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ROADMAP FOR U.S.-CHINA METHANE COLLABORATION: METHANE EMISSIONS, MITIGATION POTENTIAL, AND POLICIES

SUMMARY FOR POLICYMAKERS

November 2022

Background and Acknowledgements

From January to June 2022, researchers from a group of 20 U.S., Chinese, and international research institutions convened over two workshops to discuss opportunities for advancing methane-related research in the United States and China. The contributions of all workshop participants are gratefully acknowledged. In parallel to the workshop, and informed by those discussions, a core research team conducted additional analysis and produced a report based on the resulting research and policy guidance from a larger research team. The workshops and report were facilitated by the Center for Global Sustainability at the University of Maryland with support from Energy Foundation China.

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ROADMAP FOR U.S.-CHINA METHANE COLLABORATION: METHANE EMISSIONS, MITIGATION POTENTIAL, AND POLICIES

SUMMARY FOR POLICYMAKERS

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KEY MESSAGES

- **Methane currently contributes to 20% of human-caused climate forcing** (Forster et al., 2021). **Rapid and sustained methane reduction is critical to keeping the world on a path to 1.5°C.** Previous research suggests global anthropogenic methane emissions can be reduced by as much as 45% by 2030, which would avert nearly 0.3°C of global warming by 2045 and critically reduce the level of peak warming (CCAC &UNEP, 2021a). China and the United States are the first and third largest methane emitters, collectively accounting for a quarter of global methane emissions today (GMI, 2022). Joint U.S. and China efforts to reduce methane emissions are key to limiting near-term warming, which would also improve local air quality and yield economic and health benefits.

- **China and the United States can make important contributions toward achieving national climate targets and reducing methane emissions at levels needed to keep warming below 1.5°C with limited overshoot.** The modeling analysis in this report estimates that in the scenarios that China achieves carbon neutrality before 2060, China's methane emissions need to be reduced by 35% or 19 $TgCH_4$ (5-56% reduction across models) by 2030, 60% or 32 $TgCH_4$ (46-78% reduction across models) by 2050, and 73% or 39 $TgCH_4$ (62-82% reduction across models) by 2060, compared to 2020 levels. The U.S. Long-Term Strategy estimates that to reach net-zero greenhouse gas (GHG) emissions by 2050, U.S. methane emissions need to be reduced by 30% by 2030 and 40% by 2050, compared to 2020 levels (U.S. Department of State, 2021). Most recent analysis indicates that with an all-of-society climate strategy from the United States that combines actions from the federal government with actions from states, cities, and businesses, the United States can potentially reduce its methane emissions by 9 $TgCH_4$, or more than 30% below 2020 levels by 2030 (Zhao et al., 2022).

- **The majority of emissions reductions in China are driven by methane mitigation from coal mining, which account for 81% by 2030 and 62% by 2050 of total emissions reductions, compared to 2020 levels.** Near-term reductions from coal mining are driven by accelerated technology deployment (e.g., enhanced recovery of methane and oxidation of ventilated air methane), whereas significant additional long-term reductions would come from a decline in coal production as China transitions to carbon neutrality.

- **Methane mitigation in the United States is also driven by emissions reductions from the energy sector.** Based on the analysis of Zhao et al. (2022), energy-sector methane emissions can be reduced by 44% between 2020 and 2030. These emissions reductions can be achieved by adopting standards on existing and new oil and gas sources, implementing extensive leak detection and repair requirements, limiting venting and flaring, and taking actions to reduce methane emissions from active and abandoned coal mines.

- **Over half of the total technological methane abatement potential for the United States and China can be achieved by low-cost technologies ($0.25/kgCH_4$ or $10/tCO_2e$ and below). Of this half, over 82% is from the combined contribution of the two countries' energy sectors.** Consequently, the oil and gas and coal sectors should be the first and foremost targets for the United States and China to reduce methane emissions, respectively. In addition to the energy sector, both countries can reduce a comparatively large amount of methane emissions from the livestock and landfill sectors through technology deployment. However, more efforts are needed to improve technologies and reduce emissions activities, particularly for fossil fuel production.

- **Methane mitigation has multiple co-benefits, including air quality, public health, food and energy security, operational safety, and economic prosperity.** For the United States and China, reducing methane emissions by 50% in 2030 compared to 2030 baseline emissions would generate significant co-benefits in both countries. Co-benefits in the United States and China include, but are not limited to, reducing ground-level ozone by 0.25 ppb and 0.3 ppb, preventing 150 and 900 asthma-related emergency room visits, saving 1,050 and 4,800 lives from premature death, and avoiding 0.5 Mt crop yield losses in the United States and China, respectively. Moreover, 100-150 coal mining deaths can be avoided annually in 2030 in China if the coal mine methane drainage rate is increased by 1%. Methane mitigation in the oil and gas sector is estimated to create 85,000 oil and gas jobs annually in the United States (Keyser et al., 2015).

- **Long before COP26 in Glasgow, the United States and China had already established policy frameworks that contributed to methane emissions reductions, yet important gaps still need to be filled.** Policies that have methane reduction co-benefits - particularly those that address operational safety, pollution abatement, and energy security - have been the primary contributors in both countries. The United States and China have paid close attention to oil and gas and coal sectors, respectively. The U.S. has more climate-directed methane regulations for methane mitigation. It also has mandatory greenhouse gas emissions reporting systems that cover the majority of methane emissions sectors. In addition, the U.S. has four regional carbon markets that cover all major methane emissions sources, while methane emissions have not yet been included in China's National Emissions Trading Scheme. However, China focuses more on methane utilization including coal mine methane, coalbed methane and biogas. China also has stronger policy support for manure management and utilization, which is relatively understated in the U.S.

  With respect to policy instruments, the United States has a larger number of regulatory instruments and diversified, incentive-based instruments, such as federal grants, loans, and carbon markets, while China primarily utilizes planning instruments and subsidies/tax exemptions for methane mitigation. Both countries should implement more climate change-oriented policies and better quantify methane mitigation targets. In addition, both countries need to pay more attention to the sectors that have not been well-covered by existing methane policy frameworks, including enteric fermentation from livestock, rice cultivation, and abandoned coal mine methane.

- **The United States and China should pay significant attention to the "super-emitters",** as well as to the small but high-emitting sites that are not well covered by existing regulatory frameworks.

- **The United States and China need to address four key challenges in methane mitigation: insufficient and uncertain techno-economic information, lack of market-based solutions, ineffective policies, and institutional barriers.**

  - **Both countries need to improve monitoring systems and reporting mechanisms, as well as the accuracy of techno-economic information, including emissions data and mitigation costs and potential.** One key challenge of methane mitigation is uncertainty in estimating historical anthropogenic methane emissions and developing emissions inventories. Geological factors, transaction costs, and field investigation should be considered to improve the accuracy of inventory and mitigation costs and potential. The United States should strengthen the compliance of the mandatory GHG reporting scheme. China should establish methane emissions monitoring and reporting systems. Both countries need to deal with data underreporting and improve monitoring of methane emissions, especially for large emitting facilities. Both countries can collaborate on inventory methodologies and measurement, reporting, and verification (MRV) standards to improve emissions estimates.

- **Market mechanisms and supporting supply chains (e.g., transmission pipelines and power grids) need to be strengthened in both countries to better support methane-related transformation and technological innovation.** This is particularly important for methane emissions that have great utilization potential, but can experience barriers to implementation without more direct policy or financial incentives (e.g., ventilation air methane), and for smaller business actors who are vulnerable to financial risks. Innovative business models (e.g., public-private partnerships), along with emissions trading schemes, must be developed for methane emission sectors, including livestock enteric fermentation and rice cultivation, where few market mechanisms exist.

- **Policy effectiveness for methane mitigation must be improved**. Both countries need to distinguish between resource-directed (e.g., industrial policies) and pollution-directed policies (e.g., taxes), as well as balance "carrots" (e.g., subsidies) and "sticks" (e.g., fees) policies. Policy implementation should also be reinforced.

- **Both countries must take actions to tackle institutional barriers of methane mitigation**, including competing land and mining ownership, regional and urban-rural inequality and incapacity, and the societal and political economy challenges.

- **The United States and China have great potential to collaborate on methane mitigation.** Promising sectors of collaboration include the coal mining, oil and gas, landfill, and livestock enteric fermentation sectors. Potential collaborative opportunities include exploring circular economy and regenerative agriculture practices, enhancing policy learning, developing business models, and strengthening collaborations of subnational and non-state actors between the two countries.

BACKGROUND

Methane currently contributes to 20% of human-caused climate forcing (Forster et al., 2021). Rapid and sustained methane reduction is critical to keeping the world on a path to 1.5°C. Previous research suggests that global anthropogenic methane emissions can be reduced by as much as 45% by 2030, which would avert nearly 0.3°C of global warming by 2045 and would critically also reduce the level of peak warming (CCAC UNEP, 2021a). China and the United States are the first and third largest methane emitters, respectively, and collectively account for roughly one-quarter of total global methane emissions (GMI, 2022). Joint efforts of the U.S. and China to reduce methane emissions are key to limiting near-term warming, which would also improve local air quality and yield economic and health benefits.

This report provides new, in-depth analysis of opportunities and challenges for methane mitigation in the U.S. and China, as well as opportunities for improving methane mitigation outcomes through collaborative activities and research. It provides a comprehensive overview of the current methane emissions, policy frameworks, and mitigation opportunities in both countries. It also identifies options for methane mitigation and sheds light on opportunities for collaboration between the U.S. and China in terms of inventory development, policies and standards, and technology deployment. Moreover, building on new, multi-model analysis and the survey of recent literature, it provides a quantitative basis for methane mitigation potential in China and the U.S. under carbon neutrality or net-zero pathways.

CURRENT STATUS OF METHANE EMISSIONS IN THE UNITED STATES AND CHINA

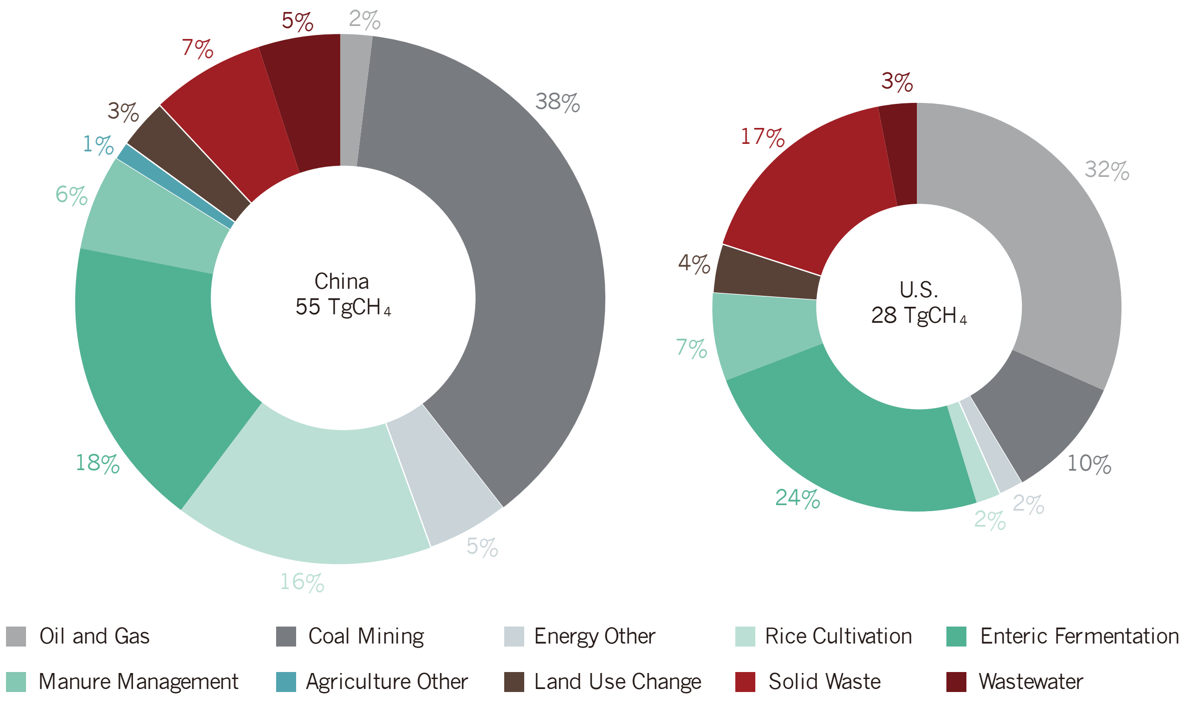
Methane Emissions in National Inventories

Methane emissions in the U.S and China differ in magnitude, sectoral makeup, and in trends over time. In 2014, the latest year that nationally reported data is available for both countries, China and the U.S. reported 55 and 28 $TgCH_4$ total methane emissions, respectively (China NCCC, 2018; EPA, 2022a).

