The National Academies of
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Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance

Report Release Briefing

Climate change impacts are increasing

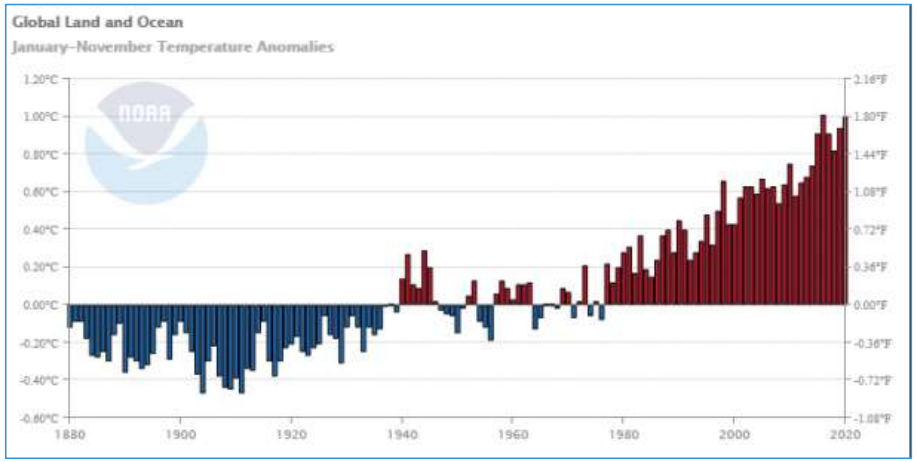
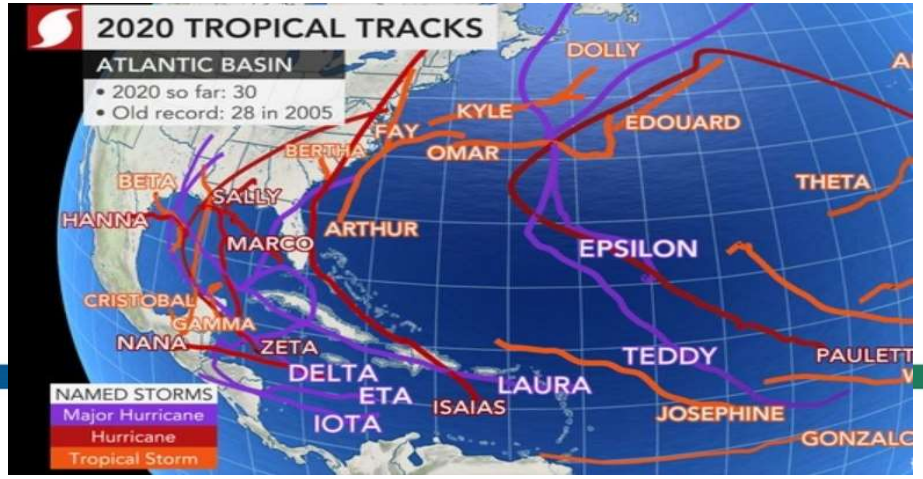


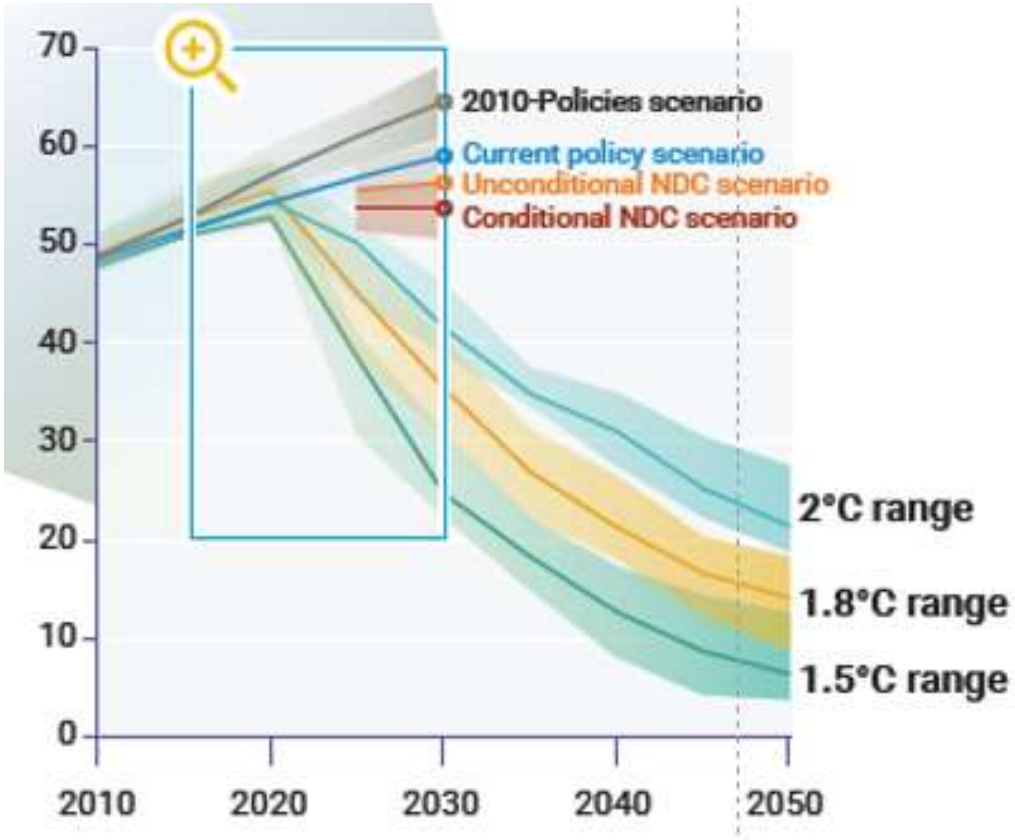
Photo from The Canadian Press

Photo By Noah Berger/AP



Credit: AccuWeather

Progress in responding to climate change is slow



UNEP Emissions Gap Report 2020

Interest and debate about geoengineering is growing

The New York Times

October 28, 2020

As Climate Disasters Pile Up, a Radical Proposal Gains Traction

The idea of modifying Earth's atmosphere to cool the planet, once seen as too risky to seriously consider, is attracting new money and attention.

