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Cooling a Warming Planet?
A Public Forum on Climate Intervention Research

The Earth's climate is changing in measurable ways. Heat-trapping gases such as carbon dioxide are building up in the atmosphere, and average global temperatures are increasing. The current rate of climate change makes it difficult for life on Earth, including humans, to adapt. Most experts predict that this problem will get worse unless society takes rapid and meaningful action to solve it.

What that action should be is a question for all of society. Scientists help us to understand the climate problem and propose ways to address it. But although science can inform our decisions, it does not tell us what we must do. Major choices about how we as a society respond to climate change are made by institutions that are ultimately answerable to the public.

It is therefore essential that your voice is a part of the process. The forum that you are participating in was designed to better understand your values and perspectives on this important issue. The answers you provide can help experts and policymakers decide on a course of action.

At the forum, you will consider a potential response to climate change called climate intervention, or geoengineering. The forum focuses on a particular type of geoengineering called solar radiation management, or SRM. SRM is a set of proposed methods to manipulate the Earth's energy balance in order to counteract some effects of climate change. It would not address the human causes of climate change, but might reduce some of its harmful effects. SRM research is in the very early stages, and it is controversial in the scientific community. Scientists don't know if any SRM methods will be feasible in the real world, if they would actually work as proposed, or what their side effects might be. To reduce these uncertainties, some scientists want to pursue research to figure out which, if any, of their ideas might eventually prove useful.

During the forum, you and your fellow participants will learn about proposed SRM methods and then share your ideas about whether and how SRM research should proceed. The forum consists of three sessions: **Research Directions**, **Research Funding**, and **Research Decision Making**. In the first session, you will express your perspectives on different types of SRM research. In the second session, you will discuss which entities you feel can be trusted to fund research on SRM. In the third session, you will share your ideas regarding the regulation, or governance, of SRM research and who should be involved in various decision-making processes.

This document will prepare you for the forum by providing background information on climate change, solar radiation management, scientific research, and research decision-making.

How Does the Earth's Climate Work?

The Earth's **climate** consists of the average weather conditions (temperature, precipitation, humidity, storms, etc.) that prevail around the world over a long period of time. Climate is different from day-to-day changes in weather. While the weather on any particular day might be quite unusual—a warm winter day in Boston or a cold, rainy day in Phoenix, for example—on average, the climate of a place is generally stable and predictable from year to year. Although the Earth's climate system is complex, it is ultimately controlled by two main factors: (1) the amount of incoming sunlight which is absorbed or reflected, and (2) the insulating effect of various gases in Earth's atmosphere.

We all know that dark surfaces absorb more sunlight than lighter, more reflective colors. The Earth's climate system works the same way. Bright white clouds and snow reflect a large amount of incoming sunlight, cooling the planet. Dark-colored ocean and land surfaces absorb more sunlight, warming the planet. Scientists use the word **albedo** to refer to how much light a surface reflects. The higher the albedo of the Earth's surface, the more of the incoming sunlight is reflected back to space.

Sunlight absorbed at the Earth's surface is converted into heat. To balance the Earth's climate, most of the heat eventually escapes back into space. But certain gases, including water vapor, methane, and carbon dioxide, block the transmission of this heat as it passes back through the atmosphere. This is known as the **greenhouse effect**. The greenhouse effect is a natural process. Without it, Earth's temperature would be close to 0 degrees Fahrenheit—cold enough to freeze all the oceans!—instead of the 59°F global average temperature we enjoy today. However, human activities have added to the amount of heat-trapping gases in the atmosphere, resulting in climate change.

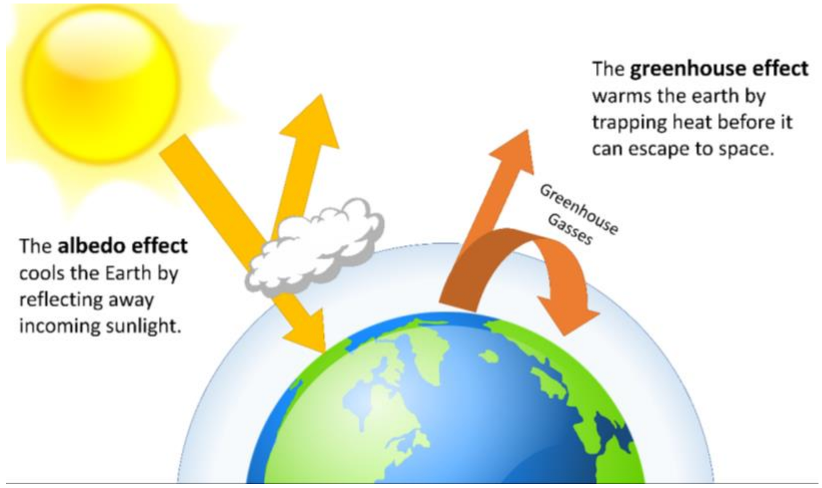


Figure 1. Earth's temperature is a balance between heating by the sun and cooling by heat loss to space. These processes are controlled by the albedo effect, which cools the planet by reflecting sunlight, and the greenhouse effect, which warms the planet by limiting the escape of heat to space.

What is Climate Change?

Over the past 2.5 million years, the concentration of the powerful **greenhouse gas** carbon dioxide (CO_2) in Earth's atmosphere has varied between 180 and 280 parts per million.

Starting with the Industrial Revolution around the middle of the nineteenth century, the concentration of carbon dioxide and other greenhouse gases in Earth's atmosphere began to rise above the levels observed during the previous 2.5 million years. Because CO_2 is a greenhouse gas, as its concentration increased in the atmosphere, the Earth's climate began to warm. Global average temperatures are now increasing faster than at any point in the last 11,300 years. Between 1880 and 2018, global average temperatures increased by approximately 0.85 °C, or 1.5 °F.

Human activities are responsible for the rising greenhouse gas concentrations that cause climate change. Humans have been extracting and burning fossil fuels such as oil, coal, and natural gas for energy in ever-increasing quantities. When burned, fossil fuels release carbon dioxide into the atmosphere, where it contributes to the greenhouse effect. The increase in global fossil fuel consumption since 1850 aligns with the increases in greenhouse gas concentrations and global average temperature over the same time period. The basic processes by which human activities release greenhouse gases and by which increases in greenhouse gas levels influence global temperature are simple and have been understood since the early 1900s.