According to national inventory data, methane emissions in both countries are primarily attributed to the energy, agriculture, and waste sectors (Figure 1). The energy sector accounts for about 40% of the total methane emissions in both the U.S. and China. The overwhelming majority of methane emissions from the energy sector in China are attributed to coal production (China NCCC, 2018). Oil and gas production accounts for nearly a third of total methane emissions in the U.S (EPA, 2022a). The agriculture sector emits more than a third of total national methane emissions in both the U.S. and China. Within the agriculture sector, sources of emissions in both countries include livestock enteric fermentation and manure management. Rice cultivation emissions are a significant source of emissions for China, accounting for about 15% of total emissions, but only account for a small portion of emissions in the U.S. Slightly more than one tenth of total Chinese and one fifth of total U.S. methane emissions are attributed to the waste sector; over half of waste emissions are attributed to solid waste and the remainder to wastewater management in both countries.

FIGURE 1. CHINA AND U.S. METHANE EMISSIONS BY SOURCE IN 2014.

This figure is based on countries' national inventories. China developed official greenhouse gas (GHG) inventories for years 1994, 2005, 2010, 2012, and 2014; the United States, as an Annex I country, submits its national GHG inventory on an annual basis. Here we compare methane emissions in 2014, the latest year that official GHG inventory data is available for both countries. Note: Shares may not sum to 100% due to rounding. Other energy is total energy emissions minus coal and oil/gas fugitive emissions.



Uncertainties in Historical Methane Emissions

Not all inventories agree with nationally reported historical emissions data (Figure 2). To enact ambitious and effective policies, historical data that reflects real-world trends is needed. However, estimating anthropogenic methane emissions accurately is challenging due to the complexity of methane emission processes, poor monitoring systems, and limited empirical observations. Methane emissions are largely from either fugitive (coal mines, oil and gas operations) or biological (flooded rice, livestock, landfills) sources, where emission rates depend on site-specific conditions and operational procedures, leading to high levels of uncertainty. There are two approaches commonly used for estimating methane emissions: (1) bottom-up calculations that use emission factors or process models to estimate emissions from historical activity levels, and (2) top-down calculations that use atmospheric measurements, generally combined with atmospheric model calculations, to estimate emissions from a given region. Inventory ranges can vary across regions and sectors significantly due to differences in methodological approaches and assumptions adopted (Figure 3). This report evaluates differences among inventories to better understand uncertainty in historical methane emissions and to help inform policies and emissions-reduction targets in the U.S. and China.

FIGURE 2. NATIONAL TOTAL METHANE EMISSIONS IN THE U.S. AND CHINA.

Note: Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) estimates are only included for China, because data is not available for the U.S. The error bar for the U.S. is the U.S. Environmental Protection Agency (EPA) uncertainty range for methane (-8 - +11%) (EPA, 2022a). Many inventories only reported an average of emissions over several years. To represent this data, we included a single data point for the latest year included in the average. Since the Global Methane Budget (GMB) data is a collection of several inventories, we included only the highest and lowest reported values, to represent the range across collected inventories. The shaded area represents the emission interval estimated from all bottom-up inventories. Triangle-shaped data points represent top-down data. Bottom-up inventories include: Community Emissions Data System (CEDS); Emissions Database for Global Atmospheric Research (EDGAR); U.S. EPA; GAINS; the China National Communication on Climate Change (China NCCC) and the U.S. Greenhouse Gas Inventory (U.S. GHGI).
Sources: Chen et al., 2022; Deng et al., 2022; Lu et al., 2021; Miller et al., 2019; Qu et al., 2021; Sheng et al., 2021; Stavert et al., 2022; Wang et al., 2021; Worden et al., 2022; Zhang et al., 2021

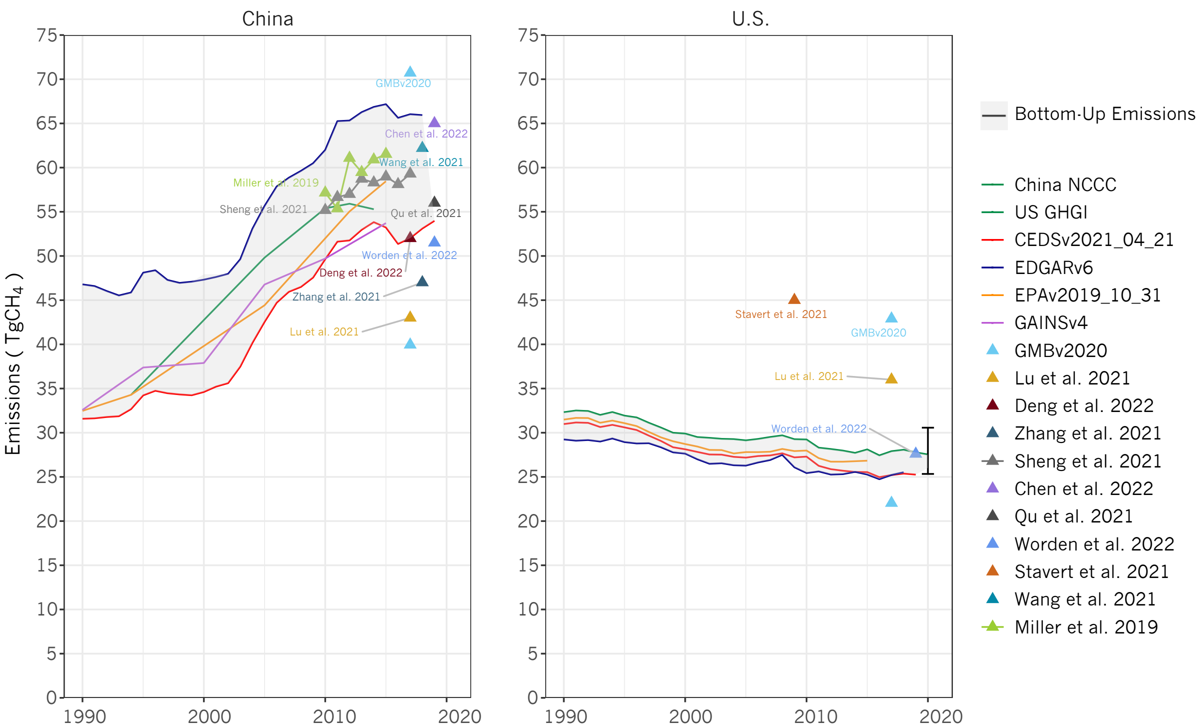
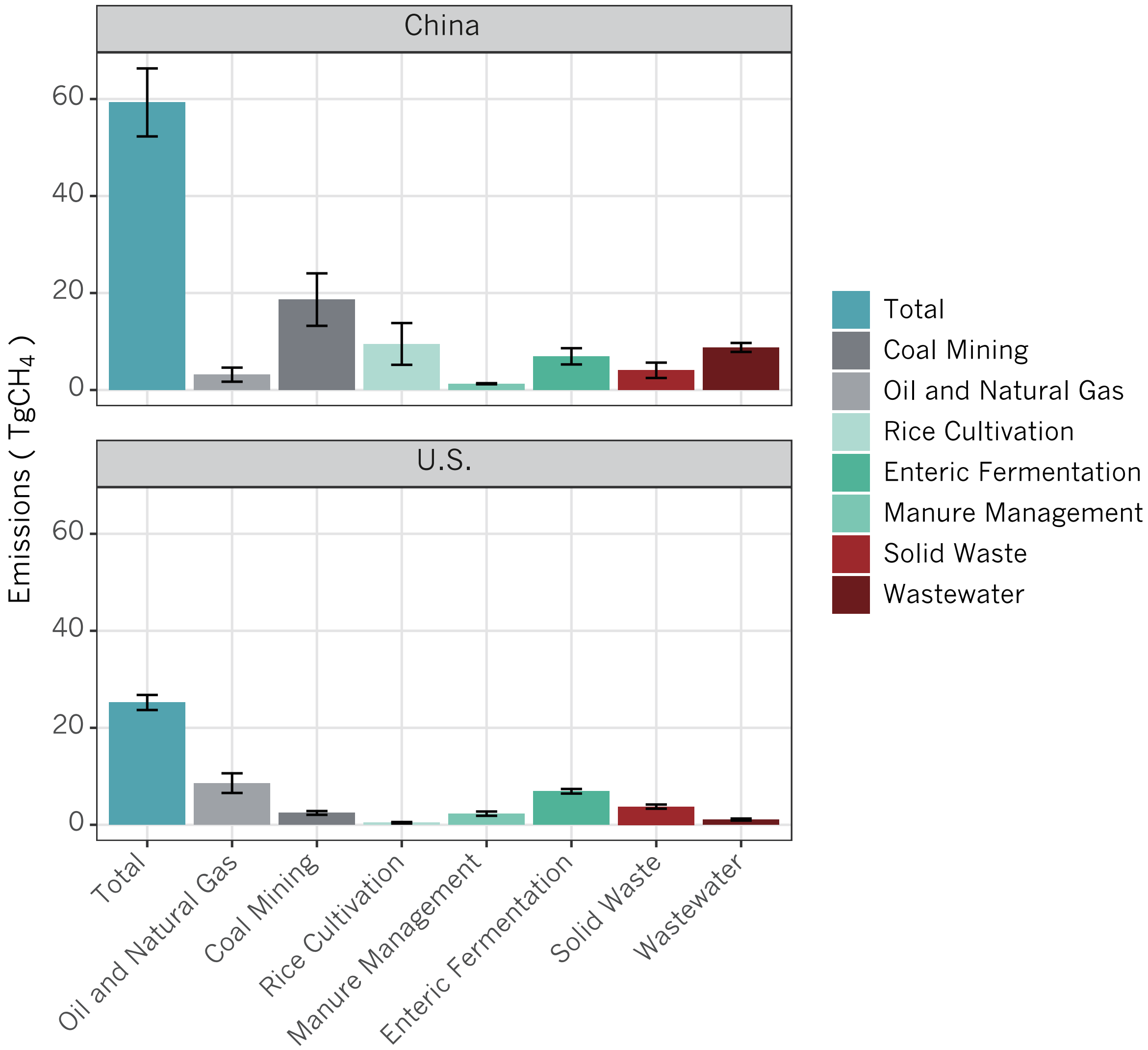


FIGURE 3. INVENTORY ESTIMATES AND UNCERTAINTIES ACROSS SECTORS IN 2017.

Bars represent the median estimate across all inventories included in Figure 2 with data reported in 2017, as it was the year with the most data available. The error bars are +/- one standard deviation from the median for each sector.



Energy

The energy sector is a major source of emissions for both the U.S. and China. According to nationally reported data, coal production and oil and gas production comprise the largest sources of emissions. Abandoned coal mine methane (AMM) emissions are an important source of emissions in China that becomes increasingly critical as the number of closed Chinese coal mines increases; however, the magnitude of AMM current emissions is still highly uncertain (Gao et al., 2021; Peng et al., 2016; Zhang et al., 2014).

Additionally, coal mine emissions can vary based on coal quality and mine depth (Gao et al., 2020; Zhu et al., 2017). These highly localized mine conditions may not be captured by aggregated or global emission factors. In the U.S., top-down inventories exceed nationally reported emissions and other bottom-up estimates for oil and gas production. Bottom-up methodologies may not adequately capture emissions from unintended events and/or emissions that occur over a short period of time (Alvarez et al., 2018; Vaughn et al., 2018; Zavala-Araiza et al., 2017).

