

**Mass Launch System
for L1 Solar Geoengineering**
Concept Proposal

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Table of Contents

A. Geoengineering Climate	1
1. Moral Hazards	1
2. Geoengineering Options	2
3. Space-Based Geoengineering Technologies	4
B. Mass Launch System (MLS)	5
1. MLS Concept	5
2. MLS Rockets	6
3. MLS Spaceport Design	7
C. MLS Spaceport Examples	8
1. Western Australia Spaceport	8
2. Congo River Spaceport	10
3. Solar vs Hydroelectric MLS	12
D. Costs and R&D Priorities	12
1. MLS Launch Costs	12
2. MLS R&D Priorities	13

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A. Geoengineering Climate

1. Moral Hazards

It’s time to get serious about solar geoengineering, our best hope to reverse global warming. With the failure of 2021 COP26 talks to agree to limit global warming to 1.5° C, the planet is on track to reach to 2.4°C the end of this century, despite net zero pledges. We’re headed for a world of hurt—tornados & hurricanes, floods, droughts, heatwaves, megafires, permafrost thaw, Greenland and Antarctic ice loss, sea level rise, acidic oceans, ecosystem collapse, food insecurity, and climate refugees—tipping points from which there is no return.

Global warming is a supreme example of “the tragedy of the commons¹” where selfish actions degrade a common resource—in this case, a stable, benign climate—and all suffer more in the end. Humans caused climate change and we must be smart enough to fix it.

We shouldn’t waste time debating the moral hazards of geoengineering²—that it will detract from efforts to curb fossil fuel use. Some fear that tampering with climate could lead to

¹ Boyle, Michael J. (2020) “[Tragedy Of The Commons](#)” Investopedia Economics

² Keith, David (2013) “[A Case for Climate Engineering](#)” MIT Press

unintended consequences, while proponents point out that our efforts to reduce greenhouse gases will not be enough. Both views are likely correct.

But, when and how do we declare a climate crisis? Climate change has arrived faster than most imagined. All mitigation strategies should move forward in parallel, including reduction of GHG emissions, regeneration of forests, iron fertilization of the ocean, clean energy technologies, carbon capture & storage, and geoengineering to reduce sunlight. All potential solutions face significant risks, engineering hurdles, and costs. It's time to test ideas—not dismiss them.

There is near-universal support for CO₂ emissions reduction. But even if we stop burning coal and hydrocarbons, that will only slow global warming. Carbon dioxide removal from the atmosphere may also be too slow. Geoengineering of sunlight is the only technology capable of *reversing* global warming and *cooling* the planet in time. However, solar geoengineering is a controversial idea and was dropped from the UN's IPCC report³.

Even if solar geoengineering is successful in reversing global warming, it will not stop ocean acidification. In the long-term, marine ecosystem collapse⁴ may be a threat just as serious as global warming on land. We must redouble our efforts at emissions control and continue development of technologies for atmospheric carbon capture and storage, iron fertilization of the ocean, and ocean de-acidification.

2. Geoengineering Options

2.1 Carbon Capture Geoengineering

Carbon capture and storage has the potential to slow or reverse global warming. There are three types of carbon capture systems:

- **Post-Combustion CO₂ Capture⁵:** This technology is used to remove CO₂ from flue gas when fossil fuels are burned. This process can only slow global warming, not reverse it to cool the planet. The experimental carbon capture project at the Petra Nova coal burning plant in Texas was shut down in June 2021, since it was not economic.
- **Direct Air CO₂ Capture⁶:** This technology is designed to remove CO₂ from the atmosphere. It has the potential to actively cool the climate. Project Orca was launched in Iceland in September 2021. This process has major challenges, including energy requirements, scalability to remove sufficient CO₂, and technology costs.
- **Biological CO₂ Capture:** The Scripps Keeling Curve⁷ of atmospheric CO₂ concentration shows a steady rise from 1956 to the present time. The sharp downward dips of the saw-tooth curve represent springtime photosynthesis of the boreal forest in the northern

³ IPCC Special Report 2021 "[Global Warming of 1.5 °C](#)"

⁴ Rothman, Daniel 2021 "[MIT geophysicist warns oceans are on the brink](#)" The Times of Israel

