**methaneaction.org**

# Catalog of Research Funding Needs to Advance Methane Removal

**January 9, 2023**

Methane removal has been proposed as a complement to anthropogenic methane emissions reductions in order to:

- address methane sources which are difficult to prevent or avoid;
- deal with legacy emissions;
- remediate increasing emissions from wetlands and water bodies induced by anthropogenic global warming; and
- prepare against the possibility of a future methane burst (where rapidly thawing permafrost and submarine methane hydrates cause catastrophic methane releases).

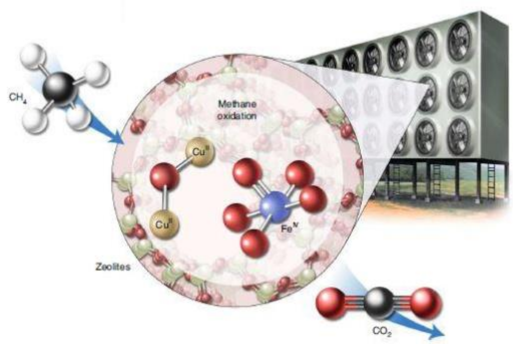
Methane emissions reductions and methane removal are complementary. Note that while the technologies described here focus largely on atmospheric methane removal, some might also be used for mitigation purposes, for instance, targeting point sources of methane such as mine ventilation systems.[1] Other methane removal methods are designed to enhance natural methane sinks in the troposphere or at ground level.

Some current and proposed research projects for methane removal technologies are listed in the table below. The table is followed by narrative descriptions and funding needs for these and other proposed projects. Projects listed below are illustrative examples only; they are not meant to be definitive or exhaustive. To compare the cost of removing methane vs. $CO_2$, the term "$CO_2$

[1] For other descriptions of the R&D agenda for methane removal see: Atmospheric methane removal: a research agenda. Jackson, R. B., et al (2021). *Philosophical Transactions of the Royal Society A*, *379*(2210), 20200454. https://doi.org/10.1098/rsta.2020.0454; Perspectives on removal of atmospheric methane. Ming, T., Li, W., Yuan, Q., Davies, P., De Richter, R., Peng, C., & Zhou, N. (2022). *Advances in Applied Energy*, 100085. https://doi.org/10.1016/j.adapen.2022.100085

equivalent" ($CO_2e$) is used and means the number of metric tons of $CO_2$ with the same global warming potential as a metric ton of methane.

All climate intervention technologies require competent cooperation and governance to succeed globally, therefore the final section of this catalog outlines steps that U.S. agencies and their counterparts in other countries can take toward the measuring, monitoring, and governance of technologies designed to remove methane and other climate forcing agents.

| **ILLUSTRATIVE PROJECTS** | **Summary** | **Team leading** | **Explanation number** |
|---|---|---|---|
| Zeolites + catalysis | Using hybrid air moving devices such as those in $CO_2$ Direct Air Capture (DAC) plants, to which zeolites and a catalyst are added.   By taking advantage of existing infrastructure and airflow, costs are lowered, with a target cost range of \$100 per ton of $CO_2e$. | Stanford University (US); M.I.T. (US) | 1 |
| Photocatalysis | Using small-scale updraft solar chimneys in urban settings. Estimated cost per ton $CO_2e$ is \$166 by 2030 with a target of \$100 by 2040. | Edinburgh University (UK) | 2 |

