A Reflectivity Plan – Stratospheric Aerosol Injection

Spending Billions of Dollars to Save Trillions…

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Preface

If we solved the global warming problem with Stratospheric Aerosol Injection (SAI), what would need to be done between now and full-scale operations, possibly 15 years from now? The answer to this question might be referred to as an "SAI Reflectivity Plan." Yet what might that look like? This document is an example plan. Also, it is open-source; therefore, it can be used in any way or modified for free.

SAI Reflectivity Plan

This plan describes a staged path for researching and potentially deploying a system that reflects a small fraction of incoming sunlight to offset global warming. The concept uses aircraft to move a limited amount of sulfur from ground-level emissions into the upper atmosphere, where it would remain aloft longer and reflect more sunlight. The plan does not assume immediate full-scale deployment. It proceeds through research, low-level operations, construction, and continuous monitoring.

The program is organized into three phases of approximately five years each. Phase I develops the scientific evidence and equipment. Phase II begins carefully controlled operations at small but increasing scales. Phase III constructs the fleet and infrastructure needed to reach full scale. Full-scale operations would follow only if the preceding phases demonstrate acceptable performance, manageable risks, and sufficient international authorization.

Phase I – Research and Development

Phase I establishes the scientific, engineering, and operational foundation for the entire program. It has two major workstreams: atmospheric experiments and development of large-scale sulfur-handling and aircraft systems.

1. SAI Atmospheric Experiments

Two principal experiment types would be developed and conducted:

- Mist experiments. Aircraft release a sulfur-based mist (e.g. H_2SO_4 aerosol) that is monitored for several hours.
- Gas experiments. Aircraft release a sulfur-based gas (SO_2) that is monitored for days to weeks as it disperses and changes chemically.

The experiments would measure how much sunlight is reflected, how the released material changes over time, how it spreads, and whether unexpected effects appear. This requires specialized release equipment, aircraft-mounted instruments, ground stations, satellite observations, atmospheric sampling systems, and data-analysis software.

2. Large-Scale Automated SAI Equipment Development

In parallel, engineers would develop the equipment needed for eventual large-scale operations. Full-scale operations would require large aircraft delivering roughly one hundred tons of sulfur gas into the upper atmosphere every several hours. Achieving this at reasonable cost could require automation of flying, refueling, reloading, and material handling.

A representative prototype would modify a large commercial aircraft, such as a Boeing 777, with a sulfur tank in the lower fuselage and a delivery pipe running toward the tail. The purpose of the first aircraft is not to begin deployment; it is to establish whether the aircraft, storage, transfer, release, and automation systems can be made safe, reliable, and economical before considering a fleet that might eventually include approximately one hundred aircraft.

Budget

We assume a budget of approximately $1 billion for experiments and approximately $1 billion for large-scale equipment development, spread over several years. This would represent a major increase over prior research funding.

Phase I Decision Gate

Proceed to Phase II only if Phase I experiments show that the material can be released, tracked, modeled, and monitored; prototype systems can operate safely; and the expected climate benefit appears large enough to justify controlled experimental operations.

Phase II – Experimental SAI Operations

Phase II begins limited reflectivity operations while maintaining an explicitly experimental posture. The objective is to learn how the system behaves at scales large enough to produce measurable effects but still small enough to reduce or stop quickly if adverse effects appear.

Controlled Scale-Up

The illustrative ramp begins at approximately one-thousandth of full scale, or 0.1%, and increases over several years to approximately one-tenth of full scale, or 10%. Each increase would occur only after review of the preceding operating period.

At every stage, the program would evaluate:

- Measured sunlight reflection and climate response.
- Atmospheric transport, chemical transformation, and persistence.
- Potential side effects and indicators of environmental harm.
- Aircraft reliability, sulfur handling, operating cost, and monitoring performance.
- Agreement between observations and global climate models.

Full-Scale Reference Point

For planning purposes, we use a rough full-scale objective of reflecting approximately 1% of sunlight. This might involve moving approximately 10% of sulfur that would otherwise be emitted near ground level, to a high altitude. These figures are reference assumptions to be tested and revised, not fixed targets.

