CLimate Improvements through Modern Biotechnology (CLIMB) -
A National Center for Bioengineering Solutions to Climate Change and Environmental Challenges

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Summary

Tackling pressing environmental challenges — such as climate change, biodiversity loss, environmental toxins and pollution — requires bold, novel approaches that can act at the scale and expediency needed to stop irreversible damage. Environmental biotechnology can provide viable and effective solutions. The America COMPETES Act, if passed, would establish a National Engineering Biology Research and Development Initiative. To lead the way in innovative environmental protection, a center should be created within this initiative that focuses on applying biotechnology and bioengineering to environmental challenges. The CLimate Improvements through Modern Biotechnology (CLIMB) Center will fast-track our nation’s ability to meet domestic and international decarbonization goals, remediate contaminated habitats, detect toxins and pathogens, and deliver on environmental-justice goals.

The CLIMB Center would (i) provide competitive grant funding across three key tracks — bioremediation, biomonitoring, and carbon capture — to catalyze comprehensive environmental biotechnology research; (ii) house a bioethics council to develop and update guidelines for safe, equitable environmental biotechnology use; (iii) manage testbeds to efficiently prototype environmental biotechnology solutions; and (iv) facilitate public-private partnerships to help transition solutions from prototype to commercial scale. Investing in the development of environmental biotechnology through the CLIMB Center will overall advance U.S. leadership on biotechnology and environmental stewardship, while helping the Biden-Harris Administration deliver on its climate and environmental-justice goals.

Challenge and Opportunity

The rapidly advancing field of biotechnology has considerable potential to aid the fight against climate change and other pressing environmental challenges. Fast and inexpensive genetic sequencing of bacterial populations, for instance, allows researchers to identify genes that enable microorganisms to degrade pollutants and synthesize toxins. Existing tools like CRISPR, as well as up-and-coming techniques such as retron-library recombineering, allow researchers to effectively design microorganisms that can break down pollutants more efficiently or capture more carbon. Biotechnology as a sector has been growing rapidly over the past two decades, with the global market value estimated to be worth nearly $3.5 trillion by 2030. These and numerous other biotechnological advances are already being used to transform sectors like medicine (which comprises nearly 50% of the biotechnology sector), but have to date been underutilized in the fight for a more sustainable world.

One reason why biotechnology and bioengineering approaches have not been widely applied to advance climate and environmental goals is that returns on investment are too uncertain, too delayed, or too small to motivate private capital — even if solving pressing environmental issues through biotechnology would deliver massive societal benefits. The federal government can act to address this market failure by creating a designated environmental-biotechnology research center as part of the National Engineering Biology Research and Development Initiative (America COMPETES act,
Plan of Action

The America COMPETES Act would establish a National Engineering Biology Research and Development Initiative “to establish new research directions and technology goals, improve interagency coordination and planning processes, drive technology transfer to the private sector, and help ensure optimal returns on the Federal investment.” The Initiative is set to be funded through agency contributions and White House Office and Science and Technology Policy (OSTP) budget requests. The America COMPETES Act also calls for creation of undesignated research centers within the Initiative. We propose creating such a center focused on environmental-biotechnology research: The CLimate Improvements through Modern Biotechnology (CLIMB) Center. The Center would be housed under the new National Science Foundation (NSF) Directorate for Technology, Innovation and Partnerships and co-led by the NSF Directorate of Biological Sciences. The Center would take a multipronged approach to support biotechnological and bioengineering solutions to environmental and climate challenges and rapid technology deployment.

We propose the Center be funded with an initial commitment of $60 million, with continuing funds of $300 million over five years. The main contributing federal agencies research offices would be determined by OSTP, but should at minimum include: NSF; the Departments of Agriculture, Defense, and Energy (USDA, DOD, and DOE); the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS).

Specifically, the CLIMB Center would:

1. Provide competitive grant funding across three key tracks — bioremediation, biomonitoring, and carbon capture — to catalyze comprehensive environmental-biotechnology research.

2. House a bioethics council to develop and update guidelines for safe, equitable environmental-biotechnology use.

3. Manage testbeds to efficiently prototype environmental-biotechnology solutions.

4. Facilitate public-private partnerships to help transition solutions from prototype to commercial scale.

More detail on each of these components is provided below.

Component 1: Provide competitive grant funding across key tracks to catalyze comprehensive environmental biotechnology research.

