Energy Implications of Geoengineering

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Harvard Energy Journal Club
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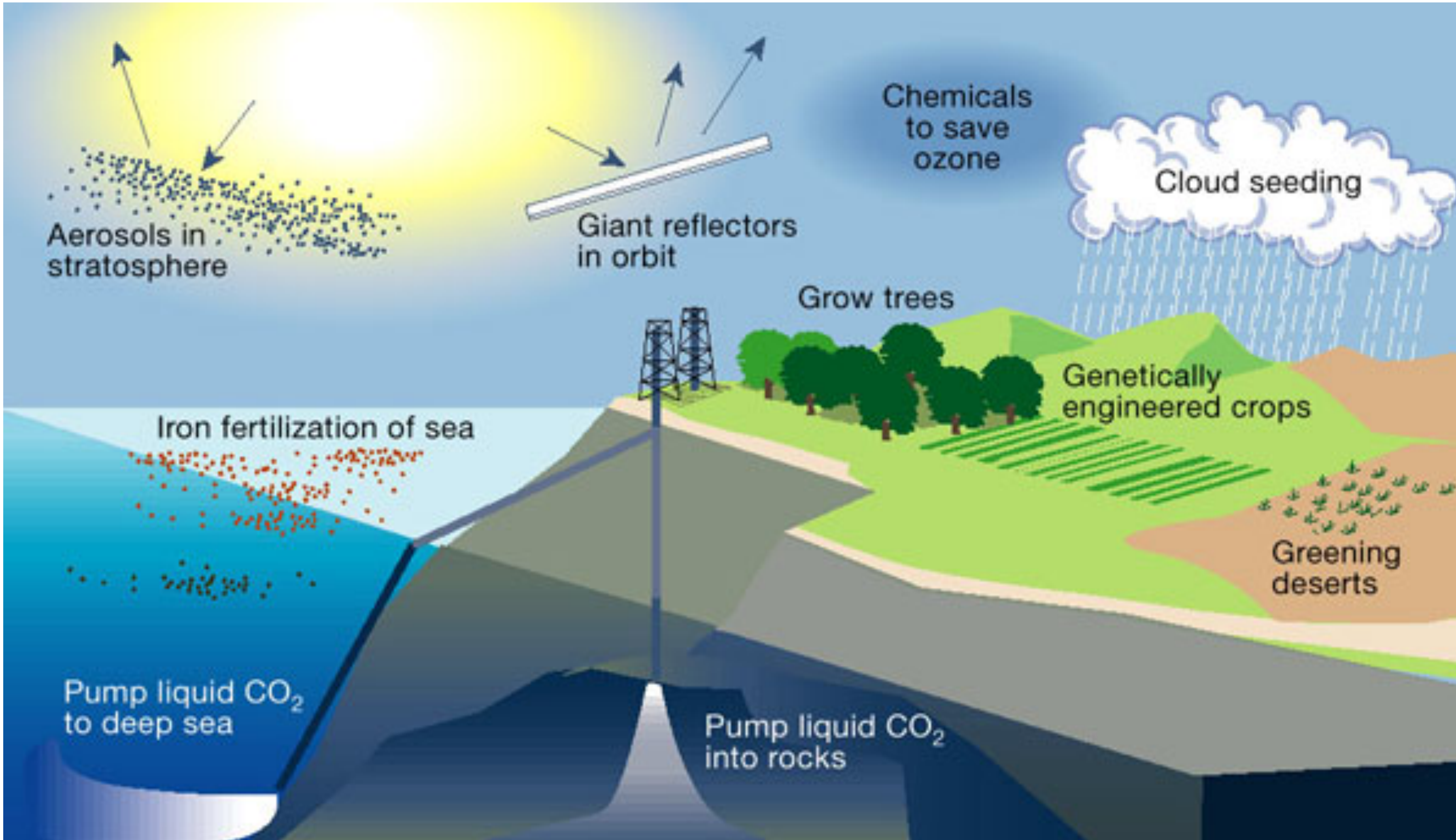
Geoengineering: intentional climate interventions to reduce the effects of climate change



Schematic representation of various climate-engineering proposals (courtesy B. Matthews).

Keith (2001)

Geoengineering: intentional climate interventions to reduce the effects of climate change

