ABANDONED COAL MINE METHANE REDUCTION

Lessons from the United States

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The California-China Climate Institute was launched in September 2019 and is a University of California-wide initiative housed jointly at UC Berkeley's School of Law (through its Center for Law, Energy, and the Environment) and the Rausser College of Natural Resources. It is chaired by Jerry Brown, former Governor of the State of California, and vice-chaired by the former Chair of the California Air Resources Board Mary Nichols. The Institute also works closely with other University of California campuses, departments, and leaders. Through joint research, training, and dialogue in and between California and China, this Institute aims to inform policymakers, foster cooperation and partnership, and drive climate solutions at all levels.

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SUMMARY FOR POLICYMAKERS

Methane is a short-lived greenhouse gas with more than 80 times the global warming impact of carbon dioxide over a 20-year timeframe. Additionally, methane is flammable and a key precursor to certain air pollutants. Therefore, reducing methane emissions is key to slowing climate change impacts in the near term, as well as managing public safety and air pollution hazards. The United States (U.S.), which has largely transitioned away from coal, still has many abandoned coal mines, and these are a significant source of methane emissions. In 2021, U.S. abandoned coal mines produced an estimated 330,000 metric tons of methane – about 12.5% of the country's methane emissions from coal mining.

Reducing methane emissions from abandoned coal mines ("abandoned mine methane") is challenging for many reasons. It requires accurate modeling and monitoring, financial investment and incentives to support mitigation and utilization projects, and collaboration among different stakeholders. However, the benefits of addressing this issue are huge: significantly slowing near-term climate change, diversifying energy sources, revitalizing local economies, and alleviating health and environmental hazards.

The U.S. has been at the forefront of efforts to mitigate and utilize abandoned mine methane. This paper analyzes the policies and programs, implementation mechanisms, and lessons learned from the U.S. in reducing abandoned mine methane. The analysis focuses on two major questions: (1) What approaches has the U.S. taken to identify and mitigate abandoned mine methane emissions?; and (2) How has the U.S. incorporated abandoned mine methane mitigation into a broader policy framework for abandoned coal mine remediation? By addressing these questions, the analysis seeks to provide insight for other regions on best practices for potential adoption, as well as challenges that may need to be overcome.

APPROACHES TO REDUCING AND UTILIZING ABANDONED MINE METHANE

In scaling up its efforts to reduce and utilize abandoned mine methane, the U.S. has adopted three key approaches:

1. **Accurate modeling and monitoring**. This is important for identifying abandoned mine methane emission sources and ensuring effective mitigation of climate impacts. The U.S. has modeled abandoned mine methane emissions for over two decades and designed a modeling methodology for its own national greenhouse gas inventory as well as international climate guidelines. Although national monitoring programs for abandoned mine methane are lacking, certain states conduct monitoring to quantify emissions reductions from mitigation and utilization projects.

2. **Implementing mitigation and utilization projects**. Beyond reducing greenhouse gas emissions, utilizing abandoned mine methane as a clean energy source can stimulate economic development in communities affected by coal mine closures. In the U.S., financial incentives, including government investments and market-based mechanisms, significantly drive these projects. Regulatory incentives, such as recognizing abandoned mine methane as a renewable energy source and clarifying property rights, also facilitate project development.

3. **Fostering effective collaboration among government agencies, industry stakeholders, and local communities**. This is essential for providing local communities with tailored solutions to mitigate and utilize abandoned mine methane. A notable example is the U.S. EPA's Coalbed Methane Outreach Program, which promotes abandoned mine methane recovery through industry collaboration. Collaborative initiatives, such as the Energy Communities Interagency Working Group, also engage stakeholders nationwide and support community-focused projects in different states.

ABANDONED MINE METHANE MITIGATION IN THE BROADER POLICY FRAMEWORK

In the U.S., policies for abandoned coal mines initially tackled health and environmental risks and only later incorporated economic development concerns. Today, abandoned mine methane mitigation and utilization are part of an integrated approach the U.S. takes to address abandoned coal mine issues.

Alleviating Health and Environmental Hazards

Addressing the risks of explosion and air pollution linked to abandoned mine methane is a key aspect of managing health and safety challenges for abandoned mine lands. Mitigating abandoned mine methane aligns with this goal. The U.S. has been tackling health and safety concerns since the 1970s by funding reclamation efforts and abandoned mine methane prevention. These efforts are ongoing, with many states actively involved in supporting abandoned mine reclamation and abandoned mine methane mitigation projects. Recent initiatives, including President Biden's Bipartisan Infrastructure Law, allocate significant resources for abandoned mine land reclamation, marking a substantial investment in addressing health and safety issues.

Supporting Economic Revitalization

Abandoned mine methane holds promise as a clean energy resource that can offer economic benefits to communities affected by the decline of coal mining. Additionally, abandoned mine methane projects create jobs in communities, aiding local economic revitalization. The U.S. has adopted several strategies to revitalize economies in communities through initiatives prioritizing abandoned mine land remediation, economic activity, and job creation. Furthermore, following the passage of key legislation, the Biden-Harris Administration has increased its funding support for economic revitalization and abandoned mine methane projects.

U.S. LESSONS LEARNED

Lessons gleaned from abandoned mine methane efforts in the U.S. have important implications for the development of related policies and programs, both in the U.S. and around the world.

For modeling and monitoring, data inadequacy remains a challenge; abandoned coal mines do not report emissions data, and there are gaps in parameters for emission prediction. Similarly, monitoring gaps persist for abandoned mines that lack methane utilization projects, and technical limitations hinder the ability of satellite or aerial surveys to pinpoint emissions from individual mines. One key lesson is that challenges with measuring abandoned mine methane can be addressed both on the ground and in the air: through ground-based technologies like vehicle-mounted methane detection systems, as well as satellite and aerial survey instruments whose precision can be enhanced through further research and development. Secondly, market-based incentives, including carbon cap-and-trade systems, encourage mitigation and utilization projects

by attracting financial investment. Thirdly, overcoming regulatory obstacles is essential and can be achieved through transparent procedures around mine ownership, methane rights transfer, and designating abandoned mine methane as a renewable resource. Further, recognizing the diverse benefits of utilizing abandoned mine methane and integrating such efforts into broader economic and coal mine reclamation policies can yield multiple benefits. Finally, effective interagency collaboration facilitates successful mitigation and utilization efforts.

With its longstanding commitment to abandoned mine methane mitigation and utilization, the U.S. has been active in tackling the substantial environmental, climate, and economic impacts associated with abandoned coal mines. A comprehensive framework that can be drawn from U.S. experience – comprising regulatory measures, substantial financial investment, interagency cooperation, active local engagement, regular modeling and monitoring, and other instruments – offers a model for jurisdictions worldwide. Jurisdictions can take this framework into account when formulating effective and sustainable policies to curb abandoned mine methane emissions.

In conclusion, five principal lessons learned from the U.S. that could be useful for China and other jurisdictions are as follows:

- A comprehensive abandoned mine methane policy package should include investment, regulations, financial incentives, and interagency collaboration frameworks.
- Continuous investment in abandoned mine methane projects and innovative monitoring technology are crucial for capitalizing on the multiple potential benefits of abandoned mine methane mitigation.
- Regulatory barriers to developing abandoned mine methane mitigation and utilization projects can be addressed through both regulatory (e.g., royalty and tax relief) and legislative approaches. Market-based financial incentives (e.g., a cap-and-trade program) are also needed to encourage investment.
- Collaboration among different stakeholders (e.g., government agencies, academics, and companies) and direct governmental engagement with communities are needed to ensure that local communities benefit from abandoned mine methane mitigation and utilization projects.
- Integrating abandoned mine methane mitigation and utilization into a broader framework is important for facilitating a sustainable economic transition for historically coal-dependent communities and the lands where they work and live.