⁵ (2020) "[Post-Combustion CO₂ Capture](#)" National Energy Technology Laboratory, US Dept of Energy

⁶ (2021) "[The world's largest climate-positive direct air capture plant](#)" Climeworks

⁷ (1956-2021) "[Scripps CO₂ Program](#)" Scripps Institute of Oceanography

hemisphere—trees rapidly remove CO₂ from the atmosphere during the growing season. Selective harvesting of mature trees can increase forest photosynthesis from new growth⁸. When harvested wood is used in construction, carbon removed from the atmosphere is stored in buildings. Iron fertilization of the ocean⁹ to promote growth of phytoplankton is also a potential method to remove CO₂ from the atmosphere.

2.2 Atmospheric Solar Geoengineering

Atmospheric geoengineering—increasing Earth’s albedo by adding particles to the upper atmosphere to partially reflect sunlight back into space—was inspired by the Mt. Pinatubo volcanic eruption of 1991, where sulfur aerosols lowered global temperatures by about 0.5 °C for two years. Proponents maintain that stratospheric SO₂ would be a quick and inexpensive method to slow or reverse global warming, giving time for other solutions to work. Opponents worry that sulfuric acid may cause ozone depletion¹⁰ or other environmental problems. A safer alternative is Australia’s experiments with local cloud brightening¹¹. Small-scale experiments to verify the safety and efficacy of atmospheric geoengineering should begin immediately.

2.3 Space-Based Solar Geoengineering

A better but more expensive long-term solution to global warming is space-based geoengineering. This would employ trillions of robotic solar-sailing mirrors or diffusers. These would orbit between the Sun and the Earth at the Lagrange One (L1) point, and would cast a diffuse penumbra shadow slightly larger than the diameter of the Earth, cooling the whole planet. Although L1 is a neutral gravity point between the Earth and the Sun, satellites deployed in the L1 region must use active station-keeping to maintain position (by raising or lowering orbital altitude). L1 objects pose no threat to the chemistry of the Earth’s atmosphere¹².

A key advantage of solar sailing mirrors at L1 is that they can dynamically modulate the amount of sunlight reaching Earth, changing solar intensity in minutes as individual mirrors tip edgewise to vary sunlight. Shadowing could be stopped temporarily by moving the solar sails away from L1. Tuning L1 orbits can reduce latitudinal and seasonal¹³ temperature changes or shade the poles preferentially. Spectral filtering of sunlight could stabilize precipitation patterns.

Another advantage of robotic mirrors at L1 is that they could be used as a “global thermostat.” Not only can space shaders reduce sunlight to cool the Earth, they can also be used to warm the planet when needed. Analysis of ice core sediments has shown that sudden cooling from ancient

⁸ Paradis, Gregory (2021) “[Young forests will likely have a higher rate of carbon capture rate than older stands](#)” UBC Faculty of Forestry; CBC Radio Quirks & Quarks

⁹ Emerson, David (2019) “[Biogenic Iron Dust: A Novel Approach to Ocean Iron Fertilization as a Means of Large-Scale Removal of Carbon Dioxide from the Atmosphere](#)” Bigelow Laboratory for Ocean Sciences

¹⁰ Richter, Jadwiga H.; et al. (2017) “[Stratospheric Dynamical Response and Ozone Feedbacks in the Presence of SO₂ Injections](#)” American Geophysical Union

¹¹ Tollefson, Jeff (2021) [Can artificially altered clouds save the Great Barrier Reef?](#) Nature News Feature

¹² Keith, David; et al. (2020) “[Reflections on a Meeting about Space-Based Solar Geoengineering](#)” Harvard’s Solar Geoengineering Research Program, Harvard University

¹³ Sánchez, Joan-Pau; McInnes, Colin (2015) “[Optimal Sunshade Configurations for Space-Based Geoengineering near the Sun-Earth L1 Point](#)” PLOS ONE

volcanic eruptions has led to prolonged droughts, political and social turmoil, and the collapse of early civilizations¹⁴. New eruptions like Mt. Pinatubo in 1991, which cooled the Earth about 0.5° C, are certain to occur in the future. When they do, solar sailing mirrors at L1 could tip or move aside to restore sunlight to counteract sudden global cooling. Ironically, it may be advantageous for the atmosphere to have a surplus of CO₂ to provide for rapid rewarming in the event of sudden cooling from volcanic eruptions (or a nuclear winter).

