AN “ALL-IN” PATHWAY TO 2030:

U.S. Methane Emissions Reduction Potential

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Key Findings

With an All-In national climate strategy combining actions from the federal government with actions from states, cities, businesses, the United States can reduce its methane emissions by 9.1 $MtCH_4$ (227 $MtCO_2e$), or more than 30% below 2020 levels by 2030. This methane abatement contributes around 8% toward the 50-52% economy-wide emissions reductions required to meet the overall NDC goal and would help fulfill the Global Methane Pledge.

To achieve a 30% reduction in methane emissions by 2030, action is required across all sectors, with significant reductions from energy and agriculture, which are responsible for around 75% of methane emissions today.

Methane policies from the federal government can bolster reductions at all levels, such as through new regulations on oil and gas facilities from the Executive Branch and comprehensive legislation such as in the Inflation Reduction Act of 2022 (IRA)—specifically, the methane fee of \$1,500/tCH_4 and \$1.5B in spending for the oil and gas industry to reduce methane.

The energy sector provides the largest reduction potential, contributing nearly 20%, or 4.7 $MtCH_4$ (118 $MtCO_2e$), towards methane emissions reductions over the next eight years. Agriculture has the second-largest potential, contributing an additional 9%, or 2.4 $MtCH_4$ (60 $MtCO_2e$). Landfills, wastewater, and industrial processes can contribute to additional reductions to achieve more than 30% economy-wide reductions.

Ambitious yet feasible bottom-up actions by states, cities, and businesses can achieve nearly half of the total emissions reductions needed, while new federal actions can deliver the remaining.

Acknowledgements

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Reducing methane emissions in the United States provides a critical, cost-effective opportunity to address climate change while also yielding immediate benefits, including in human health and agricultural productivity. Moreover, in the United States, significant methane policy opportunities exist not only for the federal government but also for states, cities, businesses, and other non-federal actors. This analysis shows how a comprehensive "All-In" strategy combining actions from different levels of government, and in partnership with businesses and other non-federal actors, can deliver methane emission reductions that exceed 30% by 2030 relative to 2020 levels.

Methane is one of the most potent greenhouse gases (GHG), and has recently emerged as a new focal area for climate mitigation through a series of major commitments from the world's leaders. For instance, at the last UN Climate Conference (COP26) in Glasgow, the United States and over 100 other countries pledged to collectively reduce anthropogenic methane emissions by 30% below 2020 levels by 2030. Also notably, the United States and China committed jointly to additional actions on methane. Earlier last year, the United States set an ambitious economy-wide emissions reduction target (NDC) of 50-52% reductions by 2030 relative to 2005 levels. Comprehensive legislation from the federal government is a critical component to achieve these reductions and the recently passed Inflation Reduction Act of 2022 (IRA) delivers significant new actions on methane as well as across the broader economy, with preliminary analyses showing emissions reductions of 32% to 42% below 2005 levels by 2030.[5,6,7]

Although methane has often been a less-familiar area for action on climate change compared to, for example, energy sector decarbonization, methane emissions reductions are critical to achieving the U.S. NDC target. Significant cost-effective mitigation potential exists for methane sources, which can support overall U.S. emission reduction pathways via climate action across U.S. oil and gas, coal, agriculture, and waste sectors. In the United States, the energy and agriculture sectors have been the two largest contributors to methane emissions, making up roughly 75% of overall methane emissions, and the waste and other land-use sectors contribute an additional 24% to current methane emissions (Figure 1).

Our analysis shows that through stepped-up action on methane, and utilizing a comprehensive, all-of-society strategy leveraging actions from states, cities, businesses and others, the United States could achieve reductions of over 30% by 2030, relative to 2020 levels. This action can deliver 227 $MtCO_2e$ in emissions reductions, which contributes around 8% toward the 50-52% economy-wide emissions reductions required to meet the overall NDC—and send a strong signal globally about its continuing commitment and potential to deliver ambitious climate action. As a result of continued cost reductions and more ambitious policies, the detailed analysis in this report reveals that the methane mitigation opportunity in the United States is roughly 4% higher than our previous analysis of 26% below 2020 levels.[8]

Our analysis builds upon the Environmental Protection Agency (EPA)'s GHG inventory data and non-CO_2 mitigation assessment reports.[9,10] Literature indicates that the fugitive methane emission rates are likely to be underestimated in the EPA inventory. These data are conservative for several reasons. First, undercounting of methane emissions is a known artifact of current inventory methods -- in the oil and gas sector, for example, actual emissions may be 60 percent to over 300 percent higher.[11,12,13,14] Furthermore, other organizations, such as the International Energy Agency, have shown higher mitigation potential in the oil and gas sector.[15]

These independent reports, while more inclusive in specific sectors and regions, do not provide the same level of comprehensive state-by-state methane emissions data, so they are not easily comparable to each other or to EPA's data. In the discussion section of this report, we assess the sensitivity of our results driven by the differences in fugitive oil and gas emission estimates. We find that when we adjust for the higher fugitive emission rates, we get a smaller share of emissions reductions in oil and gas methane compared to our standard scenario. On the other hand, if fugitive emission reduction potential also scales proportionally to historical emissions rates, the emissions reductions can be higher than our standard scenario.

METHANE AS A DANGEROUS GAS AND CRITICAL OPPORTUNITY. As the second largest contributor to climate change after carbon dioxide (CO_2), methane is a potent GHG responsible for approximately 30% of the rise in global temperature.[16,17,18] Methane emissions are over 80 times more potent than CO_2 on a 20-year time scale, and due to its short lifetime, disproportionately impacts near-term peak temperature.[19] These aspects make methane mitigation a significant opportunity to realize immediate climate and health benefits.

