Rhodium Group

Taking Stock 2021

US Greenhouse Gas Emissions Outlook Under Current Federal and State Policy

July 15, 2021

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Executive Summary

For the past seven years, Rhodium Group has provided an independent annual outlook for US greenhouse gas (GHG) emissions under current federal and state policy. This current policy baseline provides a starting point for assessing where additional work—in the form of federal, state, or corporate action—is necessary to achieve mid- and long-term US GHG emission reduction goals.

Given the current state of federal and state policy (as of May 2021) and a range of potential energy market dynamics on the horizon, we find that the US is on track to reduce emissions 20% to 22% below 2005 levels by 2025. Looking ahead to 2030, the US is on track to achieve emission reductions anywhere from 20% to 26% below 2005 levels, absent additional action. Taking into account additional uncertainty in the direction and pace of US economic growth—and in particular, the pace of recovery from the economic disruption caused by the COVID-19 pandemic—we project 2030 emission reductions as small as 17% below 2005 levels, or as great as 30%.

This analysis only considers federal and state actions that are on the books today. It is clear that more policy action is needed if the US is going to achieve deeper emission reductions, including the Biden administration's pledge to reduce US emissions 50-52% below 2005 levels by 2030. Later this fall, Rhodium Group will publish new research identifying the emissions impacts of a suite of federal and subnational actions that can help close the gap between the current US emissions trajectory and ambitious decarbonization goals.

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

Key trends by sector

In addition to the economy-wide outlook for US emissions under current federal and state policy, here are the key trends we see by sector under a range of potential energy technology and market uncertainties:

Power sector emissions increase modestly over the next few years as the US economy bounces back from the pandemic, but then continue their secular decline through 2025 due to a continued decline in coal-fired generation. After a temporary rebound in coal generation coming out of the pandemic, coal continues its downward spiral, due in large part to competitive pressure from low-cost natural gas. If natural gas prices fall below $3/MmBTU, more than 50% of the current coal fleet could shutter by 2030. By 2025, these trends help cut power sector emissions in half relative to 2005 across our scenarios.

Going forward, however, the trajectory of US power emissions isn't defined by how much coal comes offline but rather the pace of natural gas expansion. In scenarios with the cheapest gas, power sector emissions begin to rise again after 2025. Low-cost natural gas, once the primary driver of emission reductions in the power sector, will begin to hamper the pace of decarbonization as it out-competes renewables and pushes out nuclear. Wind and solar capacity increase across our outlook, but cheap natural gas and a moderate reduction in clean energy technology costs could slash this clean build-out by almost 60% by 2030, compared to a future with more expensive natural gas and steeper technology cost declines. Low natural gas prices also put pressure on zero-emitting nuclear power, which could see more than a third of today's capacity retire by 2030.

After a brief post-pandemic rebound, transportation emissions decline modestly through 2030, driven by fuel economy improvements in passenger vehicles and a shift toward electric vehicles (EVs). Assuming the most optimistic outlook for declining EV battery costs combined with high oil prices—which would increase the EV share of total new passenger vehicle sales to 35% by 2030—transportation emissions fall by 23% by that year. More moderate EV battery cost reductions coupled with low oil prices lead to EVs capturing only 9% of the market in 2030, and transportation emissions decline by 18% from 2005 levels. Across our projected range, steeper emission reductions are limited by consumer preference for larger, higher-emitting vehicles, and robust demand growth for freight and air travel.

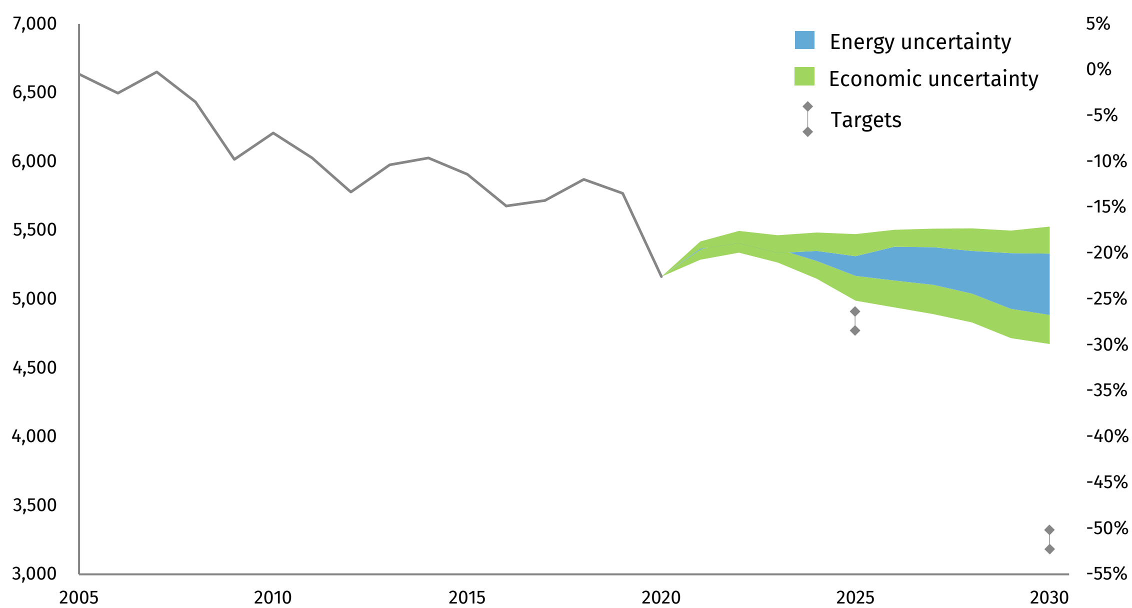
Industrial emissions continue to rise and become the top-emitting sector in the mid-2020s. Industrial emissions grow across our scenarios, but climb almost three times as fast from current levels when natural gas is cheap compared to when it's more costly. The oil and gas industry itself faces an uncertain future. If domestic natural gas and oil production never fully recover to pre-pandemic levels, emissions from upstream oil and gas activities could fall 12% by 2030 from today's levels. Conversely, a stronger outlook for the oil and gas industry could drive emissions up 25% from current levels by 2030.

Building efficiency improves but emissions from residential and commercial buildings remain effectively flat. Low-cost natural gas, increasing building square footage, and economic and population growth put upward pressure on building emissions, even while state policies make homes and businesses more efficient. Even in our highest scenario for natural gas prices, CO_2 emissions from buildings fall only 2% below 2005 levels by 2025. By 2030, emissions fall modestly to 1-4% below 2005 levels.