RESTORING THE QUALITY

OF

OUR ENVIRONMENT

Report of The

Environmental Pollution Panel

President's Science Advisory Committee

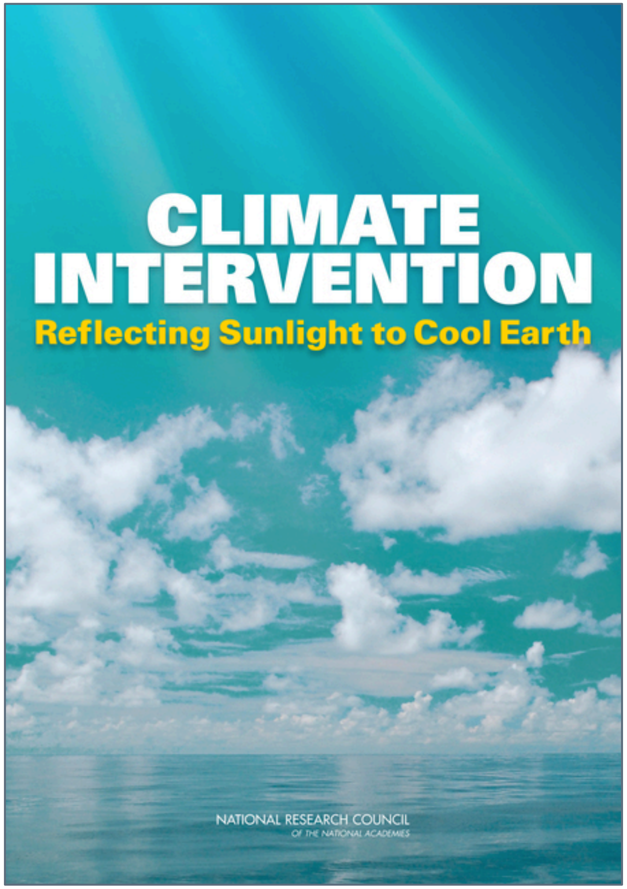
THE WHITE HOUSE

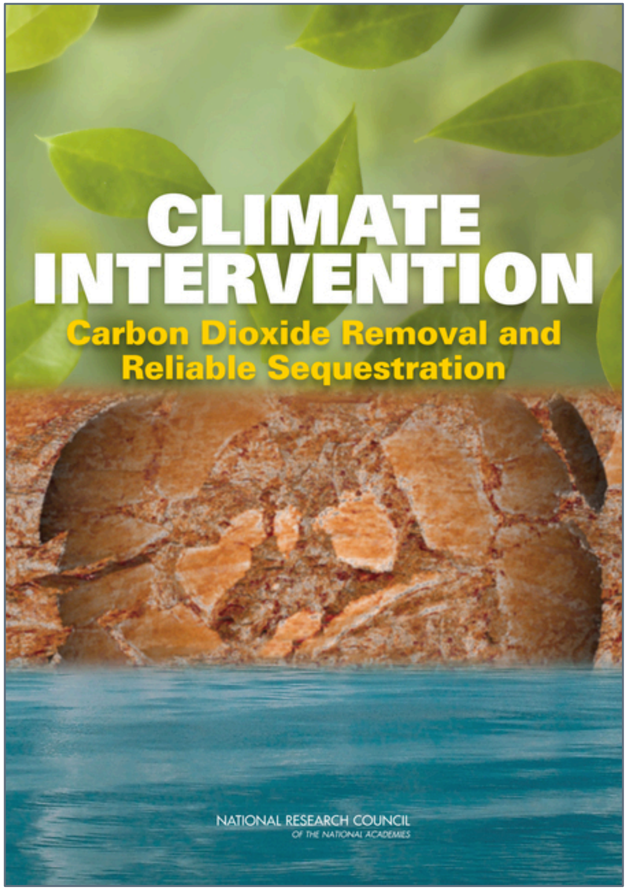
NOVEMBER 1965

Section I. CARBON DIOXIDE FROM FOSSIL FUELS—THE INVISIBLE POLLUTANT

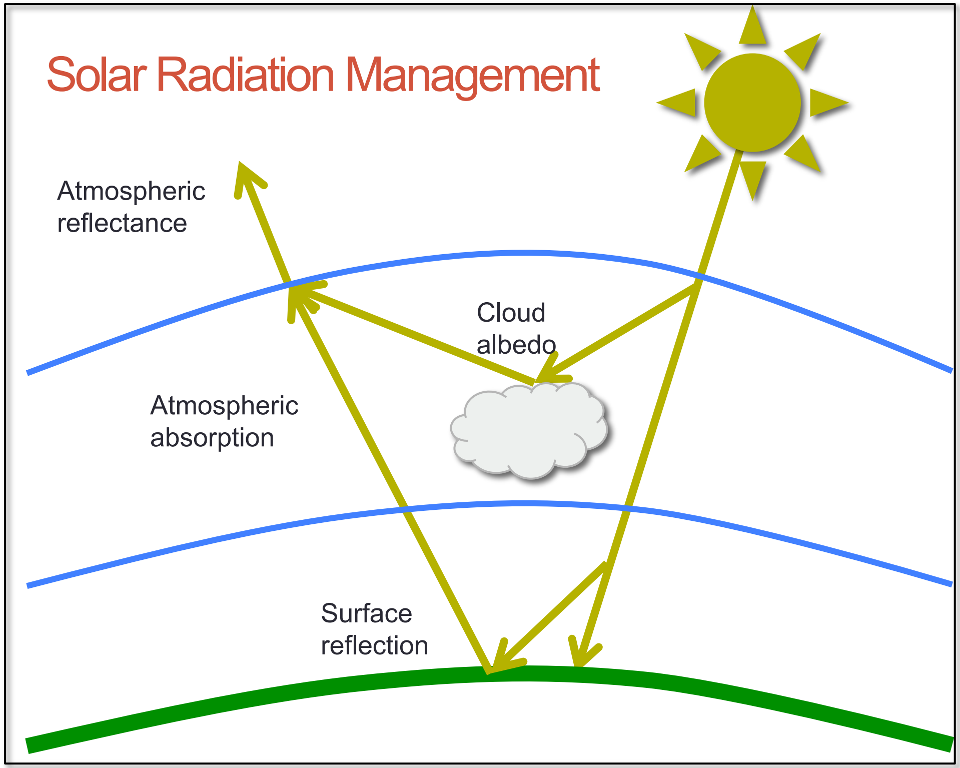
"The possibilities of **deliberately bringing about countervailing climatic changes**...need to be thoroughly explored." (PSAC, 1965)

Geoengineering: intentional climate interventions to reduce the effects of climate change





