

DEVELOPING THE U.S. MIDCENTURY STRATEGY FOR DEEP DECARBONIZATION UNDER THE PARIS AGREEMENT

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OVERVIEW

During the Obama administration, the United States sought to leverage domestic greenhouse gas (GHG) reductions to catalyze reciprocal efforts by other major economies to reduce their emissions. The goal was to spur a durable virtuous cycle between domestic¹ and international² actions to contain climate change. This included U.S. leadership in defining and securing the Paris Agreement, as well as pushing to ensure it entered into force in 2016.

This landmark agreement includes a call for countries to develop long-term GHG emissions reduction strategies. To inform long-term U.S. climate policy strategy while spurring global implementation momentum, the United States, jointly with Mexico and Canada, committed to complete in 2016 the U.S. Mid-century Strategy for Deep Decarbonization³ (MCS). The MCS report charts pathways to achieve at least 80 percent reductions in GHG emissions below 2005 levels by 2050 and includes

- ◆ the case for acting on climate;
- ◆ a summary of emissions trends;
- ◆ the vision for achieving deep GHG reductions by 2050, integrating action across the energy, land, and non-CO₂ sectors, including close attention to the role of both natural and technological negative emissions;
- ◆ three deep-dive chapters on: decarbonizing the energy sector; storing carbon and reducing emissions on lands; and reducing non-CO₂ emissions; and
- ◆ a discussion of U.S. action in global context.

The MCS yielded important insights for domestic policymaking, and the process of developing the strategy offers potential lessons for other countries as they author long-term strategies.

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CONTEXT SETTING FOR LONG-TERM STRATEGY DEVELOPMENT

In June 2016, at the North American Leaders Summit, President Barack Obama announced alongside President Enrique Peña Nieto of Mexico and Prime Minister Justin Trudeau of Canada that the three countries would complete long-term strategies by the end of 2016. This trilateral commitment was consistent with the three economically integrated neighbors' shared focus on tackling climate change, including seeking to coordinate related planning and policies where appropriate.⁴

The United States chose to develop the U.S. Mid-Century Strategy for Deep Decarbonization to underscore its commitment to the rapid entry-into-force of the Paris Agreement and to guide domestic long-term decarbonization efforts consistent with the agreement's climate objectives. The United States has long prioritized strong transparency provisions within climate agreements and has regularly communicated its national climate action reports, biennial reports, and

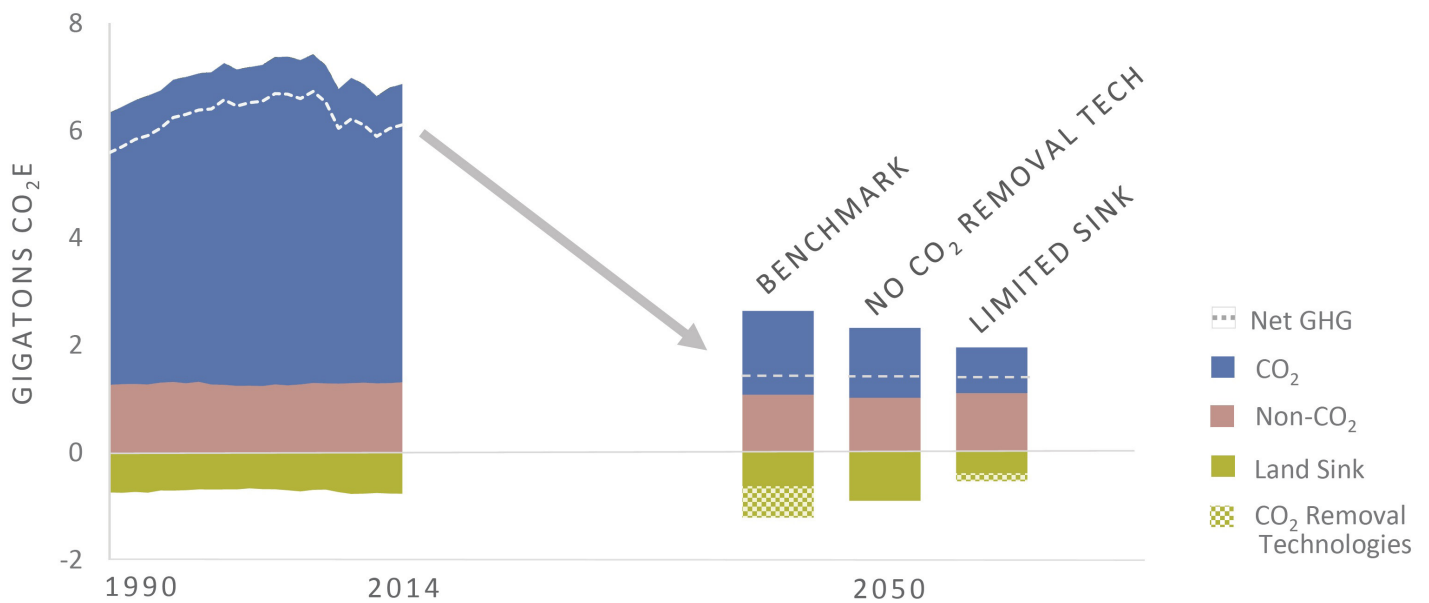
greenhouse gas inventories to the United Nations Framework Convention on Climate Change (UNFCCC). Accordingly, the Obama administration strongly supported the Paris Agreement's focus on transparency and its five-year commitment cycles to encourage near-term political accountability. At the same time, the administration viewed long-term strategies as important complementary elements of the agreement to encourage transparent long-term planning. More specifically, it was hoped that countries could draw from and inspire each other's analytic and policy insights to help ease the complex journey to deep GHG emission reductions.

The MCS highlights certain universally important features. Notably, it underscores the value of considering all greenhouse gas emissions on a "net-net" basis⁵ given the growing relative importance of land-sector carbon fluxes as countries succeed in driving down energy-sector CO₂ emissions. For instance, in the United States, forests and soils currently absorb over 10 percent of U.S. emissions. Assuming success in driving overall net GHG emissions down to 80 percent below 2005 levels, the U.S. land sector (including forests/soils and biomass paired with carbon capture and storage) could absorb nearly all of the remaining energy-sector CO₂ emissions by midcentury (Figure 1). It should be noted that achieving this land sector potential would require substantial investment and active management toward this goal. Yet the land sector has received relatively little analytic and policy attention. Accordingly, the MCS focuses nearly equal attention on land and energy sectors.

