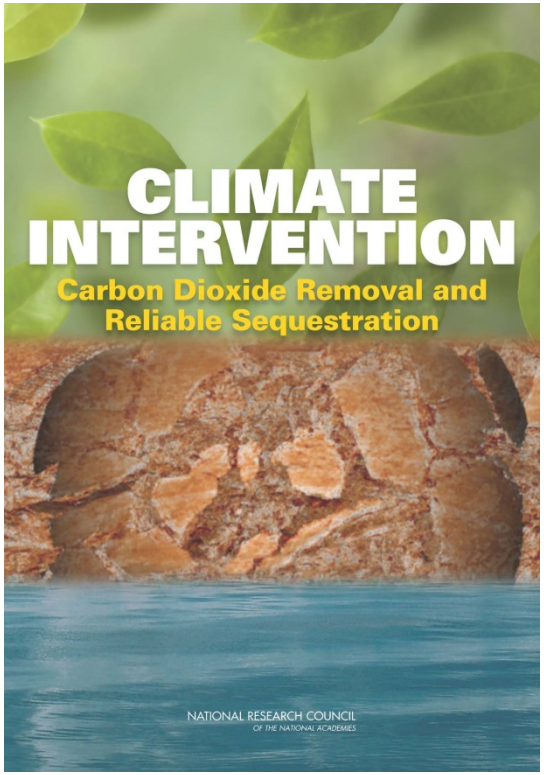
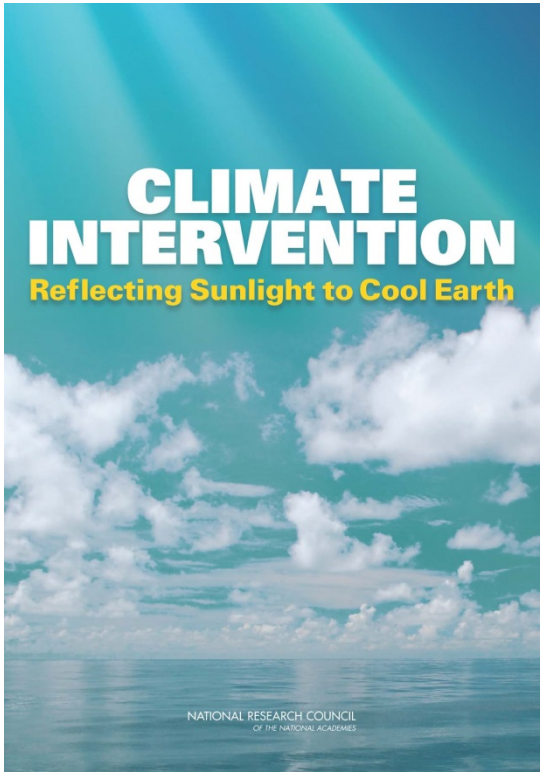
CLIMATE INTERVENTION





Marcia McNutt

Ken Caldeira

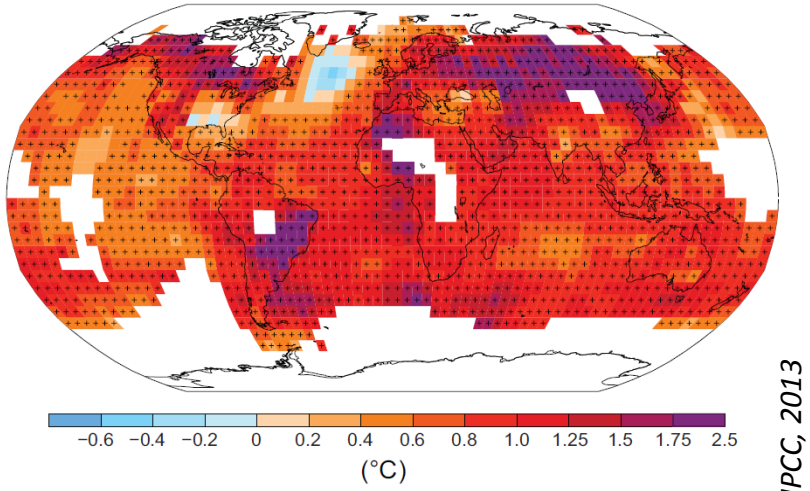
BOARD ON ATMOSPHERIC
SCIENCES AND CLIMATE

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

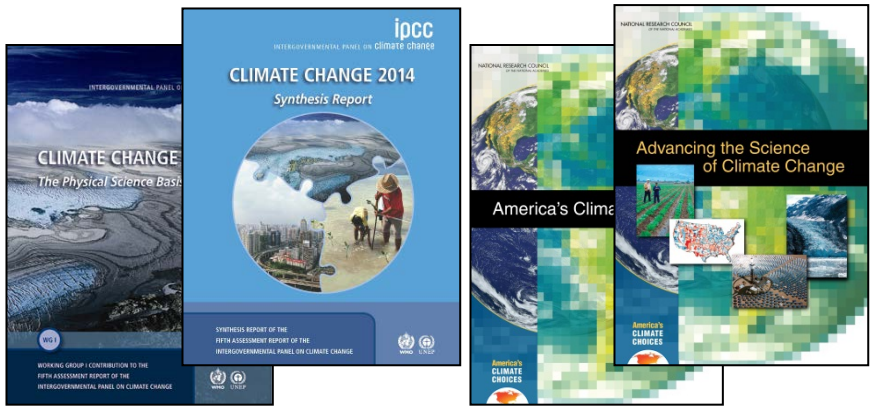
CLIMATE IS CHANGING

- The signs of changing climate are all around us:
  - Greenhouse gases are increasing
  - Sea level is rising
  - Ice sheets and glaciers are melting
  - Global temperatures are increasing
- Climate change impacts people, ecosystems, and the economy

Observed Change in Surface Temperature



IPCC, 2013



POSSIBLE CLIMATE RESPONSE OPTIONS

- Reducing greenhouse gas emissions
  - "Mitigation"
- Adapting to the impacts of climate change
  - "Adaptation"
- Climate Intervention???

COMMITTEE ON GEOENGINEERING CLIMATE: TECHNICAL EVALUATION AND DISCUSSION OF IMPACTS

DOE, NASA, NOAA, U.S. intelligence community, and National Academy of Sciences supported this study

Technical assessment of two classes of climate intervention technologies

- Removing carbon dioxide from the atmosphere
- Reducing sunlight absorbed by Earth in order to cool planet's surface

- What is currently known
  - Science - risks and consequences
  - Viability for implementation
- Identify future research needed
- Comment generally on potential societal, legal, and ethical considerations

COMMITTEE ON GEOENGINEERING CLIMATE: TECHNICAL EVALUATION AND DISCUSSION OF IMPACTS

Marcia K. McNutt (Chair)
Science / AAAS
Waleed Abdalati
University of Colorado, Boulder
Ken Caldeira
Carnegie Institution for Science
Scott C. Doney
Woods Hole Oceanographic Institution
Paul G. Falkowski
Rutgers, The State University of New Jersey
Steve Fetter
University of Maryland
James R. Fleming
Colby College
Steven P. Hamburg
Environmental Defense Fund
M. Granger Morgan
Carnegie Mellon University
Joyce E. Penner
University of Michigan
Raymond T. Pierrehumbert
University of Chicago
Philip J. Rasch
Pacific Northwest National Laboratory
Lynn M. Russell
Scripps Institution of Oceanography
John T. Snow
University of Oklahoma
David W. Titley
Penn State University
Jennifer Wilcox
Stanford University

- The Committee held four meetings and interacted with dozens of scientists
- Reports were reviewed by 16 outside experts

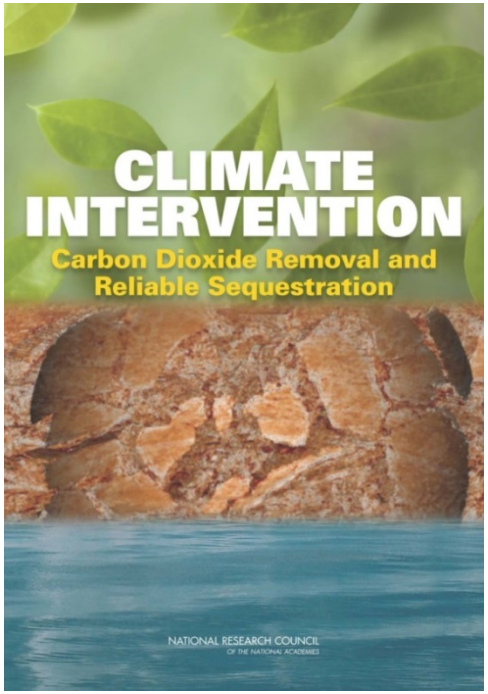
WHY "CLIMATE INTERVENTION"?

