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Solar Radiation Modification (SRM) Primer

By Mitch Poulin
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Executive Summary

Solar radiation modification (SRM) is a set of technologies proposed to cool the planet alongside greenhouse gas reduction by reflecting a portion of incoming sunlight or by helping Earth release heat. This primer explains proposed SRM technologies, current perspectives, evidence from research, and key questions.

SRM is controversial. Since 2024, many **U.S. states have considered legislation to prohibit or ban outdoor SRM research or deployment**, and Tennessee and Florida have enacted deployment bans. Some legislation reflects public confusion, conflating SRM with weather modification and "chemtrails."

Computer modeling studies suggest SRM could cool Earth but would not restore preindustrial climate conditions and might introduce new risks, like shifting rainfall patterns and continued reliance on SRM.

Small-scale outdoor experiments and private-sector activities have caused public alarm. Community opposition has stopped many scientific experiments. Scientists and the public are critical of private companies deploying small-scale SRM without oversight.

Arguments for outdoor SRM research claim:

- SRM could quickly lower temperatures while we work to reduce emissions and could lower temperatures more quickly than cutting emissions alone.
- SRM is relatively inexpensive compared to the massive cost of unchecked climate change.

Arguments against SRM research include:

- *Risks and unknowns*: SRM could disrupt weather, nature, and the air we breathe in uneven and potentially harmful ways.
- *Incomplete fix*: SRM will not stop or reverse ocean acidification, sea-level rise, or polar ice loss.
- *Termination shock*: Suddenly stopping SRM while greenhouse gas emissions remain high could trigger rapid extreme global warming.

- *Governance and geopolitical dangers*: Since SRM can be deployed locally but would have global effects, a single country or company deploying it alone could cause global conflict.
- *Less motivation to cut emissions*: People relying on SRM as a quick fix may focus less on the long-term solution (reducing pollution).
- *Fairness and trust issues*: Decisions about SRM will affect the globe but are likely to be made by wealthy countries and companies, raising questions about who should make decisions about SRM and whether the public should trust the process.
- *Other risks and unknowns*: SRM might reduce energy generated by solar panels, interfere with airplanes and satellites, create more pollution, and cause health risks.

Many experts agree that **rules and management systems (governance) must be in place before outdoor research and deployment happens**.

Priorities include:

- Clear legal definitions of SRM research and use (deployment);
- Openness around SRM funding, risks, and monitoring;
- Inclusion of Indigenous leaders and developing nations (Global South) in decisions; and
- International cooperation to establish rules, monitoring, and accountability.

Questions for lawmakers:

- Should outdoor SRM research proceed and, if so, under what safeguards?
- Who should control outdoor SRM research and use at local, national, and international levels?
- If something goes wrong and outdoor SRM research or use causes harm, who should be responsible for damage compensation?
- How can we share trusted research and fight misleading information about SRM?
- How can we ensure that SRM will not lead people to forget about the need to reduce greenhouse gas emissions?

Introduction

From 2024 to 2026, many U.S. state legislatures introduced legislation aimed at prohibiting or strictly regulating outdoor research and deployment of solar geoengineering or solar radiation modification (SRM; see Appendix). Also known as solar geoengineering, SRM encompasses a set of proposed technologies to cool Earth.[1] Some of the recent legislation proposes to ban specific technologies, like stratospheric aerosol injection (SAI) and marine cloud brightening (MCB), also known as cloud seeding (see the next section, What Is SRM?). Other legislation bans "weather modification," which is different from but often conflated with SRM.[2] Two U.S. states—Tennessee and Florida—have banned the deployment of SRM technologies.[3] Although SRM is not yet available for large-scale deployment, some scientists anticipate its widespread use within the twenty-first century.[4]

Attitudes toward outdoor SRM research and deployment are mixed, with high levels of skepticism from some quarters alongside an increasing willingness to consider SRM among scientists and entrepreneurs. However, research into the attitudes held about SRM in the Global South and among youth and Indigenous populations is notably lacking.[5]

Emerging SRM technologies are underresearched and poorly understood, so significant uncertainty remains about their proposed uses and potential effects—both desirable and undesirable. Proposed outdoor SRM experiments have generated immense distrust (see the section on Experiments, Entrepreneurship, and Community Pushback). In the United States, some anti-SRM sentiment is rooted in the technology's conflation with conspiracy theories about chemtrails—a conflation that has led to much of the aforementioned U.S. legislation.[6] These factors have spurred a protracted debate about SRM's desirability, how it should be governed, and whether research on the topic should move forward.

