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Perspective on a Timely Policy Issue

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A Policymaker's Guide to Mirror Life

Mirror life refers to organisms composed of proteins, deoxyribonucleic acid (DNA), and other biomolecules whose molecular structures are engineered to be mirror images of those in natural life. Experts warn that mirror life could pose serious risks to human, animal, and plant life, as well as to the earth's ecosystems. Scientific and policy communities are beginning to organize in response.

Mirror life does not exist at the time of this writing in 2026, but scientists might be able to develop it within the next ten to 30 years. Policymakers, therefore, have a rare window of opportunity to make decisions that could address the risks of mirror life before these risks are realized. Those decisions can be made wisely only if policymakers understand what mirror life is and why it matters. The scale of mirror life's potential risks—and the possibility that those risks become impossible to mitigate once mirror life is created—make it a uniquely dangerous challenge that requires separate consideration from other synthetic biology issues that policymakers confront.

This guide is designed for decisionmakers—legislators, regulators, national security agencies, science funders, diplomatic bodies, and international organizations—in the United States and elsewhere who might soon encounter discussions of mirror life in briefings, proposals, and global forums. This guide's goal is to provide an accessible overview of mirror life vocabulary and foundational facts that will enable these decisionmakers to participate knowledgeably in those discussions. This guide provides simple explanations of the science of mirror life, its potential risks and benefits, the pathways to its creation, and the foundations of emerging policy discussions.

This guide also serves as a practical companion to more-detailed materials that policymakers might encounter by providing the background that those documents often assume. As new research and policy ideas emerge, this guide can remain a stable point of reference.

How to Use This Guide

This guide is designed to be read quickly and referred to often. Readers can jump directly to the sections that are most relevant to a decision, briefing, or hearing, or they can read straight through. Each section explains key concepts and why they matter. The appendixes include a plain English glossary of terms and a list of selected readings.

Sources

This guide is based on research from three key sources: Adamala, Agashe, Belkaid, et al.'s 2024 article titled "Confronting Risks of Mirror Life"; the associated 2024 *Technical Report on Mirror Bacteria: Feasibility and Risks*, from Adamala, Agashe, Binder, et al.; and Kalra et al.'s 2026 report, *A U.S. Strategy to Prevent the Creation of Mirror Life*. These resources can be found in the annotated bibliography at the back of this guide. We have omitted inline citations throughout this guide to reduce repetition of these sources and improve readability.

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CHAPTER 1

The Science of Mirror Life

This section provides an overview of the concept of mirror life. It discusses the scientific basis for mirror life, the forms that mirror life could take, and whether such life could survive outside the laboratory. This content is based on Adamala, Agashe, Binder, et al. (2024) and recent research conducted by the authors of this paper. Here and throughout this guide, bolded terms are defined in the glossary.

What Is Mirror Life?

Short Definition

Mirror life is a hypothetical life-form that is built from molecular building blocks whose shapes are the mirror images of those found in nature.

Definition Explained

Biological molecules—or **biomolecules**—are the building blocks of all life on earth, including humans, animals, and plants. Key biomolecules include DNA, ribonucleic acid (RNA), and proteins. When biomolecules are enclosed within a membrane and form a self-sustaining system, they constitute cells, the basic units of life.

The simplest form of life is a single cell—for example, a bacterium—that can carry out essential processes, including metabolism, growth, and reproduction.

Most biomolecules have a property called chirality (pronounced "kai-RAL-i-tee"). Derived from the Greek for *hand*, chirality is the property of having a three-dimensional, asymmetrical shape that differs from its mirror image, similar to left and right hands (Figure 1). In nature, all DNA and RNA are considered right-handed, while all proteins are considered left-handed. Biomolecules with the opposite shapes, such as left-handed DNA and RNA and right-handed proteins, do not exist in nature, but they have been created in laboratories.

Some researchers believe it may be possible to create mirror life—a life-form built from these differently shaped, opposite chirality biomolecules—within the next ten to 30 years.

Does Mirror Life Already Exist on Earth?

There is no evidence that mirror life exists on earth. All known life on earth shares the same basic biological handedness, although scientists do not know why this is.

What Kinds of Mirror Life Could Be Created?

Although mirror life could, in theory, include any type of living thing—e.g., mirror animals, mirror plants—scientists are mainly concerned about **mirror bacteria**. Bacteria are the simplest life-forms and are the biological systems most commonly used in synthetic biology, which makes bacteria the most plausible first target if mirror life were ever pursued. Although viruses are simpler structures than bacteria, scientists are not worried about mirror viruses because they cannot reproduce on their own. They would need to infect mirror cells to survive, and mirror cells do not exist. (Because viruses cannot reproduce on their own, they are also not usually considered life forms at all.)

"Although viruses are simpler structures than bacteria, scientists are not worried about mirror viruses because they cannot reproduce on their own. They would need to infect mirror cells to survive, and mirror cells do not exist."

How Could Mirror Life Be Created?

