Closing the Gap: Delivering on the U.S. Nationally Determined Contribution

Meeting the U.S. NDC Requires Swift Use of Several Existing Federal Authorities to Reduce Greenhouse Gas Emissions

April 2023

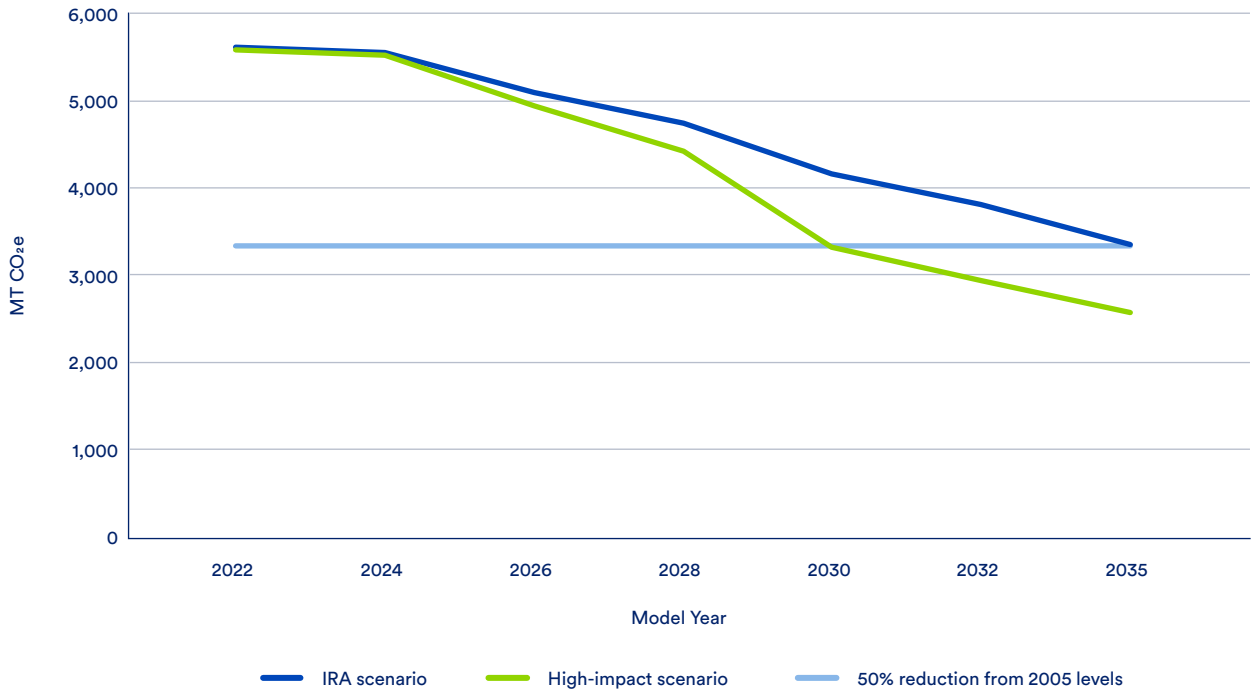
CLEAN AIR TASK FORCE

Summary

Swift U.S. action to reduce the U.S. contribution to greenhouse gas emissions is critical to keep global climate goals on track, advance domestic energy security, air quality, and economic competitiveness, and show leadership that can motivate other countries to take their own decisive climate actions. A fundamental aspect of this leadership requires the U.S. to stay on track to meet its Nationally Determined Contribution (NDC) to cut greenhouse gas emissions by 50-52% below 2005 levels by 2030. Despite the projected greenhouse gas reductions from the landmark Inflation Reduction Act (IRA) and Infrastructure Investment and Jobs Act (IIJA), the Princeton University REPEAT Project[1] estimates that in 2030 there will be a gap of 810 million tonnes CO_2e.

Figure 1: High Impact Rules Can Bridge the NDC Gap

Strong federal actions included in the CATF high impact scenario come close to meeting the NDC. Using existing federal authority to increase the carbon benefits from agriculture and forestry spending can close the NDC gap, as shown.



[1] Jenkins 2023

To keep the NDC goal within reach, the U.S. government must act with urgency over the next two years and take full advantage of existing Clean Air Act regulatory authority to control climate pollution. New analysis by Clean Air Task Force (CATF) performed by Evolved Energy Research (EER) and using the same modeling platform and assumptions as Princeton University's REPEAT Project finds that closing the gap will require strong rules to limit emissions from new and existing power plants, vehicles, industrial operations, and oil and gas production, which can provide the lion's share of the needed reductions. In addition, to completely close the gap, the federal government can use its existing authority to prioritize carbon sequestration and mitigation from agriculture and forestry investments. These actions, targeting the main areas of opportunity, are under the control of the Administration and can yield the tonnes needed to meet the NDC (Figure 1).[2] The modeled high impact scenario would also achieve an interim milestone of reaching 80% of U.S. power from emissions-free sources by 2030.

