Taking Stock 2020: Technical Appendix

This document provides additional detail on the methods and data sources used in Rhodium Group's Taking Stock 2020 report produced for the Climate Service. All historical greenhouse gas (GHG) emissions and removal estimates (1990-2018) come directly from the 2020 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 2019 (AEO2019) and maintained by Rhodium Group.

Energy Market, Technology and Economic Assumptions

In past years, we constructed a national GHG projection range accounting for uncertainties around carbon removal from forests and soils, energy markets, and federal policy, in addition to economic growth. This year, we focused exclusively on the uncertainties surrounding COVID-19 and its economic impact. To that end, we held all assumptions around carbon removal, renewable technology costs, and policy constant across our scenarios. We do, however, capture COVID-19's effect on oil and natural gas production and prices. This year we also chose to use EIA's AEO2019 instead of migrating to AEO2020. We update policy and energy market assumptions to address major differences between the AEO model vintages.

Unless otherwise stated below, we use EIA's AEO2019 reference case assumptions in our Taking Stock projections.

Scenarios to capture the COVID-19 crisis and recovery

We provide a range of potential outcomes for post-COVID GHG emissions through 2030 based on the potential depth and duration of the pandemic and its economic toll.

- Our **V-shaped recovery** scenario is the most optimistic in terms of COVID-19 infection rates and economic recovery. In this scenario, US economic output falls by 5.9% in 2020, in line with the IMF's core scenario in its April World Economic Outlook. We assume the virus is under control by the second half of the year and that there is a rapid recovery, with the US economy growing by 4.7% in 2021.

- In our **W-shaped recovery** scenario, failure to control the virus leads to a second wave of lockdowns later this year. Economic growth falls by 7.6% in 2020 and rises by only 1.3% in 2021. This is fairly close to the OECD's "Double-hit scenario" in which the economy contracts by 8.5% in 2020 and grows by 1.9% in 2021. The US economy grows at 4.1% in 2022, slightly slower thereafter than in our V-shaped recovery scenario, leaving average 2022-2030 growth rates at roughly the same 1.9%.

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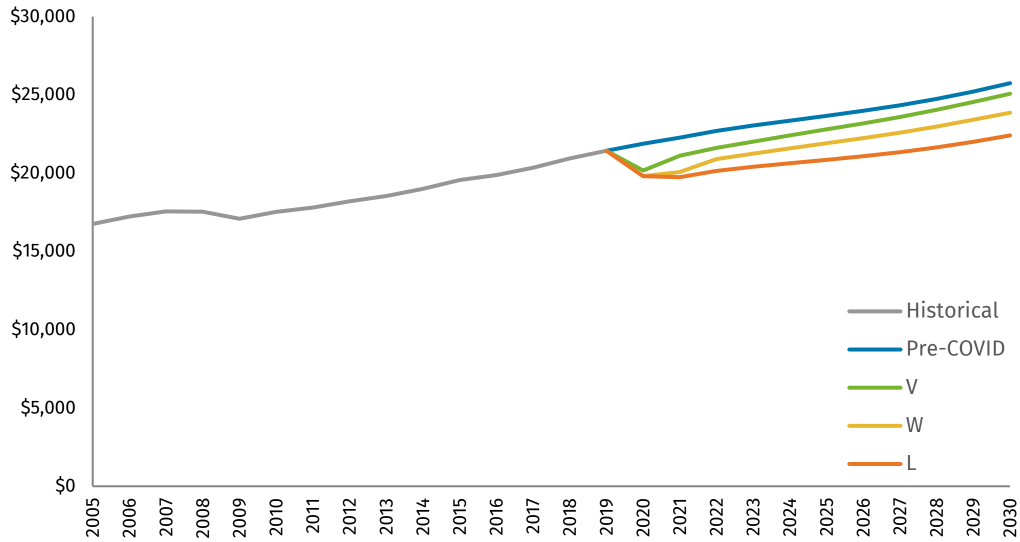
- In our **L-shaped scenario**, the US economy goes in and out of lockdowns until an effective vaccine and treatment are widely available, leading to a delayed and anemic recovery. Like the W-shaped recovery, the US economy falls by 7.6% in 2020, but then sinks again in 2021 by 0.3%. Output 10 years after the COVID-19 crisis is still 7% below pre-crisis projections.