FIGURE 1

US greenhouse gas emissions under current policy with energy market and economic uncertainty

Net million metric tons of CO_2e (left), % change from 2005 (right)



Source: Rhodium Group. Targets represent US GHG emission reduction commitments, including the 2015 Paris Agreement pledge to reduce economy-wide US emissions by 26-28% below 2005 levels by 2025, and the updated commitment made in April 2021 to achieve a 50-52% reduction below 2005 levels by 2030.

CHAPTER 1

An Evolving Policy Landscape

For the past seven years, Rhodium Group has provided an independent annual assessment of US GHG emissions and progress towards achieving the country's climate goals in our annual Taking Stock report series. Each year we explore changes in federal and state policy, energy market developments, evolving technology advancements and costs, as well as expectations for growth of the American economy—all of which are central drivers of the outlook for US GHG emissions over the coming decade.

In Taking Stock 2020 we explored the impact of the COVID-19 pandemic on US GHG emissions under a range of potential scenarios based on the severity and length of the pandemic and the associated shocks to the US economy. Thankfully, the most dire economic outcomes did not come to pass, as the US economy contracted only 3.5% in 2020 and is expected to rebound quickly in 2021, with growth projected at over 6%. And although we estimate that US GHG emissions dropped 10.3% in 2020, we expect emissions to rebound this year as the US economy bounces back.

With economic activity—and emissions—beginning to recover, this year's edition of Taking Stock focuses on the key energy market, technology, and policy trends we see driving US emissions in the coming decade. As the Biden administration and Congress negotiate measures aimed at rebuilding and decarbonizing the American economy, Taking Stock provides a starting point for assessing how much further the US will need to go to meet its Paris Agreement pledge to reduce emissions 50-52% below 2005 levels by 2030, putting it on the path for net-zero emissions by 2050.

In spite of the pandemic, there were several important policy developments in 2020 and early 2021 that will provide a much-needed boost to US climate mitigation efforts. In December 2020, as part of its end of the year funding and stimulus package, Congress passed some of the most meaningful climate legislation in over a decade. The first was passage of the American Innovation and Manufacturing (AIM) Act of 2020, which directs EPA to phase down the production and consumption of hydrofluorocarbons (HFCs) in line with the Kigali Amendment of the Montreal Protocol. The second was an extension of tax credits for clean energy and energy efficiency, and most importantly, an extension of tax credits for carbon capture (the section 45Q tax credit). Congress also reversed the rollback of Obama-era regulations to reduce methane from oil and gas fields, marking the first reinstatement of a climate regulation dismantled by the Trump administration. The Biden administration has announced plans to continue to move the regulatory agenda forward, and we expect to see new proposals to reduce GHG emissions from a host of sources, including standards regulating emissions from new passenger vehicles, methane from oil and gas systems, and efficiency standards for appliances, among others.

The last year also saw the passage of new climate and energy policies at the state level. Virginia set a target of 100% clean energy sales. California finalized deals with five major automakers that legally binds them to increase the fuel economy of new light-duty vehicles by 3.7% annually through 2026. These stricter standards will apply to the fourteen other states that follow California's stricter GHG standards under Section 177 (S177) of the Clean Air Act. In 2021, Washington became the third state (along with Oregon and California) to pass a Low Carbon Fuel Standard (LCFS), reducing the carbon intensity of the state's transportation fuel portfolio by 20% by 2035. States also made commitments to reduce Short Lived Climate Pollutants and methane. In addition to the federal HFC legislation passed in 2020, three states—Delaware, Massachusetts, and Virginia—finalized rules to phase down use of HFCs in 2021, joining seven other states that have already taken similar action. Colorado and

New Mexico passed rules to curb methane emissions from the oil and gas industry. We capture all of these developments in our Taking Stock 2021 baselines.

The last year has also ushered in a wide range of new long-term goals that set the pace and scale of transition away from GHG-emitting technologies. These include a slew of commitments by automakers and states to transition from internal combustion engines to electric and other emission-free vehicle technologies, and an increasing number of electric utility commitments to produce zero-emission electric power. These commitments represent important contributions in the nation-wide decarbonization effort, however much of the work to implement these ambitions remains to be done.

In our Taking Stock 2021 baselines, we incorporate only those sub-national policies that have been adopted and contain clear, implementable milestones and real compliance mechanisms. For that reason, we do not include 100% ZEV commitments, electric utility commitments, or any other sub-national climate goal in our baselines that have not been solidified in specific, actionable policy.

CHAPTER 2

Emissions Outlook

If the past year taught us anything, it's that the future is difficult to predict. Although the profound disruption of the pandemic and economic fallout looks to be behind us, uncertainty still surrounds the pace of economic growth and changing energy market dynamics, all of which play a critical role in shaping the trajectory of US GHG emissions.

To address these uncertainties, we model US GHG emissions under a range of economic, technological, and energy market drivers. We do so using RHG-NEMS, a modified version of the National Energy Modeling System operated and maintained by Rhodium Group. NEMS is developed and used by the US Energy Information Administration (EIA) to produce its Annual Energy Outlooks (AEO).

We expand on this model to include all sectors of the US economy and coverage for all six greenhouse gases targeted for reduction under the Kyoto Protocol. We first update the model to incorporate all policies on the books as of May 2021. With these policy adjustments in place, we substitute our own energy market, technology cost, and economic assumptions based on the most recent research and best available data in order to explore how these variables can shape US emissions in the years ahead. We model this range of assumptions to provide a reasonable range of emissions outcomes under current policy, without forecasting one case as necessarily more likely than another.

Energy market and technology uncertainty

As a starting point, we construct a central scenario. We include all announced power plant retirements: 76 gigawatts (GWs) of coal and 8 GWs of nuclear capacity through 2030. We assume natural gas and oil prices track with EIA's AEO2021 reference case. This puts the average natural gas price at $3.10/MMBTU through 2030 at Henry Hub, marking a return to gas prices of the mid-to-late 2010s. Brent crude rises from $45/barrel in 2021 to $73/barrel in 2030.

We assume renewable energy technology costs fall consistent with moderate cost reductions in the latest projections from the National Renewable Energy Laboratory (NREL). These costs from NREL are generally a bit lower than technology costs from AEO2021, especially by the late 2020s. Electric vehicle battery costs decline more rapidly than AEO2021, consistent with NREL's Electrification Futures Study. We assume the economy will grow at a real annual rate of 2.5% through 2030, in line with the long-term projections of the Congressional Budget Office. We also change relevant cost and performance parameters for power-generating facilities equipped with carbon capture technology, informed by Rhodium analysis and current literature. A full description of our input assumptions and approach can be found in the technical appendix to this report.