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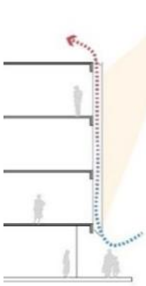
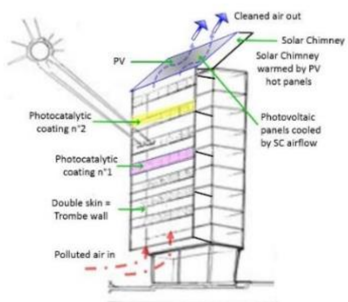
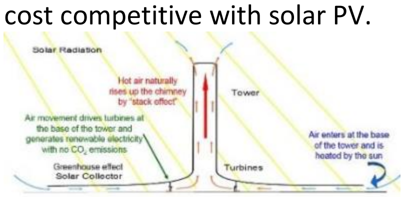
|---|---|---|---|
| | <br> | | |
| Photocatalysis | Using giant updraft solar chimney power plants, which could also generate electricity, earning $CO_2e$ credits of about $40 per ton $CO_2e$ (i.e., $1,000 per ton $CH_4$) making them cost competitive with solar PV.<br><br> | Wuhan University (CN) | 3 |
| Generation of Cl atoms | Mimicking natural processes that oxidize CH4. Cost estimates are potentially favorable ranging from $54 to as low as $1.7 per ton CO2e. However, those estimates will remain very uncertain until demonstrations and field tests are performed. | **Several proposals**<br><br>Iron-Salt Aerosols Demonstration Phase: Copenhagen U. (DK)<br><br>Chlorine-based photochemical removal Prototype: DK startup founded by Copenhagen U. | 4, 5, 6, 7 |

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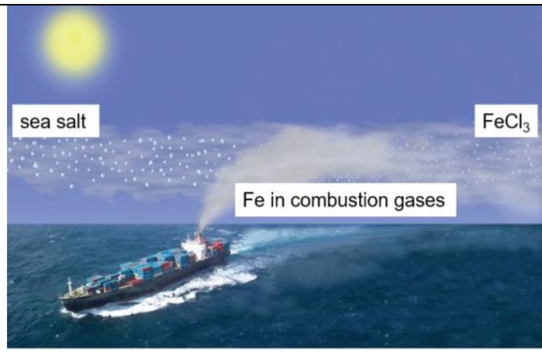
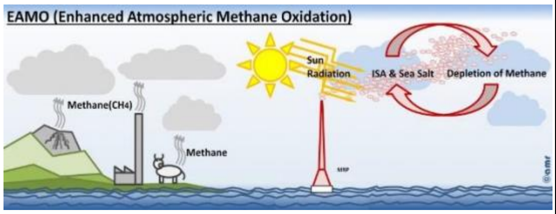
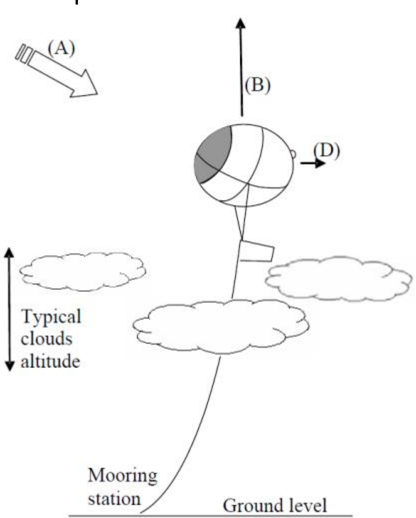
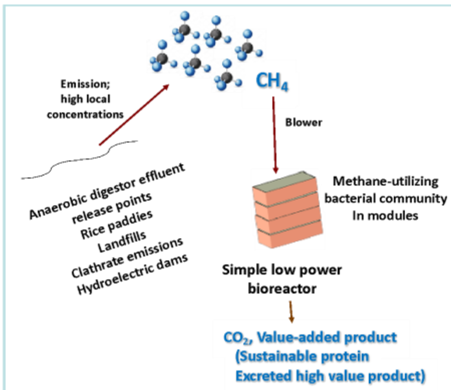
|---|---|---|---|
| | <br><br><br><br>* Four startups target costs of less than $10 per ton CO2e using Cl atoms:<br>In Denmark, Ambient Carbon Methane Holding ApS (https://dk.kompass.com/c/ambient-carbon-methane-holding-aps/dkcom188785/);<br>in Switzerland, Atmospheric Methane Removal (https://amr.earth/);<br>in Australia Iron Salt Aerosol (https://ironsaltaerosol.com/);<br>and In CA, US, Blue Dot Change (https://www.bluedotchange.com/). | Chlorine-based photochemical removal Remediation Prototypes; U.S. startup Blue Dot Change; Swiss startup AMR.<br><br>Chlorine-based photochemical removal alternative methods. University of Aston (UK).<br><br>Climate chemistry global model. ATMOS-IPSL in Paris, FR. | |
| Generation of hydroxyl radicals by photolysis and generation of UV-B/UV-C, and oxygen atoms | Study of technologies for eliminating Ozone Depleting Substances at the source or in the atmosphere.<br><br> | **Several proposals**<br><br>Climate-chemistry global model for accelerated recovery of the stratospheric ozone layer Team leading: ATMOS-IPSL in Paris, FR.<br><br>Accelerate the stratospheric ozone layer recovery<br>Team leading: Madrid U., and Canarias U., SP. | 8,9 |