Image from https://www.youtube.com/watch?v=cgJyw2cTrW4

Search | The Guardian | US edition

February 8, 2021

Balloon test flight plan under fire over solar geoengineering fears

Swedish environmental groups warn test flight could be first step towards the adoption of a potentially "dangerous, unpredictable, and unmanageable" technology

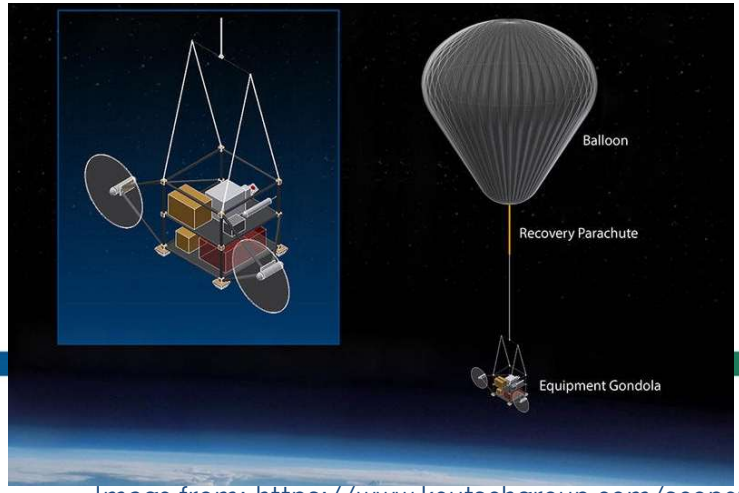
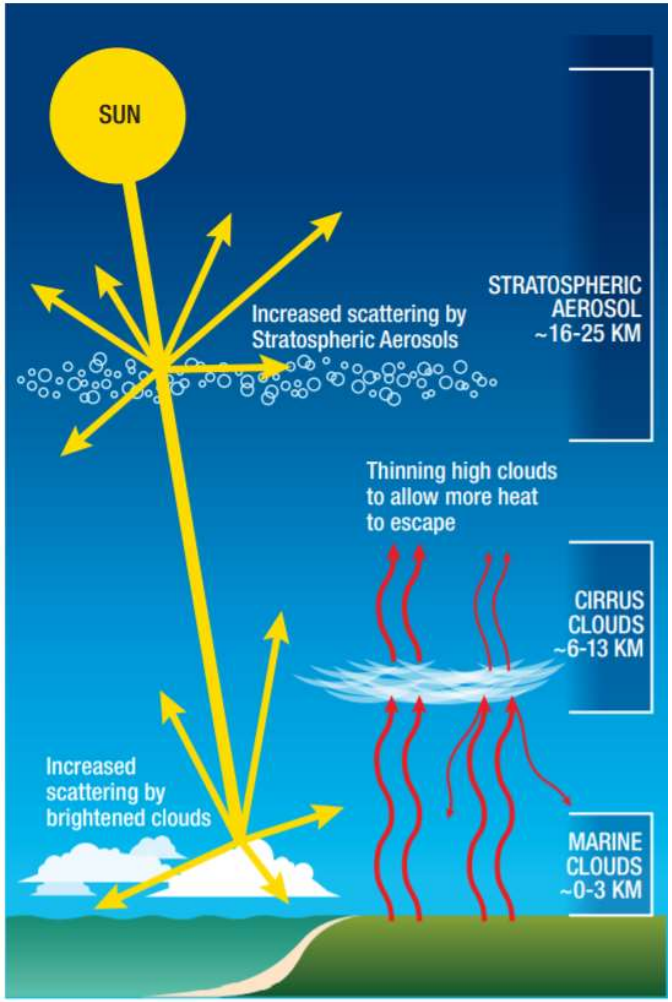


Image from: https://www.keutschgroup.com/scopex

Solar Geoengineering: attempts to moderate warming by increasing the amount of sunlight that the atmosphere reflects back to space or by reducing the trapping of outgoing thermal radiation

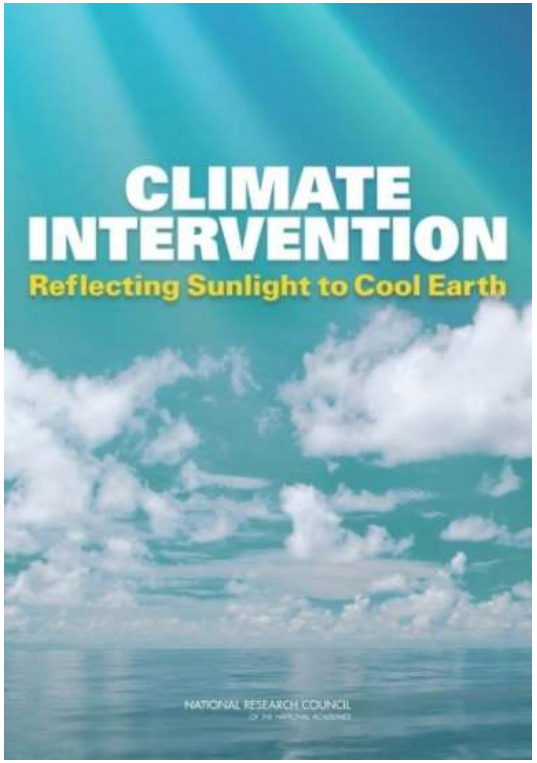


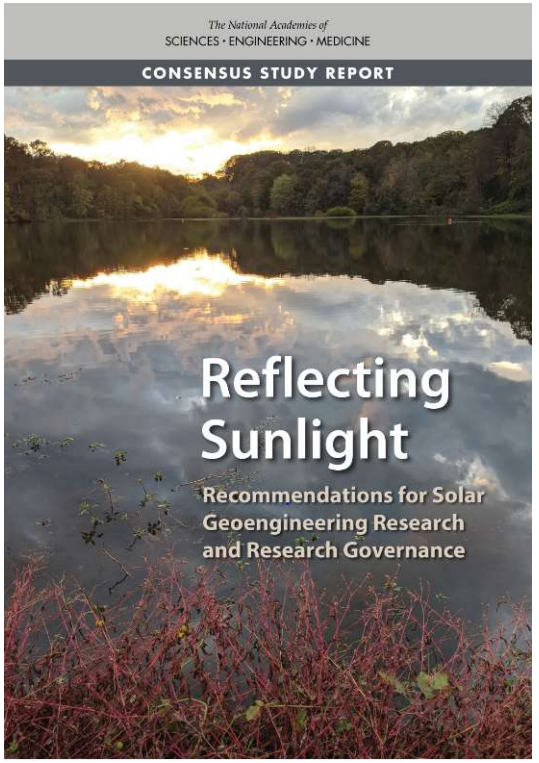
Stratospheric Aerosol Injection (SAI)

