# Geoengineering

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- **Problem:**
  - Hawaiian islands overrun with rats.
  - Significant pest for the sugar cane industry.

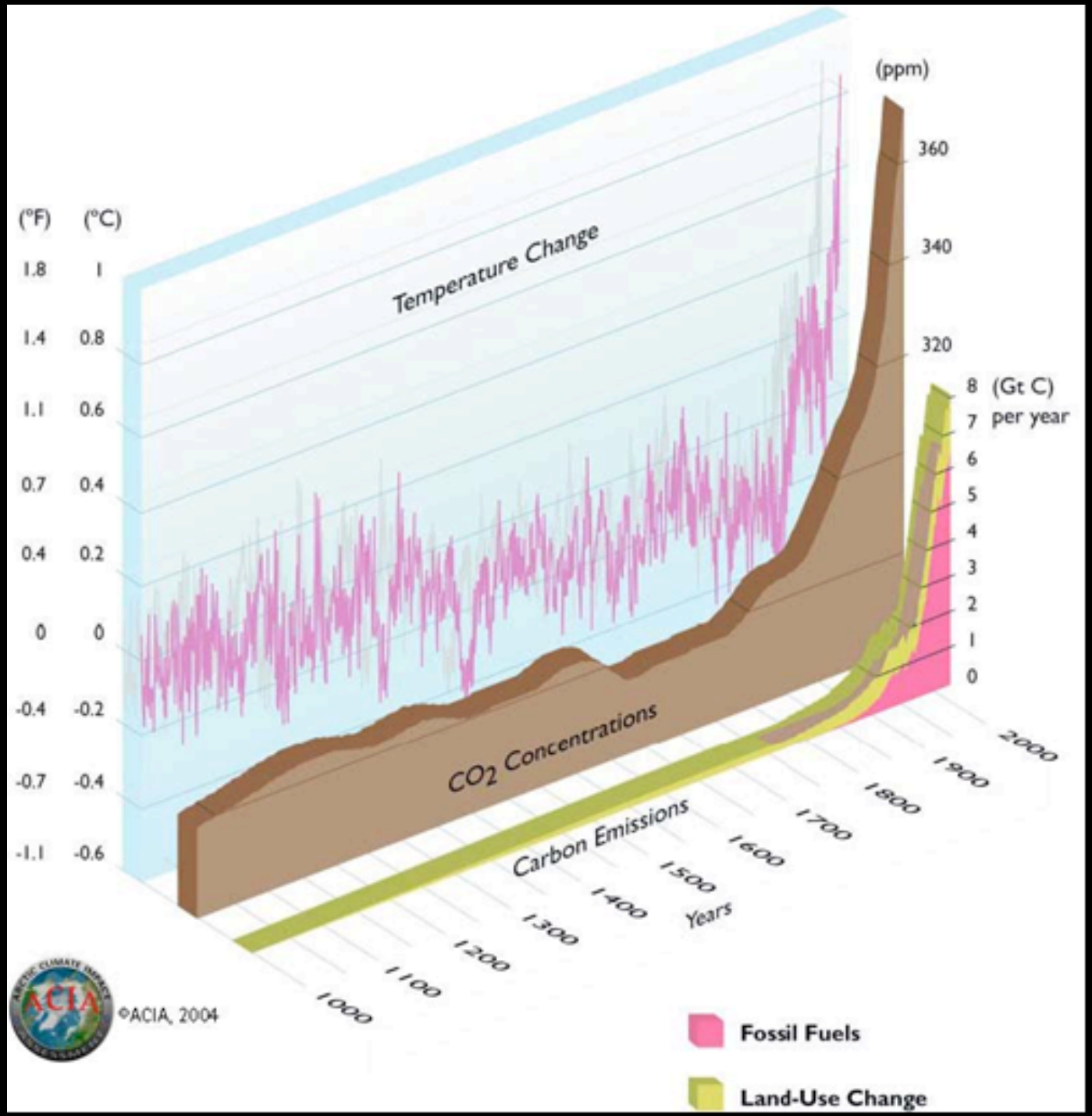
- **Solution:**
  - Introduce mongooses to hunt the rats.