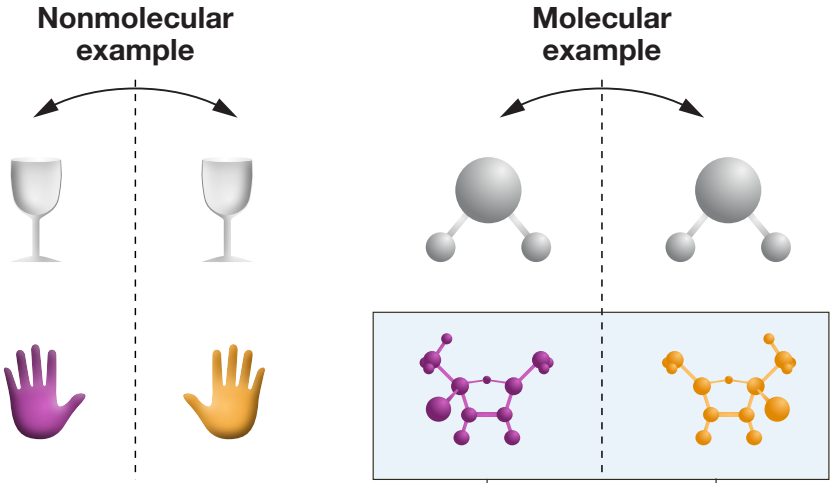
As a synthetic life-form, mirror life cannot arise from nature and could be created only through deliberate scientific efforts. Scientists see two main ways to do this.

One is a bottom-up approach in which a living cell would be built from scratch using mirror-image versions of DNA, proteins, and other components.

FIGURE 1

Chirality

	Does the image match its mirror image?
Achiral	Yes
Chiral	No



Important biological molecules—DNA, RNA, and proteins—are chiral. Although these biomolecules could, in principle, exist in either left- or right-handed forms, living cells use one chirality only for each type. Scientists have created *mirror* biomolecules with the opposite chirality in a lab, but they have not incorporated them into a living *mirror* cell.

Biomolecule	Chirality of biomolecules found in natural cells	Chirality of mirror biomolecules that would be found in mirror cells
DNA and RNA	Right-handed	Left-handed
Proteins	Left-handed	Right-handed

“Like all living things, mirror bacteria would need nutrients and energy from their environment to survive. There are several ways mirror bacteria could obtain nutrients and energy outside a laboratory.”

These components would be enclosed in a membrane to create a synthetic cell, and this cell would then be “booted up” to start its metabolism and the basic processes needed for it to live. This is the simpler of the two approaches and involves fewer steps.

The second is a top-down approach in which an existing bacterium is gradually transformed into a mirror version by replacing or modifying its parts, step by step, until the cell is composed entirely of mirror-image molecules. Experts consider this approach to be more difficult.

Would Mirror Bacteria Be Able to Survive Outside a Laboratory?

Like all living things, mirror bacteria would need nutrients and energy from their environment to survive. There are several ways that mirror bacteria could obtain nutrients and energy outside a laboratory.

Mirror bacteria could consume common nutrients that have no handedness or be modified to consume the same nutrients used by existing life.

Some bacteria can produce their own food using inputs that do not depend on molecular handedness. For example, photosynthetic ocean bacteria grow using sunlight, carbon dioxide, water, and minerals naturally present in seawater. A mirror-image version of such bacteria could similarly produce its own food and potentially survive outside the laboratory.

Other bacteria, such as *Escherichia coli* (*E. coli*), cannot produce their own food and instead rely on nutrients from their environment. Although these bacteria generally cannot consume nutrients with the opposite handedness, they can still consume many naturally occurring nutrients found in soil, water, and the human body that have no handedness at all. These nonchiral (or **achiral**) molecules are identical to their mirror images, much like a ball or wine glass (Figure 1). A mirror-image version of *E. coli* or similar bacteria could therefore potentially survive by consuming these nonchiral nutrients.

Scientists could also modify mirror bacteria to consume nutrients with the natural handedness found throughout life on earth. They could draw on existing knowledge of natural bacteria that can metabolize both natural and mirror-image forms (the **enantiomers**) of certain nutrients. Once the fundamental challenge of creating a mirror bacterium is achieved, enabling it to consume opposite-handed nutrients would likely be a simpler challenge.

CHAPTER 2

The Risks and Benefits of Mirror Life

A group of experts and concerned scientists has argued that the creation of mirror life could hold significant risks for humans, animals, plants, and the earth's environment. This section explains those potential risks. It also outlines hypothesized beneficial uses of mirror life, were it to be created. This content is based on Adamala, Agashe, Binder, et al.'s 2024 *Technical Report on Mirror Bacteria: Feasibility and Risks*, and Kalra et al.'s 2026 report, *A U.S. Strategy to Prevent the Creation of Mirror Life*.

How Might Mirror Life Cause Harm to Humans?