This primer briefly describes what SRM is, arguments for and against it, international efforts to govern it, notable simulations and outdoor experiments, and remaining questions for policymakers and scholars to consider.

What Is SRM?

Proposed SRM technologies aim to cool Earth by reflecting solar radiation away from the planet's surface or by allowing heat to more easily escape the atmosphere. SRM deployment is intended to complement, not substitute for, existing climate mitigation and adaptation techniques.[7]

Proposed SRM Technologies:

- **Stratospheric Aerosol Injection** (SAI) uses high-altitude airplanes to spray gaseous precursors of reflective particles into the stratosphere, where they reflect a fraction of incoming solar radiation.[8] SAI mirrors the cooling effect of volcanic eruptions, drawing inspiration from the 1991 eruption of Mt. Pinatubo, which cooled global surface temperatures 0.2–0.6°C in the year following the eruption.[9] SAI is highly controversial due to its potential unintended consequences, fears that its adoption will lead to the deprioritization of climate mitigation, and its conflation with chemtrail conspiracy theories.[10]
- **Marine Cloud Brightening** (MCB) enhances the ability of tropospheric marine clouds to reflect solar radiation by "seeding" them with saltwater particles. MCB is already being tested as a method to increase cloud reflectivity at Australia's Great Barrier Reef.[11]
- Mentioned less frequently in the technical literature (and thus deemed beyond the scope of this primer) are cirrus cloud thinning, surface albedo enhancement, and space-based radiation reflection.[12]

Distinguishing SRM from Chemtrails, Contrails, and Weather Modification

SRM is sometimes conflated with contrails, chemtrails, and weather modification, but the three are distinct concepts.

SRM comprises a series of proposed technologies that, if implemented, would aim to cool Earth by reflecting sunlight away from the planet.

Contrails (condensation trails) are long white clouds that are sometimes visible behind airplanes. They are composed of aircraft exhaust and water vapor and are an aviation byproduct that is not designed or intended to cool the planet.[13] Contrails both reflect solar radiation into space and trap some of Earth's heat in the atmosphere.[14] By trapping more radiation than they reflect, contrails have a small net warming effect.[15]

Conspiracy theorists define **chemtrails** (chemical trails) as contrails that have been intentionally modified to disperse toxic chemicals for population control, mind manipulation, and/or to change weather patterns.[16] This theory is not supported by evidence. However, well-known figures like U.S. Secretary of Health and Human Services Robert F. Kennedy Jr. have echoed the theory, and he is not alone; a 2017 study found that at least 10 percent of Americans believe the theory is completely true.[17] The U.S. Environmental Protection Agency (EPA) website states that, though some chemicals are intentionally sprayed from airplanes to combat fires or promote crop growth, the federal government is unaware of any chemicals being released from aircraft for weather control or other nefarious purposes.[18]

Weather modification is the act of intentionally changing localized weather patterns, usually to increase precipitation, while SRM is intended to deflect solar radiation (in the case of MCB and SAI) or facilitate atmospheric heat release (in the case of cirrus cloud thinning) to cool the planet.

Experiments, Entrepreneurship, and Community Pushback

Marine Cloud Brightening (MCB)

- **Experimentation**
  - Since 2016, researchers have been testing the use of MCB to cool the water surrounding the **Great Barrier Reef** and slow coral bleaching, which occurs when high water temperatures force coral to expel its outer algae layer, eventually killing the coral. Researchers are spraying salt water into the air over the reef from a barge to create low-lying clouds that reflect sunlight.[19] Despite some criticism that the experiments are costly, impractical, and distract from climate mitigation and adaptation, the project is ongoing as of late 2025.[20] The program is funded primarily by the Australian government.[21]
  - In early 2024, researchers from the **University of Washington**'s MCB Research Program retrofitted a decommissioned aircraft carrier to spray saltwater particles over the sea off the coast of Alameda, California.[22] The Alameda city council, which was not aware of the project before it was announced in *The New York Times*, voted unanimously to halt the experiment in May 2024.[23] The University of Washington has not announced plans to continue outdoor MCB research.[24]