Methane aids the formation of ground-level ozone, an air pollutant that adversely affects human health and agricultural productivity.[20,21,22] Cutting methane emissions by 30% could help prevent roughly 255,000 premature deaths globally, including those caused by ozone exposure.[23] Global health benefits from reduced ozone concentrations due methane mitigation are estimated at $790 and $1,775 per tonne of methane for short- and long-term premature mortality, respectively.[24]

Furthermore, marginalized communities often bear the brunt of these impacts. It is well known that poorer communities of color are more likely to live near oil and gas facilities, leaving them susceptible to health risks related to air pollution.[25,26,27] This inequity can be reflected in respiratory illness rates, which include higher asthma rates in Black and Latino children compared to White children, as well as higher probabilities of death from asthma in Black and Latino children compared to White children.[28,29] A recent study finds that marginalized communities are also more likely to live in housing with natural gas leaks and degraded pipeline infrastructure.[30]

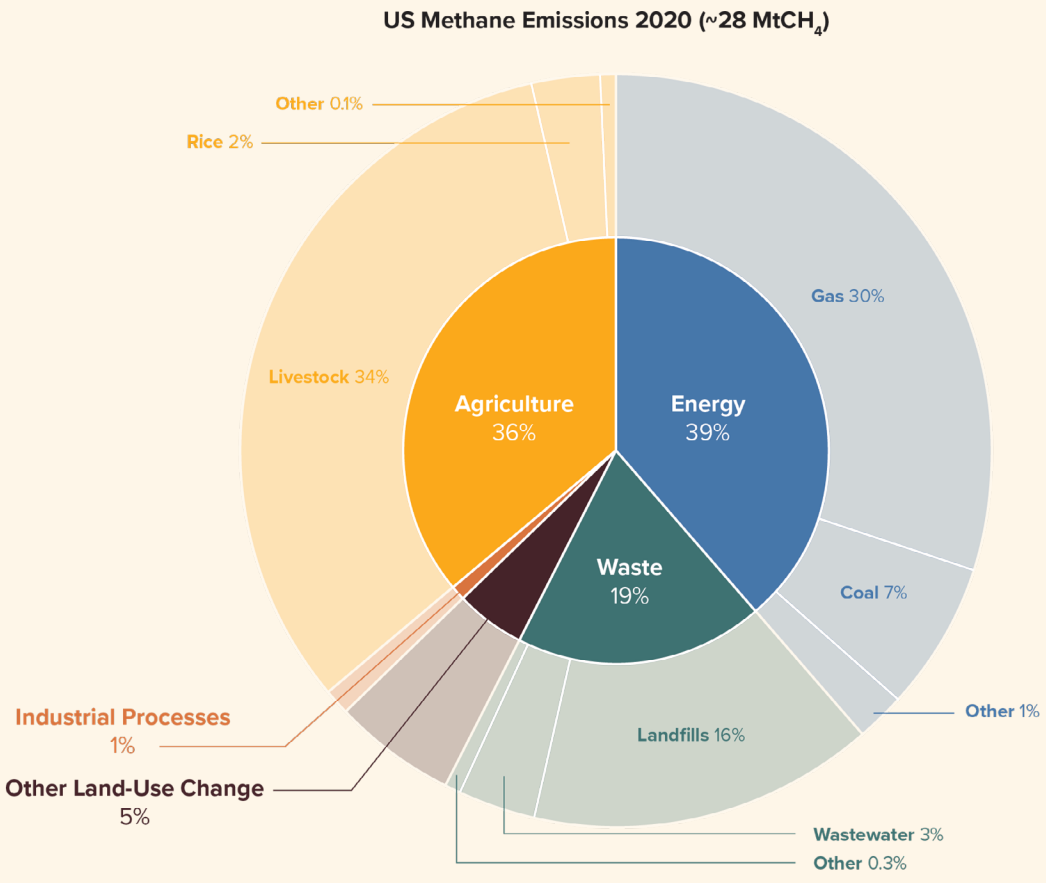

FIGURE 1 *2020 U.S. methane emissions in million tonnes broken down by sector, based on EPA inventory.*

SOURCES OF METHANE EMISSIONS. Methane emissions come from a diverse set of sources across sectors. Below we define the key sources of emissions and technical details.

- **Oil and gas methane:** Occurs from venting and leaks in upstream, midstream, and downstream oil and gas production, as well as from incomplete flaring during oil extraction.[31,32]
- **Enteric fermentation:** Results from food digestion by ruminant animals - e.g., cows, sheep, and goats. Beef and dairy cattle make up over 90% of methane emissions from enteric fermentation in the U.S.[33]
- **Livestock manure:** Contributes to methane emissions when digested by anaerobic bacteria. Dairy cattle and swine are the major sources of manure-related methane emissions.[34]
- **Waste sector methane:** Emitted as a result of the anaerobic decomposition of organic material from landfill waste and the handling and treatment of wastewater.[35]
- **Coal mining methane (CMM):** Emitted from both active and abandoned facilities, with major sources including ventilation air methane, surface mine methane, abandoned mine methane, drainage system methane, and fugitive methane.[36]
- **Other land-use change methane:** Results from forest and grassland fires, as well as the decomposition of organic matter in wetlands.[37]

CURRENT ABATEMENT STRATEGIES. Because methane emissions come from many sources and sectors, there is a large range of mitigation strategies. Below we define the main methods to reduce methane emissions in the United States.