Scientists are concerned that mirror bacteria could pose a grave risk to humans because these bacteria might not be recognized or effectively controlled by our immune systems. This is because immune cells fight bacteria by recognizing and attaching to the proteins or other molecules on bacterial surfaces. But, much as a right-handed glove does not fit a left hand, immune cells might not attach to the mirror-image molecules on mirror bacteria. This could make mirror bacteria less recognizable to the immune system. Without recognition, many parts of the immune system are unlikely to switch on properly.

Even if immune cells were to recognize mirror bacteria, they would need to break the bacteria down into small molecules to kill them and generate strong antibodies against them. Scientists anticipate that the enzymes in immune cells that normally do this would have trouble breaking up mirror bacteria because the mirror bacteria's molecules would have the wrong shape for the enzymes to work.

These impaired immune responses might allow mirror bacteria to grow and spread easily in the body, eventually causing fatal infections. Mirror bacteria might kill people simply by multiplying and physically taking up space; competing for nutrients; disrupting tissues; or, once their numbers increase, triggering enough of whatever immune response still functions normally to cause a harmful, sepsis-like inflammatory response.

This would be very different from how ordinary pathogens cause harm. Many natural bacteria and viruses express proteins or other molecules that help them evade or weaken individual parts of the immune system or cause disease by generating toxins or interfering with specific cellular processes. Mirror bacteria, on the other hand, might simply be less recognizable and much more resistant to the immune system than natural bacteria, allowing them to proliferate freely.

We know from real-world experience that when one part of the immune system does not work properly, infections can become severe or life-threatening. People with weakened immune systems are far more vulnerable to microbes than people with healthy immune systems. However, people with normal immune systems, if infected with mirror bacteria, might respond as though they had severely weakened immune systems.

How Might Mirror Life Cause Harm to Other Animals and Plants?

As with the human immune system, the immune systems of other animals and plants rely on specific molecules on pathogens to recognize and fight infections. These plants and animals' immune responses to mirror bacteria would, therefore, likely also be impaired, and mirror bacterial infections might cause similar types of harm to those in humans, described previously. However, it is less clear what a mirror bacteria infection would look like in these organisms because less is known about their immune systems.

How Might Mirror Life Cause Harm to the Environment and Ecosystems?

Mirror life might harm the environment in at least two ways: by directly harming other organisms and by growing unchecked within normal microbial systems.

First, if mirror bacteria harm plants or animals directly, the bacteria could spread among them and cause large-scale illness in or the death of domesticated animals, crops, wild animals, and wild plants. These effects alone could disrupt agriculture and destabilize natural ecosystems.

Second, mirror bacteria could disrupt the *microbial systems* (systems made up of bacteria, fungi, and other tiny organisms) that underpin ecosystems. Microbes recycle nutrients, support plant growth, and form the base of many food webs. Their populations are normally kept in balance by predators, viruses, and competition from other bacteria.

However, these predators, viruses, and other bacteria depend on the molecular structures of the bacteria. Microscopic predators recognize bacteria by their surface molecules and then grab, eat, and digest the bacteria. The mirror-image molecules of mirror bacteria might be unrecognizable, leaving them nearly invisible, ungrabbable, and indigestible as prey. ***Bacteriophages*** (viruses that infect bacteria) would face a double barrier: They would not recognize mirror bacteria as targets because they could not bind to them. And, even if bacteriophages entered a mirror cell, they would not be able to use that cell's mirror machinery to make more copies of themselves and kill the cell. Both predation and viral population control could fail entirely.

If mirror bacteria were not consumed or infected in the usual way, even slow, unchecked growth could allow them to accumulate in the environment over time. Any population will grow and spread if its individual members reproduce more quickly than they die. If mirror bacteria become widespread, they could outcompete normal microbes without transferring their energy up the food chain, potentially weakening soils, disrupting aquatic food networks, and affecting plants, animals, and marine life.

"If mirror life is as dangerous as is feared, then it would require a safety strategy that would absolutely guarantee that it would never escape the laboratory or grow outside it. Such guarantees are not realistic."

Could Mirror Life Be Made Safe?

If mirror life is as dangerous as is feared, then it would require a safety strategy that would absolutely guarantee that it would never escape the laboratory or grow outside it. Such guarantees are not realistic.

Dangerous microorganisms are routinely handled in high-containment laboratories that have multiple layers of protection against these microorganisms' escape into the environment and against their infection of laboratory personnel. However, human error and mechanical failures have led to lab leaks in the past, even in highly secure facilities.[1] Thus, even if one designed a facility to contain mirror bacteria, one could never be certain such organisms would not escape as a result of human error, mechanical malfunction, or the activities of a malicious actor.

In synthetic biology, organisms are sometimes engineered so that they cannot survive outside the laboratory. For example, they can be engineered to depend on nutrients or conditions that are available only inside the laboratory. However, these kinds of safeguards are fragile: They can be deliberately removed, inadvertently altered, or eroded over time by evolution.