Agriculture

Methane emissions from the agriculture sector in the U.S. and China are primarily attributed to emissions from rice cultivation and manure management and enteric fermentation from livestock. Variations in inventories' estimates of emissions from rice cultivation can be partially attributed to differences in assumptions about continuous flooding in rice cultivation ecosystems (Cheewaphongphan et al., 2019). Some inventories include methane emissions from freshwater aquaculture, which is typically co-located with or converted from rice paddies (Sheng et al., 2021). Discrepancies in the measurement of manure composition and variations, the duration of manure storage, and in environmental factors, such as temperature and wind, can vary across inventories (Hristov et al., 2018). In addition, there is limited on-farm data for a variety of manure management systems under differing climatic conditions, as well as a lack of knowledge of the variability of manure characteristics among farms (National Academies of Sciences, Engineering, and Medicine, 2018). Enteric fermentation assumptions about feed dry matter intake and composition of livestock diets vary between inventories (Hristov et al., 2018; National Academies of Sciences, Engineering, and Medicine, 2018).

Waste

Solid waste and wastewater management are the main sources of waste emissions in the U.S. and China. The solid waste sector includes both managed and unmanaged solid waste disposal sites, including landfills. In solid waste, there are large spatial and temporal variabilities among landfills and disagreements in literature regarding assumptions in the IPCC 2006 methodology for estimating emissions from landfills. These include assuming a robust relationship between the total mass of landfilled waste and annual methane emissions and that methane generation from a given mass of waste peaks in the year of disposal and declines exponentially thereafter (National Academies of Sciences, Engineering, and Medicine, 2018; Spokas et al., 2015). A scarcity of data for wastewater treatment, as well as the use of default emission factors in most inventories that do not account for regional variations and situational differences, contribute to uncertainty in China (Du et al., 2018). Default IPCC emission factors have also changed significantly over time, impacting inventory estimates (Wang et al., 2022). Certain assumptions can affect the estimation of wastewater methane emissions; these include the impact of sewers, wastewater temperature due to seasonality, and nitrite concentrations in wastewater (Zhao et al., 2019). Emissions can also be impacted by pH, retention times, and phosphorus ratio (Wang et al., 2022). Estimates may also vary in scope, as to whether or not they include both industrial and domestic/municipal wastewater treatment plants (Wang et al., 2022).

Spatial Distribution of Methane Emissions

Methane emissions vary spatially and temporally. Understanding the distribution of methane emissions is important for developing accurate historical estimates as well as for informing future policy development. Variations across inventories largely stem from differences in emission factors and underlying geospatial information. In both China and the U.S. the top ten emitting states or provinces were largely major agricultural regions, energy producing regions, and/or highly populated urban areas (Figure 4). There is significant variation in the U.S. regarding the magnitude of emissions across states. In Texas and North Dakota, the first and second highest emitting U.S. states, emissions are 40-80% higher than the third-largest emitting state, California, and the remaining top 10 states all emit < ~1.1 $TgCH_4$. In China, all inventories agreed on the highest emitting province, Shanxi Province, but the second and third highest emitting provinces varied. Two inventories ranked Shandong and Henan the second and third largest emitters, while another ranked Henan second, Inner Mongolia third, and Shandong fifth. This variation among top-emitters across inventories is potentially due to the similar level of emissions across the remaining 9 of the top 10 emitters, as they are all around 1.9-4.1 $TgCH_4$. However, all inventories agree that the Shanxi Province is significantly higher than other provinces, ranging from 62-152% higher than the second highest emitting province.

These high emitting states or provinces can have a significant impact on national total emissions. Total emissions in Texas and North Dakota, 3.7-7.3 and 2.1-3.5 $TgCH_4$, respectively, contribute to about 18% and 9% of total U.S. methane emissions. In China, the top 10 emitting states were responsible for over 56% of the country's total methane emissions across all three inventories. Shanxi Province's total emissions are 5.9-9.2 $TgCH_4$, accounting for more than 10% of China's total emissions. All three of these high emitting regions are energy producing hubs, with 60-74%, 90-95%, 89-93% of emissions in Texas, North Dakota, and Shanxi Province coming from the energy sector, respectively. These high emitting states present a policy opportunity for targeted, regional methane mitigation approaches in the energy sector.

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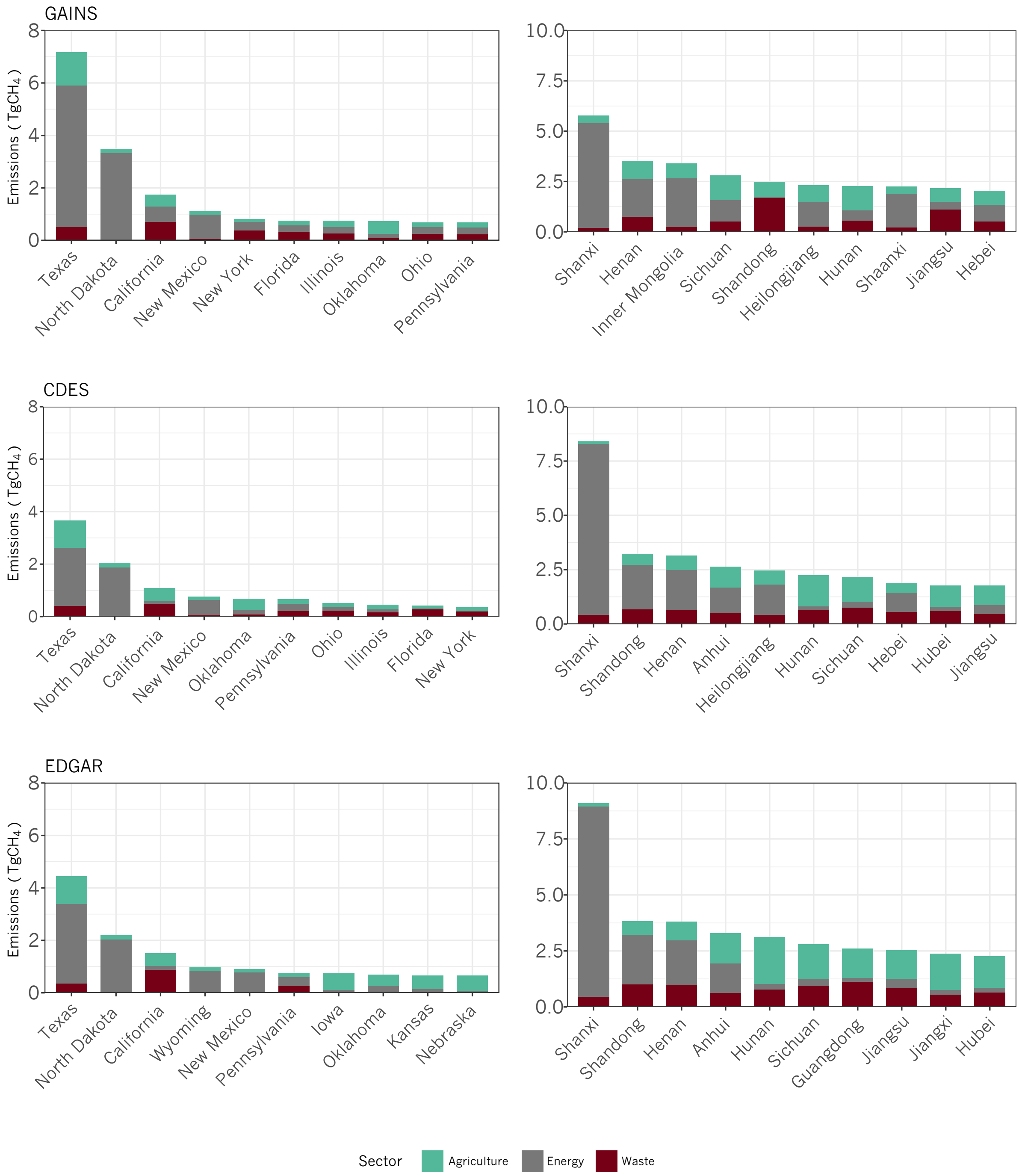
FIGURE 4. AGRICULTURE, ENERGY, AND WASTE METHANE EMISSIONS IN THE U.S. AND CHINA TOP 10 EMITTING STATES/ PROVINCES ACROSS INVENTORIES.

Note: We selected the top 10 provinces or states in terms of total emissions for each inventory. The charts only include emissions from energy, agriculture and waste, as other data is not available. GAINS data is from 2020 and CEDS and EDGAR data is from 2018. GAINS 2020 data is projected, not historical.



Measurement, Reporting, and Verification

Using locally optimized emission factors, technology and operational data, and increasing the granularity of emission factors can help to reduce uncertainty. Making activity and emission factor data publicly available will also allow for the comparison of underlying assumptions and variations across inventory sources. Understanding coal mine and abandoned coal mine emissions through enhanced data collection of emissions in both active and abandoned mines is critical for China. The oil and gas sector, especially in the U.S., should better integrate unintended and short-term events into bottom-up calculations through more frequent monitoring and emission factor updates. Collecting more data on flooding rates and harvested area size of land used for rice cultivation, known as rice paddies, and more detailed livestock production, solid waste, and wastewater treatment data is needed at the facility-level or farm-level.

CURRENT STATUS OF METHANE MITIGATION GOVERNANCE AND POLICIES IN THE UNITED STATES AND CHINA

Regarding governance and policy dimensions, methane mitigation is not exclusive to the climate change agenda since in addition to being a greenhouse gas (GHG), methane is also an explosive hazard and an energy/industrial resource, and impacts atmospheric chemistry. Governments therefore face a multi-centric challenge that calls for more collaborative, yet dispersed, governance efforts from the energy, waste, and agriculture sectors.

At the national level, responsibilities for methane mitigation are shared by various government agencies in both the U.S. and China. Key administrative elements associated with methane mitigation include developing national strategies, reducing and recovering methane emissions from the energy, agriculture and waste sectors, regulating methane for safety reasons, preventing methane leakage from pipeline transmission and transportation, and minimizing natural gas waste from coal mining and oil and gas extraction activities for mineral conservation and utilization purposes. The U.S. Environmental Protection Agency (EPA) and China's Ministry of Ecology and Environment (MEE) are the two countries' respective supervising agencies for methane mitigation. However, other than the federal government authorities, the U.S.' governance structure for methane mitigation is more complicated due to its more decentralized system of governance and land ownership. State and local-level authorities are also heavily involved in the governance of methane mitigation in the U.S.

Many policies already addressed methane emissions directly or indirectly in both the U.S. and China, thereby providing a concrete foundation for future actions. Table 1 below highlights major laws and up-to-date methane-related policies at the federal/central government level in both countries.

