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Mirror Life: Biosafety/Biosecurity Oversight Considerations

Deoxyribonucleic acid (DNA) is the molecule that carries genetic information of an organism. This genetic code is composed of nucleotide bases (adenine [A], thymine [T], cytosine [C], and guanine [G]) assembled from right to left into base pairs in the form of a double helix. An emerging field of science referred to as *mirror life* would flip the construction of DNA to its mirrored form, or left to right, changing how the molecule interacts with other molecules. Researching mirror life could expand general knowledge about biology and potentially lead to better drug development while also presenting risks. Mirror life is not technically feasible at this time. According to some scientists, it is still more than 10 years away and would require extensive investment of time and money to overcome technical barriers.

In December 2024, a group of international scientists published a technical report and an accompanying article in the journal *Science* that called for a moratorium and public dialogue on whether, or how, to pursue research related to mirror life. Some researchers, however, are not convinced that raising alarms and calling for moratoriums are prudent so far in advance of establishing the technical feasibility of as well as any documented threats posed by mirror life.

Mirror life raises questions regarding the risks and benefits of certain types of research and development (R&D). These questions may interest Congress as it continues to explore the biosafety and biosecurity implications of biotechnologies and the broader life sciences, including what types of R&D programs should receive federal support and what oversight mechanisms, if any, may be needed.

What Is Mirror Life?

Many of the key molecules common to all living organisms are *chiral*. Chiral molecules have what is referred to as handedness; they can take either of two forms that are identical in chemical composition but appear as mirror images of one another. Think of the right hand versus the left hand—no type of rotation would enable a person to superimpose one over the other. While proteins, sugars, lipids, and nucleic acids can exist in either of two mirror-image configurations, organisms primarily use only one of these two configurations, which may affect cellular function. If a *mirror* bacterium (a bacterium whose DNA mirrors that of its natural counterpart) were to be constructed, it may interact with natural and pharmaceutical immunity defenses in profoundly different ways, which has raised concerns.

Why Conduct Mirror Life R&D?

Beyond increasing basic scientific understanding, one potential purpose for research on mirror life is for drug development. Drug molecules are susceptible to degradation and "undesirable" immune reactions (e.g., allergic reactions or autoimmunity), which can reduce their efficacy. Mirrored drug molecules may retain similar programmability and functionality with enhanced stability and efficacy.

Limited federal funding has been awarded to mirror life R&D. In 2019, the U.S. National Science Foundation awarded two grants related to mirror life seeking "to design, construct, and safely deploy synthetic mirror cells in which all of the key molecules—nucleic acids, proteins, carbohydrates, and lipids—exist in chiral states opposite to their natural forms." These two awards, given to the University of California, San Diego, and Yale University, totaled nearly $4 million. The European Union and People's Republic of China have also expressed interest in mirror life research but CRS was unable to verify funding totals.

Feasibility

There are substantial technical barriers to creating mirror life. The authors of the technical report suggest that it is not possible with current technology and would require large investments of time and money to overcome the scientific and technical hurdles. Specifically, they estimated that creating mirror life within a decade would require efforts and funding equivalent to those of the Human Genome Project, which ran for about 13 years and cost nearly $3.8 billion.

A first step to creating a mirror organism would be to create a "regular" living cell (synthetic cell) from nonliving precursors, which is not yet possible. Though this research is currently under way, it is being pursued for purposes other than the creation of mirror life. If a synthetic cell can be built, it is believed that similar approaches could be used to create mirror cells from mirror components. Several companies already offer both regular and mirror DNA *oligos* (short strands of synthetic DNA or RNA). Advances in artificial intelligence (AI) may help in reducing technical hurdles for creating mirror life by improving DNA, ribonucleic acid (RNA), and other genome design tools. See CRS Report R47849, *Artificial Intelligence in the Biological Sciences: Uses, Safety, Security, and Oversight*.

Potential Risks

Two main risks of creating mirror life have been identified. Mirror life could evade many aspects of human, animal, and plant immunity, potentially causing life-threatening infections. For example, whereas the human body's immune system would likely recognize the natural form of a bacterium and institute a response, its mirror form may go undetected. If introduced into the environment, a mirror

bacterium may also act as an invasive species by evading detection and spreading potentially lethal infections, unchecked, across large fractions of plant and animal species.