Additionally, the knowledge required to create mirror life is, itself, a source of risk. Building a mirror organism would generate tools, expertise, and proof of

feasibility that others could use. Even if such an organism is built by responsible scientists, subsequent researchers might be less cautious about containment. And as the number of laboratories capable of working with mirror bacteria grows, so, too, would the probability of accidental release. Moreover, once the underlying methods of creating mirror bacteria are established, they could be used to produce more-robust or more-harmful types of mirror bacteria, even if the original research was conducted with safety in mind.

Could Mirror Life Be Eradicated Once It Is Created?

Once mirror life exists outside a lab, it might be impossible to contain or eradicate, for a few reasons.

First, very few off-the-shelf countermeasures exist. Although existing nonchiral antibiotics could be used to fight mirror bacterial infections, this potential countermeasure is imperfect and impractical. Antibiotics are generally not effective in the absence of a normal immune response, so the extent to which they would enable people to survive a mirror bacterial infection is unclear. Additionally, it would be impractical to apply antibiotics on an environmental scale. It might also be dangerous. Nonchiral antibiotics would affect both ordinary (nonmirror) bacteria and mirror bacteria. If these antibiotics were applied widely in soil, water, or agriculture—or even in humans—they could kill beneficial microbes, disrupt resident biomes, or increase the presence of antibiotic resistance, all of which would disrupt ecosystems and public health.

> "Once mirror life exists outside a lab, it might be impossible to contain or eradicate."

Second, developing new countermeasures would take time and be difficult. Mirror organism–compatible antibiotics, vaccines, or biological controls are theoretical solutions that would require significant new research, development, and manufacturing capacity. Developing such countermeasures would be challenging because they could not be fully tested in the absence of mirror bacteria.

Third, efforts to develop defenses against mirror life could inadvertently make mirror life easier to create. For example, testing realistic defenses might require mirror-like molecular systems, laboratory stand-ins, or computer models that help solve technical problems on the path to building a mirror organism.

Fourth, countermeasures might not be deployable at sufficient scale or speed. Any response tool would likely need to protect people, agriculture, and ecosystems. Effective treatments for humans would probably be unevenly distributed, leaving many populations unprotected. Moreover, even if human treatments were widely available, the inability to inoculate or protect most plant and animal life (especially organisms in the wild) might trigger widespread ecosystem collapse, and there could be cascading and potentially catastrophic consequences for humans.

> Most scientists who have studied this issue have concluded that the potential risks are extremely serious—potentially catastrophic—and that the conceivable benefits of creating mirror life are limited and uncertain."

Fifth, countermeasures would weaken over time. Mirror bacteria would evolve, reducing the effectiveness of defenses, similar to the rise of antibiotic resistance and new virus variants. Experience shows that it is very difficult to keep protections effective and widely available.

Sixth, countermeasure development could be geopolitically destabilizing. For example, others might misinterpret countermeasure development as a cover for mirror life development or as evidence that a release might be survivable, thus undermining global trust.

Are There Beneficial Uses for Mirror Life?

Very few beneficial uses have been proposed for mirror bacteria, and many scientists think these benefits could largely be realized in ways that do not involve the creation of self-replicating mirror bacteria (Figure 2). For example, some scientists have suggested that they could use mirror bacteria to manufacture mirror biomolecules, just as ordinary bacteria produce natural biomolecules. However, expanded biomanufacturing capacity could also be achieved through advances in existing chemical synthesis methods.

In contrast to mirror bacteria, mirror biomolecules—including mirror DNA and mirror proteins—have existing and potential scientific, medical, and industrial applications. For example, mirror biomolecules serve as research tools, and some are being pursued for therapeutic purposes.

Do Scientists Agree About the Dangers and Benefits of Mirror Life?

Most scientists who have studied this issue in depth have concluded that the potential risks are extremely serious—potentially catastrophic—and that the conceivable benefits of creating mirror life are limited and uncertain. Several leading researchers in the field have therefore called for a halt to any efforts to create mirror life.[2]

However, this view is not universal. Some scientists argue that because mirror life has not yet been created, it is difficult to fully anticipate its potential applications and that unknown scientific or technological benefits could emerge if the field were explored further.

CHAPTER 3

The Road to Mirror Life

This section describes the state of mirror life development in 2026 and the pathways by which this development could advance. It explains how close existing science is to creating mirror life, what resources and time such efforts might require, and which actors might be capable of pursuing it. This content is based on Adamala, Agashe, Binder, et al.'s 2024 *Technical Report on Mirror Bacteria: Feasibility and Risks*; and Kalra et al.'s 2026 report, *A U.S. Strategy to Prevent the Creation of Mirror Life.*