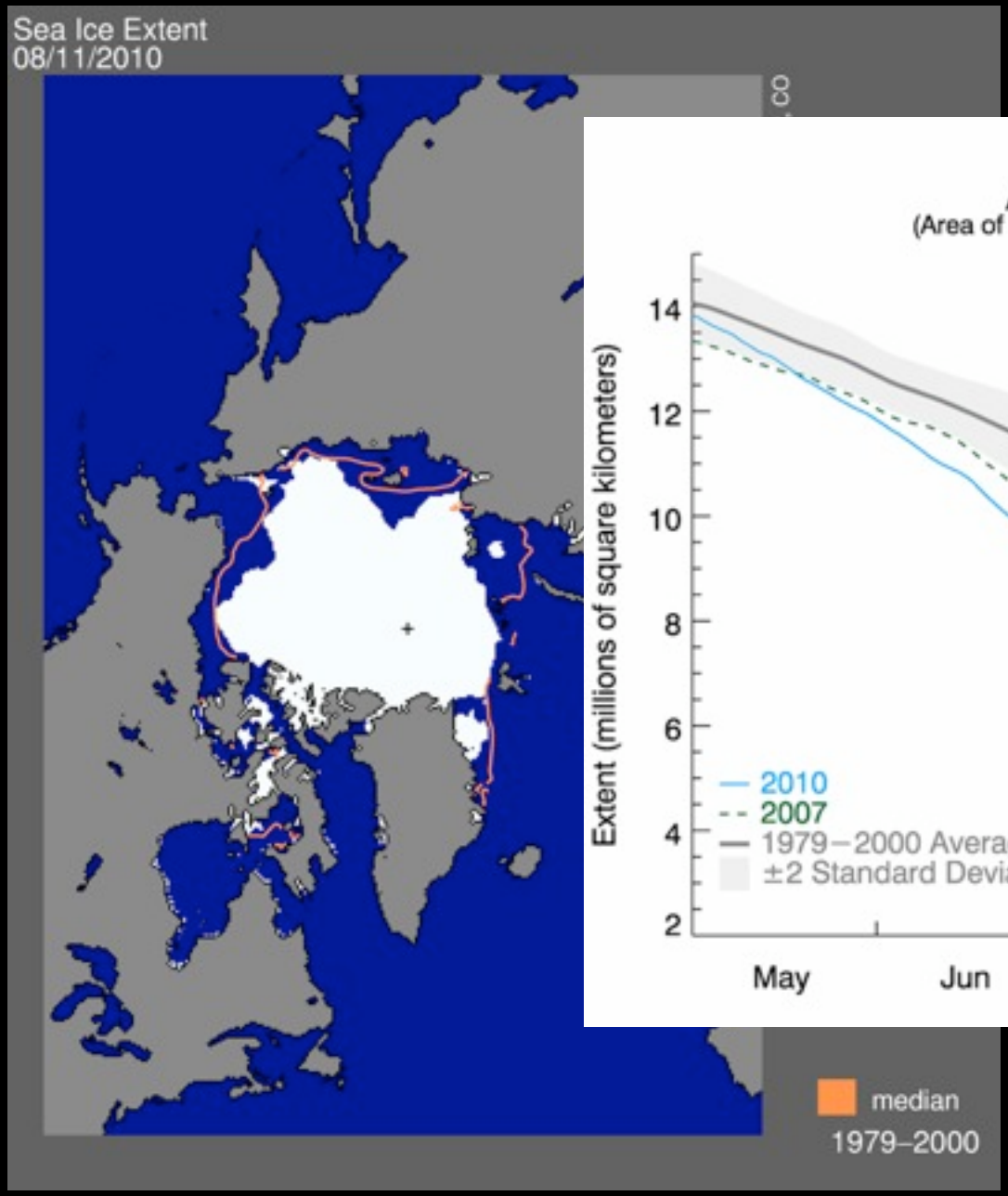
- **Did it work? No...**
  - Rats are nocturnal.  Mongooses are not.
  - Mongooses eat native birds and turtle eggs instead.

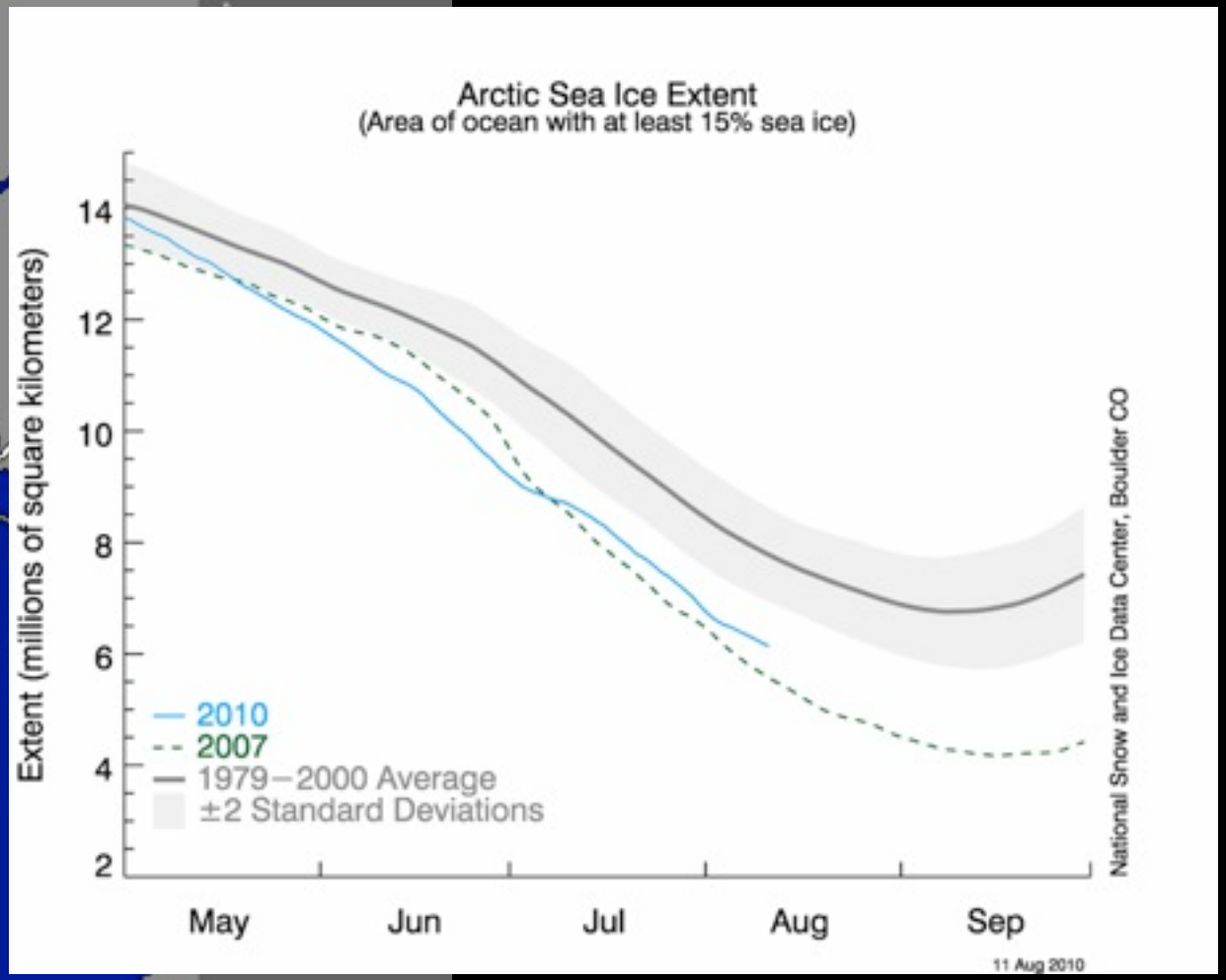
# Ecological Engineering

- Biological control ➙ introduce species to manage other invasive species
  - mongooses
  - cane toads
  - african land snails
  - freshwater shrimp

