Rhodium Group

Taking Stock 2022

US Greenhouse Gas Emissions Outlook in an Uncertain World

July 14, 2022

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Table of Contents

Executive Summary

For the past eight years, Rhodium Group has provided an independent annual assessment of US greenhouse gas (GHG) emissions and progress towards achieving the country's climate goals in our Taking Stock report series. Each year, we research trends in the key drivers of US GHG emissions—including technology cost and performance advancements, changes in energy markets, policy developments, and expectations for the economy—and estimate a range of emissions outcomes based on these trends.

Given these trends and current federal and state policies in force as of June 2022, we find that the US is on track to reduce emissions 24% to 35% below 2005 levels by 2030, absent any additional policy action. This falls significantly short of the US's pledge under the Paris Agreement to reduce emissions by 50-52% below 2005 levels by 2030. These estimates represent a rosier outlook for emissions reductions compared to Taking Stock 2021 (which estimated a 17-30% reduction by 2030 under current policy), but this change is largely attributable to slower macroeconomic growth projections and higher fossil fuel prices—not large policy changes. Even by 2035, GHG emissions remain stubbornly high at 26% to 41% below 2005 levels.

In Taking Stock 2022, we focus on a wide range of uncertainties that can affect emissions outcomes. Global and US energy markets and the economy look very different now than they did a year ago, amid the war in Ukraine and high inflationary pressures from COVID-recovery turmoil. These geopolitical and macroeconomic trends affect the energy costs and technology developments underpinning our emissions projections, and this year has reminded us all of the inherent challenge in forecasting the future in these realms. In our analysis, we account for near-term increases in fossil fuel prices attributable to global energy market instability from the war in Ukraine. We also incorporate updated medium-term price forecasts for natural gas and oil, which are generally higher than in the recent past. And we update our technology cost and performance inputs to incorporate the latest forecasts from leading experts.

Uncertainty reigns on the US policy front as well. There has been some policy movement in the past year, although not close to the level of action required to meet the US's 2030 climate target, and the recent Supreme Court ruling in *West Virginia v. EPA* has called EPA's regulatory pathways into question. In our analysis, we update our suite of current policies to include all relevant policies on the books as of June 2022. This includes passage of the Infrastructure Investment and Jobs Act at the end of 2021 and enactment of new greenhouse gas emissions and fuel economy standards for light-duty vehicles on the federal level, as well as updates to state policies like new renewable portfolio standard targets.

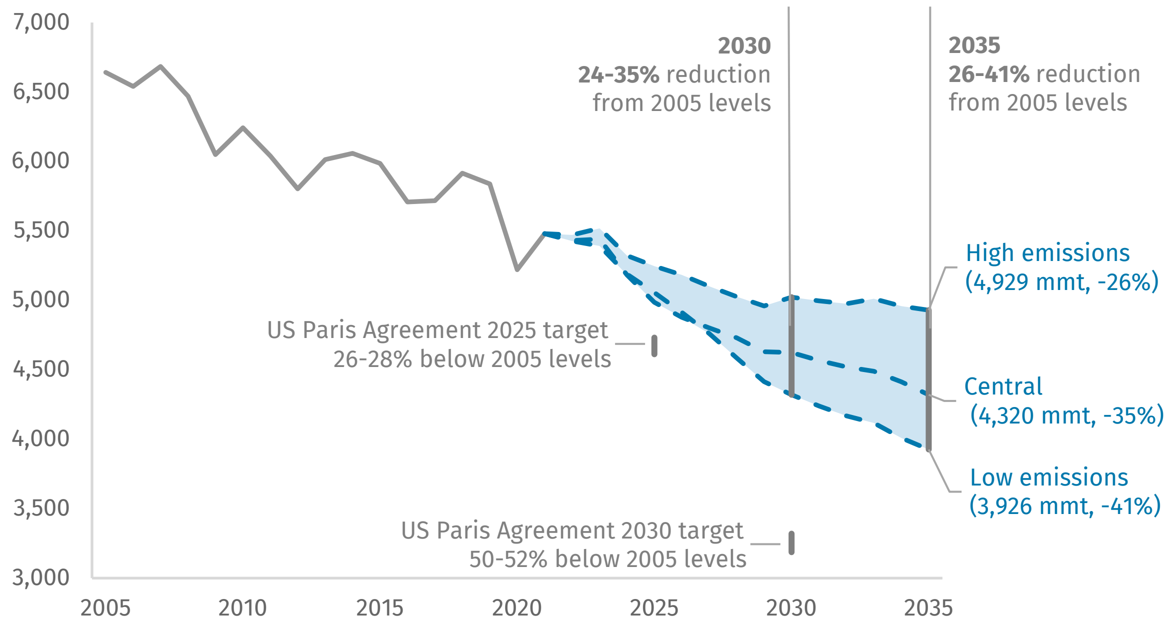
Our projections for US emissions in Taking Stock 2022 can help inform policymakers as they design decarbonization approaches that are robust to future developments. And now, more than ever, it's important for policymakers to focus on maximizing the impacts of policy: the clock is ticking on both achieving the US's 2030 climate goals and on reducing emissions to avert the worst impacts of climate change.

Detailed national and 50-state results for all Taking Stock emissions baseline scenarios—including GHG emissions and underlying sectoral data—are available in Rhodium's ClimateDeck data platform.

FIGURE ES1

US greenhouse gas emissions under current policy

Net million metric tons (mmt) of CO_2e



Source: Rhodium Group

Key findings

As shown in Figure 1, we find that under current policy and with no additional action, the US is on track to reduce emissions by 24-35% below 2005 levels in 2030, and 26-41% below 2005 levels in 2035. The range accounts for macroeconomic, energy market, and technology costs uncertainty. As is evident from the trajectories, the US is not on track to meet its 2025 or 2030 climate goals, nor does it meet those goals later in 2035.

In addition to the economy-wide outlook for US emissions under current federal and state policy, this report also unpacks key sectoral developments underpinning these topline figures, including the following trends:

- Industry becomes the largest-emitting sector absent meaningful policies to curtail emissions growth, with emissions remaining relatively flat depending on the scenario.
- Emissions from the power sector generally continue to decline, but gas and renewable prices have a major impact on the 2035 outcome.
- Fuel economy improvements and more EV sales drive declines in transportation sector emissions.
- By 2035, household energy costs drop by 16-25% relative to 2021 bills as more electric vehicles on the road lead to lower costs at the pump.

New for this year, we also model a range of additional cases beyond our core emissions scenarios, which include a steady progress case representing a return to stable declines in the cost of clean energy technologies as well as lower oil and natural gas prices from prolific domestic production; a continued volatility case in which events beyond the scope of the energy sector roil global energy markets and short-circuit clean technology growth; and a high growth case that demonstrates the impact that variation in GDP can have on emissions.

CHAPTER 1

Uncertainty in Global Energy Markets and US Policy

For the past eight years, Rhodium Group has provided an independent annual assessment of US GHG emissions and progress towards achieving the country's climate goals in our Taking Stock report series. Each year, we research trends in the key drivers of US GHG emissions, including technology cost and performance advancements, changes in energy markets, policy developments, and expectations for the economy. We take stock of what's changed in these drivers in the past year and estimate a range of emissions outcomes based on these trends.

In last year's Taking Stock 2021, we highlighted both the opportunity and the necessity of substantial new policies to achieve the Biden administration's new pledge under the Paris Agreement of a 50-52% cut in GHG emissions by 2030. We further underscored this need in Pathways to Paris: A Policy Assessment of the 2030 US Climate Target, which provided a comprehensive policy pathway across federal legislation & regulations and state-level action to achieving the target.

Today, we find the country and the world in a very different place than a year ago. As expected, 2021 saw a rebound in US GHG emissions after a COVID-induced drop in 2020, though emissions remained below pre-pandemic levels. But now, geopolitical and economic events are driving high levels of uncertainty for emissions estimates. The war in Ukraine has upended global energy markets, causing near-term price spikes and long-term uncertainty. The global response to the war matters to emissions outcomes as well. For instance, the US is looking at expanding its liquified natural gas (LNG) export capacity to help the European Union (EU) wean itself off imported Russian natural gas.

On the economic home front, inflationary pressures, both from supply chain turmoil and rising prices in the energy sector as well as developments in the wider economy, are leading to a renewed focus on energy costs faced by US consumers and businesses. And, though the US had another record year for clean energy in 2021, potential barriers to continued high levels of deployment are now much clearer, including supply chain disruptions, delays in connecting new projects to the grid, and congressional inaction on major climate and clean energy legislation.

Indeed, uncertainty reigns in policy circles as well. There has been some policy movement in the past year, as cause for optimism. In November 2021, Congress passed the Infrastructure Investment and Jobs Act (IIJA), which provides much-needed financial support to several parts of the clean economy, including existing nuclear generators, electric vehicle chargers, and low-income energy efficiency. IIJA also contains multi-billion-dollar investments in emerging clean technologies like clean hydrogen, carbon capture, and direct air capture—critical technologies that need to scale up fast to provide as many pathways to net-zero emissions by midcentury as possible. Also in the past year, the Environmental Protection Agency (EPA) established new limits on nitrogen oxide (NOx) emissions from power plants. In addition, EPA and the National Highway Traffic Safety Administration (NHTSA) replaced the Trump administration's weak light-duty vehicle (LDV) GHG and fuel efficiency standards with more aggressive targets through model year 2026.