Transparency and Review

Monitoring results should be shared broadly and quickly. Independent scientists and participating governments should be able to inspect the data, reproduce analyses, and compare the effects of reflecting with the effects of not reflecting. Transparent review is necessary both to detect harm and to reduce international conflict.

Phase II Decision Gate

Advance toward Phase III Construction only if measured effects remain consistent with acceptable environmental performance, monitoring systems are credible, operating procedures are controllable, and participating governments agree on the next scale increase.

Phase III – SAI Construction and Scale-Up

Phase III builds the physical system required to move from approximately 10% of full scale to 100%. It converts the experimental program into an operational capability while retaining the same monitoring, review, and stop mechanisms developed in the earlier phases.

Construction Program

The construction program would include:

- A fleet of specialized or modified aircraft.
- Airport and ground-support infrastructure.
- Sulfur processing, transport, transfer, storage, and loading systems.
- Automated refueling, reloading, dispatch, and flight-control systems where appropriate.
- Global monitoring networks using land instruments, satellites, and aircraft sampling.
- Data systems, operating centers, maintenance facilities, and international oversight mechanisms.

Ramp to Full Scale

The scale-up would proceed from roughly 10% to 100% over approximately five years. Construction and operations would overlap: early aircraft and infrastructure would support continued measurement while later units are built. The target scale and operating pattern would be adjusted as evidence improves.

Full-Scale Operations

After the three phases, full-scale operations would continue only while authorized by the governments involved and while monitoring indicates that the benefits exceed the harms. The system must remain capable of reducing output or stopping. If operations stop, the cooling effect would diminish and the underlying warming trend would resume; therefore, termination planning must be treated as part of system design rather than an afterthought.

Phase III Decision Gate

Enter full-scale operations, after Phase III, only when the aircraft fleet, ground infrastructure, monitoring network, governance structure, emergency procedures, and international agreements have all been demonstrated at intermediate scale.

Risks

SAI entails three primary risks:

- **Harm Risk** refers to the possibility that we detect harm as we build up SAI, and need to stop.
- **Conflict Risk** refers to the possibility that nations fight over SAI in some way.
- **Timing Risk** refers to the possibility that we do not complete the three Phases in the needed time.
- **Termination Risk** refers to the possibility that reflecting is stopped after greenhouse-gas concentrations have increased substantially, causing a rapid surge in warming.

These risks are interdependent. Harm can create Conflict; Conflict can delay the program; delay can increase pressure for a rushed deployment; and a long-running program can create Termination Risk if it later stops abruptly. The plan therefore treats risk management as a continuous activity across all three phases and during any subsequent full-scale operations.

Harm Risk

Harm Risk refers to the possibility that reflectivity operations create unacceptable environmental, climatic, or health effects and must be reduced or stopped. Moving sulfur to the upper atmosphere has not been performed at the proposed scale, so calculations and climate models must be tested against observations.

Potential harms should be identified in advance, quantified where possible, and compared with the harms expected from continued warming without reflectivity. Monitoring would combine land-based instruments, satellite observations, and direct air sampling from aircraft.

Phases I and II are intentionally small relative to full scale so that unexpected effects can be detected before large infrastructure is committed. The program should maintain the ability to pause, reduce, or terminate operations at every stage.

Conflict Risk

Conflict Risk refers to the possibility that nations disagree over whether, where, how much, or how long to reflect sunlight. Large national governments would control the principal budgets, regulations,

airspace, and security resources. Some countries might favor deployment while others oppose it, particularly if regional effects or political interests differ.

The best available safeguards are transparency, shared monitoring data, independent scientific review, multinational decision-making, and explicit comparison of the consequences of reflecting with the consequences of not reflecting. Governance arrangements should be developed during Phase I and tested during Phase II rather than postponed until construction begins.