There are several meanings to the term "geoengineering"

In general, the term "engineering" implies a more precisely tailored and controllable process than might be the case for climate interventions

Intervention is an action intended to improve a situation

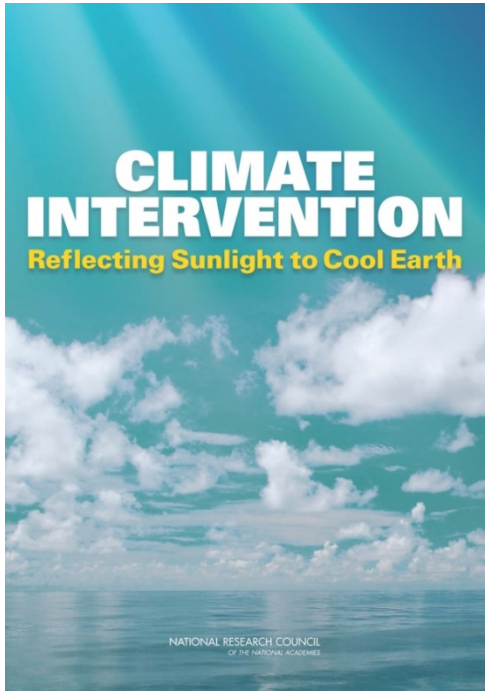
WHY TWO REPORTS?



There are vast differences in the:

- research needs,
- environmental risks, and
- social and political issues

associated with two classes of climate intervention approaches



THERE IS NO SUBSTITUTE FOR MITIGATION AND ADAPTATION

Recommendation 1:

Efforts to address climate change should continue to focus most heavily on

- **mitigating greenhouse gas emissions**
- **in combination with adapting to the impacts of climate change**

because these approaches

- **do not present poorly defined and poorly quantified risks and**
- **are at a greater state of technological readiness**

CARBON DIOXIDE REMOVAL AND RELIABLE SEQUESTRATION

Enhancing natural carbon sinks

- Changes in land use management
  - Reforestation / afforestation
  - Agricultural practices
- Accelerated weathering
  - Chemical reactions to form carbonate or silicate minerals
- Ocean iron fertilization
  - Adding iron to the ocean to boost the growth of phytoplankton

CARBON DIOXIDE REMOVAL AND RELIABLE SEQUESTRATION

Other technologies

- Direct Air Capture and Sequestration (DACS)
  - Chemical scrubbing processes
- Bioenergy with Carbon Capture and Sequestration (BECCS)
  - Use plants (biomass) to produce energy
  - Capture carbon dioxide from power plant and sequester underground

CARBON DIOXIDE REMOVAL READY FOR INCREASED RESEARCH AND DEVELOPMENT

Recommendation 2:

The Committee recommends research and development investment to

- **improve methods of carbon dioxide removal and disposal at scales that matter**

in particular to

- **minimize energy and materials consumption**
- **identify and quantify risks**
- **lower costs, and**
- **develop reliable sequestration and monitoring**

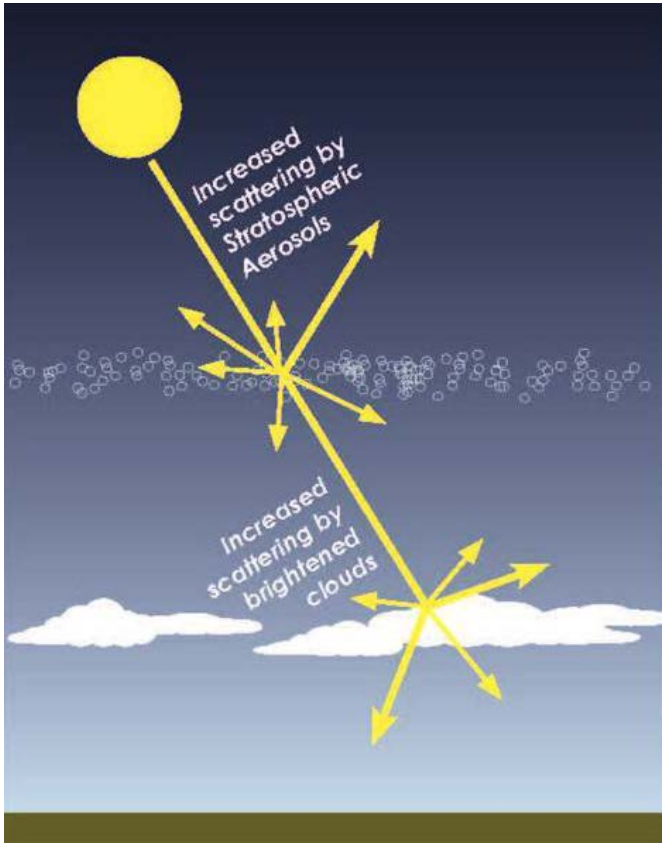
ALBEDO MODIFICATION

Albedo modification could reduce amount of sunlight absorbed by Earth in order to cool planet's surface quickly

- The report considered two strategies:
  - Stratospheric aerosols
  - Marine cloud brightening

Elsewhere referred to as "Solar Radiation Management"

"Albedo" is the proportion of incoming sunlight that is reflected back to space



ALBEDO MODIFICATION POSES SIGNIFICANT RISKS

Environmental risks – both known and poorly known

- Decreases in stratospheric ozone
- Changes in the amount and patterns of precipitation
- No reduction of root cause of climate change (greenhouse gases)
- Poorly understood regional variability
- Potential risk of millennial dependence

Significant potential for unanticipated, unmanageable, and regrettable consequences

- Including political, social, legal, economic, and ethical dimensions

Recommendation 3: Albedo modification at scales sufficient to alter climate should not be deployed at this time

ALBEDO MODIFICATION RESEARCH

Research needed to determine if albedo modification could be viable climate response

- If there were a climate emergency
- Could it be key part of a portfolio of responses?

Better understanding of consequences needed if there were an action by a unilateral / uncoordinated actor

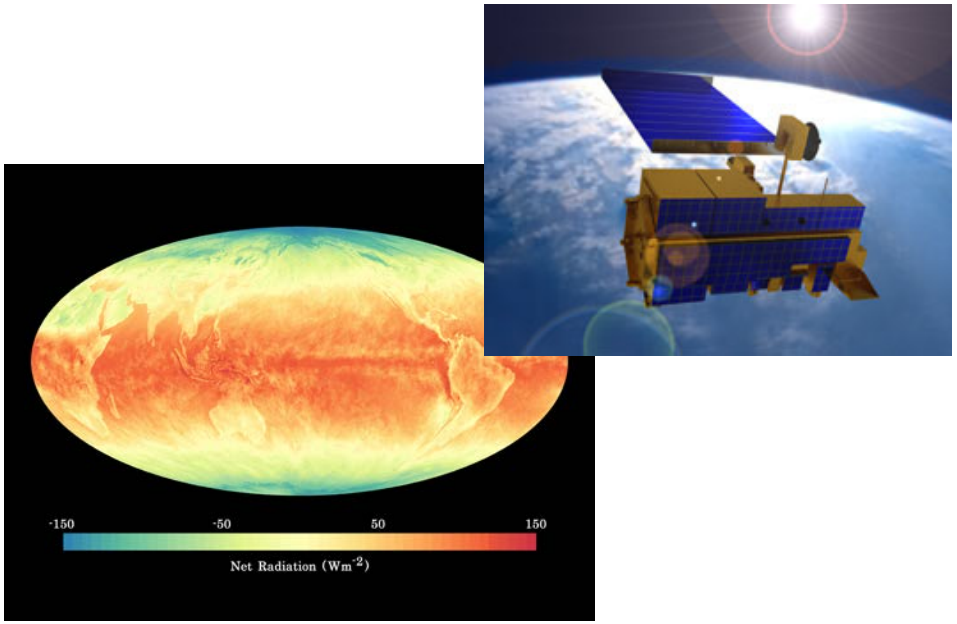
Recommendation 4:

