APPENDIX 1

Pathways to Paris: Technical Appendix

This document provides additional detail on the methods and data sources used in Rhodium Group's Pathways to Paris report. Direct access to all national energy and emissions results from our Pathways to Paris scenarios—including results broken down by gas and sector through 2030—will be available via the ClimateDeck. All historical greenhouse gas (GHG) emissions and removal estimates (1990-2019) come directly from the 2021 Environmental Protection Agency (EPA) Greenhouse Gas Inventory. Like the EPA inventory, we report all gases in carbon dioxide (CO_2)-equivalent emissions based on the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report's (AR4) 100-year global warming potential (GWP) values. To model policy scenarios, we use RHG-NEMS, a modified version of the detailed National Energy Modeling System. NEMS is developed and used by the Energy Information administration (EIA) to produce its Annual Energy Outlook 2021 (AEO2021). We make several modifications in RHG-NEMS and project impacts for all sectors of the US economy and six key greenhouse gas categories.

Energy market, technology, and natural carbon removal assumptions

To create our projection ranges, we rely on two emissions bounding scenarios that capture uncertainty in energy markets, technology costs, and performance and natural carbon removal from land-use practices. Across all scenarios, we use the Reference macroeconomic assumptions from EIA's AEO2021. We also incorporate several revisions to input assumptions beyond the AEO2021 Reference case, including announced power plant retirements and additions, and electric vehicle charging costs, availability, and uptake (see the Taking Stock 2021 Technical Appendix for further details). We apply these revisions to all scenarios.

Below are the key assumptions underlying our bounding scenarios. In our low emissions scenario, we pair low technology costs with central oil and gas assumptions and a high sequestration pathway for land use, land-use change, and forestry (LULUCF) emissions. In our high emissions scenario, we pair central technology costs with low oil and gas assumptions and a low sequestration pathway for LULUCF. See the Taking Stock 2021 Technical Appendix for charts detailing select assumptions and further information.

Electric generating technology costs: We generally assume capital costs for utility-scale and distributed solar photovoltaic, land-based and off-shore wind, and utility-scale energy storage decline according to NREL's 2020 Annual Technology Baseline's (ATB) technology cost projections. Our central cost assumptions follow ATB's Moderate Technology Innovation Scenario, while our low-cost assumptions follow the Advanced Scenario.

We also change relevant cost and performance parameters for power generating facilities equipped with carbon capture technology, informed by Rhodium analysis and current literature. Of particular note are revisions to costs for new-build natural gas plants with carbon capture. We adapt work from the National Energy Technology Laboratory, which details cost and performance for natural gas-fueled direct supercritical CO_2-fired power plants.

Electric vehicle battery costs: For light-duty electric vehicle (EV) battery costs, we draw on the Rapid Advancement case from the National Renewable

Energy Laboratory's (NREL) Electrification Futures Study (EFS) for our central costs and BNEF projections for our low costs. We assume battery costs for the suite of light-duty EV technologies modeled in NEMS match these reduction pathways, though each starts at a different current price.[1]

Natural gas and oil resource and prices: For our central cost assumptions, we use oil and natural gas resources and prices reflected in the AEO2021 reference case. In this case, natural gas averages $3.05/MMBtu through 2030 at Henry Hub, and Brent crude rises from $45/barrel in 2021 to $72/barrel in 2030. We use the oil natural gas resource and prices reflected in the AEO2021 high oil and gas supply side case for our low-cost assumptions. The resulting average natural gas price is $2.60/MMBtu through 2030, and Brent crude reaches $63 per barrel in 2030.

Industrial carbon capture costs: Rhodium has developed the Industrial Carbon Abatement Platform (ICAP) to assess technology deployment and emissions abatement potential in the industrial sector under a variety of scenarios. Using ICAP, we project future carbon capture retrofits at existing industrial facilities under low and central CCS cost assumptions. ICAP is integrated with the rest of RHG-NEMS such that industrial facilities see dynamic energy costs and expected revenue from CO_2 sales.

LULUCF: We use the 2021 EPA GHG inventory for historical LULUCF emissions and rely on the US 2016 Second Biennial Report to project baseline LULUCF emissions. The 2016 report is the latest nationwide projection from a federal agency, though US EPA and USDA Forest Service are reportedly in the process of updating projections. In the meantime, recent data suggests that the carbon stocks in western states are declining faster than models have previously predicted due to drought, insects and disease infestation, and wildfire.[2] Furthermore, land-use change trends continue to result in a net decline in carbon stocks across the land base. Consequently, while there is scientific consensus that the LULUCF sector will remain a net sink of carbon through 2030 and onward, there is debate about whether that sink will grow or shrink over time with no major interventions in land management or change in land use trends.[3]

Our baseline range of LULUCF emissions reflects this uncertainty. For our high sequestration pathway, we use the high sequestration scenario from the 2016 Biennial Report, calibrated to align with the EPA's 2021 inventory. This results in essentially flat LULUCF emissions at the 2005 level. For our low sequestration pathway, we use the low sequestration scenario from the 2016 Biennial Report, which assumes a decline in the size of the carbon sink over time.

