Taking Stock 2019: Technical Appendix

This document provides additional detail on the methods and data sources used in Rhodium Group's Taking Stock 2019 report produced for the US Climate Service.

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National GHG Emissions and Projections

All historical greenhouse gas (GHG) emissions and removal estimates (1990-2017) come directly from the 2019 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 used by the Energy Information Administration (EIA) to produce the Annual Energy Outlook 2019 (AEO2019) and maintained by Rhodium Group.

Carbon Dioxide Emissions

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

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

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

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

RHG-NEMS does not provide an Intergovernmental Panel on Climate Change (IPCC) consistent projection output for non-fossil fuel consumption CO_2 emissions from activities such as non-

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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 below.

Historical emissions and removals from land use, land-use change, and forestry (LULUCF) come directly from the 2019 EPA GHG inventory. Projected trends come from the 2016 Biennial Report of the United States (the most recent set of federal projections) calibrated to align with EPA's 2019 inventory. For emissions of N_2O and CH_4 from LULUCF we assume 2017 emissions from LULUCF remain constant through 2030, following the approach used in the 2016 Biennial Report.

Federal and State Policy Assumptions

Our Baseline scenario includes emission reductions from all existing federal and state policies "on the books" as of June 2019. To remain consistent with United Nations (UN) reporting guidelines, 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 2019, phased out based on their statutory schedules. All conventional pollutant regulations such as the Mercury Air Toxics Standards (MATS) are included. 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.

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 are also included. We assume light-duty federal CAFE standards freeze at model year (MY) 2020 levels to reflect the Trump Administration's proposed (but not yet finalized) Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule, which would replace Obama-era regulation. We apply this rollback to all states except California and the 13 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: The following recent national policies are reflected in our analysis: 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; 2016 Bureau of Land Management regulations to prevent waste of natural gas from venting, flaring and leaks on public lands; and EPA's 2016 updated NSPS and Emission Guidelines for methane from municipal solid waste landfills. The following state policies are also reflected, taking care to avoid double-counting when federal and state policies overlap: oil and gas standards in California, Colorado, Pennsylvania, Wyoming and New Mexico as of May 2019; and California's landfill methane control measures from 2010 and updated in 2017.

We model two policy scenarios to bound potential outcomes for methane. The most ambitious scenario for emissions reductions assumes all the federal policies listed above are maintained and enforced. The federal rollback scenario assumes that all are rescinded or not enforced. 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. We assume reductions from the EPA's landfill methane rules is delayed – with enforcement starting in 2020 rather than 2016 – to reflect the federal stay on the regulations that went into effect in May 2017.

Hydrofluorocarbons (HFCs): In our most ambitious policy scenario, we reflect a potential emission reduction pathway associated with the Kigali Amendment to the Montreal Protocol. In our federal rollback scenario, we assume the Kigali Amendment is not adopted or implemented. In both scenarios, 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 and Washington State's HFC control regulations. These include California's 2018 High GWP Refrigerant Emissions Reductions rules, SNAP, and Refrigerant Management Program (RMP), and Washington's HFC phasedown bill, HB 1112. We model HFC emissions based on the California Air Resources Board's 2018 SLCP assessment tool, which estimates potential national and state-level HFC emission pathways associated with a range of federal and state policies.

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 AEO2019 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 five sources of policy, market, and economic uncertainty:

- Carbon Removal: In this range we examine the influence of the ability of US forests and other lands to sequester carbon (referred to as "LULUCF").

- Policy: We account for the uncertainty surrounding the status of federal regulations through two policy cases, one assuming full rollbacks of targeted federal policies, and an alternate scenario of moderate rollbacks.

- Energy: We consider a range of energy market variables that shape emissions outcomes. These include natural gas prices, oil prices and renewable energy technology costs.

- 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 AEO2019 Reference case that are consistent across our Taking Stock emissions range. The key revisions are described below.

- Announced power plant retirements/additions: We incorporate all announced coal and nuclear power plant retirements through 2030. We account for recent state-level policy actions that will allow for continued operation of certain nuclear power plants in those states.