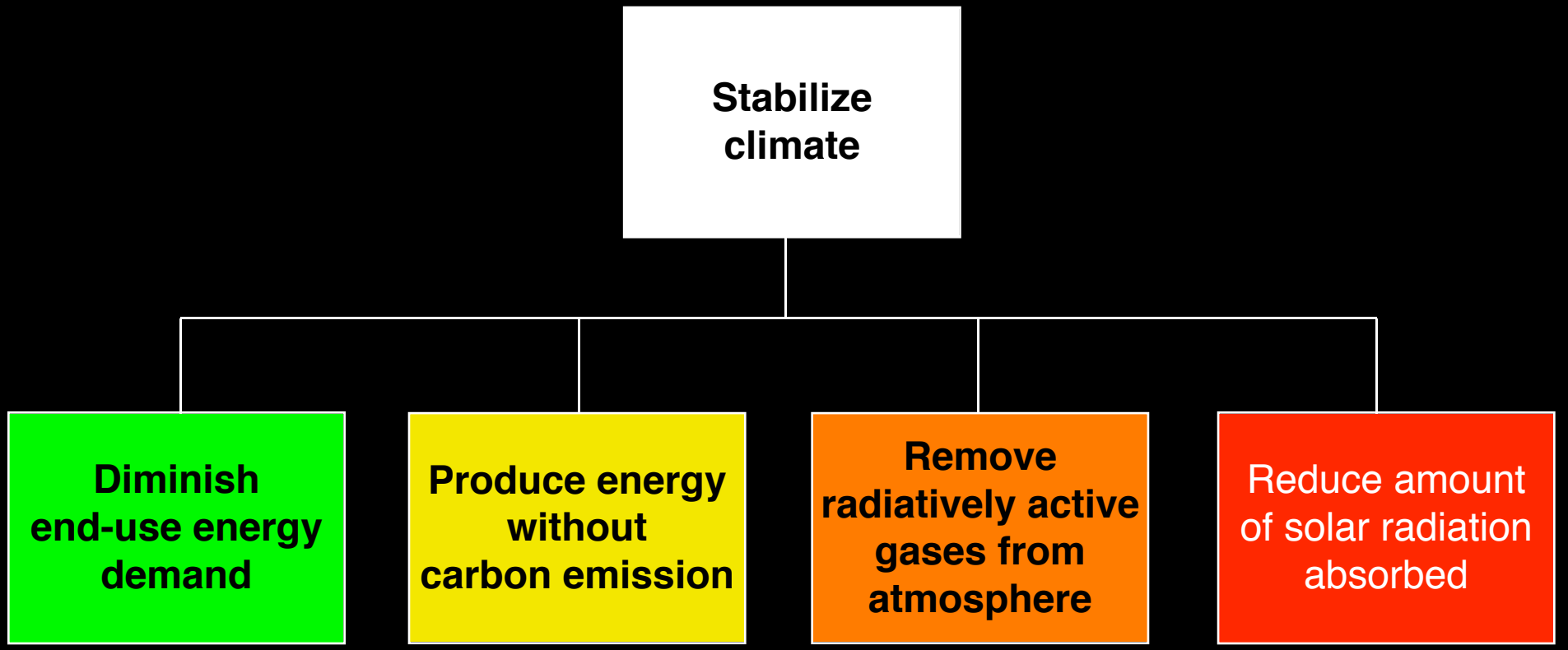
- *There are **always** unforeseen consequences*
  - **some impacts get traded for others**


(°F)
(°C)
1.8
1
1.4
0.8
1.1
0.6
0.7
0.4
0.4
0.2
0
0
-0.4
-0.2
-0.7
-0.4
-1.1
-0.6
Temperature Change
(ppm)
360
340
320
8
7
6
5
4
3
2
1
0
(Gt C)
per year
$CO_2$ Concentrations
Carbon Emissions
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
Years
©ACIA, 2004
Fossil Fuels
Land-Use Change


Sea Ice Extent
08/11/2010
median
1979–2000


Arctic Sea Ice Extent
(Area of ocean with at least 15% sea ice)
Extent (millions of square kilometers)
14
12
10
8
6
4
2
2010
2007
1979–2000 Average
±2 Standard Deviations
May
Jun
Jul
Aug
Sep
National Snow and Ice Data Center, Boulder CO
11 Aug 2010