Space-based geoengineering also can be used for regional climate control, using additional flocks of mirrors in low Earth orbit (LEO) to selectively heat or cool specific areas of the globe. Not only can space-based solar sails counteract global warming, they have the potential to more than double the arable and habitable land on Earth.

Comparison of Solar Geoengineering Technologies

Atmospheric Geoengineering	Space-Based Geoengineering
• Rapid, polluting, hard to control	• Slow, expensive & clean
• Modest costs – low tech	• Expensive – high tech & risky
• Short-term, continual replenishment	• Long-term, centuries lifetime
• Alters atmospheric chemistry	• No change to atmospheric chemistry
• Threat to the ozone layer	• No threat to the ozone layer
• Cannot rapidly modulate sunlight	• Can tune sunlight in minutes
• Cannot do regional climate control	• Enables regional climate control
• No increase of arable/habitable land	• Can double arable/habitable land
• Will not save ocean ecosystems	• Will not save ocean ecosystems

3. Space-Based Geoengineering Technologies

There are three possible types of space-based L1 geoengineering technologies:

- solar sailing mirrors that reflect sunlight;
- optical diffractors that divert a percentage of sunlight away from Earth;
- hybrid solar sails with mirrors and diffractors.

Robotic solar sails to block and reflect sunlight are flexible L1 climate control technology. Each small mirror disc would have an on-board solar cells, a CPU, a radio receiver, and micromirror arrays¹⁵ (or liquid crystal panels) to vector sunlight for steering. They could be mass produced using photolithography on thin-film silicon deposited on a mylar substrate (similar to PV solar cells). Once placed in LEO, the space mirrors can use sunlight to sail to the L1 parasol orbit around the sun to shade the Earth, without requiring extra fuel. Robotic space mirrors are proven technology—the Japanese IKAROS solar sail flew to Venus in 2010¹⁶. NASA is currently developing a Solar Cruiser¹⁷ light sail for flight demonstration in 2025.

¹⁴ Leslie, Jacques (2021) “[Climate Clues from the Past Prompt a New Look at History](#)” YaleEnvironment360, Yale School of the Environment

¹⁵ Mignardi, Michael A.; (1994) “[Digital micromirror array for projection TV](#)” Solid State Technology, vol.37. no. 7

¹⁶ Howell, Elizabeth; (2014) “[Ikaros: First Successful Solar Sail](#)” Space.com

¹⁷ (2021) “[Solar Sail Propulsion: Enabling New Destinations for Science Missions](#)” NASA

Solar sails at L1 has been proposed by Christer Fuglesang and María García de Herreros Miciano in a 2021 paper titled “Realistic sunshade system at L1 for global temperature control.”¹⁸ They specify 1.5 billion solar sails, each with an area of 2,500 square meters (≈ 56.5 m diameter). In the optimal case, the total mass at L1 would be 83 million tonnes (83 billion kg). Solar sails must handle radiation pressure from the sun, as well as solar flares and CMEs.

An alternative to reflective mirrors was proposed by Roger Angel, who published a paper in 2006 titled “Feasibility of cooling the Earth with a cloud of small spacecraft near L1.”¹⁹ Angel’s system was designed to block 1.8 percent of the solar flux with “trillions of small free-flying spacecraft [“flyers”] in a cylindrical cloud with a diameter about half that of Earth, and about 10 times “longer.” These robotic spacecraft would be made of transparent material used to refract the sunlight (rather than reflect it) so that some of it misses the Earth, thus cooling the planet. Each flyer would use 0.1-meter-long protruding electronic ears for steering. Angel’s study specified a constellation of 20 trillion flyers at L1, each weighing 1 gram (about the mass of a large butterfly), with a total mass of “20 million tonnes” (20 billion kg).

B. Mass Launch System (MLS)

1. MLS Concept

L1 solar sails cannot be manufactured in space or on the Moon in time to avert a climate crisis—Earth manufacturing is our only near-term option. This means that space-based geoengineering will require a large expansion of Earth-launch capacity, either by using larger rockets, or by a high launch rate of many smaller rockets. But rockets can barely reach orbit with a payload.