National Academies Press, 2015



Adapted from The Royal Society

SRM: address the *symptoms*

CDR: address the *cause*

Carbon Dioxide Removal

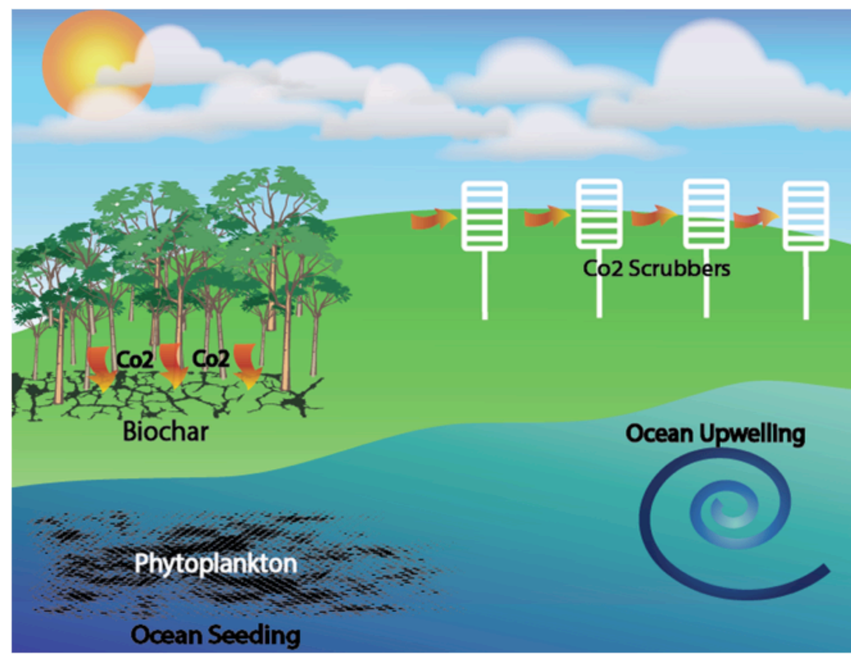
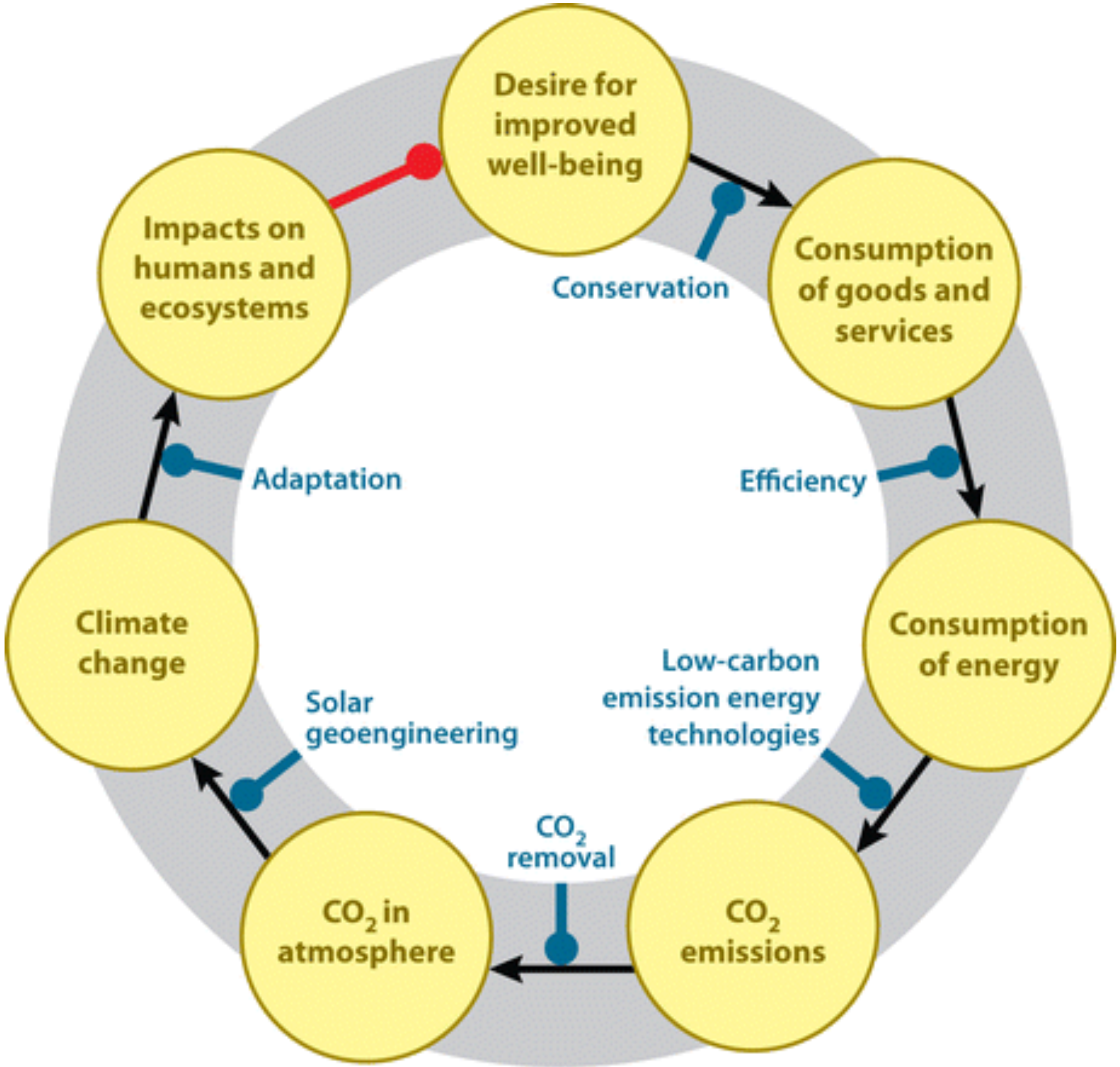
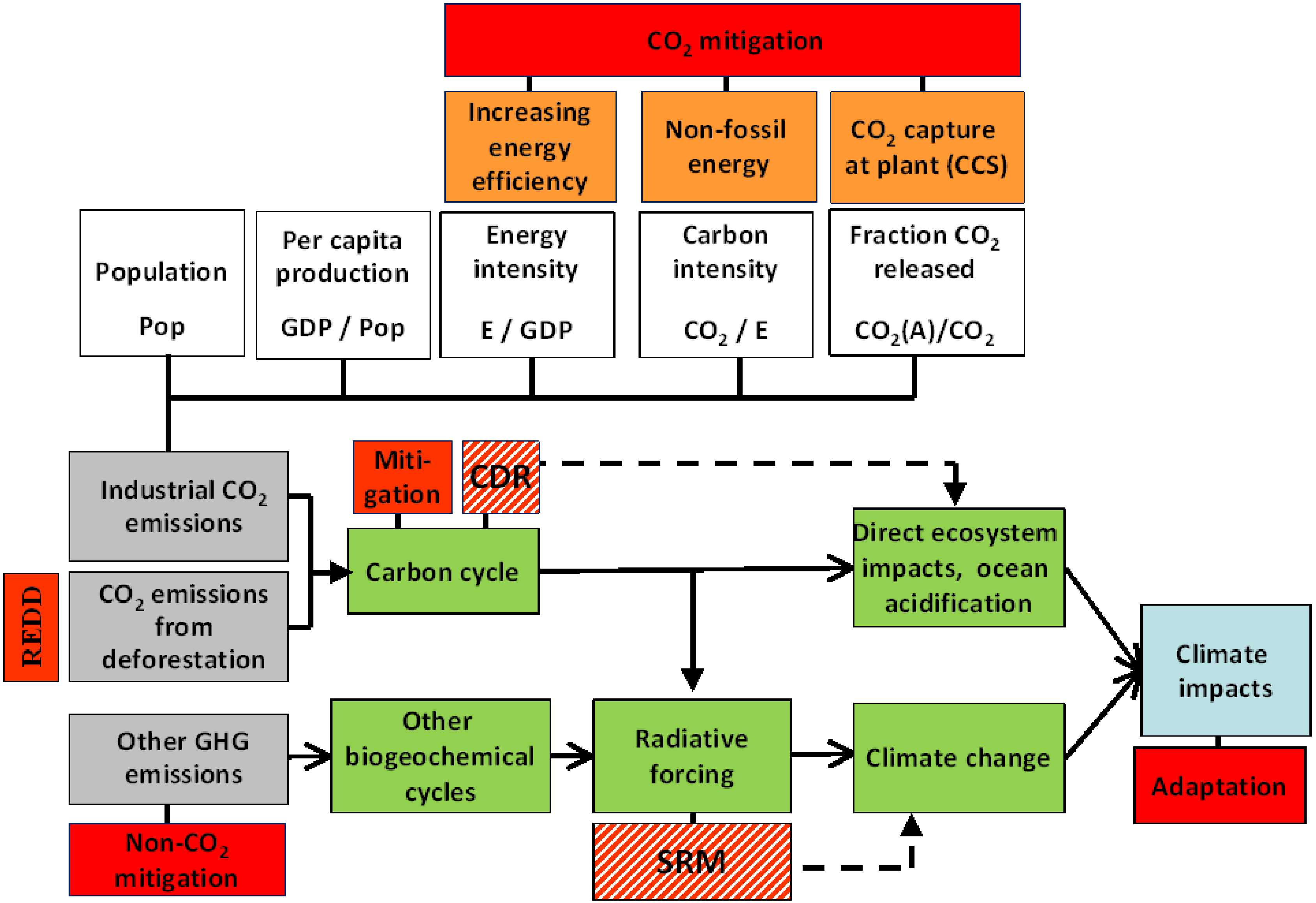


Image: blogs.worldwatch.org



Caldeira K, et al. 2013.
Annu. Rev. Earth Planet. Sci. 41:231–56



IPCC Meeting Report on Geoengineering, 2012

Carbon Dioxide Removal Techniques

	Deployed to remove 1 GtC/Yr					
Technique	Cost	Impact of anticipated environmental effects	Risk of unanticipated environmental effects	Ultimate constraint	Max reduction in CO_2 (ppm)	Reference
Land use and afforestation	Low	Low	Low	Competition with other land uses, especially agriculture	n/a	Canadell & Raupach (2008); Naidoo *et al.* (2008)
Biomass with carbon sequestration (BECS)	Medium	Medium	Medium	Competition with other land uses, especially agriculture. Availability of sequestration sites	50 to 150	Read & Parshotam (2007); Korobeinikov *et al.* (2006)
Biomass and biochar	Medium	Medium	Medium	Supply of agricultural / forestry waste	10 to 50	Gaunt & Lehmann (2008)
Enhanced weathering on land	Medium	Medium	Low	Extraction and energy costs	n/a	Schuiling & Krijgsman (2006)
Enhanced weathering—increasing ocean alkalinity	Medium	Medium	Medium	Extraction and energy costs, ocean carbonate precipitation	n/a	Kheshgi (1995); Rau (2008)
Chemical air capture and carbon sequestration	High	Low	Low	Cost availability of sequestration sites	no obvious limit	Keith *et al.* (2005)
Ocean Fe fertilisation	Low	Medium	High	Dynamics of ocean carbon system	10 to 30	Aumont & Bopp (2006)
Ocean N and P fertilisation	Medium	Medium	High	Cost and availability of nutrients	5 to 20	Lenton & Vaughan (2009)
Ocean upwelling, downwelling	Not possible				1 to 5	Zhou & Flynn (2005)

The Royal Society (2009)

