Big Problems, Microscopic Solutions:

ASM Recommendations to Address Climate Change

Overview

The science is clear: our climate is rapidly changing. Microbes, the tiniest forms of life on our planet, are adept at adapting, surviving and thriving in extreme, constantly changing environments. Understanding the world of microbes can help us harness their power for a sustainable global food supply, decarbonization, energy security and the growing bioeconomy, while curbing the impact of dangerous pathogens, or disease-causing microorganisms. It is not enough, however, to simply understand microbial sciences. We must put knowledge into action. Doing so requires policy solutions.

Policies that provide adequate infrastructure, funding and coordination will support scientists in leveraging beneficial microbes and combating disease-causing microbes as they work across disciplines to develop and deploy climate solutions. A vital first step: policymakers must recognize the importance of interdisciplinary collaboration and the applications of fundamental biological research. Microbes offer solutions that are environmentally and economically sustainable compared to existing practices. Holistic climate change strategies that include microbes will inform decisions on growing the bioeconomy; preserving and restoring ecosystems; bolstering animal and human health; supporting bioenergy development; and ensuring food security through a resilient, diversified agricultural sector. This will require coordination across the 21 federal agencies that engage in microbiome research, flexible funding streams, and policies that incentivize scalable innovation.

To deepen our understanding of microbial functions, the contributions of microbes to the generation and consumption of warming gases, to ecosystem stability, and to human well-being, the American Society for Microbiology (ASM) encourages the adoption of policies that bolster basic and applied research. We also strongly encourage lawmakers to move forward with aggressive targets for cutting greenhouse gas emissions while supporting and leveraging basic science for climate adaptation, mitigation and resilience. With an eye toward a One Health approach to addressing climate change's effects on humans, animals and our environment, the U.S. can re-establish leadership in science and innovation and increase the impact of science-based solutions.

ASM Policy Recommendations:

The American Society for Microbiology has 6 key policy recommendations to support research on microbes and leverage their power to support climate-resilient systems:

1. **Support basic research on microbial functions and the contributions of microbes to the generation and consumption of warming gases, to ecosystem stability, and to human well-being.**
    - Increase funding for basic biological and environmental research at the federal science agencies and establish new funding models to support inter-disciplinary, cross-cutting research.
    - Provide stable, long-term funding for transdisciplinary climate research infrastructure, including cross-agency data repositories, culture collections, long-term ecological monitoring systems, and integration and knowledge bases, in collaboration with the international research community.

2. **Incorporate microbes as sentinel measures of climate change, including the detection and monitoring of microbial pathogens and beneficial microbes, to predict and prevent negative impacts in humans, animals, plants, and ecosystems.Include microbial data in global and U.S. climate reports.**
    - Increase capacity and funding to detect, characterize and address zoonotic, waterborne, and vector-borne diseases through use of next generation sequencing in public health and clinical laboratories.

- Collect and report climate-related health and environmental data in each state and territory, including wastewater surveillance for antimicrobial resistant pathogens.
- Build robust data systems for monitoring soil and water health at NOAA (National Oceanic Atmospheric Administration), USDA (United States Department of Agriculture), and other relevant agencies and establish cross-agency coordination of these efforts.

3. Leverage the power of microbes to support climate-resilient systems.

- Support foundational bioenergy research.
- Increase federal agencies' support for innovative applications of biotechnology to mitigate the effects of climate change.
- Fund climate-smart practices and technologies in agriculture and work with producers and land managers to build a diverse and sustainable domestic food system.
- Support research on the microbiome of oceans and wetlands, forests, agricultural land and grasslands to maintain their capacity to naturally sequester carbon.

4. Strengthen coordination among federal agencies and programs and leadership with international partners.

- Establish a permanent office of climate change within the Executive Branch to develop and coordinate the U.S. climate response that includes a climate science research agenda with broad stakeholder input.
- Identify high impact areas that require coordination at the federal level, such as microbiome research, and establish a strategic plan to foster this research.

5. Incentivize science-based climate solutions, scalable innovation and real-world application.

- Increase support for circular bioeconomy and bioeconomy-focused public-private partnerships.
- Identify existing microbial innovations that could be applied today that could have immediate impact on mitigation strategies.
- Provide incentives and interdisciplinary training for scientific leadership to create scalable innovations and systems to bridge the research and development "valley of death."
- Create and support public private partnerships that translate research discoveries into scalable microbial innovations.

