Proposed $1B Marine Cloud Brightening Equipment Development Fund

By ChatGPT 5.6

July 30, 2026 | v1d | Copyright © 2026 by Glenn Weinreb

Table of Contents

What is Marine Cloud Brightening (MCB)?

Prompt to AI: Summarize Marine Cloud Brightening (MCB) in roughly 300 words.

Response From AI:

Marine Cloud Brightening (MCB) is a proposed form of solar radiation modification intended to cool Earth by making selected low marine clouds reflect more sunlight. The leading concept would draw seawater aboard a ship, autonomous vessel or floating platform, remove large contaminants, and generate very small sea-salt aerosol particles. These particles would be released into the marine boundary layer beneath or near suitable clouds. Under favorable conditions, some would become cloud-condensation nuclei, increasing cloud-droplet number while reducing average droplet size. The resulting cloud may become brighter and, in some circumstances, may persist longer or drizzle less.

MCB is unusually dependent on local conditions. The response can vary with background aerosol, cloud type, cloud depth, humidity, turbulence, wind, drizzle, atmospheric stability and the size distribution of the added particles. Some clouds may brighten strongly, some may respond weakly, and some may respond in an unexpected direction. Consequently, an operational system would need weather-aware targeting, careful measurement, rapid feedback and the ability to reduce or stop output.

MCB would not remove carbon dioxide, stop ocean acidification or replace emissions reductions. Its possible climate effect would last only while suitable clouds are treated. A large program could alter regional radiation, cloud cover, precipitation or circulation, so environmental assessment and international governance would be integral to development rather than added after the equipment is built.

This document addresses equipment development, not authorization to deploy MCB. The objective is to determine whether seawater handling, aerosol generation, vessels, automation, monitoring, maintenance and data systems can be made reliable, controllable, economical and transparent. Outdoor aerosol releases and cloud-response experiments should proceed only under the separate scientific, environmental and governance process described in the companion MCB Research Experiments document.

MCB Equipment Development - $1B Fund

Prompt to AI: A 15-year Marine Cloud Brightening plan is available at https://www.ma2life.org/g/film/MCB_Reflectivity_Plan.pdf. The plan allocates $1B over 5 years to develop automated large-scale equipment needed for possible future operations. This includes autonomous or semi-autonomous vessels or floating platforms; seawater intake, filtration and conditioning; fine sea-salt aerosol generators; release masts or ducts; power and energy storage; navigation and weather routing; communications and remote control; automated dispatch, shutdown, maintenance diagnostics and resupply; port and maintenance systems; and equipment that monitors MCB operations, atmospheric transport, cloud response, climate impacts and side effects. If $1B over 5 years were allocated to this activity, how might it be broken down in a budget?

Response From AI:

The $1 billion should finance engineering development through repeated prototypes and integrated sea trials. It should not be treated as money to construct a full operational fleet or to produce a measurable regional climate intervention. The companion $1 billion MCB experiments fund would finance the atmospheric science and controlled cloud-response campaigns. The two programs would share instruments, field sites, data systems and decision gates, but would maintain separate budgets so that engineering progress cannot silently expand an atmospheric-release program.

All figures below are order-of-magnitude planning estimates in constant 2026 dollars, not vendor quotations. A protected central reserve is essential because reliable submicron sea-salt production at high throughput, long-duration marine operation and end-to-end autonomous control remain technically uncertain.

Work package	Five-year budget	Share	Principal five-year deliverable
1 Sea-salt aerosol-generation systems	$160M	16.0%	Three competing generator families, two ship-ready prototype lines, verified particle output and a manufacturable design package.
2 Seawater intake, filtration and conditioning	$70M	7.0%	Corrosion-resistant intake and pretreatment modules that supply stable feedwater across representative ocean conditions.
3 Vessel and floating-platform prototypes	$160M	16.0%	At least three instrumented platform classes: crewed test vessel, autonomous surface vessel and long-endurance floating platform.
4 Autonomy, navigation, weather routing and fleet control	$90M	9.0%	Supervised autonomy, cloud-targeting workflow, collision avoidance, remote control and fleet-management prototype.

5 Power, release mast, plume placement and marine durability	$65M	6.5%	Power and energy system, elevated release structure, corrosion controls and endurance-qualified marine hardware.
6 Monitoring, verification and side-effect measurement	$120M	12.0%	Integrated prototype network for equipment output, plume transport, cloud response, radiation, precipitation and environmental indicators.
7 Port, maintenance, resupply and lifecycle logistics	$50M	5.0%	Pilot shore base, spares, automated service concepts, maintenance procedures and fleet lifecycle model.
8 Systems integration and multi-platform sea trials	$80M	8.0%	Progressive harbor, coastal and offshore demonstrations culminating in a 30- to 90-day integrated trial.
9 Models, data platform and operations center	$35M	3.5%	Digital twins, forecast/dispatch tools, open data repository and prototype operations center.
10 Program management, safety, environmental review and independent assurance	$20M	2.0%	Owner-side PMO, systems engineering, independent reviews, public reporting and Phase II procurement package.
11 Central technical and schedule reserve	$150M	15.0%	Funds released only for documented redesign, failed tests, second-source development or schedule recovery.

The baseline technical program totals $850 million. The remaining $150 million is held centrally and is not automatically assigned to any contractor. Unused reserve should remain unspent or be carried into a later authorized phase.

1. Sea-salt aerosol-generation systems - $160 million

This is the central technology-development workstream. The program should not assume that one nozzle concept has already won. It should fund competing approaches long enough to compare particle-size distribution, salt mass output, electrical efficiency, clogging, biofouling, corrosion, maintenance burden and performance in realistic wind and humidity.

- Fund at least three competing generator families, such as high-pressure impaction nozzles, effervescent or twin-fluid atomization, and mechanically or electrostatically assisted concepts.
- Measure the dry particle-size spectrum after evaporation, not merely the liquid-droplet diameter at the nozzle.
- Require stable operation with natural seawater containing organics, microorganisms and changing salinity.
- Demonstrate turndown, rapid shutdown and restart, and accurate mass and particle-number accounting.
- Deliver open drawings, control software, calibration methods, test data and a credible manufacturing-cost model.

Subtask	Budget
Requirements, competing concepts and laboratory physics	$18M
Bench prototypes and metrology	$30M
High-throughput prototype lines	$45M
Marine packaging and environmental qualification	$25M
Shipboard trials and reliability growth	$27M
Manufacturing package, independent review and training	$15M

2. Seawater intake, filtration and conditioning - $70 million

Natural seawater is not a standardized industrial feedstock. Temperature, salinity, dissolved organics, suspended sediment, plankton and biological growth vary by region and season. The conditioning system must remove material that damages the generator without altering the salt chemistry in a way that undermines the atmospheric experiment.

Subtask	Budget
Ocean-water requirements and fouling characterization	$6M
Competing intake and pretreatment concepts	$10M
Filters, separators, pumps and instrumentation prototypes	$20M
Corrosion, biofouling and cleaning development	$10M
Integrated shipboard modules and trials	$16M
Replicable design, maintenance and waste-handling package	$8M

3. Vessel and floating-platform prototypes - $160 million

No single platform should be presumed optimal. A crewed vessel is useful for early engineering and scientific access; an autonomous surface vessel may lower operating cost; and a semi-stationary or wave-powered platform may provide long endurance in a limited region. The program should develop and compare platform classes rather than committing immediately to a fleet architecture.

Prototype	Budget	Purpose
Crewed test-vessel conversion	$45M	Rapid access, large engineering payload, scientists aboard and early integrated trials.
Autonomous surface-vessel prototype	$55M	Demonstrate navigation, remote supervision, aerosol generation and maintenance intervals.
Long-endurance floating or wave-powered platform	$25M	Evaluate station keeping, low-energy operation and seasonal persistence.
Common payload module and interfaces	$20M	Allow generator, intake, monitoring and mast packages to move among platforms.
Marine certification, survivability	$15M	Establish class, safety and test requirements for later fleet

and independent review		procurement.

4. Autonomy, navigation, weather routing and fleet control - $90 million

MCB equipment would need more than ordinary autonomous navigation. The system must decide when and where operation is scientifically authorized, avoid unsuitable clouds and sensitive areas, coordinate with aircraft and ships, verify output, pause when observations disagree with forecasts, and retain a clear human chain of command.

Subtask	Budget
Concept of operations, human authority and abort architecture	$8M
Navigation, collision avoidance and station keeping	$18M
Weather and cloud-targeting decision support	$15M
Fleet communications, remote command and cybersecurity	$15M
Fault management, automated shutdown and recovery	$14M
Simulation, supervised sea trials and software assurance	$20M

5. Power, release mast, plume placement and marine durability - $65 million

Power demand and release height can dominate vessel size and operating cost. The program should compare diesel-electric, low-carbon fuels, batteries, wind, solar and wave-assist options without pretending that the first prototype must already be zero-emission. Every design should report lifecycle emissions and net radiative benefit.

Subtask	Budget
Load analysis and power-system trade studies	$6M
Generators, storage and power electronics prototypes	$15M
Release mast, duct and aerodynamic design	$14M
Corrosion, salt ingress and marine hardening	$10M
Plume-placement sensors and control	$8M
Endurance qualification and replicable design package	$12M

6. Monitoring, verification and side-effect measurement - $120 million

An equipment program must prove not only that machinery runs, but that released material is known, traceable and observable. Monitoring should cover the complete chain: water intake, particle generation, outlet conditions, near-field plume, transport to cloud base, cloud microphysical response, reflected sunlight and possible side effects.

Monitoring function	Budget
Generator output, particle size, mass flow and calibration	$20M
On-vessel meteorology and plume measurements	$15M
Uncrewed aircraft, tethered systems and direct cloud sampling	$20M
Radar, lidar, radiometers and coastal observing systems	$20M
Satellite products and data assimilation	$10M
Precipitation, air-quality, ocean and ecological indicators	$15M
Calibration, intercomparison and independent verification	$20M

7. Port, maintenance, resupply and lifecycle logistics - $50 million

A fleet that works only with constant expert attention would not be ready for Phase II. The program should develop shore-side servicing, spare-module exchange, automated cleaning, fuel or energy replenishment, data offload, corrosion inspection and repair procedures in parallel with the vessels.

Subtask	Budget
Base and site requirements	$4M
Pilot maintenance and integration facility	$14M
Spare modules, tooling and inventory system	$8M
Automated cleaning, flushing and service connections	$8M
Resupply, transport and deployment logistics	$6M
Reliability-centered maintenance and lifecycle cost model	$10M

8. Systems integration and multi-platform sea trials - $80 million

Subsystem budgets include ordinary component tests. This separate work package pays for tests that cross contractor boundaries: generator plus intake, vessel plus mast, autonomy plus weather targeting, monitoring plus data systems, and complete mission cycles under independent observation.

Campaign	Budget
Systems-integration laboratory and digital test environment	$10M
Harbor and dockside integration campaign	$8M
Nearshore engineering trials	$12M
Coastal plume and monitoring trials using authorized releases	$15M
Offshore reliability and autonomy campaign	$15M
30- to 90-day multi-platform demonstration and readiness review	$20M

9. Models, data platform and operations center - $35 million

The operating system should maintain a complete digital record for every platform and authorized release: where the platform went, what water was processed, what particle output was measured, what weather and cloud conditions existed, what commands were issued, and what observations followed.

Subtask	Budget
Data governance, interfaces and open-access architecture	$4M
Engineering digital twins and lifecycle models	$7M
Weather, plume and cloud-response decision tools	$7M
Fleet operations center and visualization	$7M
Real-time data ingestion, quality control and alerts	$6M
Public archive, APIs, documentation and handoff	$4M

10. Program management, safety and independent assurance - $20 million

This line is the owner-side function and does not replace normal contractor project management included in each work package. It should finance requirements control, integrated scheduling, procurement oversight, independent cost and safety reviews, environmental documentation, open-data audits and Phase II planning.

Function	Budget
Program office and integrated master schedule	$6M
Systems engineering and configuration control	$3M
Procurement, finance and cost assurance	$3M
Safety, environmental and maritime review	$3M
Scientific/engineering panels and public reporting	$2M
Final readiness, lifecycle cost and Phase II package	$3M

11. Central technical and schedule reserve - $150 million

The reserve should remain under Funding Source and independent board control. Contractors should not include it in expected revenue. Release should require a documented problem, corrective plan, independent estimate and a finding that the work remains aligned with the charitable and scientific purpose.

Reserve category	Maximum	Examples
Requirements and concept reserve	$15M	Additional generator concepts, revised output requirements, new environmental constraints.

Prototype redesign and second-source reserve	$35M	Failed nozzles, corrosion, fouling, power shortfalls, alternative suppliers.
Fabrication and platform reserve	$35M	Vessel modifications, long-lead equipment, replacement prototypes.
Integration and sea-trial reserve	$45M	Failed endurance tests, vessel downtime, replacement campaigns, software corrections.
Schedule recovery and final-demonstration reserve	$20M	Additional reliability cycles, documentation, regulatory or deployment delays.

Suggested five-year funding profile

Year	Baseline technical work	Reserve authority	Total	Primary emphasis
Year 1	$100M	$15M	$115M	Requirements, competing concepts, laboratory prototypes, sites, governance and design reviews.
Year 2	$150M	$30M	$180M	Bench and intermediate prototypes, vessel selection, intake modules and autonomy simulation.
Year 3	$200M	$40M	$240M	Ship-ready generators, vessel conversion, monitoring systems and coastal integration.
Year 4	$220M	$45M	$265M	Peak sea trials, autonomous vessel testing, reliability growth and data-system integration.
Year 5	$180M	$20M	$200M	Long-duration demonstrations, corrections, manufacturing packages and Phase II readiness.

What $1 billion would and would not accomplish

- It could produce several independently tested sea-salt generator designs and at least two ship-ready prototype lines.
- It could produce a crewed test vessel, an autonomous surface-vessel prototype and a long-endurance platform demonstrator.
- It could demonstrate supervised automated operation, maintenance and multi-platform coordination during controlled sea trials.
- It could establish prototype monitoring, data and operations systems sufficient to design a later experimental fleet.
- It would not construct a global or regional operational fleet, authorize climate-scale deployment, or prove that MCB is environmentally acceptable.
- It would not remove the need for the separate MCB atmospheric-experiment program, independent environmental review or international authorization.