Big rockets—e.g., the Delta IV Heavy²⁰, or SpaceX’s forthcoming Starship Launch System²¹—can carry ever-larger payloads. SpaceX’s Starship and BN4 booster stands 120 m tall and requires 4,800 tonnes of fuel. Enormous size makes it difficult to rapidly stack, refuel, and relaunch heavy-lift rockets—big rockets are not necessarily better.

As an alternative to larger rockets, a Mass Launch System (MLS) could be designed to maximize the launch rate of smaller, reusable rockets. Compared to SpaceX’s Super Heavy Booster with 33 Raptor engines, boosters with a single engine carry only 3% of the risk of an engine failure. A high launch rate could maximize payloads to LEO while reducing launch costs per kilogram.

The proposed MLS conceptual design is based on first-stage boosters with the equivalent of a single RS-68A rocket engine²² (currently used in the Delta IV Common Booster Core²³), but

¹⁸ Fuglesang, Christer; María García de Herreros Miciano (2021) “[Realistic sunshade system at L1 for global temperature control](#)” Elsevier Acta Astronautica 186 (2021) 269-279

¹⁹ Angel, Roger; (2006) “[Feasibility of cooling the Earth with a cloud of small spacecraft near the inner Lagrange point \(L1\)](#)” PNAS Proceedings of the National Academy of Sciences

²⁰ “[Delta IV Heavy](#)” Wikipedia

²¹ “[SpaceX Starship](#)” Wikipedia

²² “[RS-68 \(Rocket System 68\)](#)” Wikipedia

²³ “[Common Booster Core](#)” Wikipedia

upgraded for recovery and reuse. A single MLS two-stage rocket would be able to launch a payload of about 10,000 kg into LEO, or 10% of SpaceX's Starship Launch System payload.

The MLS could sustain rocket launches every five minutes, year-round—allowing one rocket to reach LEO before the next launch. This implies 288 launches per day, or 105,120 launches per year—a 1,000-times increase over 2020, when there were only 104 successful rocket launches to orbit worldwide. A high launch rate will reduce the time needed to deploy space mirrors at L1.

Compared to a single Delta IV Heavy launch, which can put 28,370 kg into LEO, the MLS can launch about 2,880,000 kg into LEO per day—over one million tonnes per year—about 100 times more. Compared to a SpaceX Starship Heavy launch, which can put 100,000 kg into LEO, the MLS can launch 28.8 times more.

In this concept proposal, calculations of launch requirements to L1, for both robotic space mirrors or Angel's flyers, are based on the estimates presented in Angel's 2006 paper. For estimation purposes, the number and weight of robotic space mirrors needed at L1 is assumed to be equal to Angel's flyers: 20 trillion flyers weighing 20 million tonnes (20 billion kg). At a launch rate of 1,051,200 tonnes per year, the MLS would take about 19 years to launch all of Angel's flyers or robotic space mirrors. In comparison, the SpaceX Starship Heavy rocket, which can put 100,000 kg in orbit, would require about 10,000 launches—or about 548 years (assuming one launch per day).

2. MLS Rockets

For the Mass Launch System, the simplicity of a smaller two-stage-to-orbit (TSTO) rocket is a conservative choice. Conventional rockets are our best hope—we can't wait for space elevators, launch loops, SpinLaunch, electromagnetic launch, laser launch, or other novel launch systems.

MLS first and second stage rockets should be recycled and reused thousands of times. Launch to a low LEO altitude of about 150 km would minimize rocket fuel needed and reduce stress during the second-stage re-entry into Earth's atmosphere. Once in LEO, the flock of solar-sailing mirrors could sail on sunlight to reach the L1 solar orbit, without requiring extra fuel.

In the past, single-use boosters were allowed to fall into the ocean, where seawater corrosion ruined them for relaunch. Recently, SpaceX has perfected reusable launch systems, landing first stage boosters tail-down using rocket thrust—allowing recovery and relaunch. SpaceX is experimenting with flying first-stage boosters back to the launch pad, ready for relaunch.