LIST OF ABBREVIATIONS

AML	Abandoned Mine Land
AMLER	Abandoned Mine Land Economic Revitalization program
AMM	Abandoned Mine Methane
AOAA	Anthracite Outdoor Adventure Area
CARB	California Air Resources Board
CMM	Coal Mine Methane
CMOP	Coalbed Methane Outreach Program
CO_2e	Carbon Dioxide Equivalent
ECIWG	Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization (known as the Energy Communities Interagency Working Group)
FRA	Forest Reclamation Approach
GHG	Greenhouse Gas
GHGRP	Greenhouse Gas Reporting Program
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt-Hour
MDRS	Mine Data Retrieval System
OSMRE	Office of Surface Mining Reclamation and Enforcement
POWER	Partnerships for Opportunity and Workforce and Economic Revitalization Initiative
RECs	Renewable Energy Credits
RPS	Renewable Portfolio Standards
SMCRA	Surface Mining Control and Reclamation Act
U.S.	The United States
U.S. EPA	The U.S. Environmental Protection Agency
VCG	Vessels Coal Gas

CONTEXT AND OBJECTIVES OF THIS REPORT

In support of the California-China Climate Institute's goal of spurring climate action through joint research, training, and dialogue in California and China, this report, *Abandoned Coal Mine Methane Reduction – Lessons from the United States*, provides research and models for coal mine methane mitigation that can be useful in China's efforts to further reduce methane emissions in this sector. The report should be considered in the context of China's announcement that it will strictly control coal consumption from 2021 to 2025 and gradually reduce coal consumption from 2026 to 2030.[1] Further, the report may be useful as China develops its coal mine methane utilization and mitigation policies and targets,[2] as well as incentives for coal mine methane projects through, for example, the greenhouse-gas emissions trading system.[3]

[1] Central Committee of the Chinese Communist Party & State's Council, 2021.

[2] National Development and Reform Commission, 2020; National Energy Administration, 2022.

[3] Ministry of Ecology and Environment, 2023.

INTRODUCTION

The history of coal mining in the United States (U.S.) goes back to the late 1700s, and coal mining operations supported economic growth and power generation needs throughout the 20th century.[4] Although the U.S. has transitioned away from coal due to a host of factors – including declining costs for renewable energy, more stringent environmental regulations, and climate policy objectives[5] – it still has many abandoned coal mines. In recent decades, the methane emitted from abandoned coal mines has become an increasingly important challenge for the U.S. and for global climate policy.[6] This is partly because methane has more than 80 times the global warming power of carbon dioxide for its first 20 years in the atmosphere.[7]

The cessation of coal mining does not halt methane emissions. While methane flow initially declines following a mine closure, it can later stabilize and maintain a near-constant rate for extended periods.[8] These sustained emissions make abandoned coal mines problematic on two fronts. Abandoned mine methane (AMM) can present explosive hazards and be the precursor of some air pollutants, posing health and environmental risks; and it is an important source of methane, the second most important greenhouse gas after carbon dioxide. Methane emissions from human activity are estimated to account for nearly 45% of current net warming.[9] In 2021, U.S. abandoned coal mines produced an estimated 330,000 metric tons of methane – about 12.5% of the country's methane emissions from coal mining.[10]

Mitigating and utilizing AMM is therefore important to U.S. efforts to mitigate greenhouse gas emissions and achieve climate change mitigation targets. Moreover, mitigating and utilizing AMM is cost-effective: the *Global Methane Assessment*, from the United Nations Environment Programme and the Climate and Clean Air Coalition, ranks the reduction of human-caused methane emissions as among the most cost-effective strategies for rapidly reducing the rate of warming and limiting global temperature rise to 1.5°C.[11] Mitigating and utilizing AMM also has other important benefits, namely: (1) addressing health, safety, and environmental issues around abandoned coal mines; and (2) stimulating broad economic development and an equitable clean energy transition.[12] Given these social, economic, and environmental benefits, the U.S. has integrated AMM mitigation and utilization into a broader policy framework for reclaiming abandoned coal mines and revitalizing local economies.

The U.S. has been at the forefront of efforts to mitigate and utilize AMM. For decades, financial and regulatory incentives – such as governmental investment,[13] cap-and-trade programs,[14] and royalty relief[15] – have supported project implementation for AMM mitigation and utilization. As of 2021, 34 AMM capture and utilization projects are operating at 47 mines in the U.S.[16] These projects reduced net AMM emissions from about 7.38 million metric tons of carbon dioxide equivalent (CO_2e) in

4 Larson, 2020.

5 U.S. Energy Information Administration, 2023.

6 Note that the U.S. greenhouse gas inventory is calculated using a Global Warming Potential of 28 for methane over a 100-year period, per Intergovernmental Panel on Climate Change guidelines.

7 Institute for Governance & Sustainable Development, 2023, p. 5.

8 United Nations Economic Commission for Europe, 2020.

9 Institute for Governance & Sustainable Development, 2023.

10 U.S. EPA, 2023a.

11 United Nations Environment Programme & Climate & Clean Air Coalition, 2021, p. 8.

12 U.S. EPA, 2019b.

13 The White House, 2022.

14 California Air Resources Board, 2014.

15 Denysenko et al., 2019.

16 U.S. EPA, 2022d.

2005 to about 6.37 million metric tons of CO_2e in 2021, utilizing 31.5%[17] of AMM emissions.[18] Further, modeling and monitoring of AMM have been conducted to provide accurate information about AMM emissions, identify potential leaks, and support mitigation policies and programs.[19] Recently, the White House proposed a robust program to remediate abandoned mine lands (AML) and reduce AMM under the U.S. Methane Emissions Reduction Action Plan.[20] The history and ongoing efforts devoted to AMM mitigation and utilization in the U.S. provide valuable lessons for other jurisdictions where challenges associated with AMM are becoming more pronounced.[21]

This report contains three major sections: (1) a summary of policies and implementation mechanisms that U.S. federal agencies and states have adopted to reduce and utilize methane from abandoned coal mines; (2) an introduction to a broader policy framework incorporating AMM mitigation and utilization as a key component of reclamation and economic revitalization activities; and (3) conclusions and lessons learned from U.S. experience. Collectively, these insights can guide China and other jurisdictions as they develop strategic initiatives to cut methane emissions in this sector.

[17] Among coal mining countries globally, the U.S. does not have the highest AMM utilization rate. AMM utilization rates in Germany and the United Kingdom were 99% (in 2015) and 58% (in 2017) (Denysenko et al., 2019).

[18] U.S. EPA, 2023a.

[19] California Air Resources Board, 2014; U.S. EPA, 2023a.

[20] The White House, 2021.

[21] Lu et al., 2020.