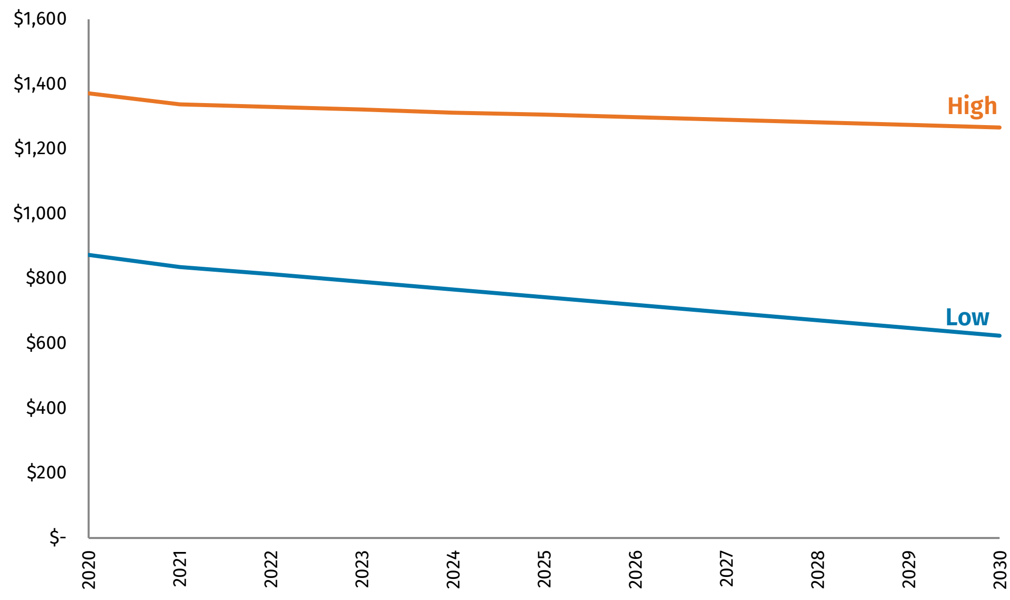
- Automated vehicle deployment: RHG-NEMs does not capture the impact of autonomous transportation technologies for personal vehicle use.

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 selected a low and a high case to reflect a range of potential market and technology cost outcomes. Charts are provided for select assumptions.

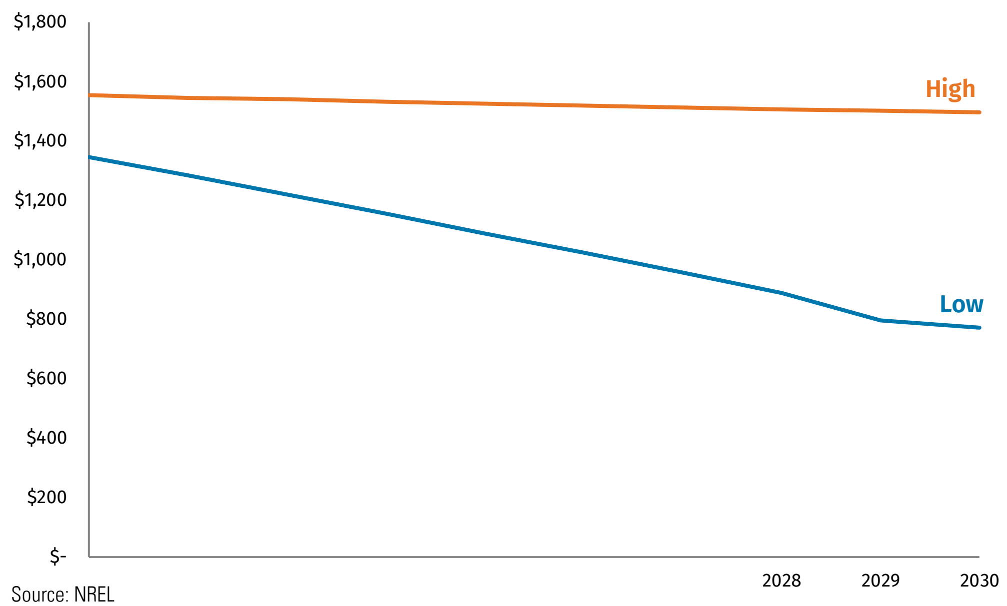
Renewable energy technology costs: In our low cost case, we assume capital costs for utility-scale and distributed solar photovoltaic and land-based and off-shore wind decline according to NREL's 2018 Annual Technology Baseline's (ATB) low-cost projections. For our high cost assumptions, we assume annual cost declines are 50% lower than ATB's mid-cost projections.