FIGURE 1

US economic recovery scenarios

GDP, Billion 2019 USD



Source: Rhodium Group estimates

TABLE 1

Annual US GDP growth

Year-on-year change in GDP (%)

	2020	2021	2022-2030 avg.
Pre-COVID	2.1%	1.8%	1.6%
V	-5.9%	4.7%	1.9%
W	-7.6%	1.3%	1.9%
L	-7.6%	-0.3%	1.4%

Source: Rhodium Group estimates

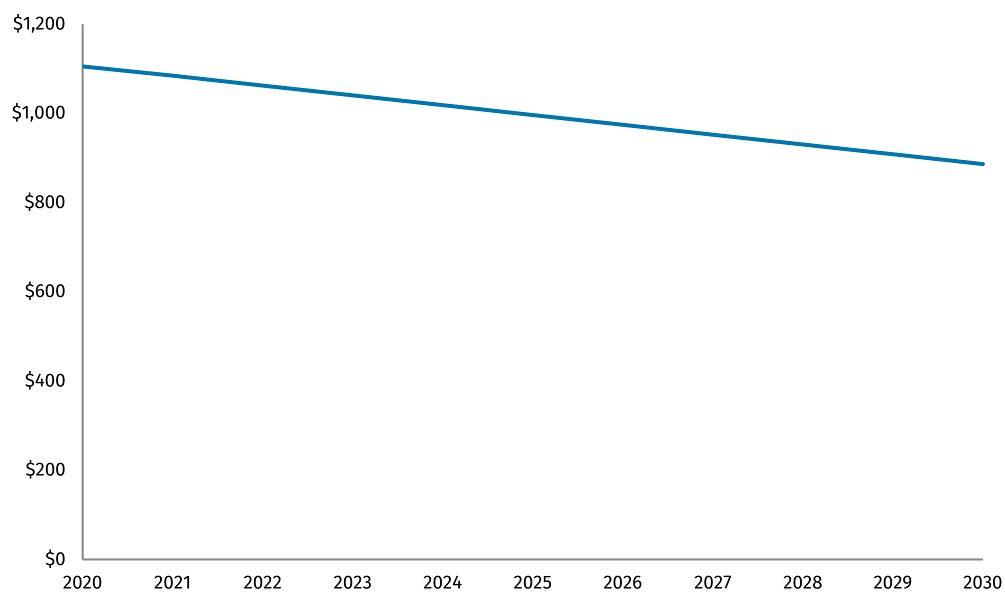
In the short term, the impact of COVID-19 on energy use and emissions depends in large part on whether there are future restrictions on activity. To estimate how future lockdowns will affect energy demand, we use energy market and activity data from the months following the first shelter-in-place orders, where possible. For example, we use the year-on-year change in gasoline, diesel, and jet fuel consumption from mid-March to mid-April – the peak of the lockdown to date – to approximate the impact of future lockdowns on fuel demand. In some cases, we used third-party analysis of COVID-19's impact on economic activity to inform our estimates. For the industrial sector, for example, we use Goldman Sachs' forecast of the impact of the crisis and the immediate recovery period on industrial output, scaled to our own economic recovery scenarios. Electric power demand is determined endogenously within the RHG-NEMs model, based on fuel price and demand from the end-use sectors.

As the restrictions ease, we assume the impact of COVID on energy use and emissions depends primarily on the pace of economic recovery. We also assume the longer the period of lockdowns, the slower individuals and businesses will be to resume their pre-COVID travel and work patterns. These lasting behavioral changes further dampen energy demand in the transportation and commercial building sectors.