APPROACHES TO REDUCING AND UTILIZING ABANDONED MINE METHANE

Scaling up AMM mitigation and utilization requires three key approaches:

- **Accurately modeling and monitoring AMM** from abandoned coal mines is crucial for identifying emission sources and developing effective mitigation strategies to reduce their climate impact. In addition, AMM monitoring can provide more accurate information about specific abandoned coal mines, identify potential leaks, and support mitigation policies and programs such as carbon emission offsets.[22]

- **Implementing AMM mitigation and utilization projects** is crucial for reducing greenhouse gas emissions by utilizing AMM as a clean energy source. These projects can also create jobs and stimulate local economic development. Various types of financial and regulatory incentives, such as a cap-and-trade program and royalty relief, can support the development of new AMM mitigation and utilization projects.[23]

- **Collaboration** among government agencies, the energy industry, and local communities enables effective resource allocation and coordinated effort. A collaborative approach can combine expertise and resources from different agencies, leverage various funding opportunities, coordinate among regulations, and provide appropriate, site-specific solutions to different communities.

Pursuing these three approaches can effectively address environmental impacts of AMM and fully realize its economic value.

MODELING AND MONITORING

The U.S. government has been modeling AMM emissions for over two decades. In 1994, the U.S. EPA launched its Coalbed Methane Outreach Program (CMOP), a voluntary program that promotes the recovery and use of coal mine methane.[24] The program produced a methodology for estimating the scale of AMM emissions in the U.S. that uses quantitative models to incorporate coal basin-specific parameters, which were calibrated using actual field measurements obtained from multiple mine sites. This methodology was integrated into the 2006 Emissions Inventory Guidelines established by the Intergovernmental Panel on Climate Change (IPCC), and today it is used to calculate AMM emissions in the U.S. national greenhouse gas inventory.[25]

Underlying the modeling of national AMM emissions is a series of databases that provide fundamental information for AMM estimation. The Mine Data Retrieval System (MDRS), maintained by the Department of Labor's Mine Safety and Health Administration, provides mine-by-mine data for all coal mines in the U.S.[26] The MDRS includes mine status information (i.e., sealed, venting, flooded, recovering methane, or unknown), which is necessary for AMM estimation as it affects AMM emission rates.[27] In addition, the U.S.

[22] United Nations Economic Commission for Europe, 2020, p. 34.
[23] Denysenko et al., 2019, p. 16.
[24] U.S. EPA, 2023b.
[25] U.S. EPA, 2004.
[26] Mine Safety and Health Administration, n.d.
[27] U.S. EPA, 2004.

EPA's Greenhouse Gas Reporting Program (GHGRP)[28] collects emissions data for all underground active coal mines that release 36,500,000 actual cubic feet of methane or more per year.[29] This data is also an important parameter for AMM emission modeling, since "initial" methane emission rates when coal mines are abandoned significantly affect AMM emission rates.[30]

While the U.S. lacks a comprehensive national monitoring program for AMM, some states are monitoring AMM to quantify AMM emissions and calculate greenhouse gas (GHG) offsets from AMM mitigation and utilization projects. For example, California introduced a compliance offset protocol for coal mine methane that includes AMM mitigation projects as a source of emissions offsets as part of its cap-and-trade regulation in 2014.[31] An important part of California's protocol is the monitoring of AMM, which requires recording the concentration of AMM from different sources and the flow rate of AMM to destruction devices at 15-minute intervals. The protocol also includes a comprehensive list of parameters that must be monitored.[32]

To date, insufficient data makes it impossible to accurately estimate AMM emissions in the U.S.[33] Abandoned mines do not report emission data to the GHGRP, for example.[34] Further, the data for three important parameters used in predicting AMM emissions rates – the coal's adsorption isotherm,[35] methane flow capacity as expressed by permeability,[36] and gas pressure at abandonment – are not available for every abandoned coal mine. Therefore, these values must be estimated using ranges of values established in IPCC guidelines.[37] There is also a lack of AMM monitoring data at abandoned coal mines without AMM utilization projects.

Although remote sensing data from satellite or aerial methane surveys is available in some regions, identifying AMM emissions from specific abandoned coal mines is difficult due to the detection threshold of these technologies. By contrast, ground-based technologies can measure AMM emissions more accurately.[38] Vehicle-mounted methane detection systems (such as GasFinder3-VB,[39] Remote Methane Leak Detector,[40] and Portable Methane Leak Observatory system[41]) should therefore be considered for road-accessible sites. Future R&D investment should target lowering the methane detection threshold of aerial survey instruments and improving their precision for low-emissions sources.

MITIGATION AND UTILIZATION

Implementing methane mitigation and utilization projects is among the most important actions for managing AMM, as these projects deliver benefits across three dimensions: they mitigate greenhouse gas emissions, utilize AMM as a clean energy source, and stimulate economic development in communities affected by coal mine closures.

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28 Surface coal mines and abandoned coal mines do not report to the GHGRP (U.S. EPA, 2022c).

29 U.S. EPA, 2022c.

30 Franklin et al., 2004.

31 U.S. EPA, 2019b.

32 California Air Resources Board, 2014.

33 Yale Carbon Containment Lab, 2022.

34 U.S. EPA, 2022c.

35 Adsorption isotherm represents the methane storage capacity of coal as a function of pressure measured at a constant temperature (Mavor et al., 1990).

36 Permeability represents a property of coal (a porous media) that plays a major role in the rate at which gas can flow from the unmined coal into the void space of the abandoned mine (U.S. EPA, 2004).

37 U.S. EPA, 2023a.

38 Yale Carbon Containment Lab, 2022.

39 Provided by Boreal Laser Inc.

40 Provided by Physical Sciences Inc.

41 Developed by the University of Calgary.

Overview of Abandoned Mine Methane Projects in the U.S.

To identify potential AMM mitigation and utilization opportunities, the U.S. EPA conducted a detailed analysis in 2017 and identified 79 abandoned coal mines with the greatest opportunities for AMM recovery projects, based on the methodology shown in Table A1 of the Appendix. It is estimated that AMM recovery projects at these 79 abandoned mines could reduce methane emissions by 5.6 billion cubic feet[42] – equal to 2.7 million[43] metric tons of CO2e, according to the U.S. EPA's Coal Mine Methane Units Converter,[44] or the GHG emissions from 601,000 passenger vehicles in a year.[45] If fully implemented, these AMM recovery projects could almost double the current AMM emissions recovery rate, mitigating and utilizing about 60% of current AMM emissions.[46] The remainder (~40%) could also be utilized if low-cost capture technologies for low-concentration methane become available.[47]

Several utilization options exist for AMM, which parallel those for natural gas. They include: (1) power generation; (2) combined heat and power for industry and/or urban areas; (3) supplying commercial natural gas markets via existing pipelines; (4) local industrial thermal use via local pipelines; (5) chemical feedstock; (6) small-scale microturbines and fuel cells; and (7) vehicle fuel.[48] To date, the most common options for commercial utilization have been sale to natural gas pipelines and power generation. The selection of end-use has been driven by local and national energy prices, local market requirements, policy priorities and incentives, transport cost, and project investment cost.[49]

In the U.S., most AMM projects have involved the injection of captured methane into existing natural gas pipelines, which still represents the largest end-use of AMM to date.[50] Nonetheless, the number of AMM-based power generation and flaring projects has notably increased in recent years. As of 2021, 34 AMM capture and utilization projects are operating at 47 U.S. mines. Some of these projects are "aggregated," including three that group 3-5 mines into a single project, one that aggregates methane from 14 mines, and three that were combined with existing coal mine methane (CMM) projects.[51] Twenty AMM projects inject recovered methane into natural gas pipelines, while two use recovered methane for power generation, and one sells recovered methane directly to manufacturers. Eleven AMM projects use flares to destroy methane from abandoned coal mines,[52] as burning the methane on-site to transform it into carbon dioxide (a weaker greenhouse gas) can be the most economically appealing solution.[53] The most common reasons for using flaring to destroy methane are a lack of access to natural gas pipelines and low regional electricity sales prices, rendering both the sale of AMM to pipelines and the use of AMM for power generation uneconomic.[54] Across all 34 AMM projects, net AMM emissions decreased from about 7.38 million metric tonnes of CO_2e in 2005 to about 6.37 million metric tons of CO_2e in 2021. Total AMM emissions in the U.S. were about 9.2 million metric tons of CO_2e in 2021, with about 31.5% of that amount (2.9 million metric tons of CO_2e) being captured and utilized for power generation and pipeline gas sales.[55]

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42 U.S. EPA, 2017.