# Strategies to Stabilize Climate



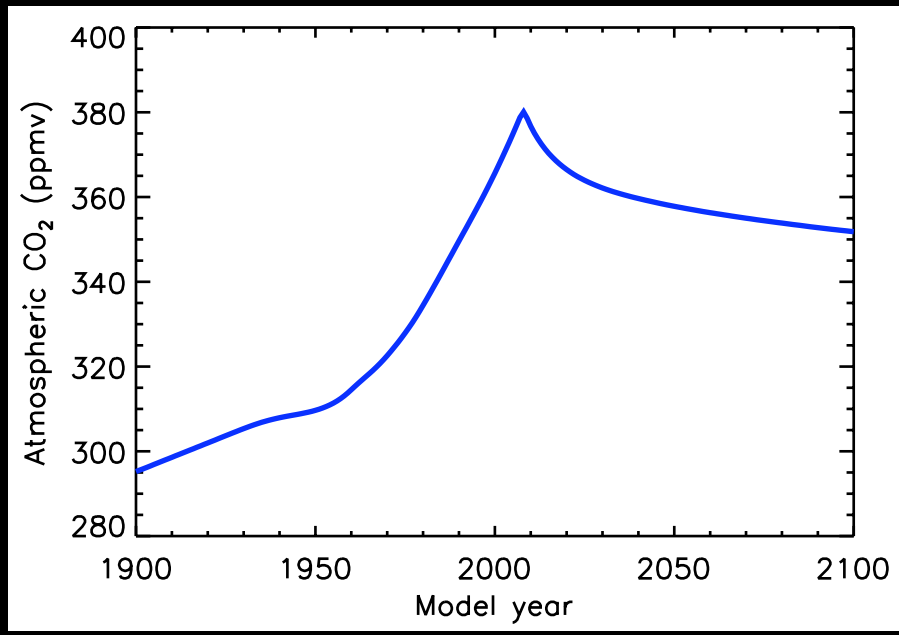

Reducing our impact on longwave radiation

Attempting to control shortwave radiation

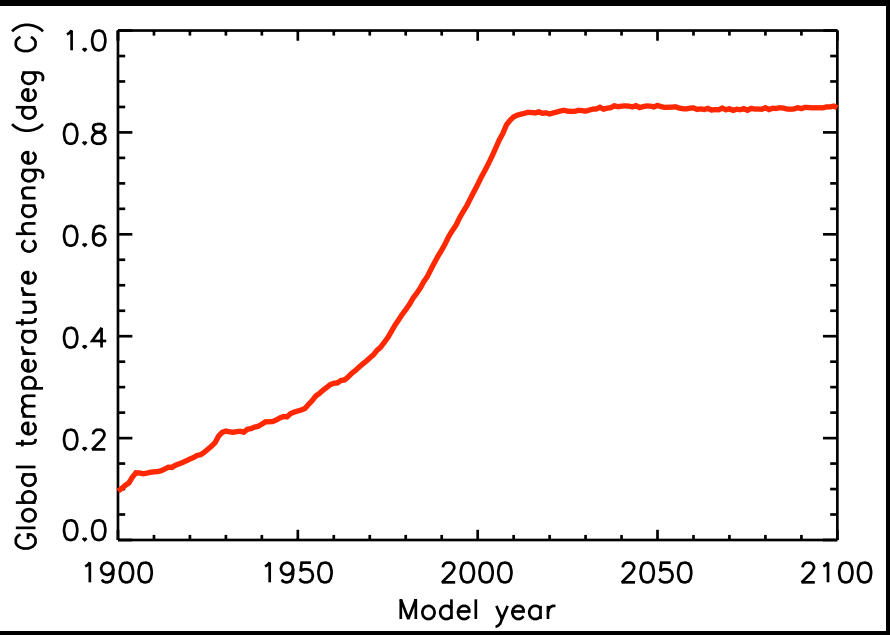
# Contrasting approaches to climate stabilization

Option 1: Stop emitting greenhouse gases

$CO_2$



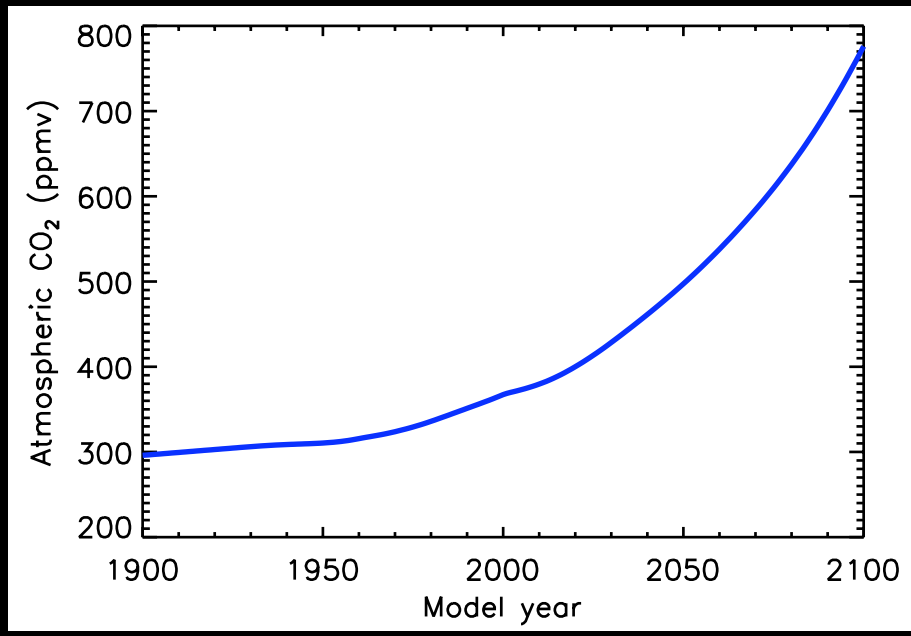

Temperature



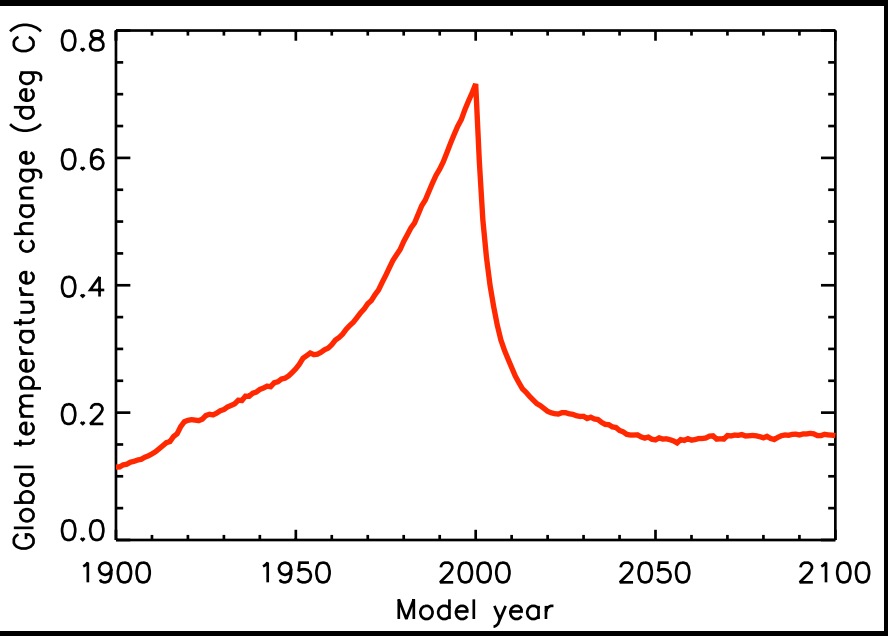
# Contrasting approaches to climate stabilization