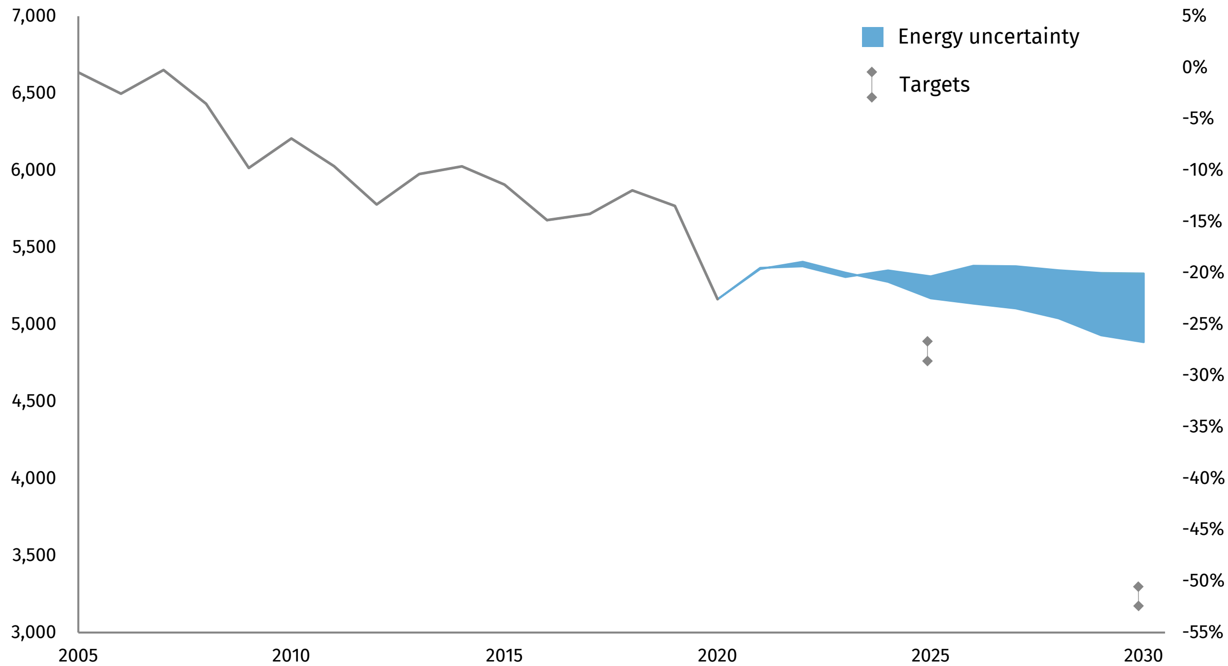
We then construct two scenarios to show the bounds of uncertainty in clean energy technology costs and oil and natural gas prices. The first scenario looks at a best-case scenario for emissions, which combines high natural gas and oil prices and low clean energy technology costs. In this case, natural gas at Henry Hub averages just under $3.70/MMBTU through 2030—about $0.60 higher than our central case—and Brent crude reaches $76 per barrel in 2030. We couple these with BloombergNEF's (BNEF) optimistic forecasts for EV battery costs, NREL's most aggressive scenario for renewable energy and utility storage cost declines, and Rhodium's lowest prices for fossil generation with carbon capture.

The second scenario represents a more pessimistic outlook for emissions, combining higher clean energy technology costs with lower natural gas and oil prices. In this case, natural gas prices average $2.55/MMBtu

FIGURE 2

US greenhouse gas emissions under current policy with energy market uncertainty

Net million metric tons of CO_2e (left), % change from 2005 (right)



Source: Rhodium Group. Targets represent US GHG emission reduction commitments, including the 2015 Paris Agreement pledge to reduce economy-wide US emissions by 26-28% below 2005 levels by 2025, and the updated commitment made in April 2021 to achieve a 50-52% reduction below 2005 levels by 2030.

through 2030 while Brent crude rises to only $62/barrel in 2030. We assume renewable energy and utility storage costs fall, but at the slowest pace projected by NREL, and carbon capture and EV battery costs also fall more slowly.

These energy scenarios capture a reasonable range of potential energy market and technology outcomes over the coming decade. Based on this range, we estimate that US GHG emissions would reach 20-22% below 2005 levels by 2025 and 20-26% by 2030, absent further policy action (Figure 2).

Macroeconomic uncertainty

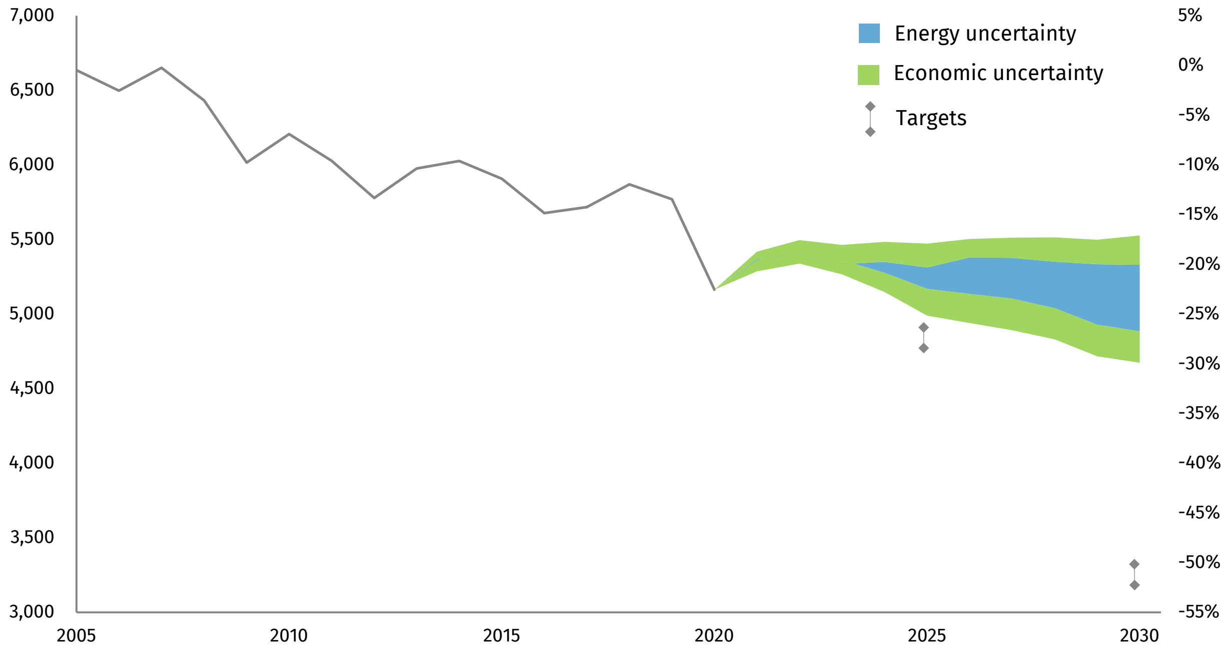
While the economy is expected to bounce back quickly in 2021, the pace of long-term economic recovery from the COVID-19 pandemic remains uncertain. To capture the potential range of emissions impacts, we model a scenario in which US GDP grows at 1.8% through 2030—or 0.7% per year slower than our central scenario of 2.5%, described above. If combined with high natural gas and oil prices and low technology costs, emissions could register as low as 25% below 2005 levels in 2025, falling to 30% by 2030.