43 This number is calculated based on 100-year Global Warming Potential.

44 U.S. EPA, 2022b.

45 Federal Highway Administration, 2021; U.S. EPA, 2023a.

46 U.S. EPA, 2023a.

47 Banks, 2012.

48 United Nations Economic Commission for Europe, 2020, p. 21.

49 United Nations Economic Commission for Europe, 2020, pp. 21–23.

50 U.S. EPA, 2022d.

51 U.S. EPA, 2022d.

52 U.S. EPA, 2022d.

53 Otárola, 2021.

54 United Nations Economic Commission for Europe, 2020, pp. 52-53.

55 U.S. EPA, 2023a.

Financial Incentives

To stimulate the development of AMM mitigation and utilization projects, the U.S. government has directed large investments to historically coal-dependent communities. Infrastructure investment by the government is an important source of financial support for AMM mitigation projects. For example, President Biden's Infrastructure Investment and Jobs Act appropriates over $11 billion to eligible states and tribal entities over 15 years, with an explicit goal to rehabilitate abandoned coal mines and mitigate methane emissions. Funding awarded by the Office of Surface Mining Reclamation and Enforcement (OSMRE) and the U.S. Economic Development Administration also supports critical infrastructure investment in AMM projects.[56] The U.S. Department of the Interior announced nearly $725 million designated for 22 states and the Navajo Nation in August 2022, bringing the total funding available to coal-dependent communities that year to nearly $1 billion.[57]

Market-based incentives also play a crucial role in facilitating the capture and utilization of AMM. Various carbon markets operating within the U.S. offer opportunities for AMM utilization projects to participate. Voluntary markets, including Verra, the Climate Action Reserve, and the American Carbon Registry, provide avenues for AMM projects to generate carbon credits. California's cap-and-trade program to regulate greenhouse gas emissions recognizes AMM projects as eligible sources for emissions offsets. In 2014, the California Air Resources Board (CARB) adopted its Mine Methane Capture Protocol, which enabled AMM projects to qualify as Compliance Offset Projects under the state's cap-and-trade program and allowed covered entities to purchase and trade Offset Credits from AMM projects across the country, sparking energy companies' interest in AMM projects. As of May 2023, CARB's offset program has issued credits to AMM projects for 3.69 million metric tons of CO_2e reductions, accounting for 1.5 percent of all compliance offset credits CARB has issued.[58] These investments and initiatives incentivize AMM utilization and align projects with broader strategies addressing climate change and sustainable energy.[59]

Royalty relief is another type of financial incentive. If coal mines are on federal lands, mining companies are obligated to pay royalties to the U.S. Bureau of Land Management if they utilize the leased gas for power generation or sell it to other entities. Generally, these royalty rates amount to roughly 12.5% of the resource's value at the wellhead.[60] To promote AMM capture and utilization, agencies overseeing federal and state lands can offer regulatory incentives to lessees in the form of royalty reductions.[61] A rule introduced in 2018 requires the Bureau of Land Management to incentivize the beneficial use of gas by waiving royalties on gas used for operational and production purposes.[62] Some states, such as Colorado, also provide royalty relief mechanisms to incentivize AMM capture and utilization.[63]

A notable AMM project that has significantly reduced methane emissions while remaining financially viable is the Elk Creek Mine project in Gunnison County, Colorado (see case study below). Other projects include the Cambria 33 Abandoned Mine Methane Capture and Use Project in Cambria County, Pennsylvania,[64] and the Corinth Abandoned Mine Methane Recovery Project in Southern Illinois.[65] These projects offer valuable insights for governments, companies, and stakeholders evaluating AMM projects in other jurisdictions.

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[56] Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization, 2021.

[57] The White House, 2022, p. 5.

[58] As of June 2023, the price of a carbon offset in the California market is about $29 per metric ton of CO_2e, according to online data (see https://carboncredits.com/carbon-prices-today/).

[59] U.S. EPA, 2020.

[60] U.S. Government Accountability Office, 2017.

[61] U.S. EPA, 2019b.

[62] Denysenko et al., 2019.

[63] U.S. EPA, 2019a.

[64] Vessels Carbon Solutions Inc., n.d.

[65] Ruby Canyon Engineering Inc., 2013.

Case Study | The Elk Creek Mine Abandoned Mine Methane Project[66]

The Elk Creek Mine has hosted an AMM mitigation and utilization project since February 2016, when the mine closed. The project seeks to extract AMM for power generation and mitigate coal mine emissions at a profit. A 3-megawatt power plant, in conjunction with an enclosed flaring system, recovers approximately 250 billion cubic feet of methane annually. The project has successfully diversified its revenue streams, which has maintained its financial viability.

The project, formally known as the "Elk Creek Permit Area Abandoned Mine Project," is located in Gunnison County, Colorado. Beginning in 2012, the Elk Creek Mine was the largest U.S. active underground coal mine to generate electricity from coal mine methane in a project developed and operated by Vessels Coal Gas (VCG). When the mine ceased operations in 2016, VCG transformed the original project into a multi-mine AMM project, incorporating the Elk Creek Mine alongside four adjacent abandoned mines. All had been classified as gassy mines during their active periods, indicating they produced more than 100,000 cubic feet of methane emissions per day when they were active.[67]

The project's financial viability has been sustained by several diverse revenue streams. These include selling electricity to an electric utility, acquiring carbon offset credits from California's compliance offset program, and receiving renewable energy credits (RECs) from Colorado's public utility commission. The acquisition of California's carbon offset credits has been particularly valuable, as local electricity prices are only 3 cents per kilowatt-hour (kWh). From 2016 to 2018, the project generated carbon offsets totaling over 500,000 million metric tons, equivalent to eliminating the emissions of 36,000 automobiles from U.S. highways. In 2018, the market value for carbon offsets under California's cap-and-trade program stood at approximately $13 per metric ton of CO_2e. Colorado RECs added $0.01/kWh to the overall price the project received for selling electricity.

To accurately quantify how much methane the project destroys, the Elk Creek project employs a combination of gas flow meters and a methane analyzer for continuous monitoring. Additionally, the project monitors engine runtime and flare temperature to guarantee that gas is destroyed and carbon offset program regulations are observed. All relevant data is gathered and stored in a "programmable logic controller," a type of on-site industrial computer, with off-site computers keeping backups for secure recordkeeping.