Cirrus Cloud Thinning (CCT)

Marine Cloud Brightening (MCB)

This report builds upon earlier Academies work





2015 2021

Charge to Study Committee

- Develop a **trans-disciplinary research agenda** for solar geoengineering that involves atmospheric interventions (marine cloud brightening, stratospheric aerosol injection, cirrus cloud modification).
- Consider the **potential impacts**, both positive and negative, of solar geoengineering on the atmosphere, climate system, natural and managed ecosystems, and human systems; and the technological feasibility of these interventions.
- Explore and recommend appropriate **governance mechanisms** for solar geoengineering research.
- Address solar geoengineering **research needs and relevant research governance in tandem**, such that the understanding and thinking on each can inform the other.

Study Sponsors

John D. and Catherine T. MacArthur Foundation

BAND Foundation *(impacts and risks on global ecosystems)*

Christopher Reynolds Foundation *(research governance mechanisms)*

V. Kann Rasmussen Foundation *(research governance mechanisms)*

National Aeronautics and Space Administration *(research agenda)*

Department of Energy *(research agenda)*

National Oceanic and Atmospheric Administration *(research agenda)*

National Academy of Sciences' Arthur L. Day Fund

Committee Members

Chris Field, Stanford University [Chair]

William Cheung, University of British Columbia

Lisa Dilling, University of Colorado

Peter Frumhoff, Union of Concerned Scientists

Hank Greely, Stanford Law School

Marion Hourdequin, Colorado College

Jim Hurrell, Colorado State University

Andrew Light, George Mason University
[until Jan. 2021]

Albert Lin, Univ. California, Davis School of Law

Douglas MacMartin, Cornell University

Robert McHenry, Bright Silicon Technologies

Juan Moreno-Cruz, University of Waterloo

Katharine Ricke, University of California, San Diego

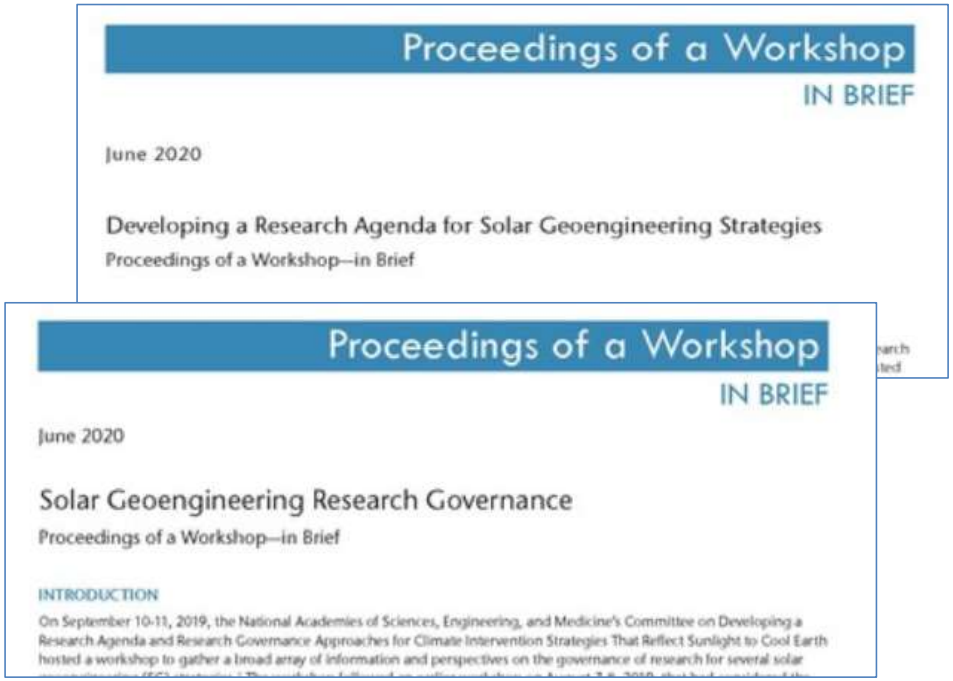
Lynn Russell, Scripps Institution of Oceanography

Ambuj Sagar, Indian Institute of Technology, Delhi

Paul Wennberg, CA Institute of Technology

Study process

- Builds on 2015 National Academies report
- Literature review
- Input from diverse voices in the United States and internationally
- Workshops on research needs and research governance
- Extensive committee deliberations
- Rigorous peer review



Key Messages

- Given the urgent, growing risks of climate change, it is important to understand the feasibility, risks, and benefits of solar geoengineering as a possible addition to the portfolio of response strategies.
- Solar geoengineering is not a substitute for reducing greenhouse gas emissions.
- The current state of understanding of solar geoengineering is not sufficient for supporting informed decisions.
- The U.S. should establish—in coordination with other countries—a transdisciplinary solar geoengineering research program. The U.S. Global Change Research Program should provide coordination and oversight for this program.
- Solar geoengineering research should operate under robust research governance.

Given the urgent, growing risks of climate change, it is important to understand the feasibility, risks, benefits of all possible response options.