Timing Risk

Timing Risk refers to the possibility that the three phases are not completed before climate impacts become severe enough to trigger panic or unilateral action. The illustrative schedule is approximately five years per phase, or fifteen years total. If ocean circulation, river flows, food production, or other systems deteriorate faster than expected, governments may attempt to compress the schedule and accept greater risk.

The timing risk can be reduced by starting research early, improving global climate models, funding multiple technical teams in parallel, setting clear decision gates, and preparing contingency plans for accelerated but still monitored operations. The purpose of early work is not to predetermine deployment; it is to ensure that future leaders have tested options and credible data rather than being forced to improvise during a crisis.

Termination Risk

Termination Risk refers to the possibility that a long-running reflectivity program stops after greenhouse-gas concentrations have risen substantially, causing rapid warming over a short period.

The average global temperature increases roughly 0.3° Celsius every ten years (0.3°C/decade), and this is referred to as the “global warming rate.” In theory, reflecting sunlight could reduce this to zero.

If this reflecting was done for ten years and then stopped, the 0.3°C/decade warming rate would return, in addition to a small short-term surge—for example, approximately 0.45°C/decade during the first decade after cessation.

However, if reflecting occurred for 200 years and then stopped, the new global warming rate could be on the order of 3.0°C/decade during the first decade after cessation, followed by 1.5°C/decade during the second decade. This assumes the atmospheric CO_2 concentration had built up to 1,200 ppm while reflecting.

This surge in warming is referred to as “termination shock,” and it is bad.

Getting Started

To fund SAI Phase I, consider presenting it as part of an effort to "solve the entire climate problem via an R&D surge." One might refer to this as a "climate moonshot." For a summary, see the following video:

Do We Need a $10B Climate Moonshot? [#20]
https://www.youtube.com/watch?v=ihTGiOEKrns

To get this started, consider producing a conference or a film, an example of which is below.

The Climate Kids (docudrama film draft manuscript draft)
https://www.ma2life.org/g/film/The_Climate_Kids.pdf

Climate Moonshot Conference (3-page draft)
https://www.ma2life.org/g/moonshot/Climate_Moonshot_Conference.pdf

Who might oversee a large research initiative such as SAI? Is it possible to set up a new laboratory and task it with solving the entire climate problem? The following document explores this question.

Do We Need a New Climate Laboratory?
https://www.ma2life.org/g/film/Do_We_Need_a_New_Lab.pdf

SAI Videos

The following videos summarize Stratospheric Aerosol Injection (SAI):

Reflecting Sunlight [#9]
https://www.youtube.com/watch?v=AJ-ddFDiA4w

Can Air Pollution Save the Planet? [#10]
https://www.youtube.com/watch?v=p4O2hv9t

The Science of Global Warming [#7]
https://www.youtube.com/watch?v=Por9aWKLdc4

SAI Research Funds

The following documents describe SAI Phase I R&D in more detail:

SAI Research Experiments $1B Fund

https://www.ma2life.org/g/film/sai_experiments_research_fund_ai.pdf *pdf file*

https://drive.google.com/drive/folders/1KRtdfFEjKmzV5XaxiyzRL4JckPzrF_sM *original files*

SAI Equipment Development $1B Fund

https://www.ma2life.org/g/film/sai_equipment_development_fund_ai.pdf *pdf file*

https://drive.google.com/drive/folders/1B0Sko2M2cl_V-_uZcPozD-s0cF8bjV-_ *original files*

AI Support

To discuss climate moonshot with artificial intelligence (AI), consider feeding the following PDF files to AI.

Climate Moonshot PDF Files
https://www.aplantosavetheplanet.org/pdf-ai

Further Reading

Is it possible to solve the climate problem with a surge of R&D in key areas; and if so, what are those areas and how much might this cost? The following documents hope to answer this question.