Federal and subnational policy assumptions

Our baseline scenarios include emission reductions from all existing federal and state policies "on the books" as of May 2021. We include only policies that have been finalized and adopted. We do not include aspirational goals or economy-wide targets that have

[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.

[2] Domke, G. *et. al.* Greenhouse Gas Emissions and Removals from Forest Land, Woodlands, and Urban Trees in the United States, 1990-2018. Resource Update FS-227. Madison, WI: US Department of Agriculture, Forest Service, Northern Research Station. 2020. Available online: https://www.fs.fed.us/nrs/pubs/ru/ru_fs227.pdf.
Wear, D. and Coulston, J. From sink to source: Regional variation in US forest carbon futures. Nature Scientific Reports. 12 Nov. 2015.
Coffield, S. *et. al.* Climate-Driven Limits to Future Carbon Storage in California's Wildland Ecosystems. *AGU Advances*, 2021; 2 (3)

[3] Tian, X. *et. al.* Will US Forests Continue to Be a Carbon Sink? Land Economics Feb. 2018. 94 (1): 97-113.
Wear, D. and Coulston, J. From sink to source: Regional variation in US forest carbon futures. Scientific Reports. 12 Nov. 2015.
Baker, J. *et. al.* "Economic Analysis of Greenhouse Gas Mitigation Potential in the US Forest Sector." RTI Press. 2017. Available online: https://doi.org/10.3768/rtipress.2017.pb.0011.1708.
Jones, J. *et. al.* "Importance of Cross-Sector Interactions When Projecting Forest Carbon across Alternative Socioeconomic Futures." *Journal of Forest Economics* 34 (3–4): 205–31. 2019.
Wade, C. *et. al.* "Projecting the Impact of Socioeconomic and Policy Factors on Greenhouse Gas Emissions and Carbon Sequestration in US Forestry and Agriculture." In press.
Coffield, S. *et. al.* Climate-Driven Limits to Future Carbon Storage in California's Wildland Ecosystems. *AGU Advances*, 2021; 2 (3)

not been solidified in specific, actionable policy, nor do we explicitly include specific city-level or corporate commitments. See the Taking Stock 2021 Technical Appendix for a detailed description of policies captured in our baselines.

In our Joint Action scenarios, we model a suite of additional policies executed through Congress, the executive branch, and subnational actors:

Congressional action: As discussed in the report, we model key components of the bipartisan infrastructure bill and the budget reconciliation bill currently under consideration in Congress. See Table 1 for the complete set of policies.

Federal regulatory action: We model a set of federal regulatory pathways that rely on authorities that have been used previously to cut emissions or energy use. Furthermore, these authorities target large sources of emissions or opportunities for substantial carbon removal. See Table 2 for the complete set of policies.

Subnational action: We model actions that leading states, defined as the 25 US Climate Alliance states, and corporate climate leaders can take to deliver earlier and greater emissions reductions than their current targets. We focus on actions that states have implemented under existing authorities and expand them across all leading states. We also accelerate key corporate clean energy targets. See Table 3 for the complete set of policies.

Six-gas projections

Emissions Adjustments and Offline Projections

Projected CO_2 emissions from all energy use in RHG-NEMS are inconsistent with EPA's accounting conventions for CO_2 from fossil-fuel combustion in its GHG inventory. We adjust international bunker fuels, industrial non-energy use of fuels (feedstocks), and transportation non-energy use of fuels (largely lubricants) to correct this discrepancy. RHG-NEMS does not provide projections of some non-fossil fuel consumption CO_2 emissions and non-CO_2 emissions. For these inventory categories, we extrapolate historical trends from EPA's latest GHG inventory or scale data based on appropriate outputs from RHG-NEMS where possible. See the Taking Stock 2021 Technical Appendix for more information.

Land use emissions and carbon removal

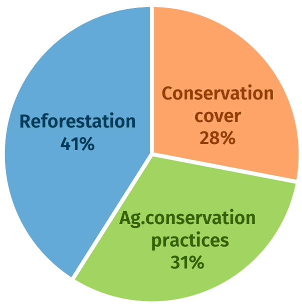
Within our carbon removal analysis, we estimate technological carbon removal impacts using ICAP, as discussed above. For the remainder of this section, we focus on our natural carbon removal, or LULUCF< analysis.