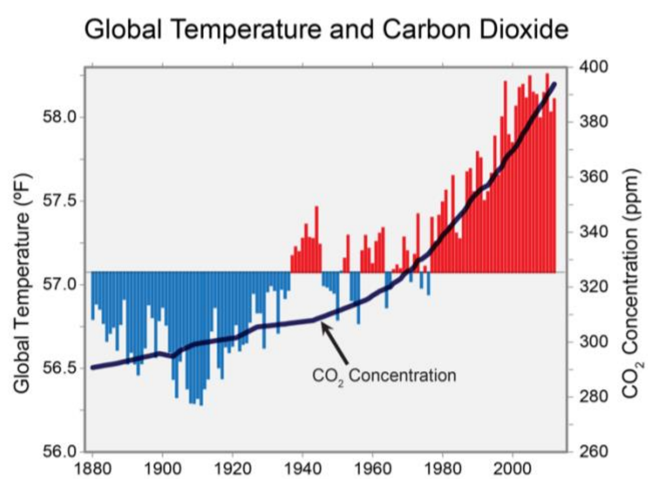


Figure 2. Global annual average temperature has increased by more than 1.5°F (0.8°C) since 1880. Red bars show temperatures above the long-term average and blue bars indicate temperatures below the long-term average. The black line shows atmospheric carbon dioxide concentration in parts per million (ppm). *Figure source: 2014 US National Climate Assessment, updated from Karl et al. 2009.*

Human activities continue to increase the levels of greenhouse gases in the atmosphere today. Fossil fuels currently account for more than 80% of global energy consumption. Even if fossil fuel emissions ceased today, global temperature averages would continue to increase as the climate finishes adjusting to new greenhouse gas levels. As discussed above, we've already warmed the planet by more than 0.8°C (1.4°F). Given current trends, climate models predict that global average temperatures will likely increase by an additional 1.4 to 4°C (2.5 to 7.2°F) by 2100.

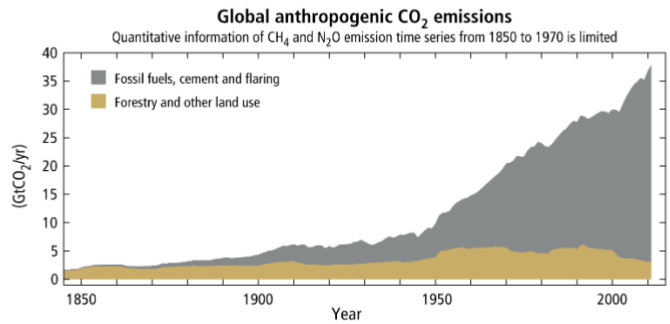


Figure 3. Carbon dioxide emissions. *Source: IPCC (2015).*

Why Does Climate Change Matter?

Climate change poses a variety of threats to both humans and natural ecosystems. Experts predict that a warmer climate will increase the frequency and intensity of extreme weather events. Changes in rainfall can affect food systems and water supplies. Oceans will become more acidic, damaging marine ecosystems and a critical human food source. Sea levels will rise, threatening low-lying islands and coastal areas. Plants and animals that cannot adjust may become extinct. Parasites and pathogens may spread to new areas. Considerable amounts of human infrastructure will need to be built or replaced to cope with changing conditions.

Although the effects of climate change will be felt worldwide, different people will experience these impacts in different ways. Poor people are likely to be the most vulnerable to climate hazards.

As global temperatures rise, there is general agreement that the costs and consequences of climate change will become more severe. As a result, many experts and politicians have suggested that we should try to keep global temperature from rising more than about 3.8°F (2°C). This number is based on the range of temperature variation experienced during the last several hundred thousand years of Earth history. Above this threshold, many scientists believe that the risks of climate change impacts on weather patterns, ecosystems, agriculture, and sea level rise become unmanageable.

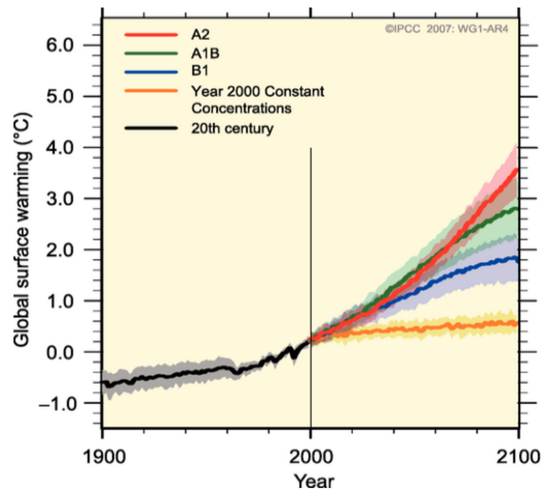


Figure 4. Predictions of future global climate change based on computer climate models. Each of the different pathways represents assumptions about future greenhouse gas emissions, ranging from no further emissions (orange) to a business-as-usual world much like the present (red). Based on these scenarios, it is likely that global average temperatures will likely increase by an additional 1.4 to 4°C (2.5 to 7.2°F) by 2100. *Source: IPCC (2007).*

What Is Being Done about Climate Change?

Policymakers and scientists have emphasized two approaches to deal with climate change over the past thirty years. The first approach addresses the cause, by attempting to reduce the amount of greenhouse gases that humans are emitting into the atmosphere. This is called **mitigation**.

Mitigation has been extraordinarily difficult because fossil fuels play such an import role in the global economy. Although renewable and carbon-free energy sources supply a significant and growing portion of our energy needs, the vast majority of the world's power is still produced through fossil fuels.

Various policies and agreements have been enacted to try to reduce emissions. These range from local legislation to global treaties, such as the 2015 Paris Climate Agreement. This agreement, which seeks to keep global average temperatures from rising more than 2°C (3.8° F) above pre-industrial levels, has now been signed by 195 countries around the world. The United States signed the Paris Climate Agreement in November 2016 but has subsequently issued notice that it intends to withdraw from the Agreement.

Yet even the Paris Agreement's emission reduction goals may not keep global temperatures below the target. The world may still see significant harms from climate change without much more stringent emissions reductions.

The second approach focuses on improving society's ability to deal with a changing climate. These efforts are called **adaptation**. Humans are very good at adapting to their environment. From the invention of air conditioning to the use of bird feathers for clothing insulation, people have created ways to flourish in nearly every part of the world. Climate adaptations include seawalls, storm warning systems, adaptive farming practices, disease monitoring, and other upgrades to human infrastructure and systems.

Some experts, however, worry that climate change could be so severe or happen so quickly that humans and ecosystems will not be able to adapt effectively or affordably.

Solar Radiation Management: An Opportunity to Combat Climate Change?