FIGURE 1
Utility-scale solar photovoltaic overnight capital costs
2018 dollars per kilowatt



Source: NREL

FIGURE 2
Land-based wind overnight capital costs
2018 dollars per kilowatt

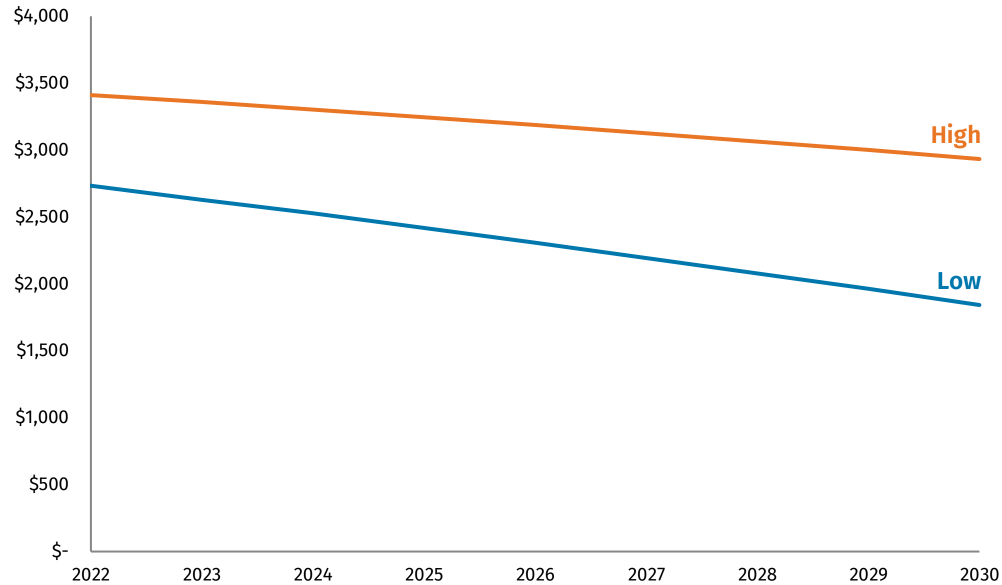


Source: NREL

FIGURE 3

Offshore wind overnight capital costs

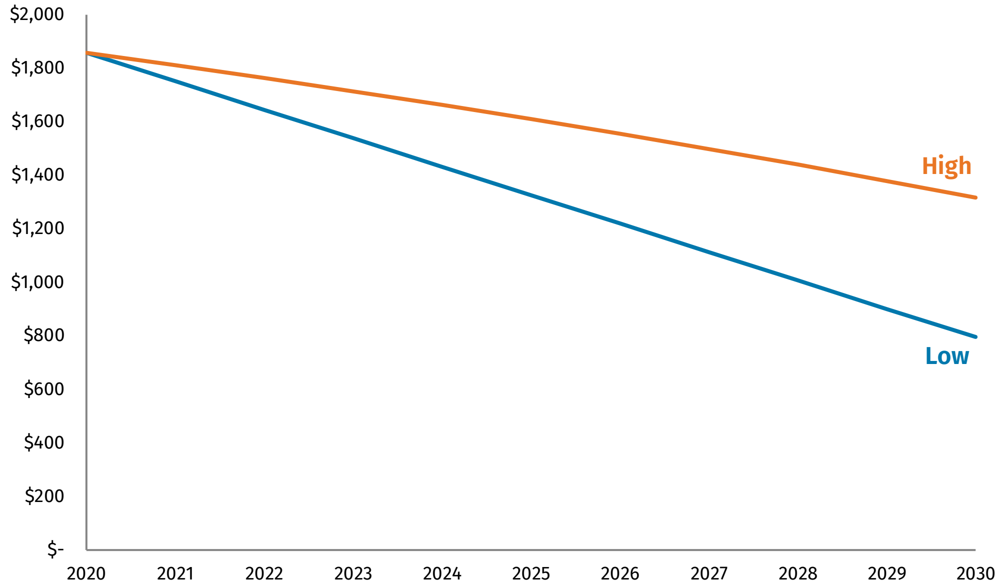
2018 dollars per kilowatt



Source: NREL

Utility scale energy storage costs: For the low cost case, we assume energy storage costs follow the cost reductions of Bloomberg New Energy Finance's (BNEF) forecast for lithium-ion storage batteries. For the high cost case, we assume annual energy storage cost reductions are 50% slower than IRENA's reference case scenario for lithium-ion nickel cobalt aluminum oxide batteries in their 2017 Electricity Storage and Renewables report, which we consider a central cost estimate.

FIGURE 4
Utility scale energy storage overnight capital costs
2018 dollars per kilowatt