The Elk Creek project has amassed several important lessons learned for consideration by governments, companies, and stakeholders:

- Always account for permitting requirements imposing limitations on criteria pollutants from the combustion of AMM, specifically nitrogen oxides and carbon monoxide, in end-use or destruction equipment.
- Pursue comprehensive education and outreach initiatives to ensure that regulators fully understand AMM emissions and the carbon neutrality attributes of individual projects.
- Recognize uncertainties in methane production forecasts by incorporating high, mid, and low production scenarios in economic evaluations.
- Highlight secondary environmental benefits from AMM projects, such as mitigating methane emissions as a precursor for volatile organic compounds and ozone.
- Engage local stakeholders and corporate entities proactively during the developmental phases of a project.

[66] United Nations Economic Commission for Europe, 2020.

[67] U.S. EPA, 2004.

Regulatory Incentives

Regulatory incentives can provide important support to help AMM mitigation and utilization projects overcome implementation challenges, such as market barriers and property rights issues.

Recognizing AMM as a "renewable" or "alternative" energy resource is one such regulatory incentive. Currently, federal incentives do not specifically promote AMM utilization.[68] However, several states have designated methane from abandoned mines as a renewable or alternative energy source. This allows electricity generated from AMM projects to count towards state Renewable Portfolio Standards (RPS) requirements, which in turn supports investment in AMM projects. As of 2019, five states with significant legacy coal production – Pennsylvania, Ohio, Utah, Indiana, and Colorado – have integrated AMM into their RPSs (Table 1).

Table 1 | Summary of State AMM Regulatory Incentives[69]

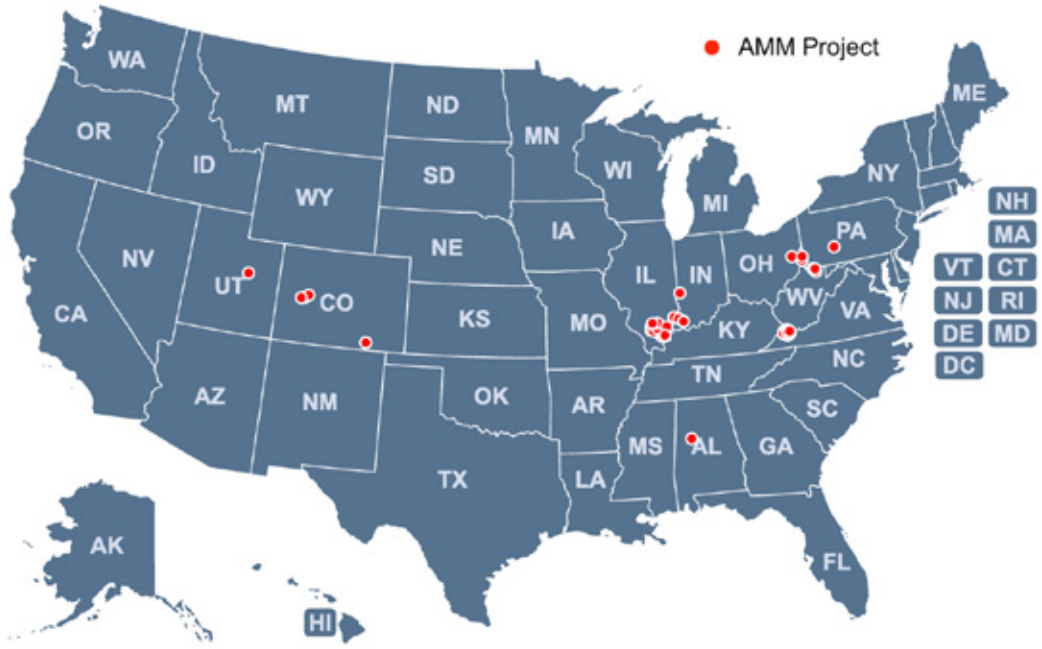
State	Definition of AMM	Regulatory Incentives and Programs
Pennsylvania	Alternative energy resource	• Alternative Energy Portfolio Standard ◦ Alternative energy credits
Ohio	Renewable energy resource	• Alternative Energy Resource Standard ◦ Renewable energy certificates
Colorado	Renewable definition determined on a case-by-case basis	• Renewable Energy Standard ◦ Renewable energy certificates • Royalty Relief
Utah	Renewable energy resource	• Renewable Energy Standard ◦ Renewable energy certificates • Royalty Relief
Indiana	Coalbed methane is an alternative energy source and clean energy resource	• Voluntary Clean Energy Portfolio Standard ◦ Financial incentives for compliance projects

Property rights can also provide incentives for AMM project development. These are particularly relevant in some eastern states (e.g., Illinois, Virginia, and West Virginia), where more coal mines (and consequently more potential AMM projects) are situated on private lands and owners have gas extraction rights for abandoned mines (upon securing environmental permits).[70] By itself, Illinois is home to 11 of 34 AMM projects in the U.S.[71] In western states (e.g., Colorado and Utah),[72] where most coal mines sit on federal lands, federal and state governments usually do not automatically grant property rights to the associated methane when issuing coal leases. This can lead to conflicts when multiple leaseholders lay claim to the same area for different resources such as AMM, coalbed methane, and natural gas, which occur at varying depths. Consequently, developing AMM projects on federal lands can entail considerable legal expenses that hamper investment prospects.[73] Generally, AMM projects are more prominent in states where property rights are clear, suggesting that greater clarity around ownership rights and lease terms is an important driver for AMM projects.[74]

[68] Denysenko et al., 2019.
[69] U.S. EPA, 2019b.
[70] Denysenko et al., 2019, pp. 14–17; The Appalachian Voice, 2022.
[71] U.S. EPA, 2022d.
[72] Denysenko et al., 2019, p. 15; Maffly, 2021.
[73] Denysenko et al., 2019.
[74] Denysenko et al., 2019.

Figure 1 shows the locations of all AMM projects across the U.S. as of 2021.

Figure 1 | Locations of U.S. AMM Projects (2021)[1]



1 U.S. EPA, 2022d.

It is also critical to address regulatory obstacles that hinder AMM project development.[75] The following regulatory reforms would help accelerate AMM project development and revitalize local economies: (1) clear, transparent procedures for acquiring AMM ownership rights for abandoned mines; (2) a mechanism for the transfer of methane rights from the mine to third-party entities, such as gas developers; and (3) the designation of AMM as a renewable, clean, or alternative energy resource through legislation or amendments.[76]

COLLABORATION AMONG GOVERNMENTS, INDUSTRY, AND COMMUNITIES

Effective collaboration among government agencies, industry stakeholders, and communities can provide important support to new AMM mitigation projects. Specialized technical and financial expertise from different stakeholders can be especially helpful in encouraging the development and implementation of effective methane mitigation strategies.