Several states have taken meaningful steps on addressing climate change in the past year as well. Since Taking Stock 2021, states have codified legislation and regulations that will drive emissions reductions in the power and transportation sectors and curb hydrofluorocarbon (HFC) emissions. Oregon adopted the Climate Protection Program, establishing an economy-wide cap and trade program. Pennsylvania became the 12th state to join the Regional Greenhouse Gas Initiative (RGGI) capping power sector emissions, while Connecticut set a 100% clean energy target for 2040.[1] Four states also updated energy efficiency resource standards (EERS) to reduce emissions in the power sector.

In transportation, Oregon, Washington, New York, New Jersey, and Massachusetts joined California in its Advanced Clean Trucks regulation, which requires medium- and heavy-duty vehicle manufacturers to sell an increasing percentage of zero-emission vehicles. And Nevada, Delaware, Minnesota, and New Mexico committed to following California's stricter light-duty vehicle GHG standards under Section 177 (S177) of the Clean Air Act. There are now 18 S177 states, covering 35% of current US transportation emissions. Washington also passed a clean fuel standard with a target to reduce the carbon intensity of fuels by 20% below 2017 levels by 2038. Two states also took action to address HFC emissions. Maine and Rhode Island adopted rules to align with EPA's federal Significant New Alternatives Policy (SNAP) rules to phase down the use of HFCs by finding substitute substances.[2]

Despite these important policy successes at the federal and state levels, further progress to address the climate crisis has largely stalled across all levels of government. We provide additional detail in our recent note, Progress on the Pathway to Paris?. Congress has so far failed to advance cornerstone climate legislation, as the Build Back Better Act has languished in the Senate since passing the House in November 2021. EPA is digesting the recent Supreme Court decision in *West Virginia v. EPA* before advancing critical carbon pollution standards in the power sector. Perhaps we will have greater clarity on some of these issues by the time we're drafting Taking Stock 2023, but for now, the clock is ticking, and policy ambiguity rules the day.

In the next chapter, we discuss the energy market, technology cost, and macroeconomic input assumptions that underlie our modeling in this year's Taking Stock. In Chapter 3, we focus on three main emissions scenarios, providing bounding estimates for the range of potential emissions outcomes through 2035. In Chapter 4, we present three side cases that fall within this overall emission range but that are based on recent trends. Finally, in Chapter 5, we discuss the broader set of modeling results available on Rhodium Group's ClimateDeck.

1 On July 8, a judge paused implementation of Pennsylvania joining RGGI.

2 To capture state-level action in our Taking Stock 2022 estimates, we include all state and sub-national polices that are codified with specific targets and timelines to measure progress. We do not include emission reduction targets that are not enforceable or not actionable.

CHAPTER 2

Building Our Emissions Scenarios

Given the current degree of uncertainty in global energy markets and the US policy landscape, it's important to understand the US emissions outlook under a range of potential future conditions. For Taking Stock 2022, we model three core emissions scenarios that represent the bounds of likely emissions outcomes through 2035 given our full set of assumptions. In this chapter, we discuss the inputs underpinning these scenarios. In Chapter 3, we unpack the economy-wide emissions outlook as well as key sectoral trends in these core scenarios.

To quantify these emissions outcomes, we use RHG-NEMS, a version of the National Energy Modeling System (NEMS) modified and maintained by Rhodium Group. NEMS is developed and used by the US Energy Information Administration (EIA) to produce its Annual Energy Outlook (AEO). We use the latest version of NEMS, which EIA developed as part of its production of AEO 2022.

We expand this version of NEMS to include all sectors of the US economy and coverage for all six greenhouse gases targeted for reduction under the Kyoto Protocol. We further update the model to incorporate all actionable policies in place as of June 2022, and we modify or substitute our own energy market, technology cost, and economic assumptions, discussed in greater detail below. We also update several near-term energy market outcomes using data from the EIA's June 2022 Short-Term Energy Outlook (STEO).

Energy market and technology uncertainty

We begin scenario construction by developing assumptions for future oil and gas prices. In all cases, we use data from STEO to adjust oil and gas prices through 2023 to reflect near-term expectations surrounding the ramifications of the war in Ukraine and other factors.

Under the central oil and gas trajectory, natural gas at Henry Hub declines to around $3/MMBtu through the late 2020s before steadily climbing above $3.50/MMBtu in 2035. Under low oil and gas prices, gas prices slide below $2.50/MMBtu by the late 2020s before a modest recovery to $2.65/MMBtu in 2035. Under high oil and gas prices, gas prices don't drop much after being adjusted for new STEO levels, remaining at or above $4.25/MMBtu through the mid-2020s before starting a steady climb to $5.85/MMBtu by 2035. We also update LNG export capacity to include all announced terminals currently under construction.

Crude oil projections follow roughly similar trajectories as gas prices. In the central case, Brent crude drops to around $65-70/barrel in the mid-2020s, then climbs to $75/barrel in 2035. Prices fall further in the low-cost case, to below $65 through 2030 and gradually upward to $68/barrel in 2035. In the high-cost case, Brent crude doesn't drop meaningfully below $70/barrel before climbing to $94/barrel in 2035.

Our renewable energy and energy storage technology costs are based on the latest Annual Technology Baseline 2022 (ATB) from the National Renewable Energy Laboratory (NREL). Our central clean technology costs are based on moderate cost and performance assumptions from the ATB, while our low and high clean tech cost cases reflect the advanced and conservative assumptions, respectively. We use Rhodium Group's estimates for central, low, and high costs for carbon capture technologies in the power sector and in industry. Finally, in the transportation sector, we use BloombergNEF's optimistic forecast for EV battery costs in the low clean cost case, while we use adjusted versions of EV battery price projections from NREL's Electrification Futures Study in the central and high-cost cases. We provide more detailed descriptions of our energy market and technology cost inputs in the Technical Appendix.

In all cases, we calculate land use, land use change, and forestry (LULUCF) emissions using the high sequestration and historical/low sequestration projections from the US Fourth Biennial Report. We consistently present net emissions using the high sequestration figures but provide the option to consider low sequestration figures in the ClimateDeck, Rhodium's data visualization platform.

Macroeconomic uncertainty

We include two pathways for economic growth in Taking Stock 2022. In our baseline macroeconomic case, we project that annual GDP growth averages at 2.3% through 2025 and slows to 1.8% average growth through 2035. These assumptions are reasonably well-aligned with current Congressional Budget Office estimates through 2032, though our estimates trend a bit higher. In our high-growth case, GDP grows at a 2.8% average rate through 2025 before slowing to 2.1% growth through 2035.

Emissions scenarios

Based on these inputs, we construct three core emissions scenarios:

- A **central** case that relies on central energy market prices, central clean technology costs, and baseline economic growth.
- A **low emissions** case that uses continued rock-bottom prices for clean energy technologies paired with high oil and gas prices and baseline economic conditions.
- A **high emissions** case that considers the inverse: expensive clean technologies, cheap oil and gas, and a high economic growth rate.

We present the results of these scenarios in the next chapter.

CHAPTER 3

Emissions Outlook and Key Trends by Sector

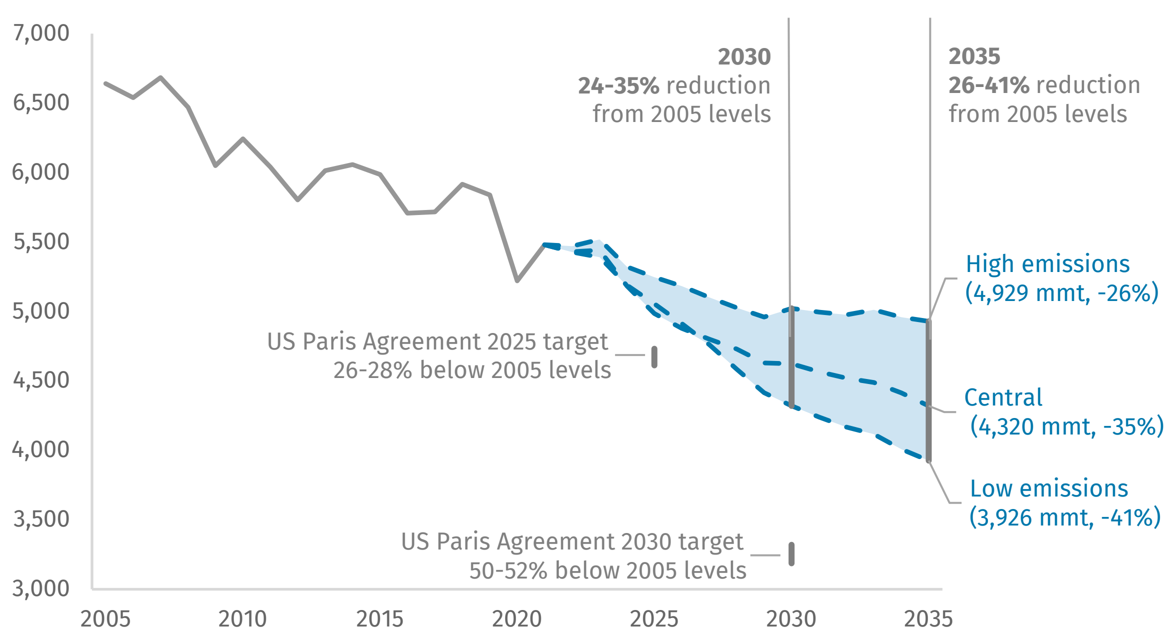
Based on the scenarios we described in Chapter 2, we find that in 2030, without any new policy action, US net GHG emissions range from 4.2 to 5.0 billion tons, a 24-35% reduction from 2005 levels. Looking out to 2035, US emissions range from 3.9 to 4.9 billion tons absent additional policy, a 26-41% reduction from 2005 levels. As is evident from the emissions trajectories in Figure 1, under current policy and without any additional action, the US is not on track to meet its 2025 or 2030 climate goals, nor does it meet those goals later in 2035. In the high emissions scenario, the rate of emissions reductions slows from an average of 0.9% annually in the last decade to an average of only 0.7% annually through 2035. In the low emissions scenario, the rate of emissions reductions accelerates to 2.3% annually, more than double the rate over the last decade. In the central scenario, emissions reductions average 1.7% per year.