Our LULUCF sector analysis estimates the GHG mitigation potential of select land restoration and management practices across forests, agricultural lands, and urban areas. It examines the subset of these practices or pathways (also known as natural climate solutions or NCS) that are expected to be implemented through policy and budget changes under the Biden administration and the 117th Congress. This analysis is not exhaustive of all the proposed or expected policies related to land use, conservation, management, and restoration. Rather, it focuses on those with an estimable link to GHG mitigation at the national scale and a pathway to implementation. We find that the combination of modeled congressional and executive action results in increasing land sequestration by 336 mmtCO_2e in 2030. Reforestation contributes most of this sequestration (41%), followed by agricultural conservation practices (31%). Conservation cover, which is comprised of a suite of restoration activities, comprises the remaining 28%. Below, we discuss key assumptions underlying our estimates of carbon removal policy impact on LULUCF emissions.

FIGURE 1.1

Natural climate solution pathway impacts, 2030

Percent of total LULUCF sequestration due to policy



Congressional action

We have estimated the net negative emissions potential of increased, beyond-baseline funding to select federal programs that support reforestation and restoration of public and private lands and private agricultural land management. The carbon removal programs and budget allocations listed in Table 1 would increase net flux by -159 mmtCO_2e in 2030. The NCS pathways listed in Table 1 represent only a fraction of beyond-baseline federal funding for land conservation, management, and restoration that is currently in play in Congress. The budget allocations in Table 1 also represent only those funds that we estimate to directly result in carbon removal, i.e., only those funds that will directly implement reforestation, urban tree planting and maintenance, and agricultural conservation practices. As a result, dollar amounts listed in Table 1 differ from proposed allocations for each program. Other expenditures may also impact carbon sequestration on policy-relevant timescales, but we omitted them from this simplified analysis. These estimates also do not include proposed funding for ecological restoration and wildfire risk reductions in the Bipartisan Infrastructure Framework or programs for private lands conservation and carbon-focused improved forest management in the budget reconciliation. This analysis assumes that all budget allocations from 2030 will supplement, not supplant, existing and expected future budget allocations, including programs that receive budget allocations through the Farm Bill.

Reforestation

The reforestation assessment relies on implementation cost and carbon accumulation data from the literature below. Implementation costs for the non-urban reforestation programs listed in Table 1 use the national average cost per acre of $511/acre from Fargione *et al.* 2021 across all non-urban land ownerships and implementing agencies.[4] The acre-based carbon accumulation coefficients for non-urban reforestation are national averages from Cook-Patton *et al.* 2020 and the Reforestation Hub and are landowner-type specific.[5] For example, reforestation funded through the REPLANT Act uses the carbon accumulation rate specific to USDA Forest Service (USFS)-owned lands (1.2 mtCO_2e/acre/year) because that spending will go to implementation on USFS land. This assessment assumes that trees accumulate carbon in the year they are planted as well as future years. For this reason, annual carbon accumulation estimates are based on the current and previous years' acres planting, starting in 2022. The implementation cost assumptions for urban forestry uses the inflation-adjusted cost identified in Kroeger *et al.* 2015 ($45.50/tree for year-one planting and maintenance) and a national tree-based carbon accumulation rate derived from the Reforestation Hub's data (0.005 mtCO_2e/tree/year).[6] Therefore, the negative emissions estimates are national averages, regionally weighted based on land ownership, implementation opportunity, and, in some cases, co-

[4] Fargione *et. al*. Challenges to the Reforestation Pipeline in the United States. Frontiers in Forests and Global Change. 04 February 2021.

[5] Reforestation Hub and supplemental data. Available online: https://www.reforestationhub.org/.

Cook-Patton, S. *et. al.* Lower cost and more feasible options to restore forest cover in the contiguous United States for climate mitigation. One Earth 3, 739-752. 18 December 2020.

[6] Kroeger *et. al*. Where the people are: Current trends and future potential targeted investments in urban trees for PM10 and temperature mitigation in 27 US Cities. Supplementary information. Landscape and Urban Planning 177 (2018) 277-240. 26 May 2018.

Reforestation Hub

benefits. Additional assumptions for reforestation expenditures:

REPLANT Act: The Repairing Existing Public Land by Adding Necessary Trees (REPLANT) Act (H.R. 2049/S. 866) would remove the $30M annual spending cap from the Reforestation Trust Fund. This would allow the entire annual Fund amount, which averages $123M annually, to be spent on public lands reforestation. The REPLANT Act has been incorporated into the Infrastructure Investment and Jobs Act. Our analysis assumes an additional $90M/year is added to the Trust Fund and that these funds are spent on the reforestation and restocking of Forest Service lands, as stipulated by Reforestation Trust Fund requirements.

Infrastructure Investment and Jobs Act: This analysis includes two line-item budget allocations for post-fire rehabilitation that represent increases over current funding levels, one to USFS ($45M/year) and one to the Department of Interior (DOI) ($45M/year). In the legislative text, these allocations would remain in place for five years, but we assume this level of supplemental funding extends through 2030. We further assume that a portion of these funds is spent on the reforestation and restocking of federally owned and tribal lands, as permitted under existing programs at USFS and DOI.[7] Specifically, given the breadth of activities funded under those programs, this analysis assumes that 25% of each ($11.25M/year) will be spent on reforestation.