In leading by example, the Obama administration hoped that other countries would commit to undertaking robust long-term strategies grounded in ambitious GHG reduction targets. For the United States, the MCS effort proved richly rewarding both in affirming and nuancing familiar themes as well as surfacing new insights. For example, it validated the commonly held view that the United States must (1) invest in energy efficiency, (2) rapidly scale clean electricity, and (3) broadly electrify the economy. Less obviously, the process of developing the MCS helped enhance understanding of the intersections between energy and land sector policies, including the keystone role of agricultural and forestry productivity, as well as densification of urban development (i.e., "smart growth") in making it possible to provide sufficient food and wood products while also scaling up use of biomass for energy and sustaining forest carbon sinks.

The authors of the MCS hope that it can remain a durable long-term vision to support U.S. climate policy even as short-term political

Figure 1. Net Emissions and Sinks from Select Scenarios of MCS



Source: Figure E1 from MCS.

cycles have disrupted certain climate policies. It is encouraging to see subnational and private sector leadership on carbon-reducing strategies consistent with the deep decarbonization vision of the MCS, including through collaborations such as the U.S. Climate Alliance and America's Pledge.

INSTITUTIONAL ARRANGEMENTS AND PUBLIC PARTICIPATION

While the U.S. team tasked with developing the report had already begun work on the effort before the June 2016 North American Leaders Summit announcement, the United States nonetheless had only about six months in total to complete the project in time for delivery at the November 2016 UNFCCC Conference of the Parties. This compressed timeline was only feasible with an aggressive push, led by the White House, that leveraged a rich foundation of prior analysis⁶ and a network of relationships through the federal government.

The process started with assembling a dedicated team within the White House, including members from both the Council on Environmental Quality (CEQ) and the Domestic Policy Council (DPC). This team had also led the development of the 2013 Climate Action Plan and the yearlong interagency process to define the U.S. intended nationally determined contribution

(INDC) for joint announcement with China in 2014, as well as efforts to deliver on these goals through domestic regulations and programs. Crucially, this allowed the MCS team to quickly activate a highly functional interagency network of climate experts. The White House authored the MCS based on deep input from all relevant federal agencies. This included modeling capacity at the Environmental Protection Agency, the Department of Energy and its National Laboratories, and the Department of Agriculture. It also drew essential expertise from a broader suite of federal agencies, including the Department of State and Department of Transportation.

Specifically, the MCS process included the following elements that other countries should take into consideration when developing their long-term strategies:

- ◆ Assembling a team with broad expertise spanning energy CO₂, land sector sources/sinks, and non-CO₂ emissions.
- ◆ Spearheading the development of the report from the White House but relying heavily on federal agency expertise, analytic tools, and institutional knowledge.
- ◆ Grounding the analysis in robust models, including an open-

source model with global scope that spans both the energy and land sectors as well as carefully vetted technology cost assumptions published as a technical appendix to the MCS.

- ◆ Recruiting project leadership with prior experience in conducting similar analyses, including for the 2nd U.S. Biennial Report.
- ◆ Cooperating with international partners to share methodologies and insights.
- ◆ Seeking interagency input and review throughout the process.
- ◆ Securing buy-in at the presidential level.
- ◆ Leveraging external literature for cross-checking assumptions and outputs.

Given the importance of forging a common vision for climate action across the three economically integrated economies in the North American Free Trade Agreement (NAFTA), the United States sought to coordinate both scope and analytic approach during the drafting process. This included regular conversations with technical experts and modelers from both Canada and Mexico. The United States also engaged with other countries actively considering or actively developing their long-term strategies, including Germany.

The MCS team was also able to organize listening sessions with key stakeholders from the private and nonprofit sectors on sectoral topics, including clean energy, energy efficiency, and land-sector issues. These stakeholder discussions were valuable both for the direct insights they offered the team and for ensuring that key stakeholders were ready to engage with the report upon its release. There were, however, many rich threads of discussion that the MCS team had to forego given the tight timeline. When developing their long-term strategies, other countries may want to allow for a longer timeline that integrates additional process steps that may benefit the development of their report, such as

- ◆ deeper discussion with key stakeholders in specific sectors such as agriculture or transportation;
- ◆ incorporating a public review period; and,
- ◆ coordinating the roll-out and follow-on discussions with key stakeholders and policymakers to ensure that the strategy informs short-term policy strategies.