Solar geoengineering is a potential additional strategy for responding to climate change, but is not a substitute for other efforts, because it:

- does not address the root cause of climate change
- raises concerns about new risks, uncertainties, and unintended impacts
- cannot provide a reliable means to restore global or regional climate to some desired prior state
- could entail unacceptable risk of catastrophically-rapid warming if interventions are suddenly terminated

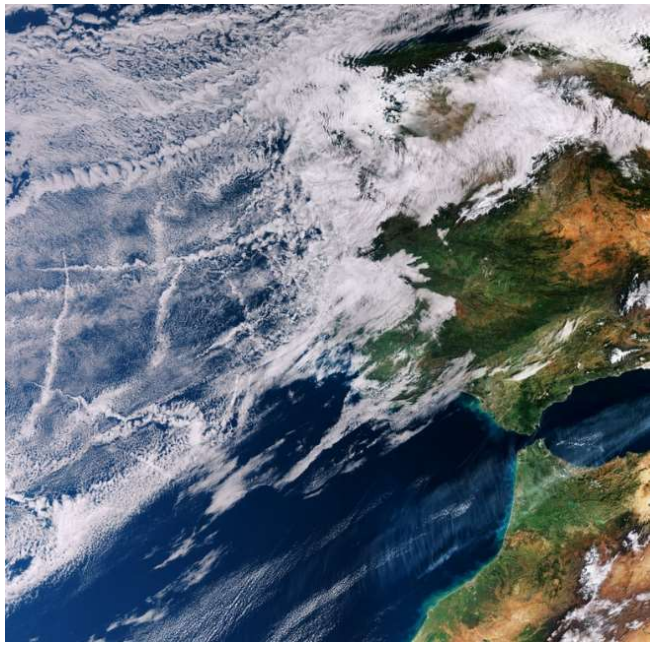
Stratospheric Aerosol Injection (SAI)

- Modeling and observational evidence (from volcanoes) suggest SAI can induce cooling on a global scale
- Limited understanding of how cooling potential varies with injection amount, location, and type; and regarding effects of injected aerosols on atmospheric chemistry and transport
- Large uncertainties in climate response and resulting impacts

Earth's horizon at sunset before and after the Mt. Pinatubo eruption (note the added aerosol layers)

Marine Cloud Brightening (MCB)

- There is strong evidence that adding aerosols to marine clouds can increase cloud reflectivity in some circumstances (as observed with ship tracks). But there are large uncertainties regarding where and by how much clouds can actually be modified.
- Key aerosol/cloud processes occur at scales too small to include in global climate models, thus is difficult to develop reliable projections of climate impacts.



Satellite images of ship tracks over the Atlantic Ocean

Cirrus Cloud Thinning (CCT)

- Efficacy is currently unknown due to very limited understanding of cirrus cloud properties and the microphysical processes determining how cirrus may be altered.
- Existing climate model simulations of CCT have yielded contradictory results.

Typical cirrus clouds

Conclusions: Cross-disciplinary Research

Integration across physical, social, and ethical research dimensions is needed.

Research to understand the magnitude and distribution of **environmental and societal impacts is in a nascent state.**

Tea pickers in Kenya's Mount Kenya region. Photo credit: Neil Palmer (CIAT).

Conclusions: Current Research Landscape

At present, **the state of understanding is limited and fragmented**, with substantial knowledge gaps and uncertainties in critical areas.

Studies to date **do not provide a sufficient basis for supporting informed decisions.**

Conclusions: Research Governance Landscape

There is currently **no coordinated or systematic governance of solar geoengineering research.**

Some legal mechanisms developed for other contexts could apply to some aspects of this research, but these focus on concerns about physical impacts.

Conclusions: Research to Reduce Uncertainties

Principal goal of an SG research program: **to better characterize and reduce uncertainties concerning benefits and risks of SG deployment**, to help inform decision makers.

But there are **limits on the level of uncertainty reduction that can be expected.** It is possible that additional research may expand some uncertainties or reveal new uncertainties.

Conclusions: Principles of Research

It is important to have a research program that is **transdisciplinary, international, and diverse in the disciplines, researchers, countries, and perspectives represented.** Research governance strategies are needed to **build trust and legitimacy.**

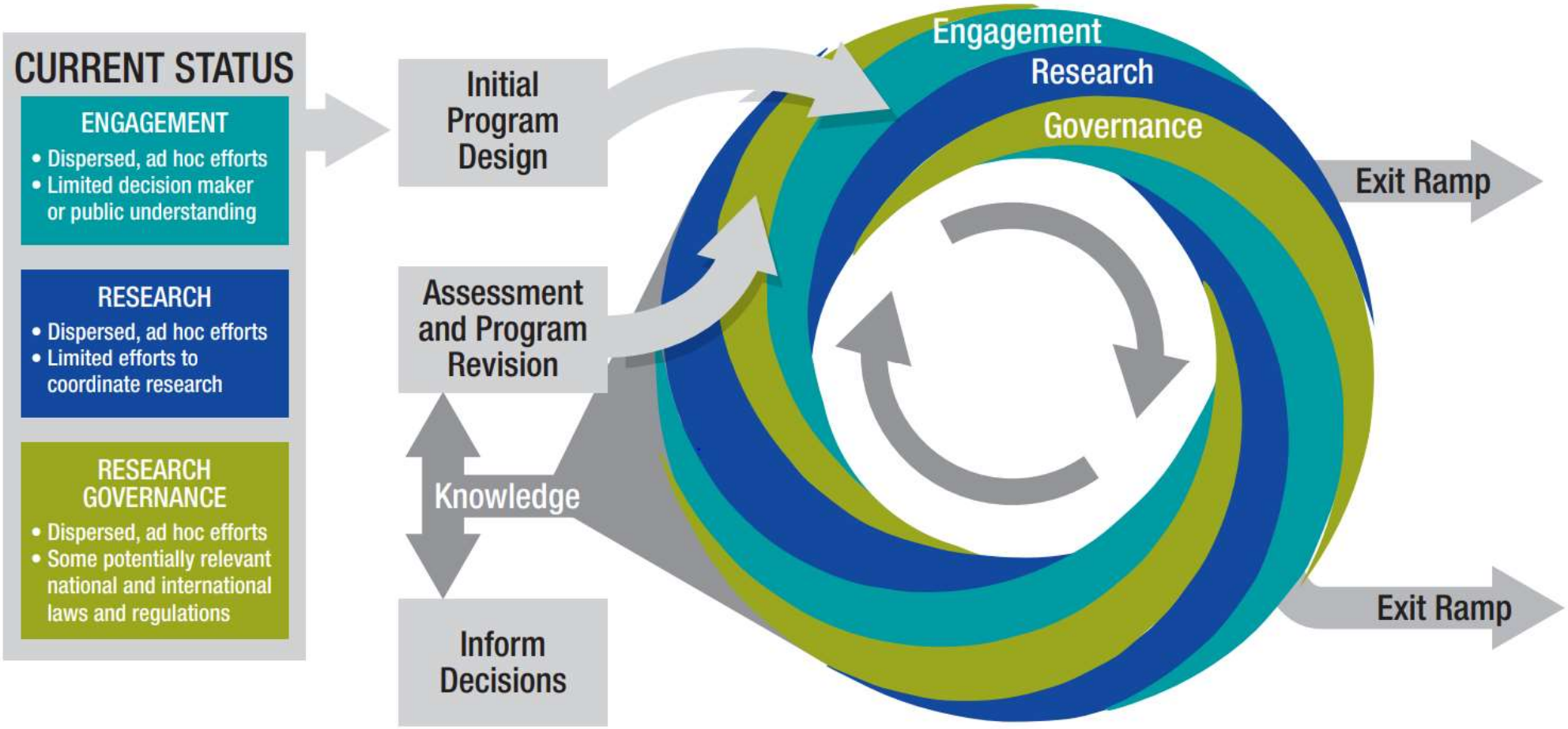
A national SG research program could provide great value to decision makers, but also brings potential risks (e.g., mitigation deterrence, slippery slope towards deployment). **A well-designed program can enhance these benefits and reduce these risks.**