TABLE 1. KEY METHANE-RELATED LAWS AND POLICIES IN THE UNITED STATES AND CHINA

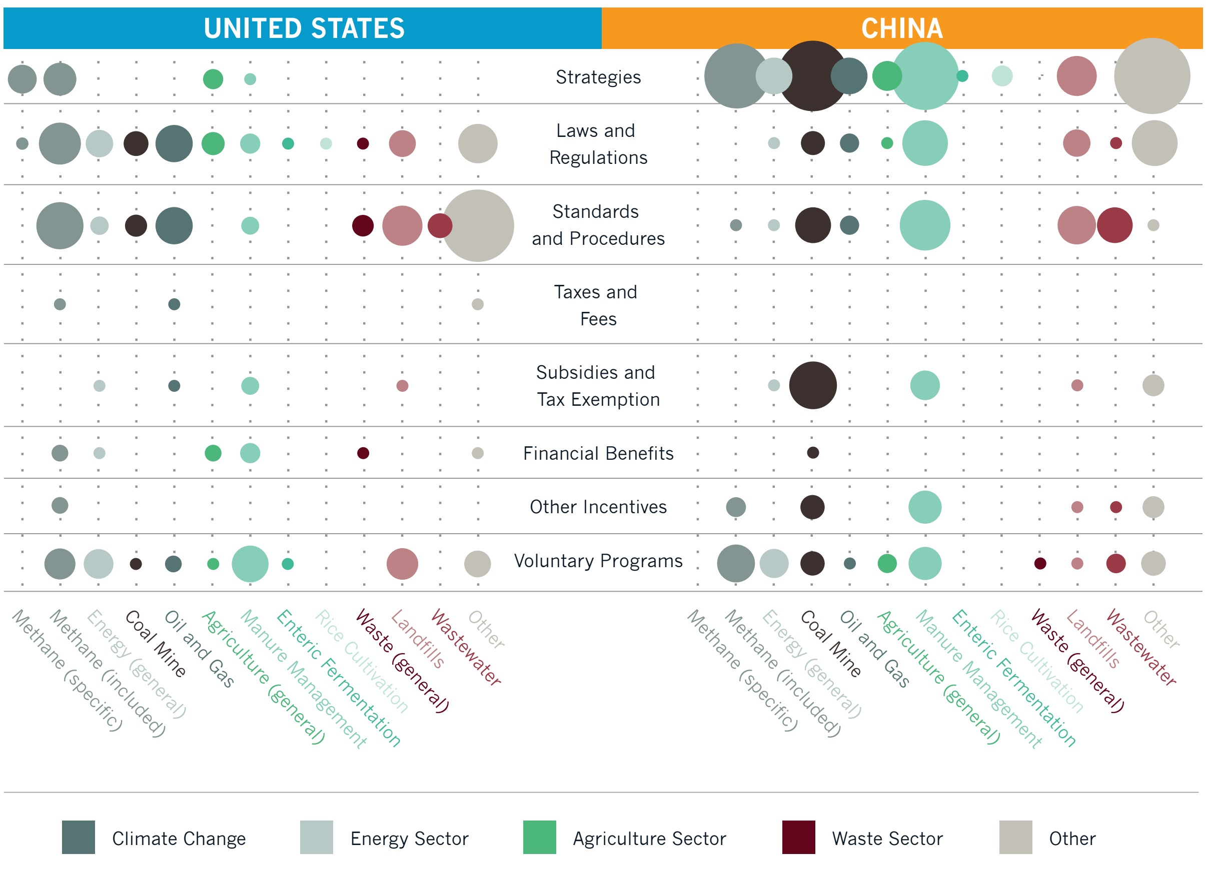
	U.S.	China
National Strategies	▶ Climate Action Plan: Strategy to Reduce Methane Emissions (2014) ▶ US Methane Emissions Reduction Action Plan (2021)	▶ China's National Climate Program (2007) ▶ China's 14th Five-Year Plan (2021) ▶ Working Guidelines for Carbon Dioxide Peak and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy (2021)
Laws	▶ Solid Waste Disposal Act (1965)/ The Resource Conservation and Recovery Act (RCRA) (1976) ▶ Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERLA)/ The Superfund Amendments and Reauthorization Act (SARA) (1986) ▶ Clean Air Act (2007) ▶ Food, Conservation, and Energy Act (2008; known as the Farm bill) ▶ Energy Policy Act (2005) ▶ Agriculture Act (2014) ▶ Protecting Our Infrastructure of Pipelines and Enhancing Safety Act (PIPES Act) (2016) ▶ Bipartisan Infrastructure Law (2021) ▶ Inflation Reduction Act (2022)	▶ Law on Prevention and Control of Environmental Pollution by Solid Waste (2020 amendments) ▶ Renewable Energy Law (2005) ▶ Animal Husbandry Law (2005) ▶ Circular Economy Promotion Law (2008) ▶ Water and Soil Conservation Law (2010) ▶ The Atmospheric Pollution Prevention and Control Law (2015 amendments) ▶ Coal Industry Law (2016 amendments) ▶ Energy Conservation Law (2018 amendments)
Energy	▶ The Greenhouse Gas Reporting Program (GHGRP) ▶ Mandatory Reporting of Greenhouse Gases from Magnesium Production, Underground Coal Mines, Industrial Wastewater Treatment, and Industrial Waste Landfills (2010) ▶ Mandatory Reporting of Greenhouse Gases: Petroleum and Natural Gas Systems (2010) ▶ Oil and Natural Gas Sector: Emission Standards for New, Reconstructed, and Modified Sources (2016,2020, updated from the New Source Performance Standards - NSPS of 2012) ▶ Waste Prevention, Production Subject to Royalties, and Resource Conservation (2016) ▶ Natural Gas STAR program ▶ Methane challenge program ▶ Coalbed Methane Outreach Program (CMOP)	▶ Notice on Tax Policies Related to Accelerating Coalbed Methane Extraction(2007) ▶ Opinions on the Implementation of Coal-Bed Methane Utilization for Power Generation (2007) ▶ Emission Standards for Coalbed Methane (Coal Mine Methane) (interim) (2008) ▶ Industrial Policy for Coalbed Methane (2013) ▶ Further Strengthening the Management of Environmental Impact Assessment in the Oil and Gas Industry (2019) ▶ Notice on Issuing the Circular on Interim Measures for the Management of the Special Fund for Clean Energy Development (2020) ▶ Emission Standard of Air Pollutants for Onshore Oil and Gas Exploitation and Production Industry (2020) ▶ Notice on Further Strengthening the Management of Environmental Impact Assessment of Coal Resources Development (2020) ▶ The Guiding Opinions on Energy-Related Work in 2021(2021) ▶ The 14th Five-Year Plan on Modern Energy System Planning (2022)

	U.S.	China
Agriculture	► The National Pollutant Discharge Elimination System (NPDES) Permit Regulation and Effluent Limitation Guidelines and Standards for Concentrated Animal Feeding Operations (CAFOs) (2003) ► Rural Energy for America Program (REAP) ► AgSTAR	► National Development Plan for Sustainability Development in Agriculture (2015-2030) (2015) ► Discharge Standard of Pollutants for Livestock and Poultry Breeding (2001) ► Notice on Improving the Price Policy of Agriculture and Forestry Biomass Power Generation (2010) ► Assessment and Evaluation Method for Rural Biogas Construction and Use (On Trial) (2011) ► Assessment Guidance on Utilization of Livestock Waste (2018) ► The "14^{th} Five-Year Plan" on Promoting the Modernization of Agriculture and Rural Areas (2021) ► Opinions on Promoting High Quality Development of Animal Husbandry (2020) ► The 14^{th} Five-Year Plan on Soil, Underground Water and Rural Ecological and Environmental Protection (2021) ► Opinions on Implementing Accelerating Rural Energy Transformation and Development to Promote Rural Revitalization (2021) ► Guidelines on Promoting Ecological Farms (2022) ► Action Plan for Agricultural and Rural Pollution Control (2021-2025) (2022) ► Implementation Plan on Emissions Reduction and Carbon Sequestration for Agriculture and Rural Areas (2022)
Waste	► The Greenhouse Gas Reporting Program (GHGRP) ► Mandatory Reporting of Greenhouse Gases from Magnesium Production, Underground Coal Mines, Industrial Wastewater Treatment, and Industrial Waste Landfills (2010) ► Standards for the Use or Disposal of Sewage Sludge (1993) ► Standards of Performance for New Stationary Sources and Guidelines for Control of Existing Sources: Municipal Solid Waste Landfills (1996, updated in 2016, known as NSPS) ► National Emission Standards for Hazardous Air Pollutants: Municipal Solid Waste Landfills (2003, updated in 2020. known as the MSW landfills NESHAP) ► Emission Guidelines and Compliances Times for Municipal Solid Waste Landfills (2016) ► Landfill Methane Outreach Program (LMOP)	► Guideline on Best Available Technologies of Pollution Prevention and Control for Treatment and Disposal of Sludge from Municipal Wastewater Treatment Plant (on Trial) (2010) ► Standard for Pollution Control on the Landfill Site of Municipal Solid Waste (2008) ► Implementation Plan for Improving Synergistic Effect of Pollution Reduction and Carbon Reduction (2022) ► Guidelines for Overall Management of Urban and Rural Sewage in County (City) Regions (on Trial) (2014) ► The Action Plan for Agricultural and Rural Pollution Control (2021-2025) (2022)

In addition, notable progress has been made since the U.S.-China Joint Glasgow Declaration at COP26 in 2021. By August 2022, 14 congressional bills and 10 policies in the U.S. and China, respectively, that directly address methane mitigation had been proposed, issued, or became law (See more details in full report). Among them, the Inflation Reduction Act of 2022 (IRA) was passed as a historic climate law and is currently the strongest regulation on methane emissions in the U.S. In China, the most recent policies have filled some key policy gaps, particularly in the agriculture sector. China is also developing its first national action plan on methane mitigation, which is expected to be issued in the near-term.

However, more efforts need to be made by both countries to accelerate future actions on methane mitigation. It is critical to identify important policy gaps by understanding how methane emissions have been addressed in the existing policy frameworks. This report provides a systematic mapping and review of existing methane-related policies at the federal and central levels in the U.S. and China (Figure 5). A total of approximately 500 of the most relevant policy documents - around 250 for each country - were selected, reviewed and categorized according to policy instrument type, including strategic planning, regulatory policies, incentive-based policies and voluntary policies.

FIGURE 5. A COMPARISON OF THE U.S.AND CHINA IN TERMS OF METHANE-RELATED POLICIES BY SECTOR AND POLICY TYPE.



Based on an extensive review of methane-related policies in both countries, this report details the development of the existing policy frameworks by sector, summarizes the actions that both countries have taken, and identifies gaps in the existing policy frameworks (Figure 6):

- **Policies that have methane reduction co-benefits - particularly those that address operational safety, pollution abatement and energy security - have been the primary contributors to existing mitigation actions in both countries.** This indicates the importance of synergies for methane mitigation. For example, safety measures in both countries contributed to the initial deployment of methane monitoring and leakage detection systems, which are fundamental for inventory data collection. The landfill sector in the U.S. and the oil and gas sector in China have both set quantified targets to reduce non-methane hydrocarbon pollutants with a co-benefit of methane emissions reduction. China's recent air pollution regulation for the oil and gas sector also aims to strengthen methane leakage detection. In addition, methane recovery and utilization for energy security purposes, such as coal mine methane (CMM), coalbed methane (CBM), and biogas play an important role in the development of methane policies in both countries, but particularly in China. Existing policies have laid a foundation for better supporting methane mitigation actions in both countries and may already help to avoid higher levels of methane emissions.

- **Both countries could better quantify their methane mitigation targets and enact more climate policies that directly support those targets.** So far, the U.S. has more climate-related policies for methane mitigation than China. For example, the U.S. has supported quantified methane targets through the Global Methane Pledge's collective goal of 30% reductions by 2030. It has already mandated GHG reporting from underground coal mines, industrial wastewater, industrial waste landfills, and oil and gas systems. It also has four regional carbon emissions trading schemes that cover major methane emissions sources, including AMM, enteric fermentation, and rice cultivation. These elements are not yet available in China's methane policy frameworks. However, both countries do not have economy-wide methane emissions reduction targets. Few sectoral emissions reduction targets exist except for the oil and gas sector in which the U.S. has some level of quantified methane emissions reduction mandates (e.g. 95% reduction of methane emissions from wet seal centrifugal compressors and pneumatic pumps) and China has quantified targets for methane emissions intensity committed by major oil and gas companies (all of which are state-owned enterprises and account for over 90% of oil and gas production in China). Except for quantified technical standards regarding safety and pollution, many of the quantitative targets in China are industry-related such as the development targets of CMM/CBM and biogas.

- **Both countries have paid uneven attention across sectors, which calls for necessary sectoral policies to close the gaps.** The U.S. and China have both paid close attention to the oil and gas and the coal mine sectors - mostly CMM and CBM, respectively. And both have paid the least attention to livestock enteric fermentation, rice cultivation, and AMM emissions.

  Specifically, the U.S. federal government has paid relatively high attention to: (1) the oil and gas sector, in which a certain level of direct methane emissions reduction requirements, economic incentives, and methane fees have been applied; (2) the landfill sector in which non-methane organic compounds (NMOCs) are controlled by a specific target and act as a surrogate for methane emissions. Not enough attention has been paid by the federal government to the following sectors: (1) the livestock enteric fermentation sector, for which few specific regulations have been developed at the federal level, except for broad funding opportunities for GHG emissions reduction in the agriculture sector ensured by the IRA; (2) the coal mine sector, in which few federal regulations have yet been enacted to reduce CMM and AMM emissions; (3) rice cultivation, in which few regulatory activities are found in the existing policy framework.

The Chinese government has paid higher attention to (1) the coal mine sector, in which the recovery and development of CMM/CBM have been strongly supported by various industrial policies, and (2) the livestock manure sector, in which manure utilization is mandatory, and biogas recovery, in particular, has been extensively promoted. The sectors to which the Chinese government has paid the least attention are: (1) the enteric fermentation and rice cultivation sectors, in which no particular policies exist to address methane emissions, and (2) AMM emissions, which are not specifically addressed in the current policy framework.