Development Phases

Prompt to AI: With each budget item, what are the different development phases, and how much might each cost?

Response From AI:

The phases below are development subphases within Phase I of the 15-year Reflectivity Plan. They overlap in time. Outdoor atmospheric work is not automatically authorized by completion of an engineering phase; each release must remain subject to the separate experiment-review process.

Common stage	Approximate timing	Purpose
A. Requirements and feasibility	Months 0-12	Define measurable requirements, compare concepts and identify safety, environmental and regulatory constraints.
B. Preliminary design and risk reduction	Months 6-24	Build laboratory prototypes and retire the largest technical uncertainties before major fabrication.
C. Detailed design and fabrication	Months 18-42	Produce drawings, software and marine-ready prototype hardware.
D. Integration and qualification	Months 30-54	Combine subsystems; test safety, durability, output, autonomy and monitoring.
E. Operational demonstration and handoff	Months 45-60	Demonstrate repeatable operating cycles and produce a Phase II procurement package.

1. Sea-salt aerosol-generation systems - $160M

Subphase	Principal activities and deliverables	Cost
1A Requirements and competing concepts	Requirements, trade studies, success criteria, risk register and independent feasibility review.	$18M
1B Bench physics and prototype metrology	Competing concepts, laboratory or early prototype work, model validation and preliminary design review.	$30M
1C High-throughput prototype fabrication	Detailed design, fabrication, controls, documentation and configuration baseline.	$45M
1D Marine packaging and qualification	Subsystem integration, environmental qualification, failure testing and safety review.	$25M
1E Shipboard trials and reliability growth	Field or sea trials, reliability growth, data analysis, deficiencies and operating procedures.	$27M
1F Manufacturing handoff and independent review	Independent acceptance, open technical archive, manufacturing or Phase II handoff package.	$15M

Decision gate: the program should not commit the largest fabrication or sea-trial expenditures until the preceding review demonstrates that the requirement remains scientifically useful, technically credible and compatible with the separate environmental authorization process.

2. Seawater intake, filtration and conditioning - $70M

Subphase	Principal activities and deliverables	Cost
2A Feedwater requirements and characterization	Requirements, trade studies, success criteria, risk register and independent feasibility review.	$6M
2B Intake and conditioning concepts	Competing concepts, laboratory or early prototype work, model validation and preliminary design review.	$10M
2C Prototype fabrication	Detailed design, fabrication, controls, documentation and configuration baseline.	$20M
2D Fouling, corrosion and cleaning development	Subsystem integration, environmental qualification, failure testing and safety review.	$10M
2E Shipboard integration and trials	Field or sea trials, reliability growth, data analysis, deficiencies and operating procedures.	$16M
2F Replicable design and maintenance handoff	Independent acceptance, open technical archive, manufacturing or Phase II handoff package.	$8M

Decision gate: the program should not commit the largest fabrication or sea-trial expenditures until the preceding review demonstrates that the requirement remains scientifically useful, technically credible and compatible with the separate environmental authorization process.

3. Vessel and floating-platform prototypes - $160M

Subphase	Principal activities and deliverables	Cost
3A Platform requirements and architecture	Requirements, trade studies, success criteria, risk register and independent feasibility review.	$12M
3B Crewed test-vessel conversion	Competing concepts, laboratory or early prototype work, model validation and preliminary design review.	$45M
3C Autonomous surface-vessel prototype	Detailed design, fabrication, controls, documentation and configuration baseline.	$55M
3D Long-endurance platform prototype	Subsystem integration, environmental qualification, failure testing and safety review.	$25M
3E Common payload and interface development	Field or sea trials, reliability growth, data analysis, deficiencies and operating procedures.	$13M
3F Marine qualification and fleet architecture	Independent acceptance, open technical archive, manufacturing or Phase II handoff package.	$10M

Decision gate: the program should not commit the largest fabrication or sea-trial expenditures until the preceding review demonstrates that the requirement remains scientifically useful, technically credible and compatible with the separate environmental authorization process.

4. Autonomy, navigation, weather routing and fleet control - $90M

Subphase	Principal activities and deliverables	Cost
4A Concept of operations and safety architecture	Requirements, trade studies, success criteria, risk register and independent feasibility review.	$8M
4B Navigation and station keeping	Competing concepts, laboratory or early prototype work, model validation and preliminary design review.	$18M
4C Weather and cloud-targeting tools	Detailed design, fabrication, controls, documentation and configuration baseline.	$15M
4D Communications, command and cybersecurity	Subsystem integration, environmental qualification, failure testing and safety review.	$15M
4E Fault management and automated shutdown	Field or sea trials, reliability growth, data analysis, deficiencies and operating procedures.	$14M
4F Simulation, sea trials and software assurance	Independent acceptance, open technical archive, manufacturing or Phase II handoff package.	$20M

Decision gate: the program should not commit the largest fabrication or sea-trial expenditures until the preceding review demonstrates that the requirement remains scientifically useful, technically credible and compatible with the separate environmental authorization process.

5. Power, release mast, plume placement and marine durability - $65M

Subphase	Principal activities and deliverables	Cost
5A Power and release requirements	Requirements, trade studies, success criteria, risk register and independent feasibility review.	$6M
5B Power-system prototypes	Competing concepts, laboratory or early prototype work, model validation and preliminary design review.	$15M
5C Release mast and duct development	Detailed design, fabrication, controls, documentation and configuration baseline.	$14M
5D Marine hardening and corrosion control	Subsystem integration, environmental qualification, failure testing and safety review.	$10M
5E Plume-placement sensing and control	Field or sea trials, reliability growth, data analysis, deficiencies and operating procedures.	$8M
5F Endurance qualification and handoff	Independent acceptance, open technical archive, manufacturing or Phase II handoff package.	$12M

Decision gate: the program should not commit the largest fabrication or sea-trial expenditures until the preceding review demonstrates that the requirement remains scientifically useful, technically credible and compatible with the separate environmental authorization process.

6. Monitoring, verification and side-effect measurement - $120M

Subphase	Principal activities and deliverables	Cost
6A Measurement requirements and uncertainty budgets	Requirements, trade studies, success criteria, risk register and independent feasibility review.	$10M
6B Monitoring-system architecture	Competing concepts, laboratory or early prototype work, model validation and preliminary design review.	$15M
6C Instrument prototype development	Detailed design, fabrication, controls, documentation and configuration baseline.	$35M
6D Calibration and intercomparison	Subsystem integration, environmental qualification, failure testing and safety review.	$20M
6E Field integration and validation	Field or sea trials, reliability growth, data analysis, deficiencies and operating procedures.	$25M
6F Operational procedures and independent readiness	Independent acceptance, open technical archive, manufacturing or Phase II handoff package.	$15M

Decision gate: the program should not commit the largest fabrication or sea-trial expenditures until the preceding review demonstrates that the requirement remains scientifically useful, technically credible and compatible with the separate environmental authorization process.

7. Port, maintenance, resupply and lifecycle logistics - $50M

Subphase	Principal activities and deliverables	Cost
7A Base and logistics requirements	Requirements, trade studies, success criteria, risk register and independent feasibility review.	$4M
7B Pilot maintenance facility	Competing concepts, laboratory or early prototype work, model validation and preliminary design review.	$14M
7C Spares, tooling and inventory systems	Detailed design, fabrication, controls, documentation and configuration baseline.	$8M
7D Automated cleaning and service connections	Subsystem integration, environmental qualification, failure testing and safety review.	$8M
7E Resupply and deployment trials	Field or sea trials, reliability growth, data analysis, deficiencies and operating procedures.	$6M
7F Lifecycle and maintenance handoff	Independent acceptance, open technical archive, manufacturing or Phase II handoff package.	$10M

Decision gate: the program should not commit the largest fabrication or sea-trial expenditures until the preceding review demonstrates that the requirement remains scientifically useful, technically credible and compatible with the separate environmental authorization process.

8. Systems integration and multi-platform sea trials - $80M

Subphase	Principal activities and deliverables	Cost
8A Master integration and verification planning	Requirements, trade studies, success criteria, risk register and independent feasibility review.	$6M
8B Systems-integration laboratory	Competing concepts, laboratory or early prototype work, model validation and preliminary design review.	$10M
8C Harbor and dockside campaign	Detailed design, fabrication, controls, documentation and configuration baseline.	$9M
8D Nearshore and coastal trials	Subsystem integration, environmental qualification, failure testing and safety review.	$20M
8E Offshore endurance campaign	Field or sea trials, reliability growth, data analysis, deficiencies and operating procedures.	$15M
8F Multi-platform final demonstration	Independent acceptance, open technical archive, manufacturing or Phase II handoff package.	$20M

Decision gate: the program should not commit the largest fabrication or sea-trial expenditures until the preceding review demonstrates that the requirement remains scientifically useful, technically credible and compatible with the separate environmental authorization process.

9. Models, data platform and operations center - $35M

Subphase	Principal activities and deliverables	Cost
9A Data governance and interfaces	Requirements, trade studies, success criteria, risk register and independent feasibility review.	$4M
9B Digital twins and forecast tools	Competing concepts, laboratory or early prototype work, model validation and preliminary design review.	$8M
9C Operations-center platform	Detailed design, fabrication, controls, documentation and configuration baseline.	$7M
9D Data ingestion and quality control	Subsystem integration, environmental qualification, failure testing and safety review.	$6M
9E Integrated simulations and exercises	Field or sea trials, reliability growth, data analysis, deficiencies and operating procedures.	$6M
9F Public archive and handoff	Independent acceptance, open technical archive, manufacturing or Phase II handoff package.	$4M

Decision gate: the program should not commit the largest fabrication or sea-trial expenditures until the preceding review demonstrates that the requirement remains scientifically useful, technically credible and compatible with the separate environmental authorization process.

10. Program management, safety, environmental review and independent assurance - $20M

Subphase	Principal activities and deliverables	Cost
10A Program formation	Requirements, trade studies, success criteria, risk register and independent feasibility review.	$4M
10B Requirements and design oversight	Competing concepts, laboratory or early prototype work, model validation and preliminary design review.	$3M
10C Procurement and execution oversight	Detailed design, fabrication, controls, documentation and configuration baseline.	$4M
10D Test, safety and environmental oversight	Subsystem integration, environmental qualification, failure testing and safety review.	$4M
10E Final readiness and Phase II planning	Field or sea trials, reliability growth, data analysis, deficiencies and operating procedures.	$5M

Decision gate: the program should not commit the largest fabrication or sea-trial expenditures until the preceding review demonstrates that the requirement remains scientifically useful, technically credible and compatible with the separate environmental authorization process.

11. Central technical and schedule reserve - $150M

Subphase	Principal activities and deliverables	Cost
11A Requirements reserve authority	Contingent authority only; no automatic contractor entitlement. Release requires documented need, independent estimate and board approval.	$15M
11B Prototype redesign and second sources	Contingent authority only; no automatic contractor entitlement. Release requires documented need, independent estimate and board approval.	$35M
11C Fabrication and platform reserve	Contingent authority only; no automatic contractor entitlement. Release requires documented need, independent estimate and board approval.	$35M
11D Integration and sea-trial reserve	Contingent authority only; no automatic contractor entitlement. Release requires documented need, independent estimate and board approval.	$45M
11E Schedule recovery and final demonstration	Contingent authority only; no automatic contractor entitlement. Release requires documented need, independent estimate and board approval.	$20M

Purchase Orders

Prompt to AI: With each phase of each budget item, what Purchase Orders, contracts, grants, task orders, or subawards might be issued?

Response From AI:

Below, "PO" means a procurement package. Depending on the recipient, the legal instrument may be a fixed-price contract, cost-reimbursement contract, cooperative agreement, university subaward, vessel charter, government reimbursable agreement or task order under a master contract. Each package should specify deliverables, acceptance tests, uncertainty or performance requirements, schedule, open-data rights, safety provisions and payment milestones.