The Committee recommends an albedo modification research program be developed and implemented that emphasizes multiple benefit research that furthers

- **basic understanding of the climate system**
- **and its human dimensions**

ALBEDO MODIFICATION RESEARCH

Current observational capabilities lack sufficient capacity to detect and monitor environmental effects of albedo modification deployment



Recommendation 5: The Committee recommends that the United States improve its capacity to detect and measure changes in radiative forcing and associated changes in climate

GOVERNANCE CONSIDERATIONS

More than just science involved in decisions on research and deployment

- Governance
- Ethical & legal considerations

Albedo modification research is not specifically addressed by any federal laws or regulations

Need for transparent and inclusive conversations

Goal of governance should be to maximize benefits of research while minimizing risks

GOVERNANCE CONSIDERATIONS

Recommendation 6:

The Committee recommends the initiation of a serious deliberative process to examine:

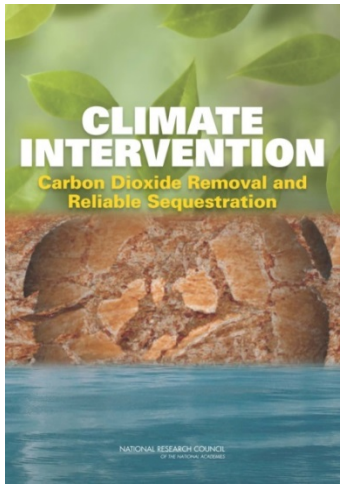
(a) what types of research governance, beyond those that already exist, may be needed for albedo modification research, and

(b) the types of research that would require such governance, potentially based on the magnitude of their expected impact on radiative forcing, their potential for detrimental direct and indirect effects, and other considerations

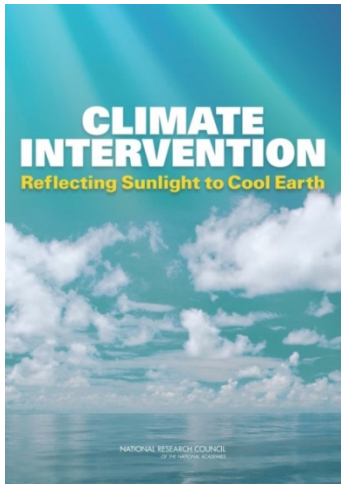
CONCLUSIONS

- The challenges of climate change require a portfolio of actions with varying degrees of risk and efficacy
- There is no substitute for mitigation and adaptation
- Carbon dioxide removal strategies offer potential to decrease carbon dioxide concentrations in the atmosphere
- Albedo modification strategies currently limited by unfamiliar and unquantifiable risks and governance issues
- Any intervention in Earth's climate should be informed by a far more substantive body of scientific research than is available at present

ACKNOWLEDGMENTS



Sponsors
Committee
Reviewers
NRC Staff
Numerous colleagues consulted during study



Please visit **americasclimatechoices.org** to find:

- Complete reports available for free PDF download
- Report in Brief (4-page lay summary)
- Press release
- Briefing slides and archived public release webcast

Join the conversation : #ClimateIntervention

Carbon Dioxide Removal proposals…	Albedo Modification proposals…
… address the cause of human-induced climate change (high atmospheric GHG concentrations).	…do not address cause of human-induced climate change (high atmospheric GHG concentrations).
…do not introduce novel global risks.	… introduce novel global risks.
…are currently expensive (or comparable to the cost of emission reduction).	…are inexpensive to deploy (relative to cost of emissions reduction).
…may produce only modest climate effects within decades.	…can produce substantial climate effects within years.
…raise fewer and less difficult issues with respect to global governance.	…raise difficult issues with respect to global governance.
…will be judged largely on questions related to cost.	…will be judged largely on questions related to risk.
…may be implemented incrementally with limited effects as society becomes more serious about reducing GHG concentrations or slowing their growth.	…could be implemented suddenly, with large-scale impacts before enough research is available to understand their risks relative to inaction.
…require cooperation by major carbon emitters to have a significant effect.	…could be done unilaterally.
…for likely future emissions scenarios, abrupt termination would have limited consequences	…for likely future emissions scenarios, abrupt termination would produce significant consequences

DISSEMINATION ACTIVITIES

Sponsor Briefings

- Multi-Agency Sponsor Briefing (Feb. 9, 2015)
- NOAA Climate Goal Team Briefing (Feb. 13, 2015)

Congressional Briefings

- Senate Climate Clearinghouse (Feb. 9, 2015)
- Senate Environment and Public Works (Feb. 9, 2015)
- Senate Commerce (Feb. 9, 2015)
- House SEEC Coalition (Feb. 9, 2015)
- House Science, Space and Technology – Majority (Feb. 9, 2015)
- House Science, Space and Technology – Minority (Feb. 9, 2015)
- House Natural Resources Subcommittee on Energy & Mineral Resources (Feb. 9, 2015)

AAAS Annual Meeting

- Feb. 14, 2015
- Two sessions
  - Going Negative: Removing Carbon Dioxide from the Atmosphere
  - Climate Intervention and Geoengineering: Albedo Modification

Public Webinars

- Public Release Event (Feb. 10, 2015)
- Resources for the Future Event (Feb. 24, 2015)
- Public NRC Webinar (Feb. 26, 2015)
- Union of Concerned Scientists Webinar (Feb. 27, 2015)
- Chevron Internal Seminar Series (March 17, 2015)

Other Briefings

- OSTP and OMB Briefing (Feb. 9, 2015)
- NGA (Feb. 11, 2014)
- Center for Climate & Security (Feb. 25, 2015)
- World Resources Institute (March 19, 2015)
- US Energy Association (March 31, 2015)
- NSF Geoscience Directorate Advisory Committee (April 9, 2015)
- University of Denver (April 14, 2015)
- Army War College (May 5, 2015)
- Governing Board Meeting (May 6, 2015)
- Energy Future Coalition (May 12, 2015)
- Green Groups (May 27, 2015)

PUBLIC REACTIONS

Media Coverage

- New York Times
- Washington Post
- Associated Press
- Los Angeles Times
- The Guardian
- USA Today
- National Public Radio
- National Geographic
- Science
- Bloomberg Business
- Forbes
- National Monitor
- National Journal
- EcoWatch
- Eos
- Physics World
- E&E News
- … more…

Report Downloads

- CDR 4,975
- Sunlight Reflection 4,309

Statements / Reactions from Non-Governmental Organizations

- Environmental Defense Fund
- ETC
- Friends of the Earth
- Natural Resources Defense Council
- Union of Concerned Scientists