- **Commonly-utilized policy types in the U.S. and in China are distinct, which creates opportunities for sharing experiences and policy learning.** The U.S. has primarily utilized regulatory policy instruments which limit methane emissions by mandatory requirements and legal compliance, and more diversified economic incentives, such as federal grants, tax credits and preferential loans (as highlighted by the IRA), and carbon markets. China has used more planning instruments - particularly industrial policies and Five-Year-Plans to encourage methane utilization. China tends to adopt subsidies and tax exemptions as key incentive-based instruments.

FIGURE 6. SUMMARY OF KEY POLICY AREAS.

This figure summarizes the key policy areas of the U.S. and China related to methane mitigation. The * in the climate change category indicates that the U.S. has partially committed to methane emissions reduction targets, subject to climate change. The * in the oil and gas category indicates that China only has mitigation targets across major oil and gas companies.

SECTOR	SAFETY REGULATIONS	POLLUTION REGULATIONS	GHG-ORIENTATED REGULATIONS	DIRECT EMISSION REDUCTION TARGETS	METHANE RECOVERY INCENTIVES AT THE NATIONAL LEVEL	MANDATORY GHG EMISSIONS REPORTING	CARBON MARKETS
Climate change	N/A	N/A	U.S.	None*	U.S.	U.S.	U.S.
Coal mines (CMM)	U.S., China	China	None	None	China	U.S.	U.S.
Coal mines (AMM)	None	None	None	None	None	None	U.S.
Oil & Gas	U.S., China	U.S., China	U.S.	U.S., China*	U.S.	U.S.	U.S.
Transmission, Leakage, and Storage	U.S., China	U.S., China	None	None	U.S.	U.S.	U.S.
New Sources	U.S., China	U.S., China	U.S.	U.S.	U.S.	U.S.	U.S.
Existing Sources	U.S., China	U.S., China	None	None	U.S.	U.S.	U.S.
Landfills	U.S., China	U.S., China	U.S.	None	U.S., China	U.S.	U.S.
New Sources	U.S., China	U.S., China	None	None	U.S., China	U.S.	U.S.
Existing Sources	U.S., China	U.S., China	None	None	U.S., China	U.S.	U.S.
Wastewater	U.S., China	U.S., China	None	None	China	U.S.	U.S.
Manure Management	N/A	U.S., China	None	None	U.S., China	None	U.S.
Enteric Fermentation	N/A	N/A	None	None	U.S.	None	U.S.
Rice Cultivation	N/A	N/A	None	None	U.S.	None	U.S.

U.S. CHINA N/A NONE

CHALLENGES OF METHANE MITIGATION IN THE UNITED STATES AND CHINA

Given existing policy gaps, numerous challenges exist that could halt ambitious actions for methane mitigation in both the U.S. and China. Key issues in the U.S. and China for each sector are identified (Table 2)

TABLE 2. IDENTIFIED KEY ISSUES OF METHANE MITIGATION IN THE U.S. AND CHINA BY SECTOR

<table>
<tr><th></th><th>U.S.</th><th>China</th></tr>
<tr><td rowspan="2">Coal Mine</td><td colspan="2">► AMM has not been addressed adequately in existing policy frameworks
► Lack of effective market mechanisms/financial support for low-concentration methane recovery and commercialization, specifically for ventilation air methane (VAM)
► Overlapping licenses between coal mines and CMM/CBM/AMM
► Inherent physical and geological challenges for CMM/CBM extraction and profitability</td></tr>
<tr><td>► Lack of federal policies/regulations for methane reduction or utilization in the coal mine sector
► Institutional barriers related to land ownership and abandoned coal mine ownership</td><td>► Insufficient/inaccurate techno-economic data for inventory, abatement costs and potential
► Underreporting of CMM data by coal mine companies
► Lack of gas transmission facilities especially for medium and small coal mines
► Existing supporting policies for CMM/CBM are not effective enough
► Strengthened coal demand and uncertain coal retirement plans</td></tr>
<tr><td rowspan="2">Oil & Gas</td><td colspan="2">► Oil and gas companies are underperforming in addressing methane emissions leaks
► Institutional barriers related to land or mineral ownership
► Methane emissions from orphan wells are understated in the existing policy framework</td></tr>
<tr><td>► Emissions from this sector appear to be underreported
► Small wells have not yet been fully covered by current regulations
► Small or less well-financed companies may not be able to afford to plug abandoned wells or use other costly methane abatement methods.
► Ineffective policy implementation of Bureau of Land Management (BLM) waste prevention regulations - BLM never implemented the gas capture requirement due to legal challenges (GAO, 2022)
► Inflexibility of EPA regulations for approving alternative technologies(GAO, 2022)
► The Federal Energy Regulatory Commission (FERC) has no specific plans to address pipeline leakage (Daly, 2022).
► Concerns about encouraging oil and gas production due to the new leasing arrangements for wind power in the IRA</td><td>► Insufficient techno-economic data for inventory, abatement costs and potential
► Inadequate regulations for oil and gas methane emissions
► No official methane mitigation targets at the national level
► Some technological options are not cost-effective, requiring more capital investment/financial support</td></tr>
</table>

<table>
<tr><th></th><th>U.S.</th><th>China</th></tr>
<tr><td rowspan="2">Landfills</td><td colspan="2">► Inadequate regulations for direct methane emissions reduction in this sector other than biogas industrial policies</td></tr>
<tr><td>► Landfill methane emissions have not attracted enough attention from policy makers and investors
► Existing regulations do not cover small landfill sites, therefore, only half of the landfills in the U.S. have gas recovery systems (RRS, 2021)
► The smaller landfills (with a capacity of 1k-100k tons per year) contribute the majority of methane emissions of the sector (RRS, 2021)
► Other barriers to increased methane recovery at landfills include informational issues related to site potential, permitting issues, financing issues, and difficulties in finding energy customers</td><td>► Large uncertainties exist in techno-economic data for inventory, abatement costs and potential
► Challenges of scaling up biogas production sites and commercialization
► Landfill gas collection devices are not fully deployed in the existing landfill sites.
► Waste management in rural areas is facing challenges in waste collection, sorting and transportation</td></tr>
<tr><td rowspan="2">Wastewater</td><td colspan="2">► Inadequate methane emissions regulations for wastewater treatment
► Challenges of commercializing wastewater methane recovery due to high capital cost</td></tr>
<tr><td>► Methane emissions from wastewater treatment facilities are often flared or burned - very little is recovered and utilized (Ha et al., 2022).
► Biogas is not recognized as a renewable energy source across all states’ Renewable Portfolio Standards (RPS) programs(Ha et al., 2022).
► Financial and budget hurdles are often high for aging WWTPs’ maintenance and operation (Seiple et al., 2020)
► The benefit of methane recovery technologies is poorly communicated to the decision-makers and the public (Ha et al., 2022)</td><td>► Large uncertainties exist in techno-economic data for inventory, abatement costs and potential
► The increased number and capacity of municipal wastewater treatment plants (WWTPs) in China have driven methane emissions (Zhao et al., 2019)
► Methane emissions are substantial but vary greatly depending on regional and technological differences (Zhang et al., 2021a)
► Rural wastewater treatment is still underdeveloped and leaves great uncertainties in methane mitigation (Xu et al., 2020)</td></tr>
<tr><td rowspan="2">Manure Management</td><td colspan="2">► Challenges of scaling up anaerobic digesters and commercializing biogas production</td></tr>
<tr><td>► Biogas is not recognized as a renewable energy source across all states’ Renewable Portfolio Standards (RPS) programs
► Inadequate regulations for methane emissions reduction in this sector</td><td>► Lack of policies for direct methane emissions reduction other than biogas industrial policies
► Biogas facilities are underused in many rural areas despite massive deployment and economic incentives
► Insufficient techno-economic data for inventory, abatement costs and potential</td></tr>
<tr><td rowspan="2">Enteric Fermentation</td><td colspan="2">► Feed additives and manure processing systems can be expensive
► Less addressed in the existing policy framework and business practices.</td></tr>
<tr><td>► Innovative solutions are needed to push forward the deployment of technological options, such as the development of enteric methane inhibitors, which need regulatory procedures for drugs (Tricarico et al., 2022)</td><td>► Huge uncertainties exist in technological and governance options</td></tr>
</table>

	U.S.	China
Rice Cultivation	▶ Not included in the national policy agenda yet	
	▶ Absent from IRA	▶ Methane mitigation in this sector will have conflict with the objective of food security ▶ Lack of incentives for local policy implementation ▶ It is a diffuse source which requires effective and strong rural governance capacity and innovative policy instrument ▶ The economic and technological feasibility and governance models in this sector are still underexplored

This report identifies four key challenges to methane mitigation, including techno-economic uncertainties, insufficient market-based solutions, policy ineffectiveness, and institutional barriers across the methane emissions sectors.

(1) Insufficient and uncertain techno-economic information. A large gap remains in the data collection process. There are many uncertainties in terms of data accuracy, especially for China.

- **Insufficient and inaccurate inventory information.** The discrepancies in historical emissions data is largely due to their high dependence on assumptions and estimates of production activities and emission factors, rather than on real-time, on-site measurements (UNECE, 2021). In this regard, the U.S. has higher consistency across bottom-up inventories in part due to its more established mandatory GHG emissions reporting schemes, whereas China has not yet established a systematic monitoring and reporting scheme for methane emissions. However, even with an emissions reporting system, there are cases in both countries in which the data may not be accurate because of data underreporting, underestimation, and/or equipment insufficiency or deterioration (Duren et al., 2019; U.S. House of Representative Committee on Science, 2022; Zhang, 2021). Moreover, methane emissions monitoring and reporting are completely missing from some sectors. Specifically, both the U.S. and China do not mandate monitoring emissions from abandoned coal mines, though the U.S. reports abandoned coal mine methane in annual inventory to the UNFCCC.

- **Uncertainty of the technological costs and potential.** Uncertainties also remain for the technological costs and abatement potential of methane mitigation. Failing to incorporate transaction costs (e.g. negotiation or regulatory costs), controversial and inaccurate country-specific data on technological costs, as well as the differences in the physical and geographical endowments can lead to large variations in the mitigation costs.

- **Uncertainty of future activities.** The projected activities and associated methane emissions also face significant uncertainty; however, the level of these activities and their trends are determined by complex socioeconomic/sociopolitical factors and associated policies, which are often hard to predict and can create significant uncertainty in methane emissions.

(2) **Lack of market-based solutions.** Incentivizing methane mitigation efforts, such as forging market mechanisms and developing business models, is essential for minimizing the social costs of methane emissions. Both the U.S. and China have seen pitfalls in these mechanisms.

- **Insufficient market mechanisms/business models for less cost-effective technology deployment.** For example, the recovery and utilization of low-concentration methane, particularly ventilation air methane (VAM), whose concentration is lower than 0.4%, are economically challenging worldwide. However, VAM usually makes up around 70% of total coal mine methane (CMM) emissions. The lack of market mechanisms to drive down technological costs and improve productivity for VAM recovery has been a major challenge for CMM mitigation. VAM manufacturers have few incentives for further R&D to improve designs and reduce costs without confirmed markets (CSIRO & GMI, 2018). In addition, market mechanisms to prevent methane emissions directly instead of encouraging the usual "emit and recover" actions have been underexplored.

- **Business models are seldom explored and less understood in the livestock enteric fermentation and rice cultivation sectors.** In particular, one of the biggest challenges is the difficulty in recovering those methane emissions, because most of the market incentives in other methane emissions sectors come from methane gas utilization. Therefore, methane mitigation efforts for emissions from livestock enteric fermentation and rice paddies are solely a form of public good provision rather than attainment of private gains. In the absence of robust carbon (offset) markets, few incentives would exist if the ranch owners and farmers are the only ones paying, but receiving no rewards in return (Foster, 2022; Searchinger & Waite, 2014).

- **A lack of financing mechanisms poses a greater threat to smaller business actors, who may have a larger impact on methane emissions.** Many small businesses, such as landfill sites or wastewater treatment plants with smaller capacity, are facing higher financial constraints and tighter budgets. Without proper market and financing mechanisms to help them stay in business, they are most likely to be affected by methane mitigation requirements. However, some small businesses, such as small-scale landfills and small oil and gas companies which may abandon the wells due to financial challenges, have a significant impact on methane emissions - abandoned oil and gas wells emit a large amount of methane and require high costs to plug them.