Energy market assumptions

We assume capital costs for utility-scale and distributed solar photovoltaic and land-based and off-shore wind decline according to the National Renewable Energy Laboratory's (NREL) 2019 Annual Technology Baseline's (ATB) mid-cost projections. We assume energy storage cost follow the cost reductions of lithium-ion nickel cobalt aluminum oxide batteries in IRENA's reference case scenario in their 2017 Electricity Storage and Renewables report. For light-duty electric vehicle (EV) battery costs, we assume cost reductions consistent with the Rapid Advancement case from NREL's Electrification Futures Study (EFS).

FIGURE 2
Utility-scale solar photovoltaic overnight capital costs
2019 dollars per kilowatt

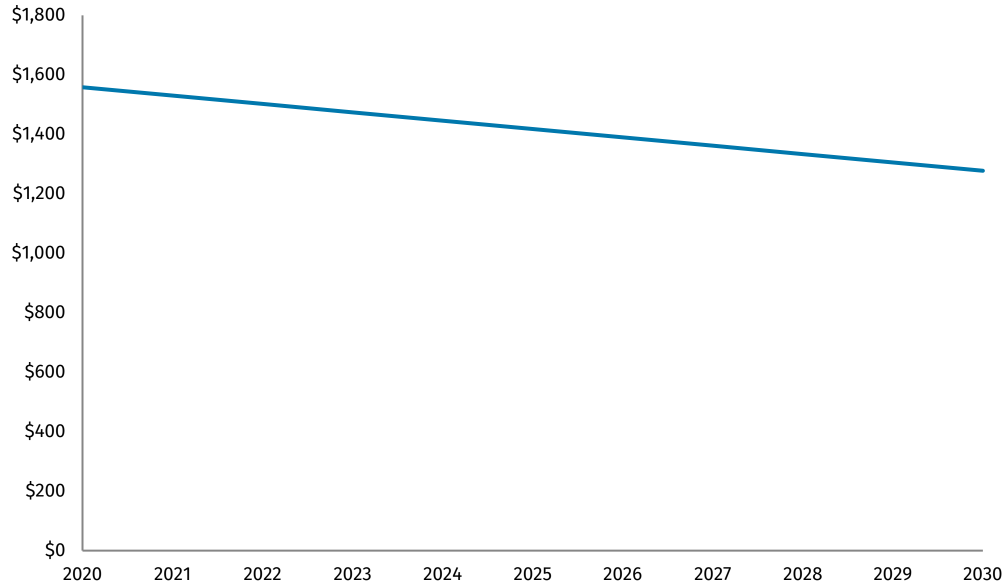


Source: NREL

FIGURE 3

Land-based wind overnight capital costs

2019 dollars per kilowatt

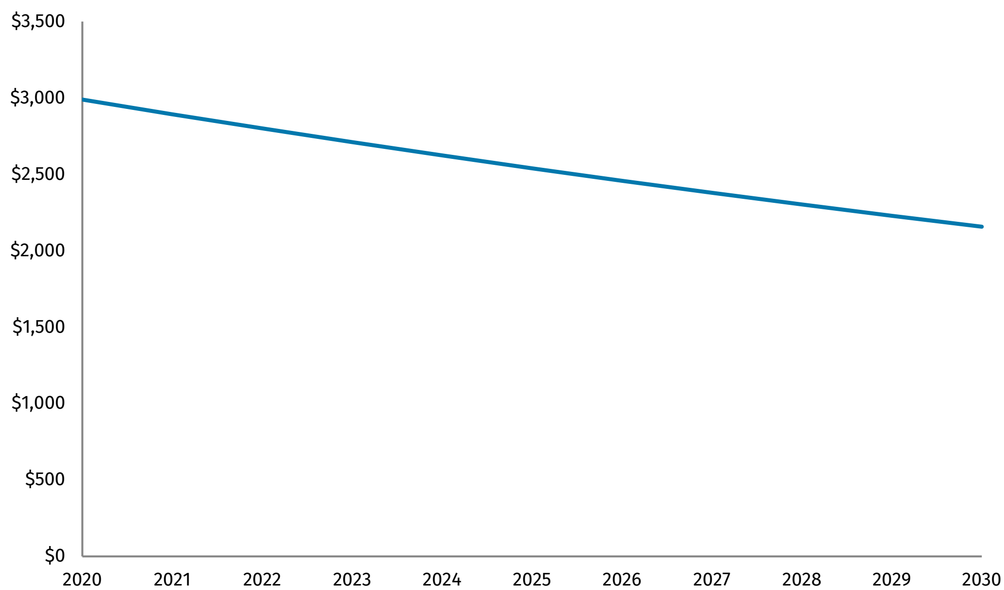


Source: NREL

FIGURE 4

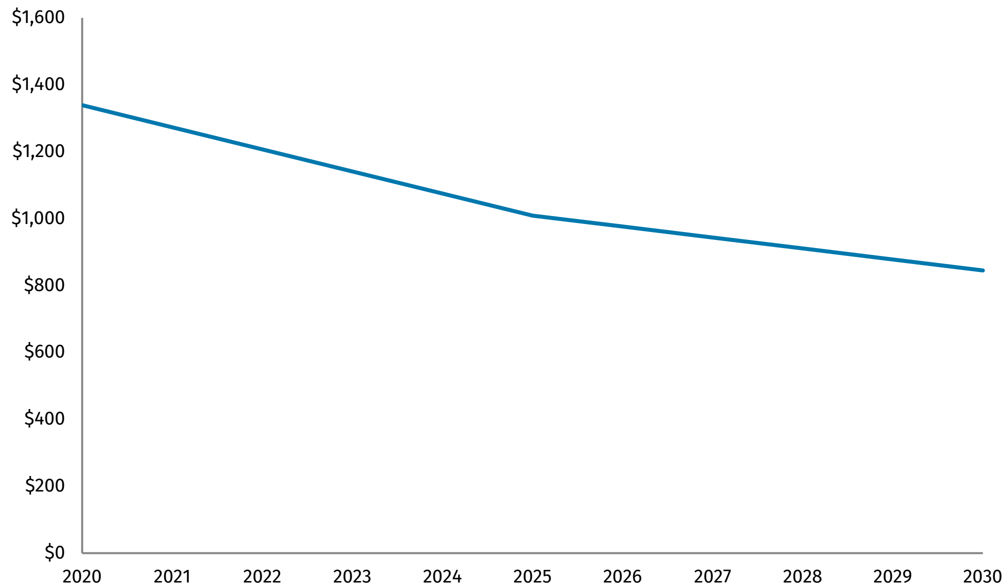
Offshore wind overnight capital costs

2019 dollars per kilowatt



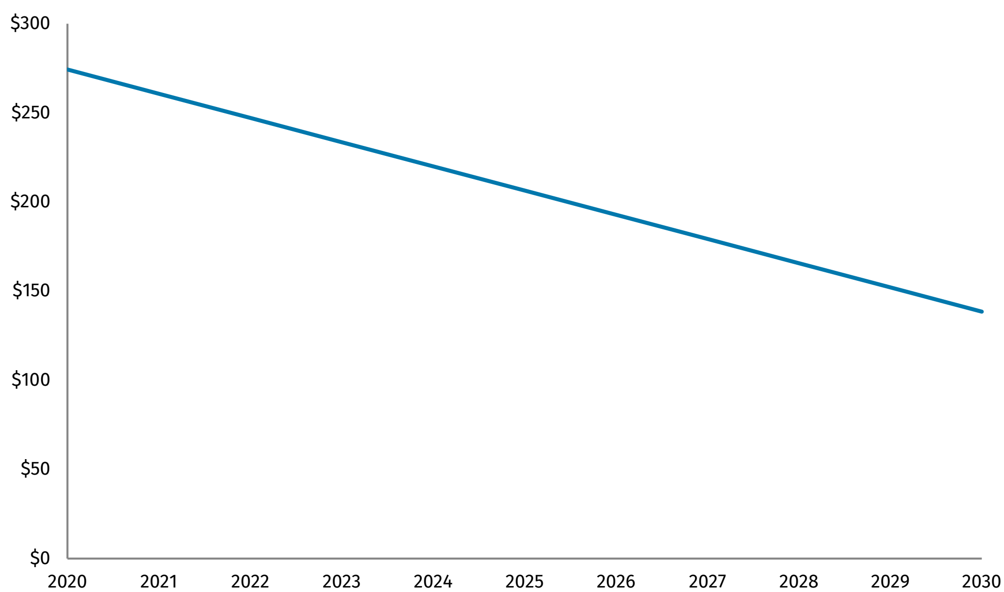
Source: NREL

FIGURE 5
Utility scale energy storage overnight capital costs
2019 dollars per kilowatt