Editorials and Blog Posts

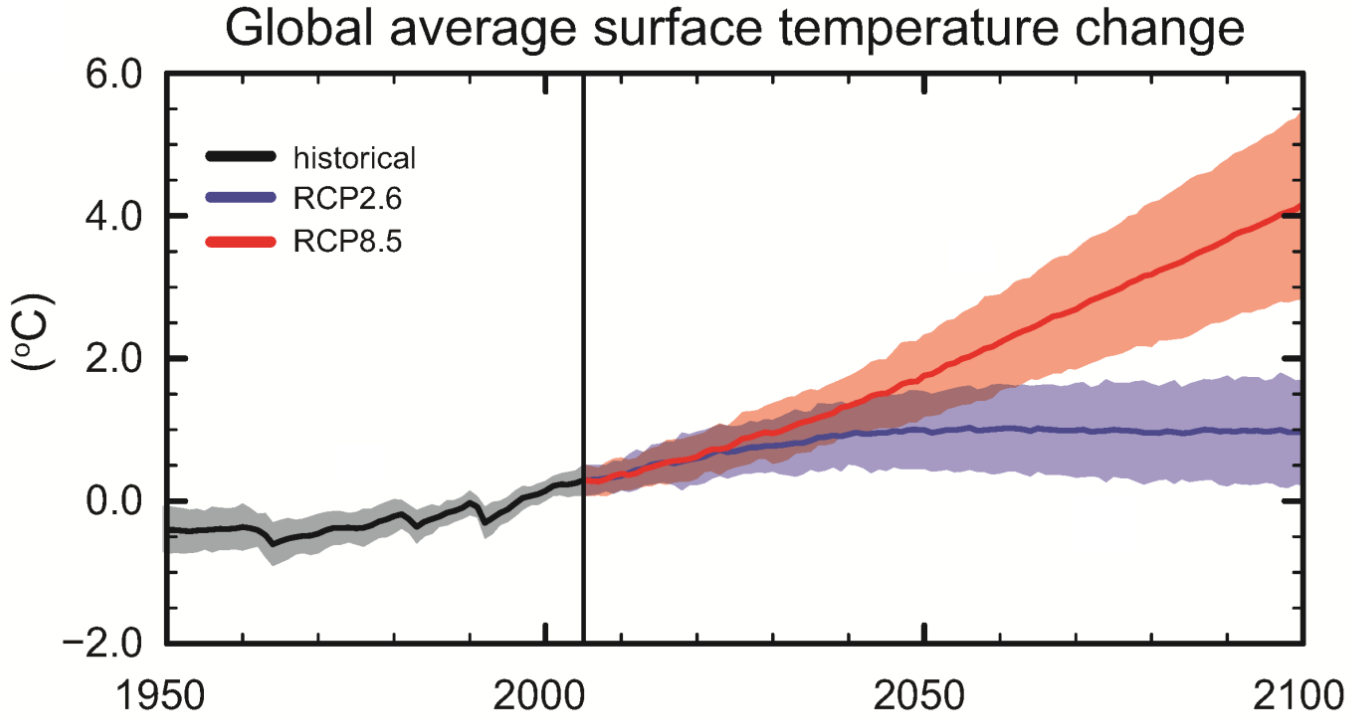
- Science Editorial
- Our Energy Policy
- BRINK
- Numerous other blog posts

Extra Slides

COMMITTEE'S STATEMENT OF TASK

- An ad hoc committee will conduct a technical evaluation of a limited number of proposed geoengineering techniques, including examples of both solar radiation management (SRM) and carbon dioxide removal (CDR) techniques, and comment generally on the potential impacts of deploying these technologies, including possible environmental, economic, and national security concerns. The study will:
  1. Evaluate what is currently known about the science of several (3-4) selected example techniques, including potential risks and consequences (both intended and unintended), such as impacts, or lack thereof, on ocean acidification,
  2. Describe what is known about the viability for implementation of the proposed techniques including technological and cost considerations,
  3. Briefly explain other geoengineering technologies that have been proposed (beyond the selected examples), and
  4. Identify future research needed to provide a credible scientific underpinning for future discussions.
- The study will also discuss historical examples of related technologies (e.g., cloud seeding and other weather modification) for lessons that might be learned about societal reactions, examine what international agreements exist which may be relevant to the experimental testing or deployment of geoengineering technologies, and briefly explore potential societal and ethical considerations related to geoengineering. This study is intended to provide a careful, clear scientific foundation that informs ethical, legal, and political discussions surrounding geoengineering.

FUTURE CLIMATE SCENARIOS



Future climate impacts largely depend on human actions

- Aggressive emission reductions needed to avoid major risks
- Extensive adaptation efforts required

SIZE OF THE CHALLENGE

- If CDR were to be used to avoid all climate change from U.S. CO_2 emissions, the United States would need to remove 110 pounds of CO_2 per day for each American.
- CO_2 is a dilute gas in the atmosphere, comprising only about 0.04% of the atmosphere by volume (and about 0.06% by mass).
- This means that if we were able to remove 100% of the CO_2 molecules from a volume of air, we would need to process about 51,000 m^3 (about 67,000 cubic yards) of air per American per day.
- This corresponds to a volume approximately 30 feet high (nearly 10 m) and the area of an American football field—to be processed for each American each day.
- Nobody is suggesting that CDR will be the only tool used to reduce CO_2 emissions, but to make a substantial contribution reducing our net CO_2 emissions, CDR would need to be deployed at a substantive level.

OTHER POSSIBLE CLIMATE RESPONSE OPTIONS

Progress on mitigation has been slow

Stabilizing atmospheric greenhouse gases requires reducing emissions by more than an order of magnitude

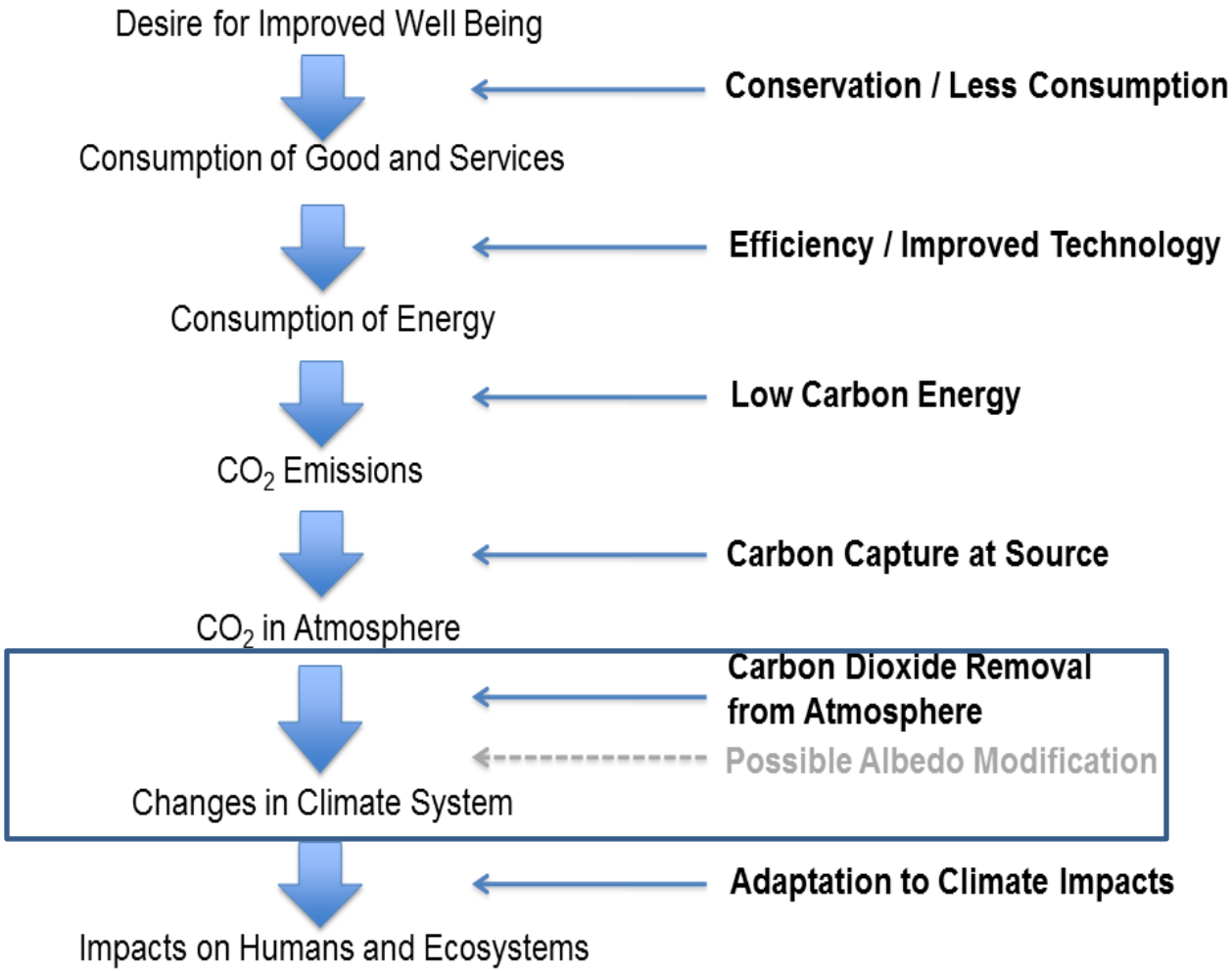
Climate adaptation poses substantial challenges