Stratospheric Aerosol Injection (SAI)

- **Experimentation**
  - Harvard professors initiated the **Stratospheric Controlled Perturbation Experiment** (SCoPEx) in 2015 and abandoned the project in 2024.[25] Funded largely by foundations and philanthropists, the researchers intended to release chalk calcite particles from a high-altitude balloon to assess their dispersal and reflective behavior.[26] A test flight over Sweden was ultimately

abandoned after organized resistance from Indigenous groups and environmental nongovernmental organizations (NGOs). In a 2024 statement celebrating the project's end, a representative from the Indigenous Environmental Network described SRM as a violation of Indigenous rights and a continuation of "racism, colonialism, and white supremacy."[27]

- **Private Sector Start-Ups**
  - In 2022, the U.S.-based start-up Make Sunsets launched its first atmospheric sulfur dioxide (SO_2) SAI balloons in Mexico. The company is funded by venture capital and "cooling credits that can be purchased on the company's website."[28] After a second round of balloon launches in 2023, the Mexican government announced its intention to ban SRM deployment.[29] Make Sunsets then pivoted to the United States, launching SO_2 balloons in Nevada and California over the next two years.[30] In April 2025, the U.S. EPA submitted a demand for information about the company's activities, and Make Sunsets' response disclosed that their balloons had released approximately 0.1 tons of SO_2. A July 2025 EPA statement said the agency is aware of the company's activities.[31] Make Sunsets has launched SO_2 balloons as recently as February 2026, according to the company's X account.[32] Researchers and environmentalists are largely opposed to Make Sunsets' activities, which they say detract from and delegitimize more "responsible" SRM research.[33]
  - In October 2025, a U.S.-Israeli start-up called Stardust Solutions announced that it had raised $60 million to conduct outdoor SAI experiments. Whether outdoor tests have or will be conducted is unclear.[34] The company, funded by Israeli-Canadian venture capital fund AWD and Israeli green energy company SolarEdge, reportedly employs twenty-five scientists and engineers.[35] While investors praise the company's staff of experienced scientists, others criticize its lack of transparency.[36]

Computer Modeling Experiments

Studies are briefly summarized below. Please use the endnote sources to learn more about each experiment's inputs and findings.

- Initiated in 2011, the **Geoengineering Model Intercomparison Project (GeoMIP)** is a coordinated effort among multiple international modeling groups to understand how the climate would respond to SRM deployment in idealized conditions. The models predicted that SRM could reduce

warming but not control temperature and precipitation at the same time. Models showed that if carbon dioxide (CO_2) continued to increase and some SRM were deployed, temperatures could be kept at their current level, but global average precipitation would be reduced. Evapotranspiration would not increase, but the CO_2 would make the atmosphere more stable, reducing convection and precipitation.[37] GeoMIP, which held its sixteenth annual workshop in Tokyo in March 2026, has produced 170 peer-reviewed publications as of this writing.

- In 2017, the **Stratospheric Aerosol Geoengineering Large Ensemble (GLENS)** project produced simulations using a feedback controller to keep global temperatures and large-scale temperature gradients at 2020 values under a high-emissions scenario using aerosol injection at multiple latitudes, whose selection was informed by sensitivity experiments. Researchers found that the modeled SAI successfully offset projected greenhouse warming, though the models also predicted extreme adverse effects on regional rainfall and temperature.[38]

- In 2022, an international group of researchers released results from the **Assessing Responses and Impacts of Solar Climate Intervention on the Earth System with Stratospheric Aerosol Injection (ARISE-SAI)** simulations. The initial ARISE-SAI simulations used a feedback-based control algorithm to adjust SO_2 injections into the stratosphere to maintain global mean surface temperatures near 1.5°C above preindustrial levels under a moderate greenhouse gas emissions future. This scenario has been described as more policy-relevant and adaptable than many earlier models. The simulations also provided extensive outputs for atmosphere, ocean, land, and sea-ice components and were designed to be reproducible across Earth system models. Among other results, the models showed that, if deployed, SAI could produce inconsistent cooling effects, including a possible "warming hole" over the North Atlantic Ocean.[39]