Source: EIA AEO2019, International Renewable Energy Association

FIGURE 6
Electric vehicle battery costs
2019 dollars per kilowatt-hour



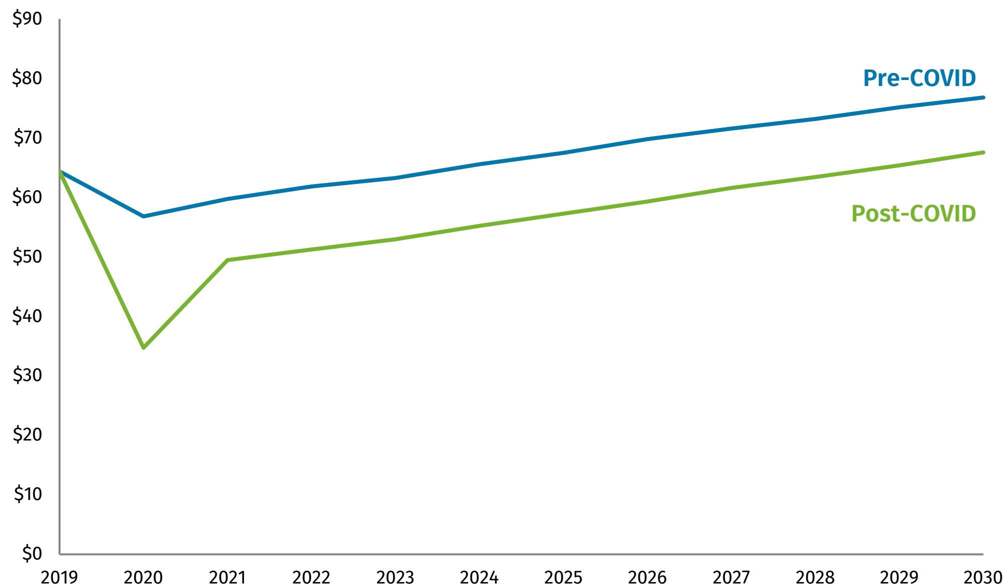
Source: EIA AEO2019, NREL

Oil resource and prices: For our pre-COVID baseline, we use the oil resources reflected in AEO's reference case and assume world oil prices rise from $57 per barrel in 2020 to $77 in 2030. In our post-COVID scenarios, we assume oil prices fall to $35 per barrel in 2020. This reflects the impact of the pandemic on oil production and prices and is largely consistent with Goldman Sachs April 2020 Base oil price projections. In these scenarios, prices slowly rebound but never to pre-pandemic levels, reaching $68 per barrel by 2030.