| | | | |
|---|---|---|---|
| Methanotroph-based methane removal or mitigation | Methane Bioreactors<br><br>Using hybrid air moving devices coupled with methanotrophic bacteria, methane is converted into $CO_2$ and potentially valuable biomass. Target is methane concentrations of 100-500 ppm in near-source air (e.g., above landfills, feedlots, rice paddies, clathrate emissions, digester effluent discharge, hydroelectric dams).<br> | Team leading: University of Washington, USA | **17, 18** |

## Explanations of the research projects:

### 1. Zeolite surfaces

Zeolites are porous, high-surface-area alumina-silicate minerals used as molecular sieves and in water-treatment applications. Copper (Cu)- and iron (Fe)-zeolites are methane-oxidizing catalysts already used to convert methane to methanol ($CH_3OH$), a partial oxidation product (one added oxygen atom). More recently, zeolites have been shown to oxidize methane to carbon dioxide.[2] The ability of zeolites to adsorb CO2 from the atmosphere is well known. Scientists have screened almost 100,000 zeolite structures as potential methane sorbents. Relatively low-temperature methane oxidation has already been demonstrated in zeolites such as Cu-ZSM-5 and Fe-ZSM-5, with iron zeolites able to oxidize methane at room temperature. Higher temperatures and pressures generally lead to greater conversion efficiencies.

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[2] Methane removal and atmospheric restoration. Jackson, R. B., Solomon, E. I., Canadell, J. G., Cargnello, M., & Field, C. B. (2019). *Nature Sustainability*, *2*(6), 436-438. https://doi.org/10.1038/s41893-019-0299-x; Atmospheric- and low-level methane abatement via an Earth-abundant catalyst. Brenneis, R.J., Johnson, E.P., Shi, W, and Plata, D.L., 29 December 2021, *ACS Environment Au*. https://doi.org/10.1021/acsenvironau.1c00034

Teams leading: Stanford University, US; Massachusetts Institute of Technology, US (partially funded to date by ARPA-E)

Cost range: Target of $100 per metric ton of CO2e.

Key risks: All systems using catalysts must address potential issues with fouling (humidity, liquid water, sulfur. etc.). For active systems with blowers, air handling would be required (which is why adding catalysts to DAC facilities already in operation is desirable in terms of energy requirements). Passive systems would not require such air handling.

Funding need: $500,000/yr, two years ($1,000,000 total) for sorbent and catalyst development at ambient methane concentration. **Total: $1,000,000**

**2. Photocatalytic surfaces (small scale urban solar chimneys) - prototype testing**

Photocatalysts are metal oxides minerals activated by sunlight or by artificial UV-light able to oxidize organic pollutants and greenhouse gases at room temperature.[3] The smaller the nanoparticles and the larger the surface area and porosity, the faster the oxidation rate. Several are proven to fully oxidize methane, such as modified zinc oxide or titanium dioxide. Trials will be conducted on the ventilation system of an agricultural facility with cows. Then a prototype will be tested on a landfill.

Team leading: Edinburgh University, UK

Cost range: Estimating the costs of the required infrastructure requested results in a cost per ton CO2e of $166 by 2030 with a target of $100 by 2040.

Key risks: Potential issues with catalyst deactivation or fouling (humidity, contamination).

