TECHNICAL APPENDIX

Taking Stock: Progress Toward Meeting US Climate Goals

The study "Taking Stock: Progress Toward Meeting US Climate Goals" (Larsen, Larsen, Herndon, and Mohan, 2016) published by Rhodium Group (RHG), quantifies the impact of all current and proposed federal policies on future greenhouse gas (GHG) emissions to assess whether the US is on track to meet its climate targets. This appendix describes the analytical framework, methods, and data sources underlying the report and its findings.

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John Larsen
jwlarsen@rhg.com

Kate Larsen
kmlarsen@rhg.com

Whitney Herndon
wjherndon@rhg.com

Shashank Mohan
smohan@rhg.com

Taking Stock contains two analyses. The first is a brief assessment of historical progress in reducing GHG emissions from 2008 to 2015. The second is a comprehensive forecast of US GHG emissions out to 2025, and a comparison with current US climate targets for 2020 and 2025. Both rely on government data as well as RHG estimates and forecasts.

DECOMPOSITION ANALYSIS

For our comparison of projected and actual 2015 energy carbon dioxide (CO_2) emissions and our assessment of the factors explaining the difference, we rely on the Energy Information Administration's (EIA's) Monthly Energy Review for historical economy-wide CO_2 data from 1990 through September of 2015. For projected emissions from 2008 through 2015 we use EIA's Annual Energy Outlook (AEO) 2008 reference case forecast. We then conduct a decomposition analysis to assess how changes in gross domestic product (GDP), the energy intensity of the economy, and the carbon intensity of energy explain the difference in 2015 emissions.

$$Emissions = GDP * \underbrace{\left(\frac{Energy\ Consumption}{GDP}\right)}_{Energy\ Intensity} * \underbrace{\left(\frac{Emissions}{Energy\ Consumption}\right)}_{Carbon\ Intensity} \qquad \ldots Equation\ 1$$

$$\ln\left(\frac{Emissions^{2015}_{Projected}}{Emissions^{2015}_{Actual}}\right) = \ln\left(\frac{GDP^{2015}_{Projected}}{GDP^{2015}_{Actual}}\right) + \ln\left(\frac{Energy\ Intensity^{2015}_{Projected}}{Energy\ Intensity^{2015}_{Actual}}\right) + \ln\left(\frac{Carbon\ Intensity^{2015}_{Projected}}{Carbon\ Intensity^{2015}_{Actual}}\right) \qquad \ldots Equation\ 2$$

The actual data used in the decomposition is constructed as follows:

GDP: AEO 2008 GDP projected for 2015 is converted from 2000 chained dollars to 2009 chained dollars using the US Bureau of Economic Analysis GDP deflator series. For 2015 actual GDP, we assume 2.5% GDP growth in 2015 (median growth projections from Bloomberg in January 2016).

- **Energy Consumption**: Currently only nine month actual energy consumption is available for 2015 from the Monthly Energy Review. We apply nine month energy consumption growth between 2014 and 2015 (0.24%) to estimate full-year 2015 consumption. For projected energy consumption, we use AEO 2008 projected consumption in 2015.

- **Energy CO_2 emissions**: Like energy consumption, only nine month actual emission data is available for 2015 from the Monthly Energy Review. We apply the carbon intensity for nine months in 2015 to full-year estimated energy consumption in 2015 to get estimated carbon emissions in 2015. For projected energy CO_2 emissions, we use AEO 2008 projected CO_2 emissions in 2015.

ASSESSMENT OF US CLIMATE TARGETS

For our assessment of US climate targets we construct a complete six-gas forecast of net GHG emissions that reflects the impact of all current policies on the books as of the end of 2015. We then add ranges around the core scenario to reflect uncertainty in sequestration from Land-use, Land-use Change, and Forestry (LULUCF), economic and technology uncertainty, and uncertainty around proposed policies. Throughout this assessment we use Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report 100-year Global Warming Potentials (GWPs) and Environmental Protection Agency (EPA) GHG accounting conventions to produce forecast estimates that are comparable to EPA's latest GHG inventory and other government reports. For historical GHG emissions we use EPA's latest GHG inventory except for Figures 1, 2, and 3 in our report where we rely on EIA's energy CO_2 data from its Monthly Energy Review.

Core Scenario

CO_2 emissions

For CO_2 emissions we start with our current policies forecast generated by RHG-NEMS. RHG-NEMS is a version of EIA's National Energy Modeling System (NEMS) keyed to AEO 2015 reference case assumptions. We include four additional policies not contained in AEO2015. These policies are:

- **Extension of the Federal Production Tax Credit and Investment Tax Credit**—Congress included extensions of these key renewable energy support policies in a year-end budget deal. Following EIA's methodologies we capture both the extension and phase down schedule, as well as the change in eligibility which allows solar projects that have commenced construction by the end of a given year to access that year's subsidy value.