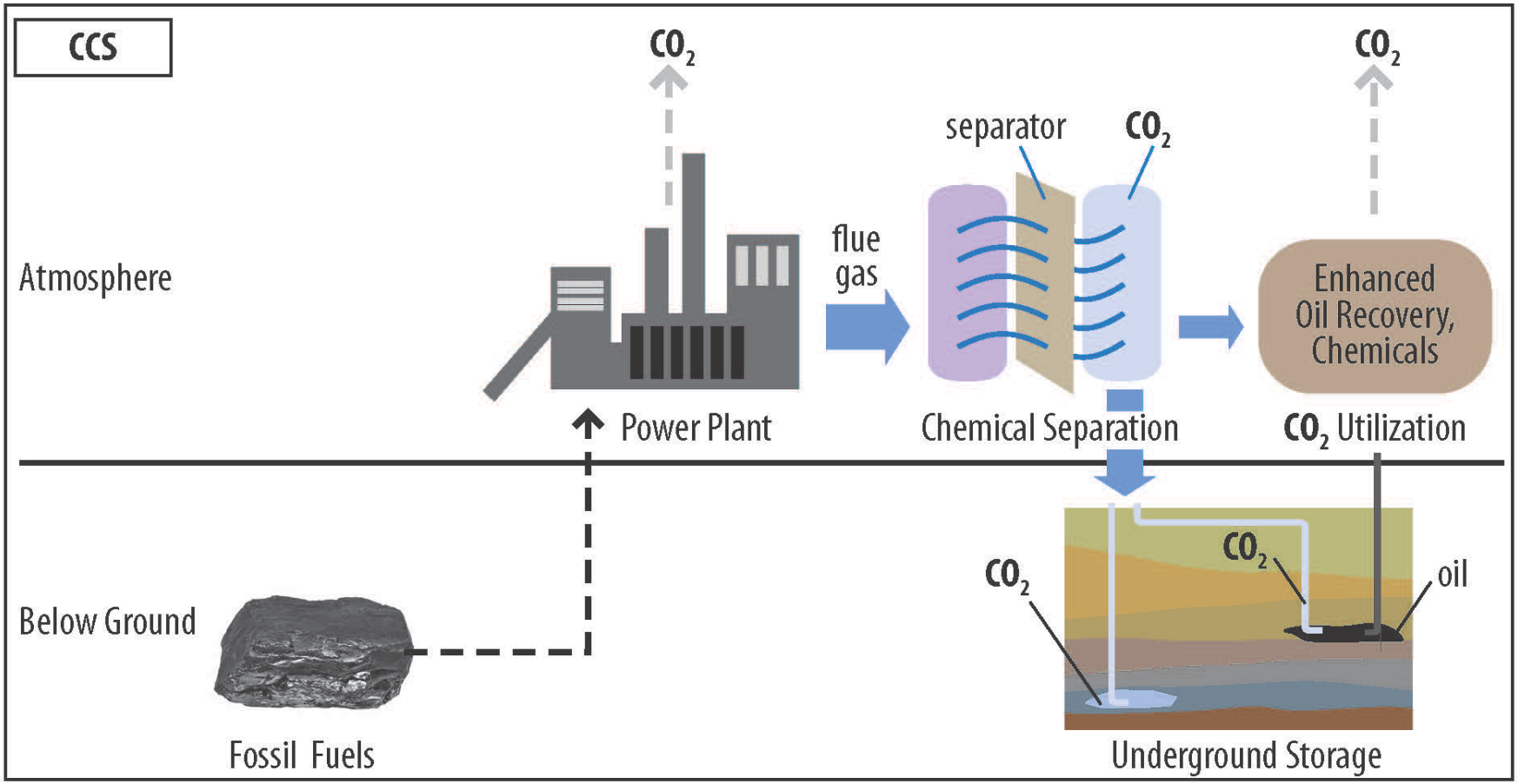
Motivates desire to understand other possible options

→ Climate intervention approaches?

CLIMATE RESPONSE OPTIONS

There is a lack of information on the impacts, benefits, and costs of climate intervention





Carbon Capture and Sequestration (CCS) from power plants not discussed
→ CCS does not remove CO_2 from atmosphere only prevents emissions

LAND USE MANAGEMENT

- Changes in land use management to enhance natural carbon sinks such as forests and agricultural lands

- Ready to deploy
- Limited carbon dioxide removal
- Requires significant amounts of land

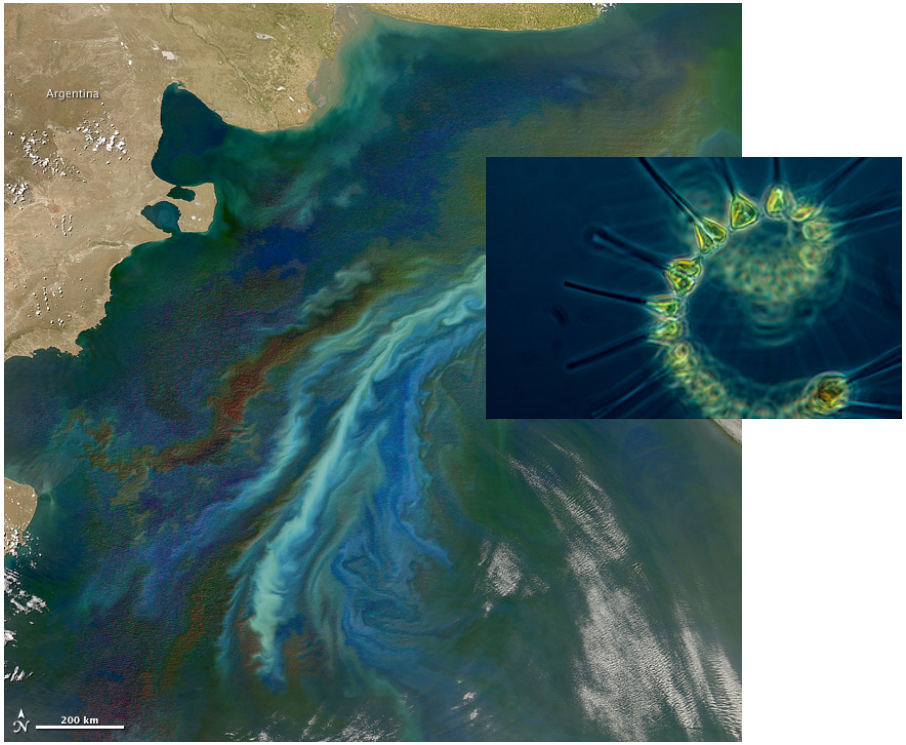
ACCELERATED WEATHERING

- Enhancing natural “weathering” reactions that convert carbon dioxide in the atmosphere into carbonate or silicate minerals
- Requires processing large amounts of minerals to reach climate relevant scale

OCEAN IRON FERTILIZATION

Adding iron to the ocean to boost the growth of phytoplankton and enhance carbon dioxide take-up