To the degree the estimated emissions reductions from the broad set of federal actions falls short of the needed ambition, the cuts in greenhouse gas emissions to meet the promised 50-52% NDC goal would have to be found elsewhere in the economy. This would mean turning to smaller-scale mitigation opportunities or measures that depend on bipartisan legislation or multi-state actions; reliance on such measures would increase the chances that the U.S. would fail to meet its NDC. Accordingly, CATF calls on the Biden Administration to expeditiously issue stringent Clean Air Act greenhouse gas regulations on power plants, vehicles, industrial operations, and oil and gas production and to utilize existing authorities to ensure agriculture and forestry expenditures prioritize climate impacts. These actions, which target the largest emitters, can be implemented under existing federal authority, and offer the best chance of success to meet the U.S. NDC.

[2] Other analysts have recently made similar recommendations. For example, Rhodium's recent note (King 2023) indicates bold federal action, including stringent standards on power plants and light-duty vehicles, is necessary for the U.S. to reach levels ranging from 41-51% below 2005 levels by 2030. Energy Innovation (Orvis 2022) runs an NDC Scenario assuming strong new federal regulations on the existing coal fleet in addition to federal regulations requiring new natural gas and coal plants to be equipped with carbon capture and sequestration and a national Clean Electricity Standard. The scenario also assumes stronger federal standards for industrial efficiency, high GWP gases, fugitive methane from oil and gas operations, new fugitive nitrous dioxide emissions, vehicle tailpipes, sales of zero-emission vehicles, and appliances.

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SECTION 1

The U.S. is committed to meeting an ambitious NDC

On Earth Day 2021, two months after the U.S. officially re-entered the Paris Agreement, President Biden communicated a new Nationally Determined Contribution (NDC) that would credibly put the U.S. on a path to reaching net-zero emissions by 2050. Specifically, the U.S. NDC sets an economy-wide target that calls for reducing its net greenhouse gas emissions by 50-52% below 2005 levels in 2030. The U.S. NDC, self-described as both ambitious and achievable through a whole-of-government approach, promotes achievement of the Paris Agreement's aim to limit the global average temperature increase to 1.5 degrees Celsius above pre-industrial levels.

NDCs are central to the Paris Agreement. Every Party to the Agreement commits to 1) establish an NDC that it intends to meet, laying out its plan to cut emissions and adapt to climate impacts, and 2) update the NDC every five years. NDCs are to reflect each Party's highest possible ambition, reflecting common but differentiated responsibilities and respective capabilities, in light of different national circumstances. To ensure that all Parties can fulfill these obligations, developing countries are given support to help implement their NDCs, recognizing that enhanced levels of support will allow for higher ambition.

Parties periodically take stock of the progress made and may push for higher ambition to reach the aims of the Agreement. Each new round of updates is expected to ratchet up ambition through steeper emissions cuts, ultimately putting the global goals within reach.

As made clear by the latest IPCC report (Sixth Assessment Report, AR6), the set of existing NDCs[3] is insufficient to meet the global goal of limiting warming to 1.5 or even 2 degrees Celsius. To keep 1.5 degrees in reach with no or limited overshoot with a greater than 50% chance, Parties must strengthen NDCs such that global greenhouse gas emissions peak before 2025, are reduced 43% by 2030 relative to 2019 levels, and drive toward net-zero levels by the early 2050s.

As the world's largest economy and second largest emitter of greenhouse gases,[4] it will be important for the U.S. to not just make ambitious pledges consistent with the need for deep global reductions this decade, but to demonstrate it is on track to meet its commitments. Failure to follow through will also make it much more difficult to convince other countries to keep their promises and continue to increase their ambition. The U.S. is off to a strong start: by providing durable new funding for a range of climate mitigation measures, the IIJA and IRA promise to deliver a substantial down payment on U.S. climate action and demonstrate the government's commitment to fulfill its promises. But to meet its commitments and exhibit global leadership, it is critical the U.S. deliver the rest of the NDC goal and accomplish the needed emission reductions.

[3] The IPCC studied the impact of NDCs announced prior to COP26.

[4] Measured as total emissions per year

SECTION 2

Existing government actions, while unprecedented, fall short

In 2022, President Biden signed the IRA, the most ambitious climate law ever passed in the United States. IRA uses a combination of tax credits, grants, loans, pollution fees and other approaches to advance a broad set of tools needed to reach climate goals, including wind and solar, nuclear energy, carbon capture and storage, geothermal energy, zero-carbon fuels, and methane abatement, among many others. This was on top of the IIJA, which also directed substantial new funds to clean energy infrastructure.

Various analysts, including Princeton University's REPEAT Project,[5] have assessed the impact of IRA provisions on greenhouse gas emissions. According to the REPEAT Project final estimates of IRA's emissions impact[6] relative to a business-as-usual scenario that includes IIJA, IRA is estimated to reduce U.S. greenhouse gas emissions by roughly 0.5 to 0.8 billion tonnes, reaching an overall reduction in greenhouse gas emissions of 37-41% below 2005 levels in 2030 (Figure 2).[7] This is similar to results from Energy Innovation[8] and Rhodium Group.[9] Even at the most optimistic end of the range, IRA still leaves the U.S. more than 630 million tonnes short of its NDC goal. In the IRA middle case, the gap is estimated at close to 810 MT.