Reforestation additions in Reconciliation: The proposed reconciliation budget includes a suite of investments for forest restoration, climate resilience, and carbon sequestration on non-federal forestlands. This includes four, ten-year allocations of $250M each to climate mitigation and forest resilience programs that can be expected to yield carbon sequestration benefits from reforestation. We assume that 75% of funds are spent on private lands reforestation annually, 2022-2031, with the remainder spent on activities not included in our model. The proposal also includes a 10-year allocation of $500M for payments to private forestland owners who implement practices to increase carbon sequestration. Of this, we assume 25% annually goes to reforestation.[8] Finally, the proposal includes a 10-year, $9B allocation for forest restoration and resilience on non-federal lands. We assume 25% annually is spent on reforestation. We use the Reforestation Hub data's average annual carbon accumulation rate for non-federal lands that have ecosystem service benefits (wildlife corridor, floodplain, post-burn rehab, stream buffers) of 2.415 $mtCO_2e$/acre/year, multiplied by the total annual reforestation acreage across these programs.

Civilian Climate Corps: The Natural Resources and Agriculture committees have proposed allocations to a Civilian Climate Corps (CCC). The House Natural Resources Committee called for a ten-year allocation of $3B, with another $500M for a Tribal CCC. We assume that 20% will be spent on reforestation annually, as the CCC will be tasked with a wide range of duties. Agriculture is calling for a ten-year, $2.25B allocation to CCC for work on National Forest System lands, and a ten-year, $2.25B allocation to CCC for non-Federal lands. We assume higher percentages of spending on reforestation for programs through Agriculture, given the focus on forest restoration and reforestation. We assume 50% of CCC funds for National Forest System lands goes to reforestation. We also assume that one-third of CCC funds for non-federal lands are used for reforestation of rural forests and one-third on urban reforestation. We use the landowner-specific carbon accumulation rates from Reforestation Hub data for rural forests, and the urban forest carbon accumulation rate of 0.005 $mtCO_2e$/tree/year for urban tree planting.

Urban Forests: New funding for expansion and management of urban forests is included in proposed

[7] This analysis assumes that the funds would flow through the Burned Area Rehabilitation Program at DOI and to burned area recovery activities at USFS.

[8] The remainder of the grant funds would, presumably, go to changes in forest management that improve carbon sequestration rates. These carbon removal benefits are not included in this model, due to uncertainties as to the regional distribution of grant funds and the associated GHG mitigation benefits.

legislation and other spending in the budget bills. The reconciliation bill includes a ten-year, $3B allocation to expand urban tree investment. We assume that all these funds would go directly to urban afforestation at the rate of $300M/year. The Infrastructure Investment and Jobs Act includes a new program, Healthy Streets, which would fund activities to reduce urban heat island (UHI) effects. The program is initially budgeted at $100M for one year, but we assume here that the program and its funding extend, at that level, through 2030. Eligible activities include installing cool pavement and increasing urban tree canopy (i.e., tree planting and maintenance). We assume here that 40% of program funds are used for urban tree planting and maintenance. Our analysis only includes the carbon sequestration impact of trees planted, i.e., not the building energy efficiency gains that can be expected with strategically placed trees and other vegetation.

The Trees for Residential Energy and Economic Savings (TREES) Act (H.R. 3522/S. 1782) would establish a new funding source, managed by the Department of Energy in consultation with USDA and USFS, that plants trees to improve building energy efficiency and reduce UHI effects, particularly in communities of need and low-canopy areas. The bill includes proposed appropriations of $50M/year through 2026; we make the additional assumption that these funds extend through 2030. We assume here that 75% of funding is directed to tree planting. Again, our analysis includes only the carbon sequestration impact of trees planted.

Agricultural Conservation Practices

The costs and GHG mitigation impact of implementing conservation practices on agricultural lands draws on the literature, USDA program data, and expert opinion. This assessment looks at the impact of additional, beyond-baseline funding to four USDA programs proposed for the Reconciliation bill, as part of a broader, $28B investment in climate-smart agriculture: the Environmental Quality Incentives Program (EQIP), the Conservation Stewardship Program (CSP), the Regional Conservation Partnership Program (RCPP), and a separate line-item for expanded use of cover crops. Annual allocations have been proposed for FY22-26; our analysis assumes that FY26 spend levels are maintained through 2030.[9] The proposal language prioritizes GHG mitigation and carbon sequestration. We assumed that funds will be spent on carbon removal through implementation of climate-smart agricultural practices related to land management. This approach is supported by major bills that have been proposed to reduce GHG emissions from agriculture and increase carbon sequestration on agricultural lands, forestlands, and coastal wetlands. The Agriculture Resilience Act (H.R. 2803/S. 1337) calls for transformational change in the agricultural sector, culminating in a 50% reduction net GHGs from 2010 levels by 2030 and net zero emissions by 2040. The Climate Stewardship Act (S. 1072/H.R. 2534) proposes to more than double funding for landowner incentive programs administered through the U.S. Department of Agriculture (USDA) and to direct that funding to climate-smart agriculture and forestry practices. This approach should be modified if the allocations ultimately support GHG reductions in the agriculture sector, such as methane mitigation.