6. Increase public engagement and understanding of how microbes impact all aspects of our daily lives, including climate change.

- Invest in a diverse scientific workforce and foster an inclusive culture.
- Create opportunities for the next generation of scientists to connect their work to real-world problems and communicate that connection to the public.
- Recognize the importance of community engagement in the microbial sciences to address climate change.

This paper explores opportunities and policy actions needed to combat climate change by leveraging microbial sciences. In the interest of brevity, we have provided high-level references to the science behind the solutions, with links to peer-reviewed journal articles, data sources and American Academy of Microbiology reports. For additional resources on a given topic, such as harmful algal blooms, soil health or biofuels, please contact us at advocacy@asmusa.org or visit https://asm.org/Resource-Pages/Climate-Change.

Microbes support life as we know it and hold the keys to the future.

Microorganisms have a vital role in climate change and as such, are essential to climate adaptation, mitigation and resilience. Recent advances in DNA sequencing technology have revealed that the greatest diversity of the biosphere is found in the microbial world and established that microbial communities (microbiomes) are intimately connected to the health of all corners of the biosphere. As noted in the Scientists' Warning to Humanity: Microorganisms and Climate Change (a recent microbiology consensus statement), "To understand how humans and other life forms on Earth (including those we are yet to discover) can withstand anthropogenic climate change, it is vital to incorporate knowledge of the microbial 'unseen majority'."

Microorganisms drive the vast interlocking systems of plants, animals and the atmosphere to sustain life on Earth by controlling the biogeochemical cycling of nutrients, transforming or "fixing" greenhouse gases such as carbon and nitrogen into usable forms. Microbes also help soils and oceans sequester carbon. Human activities that release greenhouse gases into the atmosphere can initiate enhanced microbial activity, resulting in increased carbon levels and altered temperature and precipitation patterns. A stark example of this is observed in the accelerating melting of glaciers. As ice and permafrost melt, substantial amounts of soil organic matter will become available for microbial enzyme activity, unlocking carbon that was previously stored in frozen soil to be released into the atmosphere, affecting the earth's temperature and accelerating the carbon cycle. Ultimately, human activities that instigate shifts in the microbial composition of soils and water affect crop production, greenhouse gas cycling and biodiversity.

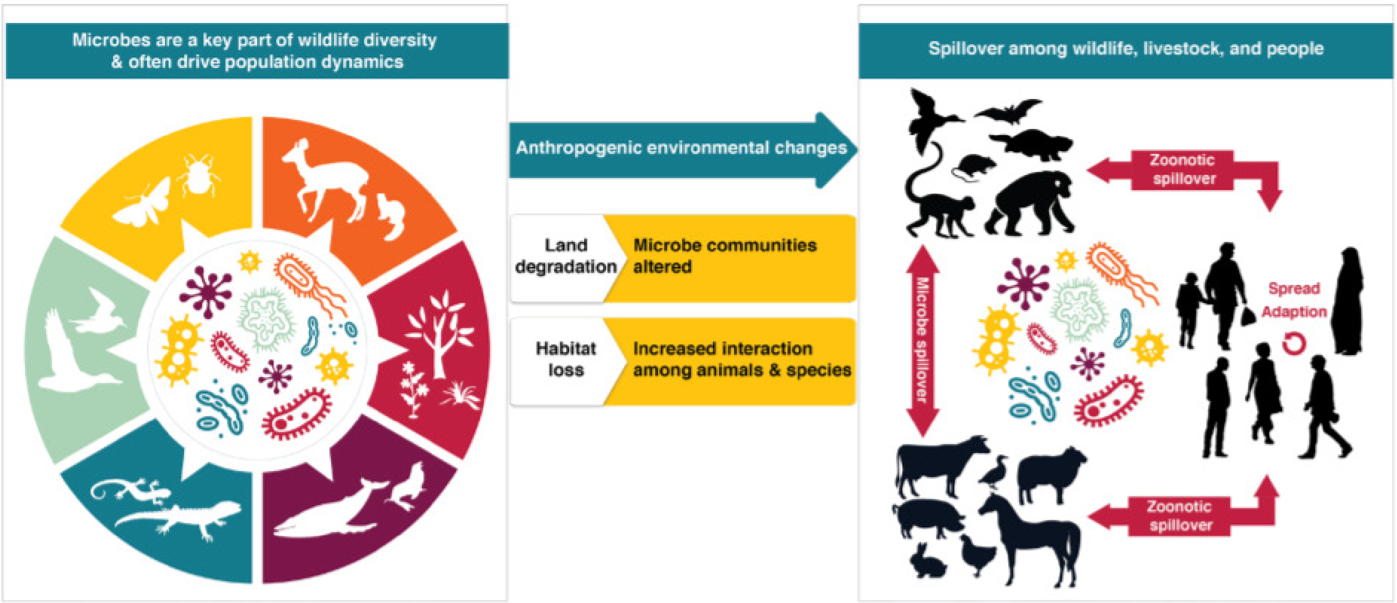
Current efforts to curb greenhouse gas emissions are not sufficient to meet U.S. and international targets and increase our vulnerability to climate-related disruptions.