Our 2030 emissions estimates are meaningfully lower than our estimates from last year's Taking Stock 2021 report, where we found a 17-30% reduction in GHG emissions over 2005 levels in 2030. While we do incorporate some new policy since last year as discussed in the previous chapter, the main drivers of the change are updates to the outlook for economic growth and energy market dynamics, in particular high near-term fossil fuel prices, rather than these new policies. Specifically, based on the latest CBO estimates, we revised our projections of GDP growth down by 0.2-0.9 percentage points through 2025 and by 0.2-0.3 percentage points from 2026 through 2035.

FIGURE 1

US greenhouse gas emissions under current policy

Net million metric tons (mmt) of CO_2e



Source: Rhodium Group

These changes flow through to energy consumption in a number of ways, including lower electricity demand, lower industrial output (and lower volumes of freight transportation), and lower vehicle-miles traveled by the light-duty fleet. Expected higher natural gas prices also help make renewables even more cost-competitive in the power sector, driving further emission reductions.

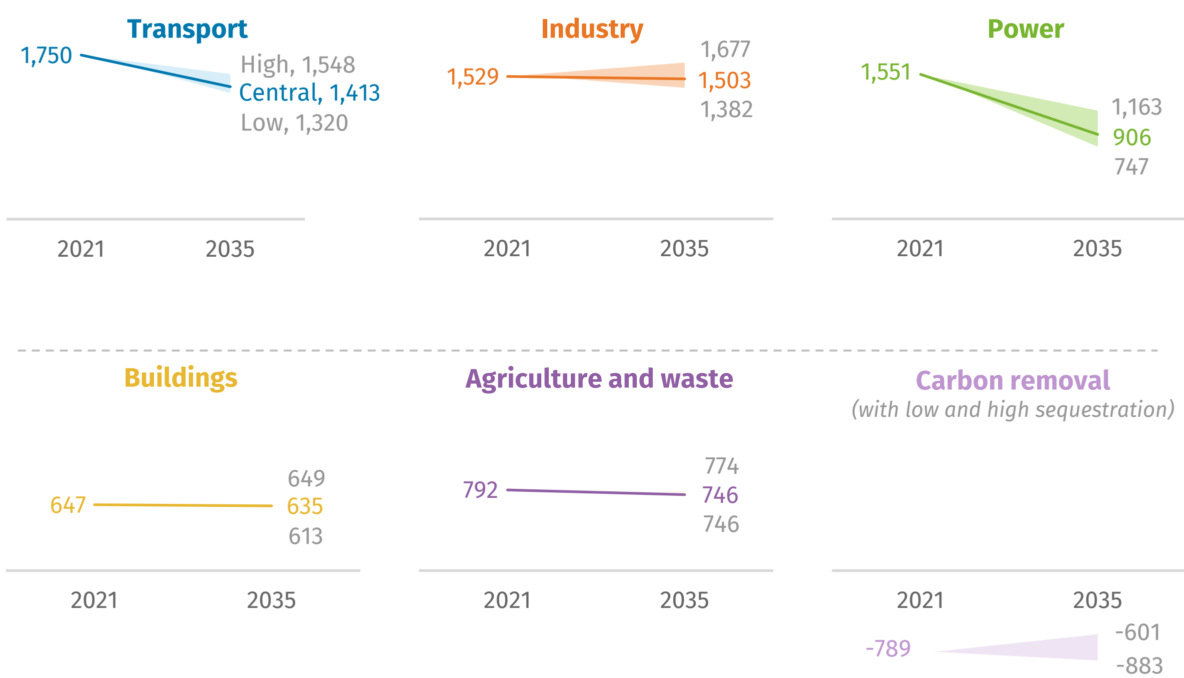
Key trends by sector

Underpinning these economy-wide emission reductions are important sectoral trends, which we unpack further in Figure 2, including a continued reordering of the highest-emitting sectors. In 2016, the transportation sector overtook the power sector as the largest contributor of GHG emissions in the US. In our Taking Stock 2022 emissions scenarios, both the power and transportation sectors reduce emissions through 2035, while industrial sector emissions continue to grow, such that in the early 2030s industry is the highest-emitting GHG sector. Outside of the three largest sectors, buildings, agriculture and waste, and carbon removal all remain effectively flat through 2035.

Industry becomes the largest-emitting sector absent meaningful policies to curtail emissions growth, with flat emissions or modest changes depending on the scenario.

In the central emissions case, industrial emissions are effectively flat from today's level through 2035, in contrast to the transport and power sectors. In the high and low emissions cases, industrial emissions increase by 10% and decrease by 9%, respectively. The growth in the high emissions case is largely attributable to relatively cheap natural gas, which industries use as both a fuel and a feedstock, increasing total gas consumption by 17% by 2035. The largest growing sub-sectors are the chemicals industry and oil and gas production, transmission, and distribution.

FIGURE 2
US greenhouse gas emissions by sector under current policy
Net million metric tons of CO_2e



Source: Rhodium Group. Note: light-colored bands represent emissions outcomes across the three emissions scenarios except for carbon removal. The carbon removal range represents the high and low sequestration estimates discussed in Chapter 2, with projected carbon capture and sequestration deployment added, but note that all estimates in this report only use the high sequestration pathway.

Only a handful of policies on the books move the needle on industrial emissions. One is the federal tax credit for carbon capture and sequestration (section 45Q of the tax code). At current levels and with a commence construction deadline of 2026, we find that the 45Q credit drives just over 21 million metric tons of emissions abatement in the industrial sector (and 59 million metric tons in total abatement, including carbon capture at ethanol production facilities) by 2035. But the size and pending expiration of the current credit are insufficient to drive larger abatement. In addition, federal and state policies that target hydrofluorocarbons (HFCs) reduce industry's emissions of those potent gases by more than 30 million metric tons of CO_2e in 2035 over today's levels.

Also of note are pending regulations on methane emissions from the oil and gas industry, which we include as part of the industrial sector. We have previously estimated those regulations could reduce emissions by at least 100 million metric tons in 2030. The magnitude of emissions abatement scales directly with the amount of oil and gas produced in this country, so abatement could be higher still in cases with cheaper gas driven by higher levels of production.

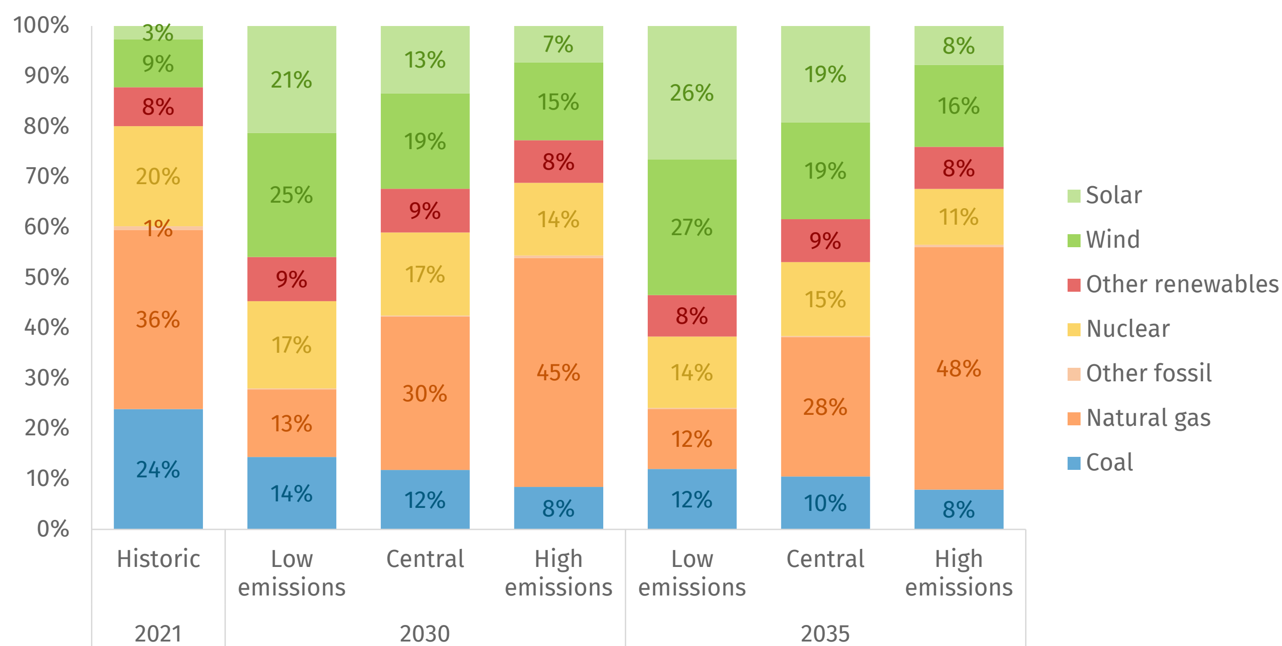
Emissions from the power sector generally continue to decline, but natural gas and renewable energy prices have a major impact on the 2035 outcome.