Funding needed: $1,500,000/ year for 3 years + additional $1,000,000 to build the pilot plant.

**Total: $5,500,000**

**3. Photocatalytic large-scale solar chimneys and solar chimney power plants**

[3] The comprehensive performance analysis on a novel high-performance air-purification-sterilization type PV-Trombe wall. Yu, B., Li, N., Yan, C., et al. (2022). *Renewable Energy*, *182*, 1201-1218. https://doi.org/10.1016/j.renene.2021.11.029; A new double-skin façade system integrated with TiO2 plates for decomposing BTEX. *Building and Environment*, *180*, 107037. Li, H., Zhong, K., & Zhai, Z. J. (2020). https://doi.org/10.1016/j.buildenv.2020.107037

Giant solar chimneys can be constructed which would cause heated air to updraft, providing airflow that can generate electricity through a turbine, comparable to a windmill.[4] Structures inside the solar chimney could remove methane from flowing air using photocatalytic coatings or other methods.

Team leading: Wuhan University, China

Cost range: Estimating the cost of the infrastructure required results in a cost per ton CO2e of $166 by 2030 with a target of $100 by 2040.

Key risks: none, consists of computer fluid dynamics studies and small-scale models

Funding need: $1,000,000 per year for 3 years. **Total: $3,000,000**

**4. Iron salt aerosols – demonstration phase**

Many ships burn low-cost bunker fuels that contain metals including iron that may have the favorable side effect of enhancing the naturally occurring chlorine atom sink for methane.[5] Existing evidence supports the theory that the mix of particle-phase iron, sunshine, and sea spray (containing natural chloride) generates chlorine atoms that will oxidize methane in the ship's plume. University researchers are prepared to demonstrate this mechanism using a combination of laboratory experiments, reaction system modeling and field tests. After appropriate assessment, consultation, permitting and governance, practitioners could then harness its power to control methane at scale. It is important to note that this approach would take advantage of present-day shipping traffic and the large volumes of air that are in contact with dilute ship plumes.

Team leading: University of Copenhagen, DK, OceansX, Netherlands.

Cost-range: $9 per metric ton of CO2e or less.

[4] Removal of non-CO2 greenhouse gases by large-scale atmospheric solar photocatalysis. De Richter, R., Ming, T., Davies, P., Liu, W., & Caillol, S. (2017). *Progress in Energy and Combustion Science*, *60*, 68-96. https://doi.org/10.1016/j.pecs.2017.01.001; Ming, T., et al. "Solar chimney power plant integrated with a photocatalytic reactor to remove atmospheric methane: A numerical analysis." *Solar Energy* 226 (2021): 101-111. https://doi.org/10.1016/j.solener.2021.08.024

[5] A nature-based negative emissions technology able to remove atmospheric methane and other greenhouse gases. Ming, T., de Richter, R., Oeste, F. D., Tulip, R., & Caillol, S. (2021). *Atmospheric Pollution Research*, *12*(5), 101035. https://doi.org/10.1016/j.apr.2021.02.017; Wittmer, J., & Zetzsch, C. (2017). Photochemical activation of chlorine by iron-oxide aerosol. *Journal of Atmospheric Chemistry*, *74*(2), 187-204. https://doi.org/10.1007/s10874-016-9336-6

Key risks: Catalytic efficiency of the process is yet to be demonstrated, so uncertainty remains in cost per CO2-eq. A full environmental impact assessment should be completed before deployment.[6]

Funds needed: $500,000 per year for 3 years **Total: $1,500,000**

**5. Chlorine-based photochemical removal at point sources**

This method generates chlorine atoms using low-cost light sources and uses a catalytic mechanism to recycle chlorine within a closed reactor. The innovators are at technology readiness level 3 (experimental proof of concept) and seek to bring this to technology readiness 5 (validation in relevant environment).

Team leading: Start-up company Ambient Carbon, Denmark.

Cost-range: Modeling based on power requirements results in an estimated cost of $9 per ton of CO2e.

Key risks: Energy input uncertainty.