If we fail to reach current targets, the impacts of climate change will be dire, according to a recent review paper in *The Lancet*. Access to clean water, food and other basic needs such as energy will become more expensive and scarcer, magnifying the impact on under-resourced populations. Increasingly frequent severe weather events pose significant threats to our communities; associated changes in rainfall patterns may increase the transmission of waterborne pathogens in addition to causing structural damage; drought conditions will threaten the ecosystem and agricultural health. The systems that we need for survival—including agriculture, energy and health—must adapt.

Growing demand for energy and global instability stresses the importance of investing in diverse energy sources, including bioenergy. Currently, 20% of U.S energy demands are met by renewable sources, including ~1.3% by biomass, which relies on microorganisms for conversion into bioenergy (U.S. Department of Energy). Biofuel derived from plant materials is among the most rapidly growing renewable energy technologies. Traditional biofuel feedstocks require land, water and other resources, putting them in direct competition with crops grown for food. Federally funded researchers have leveraged the power of microbes to develop next-generation biofuels that produce higher yields, reduce greenhouse gas production and do not compete with crops grown for food. Two major areas of research are algae and lignocellulose, which is derived from inedible plants and residues.

Microorganisms play key roles in plant and soil health and the global food web. A growing proportion of land across the globe is devoted to agriculture, making soil one of our most valuable resources in feeding a growing population. The combustion of fossil fuels and the use of fertilizers in agriculture has increased the environmental availability of nitrogen, perturbing global biogeochemical processes and threatening ecosystem sustainability. The contributions of industrial agriculture to greenhouse gas emissions and land degradation have led to calls for transforming food systems to mitigate, rather than contribute to, climate change. Reducing agriculture greenhouse gas emissions will require microbial innovation, such as feed additives, microbial fertilizers, and shifting livestock to different areas of pastures to graze, but we cannot depend on producers alone to shoulder the burden of climate change. Addressing the entrenched issues of the food supply, including dependence on a small number of resource-intensive crops, will require global cooperation of producers, governments and consumers to build diverse, sustainable food systems.

Studying microbes that consume harmful greenhouse gases as energy sources may provide insight into how humanity can imitate these processes to find alternative uses for greenhouse gas emissions. With the right data, scientists and policymakers can take action to understand and implement practices that mitigate microbial activities to decelerate the production of greenhouse gases, such as reducing soil tillage, repurposing waste using microbes, and leveraging microbes to mitigate ecosystem disruptions.



Exposures to zoonotic pathogens increase with greater frequency of human and animal interactions. Microorganisms that naturally evolved with wildlife (left) can spill over to humans because of human expansion into natural habits (center) and increased contact with wildlife or livestock (right). Zoonotic pathogens can cause pandemics when they are transmitted easily among humans and can spread quickly because of urbanization and global travel. Figure from Daszak et al. 2020.

Climate change increases human, animal and environmental vulnerability to pathogens.