The CLIMB Center will competitively fund research proposals related to (i) bioremediation, (ii) biomonitoring, and (iii) carbon capture. These three key research
tracks were chosen to span the approaches to tackle environmental problems from prevention, monitoring to large-scale remediation. Within these tracks, the Center's research portfolio will span the entire technology-development pathway, from early-stage research to market-ready applications.

Track 1: Bioremediation

Environmental pollutants are detrimental to ecosystems and human health. While the Biden-Harris Administration has taken strides to prevent the release of pollutants such as per- and polyfluoroalkyl substances (PFAS), many pollutants that have already been released into the environment persist for years or even decades. Bioremediation is the use of biological processes to degrade contaminants within the environment. It is either done within a contaminated site (in-situ bioremediation) or away from it (ex-situ). Traditional in-situ bioremediation is primarily accomplished by bioaugmentation (addition of pollutant-degrading microbes) or by biostimulation (supplying oxygen or nutrients to stimulate the growth of pollutant-degrading microbes that are already present). While these approaches work, they are costly, time-consuming, and cannot be done at large spatial scales.

Environmental biotechnology can enhance the ability of microbes to degrade contaminants quickly and at scale. Environmental-biotechnology approaches produce bacteria that are better able to break down toxic chemicals, decompose plastic waste, and process wastewater. But the potential of environmental biotechnology to improve bioremediation is still largely untapped, as technology development and regulatory regimes still need to be developed to enable widespread use. CLIMB Center research grants could support the early discovery phase to identify more gene targets for bioremediation as well as efforts to test more developed bioremediation technologies for scalability.

Track 2: Biomonitoring

Optimizing responses to environmental challenges requires collection of data on pollutant levels, toxin prevalence, spread of invasive species, and much more. Conventional approaches to environmental monitoring (like mass spectrometry or DNA amplification) require specialized equipment, are low-throughput, and need highly trained personnel. In contrast, biosensors—devices that use biological molecules to detect compounds of interest—provide rapid, cost-effective, and user-friendly alternatives to measure materials of interest. Due to these characteristics, biosensors enable users to sample more frequently and across larger spatial scales, resulting in more accurate datasets and enhancing our ability to respond. Detection of DNA or RNA is key for identifying pathogens, invasive species, and toxin-producing organisms. Standard DNA- and RNA-detection techniques like polymerase chain reaction (PCR) require specialized equipment and are slow. By contrast, biosensors detect minuscule amounts of DNA and RNA in minutes (rather than hours) and without the need for DNA/RNA amplification. SHERLOCK and DETECTR are two examples of highly successful, marketed tools used for diagnostic applications such as detecting SARS-CoV-2 and for ecological purposes such as distinguishing invasive fish species from similar-looking native species. Moving forward, these technologies
could be repurposed for other environmental applications, such as monitoring for the presence of algal toxins in water used for drinking, recreating, agriculture, or aquaculture. Furthermore, while existing biosensors can detect DNA and RNA, detecting compounds like pesticides, DNA-damaging compounds, and heavy metals requires a different class of biosensor. CLIMB Center research grants could support development of new biosensors as well as modification of existing biomonitoring tools for new applications.

Track 3: Carbon capture

Rising atmospheric levels of greenhouse gases like carbon dioxide are driving irreversible climate change. The problem has become so bad that it is no longer sufficient to merely reduce future emissions—limiting average global warming below 2°C by 2100 will require achieving negative emissions through capture and removal of atmospheric carbon. A number of carbon-capture approaches are currently being developed. These range from engineered approaches such as direct air capture, chemical weathering, and geologic sequestration to biological approaches such as reforestation, soil amendment, algal cultivation, and ocean fertilization.

Environmental-biotechnology approaches such as synthetic biology (“designed biology”) can vastly increase the amount of carbon that could be captured by natural processes. For instance, plants and crops can be engineered to produce larger root biomass that sequesters more carbon into the soil, or to store more carbon in harderto-break-down molecules such as lignin, suberin, or sporopollenin instead of easily metabolized sugars and cellulose. Alternatively, carbon capture efficiency can be improved by modifying enzymes in the photosynthetic pathway or limiting photorespiration through synthetic biology. Microalgae in particular hold great promise for enhanced carbon capture. Microalgae can be bioengineered not only to capture more carbon but also produce a greater density of lipids that can be used for biofuel. The potential for synthetic biology and other environmental-biotechnology approaches to enhanced carbon capture is vast, largely unexplored, and certainly under commercialized. CLIMB Center research grants could propel such approaches quickly.

Component 2: House a bioethics council to develop and update guidelines for safe, equitable environmental-biotechnology use.