Solar Radiation Management Techniques

SRM technique	Maximum radiative forcing (W/m^2)	Cost per year per unit of radiative forcing ($\$10^9/yr/W/m^2$)	Possible side-effects	Risk (at max likely level)
Human Settlement Albedo[(a)]	–0.2	2000	Regional Climate Change	L
Grassland and Crop Albedo[(b)]	–1	n/a	Regional Climate Change Reduction in Crop Yields	M L
Desert Surface Albedo[(c)]	–3	1000	Regional Climate Change Ecosystem impacts	H H
Cloud Albedo[(d)]	–4	0.2	Termination effect[(h)] Regional Climate Change	H H
Stratospheric Aerosols[(e)]	Unlimited	0.2	Termination effect Regional Climate Change Changes in Strat. Chem.	H M M
Space-based Reflectors[(f)]	Unlimited	5	Termination effect Regional Climate Change Reduction in Crop Yields	H M L
Conventional Mitigation[(g)] (for comparison only)	–2 to –5[(g)]	200[(g)]	Reduction in Crop Yields	L

The Royal Society (2009)

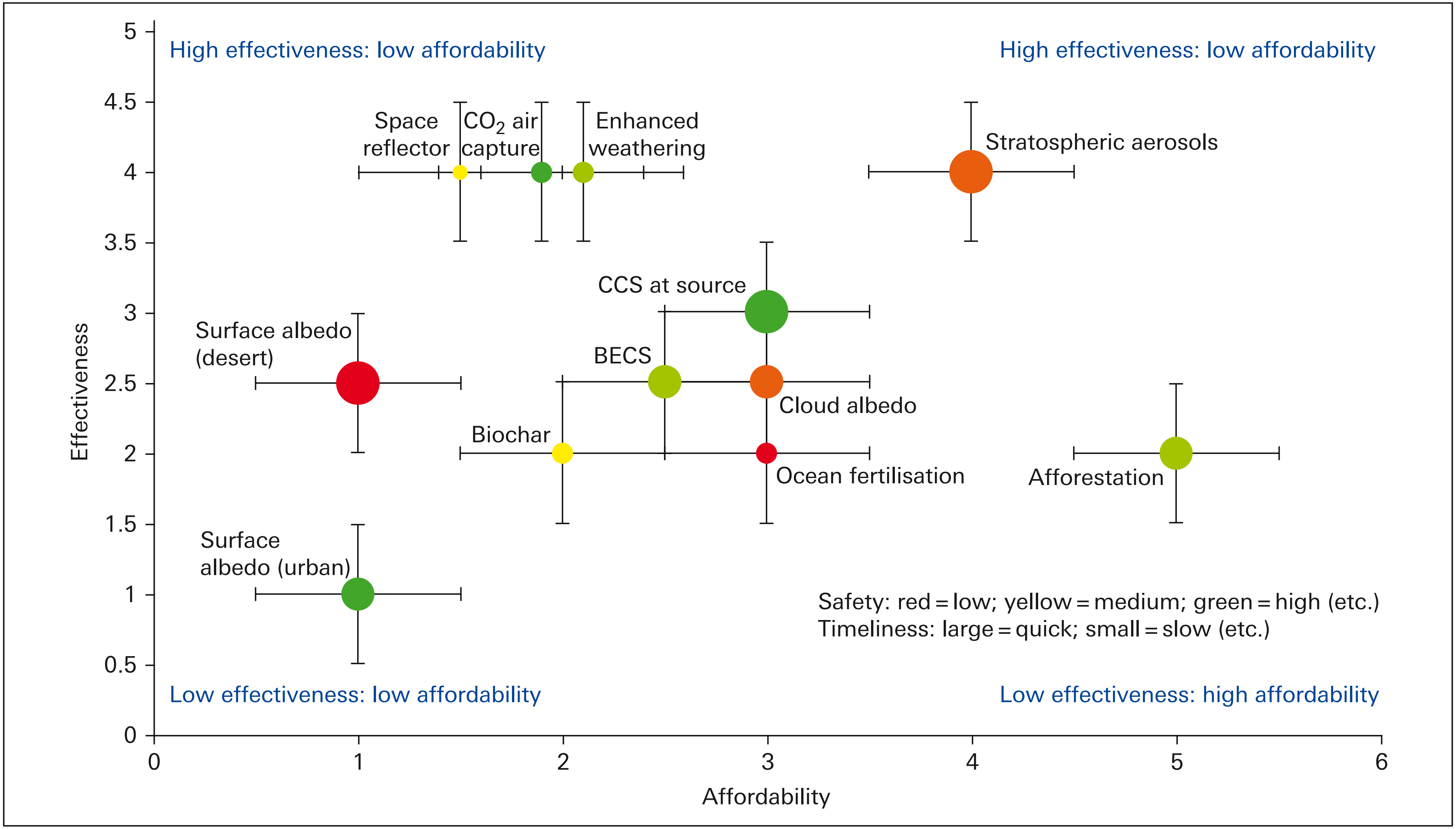


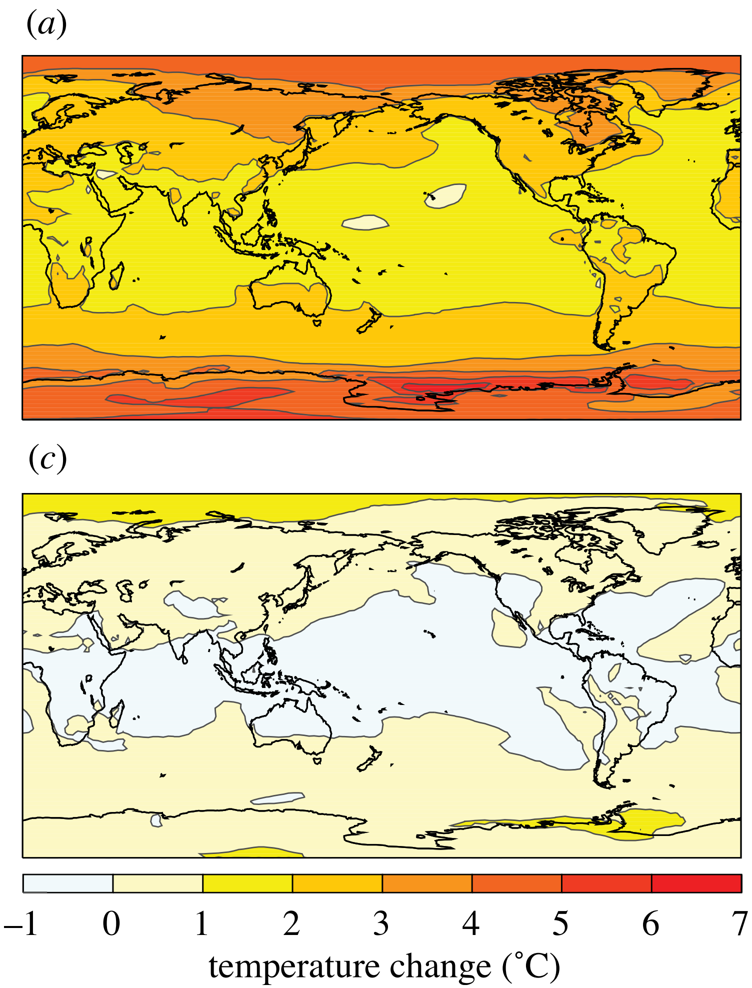
Image: The Royal Society

Potential of SRM

Caldeira & Wood (2008): SRM by 1.8% reduction in solar radiation compensates roughly for doubled CO_2 induced temperature changes.