Option 2: Block a few percent of incoming sunlight

$CO_2$

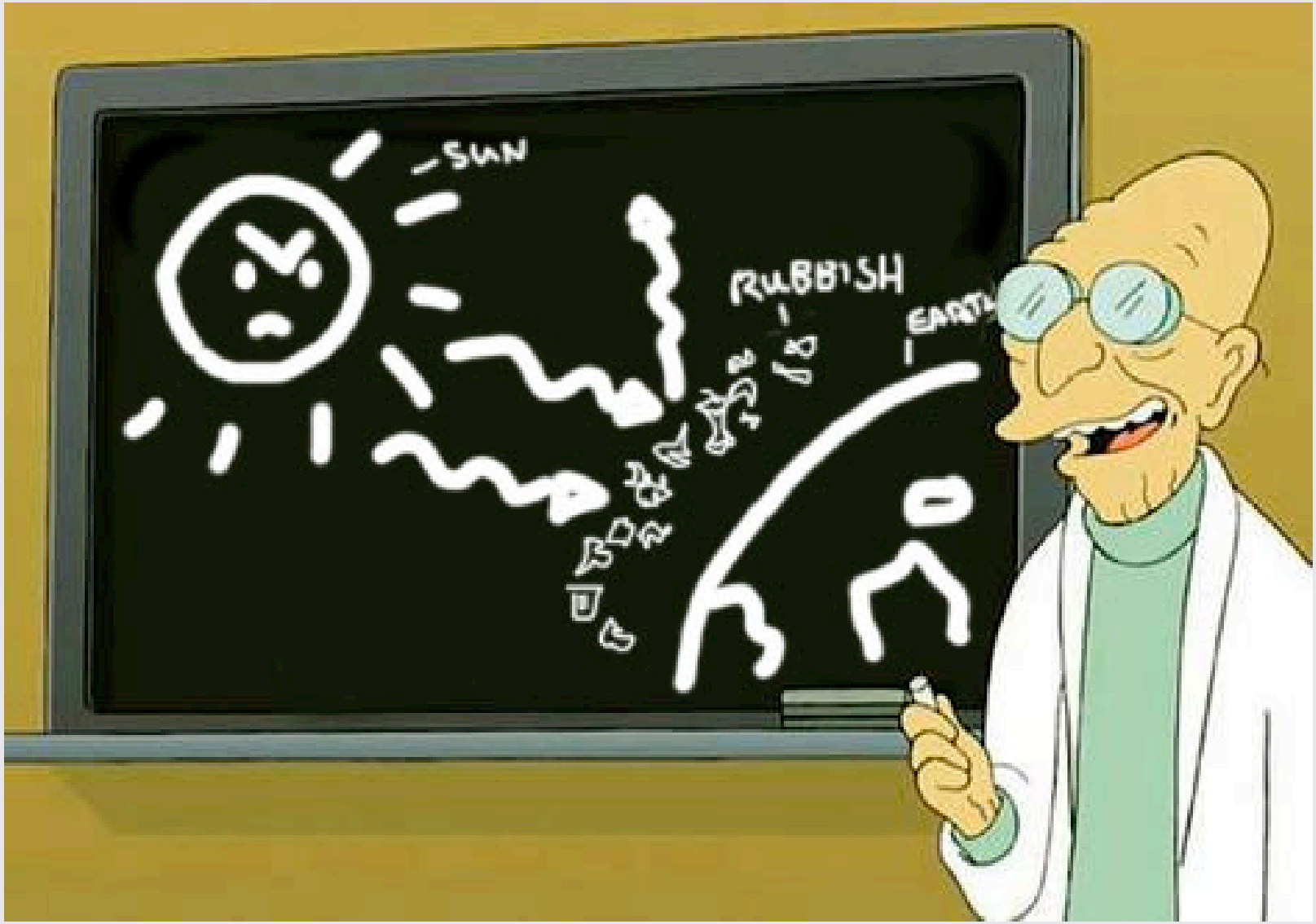



Temperature



From "Can Dr. Evil save the world?", *Rolling Stone*, Nov 2006

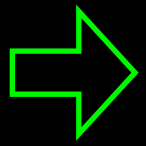
# NASA looks at plan to blot out Sun



*The intentional large-scale manipulation of the Earth's radiation balance*

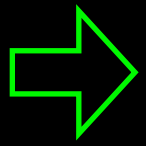
# Types of Geoengineering

1. Managing solar radiation
   - increasing surface albedo
   - increasing atmospheric albedo
   - space-based reflectors



"*climate engineering*" or "*solar radiation management*"