Research, technology development, and governance are often path dependent. Commitments to key principles in early program design will facilitate implementation of these principles going forward.

Recommendation: Implement a Research Program

The U.S. should implement a robust portfolio of climate mitigation and adaptation. In addition, given the urgency of climate change concerns and the need for a full understanding of possible response options, **the U.S. should establish—in coordination with other countries—a transdisciplinary, SG research program.**

This program should be a minor part of the overall U.S. research program related to responding to climate change, and **it should focus on developing policy-relevant knowledge, rather than advancing a path for deployment.**


CURRENT STATUS
ENGAGEMENT
• Dispersed, ad hoc efforts
• Limited decision maker or public understanding
RESEARCH
• Dispersed, ad hoc efforts
• Limited efforts to coordinate research
RESEARCH GOVERNANCE
• Dispersed, ad hoc efforts
• Some potentially relevant national and international laws and regulations
Initial Program Design
Assessment and Program Revision
Knowledge
Inform Decisions
Engagement
Research
Governance
Exit Ramp
Exit Ramp

Recommendation: USGCRP Coordination and Oversight

The U.S. Global Change Research Program should be tasked to provide coordination and transparent oversight of the research program, by, for example:

- Coordinating across federal agencies
- Fostering interdisciplinary and transdisciplinary knowledge
- Maintaining an active database of solar geoengineering research activities
- Ensuring rigorous peer-review
- Periodically assessing progress and refining program goals and research priorities
- Advancing public engagement within and beyond the U.S. and pathways for this engagement to help inform and shape the research program

Recommendations: Research Governance

A U.S. national research program should operate under robust research governance and support the eventual development or designation of international governance mechanisms.

- Code of Conduct
- Registry
- Data Sharing
- Assessments and Reviews
- Permitting
- Intellectual Property
- Participation and Stakeholder Engagement
- International Cooperation and Co-development on Research Teams
- International Cooperation Among National Scientific Agencies
- International Information Sharing and Cooperation
- International Anticipatory Governance Expert Committee

Recommendation: Code of Conduct

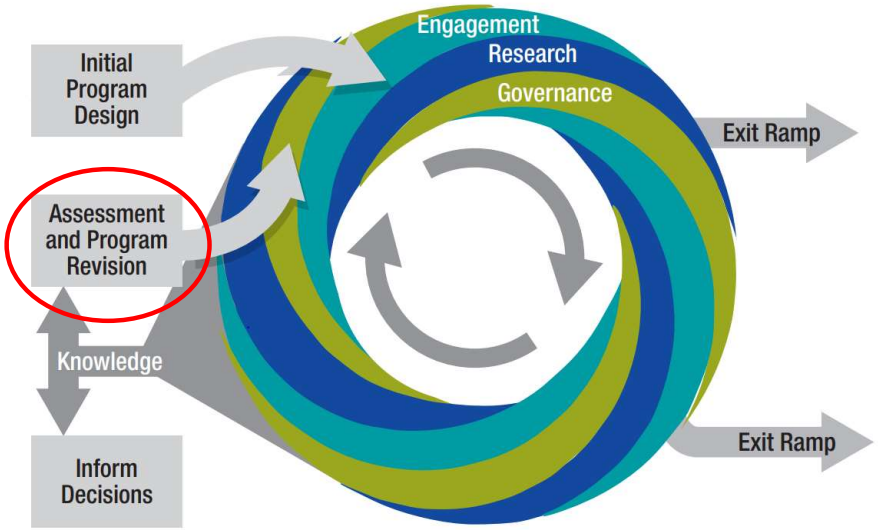
Funders of solar geoengineering research should mandate that researchers adhere to a code of conduct that includes the following elements:

- Protect the scientific quality of proposed research
- Assess, monitor, and minimize potential adverse effects from research
- Avoid atmospheric experiments with detectable climate or other environmental effects
- Accept research funding only from funding entities that recognize the importance of an overall balance of resources that prioritize mitigation and adaptation
- Make public research activities, funding sources, and results
- Identify and limit conflicts of interest
- Provide for suitable levels of public and stakeholder participation and engagement
- Actively support and advance the goals of racial, gender, geographic, and economic equity in the conduct of SG research

Recommendation: Program Assessment and Review

Any country engaged in solar geoengineering research should:

- **establish a standing advisory body** to recommend policies and practices on research and research governance.
- **prepare regular programmatic assessments** that collectively assess the health, environmental, and social impacts of all solar geoengineering research activities that it sponsors or approves and any research program it adopts.