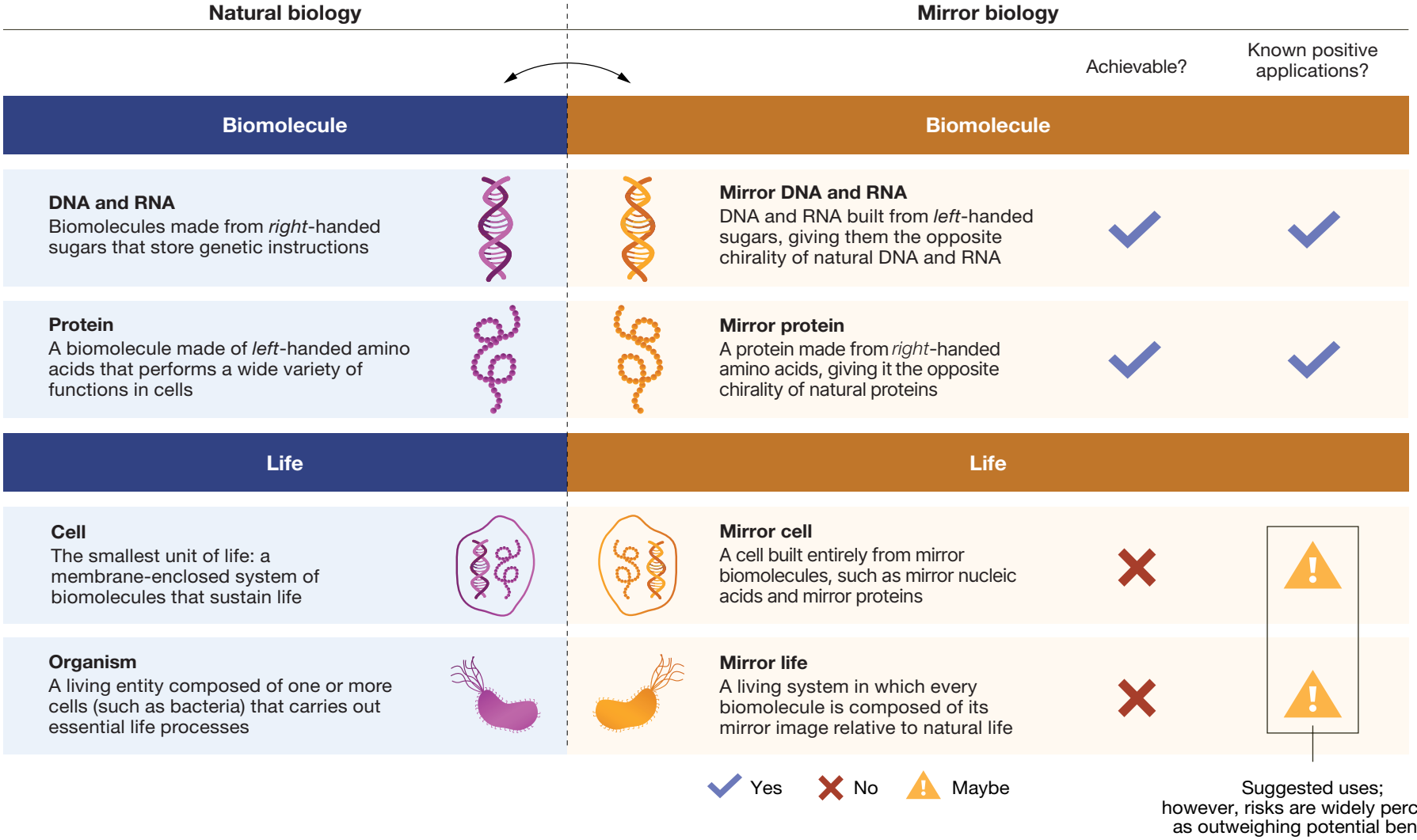
What Progress Have Scientists Made Toward Creating Mirror Life?

Although scientists already know how to make mirror proteins and mirror DNA (see Figure 2), making mirror life would require overcoming many fundamental science and engineering challenges.

Today, scientists know enough and have sufficient technology that they could probably make a mirror genome with sufficient time and effort. Scientists have also made progress toward creating mirror versions of the cellular machinery that converts genetic information into proteins. This is an important step toward building

FIGURE 2

From Mirror Biomolecules to Mirror Life: What Is Achievable and What Is Valuable



a mirror cell from scratch, known as the bottom-up approach. However, many additional capabilities would be required to create a functioning mirror cell, and some capabilities might be technically infeasible or remain scientifically uncertain.

By contrast, many steps in the top-down pathway (in which an existing cell is transformed into a mirror version) are completely infeasible and would require foundational scientific breakthroughs, some of which would be made only for the purposes of creating a mirror cell.

> "Mirror bacteria would have little military value because there would be no reliable way to direct or control the damage such bacteria could cause."

Is Anyone Trying to Make Mirror Life Today?

As of this writing, and using publicly available information, it appears that no laboratories are known to be pursuing the explicit goal of creating mirror life.

How Much Might It Cost and How Long Might It Take to Create the First Mirror Life?