With the substantial risks of climate change in mind, some scientists have proposed a third way to address the problem. Remember that two key factors in the Earth's climate system are how much solar energy is absorbed by the planet's surface and how much heat is reflected back into space. If we could change one of those variables, we might be able to limit the effects of climate change. Attempting to do this is called geoengineering.

Solar radiation management (SRM) is the geoengineering strategy you will consider at the forum. SRM encompasses a suite of ideas which scientists have proposed to deliberately manipulate the greenhouse effect and limit the severity of global temperature increase. Each of these ideas aims either to reflect a small portion of incoming solar radiation back into space or to allow more heat to escape from the atmosphere, reducing the greenhouse effect.

Research on SRM methods is still in an early stage. The feasibility, efficacy, and potential side effects are uncertain. There is considerable controversy in the scientific community about whether any of these ideas might ultimately prove safe, effective, and affordable. Because of this uncertainty, some scientists advocate for further research into these ideas to determine which, if any, might eventually prove practical.

The remainder of this document will familiarize you with various SRM ideas. It's important to remember that during this forum, we will only be discussing **research** into various SRM methods, but not the widespread deployment of technologies. The following sections provide an overview of several proposed SRM research programs, possible strategies for organizing SRM research, and short discussion of some possible factors to think about when discussing SRM research.

Proposed Solar Radiation Management Methods

There are many different ideas for technologies which might be used to cool the climate. These range from relatively simple ideas, such as painting rooftops and road surfaces white to reflect incoming sunlight, to much more complex projects, such as managing global ice and cloud cover or reflecting sunlight as it hits the Earth's stratosphere. Each of these ideas has benefits, costs, tradeoffs, and risks associated with it. This section presents a selection of six different research programs which are being seriously discussed by scientists.

Reflective Infrastructure

Painting roads, rooftops, and other infrastructure in reflective colors and increasing plant cover could help to reflect incoming sunlight and reduce temperatures at local scales, especially in urban areas. The main advantages of this method are that it can be easily targeted and it is relatively safe and predictable. Over 54% of the world's population—3.9 billion people—live in urban areas. By reducing the temperature in cities, reflective infrastructure could help protect the health of many millions of people by reducing the impact of extreme heat events. Some scientists have suggested that this approach could be extended to rural areas by planting lighter, more reflective crops, or even covering vast areas of sandy deserts, such as the Sahara, with reflective sheets.

Although reflective infrastructure is relatively simple compared to other SRM methods, the main challenge is determining the potential impacts. If only implemented in urban areas, impacts on global temperatures and effects on sea levels would be negligible. Larger-scale implementation, by planting reflective crops or covering sandy areas of the desert, could, according to optimistic projections, have a global cooling effect of 1 to 2°C (about 2 to 4°F). However, computer simulations have shown that large-scale implementation of reflective infrastructure tends to cool the land surface much more than the oceans; this uneven cooling may result in large changes in rainfall patterns around the world. More extensive field experiments and computer modeling are required to determine the feasibility of this method and better predict possible impacts on temperature and rainfall.

Ocean Surface Microbubbling

Oceans cover more than 70% of the Earth's surface. Because it is relatively dark in color, sea water absorbs more than 94% of incoming sunlight at the surface. However, bubbles produced by ship wakes form bright-colored foams that make the ocean's surface more reflective. Some scientists suggest that fleets of specially modified ships could be used to churn up enough sunlight-reflecting bubbles to help reduce climate change. Natural foaming agents produced by algae help produce bubbles that last about 10 minutes following the passage of a large ship. Advocates of ocean brightening suggest it may be possible to engineer "designer" foaming agents which would allow these tracks to last for up to 10 days. If 5% of the ocean's surface was covered with these tracks, the reflected sunlight could have a substantial effect on the global climate.

The feasibility of ocean brightening and its possible effect on regional weather and marine ecosystems are poorly understood. Scientists have proposed a series of computer models, laboratory experiments, and outdoor tests to explore this idea further. Studies need to be conducted to determine whether suitable foaming agents can be developed and whether these foaming agents are safe for use in marine ecosystems. If eventually deployed at scale, this approach would likely be resource intensive, requiring a large number of ships. The costs may still be affordable compared to the costs of climate change.

Sea Ice Thickening

One of the consequences of global climate change is the loss of Arctic sea ice. As bright white snow and ice melts, revealing the dark ocean surface beneath, the ocean absorbs more incoming sunlight, accelerating the melting process in a feedback loop. This has led some scientists to ask whether we could artificially restore sea ice, helping return Arctic ecosystems to historical conditions while also reflecting more sunlight to combat rising temperatures. These scientists suggest that a network of wind-powered pumps could be used to spray seawater onto the ice surface during Arctic winter, allowing the water to freeze more quickly than would occur naturally. By repeating this process each winter, they calculate that it would be possible to largely reverse the melting trend for Arctic sea ice.

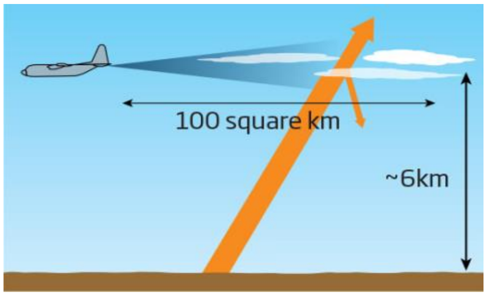
The true feasibility of sea ice thickening is poorly understood. Even if it is possible, the effects of artificially restoring sea ice on local climate and weather patterns are unknown and require careful study. Scientists have proposed a series of computer modeling studies, laboratory experiments, and outdoor tests to better understand the feasibility and risks of this approach. Although restoration of sea ice could benefit Arctic ecosystems, it could have a negative economic impact on new shipping lanes and ports which are more accessible due to the loss of sea ice.

Marine Cloud Brightening

Low-lying clouds are significantly more reflective than the ocean surface, so an increase in low clouds over the ocean could reflect more incoming sunlight back to space. For decades, scientists have observed that particles in the exhaust from large ocean-going ships help to seed long, linear clouds over shipping lanes. Specially designed ships could be developed to enhance this effect by spraying a fine mist of sea salt into the marine atmosphere. If applied at large scales, this effect could have a significant cooling impact on the global climate. Some scientists have suggested that this approach might also be deployed regionally to help protect, say, the Great Barrier reef (a coral reef off the coast of Australia) from damaging heat impacts.

However, cloud formation is a complex and poorly understood process. Many experiments would be required to understand and improve this cloud-seeding technique. Because marine cloud brightening only works over the ocean, extensive computer modeling and experiments would be required to test how cooling over the ocean would affect global climate. The effect that enhancing marine clouds would have on ocean ecosystems is also not known and would require further study before such a technology could be used at scale. If eventually deployed, this approach would likely be resource intensive, requiring a large number of ships, although the costs may still be affordable compared to the costs of climate change.