5 The REPEAT project employs geospatial planning and analysis tools coupled with detailed macro-energy system optimization models to rapidly evaluate federal policy and regulatory proposals at politically-relevant spatial resolutions (e.g., state, county, and finer resolutions).

6 Relative to the preliminary REPEAT Project estimates, the final analysis captures constraints on supply chains and other factors that are expected to limit the rate of deployment of key technologies, including electric vehicle sales and wind and solar power. The final analysis estimates a slower start to the energy system transformation under IRA than did the earlier preliminary results reported in August 2022.

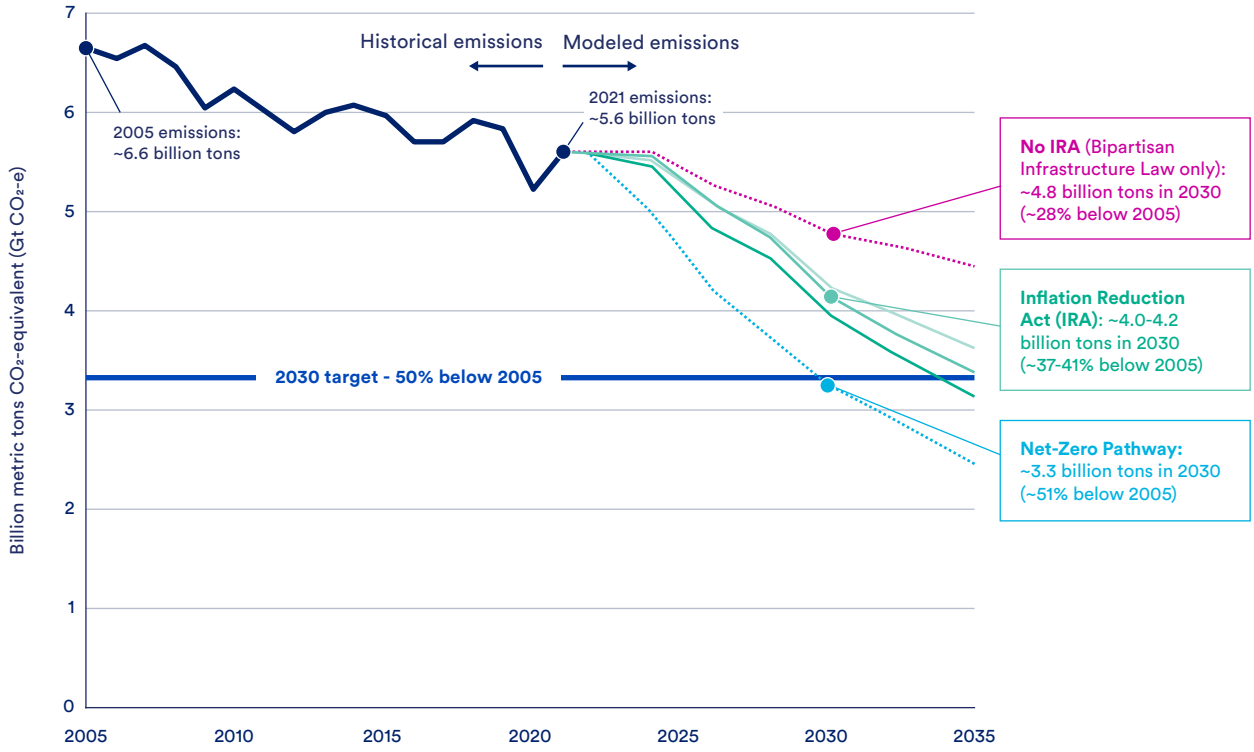
7 The range reflects conservative, middle, and optimistic estimates regarding the effectiveness of IRA provisions and the potential impacts of constraints on supply chains and other rate-limiting factors.

8 Mahajan 2022

9 Larsen 2022

Figure 2: Historical and Modeled Net U.S. Greenhouse Gas Emissions (Including Land Carbon Sinks)
Billion Tonnes CO_2-Equivalent (Gt CO_2e)

Source: Jenkins 2023 (slide 5)



SECTION 3

The REPEAT Project identifies opportunities for closing the NDC gap

By considering how the mitigation opportunities used in the different REPEAT Project IRA scenarios differ from those used to meet a net-zero scenario that fully achieves the NDC in 2030, it is possible to get a sense of the lowest cost mitigation opportunities that might be available to close the NDC gap (see Figure 3, below).

Under all three IRA scenarios (i.e., conservative, middle, and optimistic), the power sector presents the most important greenhouse gas mitigation opportunity to close the NDC gap, amounting to between 490 and 560 MT. While this may seem surprising given the strong IRA incentives to deploy new carbon-free electric generating technologies, it is notable that IRA does not mandate reductions in emissions from existing fossil-fired power plants. Therefore, even with IRA, considerable opportunity remains to lower emissions from existing coal- and natural gas-fired power generation. Reductions in non-CO_2 greenhouse gases — principally methane — (140-190 MT) and industry sector mitigation measures (100-120 MT) also present meaningful mitigation opportunities across all three IRA scenarios to help close the NDC gap. The comparison between the IRA scenarios and the net-zero scenario pathway indicates that significant opportunities may also be available through additional investments in land carbon sinks[10] and mitigation of emissions from internal combustion engines through improvements in vehicle fuel efficiency.[11]