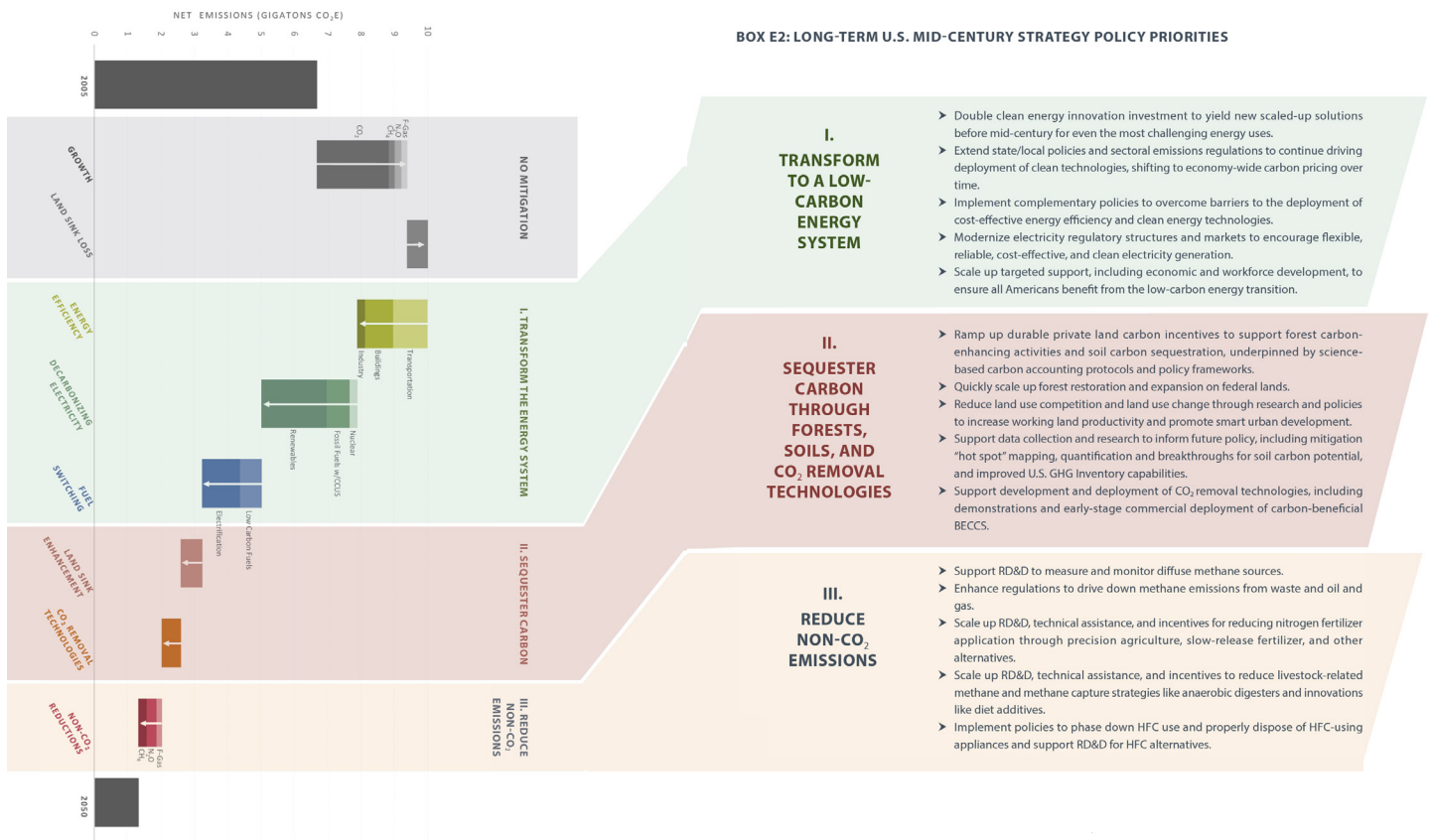
The United States benefited immensely from the rich literature on deep decarbonization and related discussions with key experts. For example, the energy sections of the report highlighted the virtuous cycle between scaled deployment and technology cost reductions and this discussion was enriched by a long-standing dialog with faculty members at MIT.⁷ The MCS would have benefited from more such deep-dive discussions with relevant experts on a wider range of topics. For instance, non-CO₂ mitigation is one of the topics that would have ideally been explored more deeply. N₂O from agriculture accounts for roughly one-fifth of remaining net emissions in 2050 under the primary “benchmark” scenario, but the analyses and models used for the MCS do not fully reflect the latest potential from advanced fertilizers and precision agriculture. A structured dialog with the private sector, nonprofits, and academic experts could have elucidated these opportunities and spurred related policy reforms and public investments.

VISION

In addition to the other goals of releasing the report in 2016 as discussed above, the Obama administration decided to complete the MCS in order to document its long-term vision for deeply decarbonizing the U.S. economy. There was a deep appreciation across the Obama administration of the urgent need to contain the risks of climate change and the crucial role of the United States in spurring comprehensive and increasingly rapid global action to cut emissions and bolster carbon sinks.

Multiple far-ranging federal analyses underpin the case for action spanning all sectors of the economy. The 2014 National Climate Assessment⁸ documented the diverse range of serious economic and environmental costs to the United States from unchecked climate change—conclusions that have been affirmed and further detailed in the 2017 National Climate Assessment released under the Trump administration.⁹ The White House Council of Economic Advisors issued a 2014 report¹⁰ that underscored the major economic costs the United States faces from unchecked climate change and the strong net benefits from cutting emissions.¹¹ The 2014 Quadrennial Defense Review underscored that climate change imposes “threat multipliers” that aggravate global political instability.¹² The Department of Energy documented far-ranging adverse impacts from climate change on the nation’s infrastructure.¹³ The Department of Agriculture documented major opportunities to simultaneously drive down emissions and increase productivity through new forest and farm management practices.¹⁴

Figure 2. Sectoral Contributions to 80 Percent Reduction in MCS Benchmark Scenario



Source: Figure E7 from MCS.

Reflecting the cross-sectoral challenge and opportunity, the Obama administration determined that the MCS should span the energy sector, the land sector, and all GHGs, with a focus on both GHG emissions and carbon dioxide removal opportunities. The land sector is critically important in global efforts to address climate change, serving both as a major source of emissions and an important carbon sink. Yet it is also often neglected in domestic policies and international negotiations. Therefore, the United States aimed to give special attention to the land sector as part of economy-wide efforts to reduce *net* emissions by 80 percent. The analysis also accounted for the cross-sectoral interactions in reducing emissions, as well as variations in emissions pathways depending on technology development and success, costs, and policies.

SETTING EMISSIONS REDUCTION TARGETS IN THE LONG-TERM STRATEGY

The United States chose to treat the MCS as a long-term planning exercise focused on reductions of at least 80 percent below 2005 levels by 2050. The pathway to at least 80 percent is consistent with:

- ◆ announcements made by the United States and other major economies at the G8 Summit in 2009;¹⁵ and
- ◆ the long-term trajectory identified in the U.S. NDC submitted to the Paris Agreement and the conditional commitment the United States submitted as part of the 2009 Copenhagen Accord.¹⁶

While Figure 3 shows that 80 percent reductions by 2050 would make remaining U.S. emissions a modest share of remaining global emissions under any plausible global scenario, the analysis also explored deeper reductions that could prove necessary, particularly to deliver on the Paris Agreement’s call to “pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels.”

The Obama administration used the MCS process to explore a range of long-term deep decarbonization scenarios, intentionally steering clear of specific target-setting implications for Paris Agreement nationally determined contributions (NDCs).