- In 2025, the British government's **Advanced Research + Invention Agency (ARIA)** gave £57 million (USD 78 million) to researchers studying SRM. From 2026 to 2029, ARIA will fund twenty-six projects "from computer modelling, to ethical frameworks, and observations of natural analogues of climate cooling approaches (like volcanoes). Where essential questions cannot be answered by models, [ARIA will fund] a limited number of small-scale, carefully controlled outdoor experiments." One of ARIA's key stated aims is to "better understand localized perspectives and governance approaches to SRM."[40]

For a comprehensive list of SRM and weather modification experiments, visit the Geoengineering Monitor Map.[41]

Main Arguments in Favor of SRM Outdoor Research and Deployment

Urgency. Current climate mitigation efforts may not cool the planet sufficiently to avoid climate catastrophe. SRM could supplement mitigation to buy extra time. This is particularly important for climate-vulnerable communities, many of which, despite having contributed little to global emissions, will feel the most severe impacts of unmitigated climate change.

Effectiveness and Timeframe. Compared to other climate mitigation measures, both SAI and MCB could cool Earth relatively quickly in regions where it is deployed (SAI on a larger scale, MCB on a smaller scale).[42] Some estimates suggest that the infrastructure necessary to deploy SAI would require two decades to develop.[43] Other researchers suggest it could be deployed sooner, using existing aircraft at low altitudes.[44]

Cost. SAI cost estimates range from $500 million per decade to $2.5 billion per year.[45] MCB is estimated to cost $10 billion per year, though actual costs would depend greatly on deployment methodology.[46] These figures are miniscule compared to the cost of unmitigated climate change, which the World Economic Forum estimates at $3.1 trillion per year by 2050.[47]

Flexibility. SRM could be deployed relatively quickly and strategically. Project Drawdown (which recommends against SRM) estimates that, if the desired effects of SRM were not achieved, the climate would return to previous conditions within months to a few years after deployment ceased.[48]

Main Arguments Against SRM Outdoor Research and Deployment

Unintended Weather Consequences. SRM's potential effects on weather and precipitation patterns are poorly understood. Though deployment might improve surface temperatures in some areas, it might negatively impact temperatures and weather patterns elsewhere in ways that are difficult to predict.[49]

Localized Effects. Even if SRM stabilizes and cools global temperatures, devastating weather patterns will still occur, and global temperatures will still fluctuate.[50]

Termination Shock. Unlike emissions reduction, which targets the root cause of greenhouse gas accumulation, SRM targets only one symptom of emissions—global mean surface temperature—and does so without reducing overall emissions. If SRM (SAI, in particular) is used for a long time and rapidly terminated, global temperatures will rapidly increase above pre-SRM temperatures if greenhouse gas emissions are not reduced during SRM's deployment.[51]

Opportunity Cost. While SRM is less expensive than the cost of unchecked climate change, it will almost certainly compete with funding for emissions reduction strategies, such as investments in energy efficiency and renewable energy. SRM may also compete with funding that supports research and deployment of carbon sequestration technologies, including reforestation, grassland management, and carbon capture and storage.

Moral Hazard. Some fear that reliance on SRM technologies will disincentivize emissions mitigation, which would increase baseline global temperatures. Additionally, SRM deployment could appear to relieve richer, more industrialized countries of their responsibility for carbon emissions and climate change.[52]

Climate Equity and Justice. SAI's potential to change precipitation patterns unintentionally or to warm certain regions while cooling others raises questions about who should decide when, where, and for how long SRM technologies are deployed, which risks are acceptable, and how to monitor deployment, resolve conflicts, and compensate communities that are negatively impacted.[53] Because nearly all SRM research, deployment, and governance efforts are based in the Global North, some have expressed concern that SRM is inherently unjust, as no currently viable governance model offers Global South stakeholders decision-making power. However, some argue that SRM deployment in the Global South could be a viable climate justice mechanism for communities that are heavily affected by climate change despite their lack of responsibility for most global emissions. The Developing Country Governance Research and Evaluation for SRM (DeGReES) Initiative started in 2010 and is an NGO dedicated to putting the Global South at the center of the SRM conversation. It currently funds 170 researchers on thirty-seven SRM projects in the Global South.[54]

Health and Social Concerns. Little research has been conducted on how SRM techniques might impact human health.[55] The U.S. EPA's website warns of SAI's potential to cause acid rain and respiratory illness.[56] Research also suggests that SAI deployment could change which regions are most susceptible to diseases like malaria, increasing infection rates.[57] In the United States, conflation of SRM with the chemtrails conspiracy theory has led to concerns on social media and in the halls of Congress about ill-intentioned actors releasing chemicals into the air for nefarious purposes, though these claims have not been substantiated.[58]

Unintended Ecological Consequences. Little to no research has been conducted on how SRM's effects (including more diffuse sunlight, unpredictable temperature and precipitation changes, and the decoupling of atmospheric CO_2 concentrations from temperature) would affect plants, animals, and microorganisms.