Recommendation: Promotion of International Cooperation & Co-development on Research Teams

Funders of solar geoengineering research should promote international cooperation—including with participants from the Global South—within research teams by:

- giving **priority to research efforts that include substantial international membership or institutional cooperation** or,
- in some cases, **requiring such cooperation and co-development as a condition for support.**

Researchers in the field at the 5th International Conference on Community Based Adaptation to Climate Change (CBA 5). Photo credit: N.A. Omolo

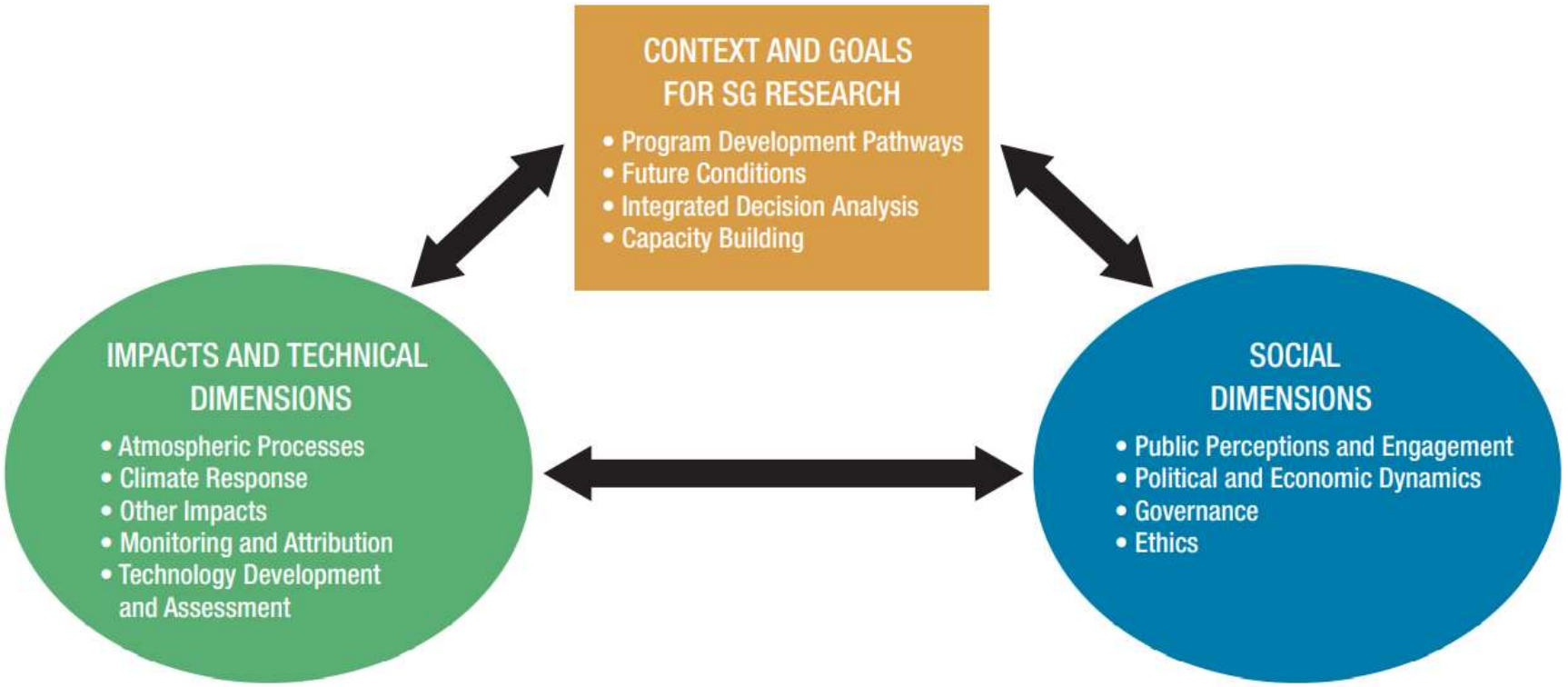
Recommendations: Outdoor Experimentation

Experiments that involve releasing substances into the atmosphere should be considered only when they can provide critical observations not already available or likely to become available through laboratory studies, modeling, and experiments of opportunity (e.g., observing volcanic eruptions, rocket plumes, ship tracks).

All outdoor experiments involving the release of substances into the atmosphere **should be subject to governance**, including a permitting system, impact assessment, and public engagement.

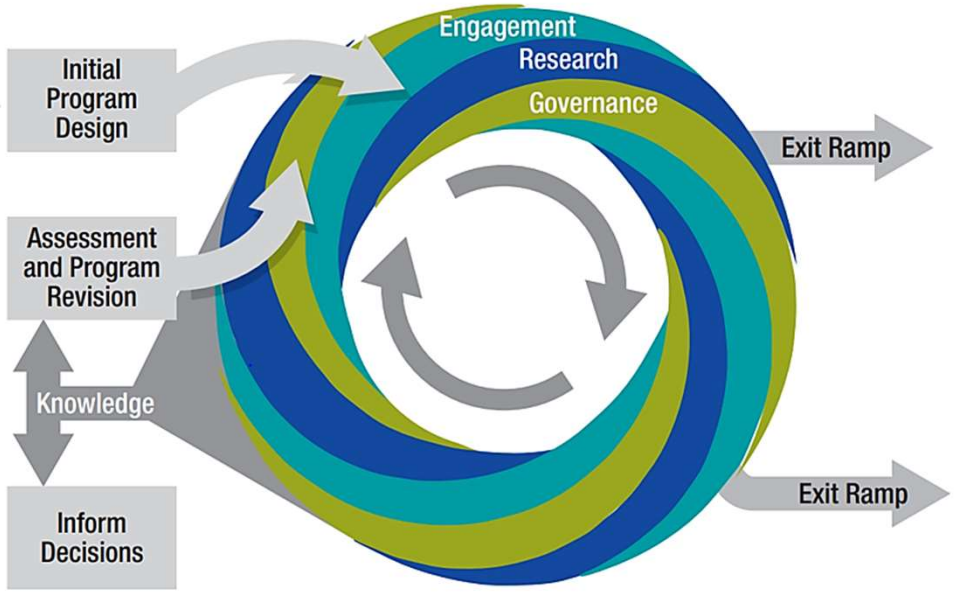
Any outdoor substance releases should be **limited to a quantity of material at least two orders of magnitude smaller than that which could cause detectable changes** in global mean temperature or adverse environmental effects.