$2xCO_2$

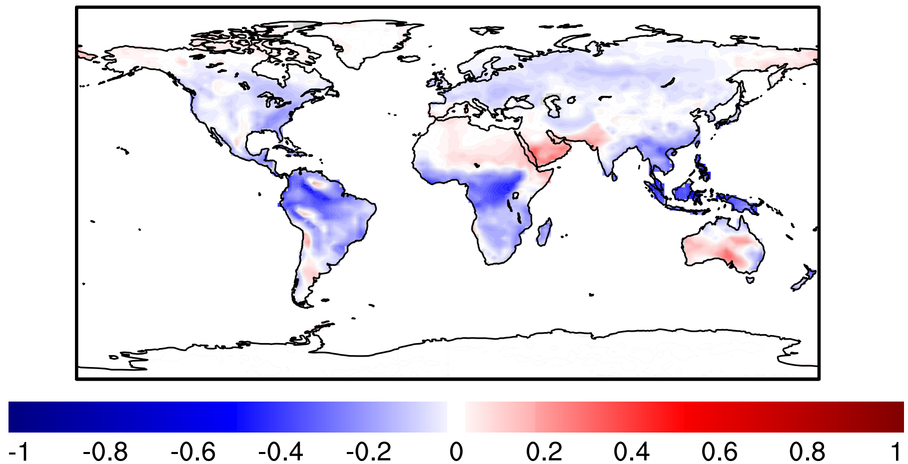
$2xCO_2$ + SRM



Hydrologic/Vegetation Impacts

Dagon & Schrag (2016): Evaporation over land decreases as CO_2 increases and solar radiation decreases; plant photosynthesis increases.

2xCO_2+2%SRM

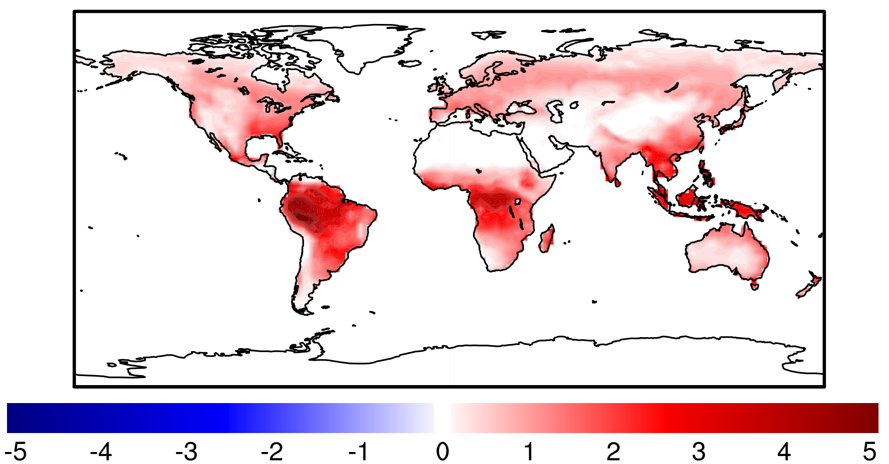


Evaporation (mm/day)

wet

dry

2xCO_2+2%SRM



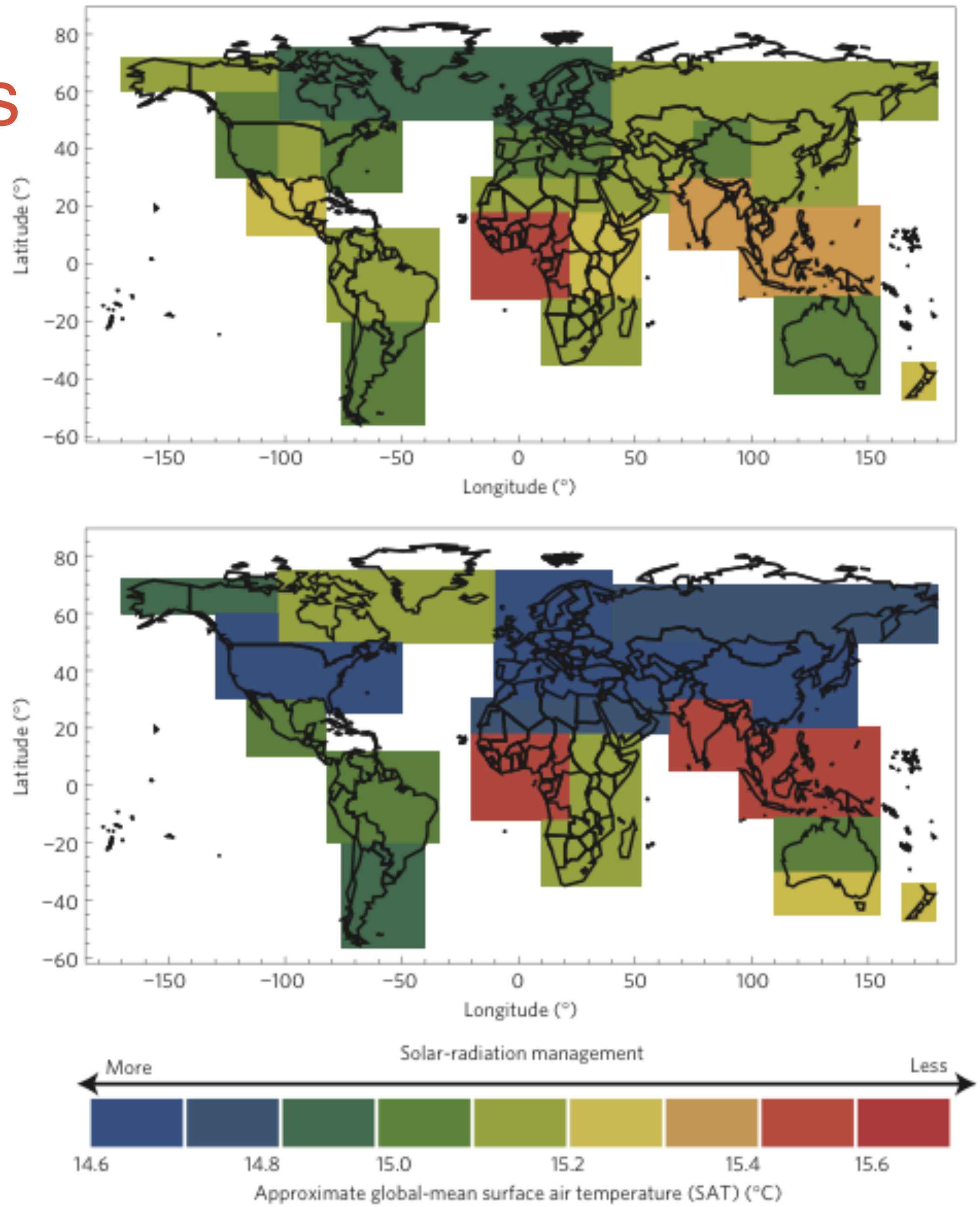
Photosynthesis (umol/m^2s)

less growth

more growth

Regional Inequalities

Attempts to optimize SRM on a global scale **cannot simultaneously stabilize** global temperature and precipitation everywhere.