The World Health Organization has reported climate change to be "the single biggest health threat facing humanity." Environmental disruptions reduce the microbial diversity that is necessary for the survival of higher organisms; thus, changes in microbial biodiversity and activities due to climate change will affect the resilience of organisms. Climate change will increase the cost and burden of infectious diseases on global populations, with low-income and disadvantaged countries and communities facing the most severe threats. Human migration due to climate change will increase microbial transmission into novel environments and create new opportunities for disease transmission across species and from wild animals to humans.

Some of the world's most biodiverse ecosystems are experiencing rapid changes, including coral reefs, rainforests and polar regions, which support countless wildlife in addition to human communities who depend on natural resources for food, medicine and sources of income. Continued habitat loss is expected to result in the migration or extinction of important animal and plant species, many of which are already facing population decline. These changes will alter the landscape of disease-causing microbes, including viruses, fungi and bacteria. However, we have limited capacity to track these changes on a large scale, as current climate change models lack data on microbial activity.

Harmful Algal Blooms

Aquatic ecosystems are home to diverse microbial species that are vital to converting carbon dioxide into organic compounds that could be used as energy stores, as well as supporting human, animal and environmental health. Our oceans, lakes and rivers face the triple threats of acidification, warming and deoxygenation due to excess carbon dioxide emissions, leading to mass die-offs of marine life and decreased biodiversity, including microorganisms. Harmful algal blooms formed by cyanobacteria involved in plant photosynthesis have increased in frequency, intensity and duration in many lakes, reservoirs, and estuaries. Bloom-forming cyanobacteria produce a variety of toxins harmful to the skin, liver cells and nervous system, which can be fatal to birds and mammals. They also threaten the use of waters for recreation, drinking water production, agricultural irrigation and fisheries.

As permafrost thaws and flooding increases, microbes may be carried to new areas, introducing foreign diseases to vulnerable populations. Additionally, as insect vectors and animal hosts respond to changing temperatures by migrating or altering their behavior, their microbes will travel with them. Human, animal and plant hosts affected by heat or drought may become more vulnerable to disease. Approximately 40% of the world's population live in areas with *Aedes aegypti* mosquitoes, a primary transmitter of yellow fever, dengue fever, and Chikungunya and Zika viruses to humans. Nearly 1 billion additional people could face their first exposure to viral transmission from heat-tolerant Aedes aegypti within the next century, according to a recent study in *PLoS Neglected Tropical Diseases* cited by the Center for Disease Control and Prevention (CDC). Mitigating the risk associated with these costly diseases will require resources and coordinated action plans.

Antimicrobial resistance is another growing threat to humans, animals and ecosystems that will be magnified by climate change. Antibiotic-resistant pathogens can often be traced back to discharge flowing from hospitals, farms or sewage systems. Extreme weather events can cause sewage overflow that disperses and mixes pathogens and other problematic antibiotic resistances into waterways, expanding the geographic range of the resistant and disease-causing microbes. As policymakers weigh options for a unified water management system, they should consider deploying methods within these systems to identify resistant pathogens as well as diseases spread by animals, water and insects.

More intense, frequent weather events are affecting wine regions globally. Recent changes in microclimates include the shifting of microbe populations within the soil microbiomes along with fungal species that previously were not able to survive in certain areas. As seen in Europe in the 1860s with the insect pest phylloxera, when over two-thirds of European vineyards were destroyed, the introduction of a new fungus can have devastating consequences to crops. More recently, the wine region of Champagne, France, experienced such heavy rains and elevated temperatures in 2021 that the 3 grapes (varietals) used to produce champagne there could not be harvested properly. One champagne house was unable to produce any champagne last year for the first time since 1700.

Building robust surveillance to predict and manage the cascading effects of climate change.

Although microbes have no borders, they do offer solutions if we know where they are and how they are interacting in the larger environment. Both independently and as part of a larger ecosystem, microbes play a crucial role that will heavily influence climate change adaptation, mitigation and resilience. But understanding and leveraging their role requires robust public health and environmental surveillance systems.

For example, a national soil data information system that incorporates microbes would support data-driven decisions on land use by producers, land managers, scientists and policymakers. Soil health is critical to farming, forestry and environmental remediation and the ability of the soil to sequester or produce carbon is affected by its microbial composition. A dynamic soil information system that includes data on influences such as land use and land management, soil moisture, weather and other variables would increase our understanding of our current soil resources.