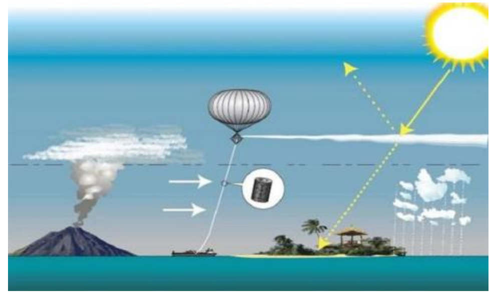
Cirrus Cloud Thinning



Cirrus clouds are high, wispy clouds composed of ice crystals which form in the upper troposphere, approximately 3 to 6 miles above the Earth's surface, or about the altitude of a high-flying commercial jet. Cirrus clouds absorb heat before it can escape to space, resulting in a net warming effect on the Earth's climate. Scientists suggest that the release of a chemical called bismuth tri-iodide at the level of cirrus clouds could decrease cloud formation and allow more heat to escape from the atmosphere.

To be effective, cirrus cloud thinning would need to be implemented at a large scale. There is concern that excessive use could actually thicken cirrus clouds, reversing the intended effect. As with all SRM ideas, the wider climate impacts of cirrus cloud thinning are deeply uncertain. Extensive computer modeling and real-world experiments would be required to understand if this method would work and how much cooling could be achieved. If implemented at scale, cirrus cloud thinning would need to be carried out continuously at many locations around the planet, which would likely increase the cost of this SRM approach.

Stratospheric Aerosol Injection



Major volcanic eruptions release large amounts of sulfur particles into the stratosphere, a layer of the Earth's atmosphere between 5 and 30 miles above sea level. In the stratosphere, these particles form a fine mist (called an aerosol) which reflects some amount of incoming sunlight back away from the Earth, measurably cooling the Earth's surface. Some scientists have suggested that we could use airplanes or high-altitude balloons to release aerosols into the stratosphere, producing a similar cooling effect.

The effects of intentionally producing a reflective stratospheric aerosols layer are not completely understood. Significant computer modeling, laboratory testing, and small outdoor experiments would be required to develop this technology. The effects of stratospheric aerosol injection on other aspects of the climate system, such as rainfall patterns, is a concern. In addition, stratospheric aerosols could impact the Earth's ozone layer, which protects the Earth's surface from ultraviolet radiation. Compared to cloud-based SRM techniques, stratospheric aerosol particles last for a year or more. Once introduced, stratospheric aerosol spread to cover the whole planet. As a result, stratospheric aerosols are likely to be more cost effective than other SRM techniques, but would also be more difficult to control and terminate quickly if problems emerge.

Session 1: Research Directions

The research and development of SRM technologies is at an extremely early stage. It is too early to determine whether or not any of these technologies might eventually prove useful and cost-effective. In addition, major questions remain about the unintended consequences of approaches, including impacts on local and regional climate such as rainfall patterns; impacts on local ecosystems and crops; and possible impacts on human health and safety.

Given these risks, private companies, universities, and federal funding agencies have been generally reluctant to fund SRM research. It is unclear whether members of the public would eventually welcome or reject further research in SRM technologies.

This section describes a series of possible research directions for you to consider, ranging from no SRM research to large-scale research investments. The main of goal of this section is to help you think about what types of research you would support.

No SRM Research

What's involved?

Considering all the uncertainties and risks of SRM technologies and approaches, one possible strategy is simply to avoid or prohibit investing in SRM research. If there was a widespread public consensus that SRM technologies are not necessary or viable, then federal agencies, private foundations, and corporations would be unlikely to support research in this area. However, even if research is blocked by some agencies and countries, other countries may start research, and it may be difficult or impossible to entirely prevent private funding of SRM research.

What could we learn?

Without significant investment in SRM research, our scientific understanding of SRM will advance only slowly, if at all. Some members of the scientific community would argue that this is a good thing because they feel SRM research distracts from the more important tasks of mitigation and adaptation. Avoiding SRM research reduces the temptation for governments to use SRM research an excuse for delaying greenhouse gas emissions cuts. Finally, some scientists feel that the technical and political obstacles to SRM research may eventually prove insurmountable, such that further research is a waste of time, money, and effort.

What are the risks?

Without significant investment, knowledge about SRM methods, their applications, and their potential impacts, both desired and undesired, will not advance. Not investing in SRM means that we will not know whether it could work, what effects it could have, or how it might be effectively or safely implemented.

Because meaningful SRM research is likely to take many years, there is a risk that if we forgo SRM research now, we could find ourselves unprepared for future events. If the consequences of climate change turn out to be more severe than anticipated, it is possible that another nation or group of nations might decide to deploy SRM technologies, even if these technologies have not been properly studied.

Computer Modeling & Indoor Experimentation

What's involved?

In order to predict changes in the Earth's climate, scientists must consider how all the different parts of the climate system—the atmosphere, oceans, land surface, ice cover, ecosystems, and humans—interact. To do this, climate scientists rely on extremely complex models to chart and predict interactions between different parts of the climate system.

However, any model is only as good as the data and ideas that scientists program into the software. To build accurate climate models, scientists rely on laboratory and field experiments, historical weather data, and satellite remote sensing to provide the inputs for modern climate models. This research strategy would limit SRM research to computer modeling and laboratory experiments. This approach would allow for scientific advances while being relatively low risk and low cost.

What could we learn?

By simulating possible SRM techniques in computer models, scientists can explore how various SRM approaches might cool the climate, affect rainfall and weather patterns, and impact humans and ecosystems around the world. These efforts can be supplemented with new data from indoor laboratory experiments. In addition, social scientists could study how SRM technologies might affect actions to address the causes of climate change.

Such research programs would likely be relatively inexpensive. Individual studies could be carried out by small research teams of fewer than a dozen scientists and would cost between $100,000 and $1 million per year, which is typical of small- to medium-sized scientific research projects.

What are the risks?

Computer models and laboratory experiments are not the real world. Although these approaches are necessary and useful, many environmental processes are difficult to simulate on a computer or test in a laboratory. By restricting research to these approaches, scientists potentially miss out on information that could be gained from outside field experiments. These research approaches necessarily simplify complex scientific phenomena and could create a false sense of confidence in our understanding of SRM.