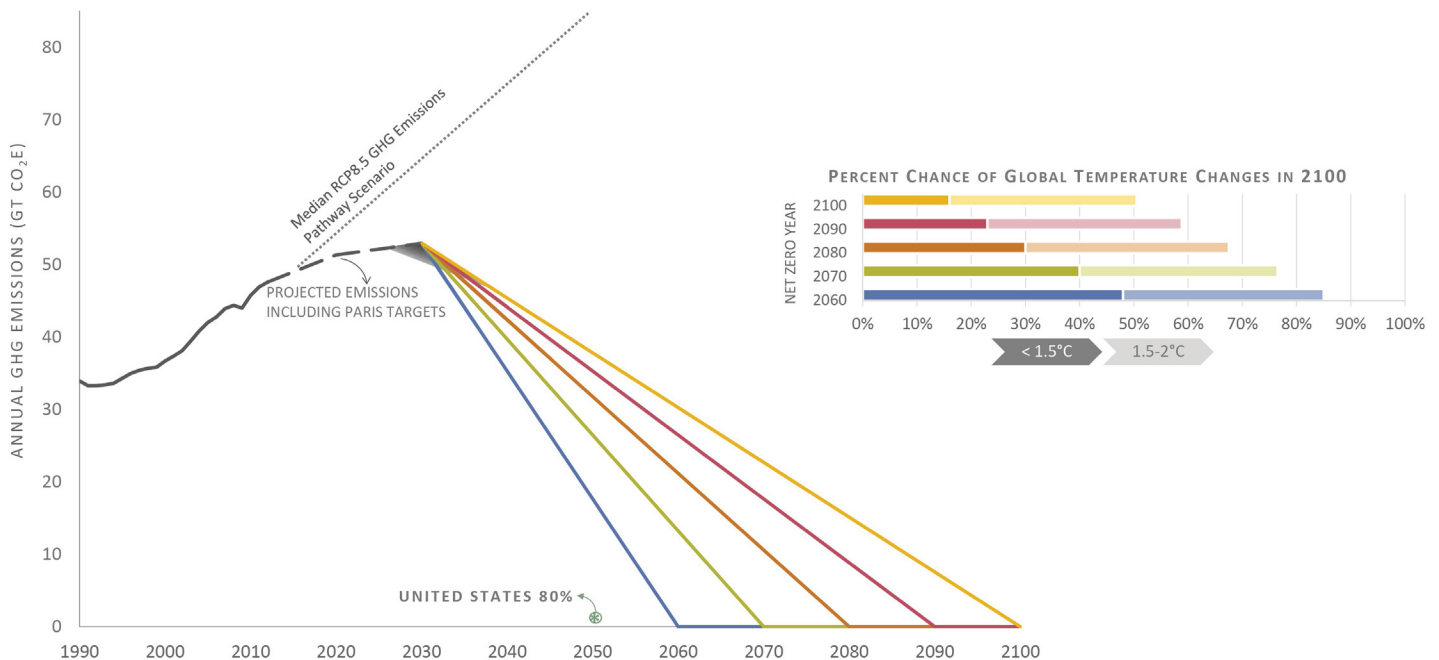
This approach ensures that countries developing long-term decarbonization strategies can freely engage stakeholders on substantive challenges and opportunities related to alternative long-term pathways, rather than bogging down in near-term political tensions that would arise if these strategies were treated as directly informing NDCs.

Furthermore, this approach gives future administrations the opportunity to leverage specific new near-term targets to encourage reciprocal ambition from other countries during successive five-year cycles, as with the U.S.-China joint announcement of potential INDCs in 2014 and the U.S.-Mexico joint submission of formal INDCs in March 2015. That said, the analyses may reveal challenges and opportunities and path dependencies that influence the viability of long-term climate goals. These conclusions may in turn inform nearer-term decision-making.

MODELING/SCENARIO BUILDING

This section details the process to develop the scenarios the United States used in its long-term strategy. First, it is important to note that the U.S. annual GHG inventory¹⁷ and its NDC commitment¹⁸ under the Paris Agreement are both grounded

Figure 3. Global Pathways to 1.5° and 2°C



Source: Figure E11 from MCS.

in net GHG emissions metrics that span the entire economy, including (1) energy CO₂, (2) land sector CO₂ sources and sinks, and (3) non-CO₂. While energy CO₂ currently dominates net emissions, the land sector sink and non-CO₂ emissions rival residual energy CO₂ emissions by 2050 in the benchmark MCS scenarios given ambitious policies to drive down energy sector emissions. Therefore, the United States chose models and scenarios that would cover this broad scope and elucidate the interactions across all three of these major GHG categories.

Models

The MCS is grounded principally in the Global Change Assessment Model (GCAM)¹⁹ because the model covers all three categories of GHGs and is well vetted and open source. Moreover, the GCAM has a global scope, which is particularly useful for considering the land-sector implications of scaling up biomass production to displace fossil fuels and supply biomass with carbon capture and storage (BECCS) facilities. Assessing these questions requires a global model capable of tracing demand and supply of biomass, food, and wood products across international commodities markets.

As a related helpful feature, the GCAM applies the economy-wide carbon price to forestry with larger carbon prices incentivizing greater forest area. While governments already employ some land sector policies that partially incentivize mitigation (e.g., forestry offsets and incentives for beneficial agricultural practices), measurement challenges and political resistance pose serious obstacles to policy interventions that optimize land-use and land-use change. Nonetheless, it is critical to include the role of the land sector in long-term decarbonization planning, and carbon pricing represents a useful proxy for the full suite of “second-best” land carbon management policies such as land use change restrictions that reduce deforestation in tropical regions or incentives for soil-carbon enhancing practices within the United States. Moreover, the scope of the global land sector opportunities for driving down emissions and bolstering carbon sinks argues for rapidly improving land carbon flux metrics, building on platforms such as WRI’s Global Forest Watch and

far-reaching academic work that integrates remote sensing (e.g., Landsat, the GEDI LIDAR satellite expected to launch in 2019) with field data (e.g., the U.S. Forest Service Forest Inventory and Analysis program).

Under current default assumptions, the GCAM’s land module typically simulates highly optimistic outcomes for both carbon sinks from healthy landscapes and BECCS.²⁰ To account for the aforementioned challenges implementing optimal land sector policy, the GCAM land module was constrained based on the team’s estimates of maximum sustainable biomass supply given other land requirements, including to maintain a robust forest carbon sink. This assumed

- ◆ medium U.N. projections of global food, timber, and crop commodities demand;
- ◆ global agriculture productivity that continues to increase at its recent pace through 2050;
- ◆ no conversion of forests and natural grassland for biomass production; and
- ◆ domestic land use policies to prompt afforestation.

Note that since the GCAM imposes equivalent carbon prices on both biomass production and forest expansion, biomass for energy is assessed against the opportunity cost of forest expansion for any given hectare. With these assumptions and constraints, the analysts assessed the amount of biomass that could be supplied in the United States from residues, waste, or dedicated energy crops on idle pastureland. The GCAM was an essential tool to conduct this analysis but deep complementary analysis was essential to generate meaningful results. The process of sustained iteration between top-down models and bottom-up estimates is critical for developing robust long-term strategies, and the United States encourages other countries to do this.