The Coalbed Methane Outreach Program (CMOP), referenced above, was launched by the U.S. EPA in 1994. A voluntary collaborative program between the U.S. EPA and the coal mining industry, CMOP promotes the profitable recovery and utilization of coal mine methane, including AMM, and provides resources to encourage AMM mitigation and utilization projects in the U.S. CMOP provides technical and financial guidance to help project developers identify AMM opportunities, evaluate project profitability, and develop projects. Two notable CMOP resources are the Coal Mine Methane Cash Flow Model (for AMM project economic viability assessment) and the Abandoned Coal Mines Opportunities Database.[77] Other CMOP tools to support AMM project development domestically and abroad are shown in Table A2 of the Appendix.[78]

75 Denysenko et al., 2019.
76 Denysenko et al., 2019.
77 U.S. EPA, 2023b.
78 U.S. EPA, 2022a.

A broad range of engagement efforts across the U.S. have established collaborative relationships and overcome investment obstacles, in addition to providing tailored, on-the-ground support for AMM projects in local communities. In July 2023, the Biden-Harris Administration established a Cabinet-level Methane Task Force to spearhead a comprehensive, government-wide strategy for methane leak identification and enhanced data transparency. The group will also support state and local efforts to mitigate methane and enforce methane emissions regulations.[79]

Another proactive engagement effort is the Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization – better known as the Energy Communities Interagency Working Group (ECIWG), established in 2021 under Executive Order 14008 – which actively prioritizes AMM mitigation and utilization. In recent years, the ECIWG has actively involved more than 9,000 stakeholders, including leaders in community economic development, government officials at the state, county, and city levels, representatives from labor organizations and tribal communities, private sector professionals, congressional staff, and representatives from academia and philanthropic organizations.[80] Through its outreach, ECIWG provides crucial support to local communities in developing AMM projects and creating new jobs. To date, ECIWG has conducted engagements in 26 states, gathering valuable input and perspectives about local needs, economic obstacles, and regulatory barriers along the way.[81] Importantly, the ECIWG is also facilitating coordination among federal agencies and local communities to enhance their ability to understand and access federal resources, in response to stakeholder feedback. To this end, the ECIWG has launched an online One-Stop Shop portal that aggregates federal funding opportunities across different agencies to reduce information barriers and support local communities in navigating and combining federal programs.[82]

[79] The White House, 2023.

[80] Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization, 2023.

[81] Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization, 2023.

[82] Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization, 2023.

ABANDONED MINE METHANE MITIGATION IN A BROADER SOCIOECONOMIC CONTEXT

Policies for abandoned coal mines in the U.S. initially focused on addressing health and environmental hazards and incorporated economic development elements only later. In parallel with this expansion, the potential for AMM mitigation and utilization was discovered and recognized as an important part of reclaiming abandoned coal mines. Today, AMM mitigation and utilization are part of an integrated approach taken in the U.S. to address issues related to abandoned coal mines.

ALLEVIATING HEALTH AND ENVIRONMENTAL HAZARDS

AMM can explode, posing hazards to residential and commercial buildings. AMM is also a precursor of air pollutants including volatile organic compounds, benzene (a carcinogen), and ozone.[83] Mitigating AMM is therefore an important component of addressing health and safety issues on lands around abandoned coal mines, known as "abandoned mine lands" (AML). Other environmental and health issues for AML include water pollution, soil erosion, and risks of subsidence and falling into mine structures.[84]

The U.S. has addressed health and safety hazards on AML since the 1970s, and methane emission prevention has been an important target. In 1977, the Surface Mining Control and Reclamation Act (SMCRA) was enacted to address health hazards and environmental degradation around AML across the U.S.[85] Subsequent remediation and restoration efforts for affected lands have expanded investments in mitigating health, safety, and environmental hazards, for example by preventing the release of methane and other hazardous gases. The SMCRA also established the Office of Surface Mining Reclamation and Enforcement (OSMRE) within the Department of the Interior to oversee SMCRA implementation.

The Abandoned Mine Land Program, introduced by Title IV of the SMCRA, provides states and tribes with federal funding for AML reclamation, including AMM release prevention.[86] OSMRE also launched the Technology Development and Transfer Program to provide local communities with technical assistance for AMM mitigation and other AML reclamation efforts.[87]

Federal coal mine reclamation efforts are ongoing. Many states, such as Pennsylvania,[88] Texas,[89] and Indiana[90] are actively reclaiming AML and addressing the hazards of AMM emissions. ECIWG also actively prioritizes AML reclamation in its agenda.[91] Additional federal resources have also been committed to address the lingering health, safety, and environmental issues posed by AML. For example, President Biden's Infrastructure Investment and Jobs Act appropriates over $11 billion to eligible states and tribal entities over 15 years, with an explicit goal to accelerate and expand AML cleanup activities across the country.[92] That legislation also extended the Abandoned Mine Land Program through 2034 to provide continued funding to states and tribes for reclaiming

[83] United Nations Economic Commission for Europe, 2020, p. 56.
[84] Favas et al., 2018.
[85] Surface Mining Control and Reclamation Act of 1977, 1977.
[86] Surface Mining Control and Reclamation Act of 1977, 1977.
[87] Office of Surface Mining Reclamation and Enforcement, n.d.
[88] Pennsylvania Department of Environmental Protection, 2022b.
[89] The Railroad Commission of Texas, n.d.
[90] Comer, 2012.
[91] Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization, 2023.
[92] Infrastructure Investment and Jobs Act, 2021.

AML.[93] Collectively, these represent among the most significant investments in AML reclamation since the SMCRA was passed in 1977.

The Ehrenfeld AML Reclamation Project, in Pennsylvania (see case study below), is among many such projects that have successfully addressed health, safety, and environmental issues in the U.S.. Incorporating lessons learned from this and other projects can benefit reclamation projects and governments, industry, and communities in other jurisdictions.

Case Study | The Ehrenfeld Abandoned Mine Land Reclamation and Watershed Restoration Project[94]

The Ehrenfeld Project in Cambria County, Pennsylvania has successfully addressed local health and environmental issues by removing dangerous coal refuse and constructing a new park to support community recreation and tourism. The project has received funding from the federal Abandoned Mine Land Program, as well as the federal Abandoned Mine Land Economic Revitalization (AMLER) Project.

Notably, the project is reclaiming abandoned and active mine lands simultaneously and has realized many benefits to date. First, by excavating coal refuse and remediating the environment around abandoned coal mines, the project successfully eliminated safety risks from sliding coal refuse. The project also restored the local environment by neutralizing acid coal refuse, improving water quality, mitigating air pollution, and reshaping the land to reduce erosion. The project area also has considerable potential to support additional future commercial, residential, and/or recreational purposes after reclamation activities have concluded.

Several lessons can be learned from this project. Many of its techniques – including topsoil excavation, storage, and placement; coal refuse excavation; lime, fertilizer, and alkaline addition material placement; and seeding and mulching – are transferable to other AML projects. Further, effective collaboration between federal, state, and local governments, local communities, and companies was instrumental in designing and implementing the project, as well as reducing its costs. Finally, the project illustrates the value of reclaiming active and abandoned mine lands simultaneously to maximize efficiency and impact while saving money.

ECONOMIC DEVELOPMENT

AMM is an important clean energy source that can deliver economic benefits to communities suffering from the decline of coal mining. Many U.S. states recognize AMM in their Renewable Portfolio Standards, while California's cap-and-trade program includes AMM projects as a source of GHG offset. AMM mitigation and utilization projects on AML can create jobs in regions affected by coal mine closures, contributing to local economic revitalization. Investing in AMM mitigation and utilization projects is an important measure that U.S. federal agencies and states have taken to simultaneously stimulate economic growth and job creation while mitigating coal mine emissions.

Coal demand in the U.S. has fallen precipitously in recent years due to the relative economics of renewable energy and natural gas, the enactment of more stringent environmental regulations, and actions to mitigate the climate change impact.[95] Communities that depended on coal mining, processing, or refining have lost jobs as a result of coal mine closures, and many have struggled to establish alternative opportunities for employment and economic growth.[96]

The U.S. government has taken several actions to revitalize local economies in coal communities. One such action was enacting the Abandoned Mine Land Economic Revitalization (AMLER)

[93] U.S. Department of the Interior, 2022.

[94] Pennsylvania Department of Environmental Protection, 2020.

[95] U.S. Energy Information Administration, 2023.

[96] Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization, 2021.