1. Sea-salt aerosol-generation systems

1A. Requirements and competing concepts - $18M

Procurement package	Deliverable	Estimate
1A-1: Science and engineering requirements	Documented requirements and competing concepts requirements, interfaces, success criteria, schedule and risk register.	$5M
1A-2: Competing generator concept or prototype	Design, hardware, software or service package for requirements and competing concepts, including test evidence and configuration records.	$6.1M
1A-3: Particle metrology and calibration	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for requirements and competing concepts.	$4.1M
1A-4: Independent design or test review	Independent review, acceptance finding and open technical archive for requirements and competing concepts.	$2.8M

1B. Bench physics and prototype metrology - $30M

Procurement package	Deliverable	Estimate
1B-1: Science and engineering requirements	Documented bench physics and prototype metrology requirements, interfaces, success criteria, schedule and risk register.	$8.4M
1B-2: Competing generator concept or prototype	Design, hardware, software or service package for bench physics and prototype metrology, including test evidence and configuration records.	$10.2M
1B-3: Particle metrology and calibration	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for bench physics and prototype metrology.	$6.9M
1B-4: Independent design or test review	Independent review, acceptance finding and open technical archive for bench physics and prototype metrology.	$4.5M

1C. High-throughput prototype fabrication - $45M

Procurement package	Deliverable	Estimate
1C-1: Science and engineering requirements	Documented high-throughput prototype fabrication requirements, interfaces, success criteria, schedule and risk register.	$12.6M
1C-2: Competing generator concept or prototype	Design, hardware, software or service package for high-throughput prototype fabrication, including test evidence and configuration records.	$15.3M
1C-3: Particle metrology and calibration	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for high-throughput prototype fabrication.	$10.3M
1C-4: Independent design or test review	Independent review, acceptance finding and open technical archive for high-throughput prototype fabrication.	$6.8M

1D. Marine packaging and qualification - $25M

Procurement package	Deliverable	Estimate
1D-1: Science and engineering requirements	Documented marine packaging and qualification requirements, interfaces, success criteria, schedule and risk register.	$7M
1D-2: Competing generator concept or prototype	Design, hardware, software or service package for marine packaging and qualification, including test evidence and configuration records.	$8.5M
1D-3: Particle metrology and calibration	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for marine packaging and qualification.	$5.8M
1D-4: Independent design or test review	Independent review, acceptance finding and open technical archive for marine packaging and qualification.	$3.7M

1E. Shipboard trials and reliability growth - $27M

Procurement package	Deliverable	Estimate
1E-1: Science and engineering requirements	Documented shipboard trials and reliability growth requirements, interfaces, success criteria, schedule and risk register.	$7.6M
1E-2: Competing generator concept or prototype	Design, hardware, software or service package for shipboard trials and reliability growth, including test evidence and configuration records.	$9.2M
1E-3: Particle metrology and calibration	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for shipboard trials and reliability growth.	$6.2M
1E-4: Independent design or test review	Independent review, acceptance finding and open technical archive for shipboard trials and reliability growth.	$4M

1F. Manufacturing handoff and independent review - $15M

Procurement package	Deliverable	Estimate
1F-1: Science and engineering requirements	Documented manufacturing handoff and independent review requirements, interfaces, success criteria, schedule and risk register.	$4.2M

1F-2: Competing generator concept or prototype	Design, hardware, software or service package for manufacturing handoff and independent review, including test evidence and configuration records.	$5.1M
1F-3: Particle metrology and calibration	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for manufacturing handoff and independent review.	$3.5M
1F-4: Independent design or test review	Independent review, acceptance finding and open technical archive for manufacturing handoff and independent review.	$2.2M

2. Seawater intake, filtration and conditioning

2A. Feedwater requirements and characterization - $6M

Procurement package	Deliverable	Estimate
2A-1: Feedwater and process requirements	Documented feedwater requirements and characterization requirements, interfaces, success criteria, schedule and risk register.	$1.7M
2A-2: Intake/filtration hardware or prototype	Design, hardware, software or service package for feedwater requirements and characterization, including test evidence and configuration records.	$2M
2A-3: Fouling, corrosion and cleaning test services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for feedwater requirements and characterization.	$1.4M
2A-4: Independent process and environmental review	Independent review, acceptance finding and open technical archive for feedwater requirements and characterization.	$0.9M

2B. Intake and conditioning concepts - $10M

Procurement package	Deliverable	Estimate
2B-1: Feedwater and process requirements	Documented intake and conditioning concepts requirements, interfaces, success criteria, schedule and risk register.	$2.8M
2B-2: Intake/filtration hardware or prototype	Design, hardware, software or service package for intake and conditioning concepts, including test evidence and configuration records.	$3.4M
2B-3: Fouling, corrosion and cleaning test services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for intake and conditioning concepts.	$2.3M
2B-4: Independent process and environmental review	Independent review, acceptance finding and open technical archive for intake and conditioning concepts.	$1.5M

2C. Prototype fabrication - $20M

Procurement package	Deliverable	Estimate
2C-1: Feedwater and process requirements	Documented prototype fabrication requirements, interfaces, success criteria, schedule and risk register.	$5.6M

2C-2: Intake/filtration hardware or prototype	Design, hardware, software or service package for prototype fabrication, including test evidence and configuration records.	$6.8M
2C-3: Fouling, corrosion and cleaning test services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for prototype fabrication.	$4.6M
2C-4: Independent process and environmental review	Independent review, acceptance finding and open technical archive for prototype fabrication.	$3M

2D. Fouling, corrosion and cleaning development - $10M

Procurement package	Deliverable	Estimate
2D-1: Feedwater and process requirements	Documented fouling, corrosion and cleaning development requirements, interfaces, success criteria, schedule and risk register.	$2.8M
2D-2: Intake/filtration hardware or prototype	Design, hardware, software or service package for fouling, corrosion and cleaning development, including test evidence and configuration records.	$3.4M
2D-3: Fouling, corrosion and cleaning test services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for fouling, corrosion and cleaning development.	$2.3M
2D-4: Independent process and environmental review	Independent review, acceptance finding and open technical archive for fouling, corrosion and cleaning development.	$1.5M

2E. Shipboard integration and trials - $16M

Procurement package	Deliverable	Estimate
2E-1: Feedwater and process requirements	Documented shipboard integration and trials requirements, interfaces, success criteria, schedule and risk register.	$4.5M
2E-2: Intake/filtration hardware or prototype	Design, hardware, software or service package for shipboard integration and trials, including test evidence and configuration records.	$5.4M
2E-3: Fouling, corrosion and cleaning test services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for shipboard integration and trials.	$3.7M
2E-4: Independent process and environmental review	Independent review, acceptance finding and open technical archive for shipboard integration and trials.	$2.4M

2F. Replicable design and maintenance handoff - $8M

Procurement package	Deliverable	Estimate
2F-1: Feedwater and process requirements	Documented replicable design and maintenance handoff requirements, interfaces, success criteria, schedule and risk register.	$2.2M
2F-2: Intake/filtration hardware or prototype	Design, hardware, software or service package for replicable design and maintenance handoff, including test evidence and configuration records.	$2.7M
2F-3: Fouling, corrosion and cleaning test services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for replicable design and maintenance handoff.	$1.8M

2F-4: Independent process and environmental review	Independent review, acceptance finding and open technical archive for replicable design and maintenance handoff.	$1.3M

3. Vessel and floating-platform prototypes

3A. Platform requirements and architecture - $12M

Procurement package	Deliverable	Estimate
3A-1: Platform requirements and naval architecture	Documented platform requirements and architecture requirements, interfaces, success criteria, schedule and risk register.	$3.4M
3A-2: Vessel acquisition, charter or conversion	Design, hardware, software or service package for platform requirements and architecture, including test evidence and configuration records.	$4.1M
3A-3: Payload integration and marine systems	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for platform requirements and architecture.	$2.8M
3A-4: Independent class, safety or acceptance review	Independent review, acceptance finding and open technical archive for platform requirements and architecture.	$1.7M

3B. Crewed test-vessel conversion - $45M

Procurement package	Deliverable	Estimate
3B-1: Platform requirements and naval architecture	Documented crewed test-vessel conversion requirements, interfaces, success criteria, schedule and risk register.	$12.6M
3B-2: Vessel acquisition, charter or conversion	Design, hardware, software or service package for crewed test-vessel conversion, including test evidence and configuration records.	$15.3M
3B-3: Payload integration and marine systems	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for crewed test-vessel conversion.	$10.3M
3B-4: Independent class, safety or acceptance review	Independent review, acceptance finding and open technical archive for crewed test-vessel conversion.	$6.8M

3C. Autonomous surface-vessel prototype - $55M

Procurement package	Deliverable	Estimate
3C-1: Platform requirements and naval architecture	Documented autonomous surface-vessel prototype requirements, interfaces, success criteria, schedule and risk register.	$15.4M
3C-2: Vessel acquisition, charter or conversion	Design, hardware, software or service package for autonomous surface-vessel prototype, including test evidence and configuration records.	$18.7M
3C-3: Payload integration and marine systems	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for autonomous surface-vessel prototype.	$12.7M
3C-4: Independent class, safety or acceptance review	Independent review, acceptance finding and open technical archive for autonomous surface-vessel prototype.	$8.2M

3D. Long-endurance platform prototype - $25M

Procurement package	Deliverable	Estimate
3D-1: Platform requirements and naval architecture	Documented long-endurance platform prototype requirements, interfaces, success criteria, schedule and risk register.	$7M
3D-2: Vessel acquisition, charter or conversion	Design, hardware, software or service package for long-endurance platform prototype, including test evidence and configuration records.	$8.5M
3D-3: Payload integration and marine systems	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for long-endurance platform prototype.	$5.8M
3D-4: Independent class, safety or acceptance review	Independent review, acceptance finding and open technical archive for long-endurance platform prototype.	$3.7M

3E. Common payload and interface development - $13M

Procurement package	Deliverable	Estimate
3E-1: Platform requirements and naval architecture	Documented common payload and interface development requirements, interfaces, success criteria, schedule and risk register.	$3.6M
3E-2: Vessel acquisition, charter or conversion	Design, hardware, software or service package for common payload and interface development, including test evidence and configuration records.	$4.4M
3E-3: Payload integration and marine systems	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for common payload and interface development.	$3M
3E-4: Independent class, safety or acceptance review	Independent review, acceptance finding and open technical archive for common payload and interface development.	$2M

3F. Marine qualification and fleet architecture - $10M

Procurement package	Deliverable	Estimate
3F-1: Platform requirements and naval architecture	Documented marine qualification and fleet architecture requirements, interfaces, success criteria, schedule and risk register.	$2.8M
3F-2: Vessel acquisition, charter or conversion	Design, hardware, software or service package for marine qualification and fleet architecture, including test evidence and configuration records.	$3.4M
3F-3: Payload integration and marine systems	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for marine qualification and fleet architecture.	$2.3M
3F-4: Independent class, safety or acceptance review	Independent review, acceptance finding and open technical archive for marine qualification and fleet architecture.	$1.5M

4. Autonomy, navigation, weather routing and fleet control

4A. Concept of operations and safety architecture - $8M

Procurement package	Deliverable	Estimate
4A-1: Autonomy requirements and system architecture	Documented concept of operations and safety architecture requirements, interfaces, success criteria, schedule and risk register.	$2.2M
4A-2: Navigation, weather or fleet-control software	Design, hardware, software or service package for concept of operations and safety architecture, including test evidence and configuration records.	$2.7M
4A-3: Communications, cybersecurity and hardware-in-loop testing	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for concept of operations and safety architecture.	$1.8M
4A-4: Independent software and safety assurance	Independent review, acceptance finding and open technical archive for concept of operations and safety architecture.	$1.3M

4B. Navigation and station keeping - $18M

Procurement package	Deliverable	Estimate
4B-1: Autonomy requirements and system architecture	Documented navigation and station keeping requirements, interfaces, success criteria, schedule and risk register.	$5M
4B-2: Navigation, weather or fleet-control software	Design, hardware, software or service package for navigation and station keeping, including test evidence and configuration records.	$6.1M
4B-3: Communications, cybersecurity and hardware-in-loop testing	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for navigation and station keeping.	$4.1M
4B-4: Independent software and safety assurance	Independent review, acceptance finding and open technical archive for navigation and station keeping.	$2.8M

4C. Weather and cloud-targeting tools - $15M

Procurement package	Deliverable	Estimate
4C-1: Autonomy requirements and system architecture	Documented weather and cloud-targeting tools requirements, interfaces, success criteria, schedule and risk register.	$4.2M
4C-2: Navigation, weather or fleet-control software	Design, hardware, software or service package for weather and cloud-targeting tools, including test evidence and configuration records.	$5.1M
4C-3: Communications, cybersecurity and hardware-in-loop testing	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for weather and cloud-targeting tools.	$3.5M
4C-4: Independent software and safety assurance	Independent review, acceptance finding and open technical archive for weather and cloud-targeting tools.	$2.2M

4D. Communications, command and cybersecurity - $15M

Procurement package	Deliverable	Estimate
4D-1: Autonomy requirements and system architecture	Documented communications, command and cybersecurity requirements, interfaces, success criteria, schedule and risk register.	$4.2M
4D-2: Navigation, weather or fleet-control software	Design, hardware, software or service package for communications, command and cybersecurity, including test evidence and configuration records.	$5.1M
4D-3: Communications, cybersecurity and hardware-in-loop testing	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for communications, command and cybersecurity.	$3.5M
4D-4: Independent software and safety assurance	Independent review, acceptance finding and open technical archive for communications, command and cybersecurity.	$2.2M

4E. Fault management and automated shutdown - $14M

Procurement package	Deliverable	Estimate
4E-1: Autonomy requirements and system architecture	Documented fault management and automated shutdown requirements, interfaces, success criteria, schedule and risk register.	$3.9M
4E-2: Navigation, weather or fleet-control software	Design, hardware, software or service package for fault management and automated shutdown, including test evidence and configuration records.	$4.8M
4E-3: Communications, cybersecurity and hardware-in-loop testing	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for fault management and automated shutdown.	$3.2M
4E-4: Independent software and safety assurance	Independent review, acceptance finding and open technical archive for fault management and automated shutdown.	$2.1M

4F. Simulation, sea trials and software assurance - $20M

Procurement package	Deliverable	Estimate
4F-1: Autonomy requirements and system architecture	Documented simulation, sea trials and software assurance requirements, interfaces, success criteria, schedule and risk register.	$5.6M
4F-2: Navigation, weather or fleet-control software	Design, hardware, software or service package for simulation, sea trials and software assurance, including test evidence and configuration records.	$6.8M
4F-3: Communications, cybersecurity and hardware-in-loop testing	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for simulation, sea trials and software assurance.	$4.6M
4F-4: Independent software and safety assurance	Independent review, acceptance finding and open technical archive for simulation, sea trials and software assurance.	$3M

5. Power, release mast, plume placement and marine durability

5A. Power and release requirements - $6M

Procurement package	Deliverable	Estimate
5A-1: Power and mast requirements	Documented power and release requirements requirements, interfaces, success criteria, schedule and risk register.	$1.7M
5A-2: Power, energy-storage or release-structure hardware	Design, hardware, software or service package for power and release requirements, including test evidence and configuration records.	$2M
5A-3: Marine durability, corrosion or plume-placement tests	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for power and release requirements.	$1.4M
5A-4: Independent qualification review	Independent review, acceptance finding and open technical archive for power and release requirements.	$0.9M

5B. Power-system prototypes - $15M

Procurement package	Deliverable	Estimate
5B-1: Power and mast requirements	Documented power-system prototypes requirements, interfaces, success criteria, schedule and risk register.	$4.2M
5B-2: Power, energy-storage or release-structure hardware	Design, hardware, software or service package for power-system prototypes, including test evidence and configuration records.	$5.1M
5B-3: Marine durability, corrosion or plume-placement tests	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for power-system prototypes.	$3.5M
5B-4: Independent qualification review	Independent review, acceptance finding and open technical archive for power-system prototypes.	$2.2M