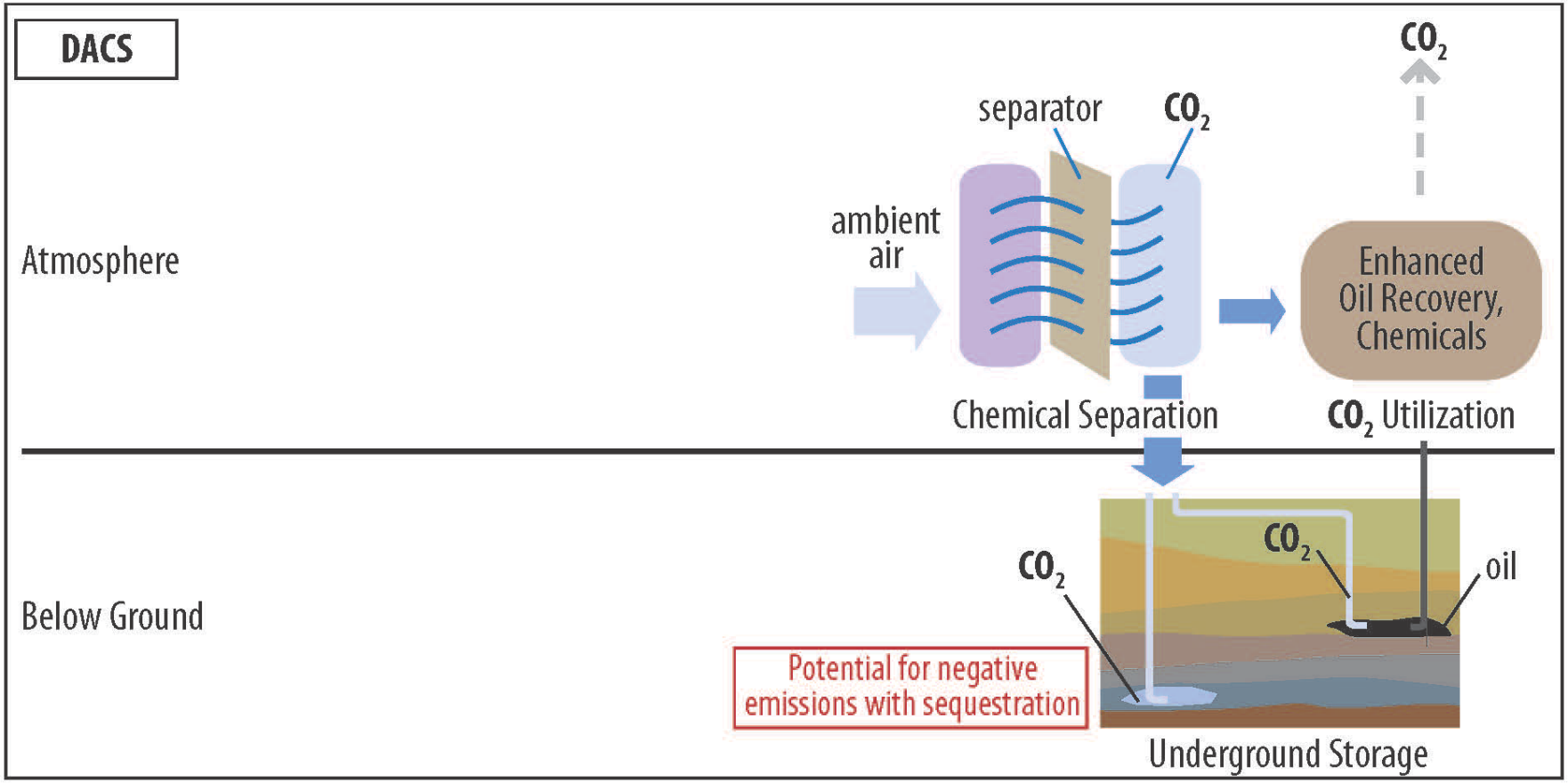
- Limited understanding of the effectiveness of this technique
- High technical and environmental risks



DIRECT AIR CAPTURE AND SEQUESTRATION (DACS)

Chemical scrubbing processes capture carbon dioxide directly from the atmosphere

- Demonstration-scale projects are in progress
- Further development needed to reduce costs

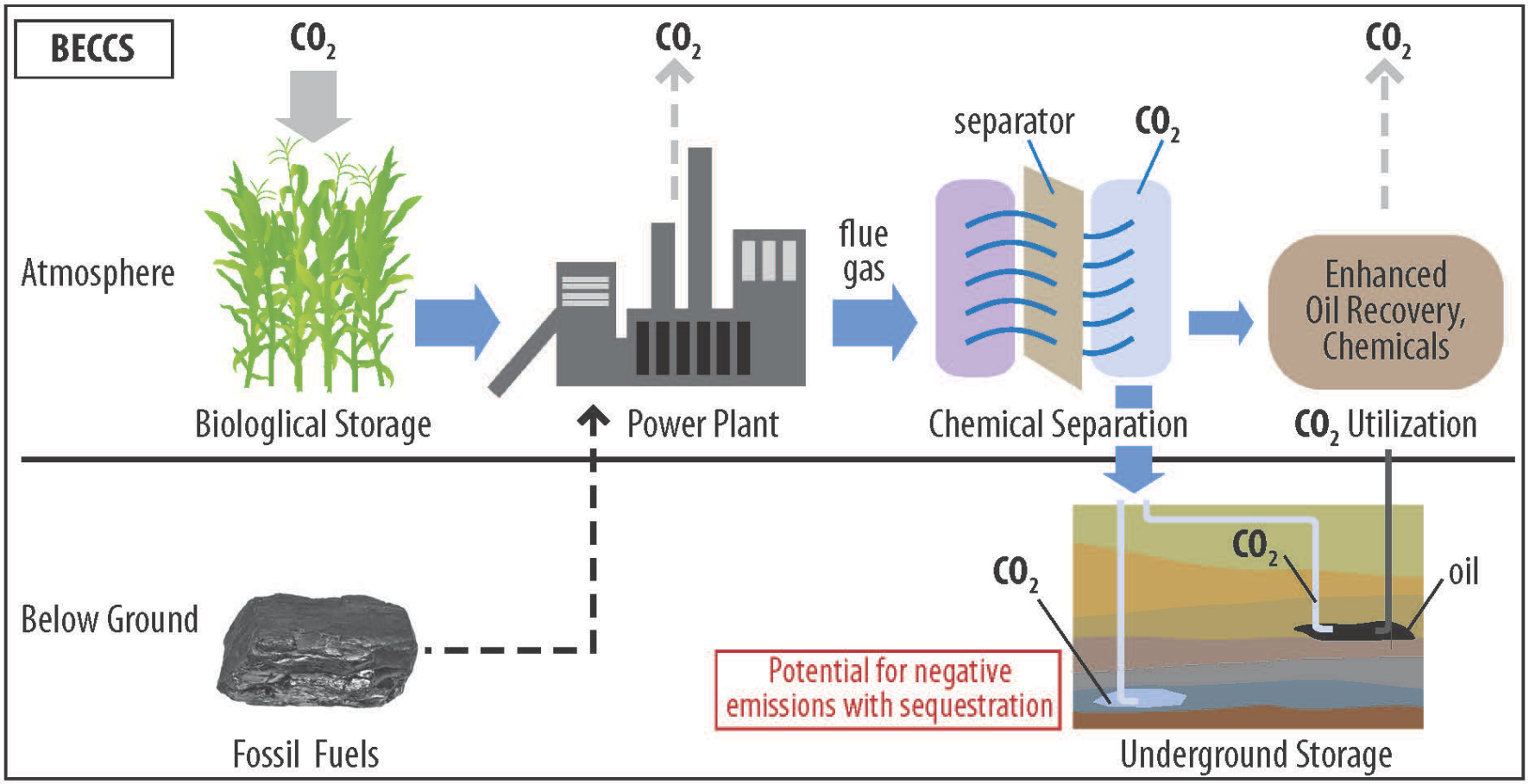

DACS
Atmosphere
Below Ground
separator
CO_2
ambient air
CO_2
Enhanced Oil Recovery, Chemicals
Chemical Separation
CO_2 Utilization
CO_2
CO_2
oil
Potential for negative emissions with sequestration
Underground Storage