Funding needed: $2 million to build a prototype to field to test at livestock barns and a coal mine vent. **Total: $2,000,000**

**6. Chlorine-based photochemical removal in the atmosphere (Method 1)**

This method generates chlorine atoms using sunlight and an aerosol of $FeCl_3$ in the marine environment where there are sea brines. The reaction is catalytic in iron, the chlorine atoms being provided by the sea salt. The innovators are at technology readiness level 4 (prototype for the aerosol generation tested in-doors) and seek to bring this to technology readiness level 5 (validation in relevant environment).

Team leading: start-up company AMR (Atmospheric Methane Removal), Switzerland.

Cost-range: Modeling based on $FeCl_3$ consumption results in a price of $2-3 per ton of CO2e.

Key risks: Limits to life expectancy of the aerosols generated and the number of catalytic cycles.

Funding needed: $2 million to build arger prototype to be tested indoors. **Total:$2,000,000**

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[6] See this study on modeling the air and marine impacts of this method: Sturtz, T.M., Jenkins, P.T., de Richter, R. Environmental impact modeling for a small-scale field test of methane removal by iron salt aerosols. *Sustainability* 2022, 14, 14060. https://www.mdpi.com/2071-1050/14/21/14060/pdf

**7. Chlorine-based photochemical removal in the atmosphere (Method 2)**

Chlorine atoms can be generated by photolysis of $Cl_2$ gas, produced by the well-established chlor-alkali industrial process. Other methods of generating chlorine atoms or molecular chlorine[7] in order to remove methane will be explored. In particular, in order to be able to rapidly react if a methane burst occurs (for instance from methane hydrates, due to a submarine landslide after an earthquake).

Team leading: University of Aston (Birmingham), UK.

Cost-range: $20 per ton of CO2e, based on estimations of chlorine gas prices and the cost of UV light at 254 nm for photolysis.

Key risks: Chlorine gas is widely used in the chemical industry but its use requires careful handling and well-known precautions.

Funding needed: $300,000 for 3 years. **Total: $900,000**

**8. Climate chemistry global model to study accelerated recovery of the stratospheric ozone layer**

Enhancing the tropospheric production of chlorine atoms will increase oxidative capacity of the troposphere and might reduce the amounts of halogenated compounds reaching the stratosphere. Before conducting open-air field tests, global computer modeling is needed to anticipate benefits and any possible side effects of halogenated gases from natural sources, such as chloromethane produced by plankton, and anthropogenic sources. This can be done using the climate-chemistry global model LMDz-INCA.

Team leading: ATMOS-IPSL in Paris, France.

Key risks: none, consists of computer modeling.

Funding needed: $200,000 per year for 3 years. **Total: $600,000**

**9. Climate chemistry global model to study the effects of enhanced hydroxyl radical generation**

The hydroxyl radical (•OH) is the most widespread oxidizer in the troposphere. It is often referred to as the "detergent" of the troposphere because it reacts with almost all volatile organic compounds and many pollutants, decomposing them. It has an important role in

[7] Sadanaga et al. Formation of molecular chlorine in dark condition: Heterogeneous reaction of ozone with sea salt in the presence of ferric ion. *Geophysical research letters* 28.23 (2001): 4433-4436.

eliminating some greenhouse gases such as methane but also HFCs and HCFCs, which are highly potent GHGs and that also deplete the stratospheric ozone layer.

New methods to enhance the hydroxyl radical are in development based on the natural pathways already known (e.g., ozone, nitrogen oxides, humidity, UV). Their potential effects locally and globally would be estimated by computer simulations.

Team leading: ATMOS-IPSL in Paris, France.

Key risks: none, consists of computer modeling.

Funding needed: $200,000 per year for 3 years: **Total: $600,000**

**10. Accelerating recovery of the stratospheric ozone layer**

Study the use of high altitude solar photovoltaic platforms, which receive 5 times more solar energy than land-based PV panels, to generate UVB and UVC light. UVB/UVC enhances photolysis of $N_2O$ and CFCs, oxidation of methane and production of oxygen atoms and ozone below the lower stratosphere.[8] Laboratory research and further R&D are needed to optimize the aerostatic platform and the UV lamps materials (quartz or other materials transparent for low wavelength UV).