5C. Release mast and duct development - $14M

Procurement package	Deliverable	Estimate
5C-1: Power and mast requirements	Documented release mast and duct development requirements, interfaces, success criteria, schedule and risk register.	$3.9M
5C-2: Power, energy-storage or release-structure hardware	Design, hardware, software or service package for release mast and duct development, including test evidence and configuration records.	$4.8M
5C-3: Marine durability, corrosion or plume-placement tests	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for release mast and duct development.	$3.2M
5C-4: Independent qualification review	Independent review, acceptance finding and open technical archive for release mast and duct development.	$2.1M

5D. Marine hardening and corrosion control - $10M

Procurement package	Deliverable	Estimate
5D-1: Power and mast requirements	Documented marine hardening and corrosion control requirements, interfaces, success criteria, schedule and risk register.	$2.8M
5D-2: Power, energy-storage or release-structure hardware	Design, hardware, software or service package for marine hardening and corrosion control, including test evidence and configuration records.	$3.4M
5D-3: Marine durability, corrosion or plume-placement tests	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for marine hardening and corrosion control.	$2.3M
5D-4: Independent qualification review	Independent review, acceptance finding and open technical archive for marine hardening and corrosion control.	$1.5M

5E. Plume-placement sensing and control - $8M

Procurement package	Deliverable	Estimate
5E-1: Power and mast requirements	Documented plume-placement sensing and control requirements, interfaces, success criteria, schedule and risk register.	$2.2M
5E-2: Power, energy-storage or release-structure hardware	Design, hardware, software or service package for plume-placement sensing and control, including test evidence and configuration records.	$2.7M
5E-3: Marine durability, corrosion or plume-placement tests	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for plume-placement sensing and control.	$1.8M
5E-4: Independent qualification review	Independent review, acceptance finding and open technical archive for plume-placement sensing and control.	$1.3M

5F. Endurance qualification and handoff - $12M

Procurement package	Deliverable	Estimate
5F-1: Power and mast requirements	Documented endurance qualification and handoff requirements, interfaces, success criteria, schedule and risk register.	$3.4M
5F-2: Power, energy-storage or release-structure hardware	Design, hardware, software or service package for endurance qualification and handoff, including test evidence and configuration records.	$4.1M
5F-3: Marine durability, corrosion or plume-placement tests	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for endurance qualification and handoff.	$2.8M
5F-4: Independent qualification review	Independent review, acceptance finding and open technical archive for endurance qualification and handoff.	$1.7M

6. Monitoring, verification and side-effect measurement

6A. Measurement requirements and uncertainty budgets - $10M

Procurement package	Deliverable	Estimate
6A-1: Measurement requirements and architecture	Documented measurement requirements and uncertainty budgets requirements, interfaces, success criteria, schedule and risk register.	$2.8M
6A-2: Instrument prototype or observation service	Design, hardware, software or service package for measurement requirements and uncertainty budgets, including test evidence and configuration records.	$3.4M
6A-3: Calibration, intercomparison and data processing	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for measurement requirements and uncertainty budgets.	$2.3M
6A-4: Independent measurement and readiness review	Independent review, acceptance finding and open technical archive for measurement requirements and uncertainty budgets.	$1.5M

6B. Monitoring-system architecture - $15M

Procurement package	Deliverable	Estimate
6B-1: Measurement requirements and architecture	Documented monitoring-system architecture requirements, interfaces, success criteria, schedule and risk register.	$4.2M
6B-2: Instrument prototype or observation service	Design, hardware, software or service package for monitoring-system architecture, including test evidence and configuration records.	$5.1M
6B-3: Calibration, intercomparison and data processing	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for monitoring-system architecture.	$3.5M
6B-4: Independent measurement and readiness review	Independent review, acceptance finding and open technical archive for monitoring-system architecture.	$2.2M

6C. Instrument prototype development - $35M

Procurement package	Deliverable	Estimate
6C-1: Measurement requirements and architecture	Documented instrument prototype development requirements, interfaces, success criteria, schedule and risk register.	$9.8M
6C-2: Instrument prototype or observation service	Design, hardware, software or service package for instrument prototype development, including test evidence and configuration records.	$11.9M
6C-3: Calibration, intercomparison and data processing	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for instrument prototype development.	$8.1M
6C-4: Independent measurement and readiness review	Independent review, acceptance finding and open technical archive for instrument prototype development.	$5.2M

6D. Calibration and intercomparison - $20M

Procurement package	Deliverable	Estimate
6D-1: Measurement requirements and architecture	Documented calibration and intercomparison requirements, interfaces, success criteria, schedule and risk register.	$5.6M
6D-2: Instrument prototype or observation service	Design, hardware, software or service package for calibration and intercomparison, including test evidence and configuration records.	$6.8M
6D-3: Calibration, intercomparison and data processing	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for calibration and intercomparison.	$4.6M
6D-4: Independent measurement and readiness review	Independent review, acceptance finding and open technical archive for calibration and intercomparison.	$3M

6E. Field integration and validation - $25M

Procurement package	Deliverable	Estimate
6E-1: Measurement requirements and architecture	Documented field integration and validation requirements, interfaces, success criteria, schedule and risk register.	$7M
6E-2: Instrument prototype or observation service	Design, hardware, software or service package for field integration and validation, including test evidence and configuration records.	$8.5M
6E-3: Calibration, intercomparison and data processing	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for field integration and validation.	$5.8M
6E-4: Independent measurement and readiness review	Independent review, acceptance finding and open technical archive for field integration and validation.	$3.7M

6F. Operational procedures and independent readiness - $15M

Procurement package	Deliverable	Estimate
6F-1: Measurement requirements and architecture	Documented operational procedures and independent readiness requirements, interfaces, success criteria, schedule and risk register.	$4.2M
6F-2: Instrument prototype or observation service	Design, hardware, software or service package for operational procedures and independent readiness, including test evidence and configuration records.	$5.1M
6F-3: Calibration, intercomparison and data processing	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for operational procedures and independent readiness.	$3.5M
6F-4: Independent measurement and readiness review	Independent review, acceptance finding and open technical archive for operational procedures and independent readiness.	$2.2M

7. Port, maintenance, resupply and lifecycle logistics

7A. Base and logistics requirements - $4M

Procurement package	Deliverable	Estimate
7A-1: Base and lifecycle requirements	Documented base and logistics requirements requirements, interfaces, success criteria, schedule and risk register.	$1.1M
7A-2: Facility, tooling, spares or service-system implementation	Design, hardware, software or service package for base and logistics requirements, including test evidence and configuration records.	$1.4M
7A-3: Maintenance, logistics and resupply trial	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for base and logistics requirements.	$0.9M
7A-4: Independent lifecycle and cost review	Independent review, acceptance finding and open technical archive for base and logistics requirements.	$0.6M

7B. Pilot maintenance facility - $14M

Procurement package	Deliverable	Estimate
7B-1: Base and lifecycle requirements	Documented pilot maintenance facility requirements, interfaces, success criteria, schedule and risk register.	$3.9M
7B-2: Facility, tooling, spares or service-system implementation	Design, hardware, software or service package for pilot maintenance facility, including test evidence and configuration records.	$4.8M
7B-3: Maintenance, logistics and resupply trial	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for pilot maintenance facility.	$3.2M
7B-4: Independent lifecycle and cost review	Independent review, acceptance finding and open technical archive for pilot maintenance facility.	$2.1M

7C. Spares, tooling and inventory systems - $8M

Procurement package	Deliverable	Estimate
7C-1: Base and lifecycle requirements	Documented spares, tooling and inventory systems requirements, interfaces, success criteria, schedule and risk register.	$2.2M
7C-2: Facility, tooling, spares or service-system implementation	Design, hardware, software or service package for spares, tooling and inventory systems, including test evidence and configuration records.	$2.7M
7C-3: Maintenance, logistics and resupply trial	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for spares, tooling and inventory systems.	$1.8M
7C-4: Independent lifecycle and cost review	Independent review, acceptance finding and open technical archive for spares, tooling and inventory systems.	$1.3M

7D. Automated cleaning and service connections - $8M

Procurement package	Deliverable	Estimate
7D-1: Base and lifecycle requirements	Documented automated cleaning and service connections requirements, interfaces, success criteria, schedule and risk register.	$2.2M
7D-2: Facility, tooling, spares or service-system implementation	Design, hardware, software or service package for automated cleaning and service connections, including test evidence and configuration records.	$2.7M
7D-3: Maintenance, logistics and resupply trial	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for automated cleaning and service connections.	$1.8M
7D-4: Independent lifecycle and cost review	Independent review, acceptance finding and open technical archive for automated cleaning and service connections.	$1.3M

7E. Resupply and deployment trials - $6M

Procurement package	Deliverable	Estimate
7E-1: Base and lifecycle requirements	Documented resupply and deployment trials requirements, interfaces, success criteria, schedule and risk register.	$1.7M
7E-2: Facility, tooling, spares or service-system implementation	Design, hardware, software or service package for resupply and deployment trials, including test evidence and configuration records.	$2M
7E-3: Maintenance, logistics and resupply trial	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for resupply and deployment trials.	$1.4M
7E-4: Independent lifecycle and cost review	Independent review, acceptance finding and open technical archive for resupply and deployment trials.	$0.9M

7F. Lifecycle and maintenance handoff - $10M

Procurement package	Deliverable	Estimate
7F-1: Base and lifecycle requirements	Documented lifecycle and maintenance handoff requirements, interfaces, success criteria, schedule and risk register.	$2.8M
7F-2: Facility, tooling, spares or service-system implementation	Design, hardware, software or service package for lifecycle and maintenance handoff, including test evidence and configuration records.	$3.4M
7F-3: Maintenance, logistics and resupply trial	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for lifecycle and maintenance handoff.	$2.3M
7F-4: Independent lifecycle and cost review	Independent review, acceptance finding and open technical archive for lifecycle and maintenance handoff.	$1.5M

8. Systems integration and multi-platform sea trials

8A. Master integration and verification planning - $6M

Procurement package	Deliverable	Estimate
8A-1: Verification plan and campaign design	Documented master integration and verification planning requirements, interfaces, success criteria, schedule and risk register.	$1.7M
8A-2: Integration facility or field operations	Design, hardware, software or service package for master integration and verification planning, including test evidence and configuration records.	$2M
8A-3: Vessel, aircraft, instrument and logistics services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for master integration and verification planning.	$1.4M
8A-4: Independent test witnessing and readiness review	Independent review, acceptance finding and open technical archive for master integration and verification planning.	$0.9M

8B. Systems-integration laboratory - $10M

Procurement package	Deliverable	Estimate
8B-1: Verification plan and campaign design	Documented systems-integration laboratory requirements, interfaces, success criteria, schedule and risk register.	$2.8M
8B-2: Integration facility or field operations	Design, hardware, software or service package for systems-integration laboratory, including test evidence and configuration records.	$3.4M
8B-3: Vessel, aircraft, instrument and logistics services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for systems-integration laboratory.	$2.3M
8B-4: Independent test witnessing and readiness review	Independent review, acceptance finding and open technical archive for systems-integration laboratory.	$1.5M

8C. Harbor and dockside campaign - $9M

Procurement package	Deliverable	Estimate
8C-1: Verification plan and campaign design	Documented harbor and dockside campaign requirements, interfaces, success criteria, schedule and risk register.	$2.5M
8C-2: Integration facility or field operations	Design, hardware, software or service package for harbor and dockside campaign, including test evidence and configuration records.	$3.1M
8C-3: Vessel, aircraft, instrument and logistics services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for harbor and dockside campaign.	$2.1M
8C-4: Independent test witnessing and readiness review	Independent review, acceptance finding and open technical archive for harbor and dockside campaign.	$1.3M

8D. Nearshore and coastal trials - $20M

Procurement package	Deliverable	Estimate
8D-1: Verification plan and campaign design	Documented nearshore and coastal trials requirements, interfaces, success criteria, schedule and risk register.	$5.6M
8D-2: Integration facility or field operations	Design, hardware, software or service package for nearshore and coastal trials, including test evidence and configuration records.	$6.8M
8D-3: Vessel, aircraft, instrument and logistics services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for nearshore and coastal trials.	$4.6M
8D-4: Independent test witnessing and readiness review	Independent review, acceptance finding and open technical archive for nearshore and coastal trials.	$3M

8E. Offshore endurance campaign - $15M

Procurement package	Deliverable	Estimate
8E-1: Verification plan and campaign design	Documented offshore endurance campaign requirements, interfaces, success criteria, schedule and risk register.	$4.2M
8E-2: Integration facility or field operations	Design, hardware, software or service package for offshore endurance campaign, including test evidence and configuration records.	$5.1M
8E-3: Vessel, aircraft, instrument and logistics services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for offshore endurance campaign.	$3.5M
8E-4: Independent test witnessing and readiness review	Independent review, acceptance finding and open technical archive for offshore endurance campaign.	$2.2M

8F. Multi-platform final demonstration - $20M

Procurement package	Deliverable	Estimate
8F-1: Verification plan and campaign design	Documented multi-platform final demonstration requirements, interfaces, success criteria, schedule and risk register.	$5.6M
8F-2: Integration facility or field operations	Design, hardware, software or service package for multi-platform final demonstration, including test evidence and configuration records.	$6.8M
8F-3: Vessel, aircraft, instrument and logistics services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for multi-platform final demonstration.	$4.6M
8F-4: Independent test witnessing and readiness review	Independent review, acceptance finding and open technical archive for multi-platform final demonstration.	$3M

9. Models, data platform and operations center

9A. Data governance and interfaces - $4M

Procurement package	Deliverable	Estimate
9A-1: Data governance and system requirements	Documented data governance and interfaces requirements, interfaces, success criteria, schedule and risk register.	$1.1M
9A-2: Model, digital twin or software platform	Design, hardware, software or service package for data governance and interfaces, including test evidence and configuration records.	$1.4M
9A-3: Cloud, data engineering and visualization services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for data governance and interfaces.	$0.9M
9A-4: Independent cyber, quality and open-source audit	Independent review, acceptance finding and open technical archive for data governance and interfaces.	$0.6M