BIOENERGY WITH CARBON CAPTURE AND SEQUESTRATION (BECCS)

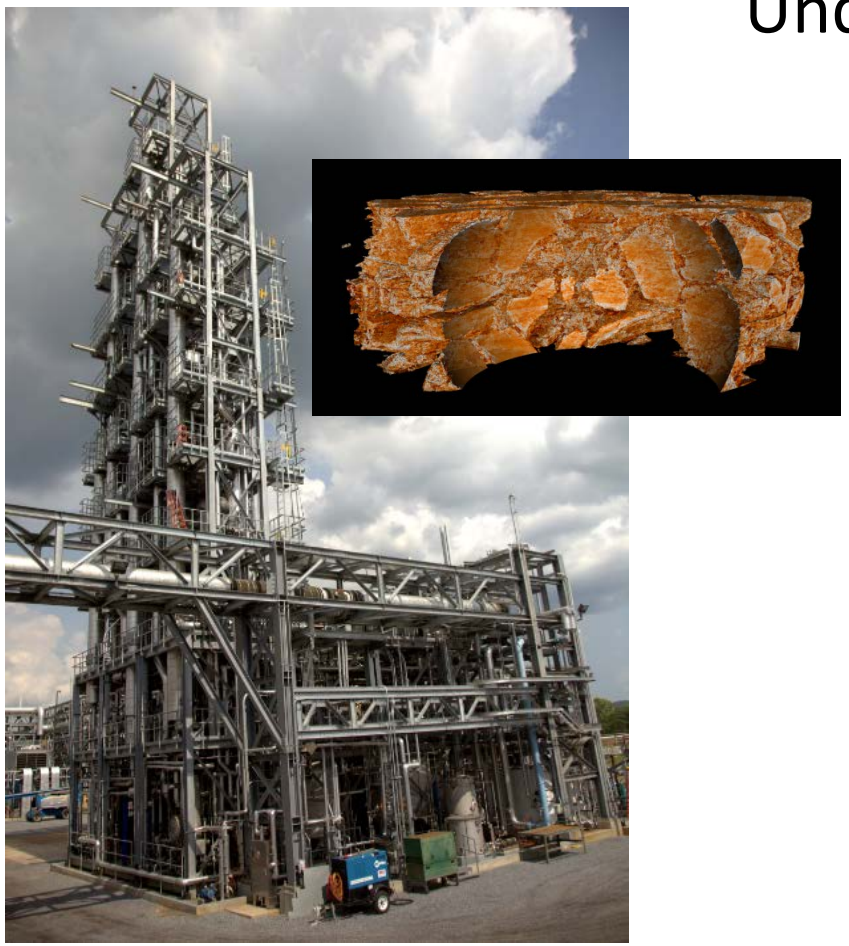
Grow plants to take up carbon dioxide from the atmosphere

- Use plants (biomass) to produce energy
- Capture carbon dioxide from power plant and sequester underground

- In theory, could capture large amounts of carbon dioxide, but competing land use is a significant challenge


BECCS
CO_2
CO_2
CO_2
separator
CO_2
Atmosphere
flue gas
Enhanced Oil Recovery, Chemicals
Biologlical Storage
Power Plant
Chemical Separation
CO_2 Utilization
Below Ground
CO_2
CO_2
oil
Potential for negative emissions with sequestration
Fossil Fuels
Underground Storage

GEOLOGICAL SEQUESTRATION OF CARBON DIOXIDE



Underground sequestration

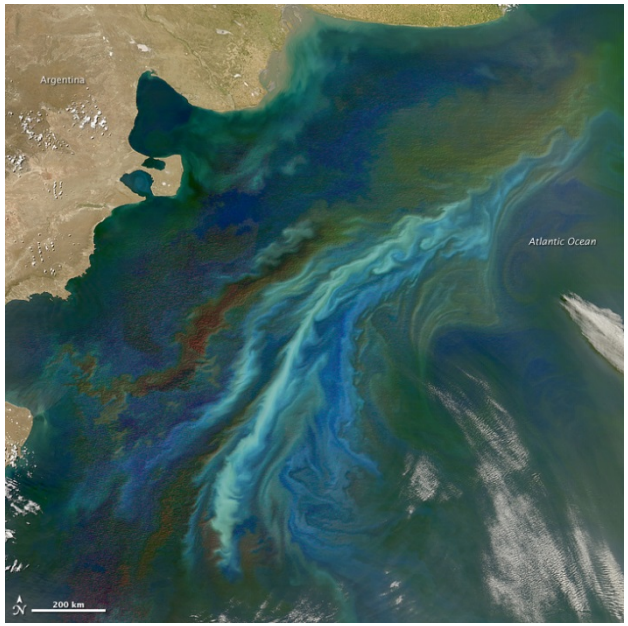
- High capacity estimates
  - Depleted hydrocarbon reservoirs
  - Saline aquifers
- Additional monitoring and leakage studies needed
- Utilization techniques are mainly for reuse
  - Enhanced oil recovery (EOR)
  - Coal-bed methane recovery

CARBON DIOXIDE REMOVAL AND RELIABLE SEQUESTRATION

All CDR approaches address root cause of climate change

Each approach presents different challenges / limitations

- All act slowly
- Some are difficult to scale up
- Some are currently expensive
- Some present risks to ecosystems
  - Ocean iron fertilization

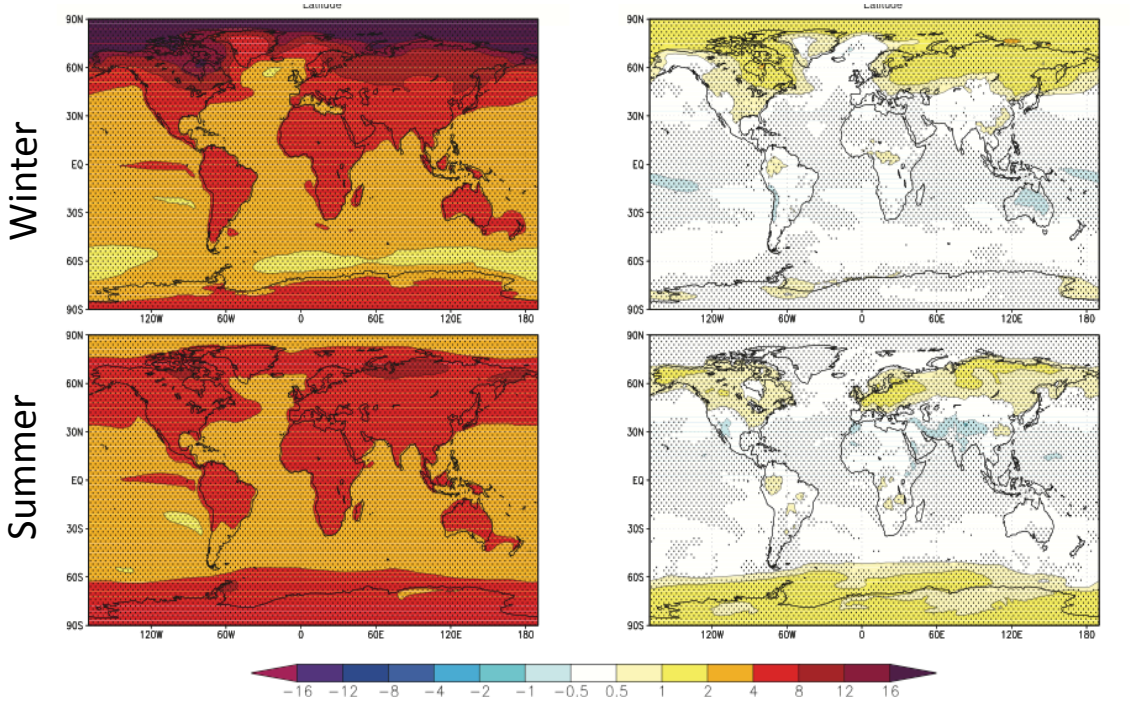


RESEARCH OPPORTUNITIES FOR CDR

- Assess and improve strategies for performing and monitoring geologic sequestration
- Explore strategies that increase the ocean's ability to store carbon without causing adverse effects
- Continued research on combining biomass energy with carbon dioxide capture and sequestration including exploration of approaches that do not form and sequester concentrated CO_2
- Solicit, foster, and develop approaches for scrubbing carbon dioxide from the atmosphere that hold the potential to bring costs and energetics into a potentially feasible range
- Land use management techniques that promote carbon sequestration
- Accelerated weathering as a CO2 removal/sequestration approach that would allow conversion to stable, storable, or useful carbonates and bicarbonates