In 2035, power sector emissions are 42% lower in the central emissions scenario than they are today, while they are 25% and 52% lower in the high and low emissions scenario relative to 2021. These declines are driven by continued reductions in generation from coal and growth in renewables—despite a 20-37% reduction in nuclear generating capacity. The trajectory of natural gas and renewable energy prices matters a lot, as evidenced by the generation shares in Figure 3. Under the low emissions scenario, continued aggressive cost declines for wind and solar along with high natural gas prices both constrain the build-out of new natural gas generating capacity and put pressure on the existing fleet, which begins to see economic retirements by 2035.

FIGURE 3

Electricity generation by source in 2021, 2030, and 2035

Percent of total generation



Source: Rhodium Group

Of note, by 2035 more than 75% of total generation is zero-emitting in this scenario—but this is still a lower share than the Biden administration is targeting even from 2030. Perhaps counterintuitively, coal generation is higher in the low emissions scenario, as higher gas prices lead coal and gas to compete to be the marginal resource in power markets. Though this is a net GHG emissions benefit, there are important public health and environmental justice considerations to keeping more of the existing coal fleet around; forthcoming regulations from EPA for both GHGs and criteria pollutants could affect this trajectory.

Conversely, in the high emissions case, rock-bottom gas prices and relatively more expensive renewables both keep existing gas generators online and lead to a more than 50% increase in total combined cycle capacity on the grid compared with 2021 levels. Owing to these dynamics, power sector emissions bottom out in 2029 in the high emissions case before beginning a 10% rise from 2029 through 2035.

Fuel economy improvements and more electric vehicle sales drive declines in transportation sector emissions.

Transportation emissions dropped by more than 15% below 2019 levels in 2020 due to COVID-induced declines in demand for gasoline and jet fuel, then rebounded modestly in 2021. We estimate that emissions from this sector won't return to 2019 levels through 2035 and will instead see declines of 12-25% over today's levels in 2035.

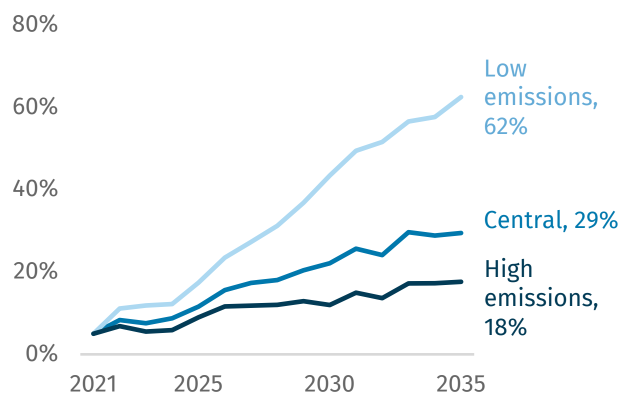
This decline is due to three main factors. First, continued declines in battery price, increased manufacturer output of electric vehicles (EVs), and greater availability of charging infrastructure due to the Infrastructure Investment and Jobs Act all combine to drive high levels of EV sales. This is especially true in our lowest battery price case, in which EV sales comprise 62% of light-duty vehicle sales in 2035.

Second, past and recently adopted fuel economy standards promulgated by the National Highway Traffic Safety Administration (NHTSA) and greenhouse gas standards for light-duty vehicles adopted by EPA both drive sales of electric vehicles and improve the fuel efficiency and emissions intensity of conventional vehicles. Since current standards run through model year 2026, the Biden administration has the opportunity to adopt standards further into the future—another chance to use regulation to push emissions further down. Relatedly, EPA's GHG standards for medium- and heavy-duty vehicles as well as state zero-emission vehicle targets for medium- and heavy-duty vehicles increase lower-emitting on-road freight transportation, yielding emissions reductions from this important subsector as well. The Biden administration has proposed updates to the EPA standards through at least model year 2027 that are not currently reflected in this modeling.

FIGURE 4

Sales of electric vehicles as a share of overall light-duty vehicle sales

Percent of total light-duty vehicle sales



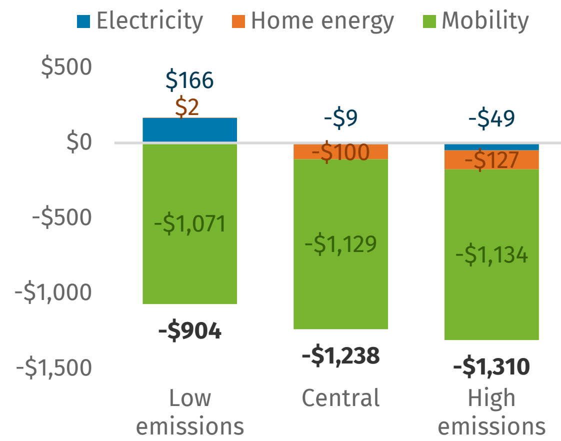
Source: Rhodium Group

By 2035, household energy costs drop by 16-25% relative to 2021 bills as more electric vehicles on the road lead to lower costs at the pump.

Household energy costs—residential electricity bills, bills for home heating fuels like natural gas or fuel oil, and expenditures on transportation fuels like motor gasoline and diesel—shrink under all three emissions scenarios, with a savings range of $900 to $1,300 each year. These savings are largely driven by reductions in expenditures on transportation liquid fuels, as more households opt for electric vehicles and gasoline vehicles continue to get more efficient.

We also only see gasoline prices rival 2021 levels in our low emissions scenario in 2035, while the price to consumers is 50-65 cents lower per gallon in the central and high emissions cases, respectively. Electricity bills, including the cost of charging EVs, range from small decreases to modest increases—but bills would be down across the board without the extra electricity use from charging EVs.

FIGURE 5
Change in household energy costs from 2021 to 2035
US dollars



Source: Rhodium Group

CHAPTER 4

An Uncertain Future

In Chapter 3, we provided estimates for a set of emissions scenarios reflecting bounds of likely emissions outcomes through 2035. In this chapter we discuss several other emissions pathways which are within those bounds but that also reflect continuations of different trends from the recent past. As is our mantra throughout this year's Taking Stock report, uncertainty remains our watchword in these scenarios. If past is prologue, which past should we consider? We model three additional scenarios based on trends in the economy and energy markets, and we present these economy-wide emissions results in Figure 6.

Before the war in Ukraine and post-COVID inflationary pressures upended global energy markets and economic expectations, the US was on pace to see continued high levels of domestic oil and gas production drive low fossil fuel prices. Likewise, before COVID laid bare issues with supply chain resilience for key clean energy technologies, wind, solar, and other technologies needed for decarbonization were expected to continue their decade-plus of enormous cost reductions.

In our **steady progress** scenario, we consider the emissions impact of a return to those longer-term historical trends for clean tech and energy markets—a step back from the edge of the energy market volatility and uncertainty that we've seen this year. In this scenario, we model the effects of continued aggressive cost declines for solar, wind and other clean technologies in line with our low clean technology cost case discussed in Chapter 2. To that, we layer on our central oil and gas prices and GDP growth continuing at its average since 2010 (excepting the COVID recession and recovery years), reflecting a higher growth rate than we assume in our central, low, and high emissions scenarios. In this scenario, economy-wide emissions are 4.4 billion tons in 2035, 34% below 2005 levels and reasonably in line with our central emissions outcomes.

Put another way, with some pressures pulling emissions higher (fossil prices and economic growth) and other pressures pushing emissions lower (clean technology prices), continuing the steady progress that has mostly characterized the past half-decade results in middle-of-the-road emissions reductions.

By contrast, in our **continued volatility** scenario, we estimate the effect on emissions if current energy market volatility and other uncertain conditions persist longer than expected. In this scenario, energy markets remain unsettled globally, leading to high oil and gas prices and a period of increased LNG demand from Europe. In addition, clean energy technology supply chains continue to be disrupted, and these impacts combined with other headwinds limit cost reductions for clean tech, keeping the US on the central clean technology cost pathway. Uncertainty also means the US economy doesn't grow as strongly as it has over the past decade. The combination of these forces, but especially low GDP growth and high natural gas prices, leads to total emissions of 4.1 billion tons in 2035—39% below 2005 levels and roughly halfway between our central and low emissions scenarios.