On the other hand, some observers worry that even SRM computer models and laboratory experiments distract time and attention from the immediate work of mitigation. Some people are concerned that governments could use even basic SRM research as an excuse to delay emissions reductions. Other people are concerned that conducting basic SRM research increases the chances that poorly understood and potentially risky SRM technologies could be deployed in the future. However, many scientists support the view that more research will lead to a better understanding and therefore reduce the risks of applying an undeveloped technology.

SRM Field Trials

What's involved?

Scientists have proposed several kinds of outdoor experiments to provide initial testing and data for future SRM technologies. For example, researchers have proposed releasing around 1 kilogram (2.2 pounds) of sulfur from a high-altitude scientific research balloon to study how reflective aerosols form in the stratosphere. Other scientists have proposed building a specially equipped ship to test whether spraying sea salt into the atmosphere over the ocean can be used to form low-lying reflective clouds.

Early experiments would be small in scale, involving a few dozen people and occupying a land or ocean area of 1 to 10 square kilometers (about 0.6 to 6 square miles) over a period of weeks to months at a time. These types of experiments would likely cost between $500,000 to $10 million per year, which is typical for medium- to large-sized scientific research projects.

What could we learn?

SRM field trials permit the study of environmental processes which are difficult or impossible to study in the laboratory or model on a computer. Stratospheric release experiments, for example, could help scientists understand the mechanics and effects of spraying liquids into the stratosphere to form aerosol droplets to reflect sunlight. Such experiments are difficult in the laboratory, due to reaction of the droplets with the walls of the experimental container, and uncertainties about the chemical composition of the stratosphere.

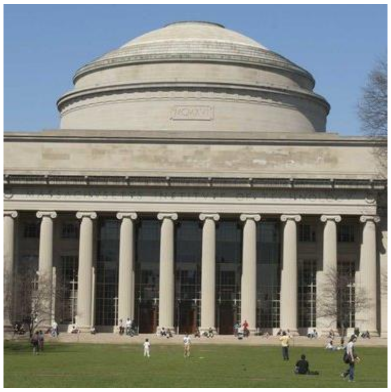
Outdoor field experiments could help researchers construct better engineering and computer models for SRM technologies. Social science researcher would be required to address issues of consent for populations affected by the experiments, among other concerns. Some scientists think these experiments are key to limiting future climate risks and making informed decisions about SRM. Other scientists, though, believe the climate system is so complex that it would take decades of global-scale experimentation to identify and understand the effects of SRM techniques.

What are the risks?

While all experiments carry risks, scientists in charge of these projects believe the risks associated with initial, small-scale SRM field trials would be relatively minor because they involve only small amounts of materials. Commercial jet airliners and large ships release much larger quantities of similar materials into the atmosphere every day.

However, small-scale SRM field trials may eventually lead to larger experiments. If not properly designed, larger scale experiments (regional to global scale experiments lasting months to years) could eventually pose health and safety risks through unexpected changes in rainfall, damage to ecosystems, or materials released into the environment at significant scales.

Decentralized, High-Investment Research



What's involved?

Large-scale scientific funding provided by private foundations, companies, or the federal government would allow loosely coordinated teams of researchers to conduct more advanced experiments and climate modeling over longer periods of time. For purposes of illustration, a large-scale funding effort could involve ten research centers within the United States, all performing both indoor laboratory and computer modeling research as well as field trials over a lengthy period of time.

This scale of investment and support would be appropriate if SRM research was considered a national or international scientific research priority. Programs of this scale would likely involve a financial investment of $10 million to $100 million per year and support hundreds of researchers and support personnel for a decade or more. The cost and scale of experiments would likely increase over the lifespans of such programs, potentially culminating in long-term experiments releasing hundreds of tons of material into the stratosphere or spraying similar amounts of seawater above the ocean.

What could we learn?

A large-scale scientific research program would allow more rapid progress in our understanding of SRM technologies and their possible impacts. Sustained and diverse funding would enable research into several different SRM approaches, allowing different approaches to be systematically compared. Social science programs to understand the social, economic, and political elements of such a program would be scaled up accordingly. Research programs of this scale would likely substantially improve climate models and data to improve our understanding of the global climate system, as well as provide policymakers with the detailed information required to make informed decisions about whether to deploy SRM technologies at scale.

What are the risks?

Increased research funding makes it possible to eventually conduct larger field trials of SRM technologies. Larger experiments carry potentially greater risks and could potentially produce serious negative impacts on ecosystems and people living in affected areas. Significant investment in SRM research would reduce the amount of funding for and people involved with other types of important research, including other forms of climate research. A large research program clearly require meaningful oversight and international governance to ensure that global stakeholder concerns are addressed and that the potential for negative impacts is fully understood.

Coordinated National Effort

What's involved?

A coordinated, national program of SRM research, similar to the Manhattan Project or Apollo space program, is the largest and most focused SRM research model of which a single nation is capable. Such a program could involve thousands of researchers and support personnel and cost billions of dollars. A program like this could potentially perform extremely large SRM experiments over a timescale of a decade or longer, potentially affecting the entire globe by releasing up to a billion tons of material each year.

Such a program would require significant physical, economic, and social infrastructure, including the consistent use of fleets of dedicated aircraft or ships, or both. Research at this scale would very likely require the participation and consent of partner nations around the world.

What could we learn?

A coordinated national research program would be capable of developing the physical and human infrastructure necessary to permit large-scale SRM research and actual SRM deployment. The social, economic, and political consequences of SRM deployment could be understood in greater depth with a large-scale social science studies. A coordinated national effort would be capable of experiments on a scale sufficient to provide information about SRM's impacts on a global scale.

What are the risks?

A nationally-scaled SRM research program carries all the direct risks of less intensive projects of research, scaled to match the national endeavor. Large-scale SRM trials could potentially alter global rainfall, temperature, or extreme weather patterns. At the largest scale, SRM testing could transition into full-scale SRM deployment; at that point, there would be little distinction between research and deployment. Although a national research program could be cancelled, such high profile and large-scale activity would carry considerable financial and political momentum. As a result, there is significant concern that such an effort would make SRM deployment more likely, and may inevitably distract from efforts to mitigate and adapt to climate change. Without international support, such a research effort could lead to global political tension, particularly if the major benefits and unintended consequences of SRM technologies are unequally distributed around the globe.

Research Considerations

There are many different factors to consider when debating the costs and benefits of scientific research, especially for controversial topics such as SRM. This section summarizes several factors to keep in mind when evaluating research directions. These are not the only things you can or should think about, but rather are concerns raised by experts thinking about SRM research. The goal of this section is to provide you with additional perspectives that can help inform your own opinions.