Program (originally called the AML Pilot Program) in 2015.[97] The AMLER program extended the scope of AML reclamation beyond health, safety, and the environment, intending to accelerate AML site remediation while supporting economic revitalization and community development.[98] By providing states, tribes, and local communities with federal funds for reclamation projects, the AMLER program has supported a wide range of projects and economic activities such as promoting recreation, attracting tourism, reclaiming lands for business, and renovating infrastructure.[99] The U.S. government has also implemented the Partnerships for Opportunity and Workforce and Economic Revitalization (POWER) Initiative, established by the Obama Administration to revitalize Appalachian communities that have been hurt by declines in coal mining and coal-fired power generation.[100] By offering federal funds, leveraging private investment, and providing technical support, the POWER Initiative created or retained nearly 21,000 jobs, created over 1,500 businesses, generated over 5,500 new visitors, and renovated or developed over 580,000 square feet of property from 2015 to 2022.[101]

Revitalizing abandoned mine lands remains an important federal priority, as evidenced by the Biden-Harris Administration's proposal of an aggressive remediation program as part of the Build Back Better agenda.[102] A new influx of funding for AML economic revitalization and AMM project development has accompanied the passage of the Bipartisan Infrastructure Law, CHIPS and Science Act, and Inflation Reduction Act.[103] OSMRE awarded $135 million in AMLER program funding during fiscal year 2023,[104] while the U.S. Economic Development Administration, under the Department of Commerce, has allocated over $551 million through its "Coal Communities Commitment" to support critical infrastructure investment and create jobs in coal communities.[105]

In April 2023, the Biden-Harris Administration announced a series of actions to drive economic development opportunities toward coal communities while addressing climate change. These include fostering interagency collaboration by a signed memorandum of understanding between 11 federal agencies,[106] establishing rapid response teams to provide targeted, on-the-ground technical assistance to local communities,[107] and allocating $450 million to solar farms and other clean energy projects.[108] Meanwhile, the ECIWG is coordinating federal investments to support economic revitalization and has identified priorities for immediate action, some of which are already underway (see Appendix, Table A3).[109] Many actions relate to boosting infrastructure investments, developing clean energy projects, and improving local economies and employment opportunities. Some actions are likely to encourage development of AMM mitigation and utilization projects, since the benefits of these projects are closely aligned with federal goals.

Many successful AML projects have helped revitalize local economies, with one such project in Pennsylvania's Bear Valley being a notable example (see case study below). The Anthracite Outdoor Adventure Area (AOAA) – Bear Valley AML Reclamation Project has rehabilitated hazardous AMLs for recreational use and economic redevelopment purposes including advanced manufacturing and renewable energy deployment. It offers several useful insights for governments, industry, and communities in other jurisdictions.

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97 Office of Surface Mining Reclamation and Enforcement, 2020

98 Office of Surface Mining Reclamation and Enforcement, 2023.

99 Pennsylvania Department of Environmental Protection, 2020.

100 Shelton et al., 2022.

101 Chamberlin & Dunn, 2022, p. ii.

102 The White House, 2021.

103 Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization, 2023.

104 U.S. Department of the Interior, 2023.

105 U.S. Economic Development Administration, n.d.

106 See Table A3 in Appendix for more information.

107 U.S. Department of the Interior, 2023.

108 Daly, 2023.

109 U.S. Department of the Interior, 2023.

Case Study | The Bear Valley Abandoned Mine Land Reclamation Project[110]

The AOAA – Bear Valley AML Reclamation Project, in Northumberland County, Pennsylvania, was pursued with three goals in mind: addressing health, safety, and environmental issues; increasing recreational opportunities for community members; and stimulating the local economy and tourism.

The project reclaimed AML by removing dangerous highwalls, remediating an acre of hazardous water, cleaning up coal mine spoils, removing hazardous equipment and facilities, and protecting bats and other local wildlife. It also transformed legacy AML features into safe recreational parks and planted new trees. The project received federal funding from both the Abandoned Mine Land Program and the Abandoned Mine Land Economic Revitalization (AMLER) Project.

The project's benefits are threefold. First, it has eliminated health and safety hazards and restored the local environment by cultivating forests, improving water quality and soil chemistry, and reducing erosion and sedimentation. Second, it has expanded recreational services for Pennsylvanians and visitors from nearby states. Finally, the project has helped revitalize the local economy, with business and tourism having significantly improved in the project area and surrounding communities. Gross sales in the AOAA – Bear Valley area reached nearly $1 million in 2021, a 6% increase from 2020, and the number of visitors grew to about 39,000. Importantly, job creation efforts have established permanent jobs to maintain AOAA – Bear Valley activities and services.

Several lessons can be learned from this project. Many of the techniques utilized at AOAA – Bear Valley are transferable to other AML projects. For instance, the forest reclamation approach (FRA) used here can be implemented elsewhere. As with other case studies, effective collaboration between federal and state governments, local communities and authorities, and companies was essential in developing this project and reducing costs. Finally, the project demonstrates that combining AML reclamation with building new recreational infrastructure can attract businesses and tourists – bolstering economic development and benefiting local communities.

[110] Pennsylvania Department of Environmental Protection, 2022a.

CONCLUSION AND LESSONS LEARNED

Methane from abandoned coal mines can lead to significant problems due to its explosive potential and unusually strong capacity to trap heat in the atmosphere. But its effective capture and utilization offers great potential as a clean energy source. Since the 1970s, U.S. federal and state governments have utilized various measures to mitigate and utilize AMM, with the aim of reducing greenhouse gas emissions and generating energy. Many lessons can be learned from the U.S. experience with AMM, which have important implications developing AMM policies and programs in the U.S. and elsewhere.

The U.S. has successfully developed models to estimate the contribution of AMM to overall greenhouse gas emissions and inform the development of effective AMM mitigation strategies, but measurement challenges remain. One lesson learned is that ground-based technologies offer an important solution for measuring AMM more precisely; these techniques currently offer greater accuracy than satellite and aerial surveys. Efforts to detect abandoned coal mine emissions should prioritize vehicle-mounted methane detection systems while investing in research and development to enhance the detection threshold of aerial survey instruments and improving precision for low-emission sources.

Its successful modeling efforts allowed the U.S. to identify many potential opportunities for AMM mitigation and utilization projects, which have been deployed nationwide. These projects have benefited from targeted government investment support, the establishment of state and voluntary cap-and-trade programs for AMM, and regulatory incentives in a handful of states. Market-based approaches, such as carbon cap-and-trade systems, are also important in developing AMM projects, as they provide economic benefits and rewards for reducing AMM emissions. These incentives encourage businesses and entrepreneurs to invest in AMM mitigation and utilization projects, develop innovative technologies, and explore economically viable opportunities for methane utilization. To implement better cap-and-trade systems, compliance offset protocols should be developed that clearly define what types of projects are eligible and how their emissions reductions should be estimated. Removing regulatory obstacles – by establishing clear procedures for acquiring AMM ownership rights, allowing the transfer of methane rights to third-party entities, and recognizing AMM as a renewable energy resource – also promotes AMM mitigation and utilization projects.