2. Managing global carbon sinks
   - terrestrial carbon storage
   - ocean carbon storage
   - geological carbon storage

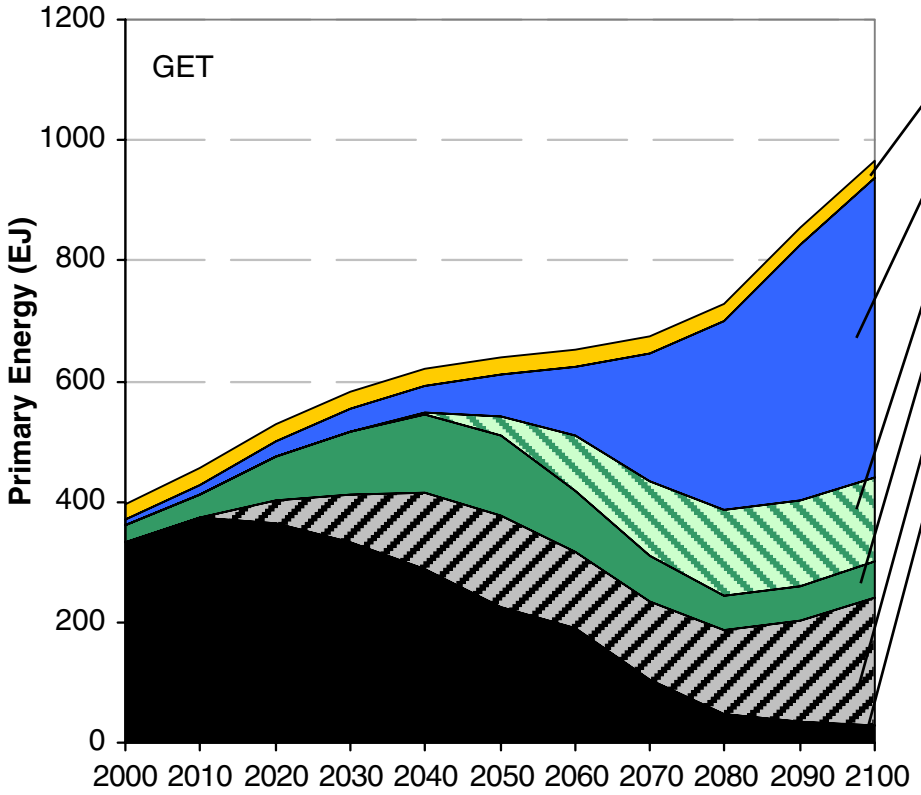


"*carbon dioxide removal*" or "*carbon cycle geoengineering*"

# Managing Carbon Sinks

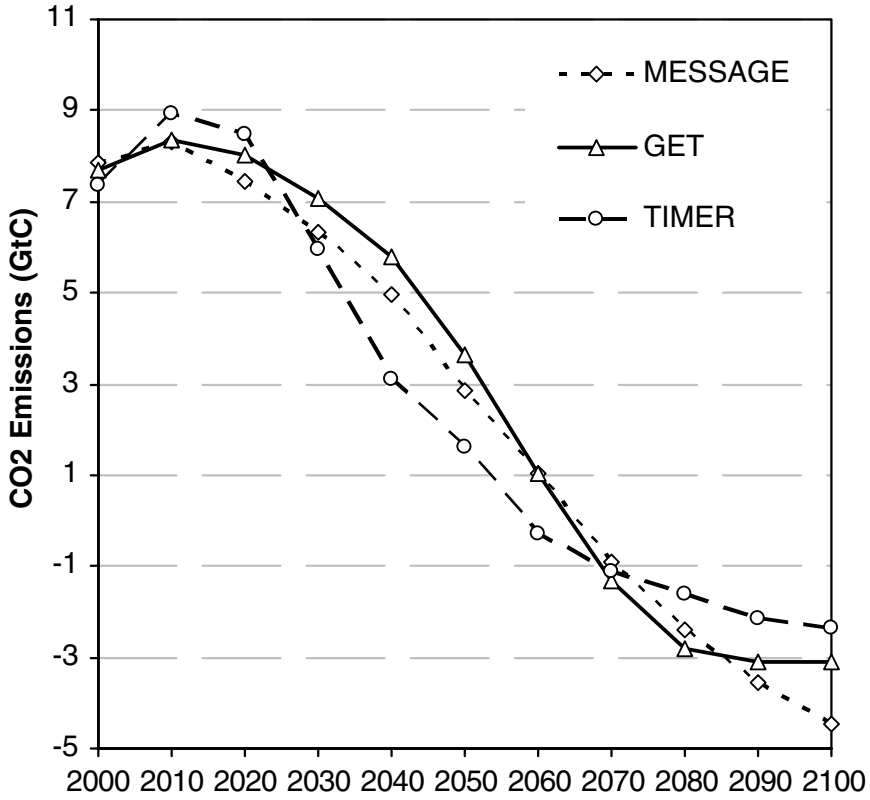
- Terrestrial carbon storage
  - afforestation, bio-char production
- Ocean carbon sinks
  - surface ocean iron fertilization
  - carbon injection into the deep ocean
  - carbonate and/or lime addition to enhance dissolution
- Geological carbon storage
  - carbon sequestration in geologic reservoirs
  - air capture (chemical or using biomass)