- **Venting and flaring restrictions:** Methane emissions from venting and flaring can be mitigated with equipment mandates and banning non-emergency venting and flaring.[38] A major barrier to bans on venting and flaring is the practice of drilling wells in locations that do not have access to pipelines to gather and transport the natural gas which is typically associated with oil drilling.[39]
- **Leak detection and repair:** Methane leaks can be prevented at gas storage facilities, liquid natural gas operations, and gas pipelines. Reporting systems that better detect and monitor methane leaks, combined with actions to repair or replace leaking equipment, would reduce fugitive emissions from active sources.[40]
- **Plugging orphan wells:** Policies that incentivize the plugging of orphan wells would reduce fugitive methane emissions.[41]
- **Anaerobic digestion:** Anaerobic digesters are used in the waste and agriculture sectors to produce biogas from manure, wastewater biosolids, food waste, and other organics. The biogas can be used as energy or purified to generate renewable natural gas.[42,43]
- **Organic waste reduction and diversion:** Abatement opportunities for landfills are focused on organic waste reduction and diversion via food donation, animal feed, and composting.[44]
- **Coal mine methane capture and reuse:** Methane emitted from existing and abandoned coal mines can be captured and used as fuel. In the U.S., it is mostly sold to natural gas pipeline systems.[45,46]
- **Forest management:** Improving forest management and preventing wildfires through practices such as prescribed fires and treatment of hazardous fuels would reduce methane emissions from the land-use sector.[47]

Policy Pathways to Go Beyond 30% Methane Reductions by 2030

Our assessment demonstrates feasible policy pathways through which the United States can achieve methane reductions of over 30% by 2030. To assess the overall potential for reductions, we established two key scenarios for this analysis:

Bottom-Up scenario

Here we include ambitious but feasible policies at the state, city, and business levels to reduce methane emissions. States and cities at the forefront of climate action strengthen their climate policies, and fast-follower jurisdictions join their efforts. Businesses are leading market innovations. However, holdout states remain largely inactive. New federal actions and IRA are not included in this scenario.

In order to model this, we grouped states into three tiers: Tier 1 states are first-mover states with ambitious climate actions related to methane; Tier 2 states are fast-follower states that are currently taking some measures to reduce methane emissions, but not as quickly; Tier 3 states have done little on climate action historically, and we assume they continue limited action in the absence of federal requirements (see technical appendix for the list of states under each tier). Ambitious action by cities and businesses would contribute to achieving the state reductions modeled. This tiered approach is based on our previous analysis.[48]

All-In scenario

Here we include comprehensive national methane reduction policies, which include a methane fee of $1,500/tCH$_4$ or $60/tCO$_2$e across all sectors, strengthened EPA oil and gas methane regulations, and other Congressional and Executive actions. These are layered on top of expanded state, city and business actions included in the Bottom-Up scenario. States and cities play a crucial role in implementing policies and funding in a climate-friendly way. Our All-In scenario is similar to IRA in its stringency, but covers broader sectors of the economy. IRA and All-In both include the critically important methane fee of $1,500/tCH$_4$ in the oil and gas sector. However, IRA exempts facilities that are in compliance with EPA oil and gas regulations, even if they have emissions from sources not covered by these regulations. Furthermore, the All-In scenario also applies the same level of methane fee to other sectors of the economy, including agriculture and landfill sectors.

Based on our modeling of the three largest emitting sectors (energy, agriculture, and landfill waste) we find a high potential for reductions under feasible policies. We did not model policies in wastewater, other land-use change and industrial processes because of their low potential for direct reductions given current costs and policy opportunities; however, we do discuss future potential for reductions as technology and market forces improve.

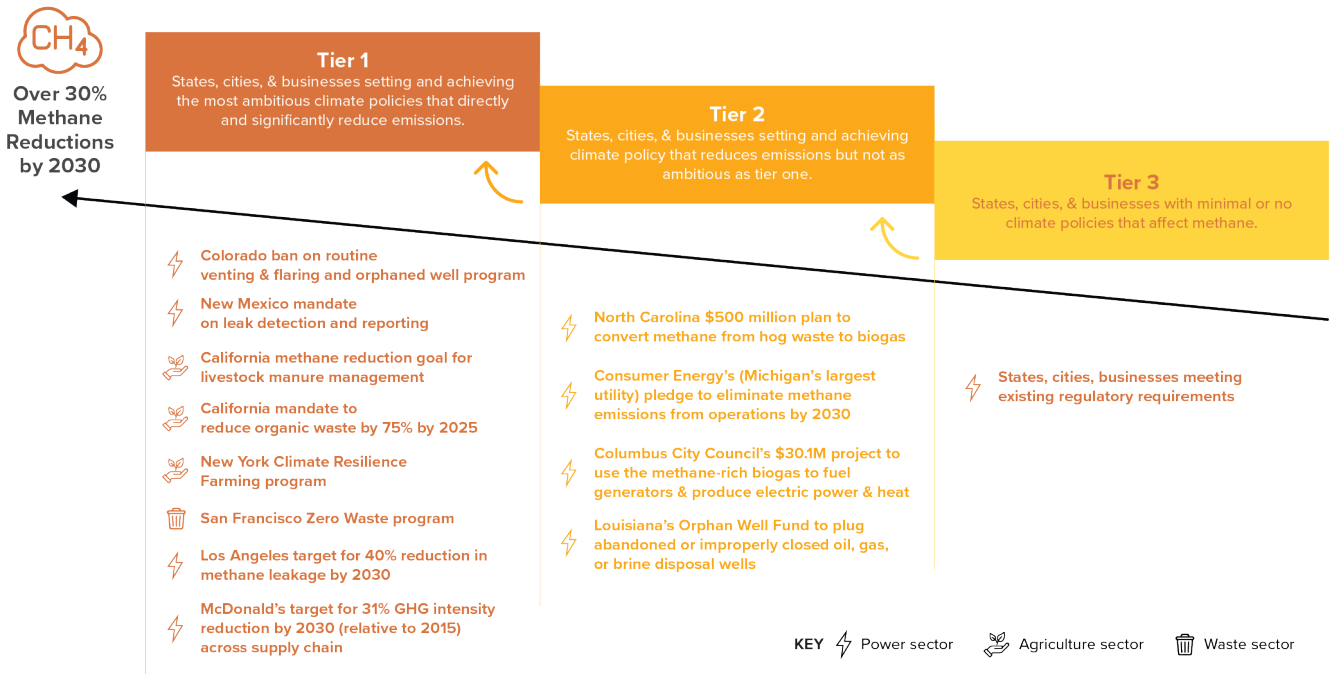

FIGURE 2 *Policies and actions in our Bottom-Up scenario, broken down by tier*

TABLE 1 *Methane mitigation policies in energy, agriculture, and waste sectors that contribute to our All-In and Bottom-Up scenarios.*