The ethical, ecological, and social implications of environmental biotechnology must be carefully considered and proactively addressed to avoid unintended damage and to ensure that benefits are distributed equitably. As such, the CLIMB Center should assemble a bioethics council comprising representatives from:

- The NSF’s Directorate for Biological Sciences, which oversees funding biological research and has insights into the ethical implications of such technologies.
- The DOE’s Offices of Science, Energy Efficiency and Renewable Energy, Fossil Fuel and Carbon Management, and Joint Genome Institute, as well as
ARPA-E. These entities each have interests in proposed CLIMB Center research, especially research related to carbon capture.

- The **National Institutes of Standard and Technology (NIST)'s Biomarker and Genomic Sciences Group**, which sets standards for tracking, monitoring, and classifying biological and genomic tools.

- **NOAA’s National Ocean Service Office**, which oversees the Harmful Algal Bloom Monitoring Network and could speak to the implications of environmental monitoring in ocean environments.

- The **National Institutes of Health's Office of Science Policy and Office of Biosafety, Biosecurity, and Emerging Biotechnology**, which are responsible for assessing the ethical implications of emerging biotechnologies. Representatives from these offices can also provide insights and lessons learned from the biomedical field.

- The **EPA's Office of Land and Emergency Management**, which oversees the Superfund program and will identify key bioremediation priorities and feasible, safe deployment strategies.

- The **USGS's Ecosystems Division**, which has interests in species and land management, biological threats, and environmental health and toxins monitoring.

- The **USDA's Office of the Chief Scientist, Natural Resources Conservation Center, Agricultural Research Service, and Forest Service**, which oversee research and management efforts in agriculture, energy, and land management.

- The **White House Environmental Justice Advisory Council**, which was recently established by Executive Order 14008 and provides recommendations for environmental-justice issues related to climate-change mitigation along with toxins, pesticides, and pollution reduction. Council representatives can provide guidance for equitable ways to deploy technologies that prioritize underserved communities.

The bioethics council will identify key ethical and equity issues surrounding emerging environmental biotechnologies. The council will then develop guidelines to ensure transparency of research to the public, engagement of key stakeholders, and safe and equitable technology deployment. These guidelines will ensure that there is a framework for the use of field-ready environmental-biotechnology devices, and that risk assessment is built consistently into regulatory-approval processes. The council's findings and guidelines will be reported to the National Engineering Biology Research and Development Initiative’s interagency governance committee which will work with federal and state regulatory agencies to incorporate guidance and streamline regulation and oversight of environmental biotechnology products.
Component 3. Manage testbeds to efficiently prototype environmental-biotechnology solutions.

The “valley of death” separating early research and prototyping and commercialization is a well-known bottleneck hampering innovation. This bottleneck could certainly inhibit innovation in environmental biotechnology, given that environmental-biotechnology tools are often intended for use in complex natural environments that are difficult to replicate in a lab. The CLIMB Center should serve as a centralized node to connect researchers with testing facilities and test sites where environmental biotechnologies can be properly validated and risk-assessed. There are numerous federal facilities that could be leveraged for environmental biotechnology testbeds, including:

- DOE National Laboratories
- Smithsonian Institution field stations
- NOAA field laboratories
- NIST Laboratories and Research Test Beds
- U.S. Forest Service Research Stations
- USDA National Wildlife Research Center Stations
- USGS Science Centers
- NSF Long Term Ecological Research Stations
- The Centers for Disease Control and Prevention’s Biotechnology Core Facility
- DOD Environmental Laboratories

The CLIMB Center could also work with industry, state, and local partners to establish other environmental-biotechnology testbeds. Access to these testbeds could be provided to researchers and technology developers as follow-on opportunities to CLIMB Center research grants and/or through stand-alone testing programs managed by the CLIMB Center.

Component 4: Facilitate public-private partnerships to help transition solutions from prototype to commercial scale.

Public-private partnerships have been highly successful in advancing biotechnology for medicine. Operation Warp Speed, to cite one recent and salient example, enabled research, development, testing, and distribution of vaccines against SARS-CoV-2 at unprecedented speeds. Public-private partnerships could play a similarly key role in advancing the efficient deployment of market-ready environmental biotechnological devices. To this end, the CLIMB Center can reduce barriers for negotiating
partnerships between environmental engineers and biotechnology manufacturers. For example, the CLIMB center can develop templates for Memoranda of Understandings (MOUs) and Collaborative Research Agreements (CDAs) to facilitate the initial establishment of the partnerships, as well as help connect interested parties.