# Negative emissions using biomass energy with CCS?



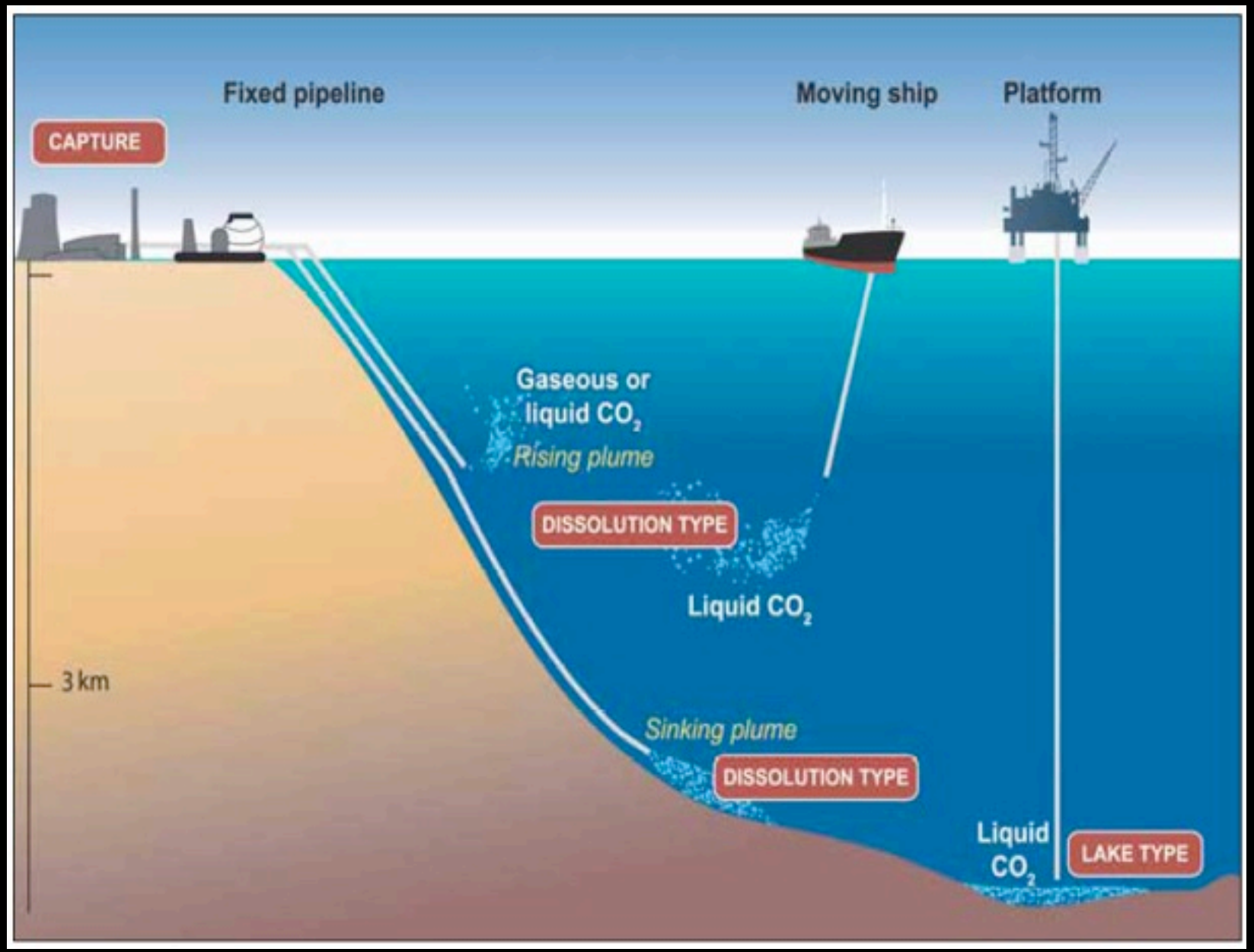

Nuclear
Renewables
Biomass with CCS
Other biofuels
Fossil fuels with CCS
Fossil fuels

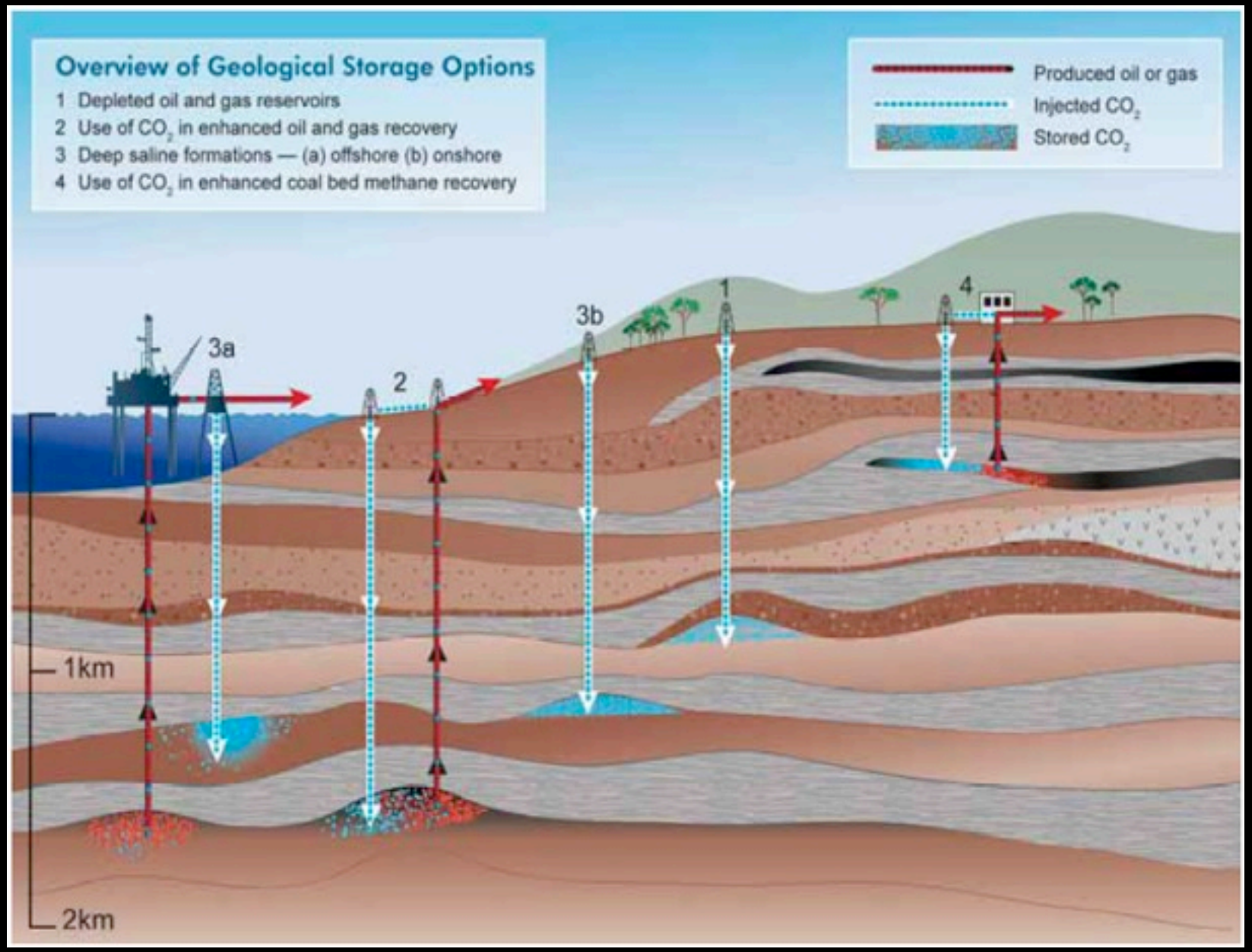
from Azar et al (2010) *Climatic Change*