- **The Clean Power Plan (CPP)**—EPA's marquee regulations on CO_2 emissions from existing fossil-fuel fired power plants. We capture the CPP as a single, national cap-and-trade program on all existing and new fossil steam and natural gas combined cycle generators. Fossil-fuel fired single-cycle combustion turbines are excluded from the cap. The cap level in any given year matches the existing and new source complements cap from the CPP final rule.

We assume all allowances under the program are auctioned and none of the revenue is recycled to the power sector. We do not include the Clean Energy Incentive Program early action provision.

- **California Renewable Portfolio Standard (RPS) Extension**—In 2015 California extended and increased its RPS program past 2020, setting a stepwise goal to require 50% of electricity sold in the state to be sourced from renewable energy by 2030. We use the existing RHG-NEMS RPS framework to reflect the increased target.

- **Heavy-Duty Vehicle (HDV) Standards Phase 1**—We observed that in AEO 2015 HDVs apparently don't achieve the required fuel economy improvements required under EPA and NHTSA's Phase 1 standards. We make adjustments that bring HDVs up to required levels.

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

- **Remove emissions from 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 forecast. First, we take the 10-year average share of total aviation emissions from international flights from the most recent US inventory (31%) and apply that to forecasted aviation emissions. We then add this amount to forecasted international shipping emissions and subtract the total from forecasted transportation emissions.

- **Remove emissions from industrial non-energy use of fuels**—In the industrial sector fossil fuels are used as feedstocks in the manufacture of a variety of products such as steel and chemicals. Generally, consumption of these feedstocks generates process CO_2 emissions that are accounted for in the industrial processes categories of the EPA inventory, not under fossil fuel combustion CO_2. We subtract CO_2 emissions from non-energy uses of CO_2 from our forecast. We do this by calculating the 20-year historical average share of non-energy use CO_2 to total CO_2 from industrial petroleum and natural gas (78% and 97%, respectively) use based on EIA's latest GHG emissions report. We take these adjustment factors and apply them to forecasted industrial petroleum and natural gas emissions. For coal, we take the forecasted ratio of metallurgical coal consumption to total coal consumption in the industrial sector (40%, on average, between 2015 and 2025) and apply that to industrial coal emissions.

- **Remove emissions from 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 use. We calculate the share of non-energy fuel use to total transportation emissions using the 20-year average from EIA's latest GHG emissions report. The result is 0.3%. We subtract this amount from forecasted petroleum CO_2 emissions in the transportation sector.

RHG-NEMS does not provide a forecast for non-fossil fuel combustion CO_2 emissions. To forecast non-fossil fuel combustion CO_2 emissions such as those from industrial processes, energy production, and land use we did the following:

- **Inventory categories with emissions below 25 million tons**—We extrapolate 10-year historical trends from EPA's latest GHG inventory in line with EPA's latest GHG projection guidance.

- **Inventory categories with emissions above 25 million tons**—We follow EPA's latest GHG projection guidance, scaling 2013 inventory data based on category appropriate RHG-NEMS forecast output. For example, CO_2 from natural gas systems is scaled based on the change from 2013 in US dry natural gas production. 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 forecast.

Non-CO_2 emissions

All projections of non-CO_2 emissions (i.e. methane, nitrous oxide, hydrofluorocarbons, perfluorocarbon, and sulfur hexafluoride) used in our core scenario are sourced directly from the 2nd Biennial Report of the United States (BR). We assume that the impacts of all policies adopted or finalized by 2015 on non-CO_2 GHGs are reflected in these data.

CO_2 emissions and removals from Land-use, Land-use change, and Forestry (LULUCF)

We use EPA estimates of historic emissions and removals from the most recent EPA GHG inventory (2015) and projections from the 2nd US BR.

Economic and technology uncertainty

Our core scenario is based on the same technology and economic assumptions as EIA's AEO 2015 reference case for CO_2, as are projections used in the 2nd US BR. Our comparison of projected and actual 2015 emissions and our associated decomposition analysis described above illustrates that a number of factors other than policy can influence emissions forecasts. To capture the impact of uncertainty surrounding economic growth and a few of the most consequential technological factors, we constructed additional scenarios to set bounds on the range of potential future emissions. Table 1, below, contains the key assumptions for each factor across our core and uncertainty bounding scenarios. Sources for boundary assumptions include:

- *Economic growth*—We use EIA's AEO 2015 high and low economic growth side case assumptions for the upper and lower bounding scenarios, respectively.

- *Vehicle miles traveled*—We use the specifications from EIA's AEO 2014 high and low VMT side cases for the upper and lower bounding scenarios, respectively.

- *Electric vehicle battery costs*—We rely on EIA's AEO 2015 reference case cost assumptions for the core and upper bound scenarios. These costs vary depending on type of vehicle. For the lower bound scenario, we use the lowest published projected cost pathway from figure 1 in Nykvist and Nilsson, 2015. We apply this cost pathway consistently for all electric and plug-in vehicles in RHG-NEMS and hold costs constant after 2025.