Recommendation: Integrated Research Agenda



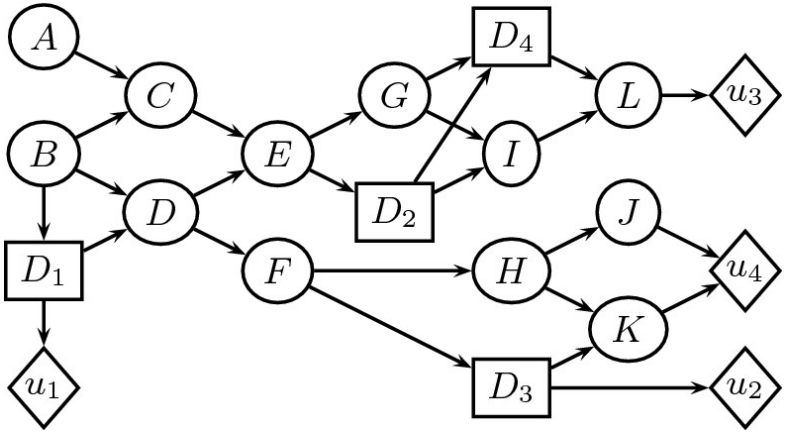
An Integrated Research Agenda

Program Development Pathways. *Designing a research program to maximize the prospects for broadly beneficial outcomes*.



An Integrated Research Agenda

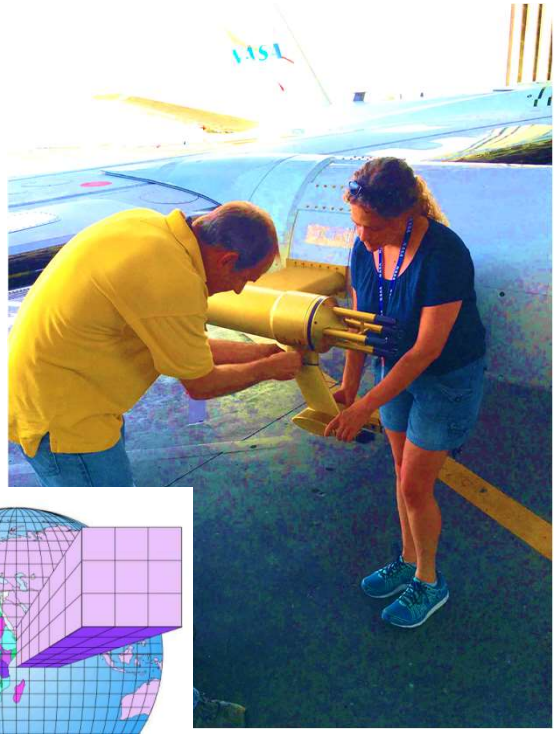
Integrated Decision Analysis.
Understanding implications of, and strategies to address, persistent uncertainties that affect decision making related to solar geoengineering.



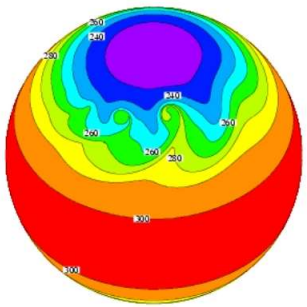
Source: Madsen et al 2019

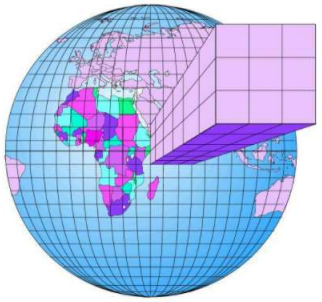
An Integrated Research Agenda

Atmospheric Processes. *Understanding chemical and physical mechanisms that determine how addition of materials to the atmosphere alters the reflection and transmission of atmospheric radiation.*



source: Susan Kimi McFadden





Source: http://clasp-research.engin.umich.edu/groups/admg/education.php

An Integrated Research Agenda

Other Impacts. *Assessing the potential environmental and societal impacts of solar geoengineering strategies.*

source: Claire Benjamin/RIPE project

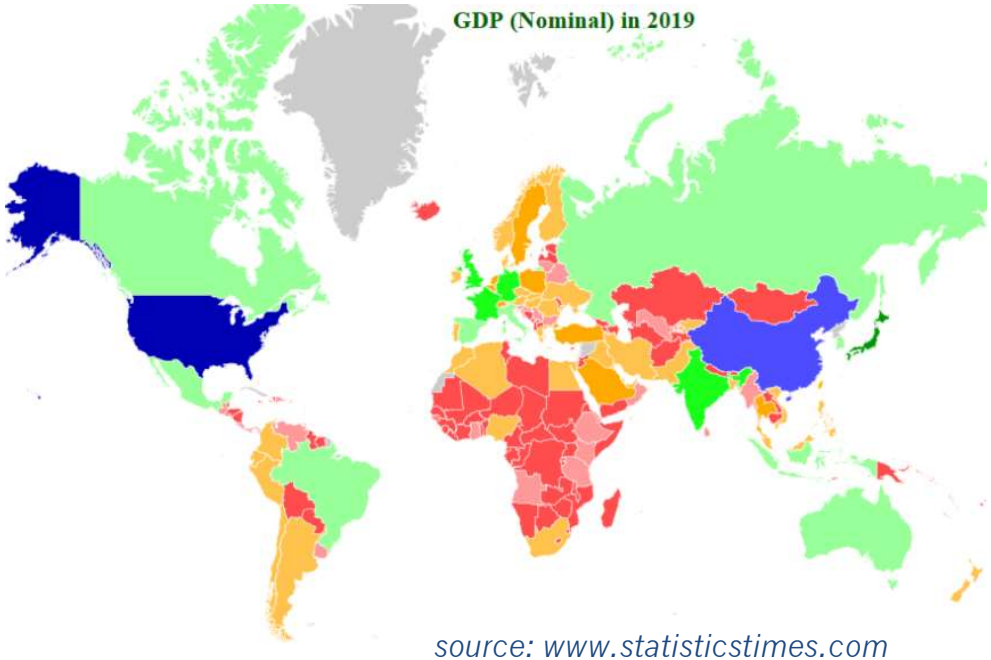
source: Getty

An Integrated Research Agenda

Public Perceptions and Engagement.
Understanding public perceptions of solar geoengineering and advancing strategies for inclusive, meaningful societal engagement.