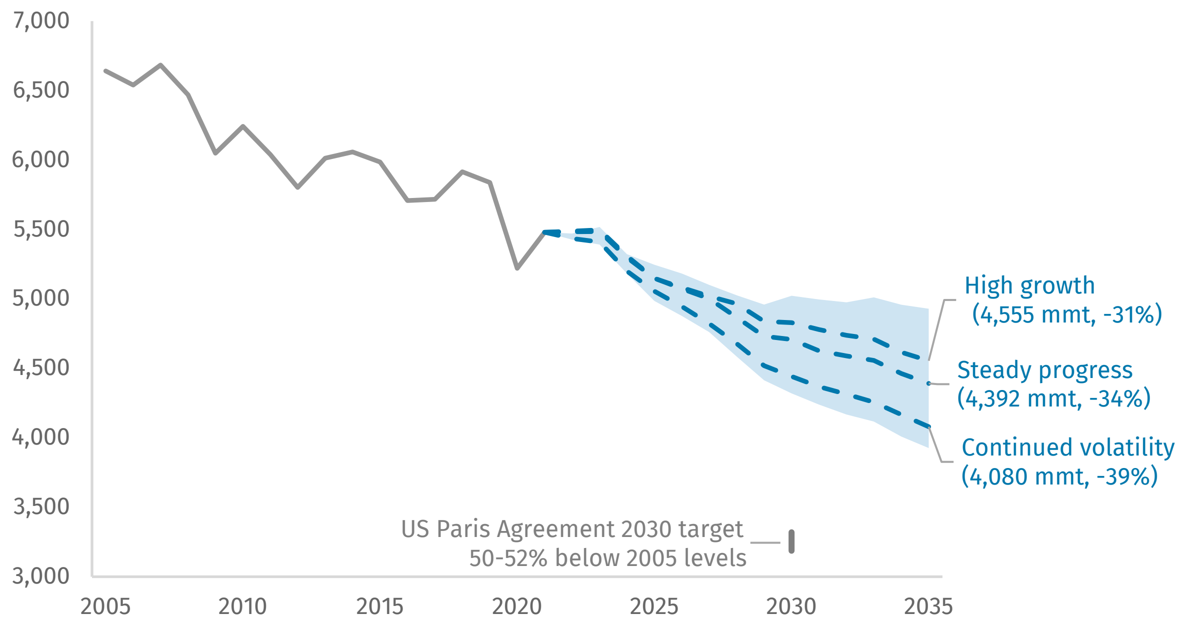
Though the resulting emissions are lower than in the steady progress case, the US achieves these reductions with pain on consumers and businesses in the form of higher energy bills and lower economic growth. As we noted in our 2020 COVID edition of Taking Stock, these aren't great ways to build sustainable progress on decarbonization—and the US *still* doesn't meet its 2030 climate target.

Finally, in our **high growth** case, we isolate the impacts of economic growth on emissions outcomes by starting with our **central emissions** case and pairing it with more aggressive macroeconomic expansion through 2035. Historically, GDP growth is the single largest

FIGURE 6

US greenhouse gas emissions under current policy

Net million metric tons (mmt) of CO_2e



Source: Rhodium Group. Note: light blue band represents emissions outcomes in the low, central, and high emissions scenarios discussed in the previous chapter.

factor impacting US emissions, and today most analysts expect relatively constrained growth in the near to medium term. But given its outsized impact on overall emissions, it's important to understand the GHG impacts if the US economy grows faster than analysts are currently expecting. Higher growth alone leads to an emissions increase of 235 million metric tons (5%) over the central emissions case, with economy-wide emissions totaling 4.6 billion tons in 2035 (31% below 2005 levels).

Exploring sources of uncertainty provides important insights

Economic growth matters to emissions outcomes.

Assuming a more aggressive economic growth rate, as we do in the steady progress and high growth cases, results in higher emissions that are driven largely by the industrial sector. In 2035, economy-wide emissions are 235 million metric tons higher in the high growth case than the central emissions case (which otherwise has the same inputs); 88 million metric tons (38%) of that difference is in the transportation sector owing to higher vehicle-miles traveled (VMT) in the light-duty vehicle sector and greater volumes of road freight transportation. Another 63 million metric tons (27%) of the difference is in the industrial sector, pointing to the need to double down on both continued research and development to keep improving and driving down the cost of industrial decarbonization solutions as well as the need for governments to drive deployment of these technologies as soon as possible via policy.

Surging demand for LNG from Europe can drive economic expansion of export capability, but gas prices need to remain relatively low for this capacity to be useful long-term.

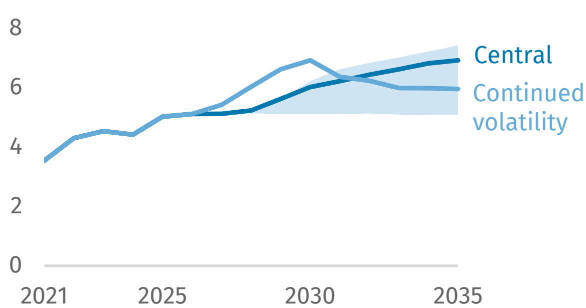
In all scenarios, we model current LNG export facilities that are under construction as coming online as scheduled, including the recently announced Plaquemines facility in Louisiana. In the central emissions scenario, the economics of gas production and export leads to modest continued growth in export capacity through the late 2020s and early 2030s, peaking at just under 7 trillion cubic feet (Tcf) per year in 2035 (Figure 7).

By contrast, in the continued volatility scenario, we model continued strong demand for LNG from Europe through 2030, with demand falling back toward historical averages thereafter. Despite the higher gas prices in the continued volatility run, the economics still pencil to continue export capacity expansion such that by 2035 annual export capacity is more than 10 Tcf per year—46% higher than in the central run. This increased European demand for gas drives Henry Hub prices about 70 cents higher than in our high oil and gas price case in 2030, but Henry Hub prices reconverge with that high price path as increased demand abates. Also, whereas the capacity utilization rate of LNG export facilities in the central case remains at or near 100% through 2035, utilization rates drop to only about 60% in 2035 in the continued volatility case as a result of shrinking European demand and high gas prices.

FIGURE 7

Net LNG exports

Trillion cubic feet



Source: Rhodium Group. Note: light blue band represents outcomes in the low, central, and high emissions scenarios discussed in the previous chapter.

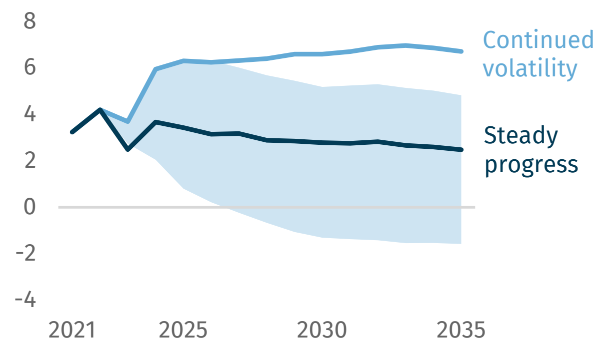
With steady progress, the US further reduces its reliance on imported crude. With continued volatility, crude imports rise from today.

Since 2010, the US has cut its net crude oil imports by more than half owing to strong domestic production, and this trend continues through 2035 in most of our scenarios. In the steady progress case, for instance, net imported crude is 2.8 million barrels per day, just 26% of what it was in 2010. In the continued volatility case, by contrast, limited domestic resources drive up the price of drilling (and the price of oil) while less favorable battery prices curtail the growth of EVs in the light-duty vehicle market. The result is that net imported crude levels are more than double what they were in 2021, and the highest in all cases we examined (Figure 8).

FIGURE 8

Net crude oil imports

Million barrels per day



Source: Rhodium Group. Note: light blue band represents outcomes in the low, central, and high emissions scenarios discussed in the previous chapter.

The only certainty: more is needed

We've focused a lot on uncertainty in this year's report because the future course of the economy, energy markets, clean technology development, and the policy environment are more unsure than in recent memory. But while there is uncertainty, what's crystal clear across all six scenarios that we've analyzed is that we are off track to achieving the US's climate targets without accelerated action to decarbonize on all fronts. The clock is ticking on Congress's and the Biden administration's efforts to enact meaningful policy changes to bend the emissions curve down further. States and the private sector may be able to make up some of the difference but, as yet, have not taken substantive steps to do so. New elections on the horizon and increased judicial scrutiny similar to the Supreme Court's recent *West Virginia v. EPA* decision underscore the need to act fast and responsibly if the US has any chance of meeting its 2030 climate target and helping to avert the worst effects of global climate change.

CHAPTER 5

Explore the Data

Rhodium's annual Taking Stock report provides objective, up-to-date analysis of the GHG emissions impact of current legislative and regulatory action at the US federal and state level in a framework consistent with accounting methodologies of the US government and United Nations Framework Convention on Climate Change. This report offers an overview of our national results. Direct access to the low, central, and high emissions scenarios results from our Taking Stock 2022 baselines—including results broken down by gas and sector for all 50 US states—is available via the ClimateDeck.

The ClimateDeck—a partnership of Rhodium Group and Breakthrough Energy—equips users in the nonprofit, philanthropic, and government sectors with comprehensive datasets, unique and responsive insights, and a robust set of tools for tracking pathways to climate targets and understanding the emissions and economic implications of major developments at the international, national, and state levels. All of this is available for exploration and download from our interactive data visualization platform. For access, contact climatedeck@rhg.com.

TABLE 1

US GHG emissions under emissions scenarios

Million metric tons of CO_2e

Gas	2005	2021	2025	2030	2035
Carbon dioxide	6,133	4,992	4,517 – 4,738	4,009 – 4,600	3,728 – 4,590
Methane	697	646	602 – 652	566 – 665	549 – 671
Nitrous oxide	453	453	427 – 434	428 – 440	430 – 448
HFCs	128	166	165	129	91
Other F-Gases	19	12	11	11	12
Gross GHG emissions	7,430	6,269	5,721 – 6,000	5,144 – 5,846	4,809 – 5,812
Carbon removal*	-790	-789	-750 - -753	-824	-883
Net GHG emissions	6,641	5,480	4,968 – 5,250	4,320 – 5,022	3,926 – 4,929
Change from 2005	0%	-17%	-21% - -25%	-24% - -35%	-26% - -41%

Source: Rhodium Group. Columns represent the minimum and maximum annual net US emissions given likely energy market, policy and carbon removal outcomes. *Includes Land Use Land Use Change and Forestry (LULUCF) from the high sequestration scenario and carbon capture and sequestration.