Stratospheric Aerosol Injection (SAI)

SAI Reflectivity Plan (7-page PDF)

https://www.ma2life.org/g/film/SAI_Reflectivity_Plan.pdf *pdf file*

https://drive.google.com/drive/folders/1Jf8jmP38b2P-vj9XTWRLGGMuahuLwxB6 *original files*

Proposed $1B SAI Experimental Research Fund

https://www.ma2life.org/g/film/sai_experiments_research_fund_ai.pdf *pdf file*

https://drive.google.com/drive/folders/1KRtdfFEjKmzV5XaxiyzRL4JckPzrF_sM *original files*

Proposed $1B SAI Equipment Development Fund

https://www.ma2life.org/g/film/sai_equipment_development_fund_ai.pdf *pdf file*

https://drive.google.com/drive/folders/1B0Sko2M2cl_V-_uZcPozD-s0cF8bjV-_ *original files*

Stratospheric Aerosol Injection Field Experiments (description)

https://ma2life.org/g/eet/eetcs_plan/decarb_plan/arctic_sai_experiment.pdf

Marine Cloud Brightening (MCB)

MCB Reflectivity Plan (7-page PDF)

https://www.ma2life.org/g/film/MCB_Reflectivity_Plan.pdf *pdf file*

https://drive.google.com/drive/folders/1Aoz9vLxKLF4qBw1xnjlCfYGXERhTY3rI *original files*

Proposed $1B MCB Experimental Research Fund

https://www.ma2life.org/g/film/mcb_experiments_research_fund_ai.pdf *pdf file*

https://drive.google.com/drive/folders/1ItaJh7OQMeZMInUkArcShi-SGVFmzvD0 *original files*

Proposed $1B MCB Equipment Development Fund

https://www.ma2life.org/g/film/mcb_equipment_development_fund_ai.pdf *pdf file*

https://drive.google.com/drive/folders/1Leivbra4GXj5VlPg_jFZfPN1UQyHgR-S *original files*

Climate Moonshot Business Plan

Climate Moonshot Business Plan (90-page PDF)

https://www.aplantosavetheplanet.org/bp *pdf file*

https://www.aplantosavetheplanet.org/lab *original files*

Links to Climate Moonshot PDF Files That Can be Fed to AI (open-source)
https://www.aplantosavetheplanet.org/pdf-ai

Climate Moonshot Videos

What are the big ideas for solving the entire climate problem? (#19…#21)
https://www.aplantosavetheplanet.org/biv

Decarbonization R&D Videos (#2, #11 to #16)

https://www.aplantosavetheplanet.org/drd

Reflecting Sunlight Videos (#6 to #10)

https://www.aplantosavetheplanet.org/rsv

Climate Moonshot Conference

Climate Moonshot Conference (3-page PDF)

https://www.ma2life.org/g/moonshot/Climate_Moonshot_Conference.pdf

Climate Moonshot Filmmaking

The Climate Kids (docudrama film)

https://www.ma2life.org/g/film/The_Climate_Kids.pdf *pdf file*

https://drive.google.com/drive/folders/1UyEyyGock43PQpnMMcEmq_94gy4m3GHI *original files*

Scientific Research

Experiments that Measure How Much Sunlight Reflects off Aerosols

https://ma2life.org/g/eet/eetcs_plan/decarb_plan/measure_aerosol_reflection_experiment.pdf

$250M Cloud Research Surge (pdf)

https://ma2life.org/g/eet/eetcs_plan/decarb_plan/cloud_science_surge_ChatGPT.pdf

Proposed Ocean Iron Fertilization $25M Research Fund (pdf)

https://www.ma2life.org/g/film/ocean_iron_fertilization_ai.pdf *pdf file*

https://drive.google.com/drive/folders/12Rn4oc_1sUcttW1_UjKNRLJxFrv0sMj0 *original files*

$2B Atmospheric Research (400-page document)

https://ma2life.org/g/eet/eetcs_plan/decarb_plan/Atmospheric_Experiments.pdf *pdf file*

https://drive.google.com/drive/folders/1e5jvAmJUfBLCpkQVKwR0dS_Ur2UtFLkG *original files*

Geothermal Moonshot (e.g. high temperature vertical tunnel boring machine)

https://ma2life.org/g/eet/eetcs_plan/decarb_plan/geothermal_conversation.pdf