Although there is significant uncertainty about timelines and costs for creating mirror life, some experts estimate that if actively pursued, mirror bacteria could be developed within approximately ten years and potentially for as little as $500 million.[3] Without a focused and prioritized effort, these experts estimate that timelines could stretch to between 15 and 30 years. However, even these coarse estimates could change: Ongoing advances in synthetic biology, artificial intelligence, and chemical engineering could speed progress and drive down costs, while disinvestment from scientific research could slow progress.

How Easy or How Hard Would It Be to Create Mirror Life Once the Know-How Exists?

Once the first mirror organism has been created and the methods that its creators used are understood, repeating that achievement would become easier over time. Given that creating such organisms would rely largely on existing materials or tools, it might eventually be achievable by a variety of actors. Nevertheless, executing such procedures would still require substantial expertise and careful laboratory practice, as is required for other highly complex biological protocols.

But there is another path to obtaining mirror life: Because mirror bacteria would be self-replicating, a single strain could, in principle, be shared and propagated by other laboratories. Modifying an existing mirror bacterium would likely be much simpler than constructing one from scratch.

Who Might Try to Make Mirror Life and Why Would They Do So?

At the time of this writing, mirror life could be created only by actors with advanced scientific capabilities, such as major countries, large research institutions, or well-funded companies. Despite mirror life's significant potential harms, such actors might be motivated to create it for scientific prestige, curiosity, or the belief that mirror bacteria could offer unspecified economic or strategic advantages. These actors might also doubt whether mirror life is as risky as some scientists have suggested.

Would Someone Try to Make Mirror Life as a Biological Weapon?

Given how dangerous mirror bacteria could prove to be, one might imagine that they could have value as biological weapons or that adversaries might pursue the creation of mirror bacteria for this purpose. However, mirror bacteria would have little military value because there would be no reliable way to direct or control the damage such bacteria could cause. Their effects could spread globally, posing equal risk to the user, making it unlikely to be attractive to any actor who is interested in self-preservation.

However, some dangerous actors, such as rogue states, extremist groups, or apocalyptic fringe movements, might seek mirror life precisely *because* of its potential for harm as a tool of coercion or to exterminate life. At the time of this writing, such actors are unlikely to have the resources to overcome the technical barriers to creating mirror bacteria. But if well-meaning researchers overcome those barriers, experts worry that the knowledge and capability to create mirror bacteria would come within reach of actors with harmful intentions.

CHAPTER 4

Policy Issues

This section explains why mirror life is attracting policy attention, even though it remains theoretical. It outlines who is involved in these policy discussions at the time of this writing and what early governance conversations are taking place, recognizing that this is a rapidly evolving landscape. This content is based on Adamala, Agashe, Binder, et al.'s 2024 *Technical Report on Mirror Bacteria: Feasibility and Risks*; and Kalra et al.'s 2026 report, *A U.S. Strategy to Prevent the Creation of Mirror Life*.

Why Does Mirror Life Warrant Separate Consideration from Other Synthetic Biology Risks?

Mirror life deserves separate consideration because of several properties that set it apart from other synthetic biology risks.

First, mirror life poses an unprecedented scale of risk. Most biosecurity risks are serious but bounded, affecting populations, regions, or species that can be protected, treated, or quarantined. Mirror life poses a fundamentally more significant risk: Experts warn that mirror bacteria could spread through ecosystems globally, threatening human, animal, and plant life on an unprecedented scale.

Second, mirror life could have potentially irreversible consequences. Most biological hazards can be contained or remediated after they emerge. Mirror life may be different: Scientists warn that the creation of the first mirror organism could represent a threshold event after which containment may no longer be possible.

Finally, policymakers have a rare governance window to act before mirror life exists. The risks of mirror life can be prevented before mirror life is created. The small number of actors capable of creating mirror life, combined with the ten- to 30-year timeline before its creation becomes feasible, creates a rare window for policy action.

If Mirror Life Is a Future Risk, Why Are Conversations Occurring Now?

Discussions are happening now before policymakers are confronted with an immediate threat and before research advances in ways that limit the options that are open to policymakers.

Mirror life is being discussed now for several reasons. First, while biologists have long considered the possibility of creating mirror life, it was not until December 2024 that scientists published a comprehensive, interdisciplinary analysis of the feasibility of doing so and the potential risks to humans, animals, plants, and the environment.[4] The magnitude of these risks and the window of opportunity to prevent them has spurred broader discussions.

Because mirror life could pose global risks, managing them would require a variety of policy responses. Adapting existing governance tools or developing new ones can take a long time. Likewise, international cooperation would almost certainly be needed and can take years to develop.

Moreover, many experts believe the risks might be difficult or impossible to manage once mirror life has been created. As a result, these experts have suggested that prevention is the soundest option.[5] This requires taking precautionary action before the threat is realized or imminent, which differs from the approach taken with other emerging technologies.

What Kinds of Policy Questions Are Being Asked?