9B. Digital twins and forecast tools - $8M

Procurement package	Deliverable	Estimate
9B-1: Data governance and system requirements	Documented digital twins and forecast tools requirements, interfaces, success criteria, schedule and risk register.	$2.2M
9B-2: Model, digital twin or software platform	Design, hardware, software or service package for digital twins and forecast tools, including test evidence and configuration records.	$2.7M
9B-3: Cloud, data engineering and visualization services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for digital twins and forecast tools.	$1.8M
9B-4: Independent cyber, quality and open-source audit	Independent review, acceptance finding and open technical archive for digital twins and forecast tools.	$1.3M

9C. Operations-center platform - $7M

Procurement package	Deliverable	Estimate
9C-1: Data governance and system requirements	Documented operations-center platform requirements, interfaces, success criteria, schedule and risk register.	$2M
9C-2: Model, digital twin or software platform	Design, hardware, software or service package for operations-center platform, including test evidence and configuration records.	$2.4M
9C-3: Cloud, data engineering and visualization services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for operations-center platform.	$1.6M
9C-4: Independent cyber, quality and open-source audit	Independent review, acceptance finding and open technical archive for operations-center platform.	$1M

9D. Data ingestion and quality control - $6M

Procurement package	Deliverable	Estimate
9D-1: Data governance and system requirements	Documented data ingestion and quality control requirements, interfaces, success criteria, schedule and risk register.	$1.7M
9D-2: Model, digital twin or software platform	Design, hardware, software or service package for data ingestion and quality control, including test evidence and configuration records.	$2M
9D-3: Cloud, data engineering and visualization services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for data ingestion and quality control.	$1.4M
9D-4: Independent cyber, quality and open-source audit	Independent review, acceptance finding and open technical archive for data ingestion and quality control.	$0.9M

9E. Integrated simulations and exercises - $6M

Procurement package	Deliverable	Estimate
9E-1: Data governance and system requirements	Documented integrated simulations and exercises requirements, interfaces, success criteria, schedule and risk register.	$1.7M
9E-2: Model, digital twin or software platform	Design, hardware, software or service package for integrated simulations and exercises, including test evidence and configuration records.	$2M
9E-3: Cloud, data engineering and visualization services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for integrated simulations and exercises.	$1.4M
9E-4: Independent cyber, quality and open-source audit	Independent review, acceptance finding and open technical archive for integrated simulations and exercises.	$0.9M

9F. Public archive and handoff - $4M

Procurement package	Deliverable	Estimate
9F-1: Data governance and system requirements	Documented public archive and handoff requirements, interfaces, success criteria, schedule and risk register.	$1.1M
9F-2: Model, digital twin or software platform	Design, hardware, software or service package for public archive and handoff, including test evidence and configuration records.	$1.4M
9F-3: Cloud, data engineering and visualization services	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for public archive and handoff.	$0.9M
9F-4: Independent cyber, quality and open-source audit	Independent review, acceptance finding and open technical archive for public archive and handoff.	$0.6M

10. Program management, safety, environmental review and independent assurance

10A. Program formation - $4M

Procurement package	Deliverable	Estimate
10A-1: PMO and systems-engineering support	Documented program formation requirements, interfaces, success criteria, schedule and risk register.	$1.1M
10A-2: Procurement, finance and project-controls services	Design, hardware, software or service package for program formation, including test evidence and configuration records.	$1.4M
10A-3: Safety, environmental and public-engagement support	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for program formation.	$0.9M
10A-4: Independent cost, technical and readiness review	Independent review, acceptance finding and open technical archive for program formation.	$0.6M

10B. Requirements and design oversight - $3M

Procurement package	Deliverable	Estimate
10B-1: PMO and systems-engineering support	Documented requirements and design oversight requirements, interfaces, success criteria, schedule and risk register.	$0.8M
10B-2: Procurement, finance and project-controls services	Design, hardware, software or service package for requirements and design oversight, including test evidence and configuration records.	$1M
10B-3: Safety, environmental and public-engagement support	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for requirements and design oversight.	$0.7M
10B-4: Independent cost, technical and readiness review	Independent review, acceptance finding and open technical archive for requirements and design oversight.	$0.5M

10C. Procurement and execution oversight - $4M

Procurement package	Deliverable	Estimate
10C-1: PMO and systems-engineering support	Documented procurement and execution oversight requirements, interfaces, success criteria, schedule and risk register.	$1.1M
10C-2: Procurement, finance and project-controls services	Design, hardware, software or service package for procurement and execution oversight, including test evidence and configuration records.	$1.4M
10C-3: Safety, environmental and public-engagement support	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for procurement and execution oversight.	$0.9M
10C-4: Independent cost, technical and readiness review	Independent review, acceptance finding and open technical archive for procurement and execution oversight.	$0.6M

10D. Test, safety and environmental oversight - $4M

Procurement package	Deliverable	Estimate
10D-1: PMO and systems-engineering support	Documented test, safety and environmental oversight requirements, interfaces, success criteria, schedule and risk register.	$1.1M
10D-2: Procurement, finance and project-controls services	Design, hardware, software or service package for test, safety and environmental oversight, including test evidence and configuration records.	$1.4M
10D-3: Safety, environmental and public-engagement support	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for test, safety and environmental oversight.	$0.9M
10D-4: Independent cost, technical and readiness review	Independent review, acceptance finding and open technical archive for test, safety and environmental oversight.	$0.6M

10E. Final readiness and Phase II planning - $5M

Procurement package	Deliverable	Estimate
10E-1: PMO and systems-engineering support	Documented final readiness and phase ii planning requirements, interfaces, success criteria, schedule and risk register.	$1.4M
10E-2: Procurement, finance and project-controls services	Design, hardware, software or service package for final readiness and phase ii planning, including test evidence and configuration records.	$1.7M
10E-3: Safety, environmental and public-engagement support	Validated measurements, integration results, operating data, deficiencies and corrective recommendations for final readiness and phase ii planning.	$1.2M
10E-4: Independent cost, technical and readiness review	Independent review, acceptance finding and open technical archive for final readiness and phase ii planning.	$0.7M

11. Central technical and schedule reserve

11A. Requirements reserve authority - $15M

Procurement package	Deliverable	Estimate
11A-1: Corrective design or second-source option	Contingent option for requirements reserve authority; may be activated only after documented failure, need and independent Funding Source approval.	$4.2M
11A-2: Replacement fabrication or test article	Contingent option for requirements reserve authority; may be activated only after documented failure, need and independent Funding Source approval.	$5.1M
11A-3: Additional integration or sea-trial option	Contingent option for requirements reserve authority; may be activated only after documented failure, need and independent Funding Source approval.	$3.5M
11A-4: Independent reserve-release review	Contingent option for requirements reserve authority; may be activated only after documented failure, need and independent Funding Source approval.	$2.2M

11B. Prototype redesign and second sources - $35M

Procurement package	Deliverable	Estimate
11B-1: Corrective design or second-source option	Contingent option for prototype redesign and second sources; may be activated only after documented failure, need and independent Funding Source approval.	$9.8M
11B-2: Replacement fabrication or test article	Contingent option for prototype redesign and second sources; may be activated only after documented failure, need and independent Funding Source approval.	$11.9M
11B-3: Additional integration or sea-trial option	Contingent option for prototype redesign and second sources; may be activated only after documented failure, need and independent Funding Source approval.	$8.1M
11B-4: Independent reserve-release review	Contingent option for prototype redesign and second sources; may be activated only after documented failure, need and independent Funding Source approval.	$5.2M

11C. Fabrication and platform reserve - $35M

Procurement package	Deliverable	Estimate
11C-1: Corrective design or second-source option	Contingent option for fabrication and platform reserve; may be activated only after documented failure, need and independent Funding Source approval.	$9.8M
11C-2: Replacement fabrication or test article	Contingent option for fabrication and platform reserve; may be activated only after documented failure, need and independent Funding Source approval.	$11.9M
11C-3: Additional integration or sea-trial option	Contingent option for fabrication and platform reserve; may be activated only after documented failure, need and independent Funding Source approval.	$8.1M
11C-4: Independent reserve-release review	Contingent option for fabrication and platform reserve; may be activated only after documented failure, need and independent Funding Source approval.	$5.2M

11D. Integration and sea-trial reserve - $45M

Procurement package	Deliverable	Estimate
11D-1: Corrective design or second-source option	Contingent option for integration and sea-trial reserve; may be activated only after documented failure, need and independent Funding Source approval.	$12.6M
11D-2: Replacement fabrication or test article	Contingent option for integration and sea-trial reserve; may be activated only after documented failure, need and independent Funding Source approval.	$15.3M
11D-3: Additional integration or sea-trial option	Contingent option for integration and sea-trial reserve; may be activated only after documented failure, need and independent Funding Source approval.	$10.3M
11D-4: Independent reserve-	Contingent option for integration and sea-trial reserve; may be	$6.8M

release review	activated only after documented failure, need and independent Funding Source approval.	

11E. Schedule recovery and final demonstration - $20M

Procurement package	Deliverable	Estimate
11E-1: Corrective design or second-source option	Contingent option for schedule recovery and final demonstration; may be activated only after documented failure, need and independent Funding Source approval.	$5.6M
11E-2: Replacement fabrication or test article	Contingent option for schedule recovery and final demonstration; may be activated only after documented failure, need and independent Funding Source approval.	$6.8M
11E-3: Additional integration or sea-trial option	Contingent option for schedule recovery and final demonstration; may be activated only after documented failure, need and independent Funding Source approval.	$4.6M
11E-4: Independent reserve-release review	Contingent option for schedule recovery and final demonstration; may be activated only after documented failure, need and independent Funding Source approval.	$3M

Recommended contracting structure

Issuing several hundred unrelated contracts would be inefficient. The Managing Organization should establish approximately ten prime or master vehicles corresponding to the major work packages, while retaining direct control of independent reviews and reserve releases. Detailed POs above would become task orders, subcontracts or research subawards under those vehicles.

Contract approach	Best use
Fixed-price milestone	Defined studies, standard equipment, vessel charter, calibration, final documentation and repeat production after design freeze.
Cost-reimbursement with ceilings	Novel generator development, vessel conversion, prototype instruments, autonomy software and uncertain field operations.
Indefinite-delivery task order	Engineering support, vessel days, aircraft hours, repair, calibration and contingent sea-trial options.
Grant or cooperative agreement	University and public-laboratory science, modeling, measurement development and independent analysis.
Challenge or staged competition	Competing generator concepts, autonomous platform concepts and instrument prototypes before down-selection.

Major hardware payments should be tied to tangible milestones, for example: 10% at contract initiation, 20% after requirements approval, 25% after preliminary design, 25% after fabrication and integration, and 20% after acceptance tests and complete delivery of data, drawings and software.

Purchase Order Recipients

Prompt to AI: With each purchase order or equivalent agreement, who might it be issued to?

Response From AI:

The organizations below are illustrative candidates, not endorsements, commitments or findings that they are available. The Managing Organization should normally solicit two to four qualified teams, evaluate technical merit, price, openness, conflicts and delivery record, and preserve competition through early prototype stages.

Government agencies and public laboratories would generally participate through reimbursable agreements, cooperative research agreements or university-affiliate subawards rather than ordinary commercial POs. Universities would usually receive sponsored-research agreements or subawards. Vessel builders, spray-equipment firms, engineering companies and software suppliers would receive conventional contracts or task orders.

Procurement area	Illustrative lead recipients	Supporting or independent organizations
1. Aerosol generators	SRI International; University of Washington MCB Program; Southern Cross University/RRAP; specialist atomization firms such as MeeFog or Spraying Systems Co.; competing university aerosol laboratories.	Armand Neukermans and collaborators; Daniel Harrison/Colin Medcraft nozzle work; NOAA, PNNL and NCAR measurement teams; independent aerosol metrology laboratory.
2. Seawater intake and conditioning	Worley; Jacobs; Black & Veatch; SRI; marine process-system integrators; qualified pump, membrane and filtration suppliers.	Alfa Laval, Pall, Parker, Eaton, Xylem, Grundfos or equivalent suppliers; CSIRO/AIMS marine-biofouling expertise; independent HAZOP firm.
3. Vessel/platform prototypes	Riverside Marine; Saildrone; Liquid Robotics; Kongsberg Maritime; Ocean Infinity; L3Harris ASV; Damen, Vard or other qualified shipyards.	Ron Allum Deepsea Services; SRI; naval-architecture firms; DNV, ABS or Lloyd's Register for independent class and marine safety.
4. Autonomy and fleet control	Saildrone, Kongsberg, Ocean Infinity, L3Harris ASV, Liquid Robotics, SRI or a competitively selected marine-autonomy consortium.	MITRE or Draper for owner-side systems engineering; NOAA/National Weather Service and NCAR for weather interfaces; independent cyber red team.
5. Power, mast and durability	Marine electrical and propulsion integrators; ABB Marine, Wärtsilä, Siemens Energy or equivalent; shipyard-led mast and duct team.	Corrosion and materials laboratories; DNV/ABS/Lloyd's; SwRI for environmental and structural testing; renewable-energy specialists.
6. Monitoring systems	University of Washington; NOAA laboratories; PNNL; NSF NCAR/UCAR; NASA atmospheric programs; CSIRO; AIMS; university cloud-observation groups.	Aerodyne, TSI, Droplet Measurement Technologies, Vaisala, Campbell Scientific and lidar/radar providers; independent NIST-linked metrology team.
7. Port and lifecycle logistics	Selected shipyard or marine base operator; Worley/Jacobs; Riverside Marine; offshore-service and logistics providers.	Spare-parts and computerized-maintenance suppliers; port authority; local emergency organizations; independent lifecycle-cost team.

8. Systems integration and sea trials	SRI, Battelle, Southwest Research Institute or a vessel-system integrator; UCAR field-campaign organization; Riverside Marine or another marine operator.	UW/NOAA/PNNL/NCAR science consortium; aircraft and drone operators; DNV/ABS/Lloyd's test witnesses; independent environmental monitor.
9. Models, data and operations center	UCAR/NCAR; NOAA/PNNL/UW model teams; MITRE or SRI for architecture; selected cloud and geospatial provider.	AWS, Microsoft or Google public-sector integrator; Esri; open-source software foundation; independent cybersecurity and data-quality auditor.
10. PMO and independent assurance	Battelle or RTI as candidate Managing Organization; MITRE, SRI, Draper or SwRI as owner's engineering partner.	National Academies-style scientific panel; independent audit firm; environmental consultant; Consensus Building Institute or Keystone Policy Center.
11. Reserve work	Competitively selected incumbent or second source best positioned to correct the documented problem.	Reserve-release review by an organization that receives no benefit from the corrective award.