This model treats grants via EQIP, CSP, and the proposed cover crops program as annual, practice-based payments: practices must be paid for with program funds each year, meaning acres do not accumulate carbon sequestration over time in this model. This is consistent with how EQIP and CSP are administered but may be conservative. Some producers continue to use land management and restoration practices once their USDA contract period ends, while others discontinue practices. The estimation approach also assumes that agricultural operators are converting from traditional (non-conservation) practices to conservation practices, consistent with USDA

[9] This analysis excludes proposed funding for agricultural and forestland conservation, although those activities are expected to result in avoided GHG emissions and ongoing carbon sequestration on those lands. Note that the assumption that program funds will continue at their FY26 level through 2030 adds significant funds to these climate-smart agriculture programs. Therefore, this should not be misconstrued as an analysis of the bills before Congress.

estimations of GHG mitigation benefits from conservation practice implementation.

We treat the RCPP differently. We assume those allocations will support implementation of restoration projects that are, by design, durable over time (particularly within the relatively short-term window of 2022-2030). The RCPP has historically targeted restoration, as opposed to annual operational management. As with the programs focused on operational improvements for soil health, program design will impact expected carbon removal.

We assume that the allocation for both EQIP and CSP goes to farm, ranch, and forest land management activities that USDA has determined to have GHG mitigation benefits. This includes 30 practices, identified by their NRCS Conservation Practice Standard (CPS) numbers, plus biochar. This exclusive spending focus on climate-smart agriculture is a notable departure from current program spending but is written into the legislative proposals and is aligned with recent USDA prioritization of climate-smart agriculture for EQIP and other producer grant programs.[10]

For EQIP and CSP, we assume that the proportion of funding used for grants to landowners and managers is consistent with EQIP's historical share of total program funding (73%).[11] We assume the balance goes to technical assistance and program administration. Those activities are essential to program success and likely contribute to negative emissions but are excluded from the carbon removal quantification because it is difficult to tie expenditures to specific outcomes. The new funds are allocated to each CPS based on its percentage of historical adoption within that set. Historically, within the set of climate-smart practices, approximately 83% of funds have gone to the following eight CPS: cover crops (CPS 340), forage and biomass planting (512), nutrient management (590), prescribed grazing (528), residue and tillage management (329), forest stand improvement (666), tree and shrub establishment (612), and conservation crop rotation (328). These practices result in approximately 90% of our model's carbon removal from EQIP and CSP investments. We use national average implementation costs of each CPS to determine acre-based implementation across practices. We estimated costs from USDA's 2021 state payment schedules (national implementation payment rates do not exist). State-level program implementation costs will vary from this national average. The national GHG mitigation rates are drawn from the literature and expert opinion and assume that operators are converting from traditional practices to conservation practices. These, too, will vary from downscaled results derived from USDA models such as COMET-Planner.

The approach to estimating GHG mitigation from use of cover crops is more straightforward. We assume a payment of $25/acre, as stipulated in the legislative proposal, and assume that 100% of the annual allocation goes directly to implementation. We use the same carbon accumulation rate for the EQIP and CSP programs (0.5 mtCO_2e/acre/year). Note that a payment of $25/acre is approximately half the average EQIP rate. This implies that this program will have to achieve major cost-efficiencies or target a segment of agricultural operators with below-average implementation costs.

The carbon removal estimate for the RCPP operates under the assumption that the proposed allocation is used to fund restoration-oriented carbon removal practices, namely, reforestation and restoration of grassland, riparian buffers, and other practices that are collectively labeled "conservation cover." We identified conservation cover practices from the suite of practices funded through the Conservation Reserve Program. We

[10] US Department of Agriculture. Natural Resources Conservation Service. Environmental Quality and Incentives Program Pilots for 2021. Available online: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/.

