A Reflectivity Plan – Marine Cloud Brightening

Spending Billions of Dollars to Save Trillions…

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Preface

If we solved the global warming problem with Marine Cloud Brightening (MCB), 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 a "MCB 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.

MCB 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. Marine Cloud Brightening would generate very small sea-salt aerosol particles from seawater and release them into the marine boundary layer beneath or near suitable low marine clouds. Under favorable conditions, some particles would become cloud-condensation nuclei, increasing the number of cloud droplets and potentially making the clouds more reflective. The plan does not assume immediate full-scale deployment. It proceeds through research, low-level experimental 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: MCB experiments and development of automated large-scale MCB equipment. Each workstream would receive approximately $1 billion over five years.

1. MCB Atmospheric Experiments

Two principal experiment types would be developed and conducted:

- Source-and-plume experiments. Shore-based systems, ships, or autonomous platforms generate sea-salt aerosol from seawater. Instruments measure particle size, number, composition, transport, dilution, persistence, and the fraction of particles that can reach cloud base.
- Cloud-response experiments. Carefully limited releases occur beneath or near suitable low marine clouds. Researchers measure changes in cloud-droplet number and size, cloud brightness, liquid-water content, cloud cover, lifetime, drizzle, precipitation, and reflected sunlight.

The experiments would determine when MCB works, how strongly clouds respond, how long the response lasts, how the aerosol plume spreads, and whether unexpected effects appear. This requires aerosol generators, research ships, autonomous vessels, aircraft, drones, buoys, ground and

coastal stations, cloud radar and lidar, radiometers, direct aerosol and cloud sampling, satellite observations, weather forecasting, and data-analysis software. Experiments would begin at very small scales and expand only after independent review.

2. Large-Scale Automated MCB Equipment Development

In parallel, engineers would develop the equipment needed for eventual large-scale operations. A full-scale MCB system would likely require a distributed fleet of vessels or floating platforms operating in selected marine-cloud regions. Achieving this at reasonable cost could require automation of navigation, weather routing, seawater intake, filtration and conditioning, aerosol generation, plume placement, communications, maintenance, energy management, and resupply.

A representative prototype would be a ship or autonomous vessel equipped with a seawater-intake system, corrosion-resistant pumps and piping, filtration and conditioning equipment, one or more fine-spray aerosol generators, a mast or duct that releases particles above the vessel, meteorological instruments, remote controls, and redundant safety systems. The purpose of the first systems is not to begin deployment; it is to establish whether seawater handling, particle production, vessel operations, automation, and maintenance can be made safe, reliable, controllable, and economical before considering a large fleet.

Budget

We assume a Phase I budget of approximately $1 billion for MCB experiments over five years and approximately $1 billion for automated large-scale equipment development over five years. This would represent a major increase over prior MCB research and would allow multiple scientific and engineering teams to work in parallel.

Phase I Decision Gate

Proceed to Phase II only if Phase I experiments show that sea-salt aerosol can be generated with the required particle characteristics; released, tracked, modeled, and monitored; delivered to suitable clouds under defined conditions; and associated with a measurable and repeatable increase in reflected sunlight. Prototype systems must operate safely and reliably, and the expected climate benefit must appear large enough to justify controlled experimental operations.

Phase II - Experimental 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 regional 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 the reference full-scale aerosol-generation capacity, or 0.1%, and increases over several years to approximately one-tenth of full scale, or 10%. Because cloud susceptibility varies by location and weather, the program would define

scale using several measures: aerosol output, number of operating platforms, area and duration of treatment, and measured radiative effect. Each increase would occur only after review of the preceding operating period.

At every stage, the program would evaluate:

- Measured sunlight reflection, cloud response, and regional climate response.
- Aerosol size, number, composition, transport, dilution, and delivery to cloud base.
- Cloud-droplet properties, cloud brightness, cloud cover, lifetime, drizzle, and precipitation.
- Potential side effects, including changes in regional weather, ocean conditions, atmospheric chemistry, ecosystems, air quality, or visibility.
- Vessel reliability, aerosol-generator performance, energy use, maintenance burden, operating cost, and monitoring performance.
- Agreement between observations and cloud-resolving, regional, and global climate models.

Full-Scale Reference Point

For continuity with this planning exercise, we use a rough full-scale climate objective equivalent to reflecting approximately 1% of incoming sunlight. MCB would not brighten every marine cloud and would not operate uniformly across the oceans. It would focus on selected regions and weather conditions where low marine clouds are sufficiently extensive and susceptible to added sea-salt aerosol. The required fleet size, aerosol output, operating regions, and attainable climate effect 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, compare treated and untreated cloud regions, 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, equipment is reliable, and participating governments agree on the next scale increase.

Phase III - 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, modified, autonomous, or semi-autonomous vessels and floating platforms.
- Ports, coastal bases, maintenance yards, spare-parts inventories, and support vessels.
- Seawater-intake, filtration, conditioning, pumping, piping, and aerosol-generation systems.
- Power-generation, energy-storage, communications, navigation, weather-routing, and remote-control systems.
- Automated dispatch, operation, monitoring, shutdown, maintenance-diagnostic, and resupply systems where appropriate.
- Global and regional monitoring networks using land and coastal instruments, satellites, aircraft, ships, buoys, drones, and direct cloud sampling.
- Data systems, forecasting centers, 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 vessels and infrastructure would support continued measurement while later units are built. The target scale, operating regions, seasonal schedule, and spray 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, moving to different operating regions, pausing, or stopping. If operations stop, the brightening 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 vessel fleet, aerosol generators, port and support infrastructure, monitoring network, governance structure, emergency procedures, and international agreements have all been demonstrated at intermediate scale.

Risks

MCB entails three primary risks:

- **Harm Risk** refers to the possibility that we detect harm as we build up MCB, and need to stop.
- **Conflict Risk** refers to the possibility that nations fight over MCB 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, ecological, or health effects and must be reduced or stopped. MCB has not been performed at the proposed scale, and cloud responses can depend strongly on aerosol size, background pollution, cloud type, atmospheric stability, humidity, wind, and regional weather. Calculations and climate models must therefore 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 examine regional precipitation and circulation, cloud cover and lifetime, ocean-surface conditions, atmospheric chemistry, salt deposition, marine and coastal ecosystems, air quality, and other possible effects. It would combine land- and coastal-based instruments, satellite observations, ships, buoys, drones, aircraft, and direct aerosol and cloud sampling.

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, relocate, 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, ports, maritime zones, airspace, environmental permits, and security resources. Some countries might favor deployment while others oppose it, particularly if regional weather effects, fisheries, shipping, coastal interests, or political interests differ.

The best available safeguards are transparency, shared monitoring data, independent scientific review, multinational decision-making, early consultation with potentially affected regions, 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, sea level, extreme heat, 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 aerosol-cloud and global climate models, funding multiple scientific and equipment-development 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 MCB 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 MCB? 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

MCB Research Funds

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

MCB Research Experiments $1B 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*

MCB Equipment Development $1B 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*

Reflecting Sunlight Videos

The following videos summarize reflecting sunlight.

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

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.

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*

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

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