Policy Sector	Bottom-Up	All-In
Energy	**Tier 1 and 2 states** adopt standards on existing and new oil and gas sources, implement extensive leak detection and repair requirements, and limit venting and flaring, plus take actions to reduce methane emissions from active and abandoned coal mines. Cities and businesses implement policies that are supportive of these standards, such as targeting reduction of methane leakage from distribution infrastructure and pledging to reduce methane emissions to near zero by 2030. **Tier 3 states** achieve reductions where policies are already in place or under development. Energy sector methane emissions are reduced by **21%** nationwide.	Federal methane rules are reinstated and strengthened. They cover new and existing oil and gas sources, repair leaks in pipelines, and close the three major gaps in the pending EPA methane regulations: 1. Ban flaring and venting except in emergencies; require all oil wells to have gas pipeline access or reinjection of captured methane. 2. Require rigorous monitoring and leak repair for closure and sealing for wells that are no longer producing sufficient oil and gas to sustain proper maintenance and monitoring. 3. Mandate proper closure of abandoned oil and gas wells so as to minimize continued leakage. Congress also provides further federal funding toward reclaiming abandoned coal mines and addressing fugitive coal mine methane. Additionally, a methane fee of $1,500/tCH$_4$ is applied to all residual emissions. Energy sector methane emissions are reduced by **44%** nationwide. (Depending on coverage and technological advancements, reductions from oil and gas sources could increase to over 70%)[49,50]
Agriculture	**Tier 1 states** set methane emissions standards and provide ample funding assistance for widespread implementation of manure management projects, anaerobic digesters, and enteric fermentation mitigation. Voluntary programs for rice producers result in increased productivity. **Tier 2 states** provide funding for livestock and rice operations to implement climate-friendly manure management practices and build anaerobic digesters while also providing technical assistance. **Tier 3 states** take no action to aid livestock or rice operations, but private companies operating in these states participate in voluntary actions driven by their national presence and the desire to increase the resilience of their supply chains and farming practices. Agricultural methane emissions are reduced by **13%** nationwide.	A methane fee of $1,500/tCH$_4$ is applied, incentivizing livestock operations to implement climate-friendly manure management practices, build anaerobic digesters, and take measures to reduce enteric emissions. Climate-friendly rice cultivation practices are adopted widely. Federal funding for voluntary programs are increased to aid in the development of projects related to livestock methane mitigation and alternative rice cultivation techniques, lowering mitigation costs for farmers. Agricultural methane emissions are reduced by **29%** nationwide.
Waste	**Tier 1 states** adopt waste diversion policies similar to California's SB1383 regulation, and implement policies to increase capture of landfill gas. Cities and businesses implement policies that are supportive of these standards, such as San Francisco's Zero Waste program. **Tier 2 states** adopt waste diversion policies, though less ambitious than targets set by Tier 1 states. **Tier 3 states** achieve reductions where policies are already in place or under development. Waste sector methane emissions are reduced by **5%** nationwide.	A methane fee of $1,500/tCH$_4$, combined with federal programs to reduce organic waste through research, outreach and investments, help achieve the federal target of halving food waste by 2030. Waste sector methane emissions are reduced by **15%** nationwide.

Overall results from the modeled scenarios are shown in Figure 3 below. We find that the energy sector can deliver the most emissions reductions, followed by the agriculture sector and the waste sector. Our All-In scenario shows that with feasible non-federal and federal actions, the United States can achieve over 30% methane reductions below 2020 levels by 2030. In the Bottom-Up scenario, in which we rely on only feasible non-federal action, the United States achieves nearly 16% methane reductions by 2030.