FIGURE 6

Brent Crude Oil Spot Price

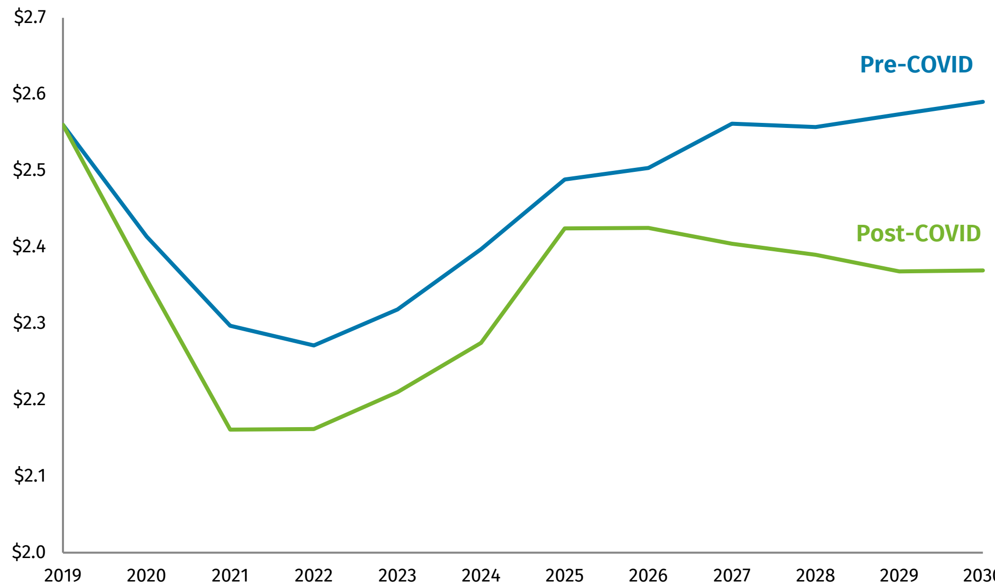
2019 dollars per barrel



Source: EIA, Rhodium Climate Service

Natural gas resource and prices: For our pre-COVID baseline, we use the natural gas resources reflected in the AEO2019 high resource and technology side case, resulting in a price of $2.2-2.5/MMBtu through 2030. In our post-COVID scenarios, natural gas prices are impacted by two main factors: the drop in the global price of oil and weak demand for natural gas. A fall in world oil prices puts upward pressure on natural gas prices as lower oil prices lead to less oil drilling and associated natural gas production. Slack demand due to the economic impact of COVID-19 puts downward pressure on natural gas prices. The net effect is slightly lower natural gas prices than in our pre-COVID scenario through 2030.

FIGURE 7
Natural Gas Spot Price at Henry Hub
2019 dollars per million Btu



Source: EIA, Rhodium Climate Service

Federal and State Policy Assumptions

Our scenarios include emission reductions from all existing federal and state policies "on the books" as of May 2020. 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 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 June 2020, phased out based on their statutory schedules. State and regional cap-and-trade programs, Renewable Portfolio Standards (RPS), Clean Energy Standards (CES), fuel standards, and zero-emission credit programs are all included. State storage and offshore wind mandates are also included. We incorporate all announced power plant additions and retirements through 2030 as of February 2020. For the post-COVID scenarios, we assume a one-year delay in wind and solar plants scheduled to come online through 2020 due to the pandemic. We account for recent state-level policy actions that will allow for continued operation of certain nuclear power plants in those states.

Transportation: We include the federal Renewable Fuels Standard, recently updated heavy-duty vehicle GHG emissions standards, and federal electric vehicle incentives. All state vehicle emission standards, zero-emission vehicle (ZEV) mandates, and low-carbon fuel standards adopted as of May 2020 are also included. We assume light-duty 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. We apply this rollback to all states except California and the 14 other states that plan to maintain the original Obama-era CAFE standards.

Industry and Buildings: We include federal building codes and appliance standards. State energy efficiency programs are implicitly captured in RHG-NEMS electric demand projections.

Non-CO_2 Policies

Methane: We assume all major federal oil and gas methane policies are effectively rolled back by the Trump Administration, including EPA's 2016 New Source Performance Standards (NSPS) and permitting rules for methane from oil and gas; 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 2020 rather than 2016 – to reflect the federal stay on the regulations that went into effect in May 2017. The following state policies are also reflected: oil and gas standards in California, Colorado, Pennsylvania, 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 the Kigali Amendment to the Montreal Protocol is not ratified or implemented. We assume the EPA's Significant New Alternatives Policy (SNAP), including Rule 20 (2015) and Rule 21 (2016), remain vacated, but we reflect emission reductions from all existing state rules, including California, Washington, Vermont and New Jersey's HFC control regulations. We model HFC emissions based on the California Air Resources Board's SLCP assessment tool, which estimates potential national and state-level HFC emission pathways associated with a range of federal and state policies.

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 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 2016 Biennial Report of the United States (the most recent set of federal projections) 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.

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