Team leading: University of Madrid and University of Canarias, Spain.

Funding needed: $300,000 per year for 3 years **Total: $900,000**

**11. Generation of hydroxyl radicals to increase methane removal by oxidation**

Hydroxyl radicals are the predominant naturally occurring agents that oxidize methane in the atmosphere. Commercially available hydroxyl generators based on UVB or UVC light exist, but energy requirements are high for large-scale use. Other methods for large-scale generation of hydroxyl radicals will be explored based on other known natural pathways (e.g. ozone, nitrogen oxides, humidity, UV, Fenton reaction).

Team leading: Edinburgh University, UK.

Cost-range: Estimated costs of required infrastructure results in an estimated initial cost-range of $200-1000 per ton of CO2e.

Funding need: $400,000 per year for 3 years **Total: $1,200,000**

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[8] Solar power generation using high altitude platforms feasibility and viability. Aglietti, G. S., Markvart, T., Tatnall, A. R., & Walker, S. J. (2008). *Progress in Photovoltaics: Research and Applications*, *16*(4), 349-359. https://doi.org/10.1002/pip.815

**12. Surface-based Photocatalytic Enhanced Methane Oxidation (SPEMO)**

The EPA, in cooperation with the Secretaries of Interior and State, USAID, and the Department of Energy, could contract for three years of research and development of SPEMO to assess alternative methods to:

(1) lower methane emissions from coal mines, oil wells and animal farms, to ensure that methane concentration from ventilated air is less than 1.7 ppm by volume, and

(2) apply photocatalytic paint to buildings, rooftops, PV panels, or in a ventilated conduit to reduce methane in the general atmosphere. Commercial photocatalytic paints and coatings are already used for their self-cleaning property and ability to reduce urban pollutants such as nitrogen oxides and volatile organic compounds.

Funding needed: $1,000,000 per year for 3 years **Total: $3,000,000**

**13. Capturing methane at Arctic seeps - field test**

The U.S. start-up Frost Methane is successfully using recycled parachutes to capture and flare methane from seeps in Arctic lakes. Through a collaboration with a large dredging company, the idea is to develop a low-cost structure made of stones and sand that can capture methane seeps in the Arctic Ocean (especially in the shallow parts of the Siberian Sea of the Russian Arctic). A typical project covers a circular field 200 meters in diameter with a layer of 150-200 mm rocks which is permeable to methane gas. That layer is then covered with two layers of smaller-sized rocks, which block the gas and guide it to an exit point, where the gas is captured and flared.

Team leading: Frost Methane, USA.

Key risks: Flaring produces some pollutants while destroying others.

Cost-range: Using seep emission of 176 $g/m^2/day$, the rough estimate of cost: $6.7 – $25 per ton CO2e.

Funding needed: $100,000, to test the concept at a research facility and plan for field testing.

**Total: $100,000**

**14. Agricultural and silvicultural methane removal with co-benefits of enhanced yields and nutrition**

In cooperation with USDA and its sub-agencies such as the USDA Office and International Research, Engagement and Cooperation, the Administrator of EPA could contract for an evaluation of GHG sequestration, uptake, oxidation, and other long-term removal methods in agricultural and silvicultural (forestry) practices including, but not limited to, the methods described below:

(1) Rice is a basic staple for nearly half the world population. Rice production accounts for about 8% of global methane emissions and 2.5% of radiative forcing, and these numbers are expected to double by 2100. With a goal of cutting methane emissions from rice cultivation in half, the Administrator of EPA in cooperation with the Administrator of USAID and the Secretary of the USDA could contract for a three-year test various potential additives to rice farming, such as iron sulfates, which are approved for organic farming to enhance yields, fight plant chlorosis, and improve the nutritional value of rice crops and fight anemia by raising iron levels. Research indicates that similar organic iron fertilization may be beneficial to forests as well. Such methods could be tested in conjunction with other changes in rice farming practices, for example more efficient targeting of rice field flooding.