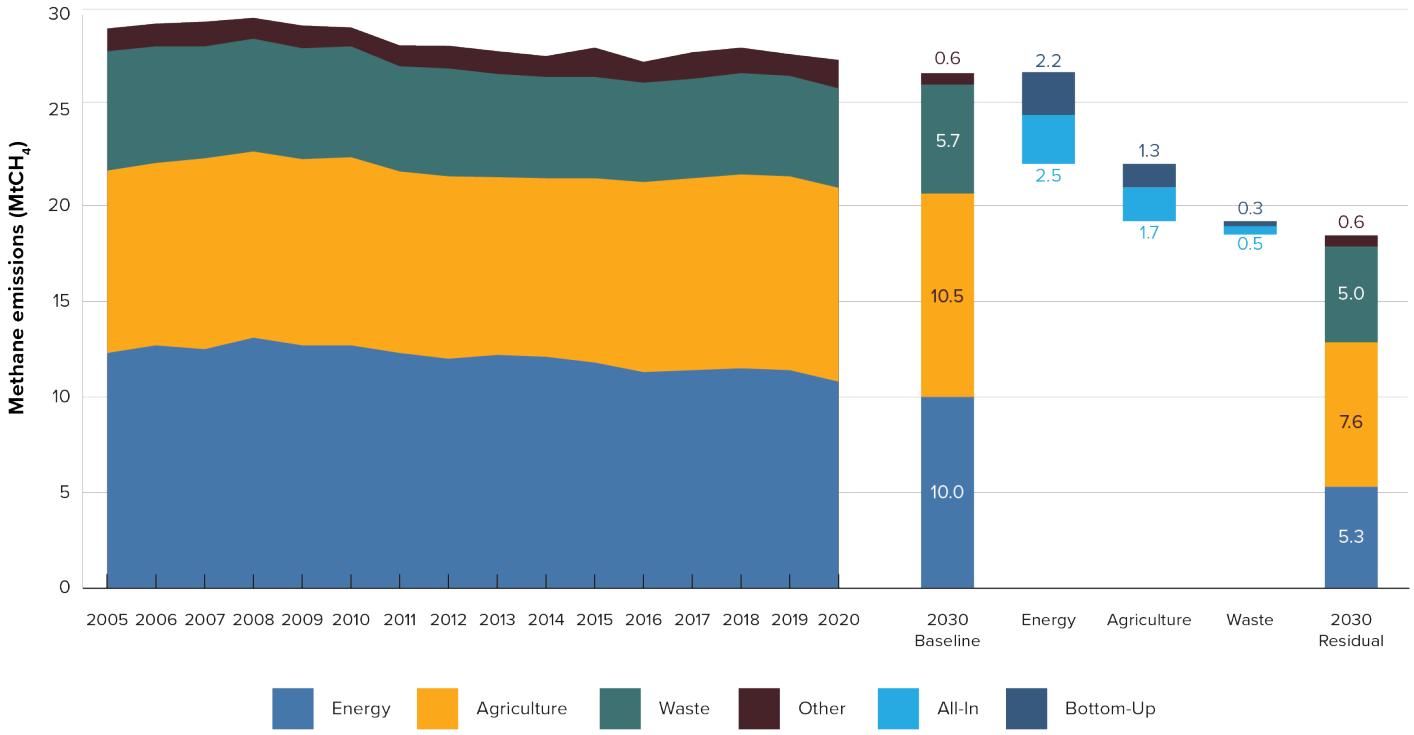

FIGURE 3 *Bars show total methane emissions, broken down by sector. Reductions are shown across energy, agriculture, and waste sectors. Reductions from our Bottom-Up scenario represent reductions from state, city, and business actions only. Our All-In scenario layers on additional federal action from Congress and the Executive Branch, allowing us to achieve over a 30% reduction in methane emissions relative to 2020 levels by 2030.*

VOLUNTARY STANDARD FOR PRIVATE SECTOR METHANE MITIGATION. In addition to state and federal regulations to limit methane emissions from the oil and gas sector, some private sector companies are making investments in reducing methane leakage voluntarily. However, voluntary action is limited because oil and gas companies may be wary of the up-front costs and the perception of limited return on investment.

Voluntary methane certifications or standards can increase the value proposition of investing in reducing methane emissions and get more oil and gas companies off the sidelines. Voluntary standards aim to more precisely account for methane emission inventories using advanced technologies and more quantitative methods, thereby improving baseline calculations and targeted reduction calculations. Increasingly, buyers of oil and gas products are demanding evidence that companies are taking steps to limit methane emissions from the oil and gas value chain. Independent certification of a company's practices allows them to guarantee lower methane emissions and sell a differentiated product to buyers that are looking for ways to lower their own emissions impact. Governments can also leverage voluntary standards through uptake of their more precise quantitative emissions inventory methodologies as well as requiring or offering incentives to companies that pursue certification.

The MiQ Standard is one example of a voluntary oil and gas methane standard, which currently certifies over 4% of the global gas market. MiQ audits certify each stage of the supply chain, allowing buyers visibility of company practices at each stage. Certifications from MiQ are also recorded in a digital registry to increase transparency, ease public reporting, and prevent double-counting.

POLICY OPPORTUNITIES IN ENERGY

The federal government has taken several measures to mitigate methane from the energy sector. The Infrastructure Investment and Jobs Act (IIJA) has provisions for plugging orphan wells and fixing abandoned mines, while the recently passed IRA contains a methane fee and funding for the oil and gas industry to monitor and reduce methane. On the regulatory side, the Department of Transportation's Pipeline and Hazardous Materials Safety Administration has finalized rules to reduce methane leaks downstream throughout the gas pipeline system.[51] The Environmental Protection Agency (EPA) has proposed new rules on existing and new oil and gas sources.[52] These rules include a quarterly monitoring program on well sites and compressor stations that are most likely to have large emissions, zero-emitting technologies for pneumatic controllers, and a ban on venting.[53] They require – and EPA is undertaking – significant strengthening as described in Table 1.

States have historically been innovators in addressing oil and gas methane, through, for example, partnerships with business as well as state-level regulation. Colorado was the first state to adopt regulations limiting methane from oil and gas operations in 2014, which reduced the number of methane leaks by 52% by 2018.[54] Colorado has since expanded upon its regulations, which now include the prohibition of routine venting and flaring, requirements for frequent inspection of all wells and transmission lines, financial requirements for oil and gas companies, and an orphaned well program.[55,56] These regulations have been held up as a model for the federal government and other states, and states like California, Massachusetts, New York, and New Mexico have adopted similar regulations.[57] At the same time, major oil and gas states like Texas and North Dakota still lack sufficient methane emissions regulations.

Many oil and gas companies are involved in efforts such as the Environmental Partnership and the Oil and Gas Climate Initiative, which aim to reduce methane emissions from supply chains. Several companies such as ExxonMobil and Shell have pledged to reduce methane emissions to near zero by 2030 through increased monitoring and capturing.[58] Some companies have partnered with state and local governments to achieve methane emission reductions. For example, in 2015, the Environmental Defense Fund, Google Earth Outreach, and Colorado State University partnered with New Jersey's largest natural gas company, providing methane leak data that enabled an 83% reduction in methane leakage over the course of three years.[59]

EMISSIONS REDUCTIONS FROM ENERGY

In the Bottom-Up scenario, non-federal action can deliver a reduction of 2.2 $MtCH_4$ relative to baseline in the energy sector through abatement of methane emissions from coal mines and oil and gas systems. These reductions are achieved through state actions to enhance leak detection and repair for oil and gas systems, limit venting and flaring, and reduce coal mine methane from active and abandoned coal mines.

Methane emissions are further reduced indirectly through reduced fossil fuel production and consumption in other parts of the economy. Our previous analysis has shown that the bottom-up actions in states, cities, and businesses can reduce nearly 30% of coal consumption and 7% of oil and gas consumption.[60] We assumed that the fossil fuel production and associated fugitive emissions are proportionately reduced. In our sensitivity analysis, we consider a case in which the reduced fossil fuel consumption results in a larger share of fossil fuel production being exported overseas. In this scenario, the reduction in fugitive emissions due to reduced fossil fuel production and consumption are estimated to be minimal.