Source: EIA AEO2019, International Renewable Energy Association, BNEF

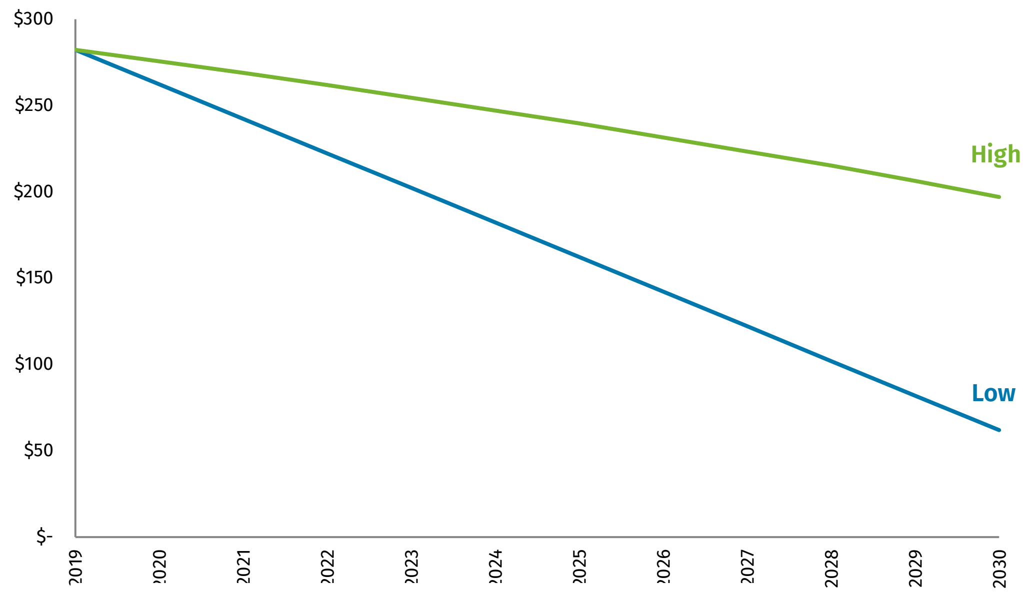
Electric vehicle battery costs: For light-duty electric vehicle (EV) battery costs, we draw on BNEF projections for the low cost case. In our high cost case, we assume annual cost reductions are 50% slower than the Rapid Advancement case from the National Renewable Energy Laboratory's (NREL) Electrification Futures Study (EFS). EFS cost curves are constructed using linear interpolations between predicted future costs, while BNEF's are not. For consistency across scenarios, we assume our low emissions battery costs for an EV 300-mile range (EV300) follow a linear cost decline consistent with BNEF cost reductions over the same period. For each scenario, we assume battery costs for other light-duty EV technologies modeled in NEMs[1] fall linearly by the same percentage decrease as they do for EV300 batteries.