The analysis also drew from multiple other models to provide a closer look at specific sectors. These models and their interactions with the MCS are detailed in the report²¹ and its technical documentation²² but include the Global Timber Model²³ and the U.S. Forest Assessment System Service Model for a closer assessment of the U.S. forestry sector. The land sector analysts engaged in sustained dialog with the U.S. Forest Service and Environmental Protection Agency (EPA) to vet and refine the lands sector elements of the analysis, including using complementary model outputs in combination with GCAM results.

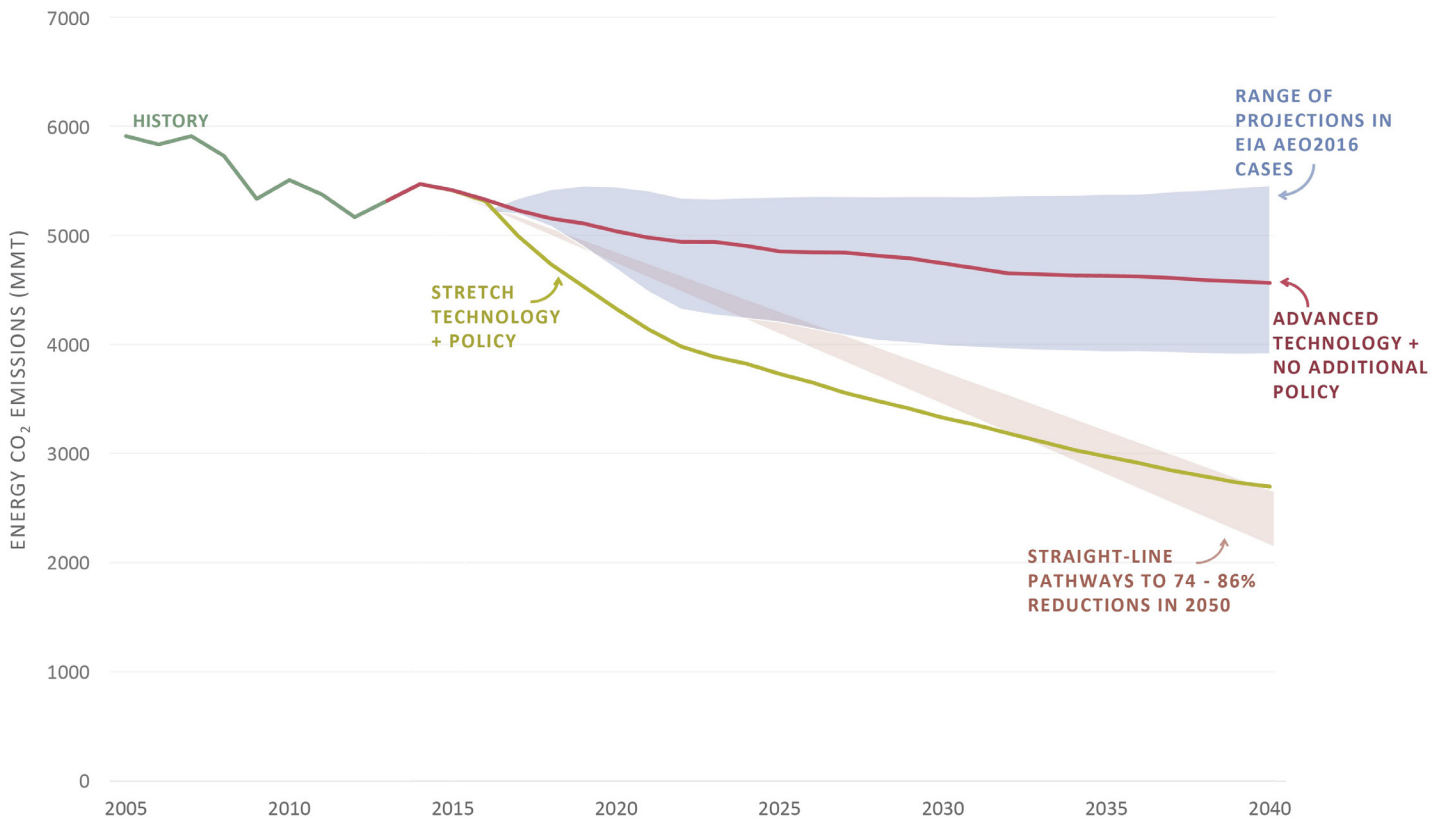
The Department of Energy (DOE) Energy Information Administration (EIA) National Energy Modeling System (NEMS)²⁴ also allowed for a closer look at the dynamics within subsectors of the U.S. energy system.²⁵ This provided both a cross-check on the GCAM results for key issues and an opportunity to indicate the technology cost assumptions and carbon price trajectory needed to realize deep reductions in

the energy sector by 2050 (see Figure 4). The DOE NEMS runs and additional EPA²⁶ and DOE analysis²⁷ were used as input for advanced technology cost assumptions.

These assumptions were all published for transparency and to facilitate related assessments by other governments and stakeholders.²⁸ The authors strongly encourage other countries conducting long-term strategies to transparently report both their assumptions and modeling results.

Finally, for the non-CO₂ gases, the MCS used the EPA's abatement cost curve.²⁹ As noted elsewhere, these gases and their sources are complex and mitigation opportunities are underresearched (both domestically and globally). Therefore, closer analysis of non-CO₂ mitigation options is needed to identify opportunities that go beyond merely stemming growth in these emissions.

Figure 4. Energy CO₂ Emissions in MCS and DOE Technology Scenarios



Source: Figure E3 from MCS.

Scenarios

The U.S. MCS is based on a core “benchmark” scenario that represents a hypothetical pathway to achieve 80 percent reductions by 2050. To model this scenario required constraining the GCAM to achieve those reductions given estimates of sustainable biomass supply (as described above) and allowing the model to define a cost-minimizing mitigation pathway. The benchmark scenario serves as a starting point for comparison of other pathways. The United States chose to model multiple scenarios in order to capture a more complete range of plausible pathways since there is immense uncertainty around issues including technology development, consumer trends, land use, and policy implementation. Modeling multiple pathways can help identify common themes across all scenarios and allows for an assessment of sector-specific requirements for different pathways. The United States chose a suite of pathways that captured the largest uncertainties associated with the energy and lands sectors. These six sensitivities included a “No CO₂ Removal Technology” scenario, a “Limited Sink” scenario, a “Smart Growth” scenario, a “No Carbon Capture and Sequestration (CCS)” scenario, a “Limited Biomass” scenario, and a “Beyond 80 Percent” scenario.