There are three methods to recover first-stage boosters for relaunch.

- Boosters can land tail-first down-range near a rail-link. Heavy lift cranes can load empty boosters onto specialized flatcars designed to transport them back to the spaceport.
- Boosters can parachute into fresh water, where they will float. Specialized tugboats can load them onto flatcars for rail transport back to the spaceport.

- Boosters equipped with grid fins (waffle-like control surfaces) and winglets can act as a lifting-bodies, allowing them to glide back to the spaceport. Using rocket thrust for a vertical landing on a launch pad, boosters will be positioned for rapid relaunch. This is the preferred solution.

The MLS second stage that delivers the payload to LEO would be similar to the Boeing X-37 spaceplane²⁴ designed for runway landings. In operation, the second-stage may orbit the Earth before returning to the launch site for reuse.

For the Mass Launch System, rockets should be fueled by liquefied oxygen and hydrogen (LH₂/LOX or hydrolox), with only water vapor exhaust—any other rocket fuel would pollute or poison the atmosphere. Hydrolox rockets also have higher specific impulse (good fuel economy). However, water vapor in the atmosphere can also act as a greenhouse gas; the impact of MLS water vapor exhaust must be evaluated, but may be small in the context of global cooling at L1.

Since the MLS may launch as many as 288 rockets per day, fuel supply would be a major challenge. Rocketdyne claims that a single RS-68A rocket engine produces more than 17 million horsepower²⁵—about 12,750 MW—during a 4-minute launch of the first stage. The second stage requires additional fuel. For launches every 5 minutes, a continuous supply of about 11,000 MW of electricity would be required just to manufacture rocket fuel. To put that into perspective, commercial nuclear power reactors typically generate about 1,000 MW.

For the MLS, hydrogen and oxygen fuel would be generated using electrolysis of water, which is about 80 percent efficient. In addition, gaseous hydrogen and oxygen must be compressed and cryo-cooled to liquefy it for use as rocket fuel. The MLS should use “green” power from renewable, non-polluting resources such as solar, wind farms or hydroelectric dams. Nuclear reactors could also power the MLS. Fusion power would be ideal, if it is developed.

3. MLS Spaceport Design

A new spaceport design is needed to sustain an MLS launch rate of one rocket every five minutes—in effect, mass production of launched rockets—a high but achievable goal. As a conceptual example, the spaceport would have two parallel ten-kilometer-long “launch lines,” separated by several kilometers. Each launch line would support 25 rocket launch pads (at 400 meters spacing) and would be serviced by a railroad track.

Empty first stage boosters would glide back to the spaceport and land tail-first at a designated launch pad. Second stage spaceplanes would land on a runway at the spaceport. After landing, the second stage spaceplanes would receive a new payloads of space mirrors. Each launch pad would have a large crane to attach the second stage with the payloads on top of the first stage booster.

Second-stage payloads would be thousands of robotic space mirrors stacked together for automatic bulk deployment in LEO. Space mirrors would be mass produced elsewhere and

²⁴ Insinna, Valerie; (2020) “[US Space Force launches the mysterious X-37B space plane](#)” DefenseNews

²⁵ Aerojet Rocketdyne website; “[RS-68A is the world’s most powerful hydrogen-fueled rocket engine](#)”

shipped to the spaceport. After the second-stage spaceplane delivers its payload to orbit, it would circle the Earth and land on a runway near the launch site—with landings every five minutes. First and second-stage rockets will be inspected and recycled for relaunch.

Parallel refueling of 25 rockets after erection would require high volume pumping of LH₂/LOX. Twenty-five rockets on a launch line would lift off in succession, one every five minutes for a period of two hours. Once a launch line has completed launching its rockets, the second launch line would begin, allowing two hours for the first launch line to be set up with 25 new rockets. Automated robots would manage launch operations, night and day, in all weather, year-round.

In summary, candidate spaceport sites should have the following characteristics:

- a location near the equator to maximize payload to orbit;
- a location remote from population centers, for safety and to minimize noise;
- an ocean freighter port to import materiel, rockets, and L1 payloads;
- transport (if needed) to return first-stage boosters to the launch site for reuse;
- a source of water for electrolysis to make hydrogen and oxygen; and
- abundant renewable energy to manufacture LH₂/LOX fuel and run operations.