[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 5

Electric vehicle battery costs

2018dollars per kilowatt-hour



Source: AEO2019, BNEF, NREL

Natural gas resource and prices: In our high cost case we use the natural gas resource and prices reflected in the AEO2019 Reference case. The resulting natural gas price is $4.3-4.7/MMBtu through 2030. For our low cost case, we used a similar methodology to the one used by EIA in the high resource and technology side case to construct a forecast with higher natural gas production and lower prices than those projected in our high cost case. The natural gas prices in our low cost case are approximately $2.1-2.50/MMBtu through 2030.

FIGURE 6
Natural Gas Spot Price at Henry Hub
2018 dollars per million Btu

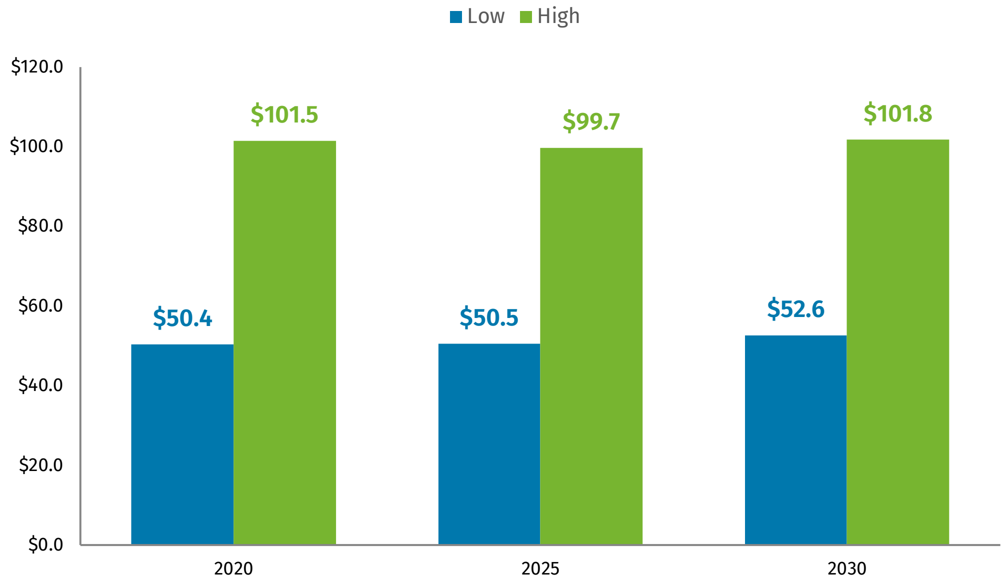
Source: EIA AEO2019, Rhodium's US Climate Service
*The natural gas prices presented here represent the average price in 2020, 2025, and 2030 for each natural gas cost case.

Oil resource and prices: For our low oil cost case, we use the oil resources reflected in AEO's high resource side case and assume world oil prices persist at around $50 per barrel though 2030. This captures we might expect to see if the US resource boom continues and global producers do not cut production. For our high oil price case, we use the oil resources reflected in the AEO2019 Reference case and assume world oil prices are $100 per barrel through 2030 to reflect the upward pressure on US oil prices that could arise if US oil resources and global production are more constrained than in our low case.

FIGURE 6

Brent Crude Oil Spot Price

2018 dollars per barrel



Source: EIA AEO2019, Rhodium's US Climate Service

*The oil prices presented here represent the average price in 2020, 2025, and 2030 for each oil cost case.

RHG-NEMS Inputs That Vary to Capture Macroeconomic Uncertainty

In our low economic growth case, we model a 1.2% average annual economic growth rate for the next 10 years to capture the downward pressure on emissions that could arise if the economy grows at a slower rate. We assume a higher 2.3% annual average growth rate in our high economic growth case, more closely matching the Trump Administration's growth outlook. The assumptions for the low and high macroeconomic growth cases match those of the AEO2019 Low and High Macroeconomic Growth side cases, respectively.

Disclosure Appendix

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