Financial investment

Research costs money. Funds are required to support the salaries of researcher and support staff, purchase equipment and materials, pay for laboratory space, and more. Research projects vary widely in scale, but larger research projects often involve amounts of money well outside most individual's everyday experience. To help provide a sense for the scale of US research investment, we provide recent annual research budgets for several large organizations in the table below.

Organization	Annual Research Budget
Arizona State University	$302.7 million
Massachusetts Institute of Technology	$719.5 million
Royal Dutch Shell Oil Company	$1 billion
US Department of Defense Advanced Research Projects Agency	$2.888 billion
Bill and Melinda Gates Foundation	$4.5 billion
US National Science Foundation	$6.2 billion
US National Institutes of Health	$37.3 billion
Total US Corporate Research and Development Expenditures	$500 billion

Improved climate system understanding

The global climate system is extremely complex, and while broad trends like climate change are relatively well understood, many of the details require more research. SRM research provides an opportunity for additional study of the atmosphere and climate systems, especially under the novel conditions induced by SRM methods. Improved understanding of the climate system could inform the design of and discourse around SRM methods, while also helping inform general climate discussion and policy choices.

Direct risks of SRM research

Direct risks include threats which research could pose to humans, wildlife, or the environment through release of substances, equipment malfunction or crash, or unexpected influence on the weather.

Indirect risks of SRM research

Indirect risks include social and political risks from SRM research. Some examples include the risk that the impacts of SRM will be unevenly distributed between wealthy and poor nations, and the risk that SRM research distracts from more immediate goals of reducing greenhouse gas emissions. Social science research is necessary to better understand and evaluate these risks.

Technological lock-in

Research on SRM methods could make their use more likely. The line between large-scale experimentation and actual deployment is blurry. Technological development tends to attract financial support, political constituencies, and physical infrastructure. It can be easier to justify continued commitment to options with high prior investment, potentially distracting from other climate action options or excluding the public from the decision-making process.

Moral hazard

SRM research may develop the capability to limit global temperature increases relatively quickly and inexpensively. Yet SRM methods would only treat the symptoms, rather than the causes, of climate change: they neither reduce emissions of greenhouse gases nor remove them from the atmosphere. Some observers fear that SRM investment may remove incentives, or distract from efforts, to reduce fossil fuel use and adapt to the alterations climate change is already producing in the environment. Because of the complexity of human choices, though, it is unclear how accurate such fears may be.

Understanding the Controversy around SRM Research

SRM research is controversial among scientists and policymakers for many reasons. Although almost all scientists agree that cutting carbon dioxide and other greenhouse gas emissions should be our immediate priority, it's unclear whether we should be considering direct intervention in the climate system at all. We do not know whether the world will choose to significantly reduce greenhouse gas emissions in the coming decades. And there are significant uncertainties about the possible impacts of climate change and how easy or difficult it will be to adapt to these changes.

SRM does nothing to address the cause of climate change: human-caused greenhouse gas emissions. Many experts fear that if geoengineering approaches are seriously considered, nations will be less inclined to rapidly reduce their emissions. On the other hand, advocates of SRM research suggest that it is increasingly unlikely that we will be able to avoid significant climate change impacts. They argue that geoengineering methods could be important tools for reducing the harms of climate change in coming decades.

As with mitigation and adaptation, even if an SRM strategy were to perfectly, it will be at best an imperfect solution. In climate models where scientists simulate SRM approaches, temperatures and rainfall patterns around the world are often different from those that prevailed before climate change. Some parts of the world would receive more or less rainfall and some places would be warmer or cooler than they had been previously. In fact, the potential impacts of SRM are currently so uncertain that it is difficult to assess whether these approaches would result in net benefit or harm around the world. SRM approaches fall short in other ways as well. For example, solar radiation management cannot counteract the impact of rising carbon dioxide concentrations in the ocean, which leads to ocean acidification.

Finally, even if we could implement solar geoengineering, many people question whether humanity should use this approach. After all, who would decide crucial factors of the Earth's climate? Can humanity be trusted with such an awesome responsibility? On the other hand, geoengineering and SRM advocates argue that these technologies might be able to limit the impacts of climate change, helping to reduce the costs and suffering of millions of people. The moral and ethical questions pose great obstacles to geoengineering research in general, and especially to SRM approaches. Social scientists have only begun to examine these issues.

Session 2: Research Funding

The proposed SRM research methods require different levels of funding. Both government agencies and nongovernmental organizations are potential funding sources for these projects. These sources involve different requirements and levels of oversight for researchers, factors that you should take into consideration when selecting projects and funding sources.

Funding for SRM research should be considered in the context of total historical funding for climate change research, which must compete with not only other research areas, but also other potential expenses that might address similar policy goals. Within the realm of climate change, resources are spent on climate research, research and development of clean energy technologies, domestic programs to minimize climate emissions, and international assistance to help decrease global greenhouse gas emissions. In 2017, the federal government spent $2.8 billion on climate science. Philanthropies also contribute to work on climate change, providing $557 million to support climate and energy initiatives from 2011 to 2015. This section outlines six potential funding sources for SRM research and highlights some of the nuances of each funding source.

Federal Government

Who are they?

Civilian federal agencies such as the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA) could fund SRM research at universities or undertake the work themselves. Government agencies are funded by tax dollars and their budgets are subject to congressional approval. Financial support for SRM research could vary over time depending on the priorities of political leadership.

What types of projects do they fund?

Federal agencies fund projects that benefit the public. This requirement is fairly broad. It can include health, education, and economic benefits. Federal research grants involve an application process, beginning with a public request for proposals. The proposals, which include a budget outline for the project, are then reviewed by independent experts. Proposals must demonstrate scientific merit and identify intended benefits to the public.

How much oversight do they provide?

As with the other funders described here, all federal research projects must comply with state and federal laws and any relevant institutional requirements (generally important for researchers at universities). The agency may also implement rules specific to a particular research program or experiment. Research supported by federal grants must consistently demonstrate that the work is addressing the grant's objectives and may have to achieve specific milestones. Researchers must submit periodic reports and might be subject to site visits and reviews.

How will they use the research?

As part of the public benefit requirement, research may be published or presented in another manner to increase public understanding of an issue. Research findings may also be used to develop new technologies.

Military

Who are they?

The US Department of Defense funds large amounts of research through each wing of the military and through initiatives like the Defense Advanced Research Projects Agency (DARPA). Military research is responsible for some things we use every day, such as airplanes, the internet, and GPS. Military research tends to be more shielded from politics than federal government research, although it is also tax-funded and subject to congressional approval.

What types of projects do they fund?