In the All-In scenario, a federal methane fee of \$1,500/tCH_4 (equivalent to \$60/tCO_2e) is applied to the entire energy sector. Furthermore, clean energy and electrification policies consistent with achieving 50-52% emissions reductions lower fugitive methane emissions associated with fossil fuel production and consumption activity.[61] These reductions are estimated to be 14% for oil and gas and 51% for coal. These policies together are estimated to deliver an additional reduction of 2.5 $MtCH_4$, bringing the total reduction in the energy sector to 4.7 $MtCH_4$ – 44% lower than in 2020. Expanded coverage of methane sources and advancements in technology could realize even greater potential for reductions.[62,63] For example, under the proposed EPA regulations, up to 74% of methane emissions can be reduced from currently covered oil and gas sources.

Our level of methane fee in the energy sector is stronger than what's written under IRA. The IRA methane fee only covers a subset of facilities in the oil and gas sector, while the All-In scenario applies the same level of methane fee to the entire energy sector, including all oil and gas facilities and coal mine methane.

POLICY OPPORTUNITIES IN AGRICULTURE

At the federal level, the U.S. Department of Agriculture (USDA) works with farmers through voluntary programs and provides funding and technical support to mitigate methane emissions from livestock and rice cultivation.[64] Many bills have also been introduced to address the agriculture sector's carbon footprint. IRA has an $8.5 billion provision that focuses on reducing methane emissions in the agriculture sector through climate-smart practices. Other bills do not explicitly call out agricultural methane, but provide a variety of incentives and support for farmers to reduce total emissions. Some examples include research funding to enhance voluntary carbon sequestration capabilities and technologies, private-public partnerships to promote technological climate solutions, and a voluntary emissions credit market for farmers.[65,66,67,68]

Many states are leading on innovative methane mitigation practices in agriculture, such as California's anaerobic digester program and manure management program, which incentivize livestock operations to install anaerobic digesters and other manure management technologies, while the state's Low Carbon Fuel Standard has provided the demand for the renewable natural gas made by upgrading biogas produced in the digesters.[69,70,71] Oregon and Washington have implemented similar fuel standards policies.

Private companies have stepped up to reduce their agricultural methane emissions footprint. For example, major food companies, including Cargill, Smithfield, and McDonald's, have set goals to reduce GHG emissions throughout their entire supply chain by 2030.[72,73,74] Food suppliers and restaurants that promote foods with low carbon intensities can help reduce emissions related to food production by driving demand for low-emissions food, such as through the Cool Food initiative.

EMISSIONS REDUCTIONS FROM AGRICULTURE

In the Bottom-Up scenario, state actions such as loan and grant programs for anaerobic digesters and manure management projects encourage businesses to take action. These subnational actions could reduce agricultural methane emissions by 1.3 $MtCH_4$ compared to the baseline by 2030.

In the All-In scenario, a federal methane fee of $1,500/$tCH_4$ would incent livestock and rice producers to implement economically feasible emission reduction actions, while federal programs work with farmers to implement mitigation strategies. These federal level policies can reduce methane emissions by an additional 1.7 $MtCH_4$, bringing the total in the agriculture sector to nearly 3 $MtCH_4$ by 2030 - 29% below 2020 levels. However, even a low methane fee of $250/$tCH_4$ ($10/$tCO_2e$) could drive over half of the emissions reductions in the sector.

While IRA does not have a methane fee for the agriculture sector, its provisions on climate-smart practices could potentially lead to the reductions in our All-In scenario.

POLICY OPPORTUNITIES IN LANDFILL WASTE

The 2021 EPA final rule for municipal solid waste (MSW) landfills requires states to submit emission reduction plans for approval or otherwise implement a federal plan developed by EPA for existing landfills, and EPA's voluntary Landfill Methane Outreach Program provides technical support for bringing methane into the renewable gas market.[75,76] EPA and USDA also have initiatives to reduce food loss and waste, with a goal of reducing organic waste by 50% by 2030.[77]

Some state and local governments are already successfully implementing new waste-diverting programs, such as California, Massachusetts, and Washington. California's SB1383 is among the most ambitious waste reduction mandates, aiming to reduce organic waste landfill disposal by 75% from 2014 levels by 2025. San Francisco and other cities have committed to a zero waste pledge.[78]

EMISSIONS REDUCTIONS FROM LANDFILL WASTE

In the Bottom-Up scenario, we find that non-federal action can reduce methane emissions by 0.3 $MtCH_4$ relative to the baseline. These reductions are achieved by state- and local level waste reduction initiatives, as well as policies to capture landfill gas and repurpose it for electricity generation, heat production and pipeline injection.

In the All-In Scenario, we find that adding EPA's goal of achieving 50% waste reduction as well as a federal methane fee of $1,500/tCH$_4$ can contribute an additional 0.5 MtCH$_4$, with total emissions reductions of 0.8 MtCH$_4$, which is 15% below 2020 levels.

ADDITIONAL OPPORTUNITIES FOR REDUCTIONS

Technological advancements, behavioral shifts, and mitigation assessment updates could provide additional opportunities for methane emissions reductions. However, these actions were not accounted for in our analysis, as further research and data availability are needed to estimate emissions reductions.

As technological innovation in climate mitigation becomes more attractive to policymakers and investors, potential tools such as feedstock additives will grow in popularity. Animal feed additives, such as a type of red algae called Asparagopsis and a molecule known as 3-nitrooxypropanol (3-NOP), have been proven to reduce enteric methane emissions by up to 97%, and 39%, respectively.[79,80] Longer-term studies are needed to affirm the longevity of those effects, potential scope for implementation, and downstream effects on food safety and animal productivity due to shifts in consumption and feed conversion efficiency.[81,82,83]

From a behavioral lens, dietary changes can also lead to further emissions reductions. Per capita red meat consumption has declined by 25% in the U.S. since 1970, while per capita poultry consumption, which is far less emissions-intensive, has increased by 240% in the same time period. A further shift away from red meat consumption could lead to per capita livestock-related methane emissions reductions, though population increases could continue to offset per capita reductions.[84]

We also did not account for methane reductions from wastewater, other land-use change, and industrial processes in our study. Updates to technology costs and policy opportunities could further mitigate methane emissions in these sectors.