(3) **Ineffective policies.** Despite a large number of methane-related policies in both countries, the existing policy frameworks for methane mitigation do not necessarily translate into desired outcomes.

- **Ambiguous principles for developing policy toolkits.** A basic question for the adoption of effective methane mitigation policies is: To what extent should methane emissions be treated as hazards/pollutants and to what extent as resources? Additionally, should the government encourage and reward emitters to cut methane emissions or penalize them for not doing so? If methane emissions are considered as resources, policies will naturally be focused on supporting methane recovery and utilization. However, that approach focuses on methane gas production rather than methane emissions reduction. As a result, there will be a higher demand for methane production activities, which may actually lead to an increase in methane emissions in the long run. If methane emissions are treated as hazards/pollutants, the emitters should be mandated by regulations (e.g., laws and rules) to reduce emissions and would be penalized if they fail to comply. In addition to the resource-versus-pollution dichotomy, there is another debate on whether the government should reward those who reduce methane emissions by "carrot" policies (e.g., preferential policies, subsidies, and tax exemptions) to encourage methane emissions reduction or penalize those who do not reduce emissions by "stick" policies (e.g., taxes, fines, and other penalties). Both principles have pros and cons, the challenge is to balance and set boundaries between the two principles, and decide when "carrots" rather than "sticks" should be used, and vice-versa.

- **Ineffective and inconsistent policy implementation.** Some existing policies have not been well-implemented. For example, in the U.S., EPA and BLM have encountered administrative and legal challenges in implementing rules for methane emissions in the oil and gas sector. Frequently changed regulations inevitably create chaotic situations and compliance issues during implementation. In China, implementation issues have mostly been related to CMM recovery and utilization, as well as in manure management in rural areas. The targets of CMM/CBM utilization have never been met due to various and persisting challenges, including technical difficulties, low profitability, inadequate supporting facilities (e.g., lack of access to transmission networks and pipelines) and administrative barriers (Lau et al., 2017; Tao et al., 2019; Yang, 2009). For manure management, despite billions worth of financial resources invested in rural biogas facilities, biogas accounts for only 1% of energy consumption in rural China, and the utilization rate of biogas is decreasing (Chen et al., 2020). It is common that manure digesters across many regions in China are idled due to various socio-economic factors.

(4) Institutional barriers are systemic challenges embedded in existing institutions (e.g., political systems, administrative arrangements, land property rights) and will most likely prevail unless fundamental changes are made. Methane mitigation in the U.S. and China has encountered multiple institutional barriers, which require more strenuous efforts to overcome.

- **Land and mining ownership.** Ownership that is not clearly defined can cause conflicts among resource owners and hinder methane mitigation efforts. Specifically, the mining rights of CMM and coal mines are usually separated in the current mining regulatory systems of both countries (Banks, 2012; Denysenko et al., 2019). This separation increases the transaction cost of CMM recovery and utilization and complicates AMM capture and utilization. Ineffective coordination may pose a threat to coal mine safety and result in lower CMM/CBM productivity. Land ownership rights also have a significant impact on the effectiveness of methane mitigation. In China, the centralized land ownership and procedures of development right approval make the implementation of methane emissions regulations for mining more straightforward. The situation is more complicated in the U.S., where land and mineral resources have much more complex ownership structures. Regulatory frameworks for land use and mining activities vary across jurisdictions, making interjurisdictional activities more challenging.

- **Socio-economic gaps and regional and urban-rural inequality.** The capacity of methane mitigation varies due to large socio-economic gaps and inequalities. Economically underperforming regions might be less capable of delivering ideal policy outcomes due to insufficient financial and human resources, as well as a lack of robust governing institutions. These challenges will prevail unless efforts are made to close the socio-economic gaps. On the other hand, it is important to understand if methane mitigation practices can benefit regional development and alleviate inequality. However, both mechanisms are seldom explored and understood. For example, this institutional barrier is particularly highlighted by the emission sectors that are closely related to rural areas in China, including rural landfills, rural wastewater, livestock manure and enteric fermentation, and rice cultivation. Therefore, rural development covers the majority of, yet the most challenging methane issues in China.

- **Social acceptance and political economy challenges.** Raising ambitions for methane mitigation will inevitably create winners and losers in the short term due to the associated costs. A key question is, who bears these costs? Both the U.S. and China have experienced cases where further actions in methane mitigation were impeded by social and political economy factors that were much more complicated than simply deploying cost-effective technologies. These societal challenges can generate indirect costs for methane mitigation. For example, energy and food security related concerns have been raised in policy conversations on future methane mitigation pathways.

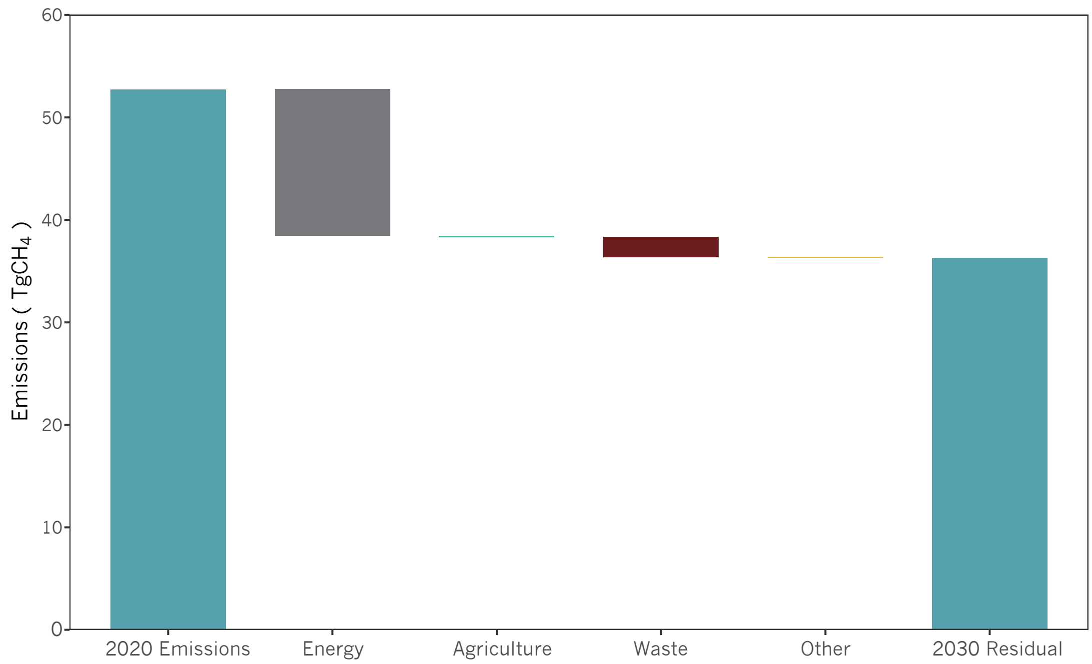
OPPORTUNITIES FOR REDUCING METHANE EMISSIONS IN THE UNITED STATES AND CHINA

Mitigation Potential from Modeling Studies

This analysis conducted a multi-model exercise involving four national and global models that shared results from scenarios consistent with China's latest nationally determined contribution and long-term strategy targets. The modeling analysis in this report estimates that in the scenarios that China achieves carbon neutrality before 2060, China's methane emissions need to be reduced by a median of 35% or 19 $TgCH_4$ (5-56% reduction across models) by 2030, 60% or 32 $TgCH_4$ (46-78% reduction across models) by 2050, and 73% or 39 $TgCH_4$ (62-82% reduction across models) by 2060, compared to 2020 levels (Figure 7). Most models' methane emissions reductions are largely driven by reductions in emissions from coal, especially in the near-term, as emissions reductions from coal account for a median of 81% and 62% of total emissions reduction by 2030 and 2050, respectively. However, the magnitude of emissions reduction and abatement potential for other sectors varied across models. In 2050, models suggest that rice cultivation, enteric fermentation, and oil and gas would each contribute to about 8% of total emissions reductions.

FIGURE 7. METHANE EMISSIONS REDUCTIONS BY SECTOR IN CHINA BETWEEN 2020 AND 2030 IN CARBON NEUTRALITY SCENARIOS.

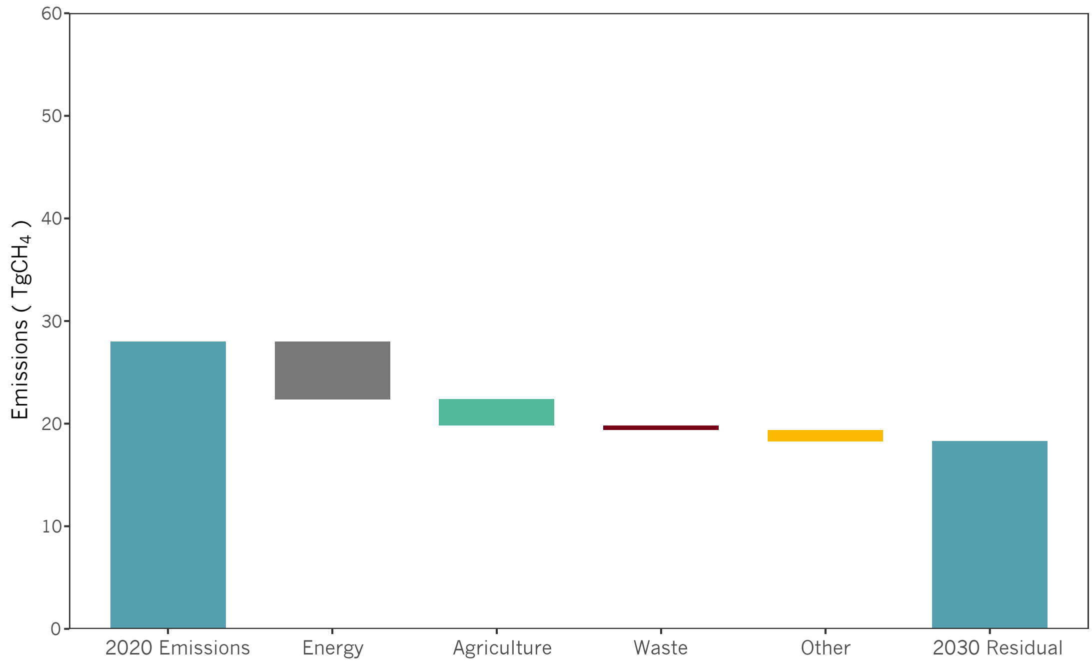
This report uses multi-model analysis to assess methane mitigation in China. The models are different in baseline emissions, sectoral resolution, modeling approaches, underlying assumptions, and emissions pathways, and therefore, have slightly different methane mitigation pathways. This chart shows methane mitigation between 2020 and 2030 from the Global Change Analysis Model in a scenario where CO_2 emissions peak around 2025 and reach net-zero around 2050 and GHG emissions reach net-zero around 2060. Other models, although differ slightly in absolute amount of methane emissions and mitigation, also indicate that more than 70% of methane mitigation between 2020 and 2030 comes from the energy sector.



The U.S. Long-Term Strategy estimates that to reach net-zero greenhouse gas emissions by 2050, U.S. methane emissions need to be reduced by 30% by 2030 and up to 40% by 2050, compared to 2020 levels (U.S. Department of State, 2021). Most recent analysis indicates that with an all-of-society climate strategy from the United States, combining actions from the federal government with actions from states, cities, and businesses, including the methane fee from IRA, the United States can potentially reduce its methane emissions by 9 $TgCH_4$, or more than 30% below 2020 levels by 2030 (Zhao et al., 2022) (Figure 8).

FIGURE 8. METHANE EMISSIONS REDUCTIONS BY SECTOR IN THE UNITED STATES BETWEEN 2020 AND 2030 WITH FEDERAL, STATE, LOCAL, AND BUSINESS ACTIONS.

Based on the analysis of Zhao et al. (2022), comprehensive U.S. actions can lead to significant reductions in methane emissions between 2020 and 2030, driven by emissions reductions in the energy and agriculture sectors. Note that the U.S. analysis in this figure (Zhao et al., 2022) and the analysis of methane mitigation in China shown in Figure 7 are country-specific and based on different modeling analyses and scenarios.



Sectoral Priorities Based on Technical Mitigation Potential

This report further analyzes the sectoral priorities and the low-hanging fruit sectors, based on the share of the emissions of each sector and the amount of low-cost abatement potential by 2030 (low-cost technologies here are defined as technologies with costs of \$0.25/$kgCH_4$ or \$10/tCO_2e and below) (Figure 9).