Collaboration among government agencies, industry stakeholders, and communities has provided local communities with critical on-the-ground technical and financial support and successfully leveraged a panoply of available resources. Local community engagement is essential, as each project and community have unique circumstances and assets, necessitating case-specific support. Therefore, a collaborative interagency approach should be taken to developing comprehensive strategies that encompass economic development, workforce training, infrastructure investment, hazard remediation, and community support. This approach allows for a holistic understanding of the complexities involved, leading to tailored AMM mitigation and utilization projects for local communities. Furthermore, education and outreach are needed for regulators at all levels to ensure they understand the challenge and opportunity of AMM emissions and the carbon neutrality of individual projects. Federal engagement alongside state involvement demonstrates genuine commitment and ensures tangible investments in local AMM mitigation and utilization projects.

Finally, it is important that governments, industry, and communities recognize the many benefits AMM projects deliver. AMM mitigation and utilization projects address health, safety, and environmental problems around abandoned coal mines while reducing climate impacts and

reliance on fossil fuels. Moreover, AMM projects can create jobs, particularly in regions affected by coal mine closures, helping to revitalize local economies. Recognizing these various benefits helps build awareness and support for AMM projects and can attract more financial investment in them. Integrating AMM mitigation and utilization into a broader policy framework for abandoned coal mine reclamation and economic revitalization can also help realize AMM projects' many benefits.

With its longstanding commitment to AMM mitigation and utilization, the U.S. has actively tackled the substantial environmental, climate, and economic impacts associated with abandoned coal mines. The comprehensive framework established in the U.S., comprising regulatory measures, substantial financial investments, interagency cooperation, active local engagement, regular modeling and monitoring, and various other approaches, offers a model for consideration by jurisdictions worldwide. When formulating policies aimed at curbing AMM emissions, other jurisdictions should consider incorporating lessons learned from the U.S. and proactively applying them to ensure beneficial and sustainable outcomes.

In conclusion, five principal lessons learned from the U.S. that could be useful for China and other jurisdictions are as follows:

- A comprehensive abandoned mine methane policy package should include investment, regulations, financial incentives, and interagency collaboration frameworks.
- Continuous investment in abandoned mine methane projects and innovative monitoring technology are crucial for capitalizing on the multiple potential benefits of abandoned mine methane mitigation.
- Regulatory barriers to developing abandoned mine methane mitigation and utilization projects can be addressed through both regulatory (e.g., royalty and tax relief) and legislative approaches. Market-based financial incentives (e.g., a cap-and-trade program) are also needed to encourage investment.
- Collaboration among different stakeholders (e.g., government agencies, academics, and companies) and direct engagement with communities are needed to ensure that local communities benefit from abandoned mine methane mitigation and utilization projects.
- Integrating abandoned mine methane mitigation and utilization into a broader framework is important for facilitating a sustainable economic transition for historically coal-dependent communities and the lands where they work and live.

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APPENDIX

Table A1 | Methodology Used to Identify Abandoned Mine Methane Recovery Opportunities[111]	
Identification Stage	**Specific Methods**
Pre-Process Elimination of Mines	**Step 1:** Flooded mines were excluded as they produce methane for only a few years after abandonment
	Step 2: Old mines without documentation and methane emission data were excluded
	Step 3: Mines that already have AMM recovery projects were excluded
	Step 4: Mines that emitted methane less than or equal to 200,000 cubic feet per day when they were active were excluded, as this has been determined as the threshold for an economically viable project
Post-Calculation Elimination of Mines	**Step 5:** Abandoned mines that generate less than 10,000 tonnes of CO_2e of methane per year were excluded, as this is considered to be the threshold for a viable carbon offset project
	Step 6: Mines in counties with less than 200,000 cubic feet per day of methane emissions were excluded

[111] U.S. EPA, 2019b.

Table A2 | Tools and Resources Provided by the CMOP for AMM Project Developmens[112]		
Project Development Phase	**Domestic Resources**	**International Resources**
Gather Background Information	• Report Coal Mine Methane Developments in the U.S.	• Coal Mine Methane Country Profiles • Basics of Coal Mine Methane Training
Identify Project Opportunities	• Online map of U.S. Coal Mine Methane Opportunities	• Prefeasibility and feasibility studies in 11 countries
Evaluate Coal Mine Methane Resources	• Online map of U.S. Coal Mine Methane Opportunities	• Interactive trainings on how to conduct prefeasibility studies at coal mines
Assess the Market for Coal Mine Methane (CMM)	• Publication State Renewable Energy Programs • Publication Emerging Financial and Regulatory Incentives for CMM Emission Reduction Project Development	• Coal Mine Methane market studies for select countries
Analyze Cash Flows	• Coal Mine Methane Cash Flow Model • Report Coal Mine Methane Finance Guide • Publication Greenhouse Gas Emissions Trading Programs that Include Coal Min e Methane	• Coal Mine Methane Cash Flow Model
Develop and Operate a Project	• CMOP webinars on specific technologies or providers	• Coal Mine Methane Mitigation and Utilization Technologies Database • Coal Mine Methane Mitigation Project List

[112] U.S. EPA, 2019b.

Table A3 | Immediate Actions for Revitalizing Economies in Historical Coal Mining Communities[113]		
Implementation Authority	**Actions**	**Specific Actions**
Department of Commerce	Investing in Job-Creating Infrastructure Projects	Conducts the Assistance to Coal Communities program to provide grants for infrastructure projects[114]
	Providing Access to Rural Broadband	Establishes three broadband grant programs to provide broadband access to tribal communities and minority communities
Department of Energy	Investing in Technological Innovations	Provides funding to install carbon capture and storage technology for coal power plants and encourage sustainable critical mineral extraction from coal and associated waste streams
Department of Treasury	Funding for Small Businesses	Explores ways to encourage the use of the State Small Business Credit Initiative funding in coal communities
	Investing in Financial Institutions Serving Energy Communities	Provides coal communities impacted by COVID-19 and the collapse in energy prices with funding through the Emergency Capital Investment Program
Department of the Interior	Creating Good Jobs by Reclaiming Abandoned Mine Lands	Supports the reclamation of AMLs through the Abandoned Mine Land Program and the AMLER Program
Department of Agriculture	Financing to Treat Mine-Impacted Water	Conducts the Water and Environmental Programs to provide financing for coal communities to establish water treatment and waste disposal facilities and clean mine-impacted water
	Funding for Rural Innovation Hubs	Conducts the Rural Innovation Stronger Economy program and offers funding to help coal communities support workforce development, create high-wage jobs, and strengthen regional economies

[113] U.S. EPA, 2019b.

[114] Those projects include roads, broadband, technology-based facilities, multitenant manufacturing and other facilities, business and industrial parks, water and sewer system improvements, expansion of port and harbor facilities, and brownfields redevelopment.

Implementation Authority	Actions	Specific Actions
Department of Labor	Financing for Economic Development Aligned Workforce Training	Conducts the Workforce Opportunity for Rural Communities demonstration grant initiative to promote workforce training in coal communities in the Appalachian and Delta regions
Department of Health and Human Services	Funding for Non-Profit Job Creators	Awards grants to non-profit community development corporations in coal communities through the Community Economic Development program to create new jobs
Department of Transportation	Funding for Transportation Infrastructure	Provides capital funding to coal communities through the Rebuilding American Infrastructure with Sustainability and Equity program, which will create good-paying jobs and reduce climate change impacts
Environmental Protection Agency	Funding to Revitalize Brownfields	Provides funding through the Brownfields Program to facilitate environmental cleanup and economic revitalization in historical coal communities
Appalachian Regional Commission	Investing in Economic Revitalization in Appalachia	Provides funding for economic revitalization to Appalachian communities through the Partnership for Opportunity and Workforce and Economic Revitalization Initiative