An Integrated Research Agenda

Ethics. *Incorporating ethics and justice considerations for current and future generations into solar geoengineering research and research governance.*

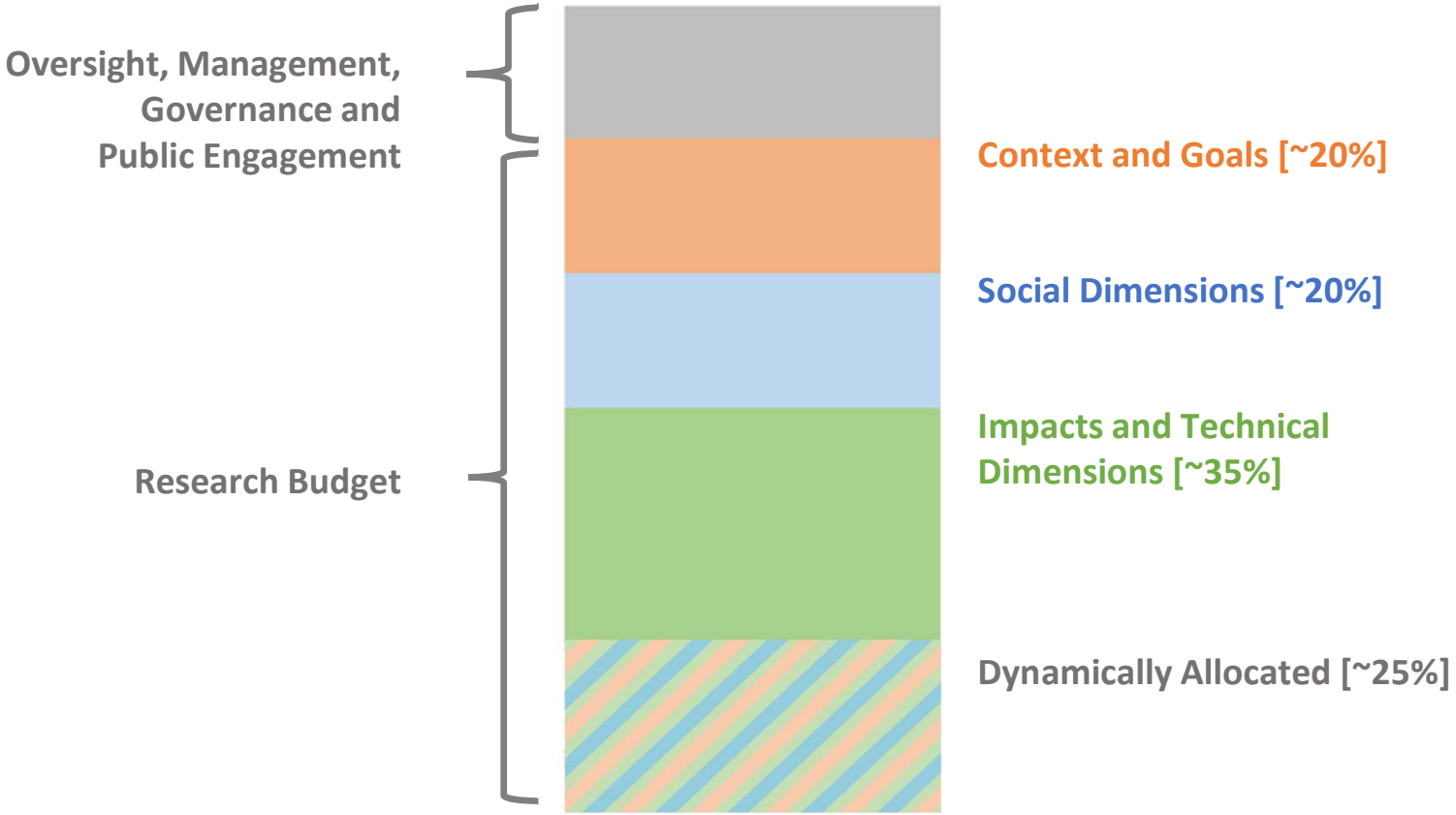


source: www.statisticstimes.com

Research program budget guidelines

- Solar geoengineering funding should **not shift the focus from other important global climate change research, nor exacerbate concerns about a slippery slope towards deployment**: the near-term budget should be small relative to total global change research budget, on the order of $100-200 million over the first 5 years.
- The program should **support equitably all of the research clusters from the outset**.
- The budget should be able to **accommodate major field campaigns**.
- A substantial fraction of the research program should be **dynamically allocated** to allow the program to adapt as learning proceeds.
- Research funding should be accompanied by **support for implementing research governance and public engagement**.

Illustrative Budget Allocation



Concluding Thoughts

- Ultimately, the goal is to find an appropriate balance and interplay among all of the strategies for responding to climate change, not to study solar geoengineering in isolation.
- These are recommendations for an initial exploratory phase of a research program. Over the longer term, the program might be continued or expand, or it may shrink, with some or all elements eventually terminated.
- This program aims to assess not only the *technical feasibility* but also the *social feasibility* of solar geoengineering. The recommended research governance and engagement efforts will help enable the program to proceed in a societally responsive and acceptable manner.
- This research program could indicate that solar geoengineering should not be considered further or that it warrants additional effort.

Thank you!

The report is available at nap.edu
(pdf is free to download)

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