The military funds research to enable or improve the nation's military capabilities or to support national security. The military issues public project proposals in research areas ranging from engineering to physical sciences. These proposals undergo review for technical merit and budgetary requirements.

How much oversight do they provide?

Military grant recipients must comply with federal and state laws. Researchers must track their spending, submit annual progress reports, and produce a final report about the project's success with respect to outlined objectives. These may be kept classified if deemed necessary for security reasons.

How will they use the research?

Military research is used to enhance the United States' military capabilities. Research may be used to improve offensive or defensive military capabilities or meet other strategic, mission-oriented needs. The most likely near-term reason for the military to be interested in SRM research is to build up observational and monitoring capacity of other countries' research into SRM, since uncoordinated deployment would pose national security and geostrategic risks.

For-Profit Corporations

Who are they?

For-profit corporations could invest in SRM research in the hope that the technology becomes profitable in the future, or out of a sense that their corporation ought to be acting directly in the public good. In other research areas, corporations invest significant amounts of money to fund research that promotes their objectives. For example, pharmaceutical companies fund research at universities or conduct research within their own R&D departments to support drug development.

What types of projects do they fund?

Corporations specifically fund research that will eventually translate into profits for the company. If research costs exceed potential profits or if the company's priorities shift, research on a topic may no longer be supported.

How much oversight do they provide?

Oversight on research projects varies based on the company, as well as whether the project is conducted within or outside of the organization. If the company provides funding to a university research group, it may require annual reports or a final report. Company-based R&D is held accountable by internal rules and reporting requirements. Results are often protected as trade secrets and not made public.

How will they use the research?

Corporations will eventually monetize the research by translating it into a technology or service for sale.

Philanthropy

Who are they?

Philanthropic organizations like the Bill & Melinda Gates Foundation and the ClimateWords Foundation support research relevant to their foundation's mission. Sometimes philanthropies will partner to fund larger-scale programs. Corporate and individual philanthropies typically fund a wide variety of projects, rather than focusing on a single issue.

What types of projects do they fund?

Philanthropies often award grants through a proposal and review system. Philanthropies and their programs are governed by boards that are not accountable to the broader public and select topics, potentially controversial ones, according to their own priorities. As with any potential funder, philanthropies can be narrowly focused. For example, they might exclude nuclear energy when funding research on sustainable energy sources.

How much oversight do they provide?

Each philanthropy has different processes for tracking project progress and providing oversight. Some organizations provide templates for tracking results, which include progress narratives, fiscal reports, and a final report. Others may only require a final report.

How will they use the research?

Philanthropies may discuss the research projects as evidence of their commitment to their stated mission, but are unlikely to further develop the research on their own. The outcome of one project could encourage or discourage further research funding for the same method.

Nongovernmental Organizations

Who are they?

Nonprofit nongovernmental organizations (NGOs) are similar to philanthropies but tend to be more focused on a specific issue or cause. NGOs can be organized on the local, national, or international scale. Multiple NGOs can also collaborate on a specific issue. The Climate Coalition, for instance, brings together many organizations to promote conversations about climate change in the United Kingdom.

What types of projects do they fund?

Similar to philanthropies, NGOs fund research that supports their organizational mission and objectives and may also be narrow in focus. NGOs receive their funding from government grants, philanthropies, or individual donors. Consequently, the size of projects that NGOs can fund directly relate to their own ability to acquire funding at that time. This might make it difficult for NGOs to fund long-term research projects.

How much oversight do they provide?

Researchers that receive grants from NGOs may need to submit periodic reports or allow NGOs to conduct project reviews. Amount of oversight will vary with each NGO. Privately funded projects may be exempt from certain public regulations and oversight.

How will they use the research?

NGOs may use research as an informational tool for the public or for key stakeholders involved with their mission.

Universities

Who are they?

Research universities provide facilities and infrastructure for professors and graduate students to perform research. Universities have been instrumental in many scientific discoveries and technological innovations, and have produced a great deal of fundamental knowledge. Universities perform research in physical and social sciences; support basic and applied research; and will sometimes partner with government or industry on larger collaborative research enterprises.

What types of projects do they fund?

Universities can provide direct financial support to SRM researchers in the form of seed money for pilot research programs. When universities receive funding through private donors or large grants, they can direct some of that funding towards specific research projects.

How much oversight do they provide?

Universities allocate funding through formal application processes and reviews or as a part of start-up funds for new faculty. Universities typically evaluate research programs based on scholarly productivity. They also have institutional review boards that oversee research programs involving human subjects.

How will they use the research?

Universities use research to generate publications and occasionally patents. They do not usually support technology development, but they may provide initial support for spin-off companies.

Session 3: Research Decision Making

Governing SRM means finding ways to balance the risks associated with research against the benefits that research could provide. Among the risks of even small-scale experiments are the possibility that research, once started, could lock in to greater and greater levels of interest and investment, so that even ideas that prove problematic might continue to be advanced. Scale is another factor: small field experiments may require little or no specialized regulation, but larger projects, with a consequently greater risk of adverse impacts on humans or the environment, may require careful oversight and new governance systems. (And you should keep in mind that research programs may not necessarily begin at a small scale.) There is also the danger that research gives legitimacy to SRM in ways that distract from other ways of responding to climate change. At the same time, if research is not conducted, then society and policymakers may not know all that they need to know to make good decisions about SRM.

Given what is at stake, SRM research requires decision-making systems that allow for evaluation and prioritization of potential research goals, processes of oversight, and any number of more detailed procedural decisions and value choices. Processes to be evaluated include the ways in which individual SRM researchers and funders determine how to design and invest in their research projects; the ways in which research sites are chosen; and methods of standard-setting and regulation by both government and other actors. This section is designed to help you think about who should be empowered and entrusted with making those decisions and what characteristics you value in a decision-making system for SRM.

Decision-Making Priorities

Decision making around SRM research would involve negotiating and balancing a complex web of different priorities, values, and interests. Instead of asking you to assess all of these different factors, here is outlined five elements in the design of decision-making processes. Each element carries a brief description of what it means for process design and a few examples of what it could entail. You'll be asked to rank these elements' importance, alongside any other factors you'd like to add, during the third section of the forum.

Flexibility

Ongoing research and technological development can often lead to unexpected problems or the discovery of new research avenues. A flexible system that can adapt and respond to these issues quickly will help the research adjust course, depending on the situation. A flexible system can also help balance between the risks associated with undertaking research and the risks associated with not undertaking research.

A flexible system requires significant resources and fast decision making; this may limit the number of stakeholders involved in the decision-making process.