STRATOSPHERIC AEROSOLS

Aerosol precursors, such as sulfur dioxide, are injected into the stratosphere where they increase reflection of sunlight



Temperature Change from Increased CO_2
Without and With Albedo Modification

- Could rapidly cool planet's surface
  - At relatively low direct cost
- Carries risks
  - Some known
  - Some unknown

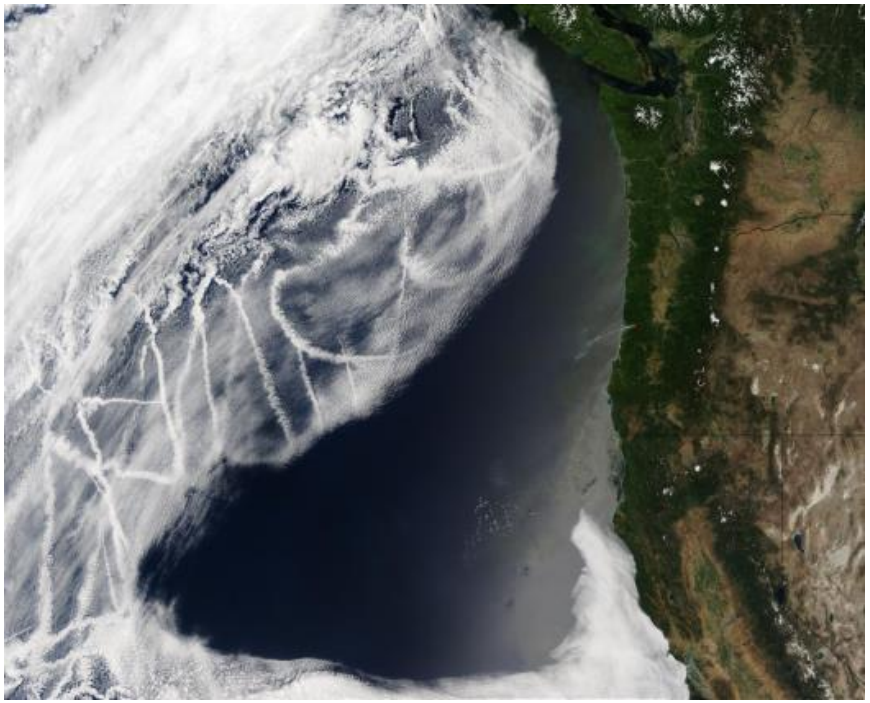
RESEARCH OPPORTUNITIES FOR SAAM

- Observational research needs:
  - New generation of short-wavelength (albedo) and long-wavelength (outgoing infrared) space-based instruments
  - Improved observational capability to make better use of future major volcanic eruptions
- Multiple-benefit research topics
  - Stratospheric aerosol microphysics (formation, growth, coalescence, dispersion)
  - Impacts on chemistry (particularly ozone)
  - Impacts on water vapor in the upper troposphere and lower stratosphere
  - Effects of additional aerosol on upper tropospheric clouds
- Research strategies
  - Model intercomparisons
  - Rapid response observational capability to make better use of future volcanic eruptions
  - Possibly outdoor experiments – see discussion of Governance (Recommendation 6)

MARINE CLOUD BRIGHTENING

Aerosols introduced to marine clouds to make them more reflective

- Evidence from ship tracks
- Could rapidly cool planet's surface
- Interactions of particles with clouds are very complex



RESEARCH OPPORTUNITIES FOR MCB

- Modeling studies
  - Model intercomparisons
    - Comparing aerosol model components
    - Comparisons across model types (global, LES, aerosol dynamics, plume models)
    - Variation with model resolution
  - Connections to field studies

- Possible small-scale controlled emissions studies
  - Comparing to a control
  - Tracking changes in a cloud system
  - Testing in different regions and seasons
  - Evaluating differences in emission strategy
  - See discussion of Governance (Recommendation 6)

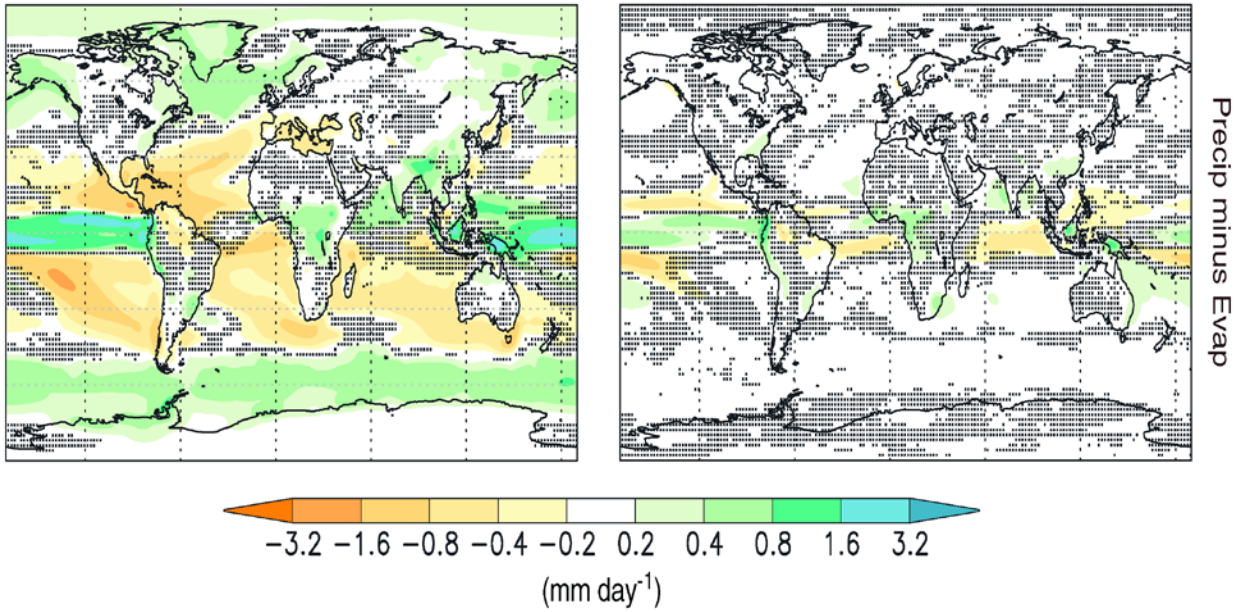
ALBEDO MODIFICATION POSES KNOWN ENVIRONMENTAL RISKS

The observed side effects from volcanic eruptions—a natural source of sunlight-reflecting aerosols—provide some indication of the environmental risks

- Decreases in stratospheric ozone
- Changes in the amount and patterns of precipitation
- Albedo modification does not reduce atmospheric carbon dioxide levels

ALBEDO MODIFICATION POSES POORLY UNDERSTOOD ENVIRONMENTAL RISKS

- Uncertainties in modeling both climate change and consequences of albedo modification
- Regional effects of albedo modification



Hydrology Changes from Increased CO_2 Without and With Albedo Modification

ALBEDO MODIFICATION POSES OTHER SIGNIFICANT RISKS

Amount of albedo modification required to offset greenhouse warming will continue to escalate for millennia

Significant potential for unanticipated, unmanageable, and regrettable consequences

- Including political, social, legal, economic, and ethical dimensions