The “No CO₂ Removal Technology,” “No CCS,” and “Limited Biomass” scenarios constrained or removed BECCS or other direct air capture technology (and in the case of the “No CCS” scenario, removed fossil-CCS technologies) to represent the risk that these technologies either do not reach scale or prove politically unattractive. These scenarios required deeper reductions in the energy sector and greater investment in afforestation, and the modeling indicated substantially increased costs. These scenarios did not induce major increases in non-CO₂ abatement, because some of these sources appeared to be very expensive to compress (e.g., agricultural methane) based

on current assessments; however, as the authors have noted, additional work to develop and assess long-term non-CO₂ mitigation options is needed.

The “Limited Sink” scenario examined the possibility of a U.S. forest sink in a worsening state of disturbance and decline. Modeling this scenario was important due to divergence in existing literature about U.S. land sector projections through midcentury. This scenario sharply limited both sustainable biomass supply and the ability to bolster the land carbon sink through afforestation. As a result, it showed even deeper reductions in the energy sector.

The “Smart Growth” scenario examined how densified urban development could free land equivalent to roughly half the total new afforestation needed to maintain the land sector carbon sink through 2050. Finally, the “Beyond 80” scenario reflected greater political and public ambition. Its core assumptions looked much like the benchmark but with deeper reductions required of all sectors by 2050.

While the GCAM produces cost-minimizing pathways³⁰ under each of these scenarios, in general the related economic costs were not included in the report because of the large uncertainties associated with analyses that span three decades. Nonetheless, the benchmark scenario and sensitivities yielded crucial insight into the qualitative mix of solutions the United States needs to develop and deploy to achieve deep decarbonization while maximizing net economic benefits. In this context, it is notable that the Trump administration’s Office of Management and Budget has affirmed that recent carbon-reducing regulations have yielded strong net economic benefits, factoring in both public health benefits (not considered directly in the MCS) as well as avoided climate change.³¹

ADDITIONAL ELEMENTS

The compressed timeline for the MCS process necessitated a tight scope. Consequently, the report does not explore additional relevant topics such as regional breakdowns of mitigation investments, assessing the net economic benefits from deep decarbonization considering reduced climate impacts and improved air quality, exploring related opportunities to spur economic development and improve public health in low-income communities, or bolstering rural economies through climate-friendly agriculture and sustainable biomass production. Similarly, it does not discuss implementation burdens or costs such as stranded assets or local impacts of renewable and biomass development.

Nonetheless, the MCS provides some discussion of policy levers needed to drive the sustained large-scale investments to reduce emissions and maintain the carbon sink. This includes the central role of carbon pricing in driving efficient investment in the lowest-cost carbon-reducing solutions within the energy sector and the value of information and incentives to encourage agricultural practices, such as cover crops, that would cut emissions while enhancing soil carbon and increasing agricultural productivity. With additional time and resources, the report would have benefited from closer analysis and a deeper dialogue with relevant stakeholders in each major sector of the economy.

The MCS focuses exclusively on emissions reductions and excludes climate adaptation, which the MCS team concluded would be best assessed in a separate undertaking such as a national adaptation strategy. While mitigation and adaptation strategies intersect in some important ways, the scale of the undertaking in each case makes it impractical to merge the efforts. Nonetheless, the U.S. and other governments could usefully undertake in-depth adaptation planning that takes into account long-term mitigation strategies and climate-impact science from sources such as the U.S. National Climate Assessment.

Finally, the MCS focused on a range of deep reduction scenarios that are consistent with U.S. responsibility to lead global efforts to drive down GHG emissions and spur development of lower cost emission-reducing technologies. The report notes that such U.S. leadership could contribute to a global virtuous cycle where deployment drives technology cost reductions (through scale and learning-by-doing), which in turn facilitate faster deployment.

CAPACITY, FINANCING, ENABLING ENVIRONMENT, AND RESOURCES TO IMPLEMENT LOW GHG EMISSIONS DEVELOPMENT STRATEGIES

The MCS was facilitated by strong leadership from President Obama, which allowed rapid engagement of the wealth of expertise across the federal government to complete a robust report. As was discussed above, the report benefited from federal agency staff with deep knowledge of climate mitigation, bolstered by insight from academic and nonprofit institutions. The authors hope that the report guides further study within and beyond the federal government and serves as a reference for future administrations that prioritize climate action.

Notwithstanding current reversals under the Trump administration, the United States remains well positioned to achieve deep decarbonization over the next three decades. Spurred by multiyear incentives in a 2015 budget deal, renewable energy continues to deploy rapidly, driving 2017 power sector emissions below 1990 levels. Many states and cities are exercising their authority to actively lead on climate. Moreover, the U.S. economy, spurred by sustained public investment in research and development, has already led development of many of the most important carbon-reducing solutions (e.g., light-emitting diode [LED] technology, solar, and wind power), and the global virtuous cycle between cost reductions and scale continues apace.

A recent cross-model economic assessment indicated that the impact of a carbon prices starting at \$25 per ton in 2020 and rising at 1 percent per year would allow the United States to meet its 2025 NDC range with only modest impacts on real GDP

growth (a reduction in GDP of less than 1 percent by 2030).³² This is one of many assessments, including the MCS, that suggest that the United States could in principle readily afford to put in place energy sector policies that place the overall economy on the path to 80 percent reductions by midcentury. This transition would yield massive benefits from reducing climate impacts and improving public health, which would ensure large net benefits to society.

However, as emphatically underscored by the MCS, the most cost-effective path to deep decarbonization requires more than just driving down energy sector CO₂. The United States must also develop better strategies to bolster the land sector carbon sink and more creatively cut non-CO₂ emissions.

For the land sector, there is a particularly urgent need to improve the ability to measure global and national carbon fluxes and the practices that drive them. Within the current official U.S. GHG inventory, land sector carbon fluxes are highly uncertain. For example, the 2016 EPA inventory estimated that forests and landscapes absorbed 9 percent of U.S. emissions in the important 2005 baseline year for its Paris Agreement target, but the 2009 EPA inventory estimated that the land sector actually absorbed 16 percent of emissions in 2005. More precise data integrating remote sensing and field data are essential to both motivate and manage policies and programs aimed at bolstering these land carbon sinks. Global collaboration on such lands sector measurement platforms would benefit the United States and other countries.

Similarly, closer attention is needed to non-CO₂ mitigation opportunities through mechanisms such as modified livestock feeding to reduce agricultural methane and precision agriculture that reduces N₂O from excessive or poorly timed application of fertilizer. The United States would benefit from international work to formulate and assess new mitigation strategies to address these and other non-CO₂ emissions.