Methane emissions by state

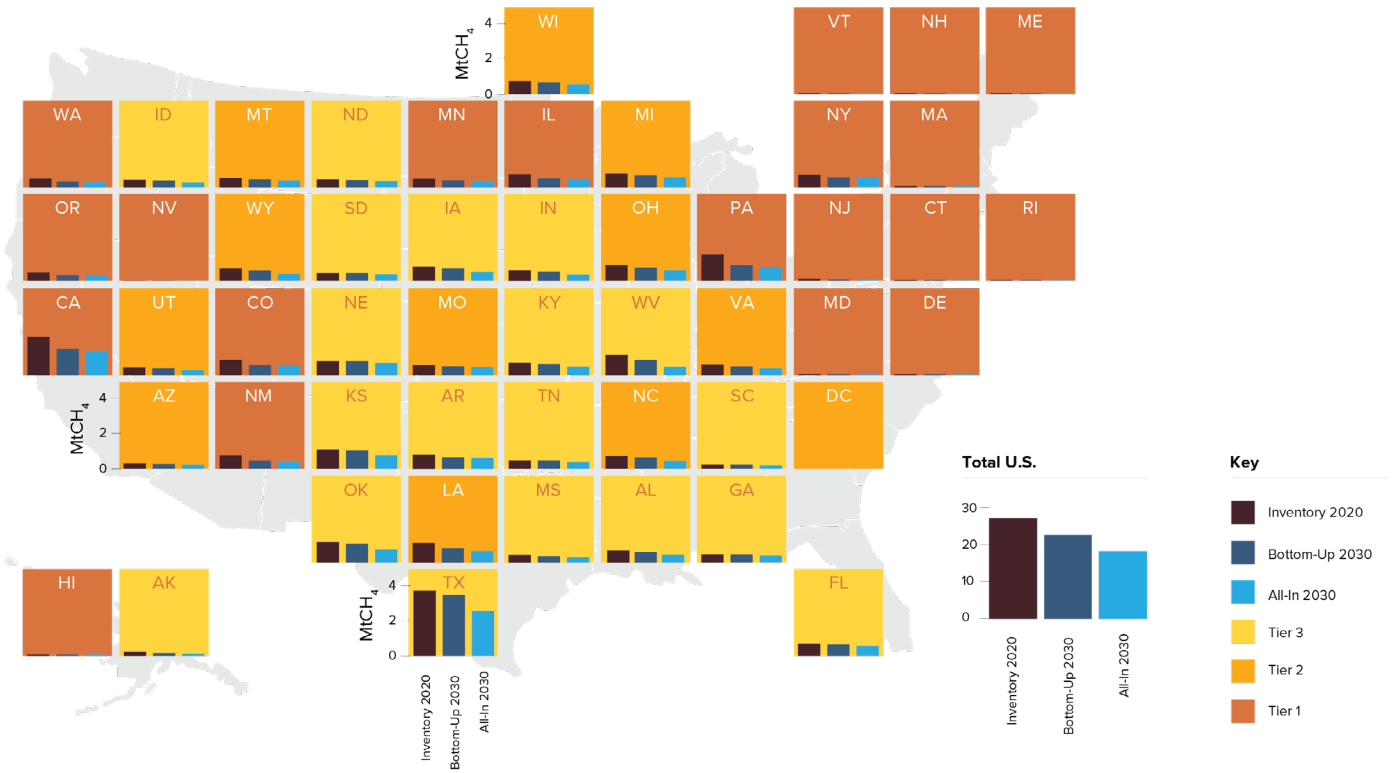

FIGURE 4 *State-level methane emissions in our Bottom-Up and All-In scenarios.*

Discussion

CONSIDERATIONS FOR CALCULATING METHANE REDUCTIONS

Sensitivities about fugitive methane emission inventory: The EPA estimates inventory for methane emissions in the oil and gas industry based on "the amount of methane that would be expected to be released from a given component or type of equipment."[85] Recent technical advances have allowed for more direct measurements of methane levels, which indicate that the EPA's inventory estimates may underestimate the actual levels of methane emissions, most notably from oil and gas.

Multiple studies directly measure large sections of U.S. oil and gas methane emissions using ground-based, satellite, and facility-scale measurements, and find that methane emissions are higher than what's reported in the EPA inventory.[86,87,88,89] Alvarez et. al (2018) estimates that oil and gas methane emissions are approximately 60% higher than EPA estimates, "likely because existing inventory methods miss emissions released during abnormal operating conditions".

To reflect these new estimates, we conduct a sensitivity analysis assuming a 60% higher level of fugitive methane emissions in the oil and gas sector (Table 2). In the first iteration of this, we assume that historical emissions and projected baseline emissions are 60% higher, but that the amount of abatement potential remains unchanged. In this "pessimistic" abatement scenario, our All-In scenario delivers a 31.2% reduction. In the normal abatement scenario, we assume that the amount of abatement potentials also increases by 60%, proportionate to the baseline emissions increase. This scenario results in a 35.9% reduction for the All-In scenario by 2030.

Sensitivities about GWP values: To avoid discrepancies associated with using different global warming potentials (GWPs), we quantify methane emissions in its native units of million tonnes of methane or $MtCH_4$ rather than CO_2 equivalent. In 2020, methane emissions in the United States were estimated to be 27.5 $MtCH_4$. In our All-In scenario, methane emissions reductions were estimated to be 9.1 $MtCH_4$, leaving 18.5 $MtCH_4$ of residual methane emissions. Table 2 below compares the reductions achieved under different GWPs from the International Panel on Climate Change (IPCC)'s Fourth Assessment Report (AR4)[90] and Sixth Assessment Report (AR6).[91] Additionally, given methane's relatively short lifetime in the atmosphere compared to CO_2, we also consider the 20-year GWP for methane.