[11] US Department of Agriculture. NRCS Conservation Programs Environmental Quality Incentives Program (EQIP). 24 February 2021. Available online: https://www.nrcs.usda.gov/Internet/NRCS_RCA/reports/fb08_cp_eqip.html.

assume that this program continues to fund multi-stakeholder project planning, such that two-thirds of annual funds go to implementation. As with EQIP and CSP, we model only funds spent on direct implementation. We further assume that 75% of implementation funds go to reforestation, and 25% go to restoration of conservation cover. We use the average annual carbon accumulation rate for reforestation on non-federal lands with ecosystem service benefits from Reforestation Hub data (2.4 $mtCO_2e$/acre/year). We use the same annual average carbon mitigation coefficient as was used for EQIP's conservation cover practice for conservation cover (1.8 $mtCO_2e$/acre/year). We assume that practices implemented in prior years, beginning in 2022, continue to generate carbon removal benefits in later years without additional payment. In other words, acre-specific carbon removal benefits to this program are cumulative and grow over time. We use the national average reforestation cost per acre of $511/acre from Fargione *et al.* 2021 to estimate reforested acreage and the EQIP cost for conservation cover to estimate those acres implemented.

Executive action

Our executive action component assumes that the Biden administration uses its authority to direct a portion of Commodity Credit Corporation (CCC) discretionary funds to support implementation of climate-smart agriculture and forestry practices on private lands and that those expenditures continue through 2030. We estimate these investments to result in a change to net flux of -177 MMT CO2e in 2030. The CCC funds activities and programs through congressional appropriations (e.g., Farm Bill appropriations to USDA), and its borrowing authority can also be used to fund administrative priorities that fit within the permitted uses of the funds.[12] Using CCC to increase the scale of agricultural conservation programs is consistent with statements from the administration and is supported by a diverse and bipartisan set of key stakeholders.[13] The USDA recently posted a Request for Information regarding a Climate Smart Agriculture and Forestry Program that would be developed under the CCC Charter Act of 1933, underscoring the possibility of using CCC to fund on-the-ground investments in GHG mitigation from forestry and agriculture.[14]

This estimate assumes that the Biden administration directs the USDA to allocate $1B to activities that deliver increased carbon sequestration on the landscape in 2022 and that spending ramps up $1B/year through 2030. Discretionary use of CCC is capped at $30 billion/year and ballooned in 2018-2020 relative to prior levels.[15] These funds could be spent through existing USDA grant programs that generate carbon sequestration, such as EQIP. Funds could also be spent as loans, price support, price guarantees, or any other financial incentive or support within the scope of CCC to increase cost-effectiveness and have the largest possible impact. This approach could be considered a proxy for the federal "carbon bank" concept that is the subject of much interest and speculation. The recent Request for Information suggests that USDA is taking a

[12] Stubbs, Megan. The Commodity Credit Corporation (CCC). Congressional Research Service. R44606. Updated 14 January 2021.

[13] Climate 21 Project: USDA Recommendations. November 2020. Available online: https://climate21.org/;
Abbott, Chuck. Vilsack Says a Carbon Bank Fits Into USDA's Portfolio. Successful Farming. March 23, 2021. Available online: https://www.agriculture.com/news/business/vilsack-says-a-carbon-bank-fits-into-usda-s-portfolio;
Food and Agriculture Climate Alliance Joint Policy Recommendations (2021). Available online: https://agclimatealliance.com/.

[14] Bipartisan Policy Center. Natural Carbon Solutions in US Farms and Forests: Building a Policy Agenda for Congressional Action. July 30, 2020. Available online: https://bipartisanpolicy.org/report/natural-carbon-solutions-in-u-s-farms-and-forests-building-a-policy-agenda-for-congressional-action/.
Agree Climate Food + Ag Dialogue. USDA National Climate Bank - Concept Note. Available online: https://climatefoodag.org/usda-national-climate-bank/; US Department of Agriculture. Notice for Public Comment: Climate-Smart Agriculture and Forestry Partnership Program. Federal Register No. 2021-21368. Posted Sep. 30, 2021. Available online: https://www.regulations.gov/document/USDA-2021-0010-0001.

[15] Stubbs 2021

broad view of possibilities in this space and that GHG benefits will be tied to agricultural and forestry products. We assume that the CCC's enabling statute will constrain USDA's flexibility in program design.

This estimate assumes that USDA can facilitate carbon removal at an average cost of $51/Mt CO2e. This average cost is equivalent to the U.S. social cost of carbon and leaves no shortage of available carbon sequestration, based on national opportunity estimates at varying marginal abatement costs.[16] Additional GHG reduction opportunities exist in the agriculture sector, such as methane and nitrous oxide emissions reductions. These are not included in this estimate, which focuses on carbon removal instead of GHG emission reduction, but underscores that opportunities for GHG mitigation in agriculture are vast. The source of increased carbon sequestration, i.e., whether it comes from agricultural and working forest land conservation, implementation of conservation practices on agricultural lands, afforestation, habitat restoration on agricultural lands, or improved forest management, depends on how USDA chooses to administer the funds. Nevertheless, peer-reviewed natural climate solutions opportunity sets indicate that this level of activity is well within ecological bounds.[17] An annual budget of $1B and an assumed cost of $51/mt CO2e would result in approximately 19.6 million mtCO2e of GHG mitigation each year (assuming each ton is paid for each year, in line with the assumptions used for EQIP and CSP). This is approximately 4.3% of the agricultural land management and reforestation opportunities identified in the literature,[18] and there are additional emission reduction opportunities from grassland and working forest conservation. These studies indicate that significant proportions of the total possible GHG mitigation could be purchased at costs below $51/ton, suggesting that there are opportunities to improve cost-effectiveness through program design and administration.