- *Utility scale wind and solar technology costs and performance*—Renewable energy technology costs in RHG-NEMS vary geographically and by level of deployment. For our core and upper bound scenarios we use AEO 2015 cost and performance assumptions. For our lower bound scenario we use the National Renewable Energy Lab's Annual Technology Baseline low RE cost scenario assumptions for costs and performance.

- *Deployment of distributed solar photovoltaics (PV)*—We use AEO 2015 assumptions for distributed solar PV deployment in our core and upper bounds scenarios. In our lower bound scenario we insert a specified distributed PV deployment path from 2015 through 2025 that matches Bloomberg New Energy Finance (BNEF) projections.

Table I. Summary of Key Assumptions for Core and Bounding Scenarios

Factor	Core	Emissions Range Upper Bound	Emissions Range Lower Bound
Economic Growth (average annual % rate 2013-2040)	2.4%	2.9%	2.4%
Vehicle Miles Traveled (average annual % rate 2013-2040)	1.2%	1.3%	0.2%
Electric Vehicle Battery costs (2025 cost, 2013$/kWh)	Varies but typically ~$600	Varies but typically ~$600	$150
Utility Scale Wind Costs (2020 overnight capital cost, 2013$/kW)	$1,968	$1,968	$1,504
Utility Scale Solar PV Costs (2020 overnight capital cost, 2013$/kW)	$2,906	$2,906	$1,660
Distributed Solar PV Deployment (average annual % rate 2015-2025)	8%	8%	22%

Scaling of non-fossil fuel combustion CO_2 and non-CO_2 gases

As mentioned above, we scale non-fossil CO_2 emissions based on category appropriate RHG-NEMS forecast output. In our upper and lower bound uncertainty scenarios, non-fossil fuel combustion CO2 adjusts in accordance with RHG-NEMS output. For non-CO_2 gases, we scale US BR emissions projections for each gas upwards for the upper bound scenario or downwards for the lower bound scenario based on changes in category appropriate RHG-NEMS outputs. Because the BR includes only projections for aggregate non-CO_2 gases and does not provide a breakdown of emissions by sub-category, we construct a non-CO2 forecast for each inventory category based on the AEO 2015 reference case. This alternative core forecast serves as the basis for scaling BR non-CO2 emissions. We then construct corresponding non-CO2 emissions forecasts for each inventory category using RHG-NEMS output from our upper and lower bound forecasts. After that we calculate the aggregate change in emissions for each gas in our bounding forecasts relative to our core scenario and scale BR emissions accordingly.

Proposed policies and policy uncertainty

For all proposed federal policies (with the exception of the HDV rule) we use official government estimates of expected emission reductions contained in regulatory impact analysis from the issuing government agency. In several instances these estimates are presented as a range of potential emission reductions (with the average range spanning only 0.4 MMt CO_2e). For the purposes of simplicity, we use the higher end of the range provided in figures 6 and 7. For emission reductions from the adoption of a Montreal Protocol Amendment to phase down HFC emissions, we use EPA estimates from the 2nd US BR.

To assess the effect of meeting EPA's proposed Phase 2 standards for HDVs, we model compliance with the rule in NEMS in order to capture the dynamic effects across the energy system. We assume that all 13 HDV regulatory classifications (representing the discrete vehicle categories set forth in the rule) meet the efficiency improvements for each model year detailed in EPA's Regulatory Impact Analysis (table 5-27 for pickups, tables 2-58 through 2-63 for vocational vehicles, and table 2-33 for heavy duty vehicles).

We do not attempt to quantify likely emission reductions from EPA's proposed voluntary program for companies to reduce methane from existing oil and gas sources: the Methane Challenge Program. As an exercise to assess the maximum potential emission reductions from one option provided to companies participating in the Challenge, we assess the potential emission reductions that would result if all natural gas companies (upstream and downstream) joined the ONE Future Coalition and achieved its methane leakage goal of 1% across the natural gas value chain. To calculate the resulting emission reductions, we used natural gas production values from our core scenario NEMS run. We estimated the difference in methane emissions using the methane leakage rate implied from EPA's most recent GHG inventory (~1.3%) and the ONE Future leakage rate goals of 1.2% in 2020 and 1.0% in 2025. We subtracted emission reductions that are assumed will occur under the proposed policies regulating methane emissions from new and modified sources, and for sources on public lands.

To provide an overview of potential US GHG emissions under current and proposed policies, we combine our estimates of emission reductions from proposed policies with our current policy core scenario. To highlight the remaining uncertainty in the implementation of the proposed policies, we provide a range of potential outcomes. At the high end of the range, we only include proposed regulations and assume they achieve the low end of the emission reduction estimates provided by the issuing agency. At the low end of the range, we assume that proposed federal policies achieve the most ambitious end of the range of outcomes. We also assume that the ONE Future Methane Challenge goals are met by the natural gas industry as a whole, and that the Montreal Protocol amendment is achieved and implemented in line with the US phase down proposal.

DISCLOSURE APPENDIX