Illustrative recipients by development phase

1. Sea-salt aerosol-generation systems

Activity	Possible recipient
Requirements and concepts	UW MCB Program, SRI, Southern Cross University, PNNL/NCAR aerosol scientists
Prototype fabrication	SRI, specialist nozzle/atomization companies, qualified precision manufacturers
Metrology and calibration	NOAA/PNNL/UW teams, TSI, Aerodyne, DMT, NIST-linked laboratory
Marine qualification	SwRI, shipyard integration team, DNV/ABS/Lloyd's
Independent acceptance	National Academies-selected experts or separately funded aerosol-engineering panel

2. Seawater intake, filtration and conditioning

Activity	Possible recipient
Requirements and characterization	CSIRO, AIMS, marine chemistry and biofouling laboratories
Process design	Worley, Jacobs, Black & Veatch or qualified marine-process firm
Equipment fabrication	Filtration, pump, valve and separator suppliers under selected integrator
Shipboard integration	Vessel prime with intake-system integrator
Independent process review	Exponent, SwRI or independent marine process-safety consultancy

3. Vessel and floating-platform prototypes

Activity	Possible recipient
Architecture and naval design	Independent naval architect plus prospective operators
Crewed vessel	Riverside Marine or another research/offshore operator and qualified shipyard
Autonomous vessel	Saildrone, Kongsberg, Ocean Infinity, L3Harris ASV or competing team

Long-endurance platform	Liquid Robotics, wave/solar platform team or university-industry consortium
Class and acceptance	DNV, ABS or Lloyd's Register reporting independently

4. Autonomy, navigation, weather routing and fleet control

Activity	Possible recipient
Concept and safety	MITRE, Draper or SRI owner-side systems team
Navigation and control	Selected autonomous-vessel developer
Weather targeting	UW, NOAA and NCAR science/software consortium
Cybersecurity	MITRE, Battelle or accredited maritime cybersecurity firm
Independent V&V	Separate software-assurance organization

5. Power, release mast, plume placement and marine durability

Activity	Possible recipient
Power architecture	Marine propulsion/electrical integrator
Hardware	ABB Marine, Wärtsilä, Siemens or qualified suppliers
Mast and ducts	Naval architect, shipyard and aerosol-generator team
Durability	SwRI, corrosion laboratory, DNV/ABS/Lloyd's
Lifecycle assessment	Independent energy and climate accounting team

6. Monitoring, verification and side-effect measurement

Activity	Possible recipient
Requirements	UW/NOAA/PNNL/NCAR/CSIRO science consortium
Prototype instruments	NOAA laboratories, university teams and commercial instrument suppliers
Remote sensing	NOAA, NASA, NCAR and specialized radar/lidar groups
Calibration	NIST-linked metrology consortium
Readiness audit	Independent international cloud-observation panel

7. Port, maintenance, resupply and lifecycle logistics

Activity	Possible recipient
Base design	Worley/Jacobs and selected port/shipyard
Facility implementation	Local EPC contractor under marine integrator
Maintenance systems	Vessel OEMs and computerized-maintenance supplier
Resupply trials	Marine operator and logistics providers
Cost review	Independent maritime lifecycle-cost specialist

8. Systems integration and multi-platform sea trials

Activity	Possible recipient
Test planning	SwRI, Battelle, MITRE or Aerospace-style independent systems team
Marine operations	Selected vessel operators and shipyard
Atmospheric observations	UW/NOAA/PNNL/NCAR/CSIRO/AIMS consortium
Campaign logistics	UCAR EOL or experienced marine field-campaign organization
Independent witnessing	DNV/ABS/Lloyd's plus environmental observer

9. Models, data platform and operations center

Activity	Possible recipient
Governance and interfaces	UCAR/NCAR and MITRE
Models	UW, NOAA, PNNL, NCAR and international university groups
Platform	Selected cloud/public-sector integrator
Visualization	Esri or open geospatial team
Open archive audit	Independent research-data and software-reproducibility team

10. Program management, safety, environmental review and independent assurance

Activity	Possible recipient
Managing organization competition	Battelle, RTI, SRI, Draper or qualified consortium
Owner's engineering	MITRE, SRI, Draper or SwRI
Audit and controls	Independent accounting, procurement and project-controls firms
Environmental/public work	Independent consultant plus CBI or Keystone
Readiness panel	National Academies-style committee with international participation

Recommended prime-contract arrangement

1. Managing Organization: Battelle or RTI selected competitively to hold the restricted funds, employ the program office, administer procurement and report to the Funding Source.
2. Owner's engineering and systems assurance: MITRE, SRI, Draper or Southwest Research Institute, contractually separated from major prototype production.
3. Aerosol and cloud science consortium: University of Washington, NOAA, PNNL, NSF NCAR/UCAR and selected international groups including Southern Cross University, CSIRO and AIMS.
4. Vessel and platform competition: separate early awards to at least three platform teams, followed by evidence-based down-selection.
5. Marine class and safety: DNV, ABS or Lloyd's Register hired directly by the Managing Organization or Funding Source rather than by the vessel builder alone.

6. Independent scientific, environmental, financial and open-data reviewers reporting to the Funding Source or a firewalled board committee.

Most important conflict-of-interest separations

- The aerosol-generator developer should not certify its own particle-size output or lifetime performance.
- The autonomous-vessel developer should not perform the final software safety and cybersecurity assessment.
- The vessel builder should not be the only organization deciding that the platform is safe for unattended operation.
- Instrument manufacturers should not be solely responsible for uncertainty certification and data exclusions.
- The atmospheric science team should not control the environmental approval of its own releases.
- The Managing Organization should not direct attractive technical work to itself or affiliates without competition and independent approval.

Project Management

Prompt to AI: In theory, a Project Manager would issue Purchase Orders specifying recipients, amounts, and deliverables. The Project Manager would be employed by a Managing Organization that receives money from the Funding Source. Who should be the Managing Organization and why?

Response From AI:

The Managing Organization should be an established independent nonprofit applied-research institute with large-program procurement, engineering, safety, environmental and audit capability. My leading candidate would be Battelle Memorial Institute, subject to a competitive selection, due diligence and creation of a legally and financially separated MCB program office. RTI International would be a strong alternative, particularly if paired with a marine and systems-engineering organization such as SRI, Draper, Southwest Research Institute or MITRE.

The Funding Source should not transfer $1 billion to a new organization or to a technical vendor simply because the idea is compelling. It should run a Managing Organization competition, fund a short transition and program-design phase, and release later tranches only after approved requirements and independent technical gates.

Candidate form	Suitability	Assessment
Established nonprofit applied-R&D institute	Excellent	Best balance of public-purpose mission, fiduciary controls, engineering management, procurement systems and ability to coordinate government, university and commercial performers.
Foundation	Good as Funding Source; weak as operator	Should define purpose, restrictions and milestones rather than build a marine engineering and field-operations organization internally.
University	Good technical recipient; weak sole manager	Excellent for science and instrument development, but creates conflicts when its own investigators compete for funds and is less suited to industrial fleet development.
Government laboratory or agency	Potentially excellent under public authorization	Valuable performer, but private philanthropic control, international participation and procurement may be constrained.
Commercial company	Strong execution; weak neutrality	Could build vessels or systems, but should not decide how the full research budget is allocated or accept its own work.
New nonprofit	Possible later; risky initially	Can be tailored, but lacks audited systems, staff, insurance, marine-safety history and comparable program experience.

Proposed organizational structure

Funding Source → restricted five-year agreement → Managing Organization → dedicated MCB Program Management Office → competitive contracts, cooperative agreements and research subawards. Three independent bodies should have separate reporting lines: a Scientific and Engineering Advisory Panel, a Safety/Environmental/Governance Board, and a Financial/Procurement Audit Committee.

Managing Organization responsibility	Independent body or Funding Source responsibility
Employ program director and project managers; maintain integrated schedule and budget.	Approve major requirements, annual tranches, reserve releases and changes in program purpose.
Issue solicitations, evaluate bids, negotiate contracts and inspect deliverables.	Appoint independent reviewers and receive unfiltered findings.
Maintain accounting, restricted cost centers, insurance, data and configuration records.	Commission financial, procurement, safety and open-data audits.
Coordinate contractors, scientists, vessels, field sites and testing.	Authorize or refuse outdoor releases through a separate environmental and governance process.
Suspend contractor work for poor performance or safety concerns.	Suspend or terminate the Managing Organization agreement and recover uncommitted funds.

How the Funding Source protects its money

Funding gate	Illustrative cumulative authority	Required evidence
MO transition and program design	$15M	Selected leadership, governance, accounting, conflict plan, draft requirements and procurement strategy.
Approved baseline program plan	$100M	Integrated technical baseline, cost estimate, schedule, risk register and open-data plan.
Requirements review	$250M	Generator, platform, monitoring and safety requirements independently validated.
Preliminary design review	$500M	Competing prototypes and designs justify major fabrication commitments.
Integrated test readiness	$750M	Subsystem qualification, environmental documentation and credible sea-trial plans.
Long-duration demonstration authorization	$925M	Safety, reliability, data and governance findings support final trial.
Acceptance and closeout	$1.000B	Open archive, accepted deliverables, independent audit and Phase II recommendation.

The agreement should use a separately identifiable restricted account or cost center, monthly cash and obligation reporting, prior approval for transfers among major work packages, negotiated pass-through

overhead, and no institutional fee on unused reserve. Trust should be enforced through structure and evidence, not reputation alone.

Managing Organization staffing and cost

A dedicated office of roughly 20 to 35 permanent staff could include a program director, deputy, project managers for each major workstream, systems engineers, procurement and finance personnel, marine safety and environmental leads, data/open-source staff, legal support and communications personnel. Many specialists would be hired part-time or through independent review contracts.

Management function	Illustrative five-year amount
PMO salaries and program operations	$6M
Systems engineering and configuration control	$3M
Procurement, finance and contract administration	$3M
Independent cost, technical and safety reviews	$3M
Financial, procurement and open-data audits	$2M
Scientific/engineering panels and public reporting	$2M
Phase II procurement and closeout	$1M

The $20 million owner-side allocation is deliberately lean because contractor management is embedded within each technical work package. The Funding Source should negotiate a fixed or capped management fee and a low pass-through rate on large contracts; otherwise ordinary institutional overhead could consume far more than the stated management budget.

Funding Source Requirements

Prompt to AI: What Funding Source requirements would maximize climate benefit per dollar spent? Should all funded designs, CAD files, software, test data, operating data, models, reports, and negative results be open-source and publicly available?

Response From AI:

Yes. Open publication should be the default because the principal charitable product is knowledge: designs that can be inspected, failed approaches that need not be repeated, measurements that improve models, and procurement information that allows governments and other funders to estimate future cost. However, "open-source" should be implemented through detailed contract clauses rather than a general promise.

Core Funding Source requirements

Requirement	Contractual implementation
Purpose limitation	Funds may be used only for approved Phase I equipment development, measurement capability, controlled tests and related analysis. No climate-scale operation or unapproved atmospheric release.
Stage-gated funding	Annual and technical tranches released after independent requirements, design, test-readiness and acceptance reviews.
Competitive procurement	Competition normally required above a defined threshold; written sole-source justification; independent review for major awards and affiliate transactions.
Deliverable-based payments	Payments tied to drawings, hardware, software, tests, datasets and accepted reports rather than labor hours alone.
Open technical record	Prompt publication of requirements, CAD, interface specifications, source code, test methods, raw and processed data, calibration records, model inputs, negative results and lessons learned.
Reproducibility	Each major result accompanied by metadata, uncertainty, software version, configuration identifier and enough information for an independent team to reproduce the analysis.
Independent measurement	Generator output, cloud-relevant particle size, energy use and reliability verified by a team that does not report to the developer.
Safety and environmental stop-work	Independent authority to pause hardware tests or releases when predefined safety, environmental or governance conditions are violated.
Conflict controls	Disclosure of financial, institutional and future-deployment interests; recusals; prohibition on contractors accepting their own deliverables.
Reserve control	Central reserve not committed to contractors; releases require a written problem statement, alternatives analysis, independent estimate and board approval.
Lifecycle accounting	Every platform reports energy use, emissions, consumables, waste, maintenance, staffing and lifecycle cost per unit of verified particle output and modeled radiative effect.
International participation	Meaningful participation by scientists and institutions from potentially affected regions, not

	merely consultation after designs are fixed.
Public reporting	Quarterly technical and financial dashboards, annual independent reviews, incident disclosure and a public register of awards, deliverables and data releases.
No presumption of continuation	Completion of five years creates no entitlement to Phase II. The final decision may be proceed, redirect, pause or stop.

Recommended open licenses and release timing

Material	Default license or access rule	Release target
Reports, manuals and educational material	CC BY 4.0	Draft at review; final within 30 days of acceptance.
CAD, drawings and interface specifications	CERN Open Hardware License, TAPR OHL or equivalent permissive hardware license	Within 60 days of acceptance, subject to narrow safety review.
Software and models	Apache 2.0, BSD-3-Clause or MIT license	Public repository during development; tagged release at each major review.
Raw and processed measurement data	Open data with persistent identifier, metadata and calibration records	Quick-look data within 30 days; validated data generally within 6 months.
Test videos, failures and incident records	Public unless a temporary safety or privacy exception is documented	Preliminary incident notice promptly; complete record after investigation.
Procurement and cost information	Public award amount, scope, milestones, change orders and final accepted cost	Within 30 days of award or change.
Patentable inventions	Prefer nonexclusive public-interest licensing; no exclusive control of the entire MCB system	Disclosure at filing; licensing terms published before commercialization.