The CLIMB center could also facilitate access for both smaller companies and researchers to existing government infrastructure necessary to deploy these technologies. For example, an established public-private partnership team could have access to government-managed gene and protein libraries, microbial strain collections, sequencing platforms, computing power, and other specialized equipment. The Center could further negotiate with companies to identify resources (equipment, safety data, and access to employee experts) they are willing to provide. Finally, the Center could determine and fast-track opportunities where the federal government would be uniquely suited to serve as an end user of biotechnology products. For instance, in the bioremediation space, the EPA’s purview for management and cleanup of Superfund sites would immensely benefit from the use of novel, safe, and effective tools to quickly address pollution and restore habitats.

**Conclusion**

Environmental and climate challenges are some of the most pressing problems facing society today. Fortunately, advances in biotechnology that enable manipulation, acceleration, and improvement of natural processes offer powerful tools to tackle these challenges. The federal government can accelerate capabilities and applications of environmental biotechnology by establishing the CLimate Improvements through Modern Biotechnology (CLIMB) Center. This center, established as part of the National Engineering Biology Research and Development Initiative, will be dedicated to advancing research, development, and commercialization of environmental biotechnology. CLIMB Center research grants will focus on advances in bioremediation, biomonitoring, and biologically assisted carbon capture, while other CLIMB Center activities will scale and commercialize emerging environmental biotechnologies safely, responsibly, and equitably. Overall, the CLIMB Center will further solidify U.S. leadership in biotechnology while helping the Biden-Harris Administration meet its ambitious climate, energy, and environmental-justice goals.

**Frequently Asked Questions**

1. **Why should the federal government take the lead in environmental biotechnology solutions?**

Environmental biotechnology can help address wide-reaching, interdisciplinary issues with huge benefits for society. Many of the applications for environmental biotechnology are within realms where the federal government is an interested or responsible party. For instance, bioremediation largely falls within governmental purview. Creating regulatory guidelines in parallel to the development of these new
technologies will enable an expedited rollout. Furthermore, environmental biotechnology approaches are still novel and using them on a wide scale in our natural environments will require careful handling, testing, and regulation to prevent unintended harm. Here again, the federal government can play a key role to help validate and test technologies before they are approved for use on a wide scale.

Finally, the largest benefits from environmental biotechnology will be societal. The development of such technology should hence be largely driven by its potential to improve environmental quality and address environmental injustices, even if these are not profitable. As such, federal investments are better suited than private investments to help develop and scale these technologies, especially during early stages when returns are too small, too uncertain, and too future-oriented.

2. How do we mitigate security risks of bioengineered products?

Bioengineered products already exist and are in use, and bioengineering innovations and technology will continue to grow over the next century. Rather than not develop these tools and lag behind other nations that will continue to do so, it is better to develop a robust regulatory framework that will address the critical ethical and safety concerns surrounding their uses. Importantly, each bioengineered product will present its own set of risks and challenges. For instance, a bacterial species that has been genetically engineered to metabolize a toxin is very different from an enzyme or DNA probe that could be used as a biosensor. The bacteria are living, can reproduce, and can impact other organisms around them, especially when released into the environment. In contrast, the biosensor probe would contain biological parts (not a living organism) and would only exist in a device. It is thus critical to ensure that every biotechnology product, with its unique characteristics, is properly tested, validated, and designed to minimize its environmental impact and maximize societal benefits. The CLIMB Center will greatly enhance the safety of environmental-biotechnology products by facilitating access to test beds and the scientific infrastructure necessary to quantify these risk-benefit trade-offs.

3. How would the CLIMB Center address the Biden-Harris Administration’s goals for environmental justice?

The Biden-Harris Administration has recognized the vast disparity in environmental quality and exposure to contaminants that exist across communities in the United States. Communities of color are more likely to be exposed to environmental hazards and bear the burden of climate change-related events. For example, the closer the distance to a Superfund site—a site deemed contaminated enough to warrant federal oversight—the higher the proportion of Black and the lower the proportion of White families. To address these disparities, the Administration issued Executive Order 14008 to advance environmental justice efforts. Through this order, President Biden created an Environmental Justice Advisory Council and launched the Justice40 initiative, which mandates that 40% of the benefits from climate investments be delivered to underserved communities. The Justice40 initiative includes priorities such as the “remediation and reduction of legacy pollution, and the development of critical clean water infrastructure.” The Executive Order also calls for the creation of a
“community notification program to monitor and provide real-time data to the public on current environmental pollution...in frontline and fenceline communities — places with the most significant exposure to such pollution.” Environmental biotechnology offers an incredible opportunity to advance these goals by enhancing water treatment and bioremediation and enabling rapid and efficient monitoring of environmental contaminants.