Likewise, the microbes in our water offer a wealth of environmental and public health data by providing early warning signs of pathogenic microbes and other pollutants in our communities. Ecosystem surveillance, including pathogen surveillance in domestic wastewater, as revealed by the COVID-19 pandemic, can be a valuable tool for monitoring disease transmission. A robust water surveillance system that supports local community water management can potentially enable early detection of bacterial and viral disease outbreaks or the presence of antibiotic-resistant genes, enabling a more efficient response. Such data systems are already in place in the U.S., largely through the CDC, but need further investment to incentivize participation, harmonize data, and support interagency collaboration.

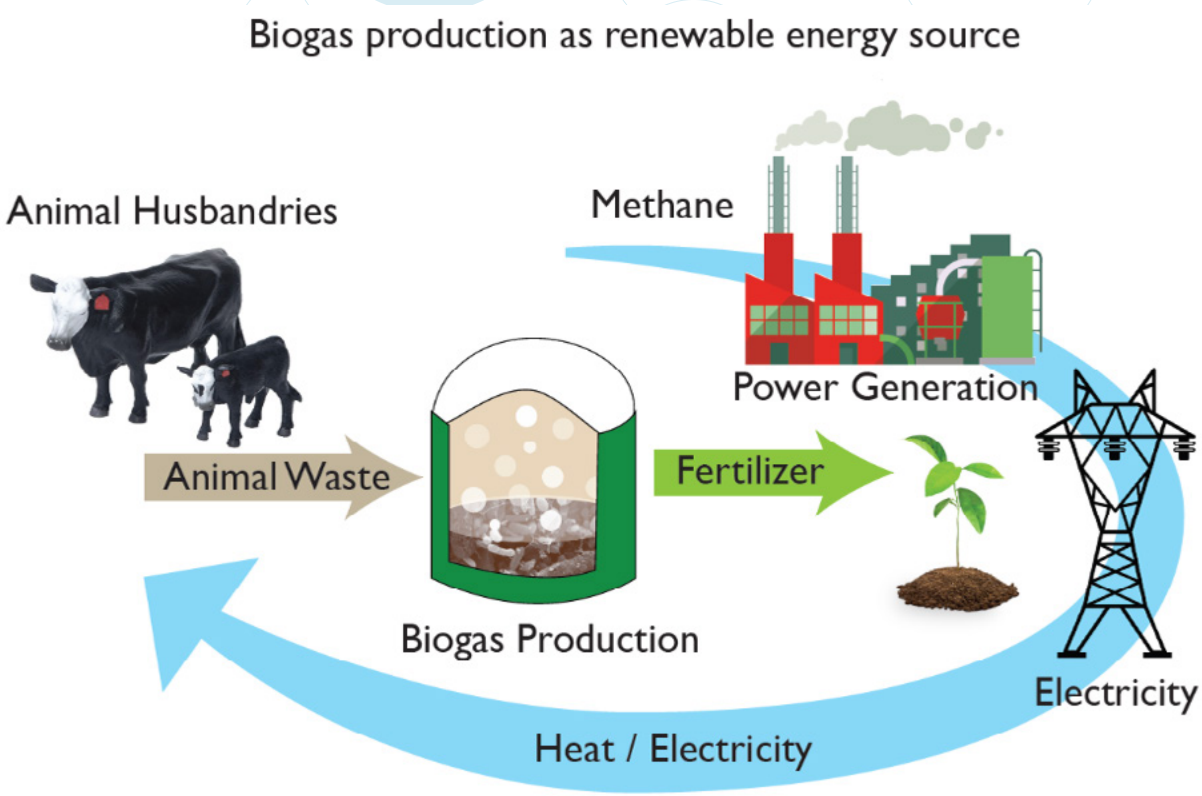
Through support for federal genomic sequencing and surveillance programs such as the CDC's Advanced Molecular Detection program, we can increase capacity to detect and characterize diseases in animals and humans spread by animal-human contact, bacteria in water, or insects and other organisms and facilitate greater cross-agency sharing and coordination of pathogen genetic and epidemiological data. Support will also aid development of innovative new surveillance methods, like xenosurveillance, a method that uses mosquitoes to detect a wide array of human pathogens at clinically relevant levels and provides insight into disease modeling.

