO_2 emissions from natural gas systems are scaled based on the projected change in US dry natural gas production from RHG-NEMS. This allows for non-combustion CO_2 emissions to change in line with changes in the economic and technology assumptions we make to account for uncertainty in our projections.

Non-CO_2 and land use emissions and removals

All projections of non-CO_2 emissions (i.e., methane, nitrous oxide, hydrofluorocarbons, perfluorocarbon, and sulfur hexafluoride) follow the same general approach as we take in projecting CO_2 emissions from non-fossil fuel combustion sources. Inventory categories with emissions less than 25 MMt CO_2e are extrapolated based on recent historical trends. Inventory categories with emissions more than 25 MMt CO_2e are scaled based on appropriate outputs from RHG-NEMS (e.g., scaling hydrofluorocarbon emissions with economic growth) unless additional modifications are necessary to reflect the impact of state and federal policies. In some instances, such as in the agricultural sector, there are no appropriate outputs from RHG-NEMS to scale emissions. In these instances, we use alternative public projections, such as the US Department of Agriculture (USDA)'s long-term projections.

Historical emissions and removals from land use, land-use change, and forestry (LULUCF) come directly from the 2017 EPA GHG inventory. Projected trends come from the 2016 Biennial Report of the United States (the most recent set of federal projections) calibrated to align with EPA's 2017 inventory. For emissions of N_2O and CH_4 from LULUCF, we assume 2016 emissions from LULUCF remain constant through 2030, following the approach used in the 2016 Biennial Report.

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