Early policy discussions are exploring how governments, scientific institutions, and international organizations should respond to the possibility that mirror life could be created. Key questions include the following:

- **What types of research and development should be allowed, limited, or prohibited?** Policymakers and scientific leaders are considering whether certain lines of research should be restricted or halted while allowing other research, including safe and potentially beneficial research on mirror biomolecules or related technologies, to continue.
- **What mechanisms can help uphold limits on research and development?** Possible approaches include funding and publication restrictions around certain research, oversight of high-risk experiments, and scientific norms and self-governance.
- **Who should be involved in making these decisions?** Decisions could involve national governments, research funders, scientific academies, and international institutions.

Who Is Thinking About the Governance of Mirror Life?

Public conversations about mirror life are being led by networks of scientists, ethicists, biosecurity experts, and policy advisers from around the world. These groups convene through meetings, workshops, and advisory forums to assess mirror life's technical feasibility, risks, bioethical implications, and governance options. Engagement spans academic research institutions, national science advisory bodies and biosafety committees, international bioethics and multilateral forums, and policy think tanks.

This remains a rapidly evolving field of discussion. New meetings, statements, and participants continue to emerge as awareness grows.

Glossary: Mirror Life in Plain English

This glossary defines terms related to mirror life that we use in this guide or that readers may encounter in other settings. It explains these terms in simple language and explains how they relate to conversations about mirror life.

Term	What It Is	Why It Matters
Achiral molecule	A molecule that is achiral or "not handed"; i.e., it can be superimposed on its mirror image.	Some nutrients are achiral, and mirror bacteria could consume them as a food source the way ordinary bacteria do.
Amino acid	A small organic molecule that is a building block of proteins.	Mirror proteins would be built from mirror amino acids, just as normal proteins are built from normal amino acids.
Bacteriophage (phage)	A virus that infects and kills bacteria.	Natural bacteriophages might not recognize or control mirror bacteria, which would remove an important ecological check.
Biocontainment	The practice of using strict safety measures, specialized equipment, and biological engineering to prevent infectious agents and toxins from escaping from laboratories into the environment.	Biocontainment might be proposed as a way to safely create mirror life, but it can be subverted through human error or mechanical malfunction or by malicious actors. Given the much higher potential consequences of the escape of mirror bacteria compared with the escape of other laboratory organisms, biocontainment might not be sufficient to reliably contain mirror bacteria.
Biomolecules	Molecules that are necessary for life, including DNA, RNA, and proteins.	Mirror life refers to life forms in which biomolecules occur in their mirrored form.
Chiral molecule	A molecule that is handed; i.e., it cannot be superimposed on its mirror image.	All known life involves interactions between chiral molecules of a particular molecular handedness, so building organisms with reversed-chirality molecules could break immune recognition and ecological interactions.
Enantiomer	One of a pair of molecules that are mirror images of each other.	Mirror life would be built entirely from enantiomers opposite those used by natural life.

Term	What It Is	Why It Matters
Immunogenic	A substance that activates an immune system response.	Mirror bacteria might be weakly immunogenic or not immunogenic at all, which would weaken immune responses against them.
Mirror life	An organism in which all chiral biomolecules exist in their mirrored forms.	This is the central concept of this guide and the source of the unique risks being discussed.
Mirror bacteria	Bacteria that have all their biomolecules in their mirrored form.	Experts think that mirror bacteria are likely to be the first form of mirror life created. They carry risks because of their mirrored biochemistry and their ability to self-replicate and spread.
Mirror biomolecules	Mirror-image versions of the molecules that are necessary for life, including amino acids, nucleotides, sugars, and proteins.	These molecules would not interact normally with many natural biological processes, but their risks are minimal because they do not self-replicate.
Nucleic acids	Biomolecules, including DNA and RNA.	Mirror life would require mirror versions of DNA and RNA.
Nucleotide	The basic building block of DNA and RNA.	Mirror life would require mirror nucleotides to build mirror DNA or RNA.
Oligonucleotide	A short piece of DNA or RNA, generally fewer than 100 nucleotides.	Synthetic oligonucleotides are commonly used in laboratories to study or engineer genes. Mirror oligonucleotides, which have been built, would be necessary to construct or replicate mirror genetic systems.
Polymerase	An enzyme (protein) that copies DNA or RNA.	Scientists would need to make and use mirror polymerases to make a mirror genome and mirror life.
Ribosome	A cellular machine that reads genetic instructions and uses them to assemble proteins.	Scientists would need to make a mirror ribosome to create mirror life in the bottom-up pathway.

Notes

[1] Wurtz et al., "Survey of Laboratory-Acquired Infections Around the World in Biosafety Level 3 and 4 Laboratories."

[2] Evans et al., "Building Decision Points into Research's Slippery Slopes"; United Nations Educational, Scientific and Cultural Organization International Bioethics Committee, *Report of the International Bioethics Committee (IBC) on the Ethical Issues of Synthetic Biology*.

[3] Adamala, Agashe, Belkaid, et al., "Confronting Risks of Mirror Life."