Outlined below are two possible spaceport sites: one in Western Australia using solar power, and another in the lower Congo River using hydroelectric power. Other favorable sites may exist. Multiple MLS spaceport sites may be needed to launch higher-mass solar sails.

C. MLS Spaceport Examples

1. Western Australia Spaceport

Western Australia has abundant sunlight—a source of green power for an MLS spaceport. However, the sun shines for less than half a day. Thus, an MLS solar powered spaceport must have at least twice the installed capacity, compared to firm hydroelectric or nuclear power (stored LH₂/LOX rocket fuel is a kind of battery). Fortunately, the price of PV panels is falling.

An example of a solar power development of a similar scale to that needed for the MLS is the currently planned Australia-Asia PowerLink project²⁶. Located 800 km south of Darwin, it will generate up to 20,000 MW of electricity (about 30,000 MW is needed for the MLS). The site will occupy 12,000 hectares of desert land (about 11 km squared). Planned power distribution to Darwin will begin in 2026, with an additional 4,200 km (2,600 miles) high-voltage DC submarine cable to Singapore to come online in 2027.

Perhaps the best MLS spaceport site in Australia is Port Hedland on the sparsely populated north-west coast. Port Hedland (population about 15,000) is the sunniest place in Australia, having an annual average of more than 10 hours a day of sunshine. Port Hedland is very warm to sweltering all year-round, with mean maximum temperatures of 36.4 °C. Yearly rainfall is highly variable and there are occasional tropical cyclones.

²⁶ Loz, Blain; (2021) “[World's biggest clean energy project to power Singapore from Australia](#)” New Atlas

Port Hedland has extensively developed industrial infrastructure and a natural deep water anchorage; its harbor is the main fuel and container port for the region. Port Hedland is the highest tonnage port in Australia, although iron ore shipments to China have declined. Its shipping channel to the Indian Ocean can accommodate vessels of over 250,000 tonnes. The port is also serviced by roads, several railways, and an airport.

The MLS launch site could be located on empty land north-east of Port Hedland; the rail link may need to be extended to facilitate ocean freighter deliveries. A solar installation of approximately 30,000 MW can be co-located near the launch site.

The city of Port Hedland has a limited freshwater supply from the De Grey River Water Reserve 60 km east of the town. Electrolysis of seawater (to obtain hydrogen and oxygen) is possible with the addition of a catalyst to prevent the formation of chlorine gas²⁷. Alternatively, seawater can be desalinated using additional solar energy. Liquefied rocket fuel (LH₂/LOX) can be stored on site for later pumping into rocket tanks.

Eastward launches from Port Hedland would be over the Pilbara region of the Australian desert. Reliable rockets should rarely fail, but those that do would fall in the desert. With hydrogen-oxygen fuel, no toxic chemicals will pollute the land.



Port Hedland, Australia (Google Maps)

If spent boosters cannot fly back to the spaceport, they could land tail-first near the Yarrlie mine to the east. The existing railway from the mine to Port Hedland may need to be extended and

²⁷ Kuang, Yun; et al. (2019) “[Solar-driven, highly sustained splitting of seawater into hydrogen and oxygen fuels](#)” PNAS Proceedings of the National Academy of Sciences

upgraded. Specialized flatcars could transport recycled first-stage boosters for re-launch at Port Hedland.

2. Congo River Spaceport

The Congo River has a potential MLS spaceport site, with planned hydroelectric dams that could produce LH₂/LOX rocket fuel and power infrastructure. Located in the Democratic Republic of the Congo (DRC), the proposed Grand Inga dams²⁸ would harness a series of colossal cataracts between the Upper and the Lower Congo River.

The Grand Inga hydroelectric power scheme could produce up to 40,000 MW of electricity, about twice the capacity of the Three Gorges Dam in China (currently, the world's largest). Construction of Grand Inga is planned in 6 phases, which would allow the MLS to grow in size (and launch frequency) according to the available power.