For a fuller assessment of opportunities for carbon removals and emission mitigation in the agriculture and forestry sector, CATF consulted a recent meta-analysis by Environmental Defense Fund (EDF) and ICF that quantified the opportunity and cost of achieving a wide set of measures by 2030.[12] This study compiled information in the literature and other well-cited reports to develop an estimate of ambitious but achievable measures that could help reach the NDC by 2030. This is the same study that was used in the REPEAT Project's final estimates of net emissions reductions from agriculture and forestry that could be achieved through IRA. Therefore, considering the 560 MT of CO_2e deemed ambitious but achievable in the meta-analysis (see Table 1), we can directly subtract the total agriculture and forestry sector net emissions reductions found to be encouraged by IRA (111 MT), resulting in a remaining mitigation potential of 449 MT.

[10] We note that different methods were used in the IRA and net zero scenarios to estimate the amount of land carbon sinks that might be taken up on an economic basis. The IRA scenarios make use of a cost curve developed from the literature and described in Eagle 2022. As discussed in more detail below, the number of land carbon sinks that could still be available through 2030 after IRA could be considerably higher than what is shown as the difference between the IRA and net zero scenarios.

[11] The gap between IRA and the net zero scenario likely underestimates the mitigation potential available from vehicles in 2030 due to the net zero scenario assuming no required improvements in the efficiency of new ICE sales after 2026.

[12] Eagle 2022

Figure 3: Difference in Sectoral Emissions VS Net Zero Pathway, in Million Tonnes CO_2-Equivalent (MT CO_2e)

Source: Jenkins 2023 (slide 8)

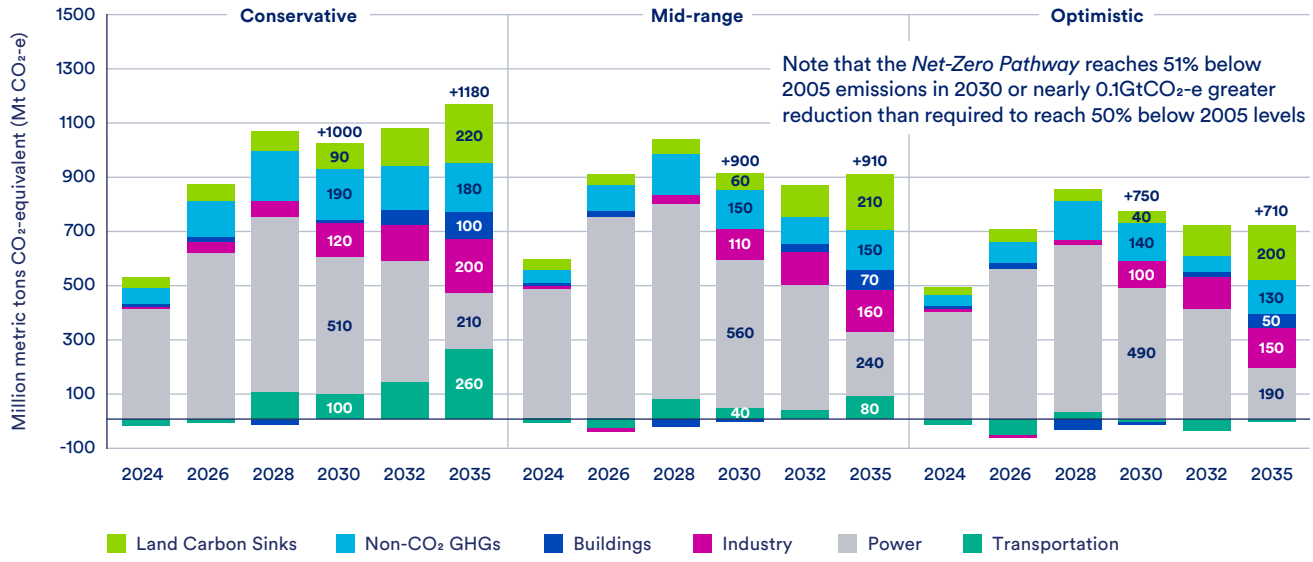


Table 1: Net Emission Reduction Targets in 2030 For Specific Mitigation Practices in the Agriculture and Forestry Sectors

Source: Eagle 2022

Greenhouse Gas	Mitigation Opportuntiy	MMT CO_2e	MMT Methane
Carbon dioxide emission reductions	Reduced demand for fertilizer (ammonia production)	6.9	–
	Reduced on-farm fossil fuel combusion	6.9	–
	Reduced on-farm electricity use	2.8	–
	Avoided conversion of forest, grassland, and wetland to cropland	55	–
	Avoided conversion of forests to settlements	63	–
	Total	**135**	–
Methane emission reductions	Reduced entreric methane emissions	34	1.4
	Reduced manure methane	25	1
	Reduced rice methane	4	0.16
	Total	**63**	**2.5**
Nitrous oxide emission reductions	Reduced soil nitrogen management nitrous oxide (fertilizer etc.)	27	–
	Reduced manure managment nitrous oxide	4.8	–
	Total	**32**	–
Carbon dioxide removals and avoided emissions	Reforestation	150	–
	Improved forest managment	100	–
	Agroforestry	80	–
	Total	**330**	–
GRAND TOTAL		**560**	**2.5**

SECTION 4

Strong actions required by the Clean Air Act and new measures to increase the carbon benefits from federal agriculture and forestry spending can meet the NDC

The Clean Air Act requires the Environmental Protection Agency (EPA)" to regulate dangerous climate pollution commensurate with the best controls available. By acting swiftly to enact the required regulations and prioritizing the largest emitters, not only will the Administration fulfill its obligations under the law, but it will also come closer to meeting its NDC commitment.