Additional potential risks include drought in Africa and Asia, ozone depletion leading to enhanced ultraviolet radiation at the surface, lowered solar electricity generation, degradation of passive solar heating capacity, effects on airplanes and airplane passengers flying in the stratosphere, impacts on satellite remote sensing, negative effects for terrestrial optical astronomy, more sunburns, and less blue sky.[59]

Domestic and International Governance Efforts

Many researchers and policy experts advocate for implementing SRM governance structures before outdoor research or deployment takes place—both to avoid potential negative outcomes and to encourage positive outcomes such as collaboration and effective deployment. Governance might include:

- A clear definition of which SRM technologies are allowed and at which stage they are permitted (i.e., the research and development phase or the implementation phase);
- Inclusive engagement with international stakeholders and Indigenous communities;
- Transparency regarding what is known about the technology, who funds it, how it will be monitored, and what risk assessments have been completed; and
- International coordination and a global governance regime to set norms, provide regulatory oversight, share research findings, and resolve disputes regarding SAI and any other large-scale SRM technologies.[60]

For a list of proposed and adopted U.S. state-level legislation banning SRM, see the Appendix. A proposed global SRM nonuse treaty is also gaining attention among global scholars and policymakers.[61] The nonuse treaty has received pushback from researchers advocating for more evidence-informed and inclusive approaches to SRM.[62]

Outstanding Questions

Many scientists and policy experts agree that more SRM research is needed to give policymakers the information necessary to put governance structures in place should SRM be considered for development or deployment. Should such SRM research be conducted? If so, how can the research be conducted safely and with public buy-in?

Which municipalities, states, nations, or multinational bodies will have the power to regulate and govern SRM technologies?

Who will be liable for harms caused by SRM research or deployment—funders, scientists, companies, or governments? What would accountability entail?

How can scientists and policymakers combat misinformation and build public trust around SRM?

How should the regional and global risks and benefits of SRM technologies be evaluated, especially at a moment when research is limited and many U.S. states are attempting to outlaw SRM research?

How will SRM's successes or failures be measured?

How should the potential for termination shock be addressed?

If SRM successfully and safely lowers global temperatures, how can we prevent it from becoming a substitute for climate mitigation and adaptation?

How do we navigate the competing and sometimes contradictory justice claims surrounding SRM (i.e., SRM could help the Global South, but SRM governance may not include Global South leadership)?

How should policymakers balance local and global perspectives on SRM research and possible deployment?

Conclusion

SRM technologies are one set of proposed options in a portfolio of strategies to combat the climate crisis. The most crucial priority for policymakers should be to bolster existing climate mitigation and adaptation efforts, including reducing emissions and investing in clean energy alternatives. Though localized SRM technologies like MCB are currently being tested regionally, whether SAI will ever be suitable for deployment is still unclear. Before deployment becomes possible on a large scale, the dilemmas posed by such technologies must be better understood. Despite SRM's potential to help limit temperature increases, possible risks and governance challenges leave many unanswered questions. These, in combination with misinformation and a lack of public awareness, make deployment uncertain.

In the United States, this has led to more than forty-four proposed state-level bans of SRM, weather control, or environmental manipulation. Whether these bans will effectively protect vulnerable populations or instead quell research that could lead to effective governance remains to be seen and will depend heavily on how legislation is structured, the extent to which scientific experts are consulted, and how the public is engaged.

Next steps for scientists, policymakers, and educators include:

- Clearly communicating with the public about SRM's known benefits and risks;
- Implementing effective governance and research agendas before SRM technologies are potentially deployed on a large scale;
- Ensuring that research agendas are transparent and involve community buy-in;
- Creating more small-scale SRM models and experiments to educate researchers and the public before larger studies and demonstrations are conducted; and
- Accelerating efforts to implement effective climate mitigation and adaptation measures.