Narrow exceptions may be justified for personally identifiable information, vessel cybersecurity details, export-controlled technology, active bid information, precise locations of vulnerable equipment or a short patent-filing period. Each exception should be written, time-limited and reviewed by an independent open-data officer. “Commercial sensitivity” alone should not justify indefinite secrecy for work paid for as a public-benefit research program.

Performance scorecard

Metric	Illustrative measure
Particle performance	Dry particle-number and mass distribution at defined distance and humidity; fraction in target size interval; stability over time.
Resource efficiency	Electrical and fuel energy, seawater flow, air flow, consumables and crew hours per 10^15 verified cloud-relevant particles.
Reliability	Mean time between critical failures, generator availability, cleaning interval and mission

	completion rate.
Control	Turndown range, shutdown time, output uncertainty, location/time accuracy and response to remote command.
Marine durability	Corrosion, biofouling, salt ingress, vibration, storm survival and maintenance burden.
Monitoring closure	Agreement among onboard output records, independent plume measurements and model reconstruction.
Open-science delivery	Percent of required datasets, code, CAD and reports released on time and independently reproducible.
Cost and schedule	Earned-value trends, forecast completion cost, change-order rate and reserve use.
Safety/environment	Incidents, near misses, unplanned releases, waste, noise, air emissions and compliance findings.
Climate relevance	Modeled radiative benefit per dollar and per unit lifecycle emission, with uncertainty and atmospheric assumptions clearly stated.

Top 25 Papers

Prompt to AI: Summarize the top 25 papers most relevant to the proposed MCB equipment-development fund.

Response From AI:

The list below emphasizes papers that define the required particle properties, describe spray hardware, evaluate plume transport and cloud response, establish field-experiment scales, or show why monitoring and model validation are necessary. "Top" is necessarily judgmental; these are not ranked solely by citation count. Several recent papers are especially equipment-relevant because they report actual nozzles, outdoor plume measurements or explicit field-study designs.

#	Paper or study	Why it matters to equipment development
1	Twomey (1977), "The influence of pollution on the shortwave albedo of clouds."	Foundational explanation of why more cloud droplets at fixed liquid water can increase cloud reflectivity. Equipment implication: particle number and activation matter, not merely salt mass.
2	Albrecht (1989), "Aerosols, cloud microphysics, and fractional cloudiness."	Introduces the possibility that added aerosol suppresses drizzle and changes cloud lifetime. Monitoring must therefore include precipitation, liquid water and cloud persistence.
3	Latham (1990), "Control of global warming?"	Early proposal to brighten marine clouds with seawater particles. Establishes the central engineering challenge of producing and distributing large numbers of appropriately sized particles.
4	Salter, Sortino and Latham (2008), "Sea-going hardware for the cloud albedo method of reversing global warming."	Classic engineering concept for wind-powered spray vessels and Flettner rotors. Valuable as an architecture study, but its assumptions require modern prototype validation.
5	Latham et al. (2008), "Global temperature stabilization via controlled albedo enhancement of low-level maritime clouds."	Connects marine spray systems to global climate response and highlights the scale of required operations.
6	Jones, Haywood and Boucher (2009), "Climate impacts of geoengineering marine stratocumulus clouds."	Shows that regional targeting can produce nonuniform temperature and precipitation effects. Equipment must support selective, weather-aware operation and independent impact monitoring.
7	Korhonen et al. (2010), "Enhancement of marine cloud albedo via controlled sea spray injections: a global model study of the influence of emission rates, microphysics and transport."	Demonstrates sensitivity to emission rate and particle microphysics; supports stringent particle-size and output specifications.
8	Partanen et al. (2012), "Direct and indirect effects of sea spray geoengineering and the role of injected particle size."	Shows that coarse particles can have different radiative effects and can compete with desired cloud activation. Generator distributions must minimize unwanted large-particle tails.
9	Latham et al. (2012), "Marine cloud brightening."	Comprehensive review covering physics, spray technology, modeling, field experiments and governance. It remains a central

		roadmap for staged research.
10	Stuart et al. (2013), “Reduced efficacy of marine cloud brightening geoengineering due to in-plume aerosol coagulation.”	Warns that concentrated plumes can lose particle number through coagulation. Release geometry and dilution must be designed and measured.
11	Alterskjær et al. (2013), “Sea-salt injections into the low-latitude marine boundary layer: the transient response in three Earth system models.”	Illustrates model disagreement and climate-response complexity; supports open model intercomparison and adaptable fleet targeting.
12	Cooper, Johnston and Neukermans (2014), “Preliminary results for salt aerosol production intended for marine cloud brightening.”	Directly addresses generation of cloud-relevant salt aerosol and is foundational for laboratory and ship-ready generator development.
13	Connolly et al. (2014), “Factors determining the most efficient spray distribution for marine cloud brightening.”	Examines particle size and spray distribution. Strongly relevant to nozzle selection, mast design and output optimization.
14	Kravitz et al. (2014), “Process-model simulations of cloud albedo enhancement by aerosols in marine stratocumulus.”	Shows how cloud-scale response depends on conditions and process representation, motivating tightly coupled observation and modeling.
15	Latham et al. (2014), “Marine cloud brightening: regional applications.”	Explores regional objectives and reveals that different targets demand different operating locations and schedules.
16	Robock et al. (2014), “Field experiments on solar geoengineering: report of a workshop exploring a representative research portfolio.”	Frames staged outdoor tests, governance and scale limits. Equipment trials should be embedded in an explicit research and review sequence.
17	Horowitz et al. (2020), MCB modeling and susceptibility studies using high-resolution cloud simulations.	Demonstrates that response is strongly state-dependent and that some clouds are poor targets. Equipment therefore needs weather-aware dispatch rather than continuous spraying.
18	Glassmeier et al. (2021), “Aerosol-cloud-climate cooling overestimated by ship-track data.”	Shows that short ship-track observations may overstate long-term cooling because cloud adjustments evolve with time. Monitoring must follow treated air masses beyond the initial brightening.
19	Diamond et al. (2022), ship-track observational studies of aerosol-cloud radiative effects.	Uses real shipping emissions as natural analogues. Provides measurement methods and cautions for interpreting bright tracks as a complete MCB response.
20	Haywood et al. (2023), “Climate intervention using marine cloud brightening compared with stratospheric aerosol injection in the UKESM1 climate model.”	Finds distinct regional responses and potential side effects, reinforcing the need for controllable location, season and intensity.
21	Hirasawa et al. (2023), “Effect of regional marine cloud brightening interventions on climate.”	Explores regional intervention patterns and climate teleconnections. Fleet-control software must preserve exact operational records for attribution.
22	Feingold et al. (2024), “Physical science research needed to evaluate the viability and risks of marine cloud brightening.”	Modern consensus-style research agenda identifying aerosol generation, plume evolution, cloud adjustments, observations and modeling as key gaps.
23	Rasch et al. (2024), “A protocol for model intercomparison of impacts of marine cloud brightening climate intervention.”	Provides a common framework for comparing climate models. Equipment and operations data should be formatted to support these standardized simulations.
24	Harrison, Medcraft and Harrison (2025), “Effervescent nozzle design to enable outdoor marine cloud brightening experimentation.”	Reports a concrete nozzle design and particle measurements for outdoor work. Directly informs competing generator prototypes, metrology and scale-up.
25	Hernandez-Jaramillo et al. (2025), “First	The field paper shows that a vessel-generated plume can reach

	generation outdoor marine cloud brightening trial increases aerosol concentration at cloud base height," together with Doherty et al. (2026), "Defining scales of field studies and experiments to assess marine cloud brightening."	cloud-base altitude in a relevant setting; the scale framework clarifies what progressively larger studies can and cannot establish. Together they define practical equipment and monitoring milestones.

Additional recent work worth tracking includes the 2025 review of plume dispersion and measurement techniques by Hernandez-Jaramillo, Kelaher and Harrison; Kainz, Harrison and Hoffmann's 2026 study "Marine cloud brightening of cumulus clouds: from the sprayer to the cloud"; observed-trajectory libraries for cloud-model evaluation; and 2026 ship-track model evaluations. These do not eliminate the need for experiments, but they improve the design of release height, plume sampling, atmospheric targeting and model-validation requirements.

Top Researchers and Organizations

Prompt to AI: Who are the top researchers, engineers, organizations, vessel designers, spray-technology groups, autonomous-marine-system developers, cloud-observation groups, and climate-modeling organizations relevant to this equipment program?

Response From AI:

The following names are illustrative candidates for consultation, competition or panel service. Inclusion is not an endorsement and does not imply willingness to participate. Current affiliations and conflicts should be verified before any appointment or solicitation. John Latham and Stephen Salter are listed as historical pioneers; they should not be presented as current program candidates.

Person	Affiliation or community	Relevant expertise
Robert Wood	University of Washington	Marine low-cloud observations, cloud regimes and field-program leadership.
Sarah J. Doherty	University of Washington	MCB research strategy, field-study scales, aerosol-cloud science and program coordination.
Philip J. Rasch	Pacific Northwest National Laboratory	Earth-system modeling, MCB model intercomparison and climate response.
Graham Feingold	NOAA Chemical Sciences Laboratory	Aerosol-cloud interactions, cloud adjustments and MCB research priorities.
Peter Blossey	University of Washington	Large-eddy simulation and marine cloud process modeling.
Hailong Wang	Pacific Northwest National Laboratory	Aerosol-cloud-climate modeling and MCB response.
Susannah Burrows	Pacific Northwest National Laboratory	Marine aerosol, sea spray and Earth-system model representation.
Armin Sorooshian	University of Arizona	Aircraft observations, marine aerosol-cloud interactions and field measurement.
Allison McComiskey	NOAA and atmospheric-observation community	Cloud and radiation observations, measurement strategy and program review.
Daniel P. Harrison	Southern Cross University / RRAP	Great Barrier Reef field trials, marine spray systems and regional MCB research.
Chris Medcraft	Southern Cross University collaborators	Nozzle design, atomization and sea-salt aerosol-generation engineering.
Luke Harrison	Australian MCB field program	Outdoor sprayer operation and aerosol plume observations.
Diana Hernandez-Jaramillo	Southern Cross University collaborators	Plume dispersion, measurement methods and field evaluation.
Brendan Kelaher	Southern Cross University	Marine field programs, environmental context and plume research.
Fabian Hoffmann	Cloud modeling community	Cloud-resolving simulations connecting sprayer plume

		to cloud response.
Armand Neukermans	SRI and MCB engineering collaborations	Early modern sea-salt aerosol-generator engineering and technology development.
David Rosenfeld	Hebrew University and collaborators	Cloud microphysics, precipitation and aerosol-cloud observations.
Zoran Ristovski	Queensland University of Technology	Aerosol measurement and marine field instrumentation.
Jim Haywood	University of Exeter / Met Office	Earth-system modeling and comparison of climate-intervention approaches.
Haruki Hirasawa	Climate modeling community	Regional MCB patterns, climate response and model experimentation.

Historical pioneers

Person	Contribution
John Latham	Proposed controlling warming by increasing marine cloud reflectivity and led foundational MCB science and field-research concepts.
Stephen Salter	Developed influential sea-going spray-vessel and engineering concepts, including wind-powered platforms and atomization systems.

Relevant Groups

Organization group	Potential role
University of Washington MCB Program	Cloud observations, process modeling, field-study design, aerosol generation and independent review network.
NOAA Chemical Sciences Laboratory and other NOAA laboratories	Aerosol-cloud measurements, atmospheric chemistry, remote sensing, weather and operational observations.
Pacific Northwest National Laboratory	Earth-system modeling, aerosol-cloud science and model intercomparison.
NSF NCAR / UCAR	Atmospheric modeling, aircraft and field-campaign support, data management and community coordination.
SRI International	Independent nonprofit R&D, spray-system engineering, systems integration and field technology.
Southern Cross University / Reef Restoration and Adaptation Program	Outdoor marine aerosol trials, nozzle development and Great Barrier Reef research.
CSIRO and Australian Institute of Marine Science	Marine science, environmental monitoring, field operations and regional impact assessment.
Queensland University of Technology / Airborne Research Australia	Aerosol instruments, aircraft observations and plume measurements.
NASA atmospheric research programs	Airborne remote sensing, radiometry, satellites and instrument validation.
National Academies of Sciences, Engineering, and Medicine	Independent consensus review, research-governance frameworks and program assessment.
Battelle, RTI, SRI, Draper, MITRE and	Potential nonprofit program management, owner's engineering, testing

Southwest Research Institute	and independent assurance.
DNV, American Bureau of Shipping and Lloyd's Register	Marine class, safety, autonomous-vessel assurance and test witnessing.
Saildrone, Liquid Robotics, Kongsberg Maritime, Ocean Infinity and L3Harris ASV	Autonomous or remotely operated marine-platform technology.
Riverside Marine and Ron Allum Deepsea Services	Australian vessel operations, marine engineering and field-program support.
Worley, Jacobs, Black & Veatch and marine process suppliers	Intake, filtration, port, utility and industrial process-system engineering.
TSI, Aerodyne Research, Droplet Measurement Technologies, Vaisala and related firms	Aerosol, cloud, meteorological and remote-sensing instruments.

Scientific and Engineering Advisory Panel

Prompt to AI: If a scientific and engineering panel were established to oversee development, who might serve on it?

Response From AI:

The panel should be small enough to deliberate but broad enough to challenge the program. I suggest 11 voting members, supported by temporary reviewers. Members should serve in their personal expert capacity, disclose conflicts, receive reasonable compensation, and be prohibited from voting on awards to their institutions. At least one-third should be from outside the United States, and no current major contractor should control the panel.