Examples

- Constant monitoring of ongoing research projects
- Anticipatory expert advice to decision makers
- Frequent review and revision of standards, regulations, and procedural requirements

Enforcement

Many entities are likely to be involved with SRM research, and they will not all agree on its course. Enforcement capabilities permit high-level decision-makers to ensure that principles, limits, and directives are actually followed by the researchers. Penalties for non-compliance can range from formal or informal reprimands, to the withdrawal of funding or support, to legal action, depending on the situation.

The monitoring and action required for enforcement require people and financial resources to do the monitoring; the more intensive the monitoring, the greater the costs.

Examples

- Penalties for deviation from standards
- Regular inspections to ensure compliance
- Independent review processes to validate adherence to standards and principles

Transparency

When a research project's goals, methods, and results are public and accessible, the research is considered to be transparent. Transparency allows for observation and critique. This can improve research practices and outcomes, but it can also slow down progress, discourage research with commercial potential, or hinder difficult decision making.

Examples

- Openly available documentation on all policy proposals and policymaker discussion
- Regular "state of SRM research" reports for general audiences
- Public research proposal review and approval process

Public Involvement

Public values and interests rarely align completely with those of researchers and funders. Public involvement in the policymaking process helps to ensure that the community's needs and values are considered throughout the process. This can lead to improved outcomes that are aligned with societal goals.

Public involvement in decision making can be time- and resource-intensive. There are also important questions about who constitutes a relevant public and when and how to involve public perspectives.

Examples

- Public impact reports for proposed research
- Public comment periods on policy and open community for engagement with decision makers
- Democratically selected decision-makers or policy options

Responsiveness to Researcher Interests

SRM research is unlikely to get done at all if researchers and funders don't feel the system will help them accomplish their own goals, whether those are increased knowledge about the climate system, or the development of a profitable product, or the deployment of an SRM technology. Having decision makers who respond to researcher interests could facilitate and incentivize research.

It is possible to over-represent researcher and funder interests at the expense of the public. This could be detrimental to research that benefits everyone, or even to public safety.

Examples

- Strong intellectual property protection
- Explicit researcher presence in policymaking process
- Abstract standards and principles for interpretation by researchers

Decision Makers

This section outlines five broad levels of potential oversight of SRM research, emphasizing the communities involved and empowered in the decision-making process. During the forum, you'll be asked to indicate which you feel are most appropriate for making decisions regarding SRM research. These levels are not exclusive, and larger-scaled methods, such as federal oversight, could mandate the establishment of smaller-scaled decision-making processes, such as local community involvement in research siting. If decision-making systems are poorly coordinated, oversight of SRM research could be fragmented and ineffective.

Researcher Self-Governance

Decisions about SRM research are made internally by SRM researchers and funders. Methods of decision-making vary depending upon the actor. Regulations, requirements, or standards are determined by the researchers and funders themselves. Most scientific disciplines have standards and codes of conduct of varying levels of formality and enforcement. However, these standards and codes could be insufficient or inapplicable to SRM research.

Who makes decisions?

Individual SRM researchers and their funders.

Whom do they represent?

The research community.

How do they make decisions?

Internal discussion and mandates in response to the interests of the researchers.

Independent Advisory Committees

Independent bodies of experts in SRM, climate, policy, social sciences, and other disciplines set standards and guidelines for SRM research, but may lack the ability to enforce them. These standards may include reporting or community engagement requirements, impact limits, high-level principles, or even informal moratoria. One example from another domain is the Presidential Commission for the Study of Bioethical Issues, which, from 2009 to 2017, advised the president on bioethical issues and issued recommendations and standards for researchers in the biological sciences.

Who makes decisions?

One or more advisory committees comprising experts may make recommendations, but their declarations typically lack the force of law or potential for enforcement.

Whom do they represent?

Expert communities, although they could be designed to represent a broader array of interests.

How do they make decisions?

Internal discussion, often in response to questions posed by their organizing or funding bodies.

Local & Regional Government

Local and regional (municipal, state, and inter-state) governmental bodies make decisions about research through democratic legislation, referendums, and community meetings. Regulations may include requirements for transparency and reporting, community engagement or participatory governance, or impact statements. This could require cooperation between municipal governments, state governments, and special community organizations or commissions created for specific projects. An example from another domain includes state commissions dedicated to siting radioactive waste storage facilities, which typically report to local government on the community's feelings toward proposed actions and issue recommendations based on their findings.

Who makes decisions?

Municipal and state governments and potentially specially organized groups local to SRM research sites.

Whom do they represent?

Constituents local to SRM research sites.

How do they make decisions?

Local government legislation, executive interpretation, and discussion in committees.

Federal Government

The federal government could set regulations and standards for SRM research through the legislative process and executive agencies. Federal regulations would work on a larger scale than local or regional government, setting approval procedures or other requirements and demanding adherence to certain high-level principles, impact limits, or moratoriums. An example from biotechnology policy, the US federal government's Coordinated Framework for Regulation of Biotechnology, guides sections of the United States Department of Agriculture, the Environmental Protection Agency, and the Food and Drug Administration in governing biotechnology research and deployment.

Who makes decisions?

In principle, the US Congress makes decisions and the Executive Branch (encompassing the Office of the President and executive agencies like the Departments of Energy, Health and Human Services, and Defense) implements them. In practice, administrators and commissions within the Executive Branch have significant flexibility in dealing with specific cases.

Whom do they represent?

The national public.

How do they make decisions?

Congressional legislation and executive interpretation.

International Negotiation

International actors could create a high-level SRM policy through negotiation and treaties, allowing international stakeholders to have a say in how and whether SRM research is conducted. The outcomes of such negotiations could include adherence to high-level principles or limitations and requirements for regulations and standard-setting at smaller scales of governance. For example, the United Nations Framework Convention on Climate Change organizes global efforts to address climate change, including hosting climate change summits and providing questions for the Intergovernmental Panel on Climate Change to be addressed in the IPCC's regular scientific reports.

Who makes decisions?

Representatives of different governments' agendas and interests.

Whom do they represent?

The international community.

How do they make decisions?

Negotiations within constraints set by participating governments.

We Want to Hear from You!

On the day of the forum, you will gather with dozens of other participants to learn more about SRM research and share your thoughts about various SRM methods and research directions. You will be asked whether you feel SRM research should proceed, and, if so, how SRM research should be funded and regulated. Your opinion is unique and valuable. During the forum, facilitators will ensure that everyone has a chance to share their thoughts and discuss how their values and priorities shape their perspectives on SRM research. Information collected during the forum will help scientists, politicians, and funding agencies better understand and respond to public perspectives and concerns about SRM research.

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