Microbes offer solutions.

Microbes are essential to the emerging bioeconomy and have contributed to advances in bioremediation (the use of microorganisms to break down environmental pollutants), biobased products, biofuel production and many other applications. As we expand our capacity for high-throughput biological data analysis, develop and advance climate modeling with considerations of microbial scale, and fundamentally shift data infrastructure and data-sharing practices to holistically support rapid dissemination, use and knowledge extraction from microbiome data, the functional potential of microbes can be translated into applications to address the pressing impacts of climate change. For example, microbes play important roles in degradation by breaking down organic waste, toxic chemical substances and even plastics. As demonstrated by the microbial response to the Deepwater Horizon oil spill, microbes demonstrate the ability to promote plant growth, metal chelation and/or mitigation of heavy-metal stress in contaminated sites.

As noted above, scientists are advancing biofuels with sophisticated approaches to feedstock development that leverage microbes, including conversion of lignocellulose and algae. Microorganisms also have been harnessed to produce biofuels from waste byproducts of agricultural and industry sectors. In addition, microbes can produce commodity chemicals previously produced from fossil fuels. Federal agencies will need to carefully coordinate the introduction of dedicated energy crops and other feedstock resources with its impact on agricultural land uses, prices of other crops and trade in agricultural products, according to a 2017 report from the U.S. Department of Agriculture.

As climate change is projected to adversely impact yields of corn, soybeans, rice and other crops that feed people around the world, we can leverage microbes to support our food system as well as make systemic changes to address global food insecurity. Research to date has shown us that plant- and animal-associated microorganisms have the potential to increase agricultural sustainability and mitigate the effects of climate change on food production.



Wastewater treatment microbial communities produce carbon and nitrogen wastes that can be utilized for power generation and agricultural fertilizer to create a circular bioeconomy

Greater investment in microbial research to further understand animal, soil and plant microbiomes will provide opportunities to improve crop production, enhance feed efficiency and increase resilience to stress and disease. While some soil microbes aid in plant growth via their role in soil protection and fertilization, others are destroyers of food, crops and livestock, and still others are direct producers of food through fermentation. Studies have shown that the use of less toxic microbial fertilizers can replenish soil and mitigate these harmful effects. Microbes are an untapped resource for adapting crops to grow in more places with fewer inputs. With adequate support, we can leverage microbiome science to further understand crop plant and pest immunity and systems and how microbes work together to create the nutrients that we need.

Microbes also can be employed to support the health of pollinators. Research on specialized gut bacteria inside the honey bee gut microbiome found that 5 microbes were responsible for ensuring that bees matured into adulthood, digested pollen and nectar, and stayed healthy in the face of viral and bacterial pathogens they are exposed to in the environment when pollinating large-scale crops. Furthermore, researchers have now developed probiotic therapies for bees' post-antibiotic exposure using the bees' own gut microbes.

Establish stronger support for scientific research and the role of science in society.

Microbes play a key role in climate change adaptation, mitigation and resilience and should be part of any comprehensive plan to address climate change. Turning scientific insights into action requires deeper research to understand how climate change affects communities. It also requires scientists to strengthen their efforts to communicate and engage a wider audience and to make efforts to increase science literacy among the general public.

The scientific community has rallied behind efforts to diversify the scientific workforce and to promote science communication and literacy; we call on policymakers to support those efforts. Engaging the federal science agencies in strengthening science, technology, engineering and math (STEM) education and connecting it to real-world problems such as climate change is essential to building widespread understanding and addressing misconceptions. Primary, secondary and post-secondary education should touch not only on basic biology but the interaction between scientific and social disciplines. Citizen science programs led or supported by federal agency grants are another powerful way to engage the public in potential local solutions and adaptations while subsequently collecting relevant data from diverse sources.

Conclusion

The contributions of microbes to the generation and consumption of warming gases, to ecosystem stability, and to human well-being cannot be ignored. The American Society for Microbiology strongly encourages policymakers to provide adequate infrastructure, funding and coordination to support the work of scientists leveraging beneficial microbes and combating disease-causing microbes as they work across disciplines to develop and deploy climate solutions.