Technical Appendix

This document provides additional detail on the methods and data sources used in Rhodium Group's Taking Stock 2022 report. Direct access to all energy and emissions results from our Taking Stock 2022 baselines—including results broken down by gas and sector for all 50 US states through 2035—is available via the ClimateDeck. All historical greenhouse gas (GHG) emissions and removal estimates (1990-2020) come directly from the Environmental Protection Agency (EPA) Greenhouse Gas Inventory. Like the EPA inventory, all gases are reported in carbon dioxide (CO2)-equivalent emissions based on the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4) 100-year global warming potential (GWP) values. To model potential future emissions scenarios, we use RHG-NEMS, a modified version of the detailed National Energy Modeling System used by the Energy Information Administration (EIA) to produce the Annual Energy Outlook 2022 (AEO2022) and maintained by Rhodium Group. We expand on this model to project all six GHGs targeted for reduction under the Kyoto Protocol.

Energy market, technology, and economic assumptions

To construct our national Taking Stock GHG emissions projections range, we revised multiple energy market, technology cost, policy, and behavioral assumptions in RHG-NEMS to be consistent with the most recent research and to reflect the range of market and economic uncertainties. Each year these assumptions are updated to reflect the best available data and information.

Unless otherwise stated below, we use EIA's AEO2022 reference case assumptions in our Taking Stock projections.

Sources of uncertainty

To construct the full range of emission projections in Taking Stock, we looked at three key sources of uncertainty:

- Energy markets: We consider a range of energy market variables that shape emissions outcomes, including natural gas and oil resource availability and prices.
- Technology cost and performance: We estimate ranges for key technology cost and performance variables, including capital and operating costs for clean electricity generators and battery costs for light-duty electric vehicles (EVs).
- Economic: We use two different projections of US gross domestic product (GDP) growth in Taking Stock: a baseline growth rate and a high growth rate.

RHG-NEMS inputs that are consistent across the emissions outlook

We make several revisions to input assumptions beyond EIA's AEO2022 Reference case that are consistent across our Taking Stock emissions range. The key revisions are described below.

- Announced power plant retirements and additions: We incorporate all announced coal and nuclear power plant retirements through 2035. We account for the Civil Nuclear Credit that was enacted as part of the IIJA as well as state-level policy actions that will allow for continued operation of certain nuclear power plants in those states.
- Electric vehicle uptake: We revise key parameters to reflect recent historical EV sales as well as expectations relating to ongoing EV research and development and industry investment.
- Electric vehicle charging costs: We alter fuel costs for electric vehicles to reflect current charging behavior.

- Automated vehicle deployment: RHG-NEMS does not capture the impact of autonomous transportation technologies for personal vehicle use.

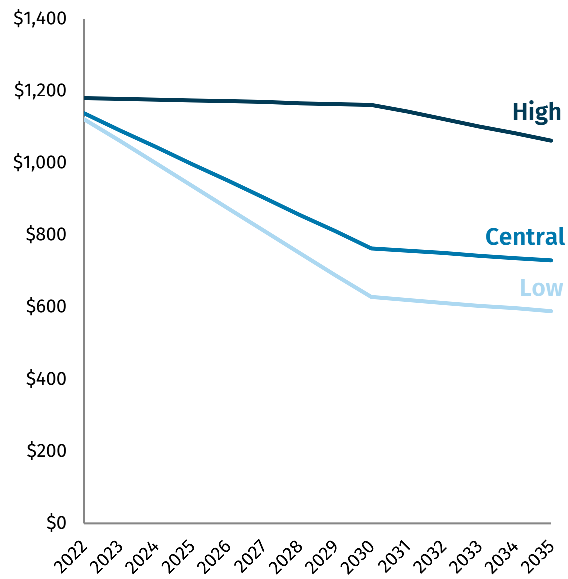
RHG-NEMS inputs that vary to capture energy market uncertainty

Below are the key assumptions that vary across our estimated emission range and underlying data sources. For each input, we defined a central, low, and high case to reflect a range of potential market and technology cost outcomes. We provide charts for select assumptions.

Electric generating technology costs: We generally assume capital costs for utility-scale and distributed solar photovoltaic, land-based and offshore wind, and utility scale energy storage decline according to NREL's 2022 Annual Technology Baseline's (ATB) technology cost projections. Our central cost assumptions follow ATB's Moderate Technology Innovation Scenario, while our low- and high-cost assumptions follow the Advanced Scenario and Conservative Scenario, respectively.

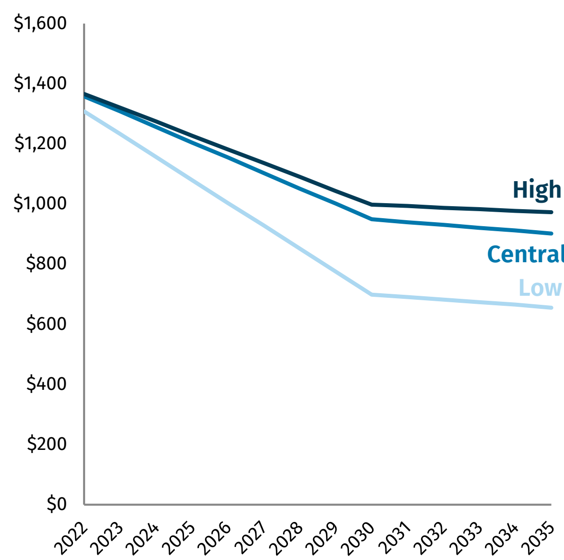
We also change relevant cost and performance parameters for power generating facilities equipped with carbon capture technology, informed by Rhodium analysis and current literature. Of particular note are revisions to costs for new-build natural gas plants with carbon capture. We adapt work from the National Energy Technology Laboratory, which details cost and performance for natural gas-fueled direct supercritical CO2-fired power plants.

FIGURE 1
Utility-scale solar photovoltaic overnight capital costs
2021 dollars per kilowatt



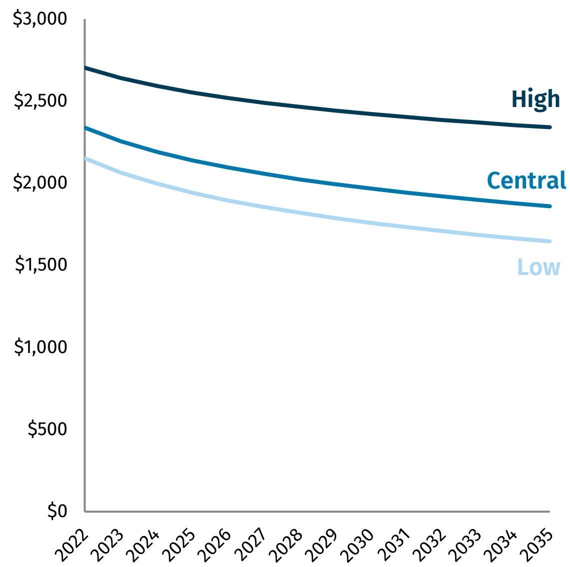
Source: Rhodium Group analysis, NREL, EIA

FIGURE 2
Land-based wind overnight capital costs
2021 dollars per kilowatt



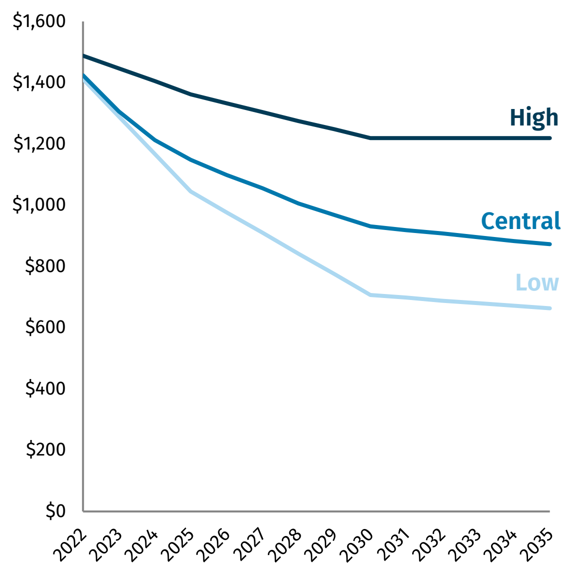
Source: Rhodium Group analysis, NREL, EIA

FIGURE 3
Offshore wind overnight capital costs
2021 dollars per kilowatt



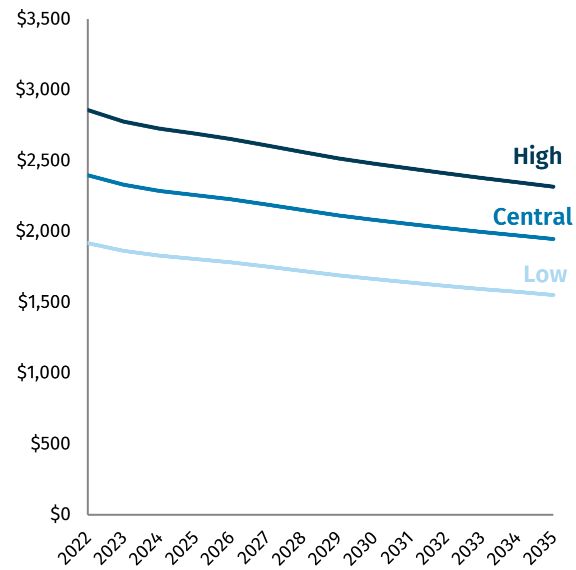
Source: Rhodium Group analysis, NREL, EIA