Appendix: State-Level SRM Legislation

State	Type	Research or Implementation Ban	Type of SRM Targeted in Legislation	Date Introduced/ Passed
Alabama	Bill	Implementation Ban	SAI	2025
Arizona	Bill	Implementation Ban	SAI	2025
Connecticut	Bill	Implementation Ban	Cloud seeding permits	2025
Florida	Law	Implementation Ban	SAI	2025
Georgia	Resolution	Implementation Ban	SAI	2025
Idaho	Bill	Implementation Ban	SAI, SRM, cloud seeding	2025
Illinois	Bill	Implementation Ban	Cloud seeding	2025
Indiana	Bill	Implementation Ban	Weather control	2025
Indiana	Bill	Implementation Ban	Weather control	2025
Iowa	Bill	Implementation Ban	SAI	2025
Iowa	Bill	Implementation Ban	SAI	2025
Kentucky	Bill	Implementation Ban	SAI	2025
Kentucky	Bill	Implementation Ban	SAI	2025

APPENDIX: STATE-LEVEL SRM LEGISLATION

State	Type	Research or Implementation Ban	Type of SRM Targeted in Legislation	Date Introduced/ Passed
Louisiana	Bill	Implementation Ban	SAI	2025
Louisiana	Resolution	Implementation Ban	SAI	2025
Maine	Bill	Research and Implementation Ban	SAI; weather modification; excessive electromagnetic, radio frequency, or microwave radiation emissions; harmful nuclear, biological, or chemical emissions; other polluting atmospheric activity	2025
Michigan	Bill	Implementation Ban	SAI	2024
Michigan	Bill	Implementation Ban	SAI	2025
Mississippi	Bill	Implementation Ban	SAI	2025
Mississippi	Bill	Implementation Ban	SAI	2025
Missouri	Bill	Implementation Ban	Environmental manipulation	2025
Montana	Bill	Implementation Ban	All forms of SRM except cloud seeding	2025
Nevada	Law	Research Ban	Cloud seeding	2025
New Hampshire	Bill	Implementation Ban	SAI, SRM, cloud seeding	2025
New Jersey	Bill	Implementation Ban	SRM	2025
New Mexico	Law	Research Ban	Cloud seeding	2024
New York	Bill	Implementation Ban	SAI	2025

APPENDIX: STATE-LEVEL SRM LEGISLATION

State	Type	Research or Implementation Ban	Type of SRM Targeted in Legislation	Date Introduced/ Passed
North Dakota	Bill	Implementation Ban	SAI, cloud seeding, electromagnetic radio frequency, microwave radiation emissions, or any other atmospheric polluting activity	2025
North Dakota	Bill	Implementation Ban	Weather modification	2025
Ohio	Bill	Implementation Ban	SRM	2025
Oklahoma	Bill	Implementation Ban	SAI	2025
Pennsylvania	Bill	Implementation Ban	SAI, SRM, cloud seeding, weather engineering	2025
Rhode Island	Bill	Implementation Ban	SRM, cloud seeding, weather modification, or other atmospheric interventions involving the release of pollutants	2025
South Carolina	Bill	Implementation Ban	SAI and SRM, with exceptions for approved cloud seeding and crop dusting	2025
South Carolina	Bill	Implementation Ban	SAI and SRM, with exceptions for approved cloud seeding and crop dusting	2025
South Carolina	Bill	Implementation Ban	SAI	2025
South Dakota	Bill	Implementation Ban	SAI, SRM, cloud seeding	2024
Tennessee	Law	Implementation Ban	SAI	2024

APPENDIX: STATE-LEVEL SRM LEGISLATION

State	Type	Research or Implementation Ban	Type of SRM Targeted in Legislation	Date Introduced/ Passed
Texas	Bill	Research and Implementation Ban	SAI	2025
Utah	Bill	Implementation Ban	SAI	2025
Vermont	Bill	Implementation Ban	SAI	2025
West Virginia	Bill	Implementation Ban	SAI	2025
West Virginia	Bill	Implementation Ban	SAI	2025
Wyoming	Bill	Implementation Ban	SAI	2025

Note: Andrew Noland, PhD candidate at the University of Minnesota, researched and compiled the Appendix. Last updated in October 2025.

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