USING THE STRATEGY TO INFORM SHORT-TERM PLANNING

While the federal government recently published a national climate assessment that strongly underscores the severe risks and costs of climate change to the economy, the Trump administration has nonetheless signaled its intention to

exit the Paris Agreement and is undertaking comprehensive efforts to remove standards and rules intended to drive U.S. emissions lower. Moreover, the Trump administration has stopped all further efforts to put in place policies and programs that would have helped accelerate progress. As a result, while GHG emissions have continued to decline through 2016,³³ and energy CO₂ emissions have declined through 2017, the pace of reductions has slackened substantially.³⁴

At the same time, a growing number of states representing more than 40 percent of the U.S. population have joined the bipartisan U.S. Climate Alliance, pledging to take actions within their jurisdictions consistent with the U.S. goal of cutting net emissions at least 26 percent by 2025.³⁵ Cities and businesses are also acting, including through “America’s Pledge” and “We Are Still In.”³⁶ These efforts underscore that much of the country continues to invest in climate action. The authors hope that members of Congress, subnational leaders, businesses, philanthropies, academics, and nonprofits will use the MCS as they develop business strategies, policies, and advocacy priorities in the years to come.

Nonetheless, renewed vigorous federal leadership will be required to deliver 26–28 percent reductions by 2025 consistent with the U.S. NDC. Economy-wide federal action, spanning carbon-intensive states not currently committed to climate action, is similarly essential to continue past 2025 on a path toward at least 80 percent reductions by midcentury.

IMPLEMENTING THE LONG-TERM STRATEGY

There is no comprehensive coordinated federal effort to implement long-term climate strategies that extend through midcentury in the United States, largely because there is no comprehensive economy-wide legislative mandate to make it happen. In 2010, a comprehensive climate law that would have led to reductions of 83 percent by 2050 in the United States failed to pass in Congress. Under the Obama administration, the Climate Action Plan was the first-ever strategy to reduce emissions by implementing policies and programs sector-by-sector. However, the Climate Action Plan focused on near-term actions and did not attempt to quantify how near-term actions cross-checked against long-term decarbonization targets.

The MCS represents the first official federal attempt to scope out a long-term strategy for cutting emissions that future policymakers can use the MCS as guidance in developing more comprehensive federal climate policies. In the meantime, it serves as a reference for subnational governments and the private sector anticipating future climate policy.

PROCESS TO REVIEW AND REVISE THE LONG-TERM LOW STRATEGY

Over the last 10 years, the United States has experienced a number of dramatic economic and technological shifts that often were not anticipated by models. These developments include the Great Recession, advancements in hydraulic fracturing, and the plummeting cost of low-carbon technologies like solar and wind. This underscores the need to periodically update long-term strategy reports. Long-term strategies must also be updated to reflect the best-available science regarding the urgency of climate action.

The MCS explicitly calls on countries to revise and submit new long-term strategies every five years (similar to the five-year cycles contained in the Paris Agreement). While the Paris Agreement does not require countries to complete more than one initial long-term strategy, the authors of the MCS believe that this would be worthwhile and would help countries to track long-term temperature targets.

The focus of a second MCS for the United States would productively remain on the year 2050, but future MCS reports might consider later time horizons as the world advances deeper into this crucial century for the global climate.

LESSONS LEARNED

The goals in completing the MCS in 2016 included encouraging implementation momentum for the Paris Agreement, guiding deep decarbonization in the United States, and surfacing insights to share with other countries. Developing the MCS provided many generalizable substantive and process insights.

Out of this process, a number of key themes emerged:

- ◆ Countries must consider what sectors will be important in 2050, not just their relative importance today. For the United States, the land sector proved to be particularly crucial on the midcentury timescale. The MCS thus gave almost equal attention to the land and energy sectors and considered interactions between the two.
- ◆ Driving down energy CO₂ by radically reducing the carbon intensity of electricity and broadly electrifying the economy represents the most important lever to achieve deep decarbonization.
- ◆ While already rapidly deploying in the United States and globally, the pace of renewables should accelerate further (e.g., a 50 percent faster pace is required through 2035 for the United States) and continue apace through midcentury, complemented by CCS and nuclear.
- ◆ The electric sector must achieve near-complete decarbonization, but it may prove cost-effective to allow limited residual electricity emissions through midcentury (e.g., to ensure supply despite seasonal variability in renewable energy output that is expensive to back up through storage or excess renewables capacity).

- ◆ It will remain cost-effective for substantial transport and industrial CO₂ emissions to continue through midcentury (partially due to slow stock turnover of vehicles).
 - ◆ Sequencing of mitigation actions is critical. For instance, in the energy sector, upfront investments in energy efficiency will ease the required pace of clean electricity scale-up, and early efforts in smart growth (i.e., dense development that spares land for agriculture or forestry) will make it easier to sustainably supply biomass while maintaining forest carbon sinks.
 - ◆ Current assessments suggest it is difficult to do more than offset growth in non-CO₂ gases, underscoring the need for deeper exploration of related mitigation options.³⁷
 - ◆ Given residual energy and non-CO₂ emissions, carbon dioxide removal (including natural options such as bolstering forests and soils as well as technological options such as BECCS or direct air capture) reduce the cost of deep decarbonization pathways.
 - ◆ Enhanced land-sector carbon data tracking systems covering all countries with significant land carbon stocks or biomass production potential are urgently needed to improve GHG inventory estimates, empower governments to manage land carbon, and ensure that scaled-up biomass usage does not induce adverse land conversion.
 - ◆ Robust and sustained investment in research, development, demonstration, and deployment lowers costs and increases net economic benefits. Specifically, the exercise indicated that through advanced technology improvements, it is possible to achieve energy-sector targets at a reasonable carbon price pathway, particularly when considering the virtuous cycle of ambition and innovation.
 - ◆ Economy-wide GHG pricing offers the most cost-effective and efficient core policy, but complementary policies are needed, including to cut energy waste and drive transformation in the land sector.
 - ◆ A diversified energy portfolio that includes nuclear and renewables, as well as carbon capture and sequestration technologies for coal, natural gas, and bioenergy offers the most effective path to deep emissions reductions.
- Moreover, the MCS experience suggests the following process insights:
- ◆ Allow sufficient time to fully integrate expertise and analytic input from all relevant government agencies and to explore complex topics through deep dialogue with external experts.³⁸
 - ◆ Avoid setting specific new near-term targets that are better established through the five-year NDC process under the Paris Agreement.
 - ◆ Model and analyze all major sectors of the economy and gases, giving extra attention to those that are understudied and expected to gain relative importance by midcentury (e.g., the land sector and non-CO₂ for the United States).
 - ◆ Focus on cost-minimizing scenarios that deliver fixed emissions reduction goals, exploring widely varying scenarios regarding technology costs and other key parameters.
 - ◆ Aggressively develop strategies to compensate for the limitations of available models. For example, as discussed above, the MCS required in-depth assessment of sustainable biomass supply and land availability for afforestation to appropriately constrain the GCAM model.