For the U.S., low-cost technologies contribute to 51% of the total abatement potential.

- **The oil & gas and coal mine sectors are the low-hanging fruits.** For the oil and gas and the coal mine sectors, 65% and 83%, respectively, of the sectoral mitigation potential can be realized with technological costs at \$0.25/$kgCH_4$ and below by 2030.

- **The livestock and landfill sectors have promising opportunities, yet challenges need to be addressed with respect to technological options.** For the livestock sector, the absolute amount of methane emissions, which can be reduced with low-cost technologies, is comparatively large. However, it is important to explore business models and policies that can reduce technological costs more effectively. For the landfill sector, 69% of the sectoral abatement potential can be achieved at a low-cost level. Actions must be taken to encourage technological improvements and innovation, as well as to reduce emission activities.

- **The wastewater and rice cultivation sectors are less urgent; however, efforts can be made when possible.** Both sectors account for a small share of total methane emissions and the abatement potential for both sectors is low and costly. Therefore, while these sectors might not be the priority for the U.S. in methane mitigation, actions can be taken to address some of these challenges when possible.

For China, about 62% of the total abatement potential can be mitigated by 2030 using low-cost technologies.

- **The coal mine sector is the low-hanging fruit.** 75% of the total sectoral abatement potential for this sector can be actualized with low-cost technology.

- **A comparatively large amount of emissions can be reduced in the landfill and livestock sectors at a low-cost level.** Both of these sectors combined have greater than twice the mitigation potential of oil and gas at any cost in China. However, challenges need to be addressed to increase the sectoral abatement potential and lower the technological costs.

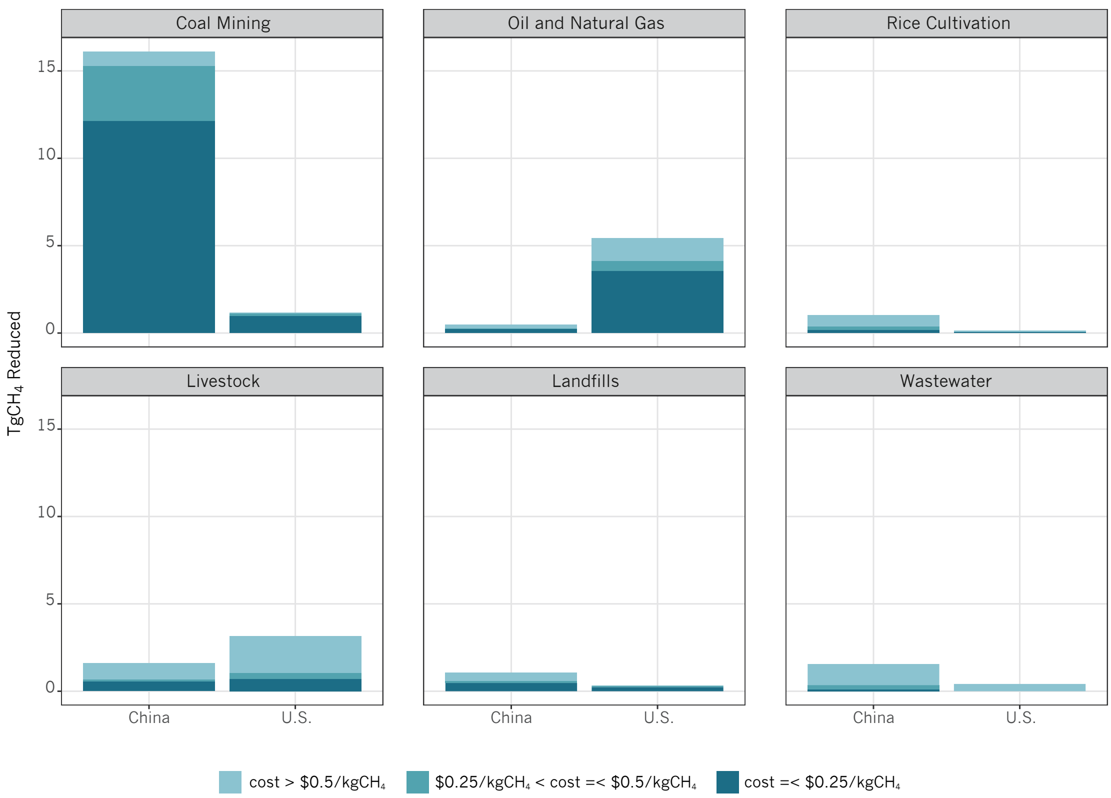
The low-cost abatement potential of the livestock and the landfill sectors contribute to only 34% and 44% of the sectoral potential, respectively.

- **The oil and gas sector is less influential on total emissions but has promising opportunities.** Around half of the emissions can be mitigated by existing technologies, and 47% of the abatement potential is contributed by low-cost technological opportunities.

- **Methane mitigation in the wastewater and rice cultivation sectors are costly.** Most of the sectoral mitigation potential of these two sectors can be achieved only by high-cost technologies.

FIGURE 9. METHANE MITIGATION TECHNICAL POTENTIAL BY SECTOR IN THE U.S. AND CHINA IN 2030 ($TgCH_4$).

This figure shows potential methane emissions reductions in 2030 by mitigation cost ranges ($USD/kgCH_4$). It is constructed from abatement cost curves using different technologies. Low-cost technologies are defined here as cost equals to or lower than $\$0.25/kgCH_4$ ($\$10/mtCO_2e$ using 100-year GWP coefficient from the Fourth Assessment Report of the United Nations Intergovernmental Panel on Climate Change). Data comes from EPA Non-CO_2 Greenhouse Gas Data Tool (EPA, 2022b).

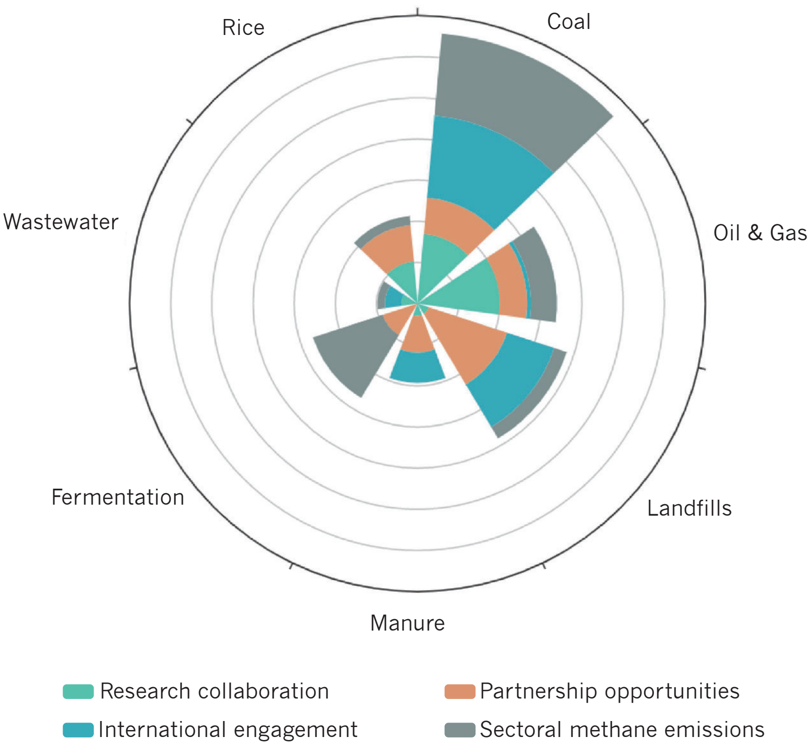


Readiness and Potential of U.S.-China Collaboration

This report has identified the sectors and policy areas that the U.S. and China are most ready to address and have the greatest potential for collaboration in the near term (Figure 10). To do this, a set of indicators was selected to assess the level of readiness and potential for each of the subsectors, including coal mine, oil and gas, landfills, wastewater, livestock manure, livestock enteric fermentation, and rice cultivation. In summary, U.S.-China collaboration on methane mitigation can focus on the following, ranked in terms of readiness: (1) the coal mine sector, which has a concrete foundation and large potential and is well prepared for future collaboration; (2) the oil and gas sector, in which the U.S. and China have already conducted extensive research collaborations; (3) the landfill sector, which has significant potential opportunities for U.S.-China collaboration despite its comparatively low emissions level. Notably, the enteric fermentation sector can be highlighted as a potential focus due to its high level of methane emissions, despite the fact that existing efforts have so far been limited.

FIGURE 10. U.S.-CHINA COLLABORATION POTENTIAL BY SECTOR.

The four indicators include research collaboration – measured by the number of peer-reviewed journal articles co-authored by researchers from institutions in the U.S. and China; partnership opportunity – measured as the presence or absence of existing U.S. - China engagement activities and the number of business or non-profit opportunities in each subsector; international engagement – measured by the number of international projects/ industrial organizations in each sector; and U.S. - China combined sectoral methane emissions in 2020. The indicators are normalized with a min-max approach and transformed to a 0-100 range. The final score of the collaboration potential is the sum of the four indicators. The size of the shade indicates the score.



Co-benefits of Methane Mitigation

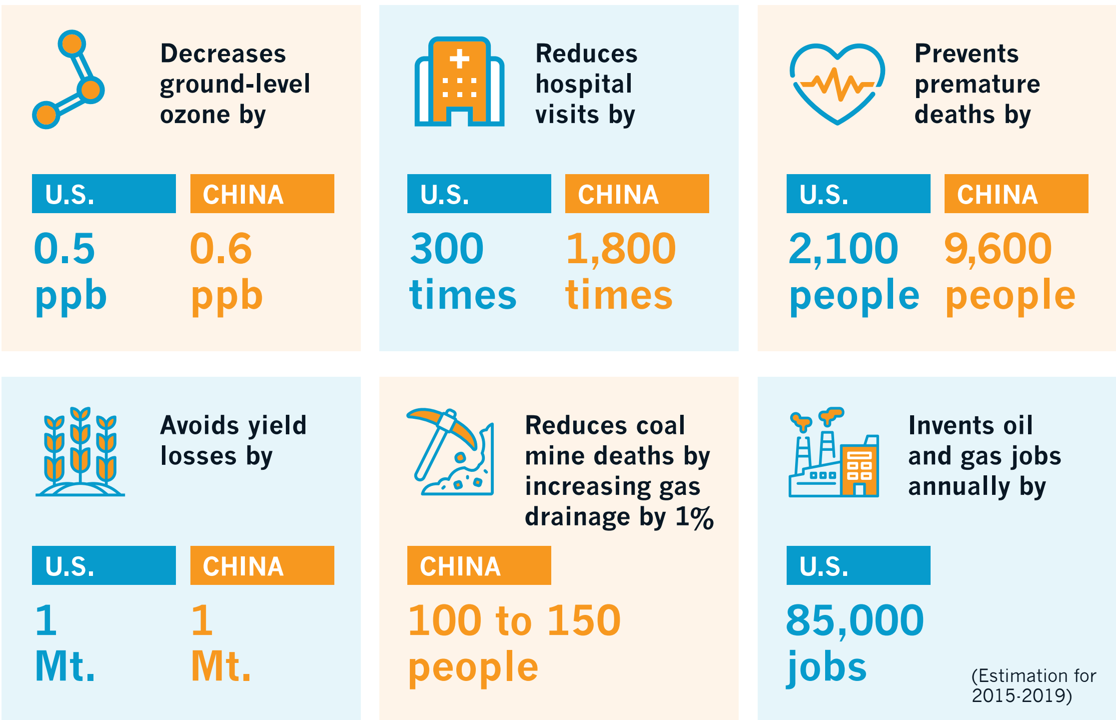
Methane mitigation has multiple co-benefits with respect to air quality, public health, food security, operation safety, and economic prosperity. For the U.S. and China, reducing national methane emissions to zero (hypothetical condition) in 2030 would have the following co-benefits, respectively: reducing 0.5 ppb and 0.6 ppb ground-level ozone; preventing 300 and 1800 asthma-related emergency room visits; saving 2,100 and 9,600 lives from premature death; and avoiding 1 Mt crop yield losses respectively (Figure 11).