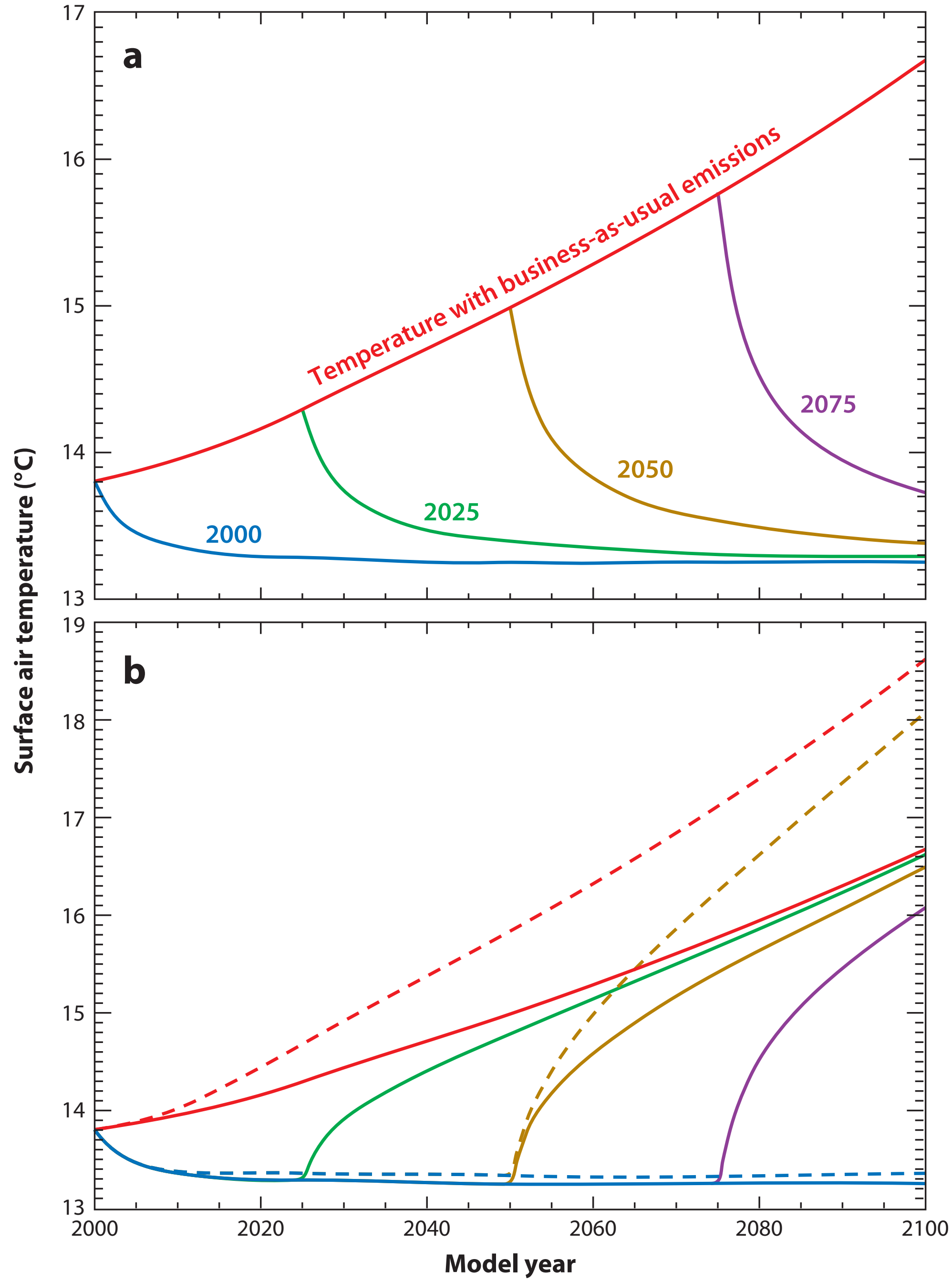


Ricke et al. 2010

Termination Effect

Temperature response when SRM is **deployed** in the years shown

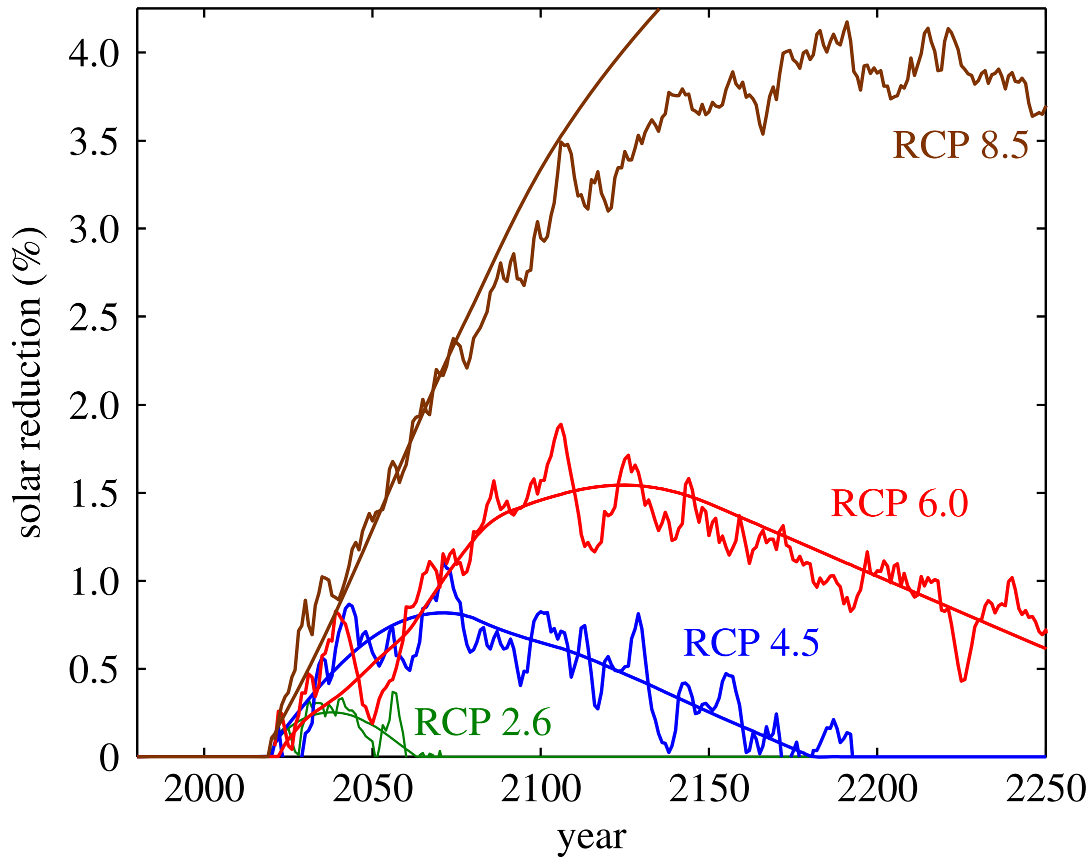
Temperature response when SRM is **terminated** (dashed lines show doubled climate sensitivity)