4. How would the CLIMB Center address the Biden-Harris Administration's goals for climate change?

President Biden has set targets for a 50–52% reduction (relative to 2005 levels) in net greenhouse-gas pollution by the year 2030, and has directed federal government operations to reach 100% carbon-pollution-free electricity by 2030 (Executive Order 14057). It is well established that meeting such climate goals and limiting global warming to less than 2°C will require negative emissions technologies (carbon capture) in addition to reducing the amount of emissions created by energy and other sectors. Carbon-capture technologies will need to be widely available, cost-effective, and scalable. Environmental biotechnology can help address these needs by enhancing our capacity for biological carbon capture through the use of organisms such as microalgae and macroalgae, which can even serve the dual role of producing biofuels, feedstock, and other products in a carbon-neutral or carbon-negative way. The CLIMB Center can establish the United States as the global leader in advancing both biotechnology and the many untapped environmental and climate solutions it can offer.

5. What are the current federal funding mechanisms available for the research and development of bioengineered environmental solutions?

There are multiple avenues for funding foundational research and development in bioengineering. Federal agencies and offices that currently fund bioengineering with an environmental focus include (but are not necessarily limited to):

- DOE's Office of Science's various research programs, ARPA-E, and DOE's Bioenergy Technologies Office
- EPA's Office of Research and Development, Science to Achieve Results (STAR) Program
- National Science Foundation's Biological Sciences and Engineering Directorates
- USDA's National Institute of Food and Agriculture, Biotechnology Risk Assessment Research Grants Program
- NOAA's Office of Ocean Exploration and Research
- NASA's Space Technology Mission Directorate
6. How could biosensor inform management and policy decisions?

Compared to conventional analytical techniques, biosensors are fast, cost-effective, easy-to-use, and largely portable and largely portable. However, biosensors are not always poised to take-over conventional techniques. In many cases, regulatory bodies have approved analytical techniques that can be used for compliance. Novel biosensors are rarely included in the suite of approved techniques, even though biosensors can complement conventional techniques—such as by allowing regulators to rapidly screen more samples to prioritize which require further processing using approved conventional methods. Moreover, as conventional methods can only provide snapshot measurements, potentially missing critical time periods where toxins, contaminants, or pathogens can go unnoticed. Biosensors, on the other hand, could be used to continuously monitor a given area. For example, algae can accumulate (bloom) and produce potent toxins that accumulate in seafood. To protect human health, seafood is tested using analytical chemical approaches (direct measurement of toxins) or biological assays (health monitoring in exposed laboratory animals). This requires regulators to decide when it is best to sample. However, if a biosensor was deployed in an monitoring array out in the ocean or available to people who collect the seafood, it could serve as an early detection system for the presence of these toxins. This application will become especially important moving forward since climate change has altered the geographic distribution and seasonality of these algal blooms, making it harder to forecast when it is best to measure seawater and seafood for these toxins.

7. How do we ensure that benefits from environmental biotechnologies extend equitably to historically excluded populations?

Communities of color are more likely to live near Superfund sites, be disproportionately exposed to pollutants, and bear the heaviest burdens from the effects of climate change. These communities have also been disproportionately affected by unethical environmental and medical-research practices. It is imperative that novel tools designed to improve environmental outcomes benefit these communities and do not cause unintended harm. Guidelines established by the CLIMB Center’s bioethics council coupled with evaluation of environmental biotechnologies in realistic testbeds will help ensure that this is the case.
Jennifer M. Panlilio is a neurotoxicologist who studies neural circuits that underlie behavior and determines how these are impacted by chemical exposures. As postdoctoral fellow at the National Institutes of Health, she studies the neurons and the chemicals they produce that control changes in waking arousal. She obtained her Ph.D. in Neurotoxicology and Oceanography from the Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution, studying the effects of developmental exposure to a harmful algal bloom neurotoxin. Jennifer is also a social scientist by training, holding an M.A. in Anthropology from Stanford University. For her master's research, Jennifer identified social factors important for successful management of marine reserves. Jennifer’s interests lie in integrating biological and social sciences, and she believes that building sustainable and robust environments is integral to human health.

Dr. Jennifer M. Panlilio contributed to this article in her personal capacity. The views expressed are her own and do not necessarily represent the views of the National Institutes of Health or the United States Government.

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