[4] Adamala, Agashe, Belkaid, et al., "Confronting Risks of Mirror Life"; Adamala, Agashe, Binder, et al., *Technical Report on Mirror Bacteria*.

[5] "We believe that mirror life should not be created unless future research convincingly demonstrates that it would not pose severe risks" (Abbott et al., "Spirit of Asilomar Entreaty 2025.4.4"). See also Evans et al., "Building Decision Points into Research's Slippery Slopes"; and United Nations Educational, Scientific and Cultural Organization International Bioethics Committee, *Report of the International Bioethics Committee (IBC) on the Ethical Issues of Synthetic Biology*.

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Wurtz, N., A. Papa, M. Hukic, A. Di Caro, I. Leparc-Goffart, E. Leroy, M. P. Landini, Z. Sekeyova, J. S. Dumler, D. Bădescu, et al., "Survey of Laboratory-Acquired Infections Around the World in Biosafety Level 3 and 4 Laboratories," *European Journal of Clinical Microbiology and Infectious Diseases*, Vol. 35, No. 8, August 2016.

Annotated Bibliography

Adamala, Katarzyna P., Deepa Agashe, Yasmine Belkaid, Daniela Matias de C. Bittencourt, Yizhi Cai, Matthew W. Chang, Irene A. Chen, George M. Church, Vaughn S. Cooper, Mark M. Davis, et al., "Confronting Risks of Mirror Life," *Science*, Vol. 386, No. 6728, December 12, 2024.

This article is the first major peer-reviewed publication to clearly frame mirror life as a serious global risk rather than a speculative scientific idea. The authors explain how mirror bacteria could evade immune systems and natural ecological controls, thus creating risks to human health and the environment, and call for early international discussion and restraint. Because this article appears in the internationally prestigious journal *Science*, it puts mirror life on the agenda for many researchers, policymakers, biosecurity experts, and interested public audiences who had not previously considered mirror life's implications.

Adamala, Katarzyna, Deepa Agashe, Damon Binder, Yizhi Cai, Vaughn Cooper, Ryan Duncombe, Kevin Esvelt, John Glass, Timothy Hand, Thomas Inglesby, et al., *Technical Report on Mirror Bacteria: Feasibility and Risks*, Stanford Digital Repository, 2024.

This in-depth report is the scientific companion to the *Science* article. It provides the first comprehensive examination of how mirror bacteria might be built and what the risks of creating such organisms could be, drawing on expertise in synthetic biology, immunology, ecology, and biosecurity. The authors assess in detail how mirror bacteria could evade natural defenses and spread in the environment, and they outline why developing these organisms could pose serious threats to health and ecosystems that deserve wide attention before the science advances further.

Epstein, Gerald L., Forrest W. Crawford, and Sella Nevo, *Policy Options to Prevent the Creation of Mirror Organisms*, RAND Corporation, PE-A3436-1, March 2025. As of June 18, 2026: https://www.rand.org/pubs/perspectives/PEA3436-1.html

The authors of this paper describe a variety of U.S. and international policy mechanisms that could be used to halt research and development programs to create mirror life. They discuss potential limits on federal funding, regulatory and export controls, norm-setting by the U.S. executive branch, and new legislation. Internationally, they examine such options as using existing treaties and institutions or developing a new global agreement to prohibit the creation of mirror life.

Kalra, Nidhi, Forrest W. Crawford, Matthew L. Nicotra, Scott Behmer, Josh Dettman, Gerald L. Epstein, Edward Geist, David Glickstein, Graham Griffin, and Krista Langeland, *A U.S. Strategy to Prevent the Creation of Mirror Life*, RAND Corporation, RR-A4335-1, 2026. As of June 18, 2026: https://www.rand.org/pubs/research_reports/RRA4335-1.html

The authors define the strategic challenges to preventing the creation of mirror life, and they examine mechanisms that can help avoid its potential risks before it becomes an irreversible reality. The authors suggest a strategy that the United States could pursue to realize a world in which the potential for mirror life development is minimized.

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About This Paper

Advances in synthetic biology and molecular engineering have raised the possibility that future scientists might create mirror life, a hypothetical form of life built from molecules whose structures are engineered to be mirror images of the molecules found in all known life on earth. Although mirror life has not been created yet, scientists have warned that if it were realized, it could pose catastrophic risks to human health and ecosystems. This paper is intended for policymakers and advisers who might encounter the mirror life concept in briefings, research proposals, or international discussions. This paper establishes a shared factual foundation—explaining what mirror life is, how it might be created, and why it differs from other biological or technological risks—so that subsequent policy and governance discussions can proceed from a common, accurate understanding.

This effort builds on prior RAND research on mirror life, including Kalra et al., 2026, and Epstein, Crawford, and Nevo, 2025, as well as research on biosecurity, dual-use technologies, and emerging technology governance. It contributes to a broader institutional effort to help policymakers understand and manage the risks of mirror life.

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