FIGURE 4
Utility scale energy storage overnight capital costs
2021 dollars per kilowatt



Source: Rhodium Group analysis, NREL, EIA

FIGURE 5
Natural gas with CCS overnight capital costs
2021 dollars per kilowatt

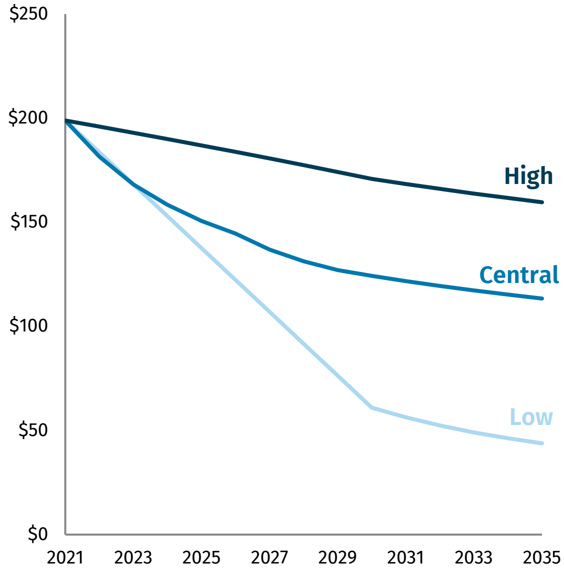


Source: Rhodium Group analysis, NETL, EIA

Electric vehicle battery costs: For light-duty electric vehicle (EV) battery costs, we draw on AEO 2022 reference battery cost projections for our central case and BNEF projections for our low-cost case. In our high-cost case, we assume annual cost reductions are 50% slower than the Rapid Advancement case from the National Renewable Energy Laboratory's (NREL) Electrification Futures Study (EFS). We assume battery costs for the suite of light-duty EV technologies modeled in NEMS[3] match these reduction pathways.

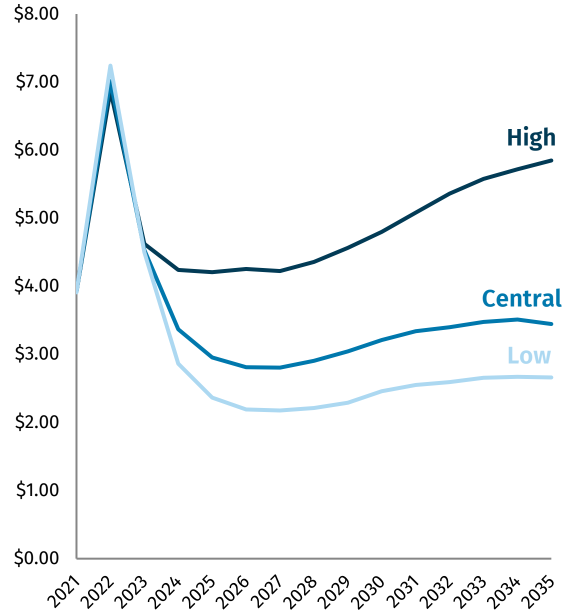
[3] EV technologies modeled in NEMs include EV100- and 200-mile range, plug-in hybrid 10 and 40-mile range, diesel hybrid, fuel cell methanol, fuel cell hydrogen, and gasoline hybrid.

FIGURE 6
Electric vehicle battery costs
2021 dollars per kilowatt-hour



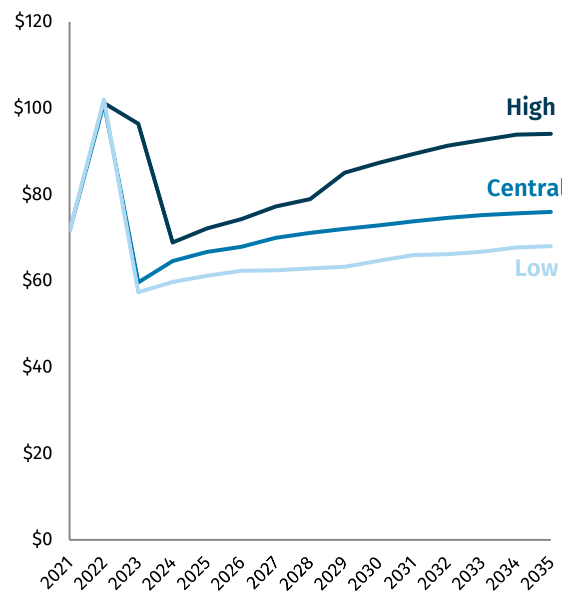
Source: Rhodium Group analysis, BNEF, NREL, EIA

FIGURE 7
Natural gas spot price at Henry Hub
2021 dollars per million Btu



Source: Rhodium Group analysis, EIA

FIGURE 8
Brent crude oil spot price
2021 dollars per barrel



Source: Rhodium Group analysis, EIA

Natural gas and oil resource and prices: Across all scenarios, for years 2022 and 2023, we calibrate oil and natural gas prices as closely as possible with EIA's June 2022 Short-Term Energy Outlook (STEO). From 2024 onwards, our price forecasts diverge in accordance with EIA's long-term projections as well as our own research and expectations. For our central cost case, we use the oil and natural gas resource and prices reflected in the AEO2022 reference case. In this case, natural gas averages $3.19/MMBtu through 2035 at Henry Hub, and Brent crude rises from $65/barrel in 2024 to $76/barrel in 2035. In our low-cost case, we use the oil and natural gas resource and prices reflected in EIA's high oil and gas supply side case. The resulting average natural gas price is $2.47/MMBtu from 2024 through 2035, and Brent crude reaches $68 per barrel in 2035. In our high-cost case, we use the oil and natural gas resource and prices reflected in EIA's low oil and gas supply side case. Natural gas prices in our high-cost case average $4.85/MMBtu through 2035, while Brent crude rises to $94/barrel in 2035. In the continued volatility case discussed in Chapter 4, we also increase demand from Europe on the global LNG market, maintaining prices at double the model baseline through 2030.

Industrial carbon capture costs: Rhodium has developed the Industrial Carbon Abatement Platform (ICAP) to assess technology deployment and emissions abatement potential in the industrial sector under a variety of scenarios. Using ICAP, we project future carbon capture retrofits at existing industrial facilities under low, central, and high CCS cost assumptions. ICAP is integrated with the rest of RHG-NEMS such that industrial facilities see dynamic energy costs and expected revenue from CO_2 sales.

RHG-NEMS inputs that vary to capture macro-economic uncertainty

We model a range of future economic growth scenarios to capture the emissions impact of uncertainty in the annual growth rate of the US economy. Our baseline economic assumptions deliver an average 2.3% real annual rate of growth from 2022 to 2025 and a 1.8% real annual rate of growth from 2026 to 2035. In 2022 in our high economic growth case, GDP grows at an average 2.8% rate from 2022 to 2025 and 2.1% from 2026 to 2035. These assumptions are aligned with the AEO 2022 Low Economic Growth and Reference cases, respectively.

Federal and state policy assumptions

Our scenarios include emission reductions from all actionable and quantifiable existing federal and state policies as of June 2022. To remain consistent with United Nations (UN) guidelines for reporting the impact of current measures, we include only policies that have been finalized and adopted. We do not include aspirational goals or economy-wide targets that have not been solidified in specific, actionable policy, nor do we explicitly include specific city-level or corporate commitments.

CO_2 policies

Carbon pricing: We include the California Cap-and-Trade Program and the Regional Greenhouse Gas Initiative (RGGI), which prices electricity sector carbon emissions from 12 states. Carbon pricing policies that have not been finalized with clear, implementable milestones have not been included in our analysis. This includes the Transportation and Climate Initiative (TCI), whose final model rule was not released by May 2021, Oregon's Climate Protection Program, a cap-and-trade program currently under development, and the Washington Climate Commitment Act (CCA) which directs policymakers to design an economy-wide cap-and-trade program to be implemented in 2023.

Electric power: In the power sector, we include all federal renewable energy and nuclear tax incentives in place as of June 2022, phased out based on their current statutory schedules. We also include the tax credit for carbon oxide sequestration (45Q) as amended in December 2020 and the IIJA Civil Nuclear Credit. We reflect the judicial vacation of the Affordable Clean Energy (ACE) rule. The California cap-and-trade program, RGGI, Renewable Portfolio Standards (RPS), Clean Energy Standards (CES), and zero-emission credit programs are all included. We also include state offshore wind mandates that reflect capacity already in operation or for which there are purchase agreements in place and state energy storage mandates.

Transportation: We also include the National Highway Traffic Safety Administration's new CAFE standards finalized in April 2022, which establish a standard for light-duty fuel economy to increase 8% annually in model years 2024 and 2025 and 10% annually in model year 2026.