Reducing methane emissions by 50% in 2030 would generate significant co-benefits in both countries, including reducing 0.25 ppb and 0.3 ppb ground-level ozone, preventing 150 and 900 hospital visits, saving 1,050 and 4,800 lives from premature death, and avoiding 0.5 Mt crop yield losses in the U.S. and China, respectively.

In addition, for China, 100-150 coal mining deaths can be avoided if the coal mine methane drainage rate increases by 1% in 2030. For the U.S., methane mitigation in the oil and gas sector alone is estimated to create 85,000 jobs (Keyser et al., 2015).

FIGURE 11. CO-BENEFITS OF METHANE MITIGATION IN 2030 ASSUMING ZERO METHANE EMISSIONS (HYPOTHETICAL CONDITION)[1].

Co-benefit coefficients from Climate & Clean Air Coalition (CCAC & UNEP, 2021b).



1 Co-benefits for ground-level ozone, yield losses, hospital visits, and premature death are estimated based on the impact coefficient and total methane emissions in 2030. Co-benefits for coal mine safety are estimated based on fatality rate per million tons reduction by increasing 1% gas drainage and coal production in 2030.

Policy Recommendations for Reducing Methane Emissions in the United States and China

A range of actions can be taken in both countries to address current policy challenges and enhance methane mitigation:

- **Fill existing policy gaps**. Immediate actions should be taken to initiate or accelerate policy-making or legislative processes for these sectors.
  - Both the U.S. and China should (1) fill the policy gaps for abandoned coal mine methane, livestock enteric fermentation and rice cultivation, and (2) adopt more policies that directly address methane emissions reduction for climate mitigation purposes.
  - The U.S. should also (1) pay greater attention to coal mine methane, and (2) strengthen regulations on small and orphan wells, and (3) improve measurement, reporting, and verification (MRV) in the agriculture sector.
  - China should (1) put more emphasis on the oil and gas, and rural landfills and wastewater sectors, (2) develop comprehensive and robust GHG reporting mechanisms and MRV systems across sectors and (3) incorporate methane into the national carbon emissions trading scheme.
- **Improve techno-economic information quality and increase confidence in historical emission estimates** through enhanced transparency of data sources and development of localized, technology-specific emission factors. Both countries should work on building robust MRV systems and take physical/geological factors, transaction costs and field investigation into consideration to improve the accuracy of inventory and mitigation costs and potentials. Both countries need to deal with data underreporting.
  - For the U.S.: (1) The compliance of the mandatory GHG reporting scheme can be strengthened, as underreporting of emissions data has been seen in the oil and gas sector. Additionally, methane emissions from landfills in the U.S. may also be underestimated. (2) Tracking methane emissions from the agriculture sector should be encouraged and it can be incorporated into the existing GHG reporting scheme. (3) Increase monitoring for unintended, short-term emission events from oil and gas production facilities.
  - For China: (1) A methane emissions measurement, reporting and verification (MRV) scheme should be built across all the emission sectors as soon as possible because there is currently no system to monitor methane emissions in China. (2) Improving the compliance of data reporting is also important, as underreporting of methane concentration data is still common in coal mine operations, which are already relatively well-prepared for methane mitigation in China. (3) Thorough field investigations on the abatement costs for methane mitigation are crucial, since non-technical and transaction costs can be large and may not be comprehensively considered. (4) Monitor emissions from abandoned coal mines.
- **Better quantify methane mitigation targets.** Both countries should set more direct and quantifiable targets for methane emissions reduction. However, it is also urgent to establish more quantifiable technology-based standards that can be implemented in the absence of quantitative targets.
- **Reinforce the co-benefits of methane mitigation, and demonstrate higher ambition through more climate change-oriented**

policies. Co-benefits of methane mitigation, such as environmental quality, mining safety and industrial development, have been primary drivers of existing actions toward methane emissions reduction. It is essential to reinforce those co-benefits to create larger social benefits, mobilize as many resources as possible, and alleviate political obstacles for methane mitigation. Nevertheless, more GHG/climate change-oriented policies for methane mitigation are needed for both countries, in contrast to the safety and pollution-oriented regulations that are already largely available in both countries (while still recognizing the importance and political feasibility of addressing those co-benefits). Climate change-oriented policies for methane mitigation can serve as a demonstration of higher ambitions and would provide different incentives for further actions.

- **Strengthen the role of market mechanisms.** More business and financial models should be explored to support methane emissions with great utilization potential, but which are not yet fully cost-effective (e.g., VAM), as well as sectors without clear market incentives (e.g., livestock enteric fermentation and rice cultivation). Specific attention should be paid to small businesses associated with methane emissions.

  Actions can include: (1) facilitate carbon markets in the U.S. and China, especially carbon offset markets as they are particularly important for methane emissions that are difficult to recover, such as emissions from enteric fermentation and rice cultivation; (2) reinitiate the China Certified Emissions Reduction (CCER) scheme; (3) provide financial support for technology innovation, especially for the technologies that can directly prevent or reduce methane emissions; (4) improve supporting infrastructures and supply chains, such as the access to gas pipelines and power grids for recovered methane gas; and (5) mobilizing private sector investments, such as venture capital and public-private partnerships in technologies that can prevent or directly capture and reduce methane emissions, such as special feed additives for cattle.

- **Focus on "super-emitters" and small but high-emitting sites.** Both countries should pay significant attention to the "super emitters," as well as the small but high-emitting sites that are not well covered by the existing regulatory framework, such as small landfills and small or orphan gas wells in the U.S.. Small sites can contribute a large share of methane emissions. In addition, our analysis shows high emissions from major agricultural and energy producing regions and highly populated urban areas in both countries. Targeting sources of methane emissions from facilities with outsized methane emissions and the highest emitting states/provinces could have a significant impact on overall emissions reduction.

- **Clarify the rationale for selecting policy toolkits** with respect to the resource-versus-pollution dichotomy and balance between the "carrots" (e.g., preferential policies, subsidies, and tax exemptions) and "sticks" policies (e.g., taxes, fines, and other penalties). Improve policy implementation.

- **Tackle institutional barriers**, including land and mining ownership arrangements, capacity building for less-developed (rural) areas, social acceptance and the political economy of stakeholder interests to ensure robust and just methane mitigation actions.

  - **Resolving conflicts associated with land and mining ownership** by eliminating restrictions on transferring rights to gas, regardless of whether it will be sold as gas or converted to electricity.

  - **Building capacities for less-developed regions and communities to ensure robust and just methane mitigation actions**. In particular for China, robust rural governance and institutions are key to many of the methane challenges, including rural landfills and wastewater treatment, livestock manure management, livestock enteric fermentation, and rice cultivation. Policies should also emphasize improving benefits for the lower income communities

- **Understanding the societal and political economy challenges**. It is necessary to conduct a stakeholder analysis before policy-making to reduce potential opposition against further actions.

- **Incorporate local contexts, and encourage policy experiments**. There is no "one-size fits all" policy for methane mitigation. Policy experiments, such as demonstration projects, voluntary programs and pilot cities, should be encouraged to take local contexts into account when exploring the best practices for methane mitigation.

- **Prioritize sectors with abundant low-cost opportunities** (Table 3). (1) ensure technology deployment and implementation for the low-hanging fruits. (2) encourage technology improvement and innovation. (3) reduce emission activities for sectors with low technological mitigation potential. (4) drive down technological costs through innovative business models and effective policies for sectors with large potential and high mitigation costs.

TABLE 3. SECTORAL PRIORITIES FOR METHANE MITIGATION.

U.S.	China
▸ The oil and gas sector and coal mine sector are low-hanging fruits. ▸ The livestock and landfill sectors have promising opportunities to reduce a comparatively large amount of methane emissions at a low-cost level. ▸ Methane emissions from rice cultivation and wastewater are expensive to mitigate, however, they account for a small proportion of total methane emissions.	▸ The coal mine sector is a low-hanging fruit. In the near term, emissions reduction relies on adoption of abatement measures, but in the long-term, declining coal production will likely be the main driver of emissions reduction. However, understanding the magnitude of current AMM emissions and how they will change over time in China is needed to fully evaluate mitigation potential. ▸ A promising mitigation potential can be achieved in the landfill and livestock sectors at a low-cost level. However, more efforts should be made to reduce technological costs and accelerate innovation for better mitigation options. ▸ Methane mitigation in the wastewater and rice cultivation sectors is particularly challenging.

Potential Areas for U.S.-China Collaboration

- **Prioritize sectors based on collaboration readiness and mitigation potential.** U.S.-China collaboration on methane mitigation should prioritize collaborative opportunities in the coal mining, oil and gas, landfill, and livestock enteric fermentation sectors based on the assessment of collaboration readiness and potential.

- **Circular economy (CE) can be a key collaborative area**. Most CE-related methane mitigation opportunities are in bioenergy/bioeconomy, particularly in the waste and agriculture sectors. Biogas derived from organics in landfills, wastewater, and livestock manure is directly associated with the application of CE as a way to minimize waste and improve utilization. Waste-to-biogas-based circular economy requires an integration of waste management, biogas production, and utilization and policy support (Kapoor et al., 2020). The other way that CE can help with methane emissions reduction in landfills is to use technologies such as aerobic bioreactor or semi-aerobic bioreactor to prevent methane production. There are several potential mechanisms by which CE may contribute to GHG emissions reduction and methane mitigation:

- **Carbon sequestration and limiting methane emissions through regenerative agriculture,** which builds up both organic soil carbon and nitrogen stocks while reducing nitrogen losses with proper management. The livestock management system under regenerative agriculture is also effective at reducing methane emissions from more effective manure management, and, more importantly, from enteric fermentation by providing high-quality feed, which is easier for livestock to digest and decreases the need for antibiotics.

- **Recycling carbon through circular carbon economy (CCE).** The core idea is to take carbon emissions as a material that can be reduced, reused, recycled, and removed within a closed-loop system in which carbon emissions can be fully captured and sequestered, then chemically transformed into new products. With respect to methane mitigation, coal mines and the oil and gas sectors are the major methane emission sources for both the U.S. and China. The CCE framework has the potential to catalyze waste gas reduction and recovery in these sectors.

- **Forge conversations on policy instruments selection and regulatory frameworks.** The U.S. and China have different strengths and weaknesses in terms of policy-making strategies. In addition, both countries can collaborate on measures that can improve techno-economic data accuracy such as MRV. Policy learning is important for the effectiveness of methane governance and policy frameworks and may be achieved through extensive conversations and communication between the U.S. and China.

- **Encourage subnational and non-state collaborations between the two countries**, including cities, industries, NGOs, and research institutes. The U.S. and China already have significant experience in climate cooperation. The U.S.-China Joint Announcement on Climate Change in 2014 and the establishment of U.S.-China Clean Energy Research Center (CERC) were major achievements of the U.S.-China collaboration on climate change, among other outcomes. There are both positive and negative lessons to be learned, reflecting on successes as well as missteps in the collaboration. For instance, at the subnational level, the state of California has developed extensive cooperation on low-carbon city strategies with China. Future U.S.-China cooperation on methane can build on these experiences and platforms.

CONCLUSIONS

Rapid, economy-wide reductions in methane emissions will be critical for the world to achieve a 1.5°C pathway. Both the United States and China have highlighted the urgency of reducing methane emissions in the Glasgow Joint Declaration. However, ambitious actions by both countries to reduce methane will be needed to deliver reductions needed to support this high-ambition global outcome. As two of the top three methane emitters in the world, China and the United States are well positioned to lead global methane mitigation efforts and collaborate on methane policies, technologies, and strategies. Several challenges present obstacles for enhanced methane abatement, including uncertainty in historical emissions estimates and mitigation potential, limited market mechanisms, and institutional barriers. However, there are opportunities for collaborative action, including identifying low-hanging fruit abatement opportunities and realizing co-benefits to methane emissions reduction, such as improved air quality and public health.

Our results suggest prioritizing mitigation measures in coal and oil and gas production, for China and the United States, respectively, as these are low-cost, high mitigation potential sources that contribute to over a third of each country's total methane emissions. Other key areas for collaboration between these two countries include improving monitoring and measurement of methane emissions, developing methane emission recovery markets, and engaging in cross-country subnational and national conversations on regulatory frameworks for mitigation. The United States and China can helpfully collaborate on strategies for emissions sources prevalent in both countries that have high mitigation potential and act to rapidly reduce methane emissions to improve our chances of limiting global temperature rise to 1.5°C.

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