Text Box 1: Elements of the High Impact Scenario

Strong power sector rules under section 111 of the Clean Air Act

- 111(b) New Source Performance Standards for new natural gas-fired power plants
- 111(d) Existing Source Performance Standards for existing coal- and natural gas-fired power plants

Strong rules regulating methane emissions from upstream oil and gas operations[13]

- 111(b) New Source Performance Standards
- 111(d) Existing Source Performance Standards

Strong rules regulating greenhouse gas emissions from large industrial sectors

- 111(b) New Source Performance Standards[14]
- 111(d) Existing Source Performance Standards

Strong rules aimed at further reducing emissions in the transportation sector

- Fuel efficiency standards for internal combustion engine vehicles
- Emission rate standards consistent with California ZEV standards for light duty, medium duty and heavy duty vehicles

[13] Includes oil and natural gas well sites, natural gas gathering and boosting compressor stations, natural gas processing, and transmission and storage.

[14] Note that this analysis only assesses emissions reductions from existing industrial sources in the ethanol, cement, LNG, refinery (both crackers, FCCU, and steam methane reformation, SMR), iron and steel, and pulp and paper sectors. New source standards would need to precede or accompany the existing source standards.

Building on the REPEAT Project's "middle" IRA scenario and targeting the most meaningful remaining mitigation opportunities identified in the REPEAT gap analysis (Figure 3), CATF evaluated possible emissions reductions in 2030 that could be achieved through fulsome use of existing Clean Air Act regulatory authority (Text Box 1) considering technologies and resulting emission standards that are not only justified, but required, under the relevant statutory requirements. We undertook a new "high impact" policy scenario using the RIO- and EnergyPATHWAYS modeling platforms incorporating impactful power sector and transportation measures. Using the resulting fuel consumption data, we used our in-house methane projection model to estimate the impact of strong methane mitigation measures in the oil and gas sector. Considering the industrial sector greenhouse gas emissions in RIO-PATHWAYS, we estimated the potential impacts of strong industrial sector climate regulations. The components of our "high impact" Clean Air Act regulatory scenario are described in more detail in Annex 1.

We found the suite of strong Clean Air Act regulatory measures evaluated in the high impact scenario could reduce greenhouse gas emissions by 764 million tonnes in 2030 (see Table 2), yielding an overall 49% reduction in greenhouse gas emissions as compared to 2005 levels—**just 46 million tonnes shy of the NDC target**.

Table 2: Additional CO_2e Reduced in the High Impact Scenario Plus Agriculture and Forestry Measures to Close the NDC Gap

Sector	MT CO_2 Reduced or Sequestered	MT CH_4 Reduced	MT CO_2e Reduced or Sequestered
Power	267		267
Transportation	77		77
Industry	326		326
Cement	*84*		*84*
Ethanol	*5*		*5*
Iron and Steel	*66*		*66*
LNG	*21*		*21*
Pulp and Paper	*63*		*63*
Refining	*87*		*87*
Oil and Gas		3.5	94[15]
Total High Impact Scenario	**670**	**3.5**	**764**
Agriculture and Forestry	46		46
Total Federal Actions to Close the NDC Gap	**716**	**3.5**	**810**

[15] CO_2e figures are calculated using the 100-year global warming potential (GWP) for non-fossil methane from the IPCC's Fifth Assessment Report (AR5), consistent with U.S. inventories. Using the 100-year GWP for methane significantly underestimates the climate benefits of substantial methane mitigation that would occur over the next few decades (2030-2050), but we use these figures here for consistency with U.S. Government inventories and analyses. We expect the 100-year GWP to be adjusted over the coming years to reflect more recent assessments by the IPCC and the higher climate impact of methane originating from fossil sources such as oil and natural gas.

The EDF/ICF study noted above estimated that the agriculture and forestry sectors could potentially deliver an estimated 449 MT in carbon emissions reductions and carbon removals by 2030. To fully achieve the NDC goal, the Biden administration should also pursue opportunities to mitigate emissions and enhance sequestration by prioritizing climate mitigation in federal spending programs for land management and conservation. If EPA regulations secure the emissions reductions we estimate they can through impactful standards in the power, transportation, oil and gas, and industry sectors, as shown in Table 2, an additional 46 MT in emissions reductions from agriculture and forestry in 2030 would reach the U.S. NDC. Considering the cost curves from the EDF/ICF study and assuming the most cost-effective measures are prioritized, these gap-closing tons would cost an estimated $460M—a fraction of current conservation spending.[16]

While 46 MT would be sufficient to close the NDC gap estimated here, given the large opportunity and relatively low cost of land-based climate mitigation measures, Congress should target funding in the reauthorization of the Farm Bill to achieve even larger carbon benefits in the agriculture and forestry sectors. In doing so, USDA can ramp-up emissions reductions and removals to reach the estimated technical potential for climate mitigation in agriculture and forestry over time. Greater investment would provide a hedge against the risk of technologies, policies, and investments performing below their estimated targets, including in the land sector itself. By increasing the investment in climate mitigation in the agriculture and forestry sectors, more private landowners can benefit from climate-related federal spending programs and payments for climate-smart practices can also improve soil health and help these sectors adapt or become more resilient to the impacts of climate change that are expected to continue.