The Grand Inga hydroelectric dams will have modest environmental impacts, since no greenhouse gases would be produced and there would be no flooding of the 1,700-kilometer navigable section of the Upper Congo River. The dams haven't been built due to political instability and a lack of local demand for the vast power. In 2016, the World Bank cancelled its support for the Grand Inga project (an estimated \$80 billion is needed to build the dams).

The DRC has recently picked Australia's Fortescue Metals Group²⁹ to develop Grand Inga. Fortescue says it "would use the energy from Inga to produce hydrogen to export around the world"—similar to the proposed LH₂/LOX rocket fuel production for the MLS. Both the MLS and Fortescue are examples of continued foreign exploitation of Congo's resources—a morally complicated question, since only 13% of the population in the DRC have access to electricity.



Lower Congo River from the Inga Dams to the Atlantic Ocean (Google Maps)

²⁸ Author unknown; (2013) "[Grand Inga Hydroelectric Project: An Overview](#)" International Rivers

²⁹ Holland, Hereward; Burton, Melanie; (2021) "[Congo picks Australia's Fortescue to develop giant hydro project](#)" Reuters

Mateba Island, in the Lower Congo River near the Atlantic Ocean, is a possible MLS spaceport site. The 100-square-kilometer flat island is about 40 km upstream from the mouth of the Congo River in a valley between hills, so it is sheltered from ocean storms. The island and the nearby settlements of Boma and Matadi are accessible to freighters from the Atlantic Ocean, allowing deliveries of materiel. The site is also close to the equator and near the proposed Grand Inga hydroelectric energy supply.

As with the Australian site, Mateba Island would use two launch lines to launch two-stage rockets every five minutes to LEO. Mateba Island is big enough to support most of the spaceport infrastructure, including electrolysis of river water and storage of cryo-cooled LH₂/LOX.



Mateba Island Spaceport Site (Google Maps)

If spent boosters cannot fly back to the spaceport, they could descend tail-first into Pool Malebo (formerly Stanley Pool), a 500-square-kilometer lake-like widening of the Upper Congo River about 350 km east of the launch site on Mateba Island.

The boosters would float on the fresh water due to empty fuel tanks. Using a fleet of towboats, the rockets could be rafted together and towed downriver to a dedicated Kinshasa rail yard. Boosters would be loaded onto specialized flatcars (25 per train) for transport back to Mateba Island for re-launch. Trains would leave Kinshasa every two hours via the existing Matadi–Kinshasa Railway (upgraded).

As with the previous example, the second-stage rocket would be a small spaceplane. After releasing the payload of space mirrors in LEO and circling the Earth, it would land on a runway on Mateba Island. After landing, a new payload of space mirrors would be loaded, ready for relaunch.

3. Solar vs Hydroelectric MLS

A comparison of Western Australian versus Congo River MLS spaceport sites is shown below. If a global climate crisis becomes severe, multiple spaceport sites could be developed.

Pros for Port Hedland Spaceport	Cons for Port Hedland Spaceport
<ul style="list-style-type: none"> • Australia is politically stable 	<ul style="list-style-type: none"> • Western Australia is remote & hot
<ul style="list-style-type: none"> • Excellent solar energy site 	<ul style="list-style-type: none"> • Daytime-only solar power
<ul style="list-style-type: none"> • Solar power: low cost & rapid install 	<ul style="list-style-type: none"> • Need twice the solar power installed
<ul style="list-style-type: none"> • Empty land available for spaceport 	<ul style="list-style-type: none"> • Limited fresh water for electrolysis
<ul style="list-style-type: none"> • Port accessible by freighters 	<ul style="list-style-type: none"> • Need cryo-cooled rocket fuel storage
<ul style="list-style-type: none"> • Available rail transport for boosters 	

Pros for a Congo River Spaceport	Cons for a Congo River Spaceport
<ul style="list-style-type: none"> • Abundant hydro-power is available 	<ul style="list-style-type: none"> • The DRC is politically unstable
<ul style="list-style-type: none"> • The Congo River is near the equator 	<ul style="list-style-type: none"> • Grand Inga dams expensive
<ul style="list-style-type: none"> • Mateba Island accessible by freighters 	<ul style="list-style-type: none"> • Long hydroelectric development time
<ul style="list-style-type: none"> • Boosters can land in Pool Malebo 	<ul style="list-style-type: none"> • Tropical jungle climate
<ul style="list-style-type: none"> • Available rail transport for boosters 	

D. Costs and R&D Priorities

1. MLS Launch Costs

Historically, the cost to launch payloads to orbit has declined. The Space Shuttle had a cost of \$18,500 / kg in LEO³⁰. The Delta IV single-use booster achieved a cost of \$10,400 / kg to LEO³¹. The reusable Falcon Heavy has reduced launch costs to \$1,500 / kg in LEO²⁹.