We also model federal Renewable Fuels Standard, medium and heavy-duty vehicle GHG emissions standards, and state and federal electric vehicle incentives. We also include vehicle emission standards and zero-emission vehicle (ZEV) mandates for California and 17 states that follow California's tighter standards under Section 177 of the Clean Air Act (S177 states). We also include the California and Oregon low-carbon fuel standards. The Washington Clean Fuel Standard is not included as the program is not yet final. California's Advanced Clean Truck (ACT) regulation (requiring 100% zero-emission truck sales by 2045) and the Innovative Clean Transit regulation (requiring

100% zero-emission bus sales by 2040) are also included. Oregon, Washington, New York, New Jersey, and Massachusetts have also adopted California's ACT rule and are also included. State ZEV commitments with no underlying regulatory policy are not included in our modeling.

Industry and buildings: We include current federal minimum energy conservation standards for appliances and equipment. We also include the tax credit for carbon dioxide sequestration (45Q) as amended in December 2020. State energy efficiency programs are implicitly captured in RHG-NEMS electric demand projections. We also capture the impacts of federal investment in clean hydrogen and direct air capture hubs that were funded as part of the IIJA.

Non-CO_2 policies

Methane: We assume the reinstatement of federal methane emission rules for the oil and gas industry, following the 2021 Congressional Review Act vote to invalidate the Trump administration's rollback of Obama-era rules. We assume other major federal oil and gas methane policies undone by the Trump administration remain effectively rolled back, including EPA's 2016 Control Techniques Guidelines (CTGs) for volatile organic compounds (VOCs) from oil and natural gas; and 2016 Bureau of Land Management regulations to prevent waste of natural gas from venting, flaring and leaks on public lands.

We assume emission reductions from EPA's 2016 updated NSPS and emission guidelines for methane from municipal solid waste landfills rules are delayed—with enforcement starting in 2021 rather than 2016—to reflect EPA's recent update to the Obama-era rule. The following state policies are also reflected: oil and gas standards in California, Colorado, Pennsylvania, New Mexico, Ohio, Utah, and Wyoming; and California's landfill methane control measures from 2010 and updated in 2017. All estimates associated with federal and state oil and gas rules are based on modeled estimates from the Clean Air Task Force that align with oil and gas production from each of our scenarios. For landfills, we used emission reduction estimates from EPA and California's Air Resources Board.

Hydrofluorocarbons (HFCs): In all our scenarios we assume a phasedown in the production and consumption of HFCs in line with the Kigali Amendment of the Montreal Protocol, consistent with the American Innovation and Manufacturing (AIM) Act of December 2020. We reflect emission reductions from all existing state rules, including California, Colorado, Delaware, Maine, Maryland, Massachusetts, Rhode Island, New Jersey, New York, Virginia, Vermont, and Washington's HFC control regulations. We model HFC emissions based on the California Air Resources Board's Short-Lived Climate Pollutant assessment tool, which estimates potential national and state-level HFC emission pathways associated with a range of federal and state policies.

Table 1: Federal and state policies included in Taking Stock 2022 baselines

Sector	Federal policy	State policy	State
Power			
	Renewable energy tax incentives as amended in December 2020, phased out based on their statutory schedules	Renewables portfolio standard (RPS) and clean electricity standard (CES)	AZ CA CO CT DE DC HI IL IA ME MD MA MI MN MO MT NV NH NJ NM NY NC OH OR PA RI TX VT VA WA WI
	Tax credit for carbon dioxide sequestration as amended in December 2020 (45Q)	Offshore wind mandates	CT MA MD ME NJ NY RI VA
	Civil Nuclear Credit Program	Nuclear zero emission credit (ZEC) programs	CT IL NJ NY OH
	Judicial vacation of the Affordable Clean Energy (ACE) rule	Energy storage mandates	CA MA NV NJ NY OR VA
	Cross-State Air Pollution Rules (CSAPR)		
	Mercury and Toxics Standards (MATS)		
	New Source Review (NSR)		
Transportation			
	MY2024-2026 Corporate Average Fuel Economy standards	California light-duty vehicle GHG standards or zero emissions vehicle (ZEV) mandate	CA CO CT DE ME MD MA MN NJ NM NV NY OR PA RI VA VT WA
	Alternative fuel vehicle tax credits	Low-carbon fuel standard (LCFS)	CA OR
	Renewable fuel standard (RFS)	Medium and heavy-duty ZEV policy	CA MA NJ NY OR WA

	GHG and fuel consumption standards for heavy-duty vehicles Plug-in Electric Drive Vehicle (PEV) tax credit	State electric, hybrid, and alternative-fuel vehicle tax and other incentives	AR AK CA CO CT DE DC FL GA HI ID IL LA MD MA MI MO MT NV NJ NY NC OH OR PA RI TN TX UT VA WA WI
	Tier 3 Motor Vehicle Emission and Fuel Standards Program	Zero emission bus mandate	CA
	International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI		

Industry and buildings	Federal minimum energy conservation standards for appliances and equipment Federal investments in clean hydrogen and direct air capture hubs in IIJA Tax credit for carbon dioxide sequestration (45Q) as amended in December 2020 Clean Air Act Amendments of 1990 emission requirements for industrial processes	Energy Efficiency Resource Standards (EERS)	AK AZ CA CO CT DC HI IA IL LA MA MD ME MI MN MO MS NC NH NV NJ NM NY OH OR PA RI TX UT VA VT WA WI

Hydrofluorocarbons (HFCs)	Phasedown in the production and consumption of HFCs in line with the Kigali Amendment of the Montreal Protocol, consistent with the American Innovation and Manufacturing (AIM) Act of December 2020	State HFC phasedowns	CA CO DE MA ME MD NJ NY RI VA VT WA

Methane			
	Reversal via 2021 Congressional Review Act of Trump-era rollback of EPA's 2012 and 2016 Oil and Gas New Source Performance Standards for transmission and storage sources	State oil and gas standards	CA CO NM OH PA UT WY
		Landfill methane regulation (LMR) and SB1383 agricultural methane targets	CA
	EPA Municipal Solid Waste landfill methane rule		
Carbon pricing			
		Cap and trade program	CA
		Regional Greenhouse Gas Initiative (RGGI)	CT DE ME MD MA NH NJ NY PA[4] RI VT VA

Projection and 50-state downscaling methodology

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.
- 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

[4] On July 8, a judge paused implementation of Pennsylvania joining RGGI.

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 dry natural gas production available at the play level 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- where possible. In some instances, such as agriculture, 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. Additional modifications are made to reflect the impact of state and federal policies as discussed above.

Historical emissions and removals from land use, land-use change, and forestry (LULUCF) come directly from the 2020 EPA GHG inventory. Projected trends come from the high sequestration scenario from the 2021 Biennial Report of the United States calibrated to align with EPA's 2020 inventory. For emissions of N_2O and CH_4 from LULUCF, we assume 2018 emissions from LULUCF remain constant through 2030, following the approach used in the 2016 Biennial Report.

Downscaling national emissions projections to the state level

RHG-NEMS forecasts fuel consumption by sector at various levels of geographical aggregation, which is then downscaled to the state level using state-level activity data. For the power sector, generation-based emissions are taken directly from RHG-NEMS which reports individual plant-level emissions. NEMS builds new fossil-fuel fired plants to meet electricity demand and those plants and their respective emissions are attributed to individual states within an electricity market region based on historical trends. We estimate generation-based power emissions based on the production of electricity within a state, a portion of which may be exported outside the state. We also estimate power sector emissions associated with the consumption of electricity within a state, accounting for the carbon intensity of generation that produced that electricity.

Projections of fuel consumption by other end-use sectors, including industry, buildings (a combination of the residential and commercial sectors) and transportation, are downscaled to the state level from nine census-level regions. In the building sector, we apportion census-level GHG emissions to constituent states using each state's share of historical fuel consumption. In the transportation sector, we use historical demand to divide up fuel consumption by mode in each census region between constituent states. For example, we use the historical share of vehicle miles traveled (VMT) for light-duty vehicle fuel demand, and truck ton-miles for freight fuel demand. For industry, we use EPA's Facility Level Information on Greenhouse

Gases Tool (FLIGHT) as weights to apportion census region GHG emissions to constituent states for large industrial facilities, and total value-added as weights to apportion census region fuel consumption for smaller facilities.

For non-fossil fuel combustion CO_2 emissions at the state level, all other GHG emissions and LULUCF emissions and removals we use activity data from RHG-NEMS where available. For example, methane emissions from fossil fuel production are downscaled based on production output from RHG-NEMS which is available by fuel basin/play and can be attributed to individual states. In cases where there are no appropriate outputs from RHG-NEMS, we draw on other sources of activity data, including EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks by State, FLIGHT, the EIA, and USDA.

About this Report

About Rhodium Group

Rhodium Group is an independent research provider combining economic data and policy insight to analyze global trends. Rhodium's Energy & Climate team analyzes the market impact of energy and climate policy and the economic risks of global climate change. This interdisciplinary group of policy experts, economic analysts, energy modelers, data engineers, and climate scientists supports decision-makers in the public, financial services, corporate, philanthropic and nonprofit sectors. More information is available at www.rhg.com.

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Whitney Herndon is an Associate Director at Rhodium Group and manages the firm's US energy research. Whitney manages a team of analysts that use a range of energy and economic models to analyze the impact of policy proposals and market shifts on the US energy system and macroeconomy. Her expertise includes carbon capture, energy and electric power systems modeling, and economy-wide decarbonization.

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Disclosures

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