Enhancing the climate mitigation benefits in the agriculture and forestry sectors can be achieved by using existing federal authority available through conservation and commodity programs. For example, the Department of Agriculture could expand the existing Climate Smart Commodities program[17] and further prioritize climate mitigation in current spending programs that are up for reauthorization in the 2023 Farm Bill including, the Regional Conservation Partnership Program (RCPP), the Environmental Quality Incentives Program (EQIP), the Conservation Stewardship Program (CSP), the Conservation Reserve Program (CRP), and the Agricultural Conservation Easement Program (ACEP).[18] To generate larger emissions reductions and carbon removals through the 2023 Farm Bill, Congress should:

1. Maintain current IRA and Farm Bill conservation title funding levels.
2. Streamline the NRCS process for making funds available to achieve more near-term emissions reductions and removals.
3. Target more funding in the existing Farm Bill programs to climate-smart practices.
4. Increase data collection efforts and use that information to update USDA's estimated greenhouse gas benefits of agricultural and forestry practices and reduce uncertainty in accounting for land emissions and removals.

For more details, see CATF's recommendations for the 2023 Farm Bill.

[16] Spending on Farm Bill stewardship practices, not including IRA spending, is $6B per year (Faber 2022).

[17] According to the USDA, the first two funding pools of the Climate Smart Commodities Program are estimated to achieve 60 MT over the lives of the projects.

[18] As highlighted in Faber 2022, much of the spending on Farm Bill stewardship practices goes towards measures that are not aimed at reducing greenhouse gases or increasing carbon sequestration, and in some cases, the spending does the opposite

SECTION 5

Additional actions that can help realize the NDC, including some that go beyond existing federal authority and opportunity

CATF's high impact scenario coupled with measures to prioritize climate mitigation and sequestration in existing conservation and commodity programs described in Section 4 of this report shows a pathway to meet the U.S. NDC through aggressive federal action targeting major mitigation opportunities where there is not only federal authority, but federal duty. In the event that some of those rulemaking authorities are not used to the extent modeled, additional tonnes of emissions reductions would be needed from other emissions sources. One pathway for additional reductions would be to capture more of the extensive mitigation and sequestration opportunity from the agriculture and forestry sector. Heavy reliance on agriculture and forestry measures would likely require new funding through the Farm Bill or other legislation. Beyond such measures, in this section (Text Box 2), we present a short menu of additional actions (not fully characterized) that could help close the NDC gap. Some of these measures will require new legislation while others rely on actions by independent agencies or state and local governments.

Text Box 2: Menu of Additional Mitigation Actions

Permitting reform. Permitting reform and FERC policy have a key role in determining whether the power sector mitigation incentives realize a low, medium or high level of ambition, and are key factors in the REPEAT Project's estimates of conservative, middle, and optimistic impact. The REPEAT Project identified that accelerating the siting of clean energy infrastructure, for example, through permitting reform and FERC policy, could yield more mitigation opportunity from the electric power sector, potentially equivalent to the difference in power sector emissions reduced between the IRA middle and optimistic scenarios (70 MT).[19]

Electrification and building efficiency. Except for certain federal buildings, state and local governments have authority over building standards. High electrification building standards (e.g., heat pumps) could realize 20 MT in 2030 and 65 MT by 2035.[20] Federal appliance standards reducing electricity and natural gas use could achieve an additional 13 MT in 2030.[21]

[19] Jenkins 2023 (slide 8)

[20] Reflects the rate of new home construction in EER's model and the fact that much of that construction is in warm climates where the benefits are lower.

[21] Estimated emissions reductions were calculated using projected energy savings from the Appliance Standards Awareness Project and forecasted emissions rates derived from the High Impact Scenario model run.

Aviation sector mitigation. In 2021, the U.S. aviation sector was responsible for 205.3 MT CO_2. The U.S. government set a goal to produce 3B gallons of sustainable aviation fuel (SAF) by 2030.[22] Based on 2019 emissions[23] and fuel[24] data and considering that SAF has a greenhouse gas reduction potential of 73-99%,[25] this could amount to an estimated 25-33 MT of CO_2e reduced from the aviation sector. Additional progress towards the administration's goal could be realized by fully funding the Aviation Emissions Reduction Opportunity (AERO) Act or by extending the IRA tax credits past 2027.[26]

Reducing emissions from rail. According to EPA's most recent draft inventory, the rail sector accounts for 32.1 MT in 2021. California is deliberating regulations for in-use locomotives that would facilitate the transition to zero-emission locomotives.