TABLE 2 *Methane emissions in the sensitivity analyses.*

Sensitivity	Global Warming Potential	Units	2020	2030 Bottom-Up			2030 All-In		
			History	Residual Methane	% Reduction from 2020 Methane	% Contribution Towards NDC	Residual Methane	% Reduction from 2020 Methane	% Contribution Towards NDC
Standard	Native Units	$MTCH_4$	27.5	23.1	16.1%	4.5%	18.5	32.9%	7.9%
Higher fugitive methane	Native Units	$MTCH_4$	32.6	26.8	17.9%	5.6%	20.9	35.9%	9.8%
Higher fugitive methane with pessimistic abatement	Native Units	$MTCH_4$	32.6	27.4	16.0%	5.2%	22.4	31.2%	8.8%
GWP Conversion IPCC AR4, 100-Year GWP	25.0 (fossil) 25.0 (non-fossil)	$MTCO_2e$	688.5	577.5	16.1%	4.5%	461.8	32.9%	7.9%
Updated GWP Conversion IPCC AR6, 100-Year GWP	29.8 (fossil) 27.0 (non-fossil)	$MTCO_2e$	773.7	645.6	16.6%	5.1%	513.6	33.6%	8.9%
Short-Term GWP Conversion IPCC AR6, 20-Year GWP	82.5 (fossil) 79.7 (non-fossil)	$MTCO_2e$	2171.9	1863.0	14.2%	11.7%	1487.2	31.5%	20.6%

COMPARISON TO THE INFLATION REDUCTION ACT

An All-In strategy proposed here includes climate actions from all of society. It includes federal regulatory measures, actions from Congress similar to those in the recently passed Inflation Reduction Act (IRA), and diverse climate actions at city, state, and business levels. Such a strategy can help the United States deliver methane emissions reductions of more than 30% by 2030. This ambitious yet feasible methane reduction would be a critical contributor to help the U.S. meet its overall 2030 climate target (NDC) and simultaneously would support global commitments like the Global Methane Pledge. Achieving an aggressive methane reduction goal can help the United States lead internationally in delivering these commitments and help keep the global goal of limiting warming to below 1.5°C within reach.

IRA takes a significant step in the right direction toward meeting U.S. climate goals and reducing methane emissions. However, further actions will be needed to achieve over 30% in methane emissions reductions by 2030. Our All-In scenario lays out the additional actions that are needed to achieve the ambitious methane reduction beyond IRA. Key actions include: strengthened EPA oil and gas regulations, a comprehensive methane fee covering all oil and gas facilities, additional funding for coal mine methane reduction, agricultural practices on manure management and crop cultivation, and waste diversion policies. Our initial estimates indicate that, given these gaps, additional actions from Congress, the Executive Branch, and states, cities and businesses would be needed in these sectors to help reach levels of 30% or more. Without such actions, we estimate 2030 methane reductions of 6-19% from IRA alone. This wide range exists because of uncertainties related to the coverage of oil and gas sources by the methane fee and related to specific measures that will be taken in the agriculture sector.

NEW POLICY ACTIONS FROM NON-FEDERAL ACTORS

We find that several of the key actions missing in IRA are already a part of the strong innovation and policymaking happening at the non-federal level. The opportunity to expand and enhance these policies across states, cities, businesses, and more can help fill the gap.

- **Enhanced regulations on oil and gas facilities:** States can require leak detection and repair, generate funding to plug orphaned wells, and ban routine methane venting and flaring, following Colorado's and California's examples.
- **Funding and policies for coal mine methane:** States can direct funding for efforts to clean up abandoned coal mines, and encourage best practices such as coal drying, flaring and degasification for power generation. These could be particularly valuable in filling in given the lack of these provisions in IRA.
- **Accelerating research and development in agricultural abatement strategies:** States, cities and businesses can complement federal programs to encourage climate-smart practices, and generate additional funding and research capacity for innovative technologies and practices. They should follow existing mitigation practices, such as California's anaerobic digester program and manure management program. Implementation could also include various crop/rice cultivation practices, including no till, alternate wetting and drying, and reduced fertilizer use.
- **Investing in landfill waste infrastructure:** States and cities need proper infrastructure for collecting, processing, and treating waste to increase waste diversion, and they can implement policies to capture methane emissions from landfill gas. Waste diversion mandates can look like California's SB1383 and San Francisco's zero waste pledge.

These policies not only reduce emissions, but they also result in a number of near-term benefits including cost savings, human health improvements, reductions from other greenhouse gases such as CO_2 and N_2O, and increased employment opportunities.

Methane mitigation and the broader clean energy sector can offer economic opportunities for oil and gas workers. In 2021, total oil and gas production increased, but the oil and gas industry experienced substantial job losses.[92,93] The methane mitigation industry is growing quickly and could add many more jobs in the coming years. Over 215 U.S. companies currently manufacture technologies and provide services to reduce oil and gas leaks across 47 states. States with more oil and gas jobs tend to have more employee locations for methane mitigation.[94] Some methane mitigation jobs also likely overlap with skills for oil and gas. Methane mitigation will employ welders, pipeline workers, electricians, engineers, construction and building trades workers.

Policymakers can further promote methane mitigation jobs by increasing methane mitigation rules and job training. States with methane emissions rules have more methane mitigation jobs and methane mitigation firms overwhelmingly believe that new methane rules will allow them to hire more workers. Policymakers can also seek out where better education, job training, and apprenticeship programs will be most effective in helping oil and gas workers transition to potentially higher paying jobs in clean energy and methane mitigation.[95]

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