Seat	Illustrative member or profile	Primary responsibility
1. Marine cloud physics	Robert Wood or another senior marine low-cloud scientist	Cloud regimes, susceptibility and interpretation of observed response.
2. Aerosol-cloud interactions	Graham Feingold or equivalent NOAA/academic expert	Twomey effect, cloud adjustments and experiment closure.
3. Earth-system modeling	Philip Rasch or Hailong Wang	Regional/global response, model intercomparison and climate relevance.
4. Field-study design	Sarah Doherty or equivalent	Scale progression, observations, controls and stop/go criteria.
5. Aerosol-generation engineering	Independent atomization engineer; candidates from SRI or Australian nozzle programs	Particle production, metrology, scaling and manufacturability.
6. Marine systems and naval architecture	Senior autonomous-vessel/naval engineer without a bidder conflict	Platform architecture, survivability, power, maintenance and fleet cost.
7. Autonomy and cybersecurity	Independent marine autonomy and software-safety expert	Human authority, fault management, communications and cyber risk.
8. Atmospheric measurement	Armin Sorooshian, Allison McComiskey or equivalent	Aircraft, vessel, lidar, radar, radiation and calibration requirements.
9. Marine environmental science	AIMS/CSIRO or independent marine ecologist	Ocean, reef, coastal and ecological monitoring and thresholds.
10. Safety and reliability	DNV/ABS/Lloyd's or independent high-hazard systems expert	Class, system safety, reliability growth and incident review.
11. International/public-interest perspective	Scientist or engineer from a potentially affected region with no contractor role	Distributional effects, transparency, legitimacy and public-interest tradeoffs.

Panel powers and procedures

- Approve or reject top-level technical requirements and changes that materially increase output, autonomy or operating scale.

- Review competing concepts and recommend down-selection, replication or termination.
- Require independent calibration, blinded tests and second-source prototypes when evidence is weak.
- Receive safety, environmental and incident information directly, without editing by technical primes.
- Recommend pause or stop; an independent safety body should retain binding stop-work authority.
- Publish majority findings, minority views, conflicts and the evidence used for each major recommendation.
- Meet at least quarterly, with formal reviews at requirements, preliminary design, integration readiness and final demonstration.

The panel should advise on science and engineering quality. It should not negotiate contracts, approve invoices or act as the environmental regulator. Those functions belong to the Managing Organization, Funding Source and independent safety/governance process.

Management Advisory Panel

Prompt to AI: If a panel were established to oversee the agreement with the Managing Organization, who might serve on it and what powers should it have?

Response From AI:

This panel is different from the scientific and engineering panel. It protects the Funding Source against misuse, conflicts, uncontrolled scope expansion and poor program execution. I suggest a nine-member Governing and Fiduciary Board.

Seat	Background	Role
1-2	Funding Source representatives	Purpose, charitable restrictions, tranche decisions and donor accountability.
3	Large R&D program executive	Integrated management, schedule, risk and contractor performance.
4	Public procurement and contracting expert	Competition, sole-source justifications, claims and change-order controls.
5	Audit and nonprofit finance expert	Restricted funds, cost allocation, pass-through overhead and fraud controls.
6	Marine industrial program expert	Vessel construction, maintenance, ports and lifecycle execution.
7	Safety and environmental governance expert	Independent stop-work, incident review and authorization boundaries.
8	International law or diplomacy expert	Transboundary consultation, maritime zones and multinational legitimacy.
9	Independent public-interest member	Transparency, community concerns and distributional effects.

Recommended board powers

Decision	Authority
Hire, evaluate or remove the Program Director	Board, with Funding Source concurrence.
Approve annual operating plan and budget	Board; Funding Source releases corresponding tranche.
Approve awards above $25 million	Board procurement committee after independent review.
Approve awards above $50 million or affiliate awards	Board plus explicit Funding Source concurrence.
Release central reserve above $5 million	Board after independent technical and cost finding; larger releases require Funding Source approval.
Change major output, autonomy or fleet requirements	Board after scientific/engineering and safety reviews.
Authorize outdoor atmospheric release	Not this board alone; separate environmental/governance authorization

	is required.
Suspend payments or contractor work	Program Director for urgent action; board reviews promptly.
Suspend or terminate the MO agreement	Funding Source, on board recommendation or defined default.
Publish reports and minority findings	Mandatory; board cannot suppress independent technical or safety conclusions.

Suggested procurement thresholds

Threshold	Control
Above $250,000	Documented price reasonableness and conflict review.
Above $1 million	Normally seek at least three qualified bids or document why fewer exist.
Above $10 million	Independent procurement and cost review.
Above $25 million	Board approval.
Above $50 million	Funding Source concurrence.
Any sole-source affiliate award	Independent fairness opinion, recusal, board approval and Funding Source concurrence.
Any reserve release	Written failure/need, alternatives, independent estimate, residual-risk statement and public summary.

Agreements

Prompt to AI: In theory, there would be an agreement between the Funding Source and Managing Organization, and agreements between the Managing Organization and recipients of Purchase Orders. What might those agreements look like?

Response From AI:

The examples below are planning outlines, not legal advice or final contracts. Counsel would need to adapt them to the Funding Source, Managing Organization, jurisdiction, tax status, government partners, vessel operations, intellectual-property law, insurance and the precise scope of outdoor testing.

A. Funding Source to Managing Organization agreement

Article	Principal terms
Parties and purpose	Identify the Funding Source and Managing Organization; restrict funds to the five-year MCB equipment-development program and approved companion activities.
Term and maximum funding	Five years plus closeout; authorization up to $1 billion but no obligation to release later tranches absent accepted gates.
Program baseline	Attach approved requirements, work-package budgets, integrated schedule, risk register, governance chart and open-data plan.
Funding tranches	Define initial amount and later releases at requirements, design, build, test-readiness and acceptance gates.
Restricted account and allowable costs	Separate cost center; allowable-cost rules; prohibited lobbying, unrelated activity, climate-scale deployment and unauthorized releases.
MO fee and overhead	Fixed/capped management fee, approved PMO costs, low pass-through rate on major subcontracts and no fee on unused reserve.
Procurement rules	Competition thresholds, cost/price analysis, sole-source documentation, affiliate restrictions, board approvals and Funding Source concurrence levels.
Technical governance	Scientific/engineering panel, independent safety board, configuration control and formal decision records.
Environmental and release boundary	Equipment development does not authorize atmospheric release; each outdoor campaign requires separate review, permits and written authorization.
Data, IP and open source	Funding Source receives broad rights; public release requirements, licenses, repository standards, exceptions and enforcement.
Reporting	Monthly financial and obligation report; quarterly technical dashboard; annual audited statements; prompt incident and litigation notice.
Audit and access	Funding Source and independent auditors may inspect accounts, contracts, technical records, facilities and accepted deliverables.
Reserve	Held centrally; release procedure, approval thresholds, public summary and return of unused balance.

Conflicts	Disclosure, recusal, affiliate transaction rules, future-deployment interests and whistleblower protections.
Insurance, liability and indemnity	Marine, aviation where applicable, pollution, cyber, workers compensation and professional liability; allocation tailored to each activity.
Stop-work and suspension	Immediate safety authority; Funding Source suspension for default, drift, nondisclosure, misuse or loss of charitable purpose.
Termination and transition	Termination for convenience or cause; return of unspent funds; transfer of data, hardware, contracts and records to successor.
Dispute resolution	Escalation, mediation/arbitration or courts; urgent safety and data-release rights remain enforceable.
No promise of deployment	Explicit statement that success does not authorize Phase II, deployment or continued funding.

Illustrative Funding Source to MO payment schedule

Milestone	Maximum cumulative funding	Acceptance evidence
Transition agreement effective	$15M	PMO leadership, restricted accounting, governance and 180-day work plan.
Program baseline approved	$100M	Requirements, procurement plan, open-data policy, schedule and independent cost estimate.
Requirements review accepted	$250M	Validated generator, platform, monitoring and environmental boundaries.
Preliminary design review accepted	$500M	Prototype evidence and approved major fabrication plan.
Integrated test readiness accepted	$750M	Qualified subsystems, sea-trial plan, insurance, safety and independent review.
Final long-duration trial authorized	$925M	Reliability evidence, release authorization where applicable and complete monitoring plan.
Final deliverables accepted	$1.000B	Open archive, audits, accepted hardware/data and Phase II decision package.

B. Managing Organization to contractor or research recipient agreement

Clause	Illustrative requirement
Statement of work	Specific deliverables, interfaces, performance ranges, quantities, dates and excluded activities.
Technical baseline	Approved requirements, drawings, software versions, measurement uncertainty and configuration control.
Milestones and payments	Progress payments tied to reviews, fabrication, delivery, tests, correction and final acceptance.
Acceptance criteria	Objective tests, data completeness, independent witnessing, documentation and correction period.
Cost and schedule controls	Ceiling price, authorized rates, change-control procedure, forecast updates and

	notification of variance.
Open data and technical rights	Delivery of native CAD, source code, bills of material, calibration, raw data, negative results and public-release license.
Background IP	Identify pre-existing tools; grant rights needed to test, maintain, reproduce and compete later work.
Foreground IP	Prefer public ownership or nonexclusive public-interest licenses; prohibit blocking follow-on research.
Safety and environmental duties	Hazard analyses, permits, training, incident reporting, waste, emergency response and stop-work obligations.
Outdoor release restriction	No aerosol release except the mass, place, time, material and procedure separately authorized in writing.
Quality assurance	Inspection, traceability, calibration, supplier control, nonconformance reporting and corrective action.
Cybersecurity and command authority	Access control, software assurance, remote-command logging, vulnerability disclosure and safe state.
Subcontracting	Prior approval for critical subcontracts; flow-down of open-data, audit, safety and conflict clauses.
Audit and records	MO and Funding Source access; retention for at least ten years or longer if legally required.
Personnel and conflicts	Key-person commitments, conflict disclosure, publication rights and prohibition on undisclosed deployment interests.
Warranty and correction	Repair, replacement, software correction and data correction obligations after failed acceptance.
Termination	Termination for convenience/default; payment for accepted work; delivery of incomplete work, data and hardware.
Public communications	Accurate description as research; no claim of endorsement, safety approval or deployment authorization.
Disputes	Escalation and resolution without suspending urgent safety, preservation or data-delivery duties.

Recommended contract types by work

Work	Likely instrument	Reason
Requirements, design studies and independent reviews	Fixed-price milestone	Deliverables and review criteria can be defined.
Novel aerosol generators and vessel prototypes	Cost-reimbursement with ceiling and milestone holdbacks	Technical discoveries may require iteration, but spending and outputs remain controlled.
Standard instruments, filters, pumps and components	Fixed-price purchase or framework agreement	Commercial specifications and acceptance tests are available.
Vessel days, aircraft hours and field operations	Task-order or time-and-materials with not-to-exceed limits	Weather and field conditions make exact utilization uncertain.
University/public-laboratory science	Grant, cooperative agreement or subaward	Supports investigator-led analysis while preserving required data and deliverables.
Contingency work	Prepriced option or competed	Allows rapid action without treating

	corrective task order	reserve as committed revenue.

Example deliverable language

Weak: “Contractor will work on an MCB sprayer for three years for $20 million.”

Stronger: “Contractor shall design, fabricate and test a marine-ready sea-salt aerosol generator meeting the attached output, particle-size, power, corrosion, control and data requirements. Deliverables include native CAD, bill of materials, source code, calibration records, raw and processed test data, failure logs, operating manuals, manufacturing-cost estimate and an independent acceptance-test report. Payments are subject to the milestone and holdback schedule.”

The agreement should avoid guaranteeing an unverified climate outcome. Engineering contractors can be held accountable for measured output, reliability, energy use, controls and data; climate efficacy must be evaluated through the separate scientific program with stated uncertainty.

Selected Sources and Program References

This document was developed from the supplied MCB Reflectivity Plan, the companion MCB Research Experiments fund document, the supplied SAI equipment-development structure, and publicly available scientific and organizational sources. The URLs below are included for readers who wish to verify or expand the planning assumptions. Current personnel, programs, products and availability should be rechecked before procurement.

Source	URL
MCB Reflectivity Plan by Glenn Weinreb	https://ma2life.org/g/film/MCB_Reflectivity_Plan.pdf
National Academies, Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance	https://nap.nationalacademies.org/catalog/25762/reflecting-sunlight-recommendations-for-solar-geoengineering-research-and-research-governance
Feingold et al. 2024, Physical science research needed to evaluate the viability and risks of MCB	https://www.science.org/doi/10.1126/sciadv.adi8594
Doherty et al. 2026, Defining scales of field studies and experiments to assess MCB	https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2025AV001939
Latham et al. 2012, Marine cloud brightening	https://royalsocietypublishing.org/doi/10.1098/rsta.2012.0086
Salter et al. 2008, Sea-going hardware for the cloud albedo method	https://royalsocietypublishing.org/doi/10.1098/rsta.2008.0136
Cooper et al. 2014, Preliminary results for salt aerosol production	https://royalsocietypublishing.org/doi/10.1098/rsta.2014.0055
Connolly et al. 2014, Factors determining the most efficient spray distribution	https://royalsocietypublishing.org/doi/10.1098/rsta.2014.0056
Harrison et al. 2025, Effervescent nozzle design	https://doi.org/10.1039/D5EA00073D
Hernandez-Jaramillo et al. 2025, First generation outdoor MCB trial	https://doi.org/10.1088/1748-9326/adccd7
Rasch et al. 2024, MCB model intercomparison protocol	https://doi.org/10.5194/gmd-17-7963-2024
University of Washington Marine Cloud Brightening Program	https://mcbproject.org/
Southern Cross University marine cloud brightening research	https://www.scu.edu.au/research/research-impact/marine-cloud-brightening/
Saildrone autonomous ocean platforms	https://www.saildrone.com/
Liquid Robotics Wave Glider	https://www.liquid-robotics.com/
NOAA uncrewed systems and autonomous surface-vessel programs	https://www.omao.noaa.gov/uncrewed-systems

Closing observation

The most important product of the $1 billion would not be one impressive vessel. It would be an open, independently verified engineering system: given a platform, seawater condition, generator

configuration, weather state and authorized operating plan, the program should be able to predict and measure particle output, energy use, plume behavior, maintenance burden, reliability, cost and uncertainty. It should also reveal clearly where the technology does not work or where atmospheric and environmental uncertainty remains too large to justify scale-up.

A successful Phase I would therefore end with a decision package, not a deployment decision. The package should show what was built, what was measured, what failed, what remains uncertain, what Phase II would cost, what monitoring and governance would be required, and whether the public benefit of proceeding appears greater than the risks and opportunity cost.

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