We also consider a scenario with a slightly higher annual average growth rate of 3.2% coupled with low natural gas and oil prices and high technology costs. We find that US emissions reductions could be limited to only 18% below 2005 levels in 2025, and 17% by 2030.

FIGURE 3

US greenhouse gas emissions under current policy with energy market and economic uncertainty

Net million metric tons of CO_2e (left), % change from 2005 (right)



Source: Rhodium Group. Targets represent US GHG emission reduction commitments, including the 2015 Paris Agreement pledge to reduce economy-wide US emissions by 26-28% below 2005 levels by 2025, and the updated commitment made in April 2021 to achieve a 50-52% reduction below 2005 levels by 2030.

CHAPTER 3

Drilling Deeper: Key Trends by Sector

At the economy-wide level, we find that US GHG emissions fall by 20-22% from 2005 levels in 2025, and 20-26% by 2030 under a range of potential energy technology and market uncertainties. Here we explore what's going on under the hood by examining key trends in each major-emitting sector.

Key Trends

Power sector emissions increase modestly over the next couple of years as the US economy bounces back from the pandemic, but then continue their secular decline through 2025 due to a continued decline in coal-fired generation.

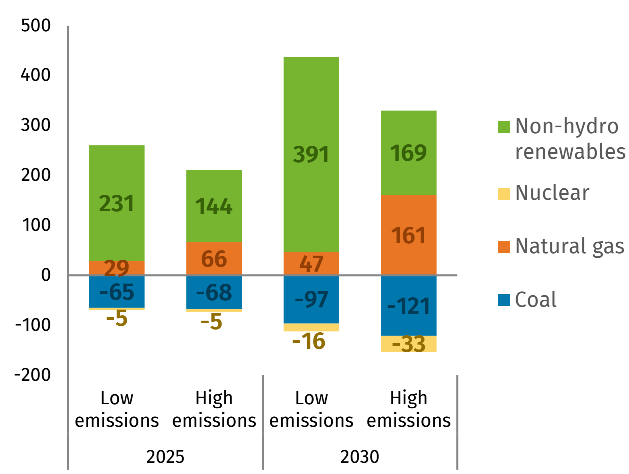
Demand for electricity from consumers and business, combined with higher natural gas prices, cause a blip in emissions in 2021-2022, but they never rebound fully to pre-COVID levels. Once these factors equilibrate, the now multi-decade decline of power sector emissions resumes, in large part due to continued competitive pressure on coal. In trouble before the pandemic, COVID-19 only accelerated coal's decline. Coming out of 2020, which registered the steepest drop in coal-fired power generation in history, the industry makes a temporary come-back but then resumes its steady downward spiral. Even in the best-case scenario for coal, with natural gas prices around $4/MMBTU, 93 GW of coal, or more than 40% of the remaining coal fleet, retires by 2030. If natural gas prices remain below $3/MMBTU, up to 115 GW of coal plants could retire by 2030—more than half of today's remaining fleet. These trends help cut power sector emissions in half by 2025 relative to 2005 across our scenarios.

In the long-term, however, the worst-case scenario for reducing US power emissions isn't defined by how much coal comes offline but rather the pace of natural gas expansion. In scenarios with the cheapest gas, power sector emissions begin to rise again after 2025. For many years, emission reductions in the power sector have been driven by the shrinking coal fleet, caused in large part by an extended period of low natural gas prices. Going forward, however, although cheap natural gas continues to shutter coal plants, it increasingly becomes a threat to decarbonizing the power sector. Wind and solar grow across all our scenarios thanks to declining costs, along with near-term tax credit support and state renewable policies. How fast renewables deploy depends on their ability to compete with natural gas. In the best-case scenario for reducing emissions, high natural gas prices combined with steep declines in the cost of renewables would, by 2030, result in six times as much solar capacity and a doubling of wind capacity compared to today's grid. With cheap natural gas and only moderate reductions in renewable costs, wind grows by 60% and solar triples from current levels by 2030. Meanwhile, low natural gas prices continue to put economic pressure on the existing nuclear fleet, which could see more than a third of today's capacity retire by 2030 if natural gas stays below $3/MMBTU. In this case, power sector emissions begin to rise after 2025.

FIGURE 4

Change in utility-scale electric power capacity from 2020 levels

Gigawatts



Source: Rhodium Group, EIA. The low and high emissions scenarios represent power sector capacity under energy market uncertainty.

After a brief post-pandemic rebound, transportation emissions decline modestly through 2030, driven by fuel economy improvements in passenger vehicles and a shift toward electric vehicles (EVs).

Hard-hit by the pandemic, transportation emissions bounce back in the early 2020s before starting a modest decline. Emissions from passenger vehicles see the steepest cuts, driven largely by fuel economy improvements in passenger vehicles, slowing of vehicle miles traveled (VMT) growth, and growing EV sales. If battery costs continue their recent steep cost reductions throughout the decade, EV sales could make up 35% of the light-duty market by 2030, and transportation emissions fall to 23% below 2005 levels by that year. If battery costs fall more moderately, EVs would capture only 9% of the market in 2030, and transportation emissions decline only 18% from 2005 levels. Across our scenarios, steeper emission reductions are limited by consumer preference for larger, higher-emitting vehicles, and robust demand growth for freight and air travel.

Our baseline captures fuel economy improvements from California's deal with automakers, assuming the standards apply to the five companies that have signed on, while the remaining auto-market adheres to the Trump administration's weaker rule. In one of his first executive orders after taking office, President Biden directed the EPA to present a proposal for revised fuel economy standards for passenger vehicles by this July. If the EPA acts soon and models the new rules after California's deals with automakers, we estimate the standards would drive down transportation emissions to 19-24% below 2005 levels by 2030, depending on oil prices and EV battery costs.