Caldeira et al. 2013, adapted from Matthews & Caldeira 2007

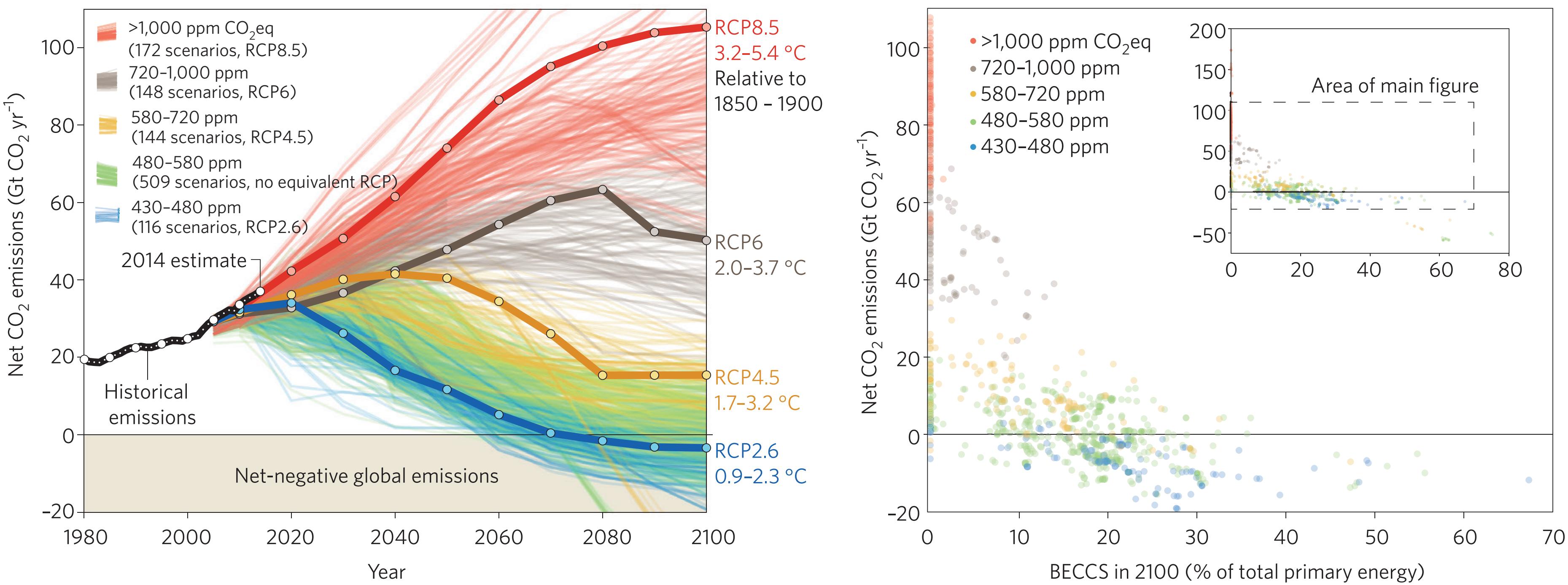
Comparison with Emissions Pathways

MacMartin et al. (2014): % solar reduction required to maintain a constant 0.1°C per decade rate of temperature change



Comparison with Emissions Pathways

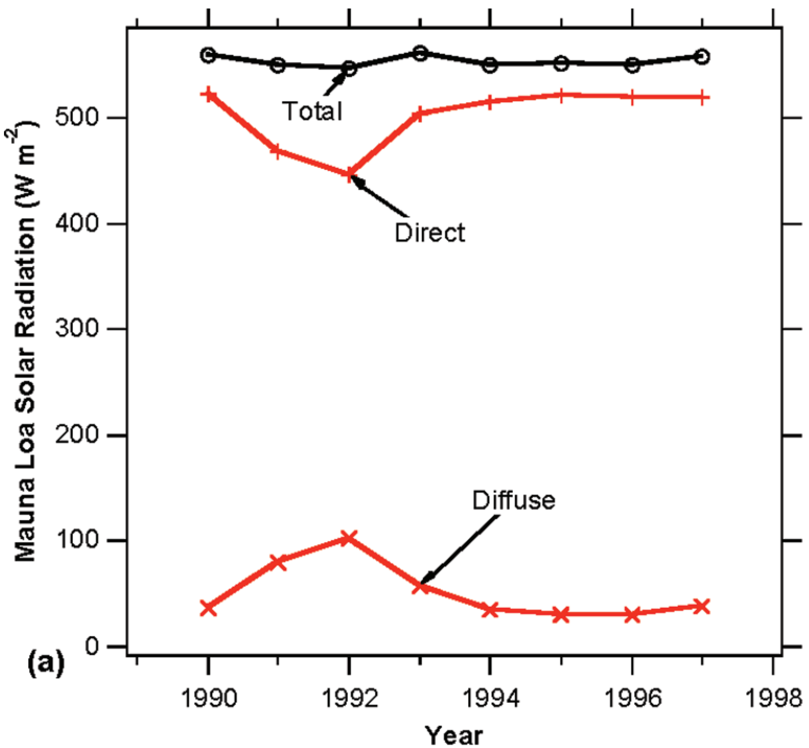
Fuss et al. (2014): most scenarios limiting warming to below 2°C include moderate amount of BECCS and even net negative emissions



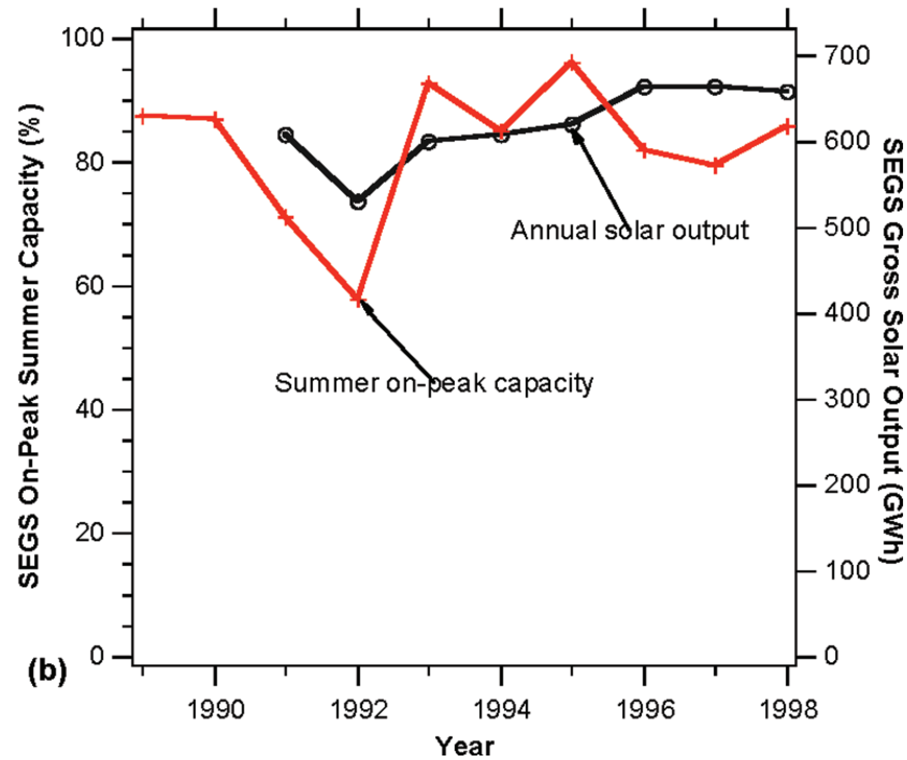
How could SRM impact solar energy?

- 1982 eruption of El Chichon resulted in 2% decrease in total solar radiation, **25% decrease in direct radiation/power production** at the Barstow prototype solar power tower installation *(MacCracken, 2006)*
- 1991 eruption of Mount Pinatubo resulted in **decrease in peak power output of 20%** in California *(Murphy, 2009; Robock et al., 2009)*
- Different solar power systems **respond nonlinearly** to changes in total available sunlight, particularly concentrated solar *(Robock, 2008)*

How could SRM impact solar energy?