Subtotal: **$3,000,000**

(2) EPA, USDA, State, and USAID could collaborate in a broad livestock methane reduction and removal research, development, and demonstration program. Methods for reducing methane emissions from cows, sheep, and other livestock range from adding food supplements made of red seaweed (US) to planting native plants that reduce methane generation in sheep that graze on them (France). Active methane removal from livestock barns is soon to be tested in Denmark, using a method that may potentially work at the mouths of coal mines as well.

Subtotal: **$4,000,000**

**Total: $7,000,000**

**15. Methane mitigation via wetlands management**

Wetlands are a major methane source, accounting for 31% of overall methane emissions. The EPA Administrator, in cooperation with USDA, the Departments of Energy and the Interior, the Army Corps of Engineers, and the Bureau of Reclamation, could contract for an investigation of relative wetland emissions reductions of methane, through field surveys and laboratory experiments, to determine whether alternative management practices, e.g., re-wetting drained wetlands, could reduce greenhouse gas emissions.

Funding needed: $500,000 per year for 3 years **Total: $1,500,000**

**16. Methanotroph-based methane removal—laboratory testing**

Bacteria that grow on methane as their main nutrient source (methanotrophs) are able to consume methane from the air at ambient temperatures, generating $CO_2$ and biomass, which can be converted into valuable products. Technology is under development which uses methanotrophs adapted to low levels of methane in the air, combined with novel thin film bioreactor design. The value-added is the increased understanding/control of methanotrophic consumption for possible use across diverse settings.

Team leading: University of Washington, USA.

Cost: target is $50 per ton CO2e

Funding needed: $1,500,000 per year for 3 years **Total: $4,500,000**

**17. Methanotroph-based methane removal—pilot deployment and testing**

Based on laboratory results, 2-5 $m^3$ scale pilots will be constructed and deployed in the field at sites with elevated methane in overlying air, such as feedlots, landfills, and rice paddies.[9]

Team leading: University of Washington, US

Cost: target is $50 per ton CO2e

Key risks: scale up of bioreactor design not yet tested

Funding needed: $2,000,000 per year for 3 years. **Total: $6,000,000**

**18. Biochar-based methane emissions reduction from sewage sludge management facilities**

Sludge accumulation is a challenge both for wastewater treatment plants and for livestock breeders. Often sewage sludge and livestock manure are dewatered and dried without external heat sources, under greenhouses using solar energy. Those facilities emit GHGs including methane. Sometimes dry sludge is then composted alone or mixed with garbage or agricultural residues and the composting process also emits GHGs and methane. A promising way of reducing methane emissions of these processes is by mixing the sludge with biochar. When the final product is used as fertilizer the stability of this organic amendment makes it a negative emissions technology. Depending both on the sludge and on the sources and nature of the biochar, different GHGs emissions reductions profiles are possible. The value-added of this research is increased understanding and optimization of methane and other GHGs emissions reductions.[10]

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[9] Chistoserdova L, Kalyuzhnaya MG. 2018. Current trends in methylotrophy. *Trends Microbiol.* 26(8):703-714.

[10] See, Sorrenti, A, et al. 2022. Enhanced sewage sludge drying with a modified solar greenhouse. *Clean Technol. 4*, 407-419. https://doi.org/10.3390/cleantechnol4020025 ; Zhou, Qian, et al. 2022. Impact of

Team leading: (Related research has taken place at North Carolina State University but for this project a leading team has not yet been identified.)

Cost: target is $20 per ton CO2e

Key risks: methane emissions reduction might result in slightly increased nitrous oxide emissions depending on the level of nitrogen in the sludge, but that might be solved by diversifying biochar sources and production methods.

Funding needed: $1,500,000 per year for 3 years **Total: $4,500,000**

**19. Reducing methane emissions from hydroelectric dams and reservoirs**

Hydroelectric power supplies one sixth of the world's electricity, more than all other renewable sources combined and also more than nuclear power. Hydroelectricity is not carbon neutral. Despite common belief, hydropower reservoirs do emit GHGs. The emissions primarily come from microbial processes that decompose organic matter into GHGs (mainly methane and $CO_2$, but also $N_2O$).