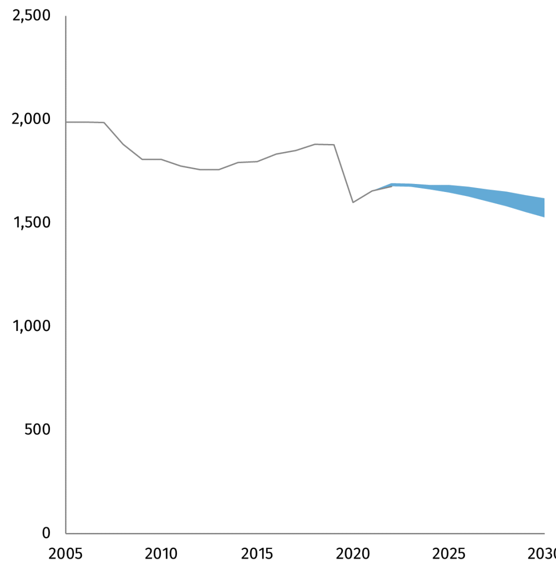
Industrial emissions continue to rise and become the top-emitting sector in the mid-2020s.

Apart from 2020, industrial emissions, including methane leakage from upstream oil and gas production and pipelines, have grown steadily since 2016, bolstered by low-cost natural gas and domestic oil production. Post-pandemic, industrial emissions resume their steady climb. Emissions climb highest when natural gas is cheap, rising 18% from 2020

FIGURE 5

Transportation GHG emissions

Million metric tons of CO_2e

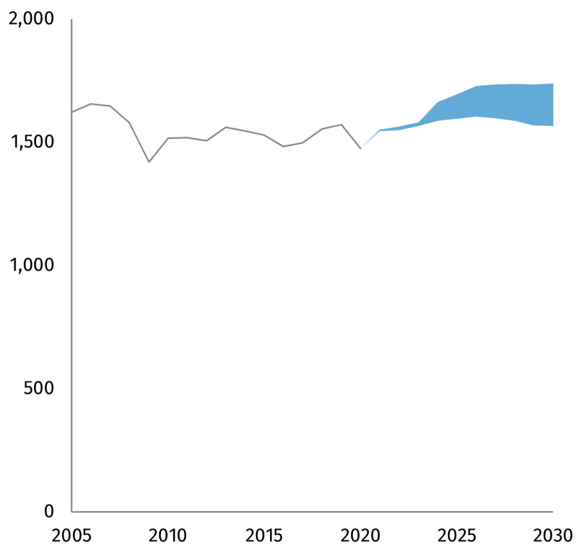


Source: Rhodium Group. The range represents transportation sector GHG emissions under energy market uncertainty.

levels by 2030, compared to 6% when natural gas is more expensive. The extension of the section 45Q tax credits for carbon capture passed by Congress last fall helps slow the pace of industrial emissions growth, resulting in 57 MMt of avoided CO_2e emissions annually by 2030. But without additional policy action—and regardless of natural gas prices—industry overtakes transport as the number one source of US GHGs within the next six years.

Today's top contributor to industrial emissions is oil and gas production. Hard hit by the pandemic, the future of the oil and gas industry is uncertain. If domestic natural gas and oil production never fully recover to pre-pandemic levels, emissions from upstream oil and gas activities could fall 12% from today's levels by 2030. Conversely, a stronger outlook for the oil and gas industry could drive emissions up 25% from today's levels by 2030. This is assuming methane leakage rates based on the EPA's methodology, which we use for consistency with the rest of our GHG inventory. Emissions from oil and gas would be as much as 33% higher in 2030 if we instead assume higher leakage rates consistent with Alvarez et al (2018), which captures pollution from heavily-polluting methane "super emitter" sources.

FIGURE 6
Industrial GHG emissions under energy market uncertainty
Million metric tons of CO_2e



Source: Rhodium Group. The range represents industrial sector GHG emissions under energy market uncertainty.

Building efficiency improves but emissions from residential and commercial buildings remain effectively flat.

Low-cost natural gas prices, increasing building square footage, and economic and population growth put upward pressure on building emissions, even while state policies make homes and businesses more efficient. Even in our highest scenario for natural gas prices, CO_2 emissions from buildings fall only 2% below 2005 levels by 2025. By 2030, emissions fall modestly to 1-4% below 2005 levels. Without further state and federal policy, there is no major change in electrification levels in key end uses across the buildings sector, despite growing recognition of the important role it will play in decarbonizing the economy.

Substantial new policies are necessary to achieve President Biden's 2030 pledge of a 50-52% cut in GHG emissions.

As our findings show, current policy at best only gets the US halfway to its pledge to reduce emissions 50-52% below 2005 levels by 2030. Congressional action in late 2020 will help rein in HFC emissions and drive deployment of carbon capture technologies in the industrial sector. Congress has also taken steps to undo some of the Trump administration's regulatory rollbacks. Key states continue to adopt new policies to tackle emissions from vehicles, the electric power sector, and oil and gas methane, as well as to further curb HFCs. And some corporations have stepped up their climate commitments. But the gap to 50-52% is still large.

This finding points to the urgent need for significant steps from the White House, Capitol Hill, state capitols, and corporate boardrooms if the country is to further reduce emissions and meet its climate targets. Previous Rhodium work has shown the impact of some commonly discussed solutions in the power and transportation sectors at the federal level. But we'll be taking a much more expansive look at what policies can do to put the US on track to meet its climate ambitions in future work this fall.

CHAPTER 4

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 all energy and emissions results from our Taking Stock 2021 baselines—including results broken down by gas and sector for all 50 US states through 2035—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 energy market uncertainty

Million metric tons of CO_2e

Gas	2005	2019	2025			2030		
Carbon Dioxide	6,135	5,256	4,847	to	4,741	4,859	to	4,483
Methane	686	660	655	to	620	667	to	602
Nitrous Oxide	456	457	462	to	460	469	to	465
HFCs	128	175	166			131		
Other F-Gases	19	11	11			11		
Gross GHG emissions	7,423	6,559	6,141	to	5,999	6,138	to	5,692
Carbon Removal*	-788	-789	-830			-808		
Net GHG emissions	6,635	5,769	5,312	to	5,170	5,330	to	4,885
% change from 2005	*0%*	*-13%*	*-20%*	*to*	*-22%*	*-20%*	*to*	*-26%*

Source: Rhodium Group. Columns represents the minimum and maximum annual net US emissions given energy market uncertainty. *Includes Land Use Land Use Change and Forestry (LULUCF) and bioenergy with carbon capture and sequestration.