MLS launch costs would be driven by the number of times that rockets can be recycled. Currently, SpaceX has reused Falcon 9 boosters with Merlin engines less than 10 times. If an MLS booster (similar to the Delta IV core) can be reused 1,000 times (a major design challenge), the launch cost to LEO may decline to \$14 / kg. This does not include the cost of the payload.

At a rate of 105,120 launches per year, over a period of 20 years (the length of time needed to launch 20 million tonnes of Angel's flyers or robotic space mirrors into orbit) about 2,100 boosters would be required. Based on the above, the cost to place 20 million tonnes (20 billion kg) in orbit will be about \$280 billion. This estimate does not include costs of launch infrastructure, industrial-scale electrolysis of water, and liquefaction of cryogenic fuels.

2. MLS R&D Priorities

The Mass Launch System concept is an extreme megaproject designed to reverse a global warming emergency. A project this large would require political consensus, international

³⁰ Whitman Cobb, Wendy (2019) "[How SpaceX lowered costs and reduced barriers to space](#)" The Conversation

³¹ Roberts, Thomas G. (2020) "[Space Launch to Low Earth Orbit: How Much Does It Cost?](#)" Aerospace Security

cooperation and long-term financing. These are unlikely—at least until a climate catastrophe is obvious to all. As a precaution, we should begin now with engineering feasibility studies:

- Design and prototype testing of platter-sized robotic space mirrors suited for L1 orbit.
- Design of second-stage payload stacking and bulk deployment of space mirrors in orbit.
- Design rocket first-stage booster and second-stage orbiter for minimum fuel use.
- Design of a second-stage spaceplane to deploy space mirrors in LEO.
- Design of a first-stage LH₂/LOX rocket engine that can be reused 1,000 times.
- Selection of MLS spaceport sites, including preliminary negotiations with host countries.
- Design of a very large scale solar power installation—30,000-40,000 MW.
- Design of first stage booster that can fly back to the launch site.
- Design of booster recovery and rail transport systems.
- Design of large-scale LH₂/LOX rocket fuel production and storage facilities.
- Design MLS launch infrastructure: railways, launch lines, erection cranes, refueling, etc.
- Optimize MLS spaceport design for maximum launch rate.
- Assess MLS environmental, social, and economic impacts.
- Assess impact of water vapor rocket exhaust on global climate.
- Investigate other uses for the MLS: space solar power, Moon/Mars colonies, etc.

The MLS would open space for human development, beyond the urgent need to geoengineer climate to reverse global warming. Increased launch capacity is required for other major space projects, including industrialization of space, asteroid mining, lunar and Mars colonies, and space energy systems.

As an example, the MLS is needed for the “Space Solar Power Project”³² at the California Institute of Technology. Funded with a \$100 million grant, Caltech is designing an orbiting flock of modular solar arrays that would beam microwave energy to Earth. Thousands of lightweight “tiles” would fly in formation to form a hexagonal power station up to 3 kilometers long on a side. A major goal is to reduce the weight to 10 or 20 grams per square meter. Nonetheless, this scheme requires millions of tonnes to be launched into orbit. Not only can the Space Solar Power Project reduce CO₂ emissions on Earth, it can also act as an L1 planetary sunshade to help reverse global warming—an ideal synergy.

A Mass Launch System is more than a radical solution to counteract a world climate catastrophe. In the long run, if human civilization lasts another 1,000 years, global climate control will be both necessary and inevitable. Beyond that, the MLS may enable humanity’s transition to a true space-faring species, with the solar system as our backyard.

³² Wall, Mike; (2021) “[Space solar power project got off the ground with billionaire's \\$100 million donation](#)” Space.com