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[16] Fargione, J. *et. al.* Natural climate solutions for the United States. Science Advances Vol 4, No. 11. 14 November 2018.
Cook-Patton, S. *et. al.* Lower cost and more feasible options to restore forest cover in the contiguous United States for climate mitigation. One Earth 3, 739-752. 18 December 2020.
[17] *Ibid.*
Wade, C. *et. al.* "Projecting the Impact of Socioeconomic and Policy Factors on Greenhouse Gas Emissions and Carbon Sequestration in US Forestry and Agriculture." In press.
Griscom, B. *et. al.* Natural Climate Solutions. Proceedings of the National Academy of Sciences. 114 (44) 11645-11650. 16 October 2017.
[18] Using 221 mt CO2e/yr available at $50/ton from Cook-Patton and 232 mt CO2e/yr available at $50/ton from the Nature4Climate US State Mapper (data from Griscom *et. al.* 2017 and Fargione *et. al.* 2018) across the following mitigation pathways: grassland restoration, alley cropping, cover crops, cropland nutrient management, improved manure management, and improved rice cultivation.

TABLE 1

Congressional policies in the joint action scenario

Policy	Target Sector	Description
Clean electricity tax credits	Electric power	• $25/MWh or 30% ITC base credit values available to all new renewable technologies. • Must commence construction by 2034, with credit phasedowns beginning in 2032. • Bonus credit provides a 10% increase in the PTC value or an extra 10% to the ITC for technologies that meet domestic content requirements. • Direct pay is available for all projects that take tax credits
Nuclear support	Electric power	• $6 billion provided for FY22-26 for a civil nuclear credit program, through which nuclear plants bid to receive credits from DOE plants at risk of retirement • Up to $15/MWh provided for existing nuclear plants through 2031 via a new nuclear power production tax credit (45W)
Rural cooperative incentives	Electric power	• Rural Utility Service loan forgiveness incents the retirement of all remaining coal plants owned by electric coops by 2025.
Carbon capture tax credits	Electric power and industry	• $85 per ton of CO2 captured and sequestered via geologic storage • $35 per ton of CO2 captured and used in enhanced oil recovery • No absolute or percentage minimum capture thresholds • Credit extended through 2031 • Direct air capture receives $180 per ton of CO2 captured and sequestered via geologic storage
CCS demonstration and pilot projects	Power and Industry	• $3.5 billion in funding for carbon capture demonstration and pilot projects
EV tax credits	Transportation	• $4,000 base credit plus $3,500 battery capacity credit assumed for all EVs • $4,500 available credit for domestic final assembly and production in a facility operating with a collective bargaining agreement. Requirement for domestic final assembly to claim the credit after 2026 • $500 bonus credit for at least 50% domestic content • No manufacturer cap • Credit expires after 2031.
EV charging infrastructure	Transportation	• $7.5 billion in grants for EV charging infrastructure
Clean fuels tax credit	Transportation	• Existing biodiesel, renewable diesel, and alternative fuels tax credit extended through 2031. • $1.25/gallon of gasoline equivalent (gge) base sustainable aviation fuel credit plus up to another $0.50/gge in bonus credits for lifecycle GHG reductions over conventional jet fuel
Clean hydrogen production tax credit	Transportation and industry	• Up to $3/kg, scaled based on lifecycle GHG intensity, for production of clean hydrogen. • Available for up to 10 years after online date. Credit expires after 2028. • A facility cannot receive the H2 PTC and a payout under 45Q.

Programmatic efficiency spending in the infrastructure bill	Buildings	• $3.5 billion in funding in FY22 for WAP • $550 million in funding for a new EECBG • $500 million total in funding for SEP over FY22-FY26
Building efficiency tax credits	Buildings	• Non-business energy property credit (25C) expands to a 30% ITC with an annual limit of $1,200. • Residential energy efficient property credit (25D, for residential PV and other distributed renewables) is extended through 2034, with a phaseout beginning in 2032. • New energy efficiency home credit (45L) is extended through 2031 and levels are increased: ○ $2,500 credit for homes built to Energy Star Residential New Construction specs ○ $5,000 credit for homes built to Zero Energy Ready Homes specs
Electrification and efficiency grants	Buildings	• $8.5 billion for performance-based whole-home energy rebates, prioritized for electrification • $3.5 billion for high-efficiency electric home rebates
Orphaned mine and well remediation	Industry	• $11.3 billion for the Abandoned Mine Reclamation Fund to remediate abandoned coal mines. • $4.3 billion in grants to states for orphaned oil and gas well site remediation, plus $250 million in federal spending on federal and tribal lands.
Increased federal funding for natural climate solutions	Carbon removal	Policy (total spending increase over nine years, as modeled): • Reforestation via REPLANT Act ($810 million) • Reforestation in Infrastructure Investment and Jobs Act ($203 million) • Restoration and reforestation on non-federal lands via reconciliation ($2.4 billion) • Rural Reforestation via Civilian Climate Corps ($2.3 billion) • Urban Reforestation via CCC, TREES Act, Healthy Streets ($4.0 billion) • Agricultural conservation practices via Environmental Quality Incentives Program (EQIP) and Conservation Stewardship Program (CSP) ($24 billion) • Agricultural conservation, restoration practices via Regional Conservation Partnership Program (RCPP) ($15.2 billion) • Direct payment for cover crops ($9 billion)