Technical Appendix

This document provides additional detail on the methods and data sources used in Rhodium Group's Taking Stock 2021 report. Direct access to all energy and emissions results from our Taking Stock 2021 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 (1990-2019) come directly from the 2021 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. To model potential future emissions scenarios, we use RHG-NEMS, a modified version of the detailed National Energy Modeling System. NEMS is developed and used by the Energy Information Administration (EIA) to produce its Annual Energy Outlook 2021 (AEO2021). We make several modifications in RHG-NEMS and project impacts for all sectors of the US economy and six key greenhouse gas categories.

Energy Market, Technology and Economic Assumptions

To construct our national Taking Stock GHG projection 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 AEO2021 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: Our emissions range is bounded by a high and a low economic growth scenario.

RHG-NEMS Inputs That are Consistent Across the Emissions Outlook

We make several revisions to input assumptions beyond EIA's AEO2021 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 2030. Announced coal retirements are informed by coal plant data tracked by the Sierra Club. We account for recent state-level policy actions that will allow for continued operation of certain nuclear power plants in those states.
- Electric vehicle availability and uptake: We revise the year that several classes of light-duty electric vehicles are first available on the basis of recent automaker announcements. We also 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 and Technology 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. Charts are provided for select assumptions.

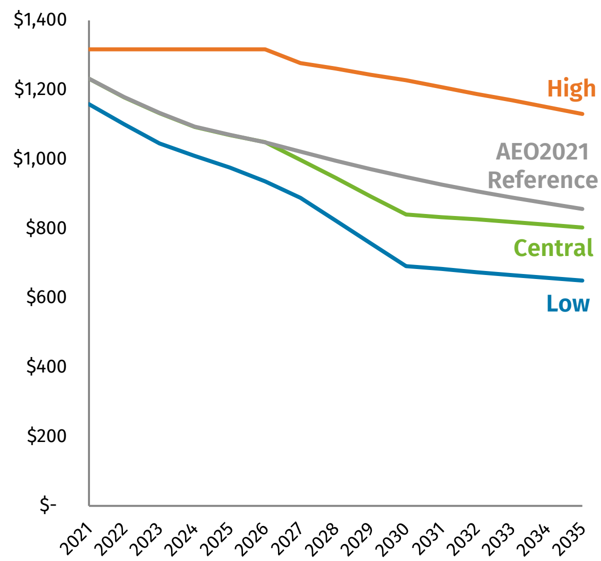
Electric generating technology costs: We generally assume capital costs for utility-scale and distributed solar photovoltaic, land-based and off-shore wind, and utility scale energy storage decline according to NREL's 2020 Annual Technology Baseline's (ATB) technology cost projections. Our central cost assumptions follow ATB's Moderate Technology Innovation Scenario, while our low- and high-cost assumptions follow the Advanced Scenario and Conservative Scenario, respectively. For onshore wind and utility-scale solar photovoltaic technologies, we retain EIA's mid, low and high cost assumptions in the early 2020s, since these cost assumptions are based on slightly different technologies than the ATB and are better aligned with technological performance during those early years. However, the ATB captures technology improvements that result in long-term aggressive cost declines, so we transition to ATB costs starting in the late 2020s.

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 CO_2-fired power plants.