One well-known method to reduce methane emissions from lakes is to prevent stratification, eutrophication and anoxia in their bottom layers by oxygenating them (with bubbling air). R&D and computer modeling is further needed to explore and evaluate the synergistic effects of oxygenation of lakes and dams coupled with floating photovoltaic power plants on GHGs emissions reductions, but also on co-benefits such as reducing water evaporation, supporting fish and other aquatic life and preventing toxic algal blooms while also producing more power.

Team leading: Leading team has not yet been identified.

Cost: The target is a negative cost. Cost savings would come from avoided methane emissions, clear water saved from evaporation, and increased co-production of electricity.

Key risks: Floating PV and air-compressor equipment could be vulnerable to storms.

Funding needed: $150,000 per year for 3 years **Total: $450,000**

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different structures of biochar on decreasing methane emissions from sewage sludge composting. *Waste Management & Research*: 0734242X221122586. https://doi.org/10.1177/0734242X221122586; Das, Shaon, Kumar, et al. 2021. Innovative biochar and organic manure co-composting technology for yield maximization in maize-black gram cropping system. *Biomass Conversion and Biorefinery*, 1-13. https://doi.org/10.1007/s13399-021-01519-5

## Measuring, Monitoring and Governance Components

### 20. Comprehensive assessment of atmospheric methane sources, sinks and solutions

The EPA Administrator, in cooperation with the Secretaries of Energy, Agriculture, and State, could commission a report from the National Academy of Sciences providing the following analysis:

(1) an assessment of the size and changes occurring in emission and sinks of methane globally;
(2) an analysis of the likely impact of atmospheric methane on climate change and other problems caused by atmospheric methane;
(3) a review of each major methane emission source and sink to determine what options are available to affect their impact on atmospheric methane levels;
(4) a review of all possible, and all currently practicable, technologies, programs, policy and regulatory changes that could help reduce atmospheric methane levels, whether by abatement (emissions reduction) or removal, and for each proposed technology or policy change, consideration of their technological readiness, likelihood of success, barriers hindering implementation, cost-effectiveness and cost-benefit analysis, and likely overall impact on atmospheric methane levels;
(5) draft national and global plans for atmospheric methane reduction and removal, with goals and recommendations, discussion of options for investment in new technologies, possible regulatory and land management changes, and other means lowering barriers to implementation.

**Total: $2,000,000**

### 21. Enhance global governance of GHG removal methods

The Secretaries of Agriculture and Commerce and the Administrator of the EPA could assist the Secretary of State, the Administrator of the U.S. Agency for International Development and the U.S. Trade Representative, in consultation with the Special Envoy for Climate Change, and the agencies participating in the affected U.S. delegations, in implementing the Methane Pledge and pursuing a Methane Agreement or Declaration, as well as other relevant resolutions and agreements.

With grants for nongovernmental agencies with appropriate expertise, such collaborations could support the proper assessment, deployment, and domestic and international governance of greenhouse gas removal. This would provide assessment of the effects of reducing atmospheric concentrations of methane and other climate forcing agents to preindustrial levels and help ensure sufficient, safe and proper use of greenhouse gas removal technologies, including those designed to reduce or actively remove emissions of carbon dioxide, methane, chlorofluorocarbons, hydrofluorocarbons, black soot, and other climate forcing agents.

A Declaration or Agreement building on the Global Methane Pledge could be implemented in support of (though not necessarily under) existing agreements such as  the United Nations Framework Convention on Climate Change and its protocols and accords.

**Total: $5,000,000 per year per agency**

**22.  Small grants program**

The Secretaries of Agriculture, Energy and the Interior and the Administrator of the EPA could each devote $500,000 for a small grants program to seed promising innovations in the methane removal field for FY2023 and the following years as authorized by the Inflation Reduction Act.

**Total: $500,000 per year per agency**