Reducing methane from solid waste management. According to EPA's most recent draft inventory, landfills and composting account for 127 MT CO_2e in 2021 from methane and N_2O. States and localities have control over waste management decisions. A study that looked at the mitigation impacts in 2030 of over 30 states adopting more ambitious policies aimed at reducing landfill methane emissions found emissions reductions of roughly 8 MT CO_2e, assuming a 100-year global warming potential.[27,28]

22 https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge

23 U.S. Environmental Protection Agency 2023, Table 3-13

24 U.S. Department of Energy 2022, p.1

25 According to O'Rear 2022, sustainable aviation fuels can achieve a greenhouse gas reduction of 73-99%, however, the most mature pathway falls at the lower end of that range.

26 The AERO Act provides grant funding for projects that produce, transport, blend, or store SAF and projects that develop, demonstrate, or apply low-emission aviation technologies. IRA tax credits for SAF are assumed to have no impact on emissions in 2030 as they expire in 2027 and the credits apply to a single calendar year.

27 Zhao 2022

28 The modeling assumed that 20 "first mover" states would adopt high ambition waste diversion policies similar to California's SB1383 regulation, which aims to reduce organic waste landfill disposal by 75% from 2014 levels by 2025, and implement policies to capture and repurpose landfill gas, while eleven "fast follower" states and the District of Columbia would adopt moderate ambition waste diversion.

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Annex 1

Description of the CATF High-Impact Scenario

The CATF high-impact scenario seeks to illustrate how fulsome use of existing authorities can help the U.S. reach a 50% reduction in greenhouse gas emissions by 2030 from 2005 levels. The work aims to identify the scale of effort required to keep the NDC in play. The analysis uses the RIO-Pathways model (find the technical documentation here) and starts from Princeton University's REPEAT Project middle IRA scenario to consider the greenhouse gas impacts from ambitious promulgation of power, vehicle, industrial, and oil and gas methane Clean Air Act rules.

Power sector high-impact scenario

For the power sector, we model Clean Air Act section 111 New and Existing Source Performance Standards for CO_2 that assume:

1. **New gas EGUs:** New gas-fired electric generating units (EGUs) must meet an emission rate standard (averaged annually) equivalent to 90% CCS by 2024 (the first future model year).
2. **Existing coal EGUs:** Each existing coal plant must meet an emission rate standard (averaged annually) equivalent to 50% CCS by 2030.
3. **Existing gas EGUs:** Each existing natural gas-fired power plant must meet an emission rate standard (averaged annually) equivalent to 50% CCS by 2030.
4. **Trading is allowed:** EGUs that over-comply may sell excess emissions reductions to units that may need emissions reductions to operate, such as combustion turbines. There is no exemption for combustion turbines or for units operating at low capacity factors.

Transportation sector high-impact scenario

For the transportation sector, we model two separate measures: the first assumes national standards based on California's light duty vehicle (LDV), medium-duty vehicle (MDV), and heavy-duty vehicle (HDV) standards, while the second adds fuel efficiency standards for internal combustion engines. These measures are layered as separate policies that do not interact with each other.

California Zero-Emission Vehicle Standards

The analysis assumes an emission rate standard for LDVs consistent with the trajectory called for in the California Air Resources Board's Advanced Clean Cars II rule and following the emission rate trajectory shown below (Annex Figure 1).[29] In the case of LDVs, we assume all new ZEV vehicles in 2030 are battery operated.

The analysis likewise assumes an emission rate standard for new MDVs and HDVs that declines to zero by 2045, consistent with California's vehicle standards. These vehicles were assumed to comprise a mixture of new battery-operated electric vehicles and new fuel cell electric vehicles. MDV and HDV sales penetration is assumed to follow an s-curve, and saturating in 2045, which aligns with a recent NREL MDV and HDV analysis.[30]

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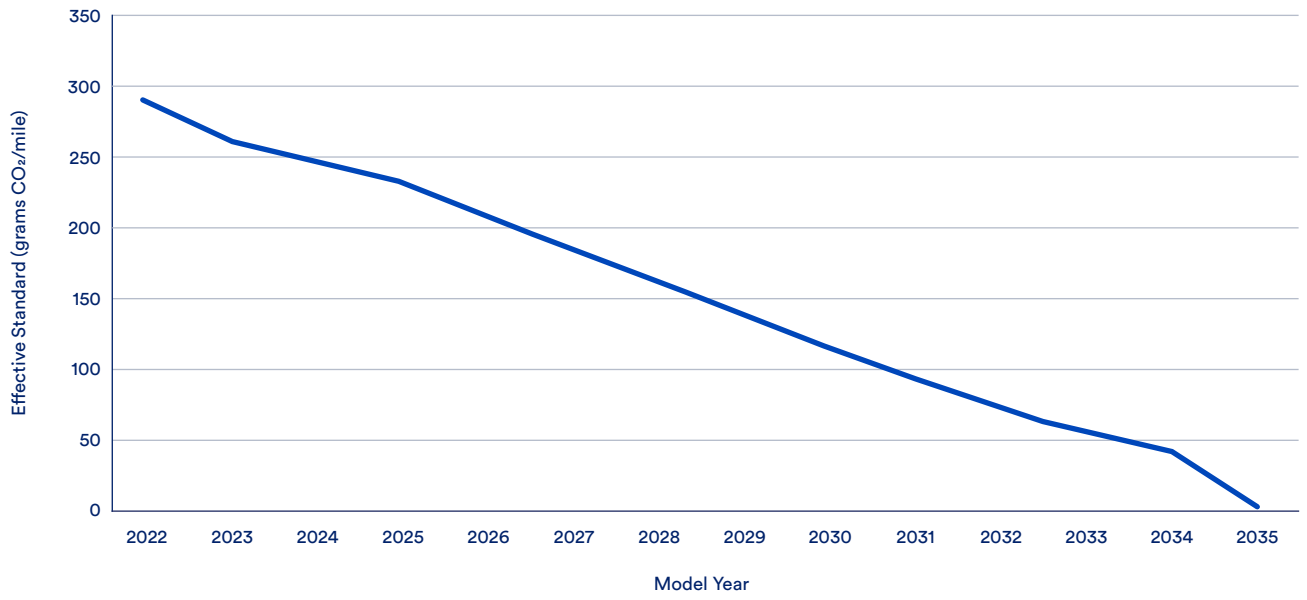
[29] https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii

[30] See slides 20-22 and 61.

Annex Figure 1: High-Impact Standard Evaluated for New LDVs



Internal Combustion Engine Standards

Recognizing that even as the vehicle mix is changing as rising shares of new vehicles are ZEVs, there is still a meaningful share of new internal combustion engines (ICE). To capture the opportunity to reduce greenhouse gas emissions from new ICE vehicles, we assume continuous improvement in ICE engine standards at the same pace that CAFE standards have increased from 2012-2021. These standards are layered on top of the California-based standards discussed above.

Oil and gas methane high-impact scenario

To assess the potential impacts of strong EPA regulations of methane emissions from oil and gas operations, we iterated between the RIO-Pathways model and CATF's in-house methane projection model. We assumed implementation of new oil and gas methane rules starting in 2026. Estimated oil and gas production levels projected to result from implementation of the power sector and transportation rules, described above, were input to the methane projection model to estimate the reduction in CO_2e that would be achieved through ambitious oil and gas regulation.

Not considering the impacts of super-emitters, we found that ambitious oil and gas methane regulations could reduce 3.5 million tonnes of methane, a 50% reduction from baseline levels in 2030, equivalent to 94.4 MT CO_2e assuming a 100-year global warming potential for methane of 27.[31] If super-emitters are considered, ambitious oil and gas regulations

[31] Here, and throughout this document, CO_2e figures for emissions and mitigation categories which include methane are calculated using the 100-year global warming potential (GWP) for non-fossil methane from the IPCC's Fifth Assessment Report (AR5), consistent with U.S. inventories. Using the 100-year GWP for methane significantly underestimates the climate benefits of substantial methane mitigation that would occur over the next few decades (2030-2050), but we use these figures here for consistency with U.S. Government inventories and analyses. We also expect the 100-year GWP to be adjusted over the coming years to reflect more recent assessments by the IPCC and the higher climate impact of methane originating from fossil sources such as oil and natural gas.

could reduce methane by 61% below baseline levels, amounting to 6.7 million tonnes of methane reduced (equivalent to 179.6 MT CO_2e). Our estimates make use of the calculated emissions without super-emitters given that the U.S. inventory baseline does not account for these emissions.

Industrial sector high-impact scenario

Building on the high impact scenario modeling results, we applied strong CAA 111 standards to new and existing industrial facilities, as follows:

- **Ethanol and cement.** These industries are assumed to meet an emission rate standard equivalent to a **90% reduction in CO_2 emissions** based on application of carbon capture. Note that the incremental mitigation opportunity from the ethanol sector is relatively limited as a considerable share of emissions reductions was captured by IRA.
- **LNG.** Liquified natural gas (LNG) terminals are assumed to meet an emission rate standard equivalent to a **90% reduction in CO_2 emissions,** either through carbon capture or electrification. This sector is important for emissions control because there are roughly 20 new LNG terminals proposed, and each one requires an energy source equivalent to a 600 MW power plant. Absent regulation, this could mean 90 MT/year of new emissions.
- **Refinery sector.** It is estimated that 50% of CO_2 emissions from refineries come from the fluid catalytic cracking unit (FCCU) and steam methane reforming (SMR). It is further assumed these emissions can be reduced 90% with CCS. Overall, the analysis assumes an emission rate standard equivalent to a **45% reduction in refinery sector CO_2 emissions** (0.5*0.9). Before CAA 111 standards and guidance can be set for SMR units, a precursor rulemaking would be required to list SMRs as a source category.
- **Pulp and paper.** The analysis assumes an emission rate standard equivalent to a **90% reduction in CO_2 emissions** via CCS. The standard is assumed to apply equally to combustion of biomass fuels (77%) and fossil fuels (23%).
- **Iron and steel.** The analysis assumes an emission rate standard consistent with a **70% reduction in CO_2 emissions** from iron and steel, premised on CCS, hydrogen fuel, or direct reduced iron-electric arc furnace technology.