TABLE 2

Executive branch actions in the joint action scenario

Policy	Target Sector	Description
New Source Performance Standards (NSPS) for electric generating units (EGUs)	Electric power	• No new fossil generators may be built in the US without meeting a CO2 emission rate equal to a 90% carbon capture rate starting in 2022.
Existing Source Performance Standards (ESPS) for EGUs	Electric power	• EPA adopts ESPS for CO_2 from all fossil fuel-fired power plants not subject to NSPS, with binding reduction requirements starting in 2026 • Applies the same methodology as the original CPP to generate emissions constraints, but using up-to-date input data. State plan compliance is assumed to be effective in 2026. Assumes all state plans are mass-based, decline steadily on an annual basis and provide for interstate credit trading
LDV GHG standards	Transportation	• New fuel economy standards take effect in 2023, declining linearly to a 90 g/mi target in 2030 for all new LDVs inclusive of off-cycle and A/C efficiency credits.
MDV & HDV GHG standards	Transportation	• New emissions standards for all new medium and heavy-duty vehicles that require a 50% faster annual improvement in new vehicle emissions rates than current standards, starting in 2028
NSPS for industrial sources	Industry	• EPA promulgates new source performance standards requiring 90% capture (or equivalent emission rate reductions) for facility-wide emissions for new chemical manufacturing facilities, liquified natural gas (LNG) import/export terminals, and refineries. These regulations come into effect in 2023-2024.
ESPS for industrial sources	Industry	• EPA promulgates existing source performance standards requiring emission reductions in line with the installation of carbon capture equipment on fluid catalytic crackers at most refineries, at ethylene oxide and methanol production facilities, and at existing LNG import/export terminals.
ESPS for methane from oil and gas production	Industry	• EPA adopts an ESPS on oil and gas production, processing, transmission, and distribution facilities not subject to the reinstated NSPS requiring frequent leak detection and repair, replacement of gas-driven pneumatic equipment, and other technology and operational changes. This policy is based on work from the Clean Air Task Force.
Minimum equipment performance standards	Buildings and industry	• DOE exercises Energy Policy and Conservation Act (as amended) authorities to adopt ambitious but achievable minimum efficiency standards for covered equipment by meeting statutory deadlines and prioritizing emissions reductions.
Climate-smart agriculture and forestry practices on private lands	Carbon removal	• The Biden administration uses its authority to direct a portion of Commodity Credit Corporation (CCC) discretionary funds to support implementation of climate-smart agriculture and forestry practices on private lands, reaching $9 billion in expenditures per year by 2030.

TABLE 3

Subnational policies in the joint action scenario

Policy	Target Sector	Description
Clean electricity standards (CES)	Electric power	• Leadership states (defined as members of the US Climate Alliance) establish or accelerate 100% clean electricity standards, reaching that target by 2035.
Utility clean power targets	Electric power	• Utilities with 100% clean energy targets accelerate target date of achievement to 2035.
LDV ZEV Mandate	Transportation	• Leadership states require 100% zero emission light-duty vehicle sales by 2035.
MDV/HDV ZEV Mandate	Transportation	• Leadership states require 100% zero emission medium-and heavy-duty vehicle sales by 2045
Low-carbon fuel standards (LCFS)	Transportation	• Leadership states adopt low carbon fuel standards that reducing carbon intensity of liquid fuels in the LDV sector by 20% over today's levels by 2030.
VMT management	Transportation	• Leadership states prioritize new congressional transportation infrastructure funding from the infrastructure bill explicitly toward reducing vehicle miles traveled.
Methane abatement	Agriculture and waste	• Leadership states establish and achieve targets that reduce agricultural and waste methane by 40% from 2013 levels by 2030.
N_2O abatement	Agriculture and waste	• Leadership states reduce N_2O via changes to crop management practices
EERS	Buildings	• Leadership states adopt and/or strengthen energy efficiency resource standards (EERS) to achieve 2.5% electricity savings and 1.25% natural gas savings annually.

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