ENDNOTES

1. During President Barack Obama's first term, the United States provided \$80 billion in clean energy investment under the American Reinvestment and Recovery Act (ARRA) and finalized efficiency standards for both vehicles and appliances. In his second term, the president released the Climate Action Plan, which formalized a vision of domestic action to spur global progress. It initiated a government-wide effort to address domestic emissions across all major sectors, including the electric sector, heavy-duty vehicles, oil and gas methane, agricultural emissions, hydrofluorocarbons (HFCs), the forest carbon sink, and the agriculture sector.
2. Under President Obama, the United States played a pivotal role in advancing global climate diplomacy through sustained bilateral and multilateral engagement backed by technical, legal, and financial commitments. This included securing the Paris Agreement (e.g., galvanizing countries to put forward strong intended nationally determined contributions (INDCs) with the 2014 U.S.-China Joint Announcement), the Kigali Amendment to the Montreal Protocol (e.g., catalyzing an \$80 million fast-start finance package), and the Carbon Offsetting and Reduction Scheme for International Aviation (e.g., intensive bilateral engagement with China and other key players).
3. White House, "U.S. Mid-century Strategy for Deep Decarbonization," November 2016, http://unfccc.int/files/focus/long-term_strategies/application/pdf/mid_century_strategy_report-final_red.pdf.
4. In addition to announcing the commitment to complete long-term strategies, the countries agreed to coordinate and align standards across a range of issues. For energy and climate policies, the three countries agreed to align standards for heavy-duty vehicles and consumer appliances, pledged to increase the share of their electricity from zero-carbon sources from 37 percent to 50 percent by 2025, and committed to reducing oil and gas methane 40–45 percent by 2025.
5. Countries that measure on a "net-net" basis account for emissions and removals from both the base year and the commitment period. The United States would measure its 2020 target against its net emissions in 2005 and its net emissions in 2020.
6. The MCS built on interagency analysis conducted to define the 2025 INDC jointly announced by President Obama with President Xi Jinping in the fall of 2014 in China as well as analysis conducted for the 2016 Biennial Report to the UNFCCC. See White House, "Factsheet: U.S.-China Joint Announcement on Climate Change and Clean Energy Cooperation," November 11, 2014, <https://obamawhitehouse.archives.gov/the-press-office/2014/11/11/fact-sheet-us-china-joint-announcement-climate-change-and-clean-energy-c>; and U.S. Department of State, "2016 Second Biennial Report of the United States of America," January 2016, https://unfccc.int/files/national_reports/biennial_reports_and_jar/submitted_biennial_reports/application/pdf/2016_second_biennial_report_of_the_united_states_.pdf.
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12. U.S. Department of Defense, "2014 Quadrennial Defense Review," http://archive.defense.gov/pubs/2014_Quadrennial_Defense_Review.pdf.
13. U.S. Department of Energy, "U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather," July 2013, <https://energy.gov/sites/prod/files/2013/07/f2/20130716-Energy%20Sector%20Vulnerabilities%20Report.pdf>.
14. U.S. Department of Agriculture, "Building Blocks for Climate Smart Agriculture and Forestry," May 2016, <https://www.usda.gov/sites/default/files/documents/building-blocks-implementation-plan-progress-report.pdf>.
15. Group of Eight Summit, "Chair's Summary," July 10, 2009, http://ec.europa.eu/economy_finance/publications/pages/publication15572_en.pdf.
16. During the 2009 Copenhagen Conference of the Parties, the United States referenced a long-term goal of reducing its emissions by 83 percent below 2005 levels by 2050. That goal was, however, conditional on passage of pending climate legislation that unfortunately did not become law. For the U.S. Copenhagen commitment and the Paris NDC, see U.S. Department of State, "Letter from the Office of the Special Envoy for Climate Change to Mr. Yvo de Boer," January 28, 2010, https://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf/unitedstatescphaccord_app.1.pdf; and U.S. Department of State, "U.S. First Nationally Determined Contribution Submission," <http://www4.unfccc.int/ndcregistry/PublishedDocuments/United%20States%20of%20America%20First/U.S.A.%20First%20NDC%20Submission.pdf>.

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23. Documentation of the Global Timber Model can be found at <https://aede.osu.edu/research/forests-and-land-use/global-timber-market-and-forestry-data-project>.
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30. The MCS went beyond a simple cost-minimizing modeling exercise and assumed specific policy and technology "pushes" (assuming accelerated development of solar, electric vehicles, energy efficiency, and other technologies).
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33. U.S. Environmental Protection Agency, "U.S. Inventory of Greenhouse Gas Emissions and Sinks."
34. Trevor Houser and Peter Marsters, "Final U.S. Emissions Numbers for 2017," Rhodium Group, March 29, 2018, <https://rhg.com/research/final-us-emissions-numbers-for-2017/>.
35. See U.S. Climate Alliance at <https://www.usclimatealliance.org/>.
36. See "America's Pledge" at <https://www.americaspledgeonclimate.com/>; and "We Are Still In" at <https://www.wearestillin.com/us-action-climate-change-irreversible>.
37. As with the land sector, non-CO₂ emissions rivaled residual energy CO₂ emissions by 2050. For instance, the analysis shows a surprising amount of remaining HFC emissions in the United States through 2050 from gradual leaks from existing stocks, despite the rapid phase down of production and consumption of these gases under the Kigali Amendment. There is uncertainty about the costs and potential for options to collect and destroy HFCs before they gradually leak from dispersed sources such as foams, equipment, and appliances. Additional research on both of these themes would be useful for all countries facing similar analytic and mitigation challenges.
38. The highly compressed six-month time frame substantially constrained engagement with other governments and stakeholders. Moreover, since the Obama administration delivered the MCS two months before the end of its tenure, policymakers were unable to engage broadly with stakeholders, other governments, and other policymakers on the results. Other governments should invest fully in such conversations as they were one of the most rewarding aspects of the effort by the U.S. MCS team.

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