FIGURE 1

Utility-scale solar photovoltaic overnight capital costs

2020 dollars per kilowatt

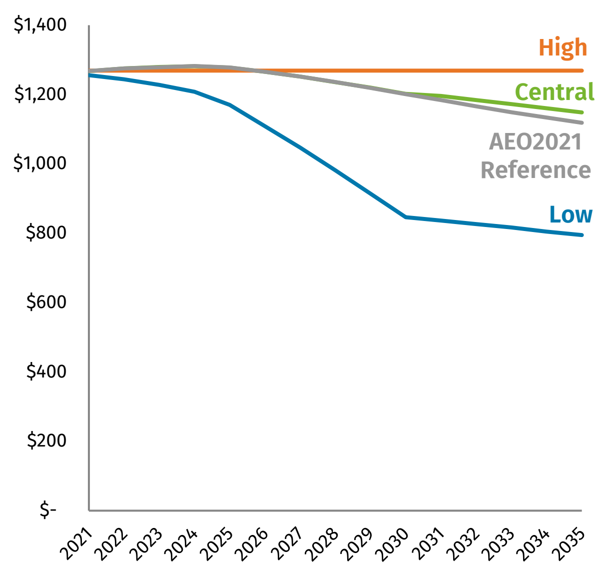


Source: Rhodium Group, NREL, EIA

FIGURE 2

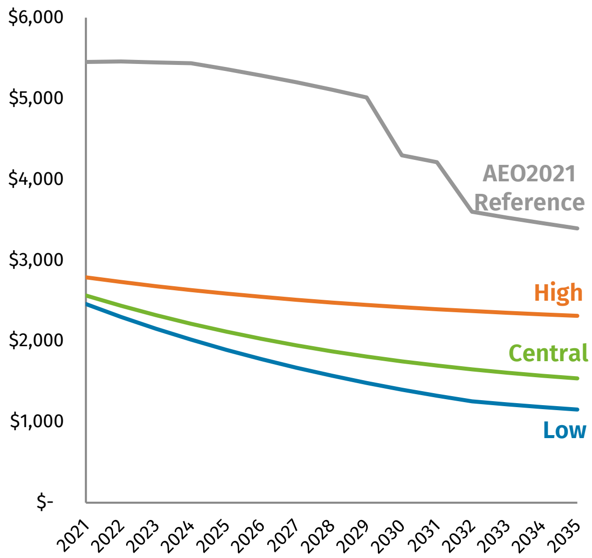
Land-based wind overnight capital costs

2020 dollars per kilowatt



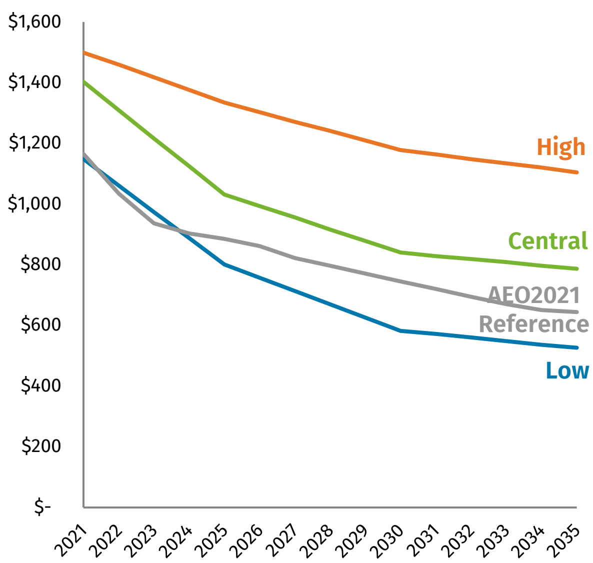
Source: Rhodium Group, NREL, EIA

FIGURE 3
Offshore wind overnight capital costs
2020 dollars per kilowatt



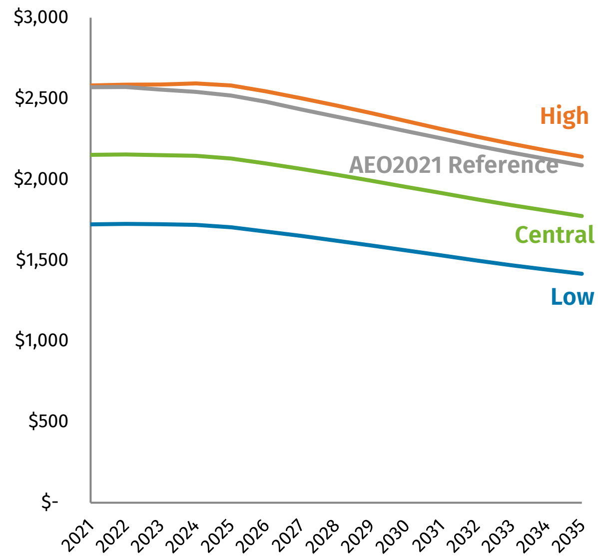
Source: Rhodium Group, NREL, EIA

FIGURE 4
Utility-scale energy storage overnight capital costs
2020 dollars per kilowatt



Source: Rhodium Group, NREL, EIA

FIGURE 5
Natural gas with CCS overnight capital costs
2020 dollars per kilowatt



Source: Rhodium Group, NETL, EIA

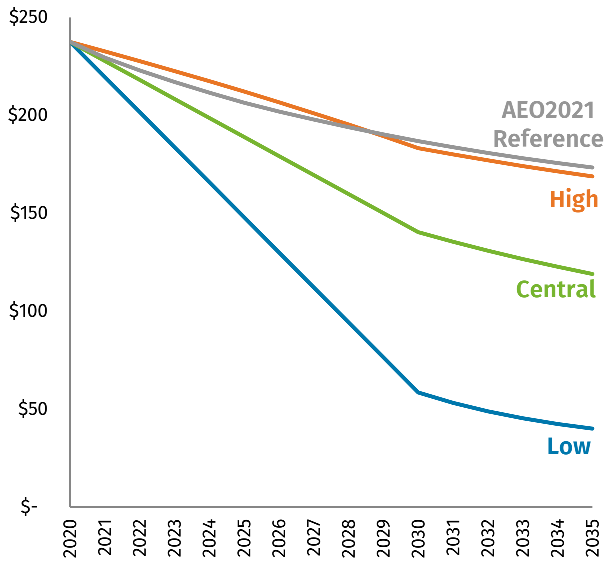
Electric vehicle battery costs: For light-duty electric vehicle (EV) battery costs, we draw on the Rapid Advancement case from the National Renewable Energy Laboratory's (NREL) Electrification Futures Study (EFS) for our central case and BNEF projections for our low-cost case. In our high-cost case, we assume annual cost reductions are 50% slower than the central case. We assume battery costs for the suite of light-duty EV technologies modeled in NEMS[1] match these reduction pathways, though each starts at a different current price.

[1] 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

Battery costs for 300-mile electric vehicles

2020 dollars per kilowatt-hour

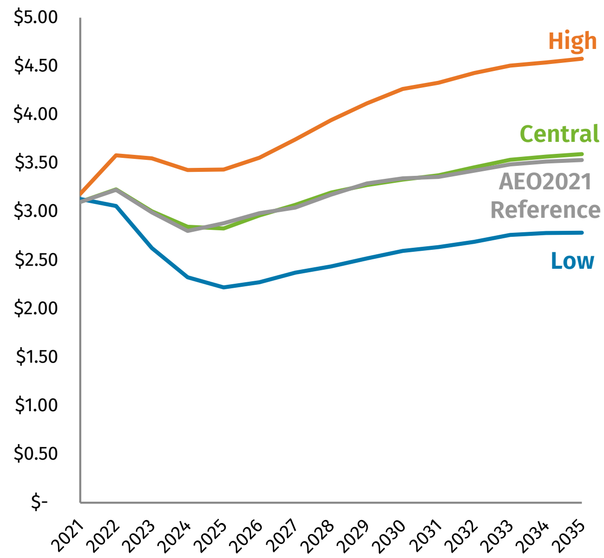


Source: Rhodium Group, BNEF, NREL, EIA

FIGURE 7

Natural gas spot price at Henry Hub

2020 dollars per million Btu



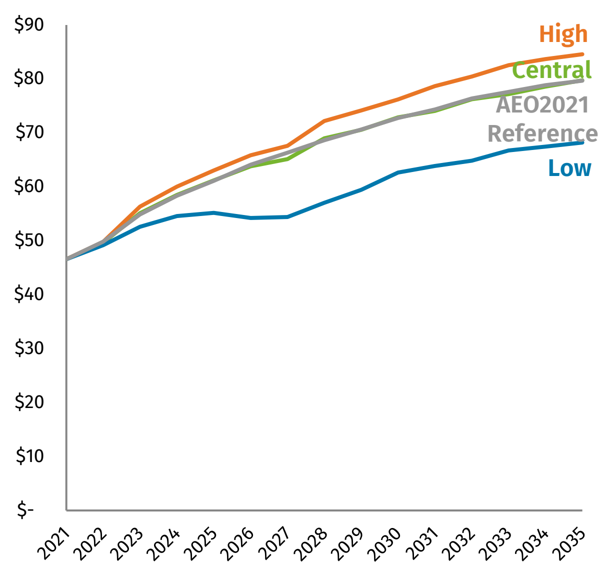
Source: Rhodium Group, EIA

Natural gas and oil resource and prices: For our central cost case we use the oil and natural gas resource and prices reflected in the AEO2021 reference case. In this case, natural gas averages $3.20/MMBtu through 2035 at Henry Hub, and Brent crude rises from $45/barrel in 2021 to $80/barrel in 2035. In our low cost case, we use the oil natural gas resource and prices reflected in the AEO2021 high oil and gas supply side case. The resulting average natural gas price is $2.60/MMBtu through 2035, and Brent crude reaches $68 per barrel in 2035. For our high cost case, we modify EIA's low oil and gas supply side case to reflect a less-constrained resource space than EIA models. This results in lower fossil production and higher prices than those projected in our central cost case, but higher production and lower prices than EIA's low oil and gas supply case. Natural gas prices in our high cost case average $4.00/MMBtu through 2035, while Brent crude rises to $85/barrel in 2035.