Calls for Moratorium

Calls from the scientific community for a moratorium, or pause, on certain lines of research have occurred in the past. In the 1970s, as recombinant DNA technology began to emerge, scientists called for a moratorium on the work until the risks could be assessed. Participants in the 1975 International Congress on Recombinant DNA Molecules (known as Asilomar) agreed that the research should continue but under stringent guidelines, which influenced the National Institutes of Health (NIH) *Guidelines for Research Involving Recombinant or Synthetic Nucleic Acid Molecules*. More recently, in 2012, scientists self-imposed a 60-day moratorium on certain research involving bird flu virus after two NIH-funded research groups studying respiratory transmission of the highly pathogenic avian influenza virus, H5N1, found evidence that a more transmissible virus could be created. This self-imposed pause was followed by subsequent U.S. policies and guidance related to research that confers new or enhanced abilities to an organism, specifically research that is anticipated to create, transfer, or use enhanced pathogens with pandemic potential, referred to as *gain-of-function* research. An update to these policies was incorporated into the 2024 *United States Government Policy for Oversight of Dual Use Research of Concern and Pathogens with Enhanced Pandemic Potential* (2024 Policy). See CRS Report R48155, *Oversight of Laboratory Biosafety and Biosecurity: Current Policies and Options for Congress*.

The risks associated with mirror life research led the scientists who authored the technical report to call for a moratorium on creating mirror life until "compelling evidence for reassurance" to address those risks is established. The authors suggest that a moratorium would have minimal impact on any beneficial research associated with mirror life. In addition, they call for public dialogues to discuss the risks and benefits of mirror life and whether or not research should proceed at all.

Instituting a research moratorium may involve trade-offs. For example, moratoriums may provide time and space for dialogues that examine the risks and benefits of a particular line of research while developing potential oversight mechanisms. However, moratoriums may also hinder research and slow down development. Additionally, if not implemented equally across the globe, a moratorium in the United States could encourage scientists to move to other countries.

Congressional Considerations

How do the issues raised about mirror life align with broader discussions surrounding the oversight and risks and benefits of life sciences research? These include pathogen and gain-of-function research, issues related to the intersection of engineering biology and AI, and other laboratory biosafety and biosecurity issues.

While mirror life is not technically feasible at this time, Congress may consider whether current policies, guidelines, and other oversight mechanisms are sufficient to address the risks and benefits associated with mirror life. For example, how might the implementation of the 2024 Policy and the 2024 *Framework for Nucleic Acid Synthesis Screening* (2024 Framework), which outlines a unified process for screening purchases of synthetic nucleic acids and benchtop nucleic acid synthesis equipment, be applied toward mirror life and other potential research that is deemed risky? Congress may also consider whether the current policy framework is sufficient or whether new oversight authorities are needed to address biosafety and biosecurity concerns related to certain research. For example, would mirror life R&D require additional laboratory biosafety and biosecurity oversight given the potential risks if mirror life were to escape the laboratory, come into contact with humans, and enter the environment? Congress might also consider whether funding agencies need to establish new research programs, or increase research funding in other areas, to examine the potential ecological impacts of mirror life.

Impacts of President Trump's Executive Orders

On January 20, 2025, the White House issued two executive orders that may impact the implementation of both the 2024 Policy and the 2024 Framework. "Initial Rescissions of Harmful Executive Orders and Actions" rescinded Executive Order 14110, "Safe, Secure, and Trustworthy Development and Use of Artificial Intelligence," which enabled the 2024 Framework. A second executive order, "Regulatory Freeze Pending Review," directs executive agencies to consider postponing the effective date for any rules that have been issued but have not taken effect, in order to review any questions of fact, law, and policy that the rules may raise. The 2024 Policy is scheduled to take effect in May 2025, and the 2024 Framework is scheduled to take effect in April 2025.

As part of its oversight responsibilities, Congress may wish to examine the impacts these executive orders may have on agencies' current and anticipated abilities to regulate the risks and benefits of life sciences R&D and what impacts they may have on emerging science and technologies, such as mirror life.

Public Dialogues and Moratoriums

The authors of the technical report have called for public dialogues related to mirror life. Congress may consider how to engage with those dialogues, should they occur, and how the results of those discussions might be incorporated into any actions Congress may take. Congress may also consider whether international dialogues may be needed to address cross-border biosafety and biosecurity concerns.

For research such as mirror life, which is not technically possible with current technologies, imposing a moratorium could provide time and space for Congress and the broader public to discuss the merits of the research and whether oversight mechanisms to govern its potential risks and benefits are needed. Congress may consider what impact, if any, a moratorium would have on U.S. competitiveness if other countries do not impose similar moratoriums.

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Todd Kuiken, Analyst in Science and Technology Policy

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