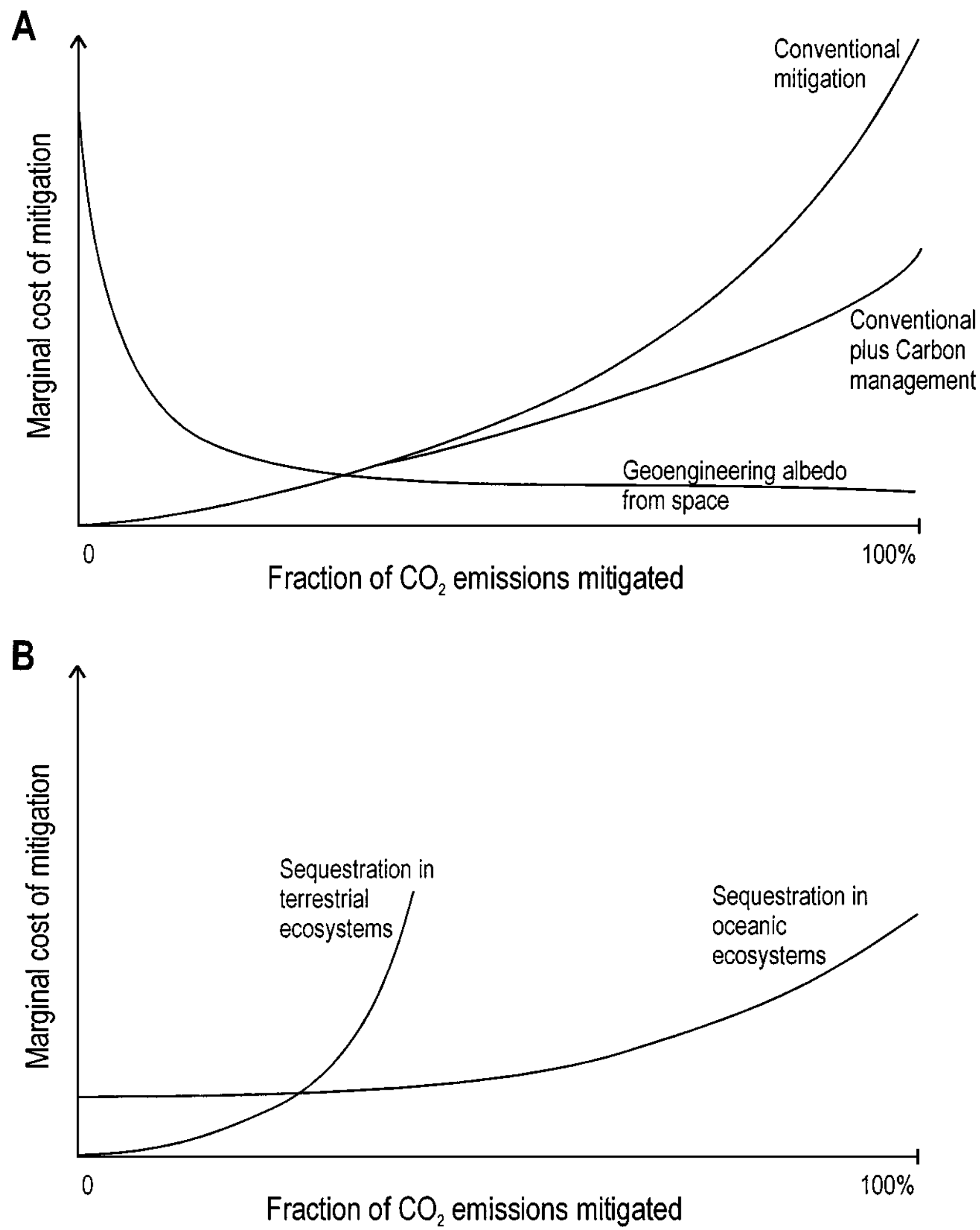


Sunlight at Mauna Loa



Power production at solar thermal plants in CA

Murphy (2009)


A
Marginal cost of mitigation
Conventional mitigation
Conventional plus Carbon management
Geoengineering albedo from space
0
100%
Fraction of CO_2 emissions mitigated
B
Marginal cost of mitigation
Sequestration in terrestrial ecosystems
Sequestration in oceanic ecosystems
0
100%
Fraction of CO_2 emissions mitigated

Keith 2000

Climate Engineering: some questions

How do we do it?

What does it do to the climate system?

What does it do to the Earth system?

What might go wrong?

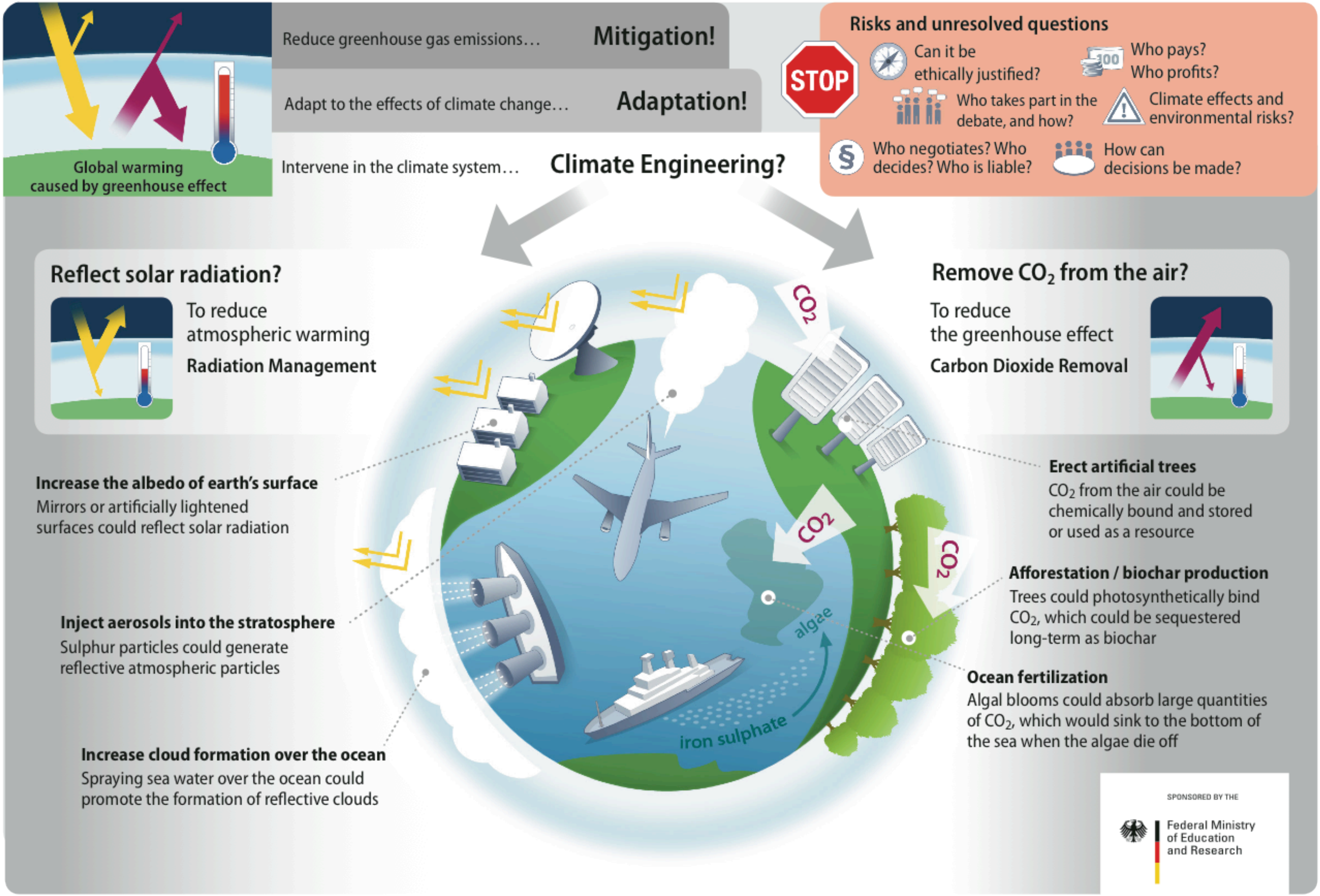
Does it postpone the need to reduce CO2 emissions?

Will it postpone the reduction of CO2 emissions?

Who controls it?

When should we start (if at all)?

What do we need to know before we start?



Overview of selected Climate Engineering approaches (Source: German Federal Ministry of Education and Research)