FIGURE 8

Brent Crude oil spot price

2020 dollars per barrel



Source: Rhodium Group, EIA

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, medium, 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 Macroeconomic 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 a 2.4% real annual rate of growth, on average, through 2035. In our low economic growth case we model a 1.7% average annual economic growth rate through 2035 to capture the downward pressure on emissions that could arise if the economy grows at a slower rate coming out of the COVID 19 pandemic. We assume a higher 2.9% annual average growth rate in our high economic growth case, to capture the emissions impact of sustained bullish economic growth. The assumptions for the central, low and high macroeconomic growth cases match those of the AEO2021 Low, Reference, and High Macroeconomic Growth side cases, respectively.

Federal and State Policy Assumptions

Our scenarios include emission reductions from all existing federal and state policies "on the books" as of May 2021. 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

Electric Power: The following national policies are reflected in our analysis: renewable energy and nuclear tax incentives in place as of May 2021, phased out based on their current statutory schedules. We also include the tax credit for carbon oxide sequestration (45Q) as amended in December 2020. We reflect the judicial vacation of the Affordable Clean Energy (ACE) rule. State and regional cap-and-trade programs, Renewable Portfolio Standards (RPS), Clean Energy Standards (CES), and zero-emission credit programs are all included. We also include state offshore wind and energy storage mandates. We incorporate all announced power plant additions and retirements through 2030 as of May 2021.

Transportation: We include the federal Renewable Fuels Standard, medium and heavy-duty vehicle GHG emissions standards, and state and federal electric vehicle incentives. All state zero-emission vehicle (ZEV) mandates and low-carbon fuel standards adopted as of May 2021 are also included. California's Advanced Clean Truck 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. Additional states have announced their intention to follow California's ZEV commitments for trucks, and a number of states have set 100% ZEV sales goals in the light-duty sector. However, these are excluded from our baselines as they have yet to be finalized and adopted.

We assume light-duty Corporate Average Fuel Economy (CAFE) standards increase 1.5% annually from model year 2021 to 2026, reflecting the Trump Administration Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule finalized in February 2020, which replaces Obama-era standards. In August 2020, California finalized deals with five automakers (Ford, VW, Honda, BMW, and Volvo) committing to improve their US light-duty vehicle fuel economy 3.7% annually from 2022 to 2026. We apply this increased fuel economy to these automakers' US passenger vehicle sales.

Industry and Buildings: We include current federal minimum energy conservation standards for appliances and equipment. We also include the tax credit for carbon oxide sequestration (45Q) as amended in December 2020. State energy efficiency programs are implicitly captured in RHG-NEMS electric demand projections.

Carbon Pricing: We include the California Cap-and-Trade Program and the Regional Greenhouse Gas Initiative (RGGI), which prices electricity sector carbon emissions from 11 states. We exclude the Transportation and Climate Initiative (TCI), which was not finalized by May 2021, and the Washington Climate Commitment Act (CCA), which directs policymakers to design an economy-wide Cap-and-Trade Program to be implemented in 2023.

Non-CO_2 Policies

Methane: We assume the reinstatement of the 2012 and 2016 Oil and Natural Gas New Source Performance Standards that regulate methane emissions from the oil and gas industry. This follows a Congressional Review Act vote, subsequently signed by President Biden, to invalidate the Trump administration's Review Rule, which rolled back some of the Obama-era rules. We assume the 2016 Bureau of Land Management regulations to prevent waste of natural gas from venting, flaring and leaks on public lands—undone by the Trump administration—remains rolled back. 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 the EPA's May 2021 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, Massachusetts, Maryland, New Jersey, New York, Vermont, Virginia, 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 2021 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)	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
	Judicial vacation of the Affordable Clean Energy (ACE) rule	Nuclear Zero Emission Credit (ZEC) Programs	CT IL NJ NY OH
	Cross-State Air Pollution Rules (CSAPR)	Energy Storage Mandates	CA MA NV NJ NY OR VA
	Mercury and Toxics Standards (MATS)		
	New Source Review (NSR)		
Transportation			
	The Safer Affordable Fuel-Efficient (SAFE) Vehicles rule Alternative Fuel Vehicle Tax Credits	California's Framework Agreements on Clean Cars with automakers	CA CO CT DE ME MA MD NJ NY OR PA RI VT WA
	Renewable Fuel Standard (RFS) GHG and fuel consumption standards for heavy-duty vehicles	California Light Duty Vehicle Zero Emission Vehicle (ZEV) Program	CA CO CT ME MD MA NJ NY OR RI VT WA

	Plug-in Electric Drive Vehicle (PEV) tax credit	Low Carbon Fuel Standard (LCFS)	CA OR WA
	Tier 3 Motor Vehicle Emission and Fuel Standards Program	Medium and Heavy-Duty ZEV Policy	CA
	International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI	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
		Zero Emission Bus Mandate	CA
Industry and Buildings	Federal minimum energy conservation standards for appliances and equipment	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
	Tax credit for carbon dioxide sequestration (45Q) as amended in December 2020		
	Clean Air Act Amendments of 1990 emission requirements for industrial processes		
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 and management programs	CA CO DE MA MD NJ NY VA VT WA

Methane			
	Reversal of Trump-era amendments to EPA's 2012 and 2016 Oil and Gas New Source Performance Standards	State oil and gas standards	CA CO NM OH PA UT WY
	EPA Municipal Solid Waste landfill methane rule	Landfill methane regulation (LMR) and SB1383 agricultural methane targets	CA
Carbon Pricing			
		Cap and Trade Program	CA
		Regional Greenhouse Gas Initiative (RGGI)	CT DE ME MD MA NH NJ NY RI VT VA

This list is not exhaustive, but rather reflects the most meaningful state and federal policies included in our projections.

Projection and 50-state downscaling methodology

Carbon Dioxide Emissions

Projected CO_2 emissions from all energy use in RHG-NEMS are 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 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 2021 EPA GHG inventory. Projected trends come from the high sequestration scenario from the 2016 Biennial Report of the United States (the most recent set of federal projections) calibrated to align with EPA's 2021 inventory. For emissions of N_2O and CH_4 from LULUCF we assume 2019 emissions from LULUCF remain constant through 2035, 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 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 FLIGHT, the EIA, and USDA.

Disclosure Appendix

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