Klaus Lackner's vision of a $CO_2$-scrubbing farm

David Keith with his carbon-capture machine

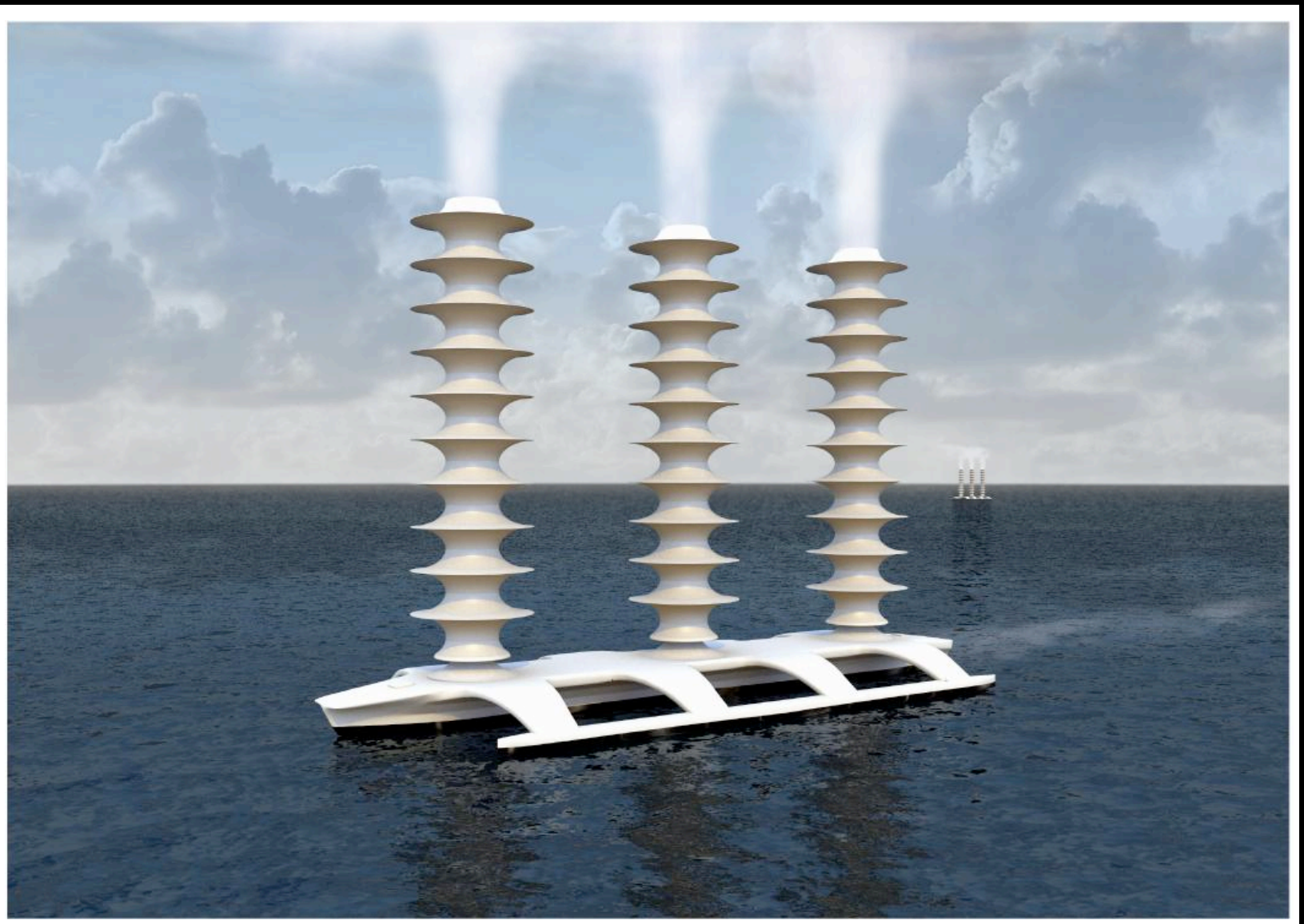

Fixed pipeline
Moving ship
Platform
CAPTURE
Gaseous or liquid $CO_2$
Rising plume
DISSOLUTION TYPE
Liquid $CO_2$
3 km
Sinking plume
DISSOLUTION TYPE
Liquid $CO_2$
LAKE TYPE


Overview of Geological Storage Options
1 Depleted oil and gas reservoirs
2 Use of $CO_2$ in enhanced oil and gas recovery
3 Deep saline formations — (a) offshore (b) onshore
4 Use of $CO_2$ in enhanced coal bed methane recovery
Produced oil or gas
Injected $CO_2$
Stored $CO_2$
3a
2
3b
1
4
1km
2km

# Managing Solar Radiation

- Increase surface albedo
  - cities, deserts, crops ...
- Increase cloud albedo
  - spray sea-salt to enhance marine cloud cover
- Increase stratospheric albedo
  - sulphate aerosols, dust, micro-balloons, other aerosols…
- Space-based reflectors

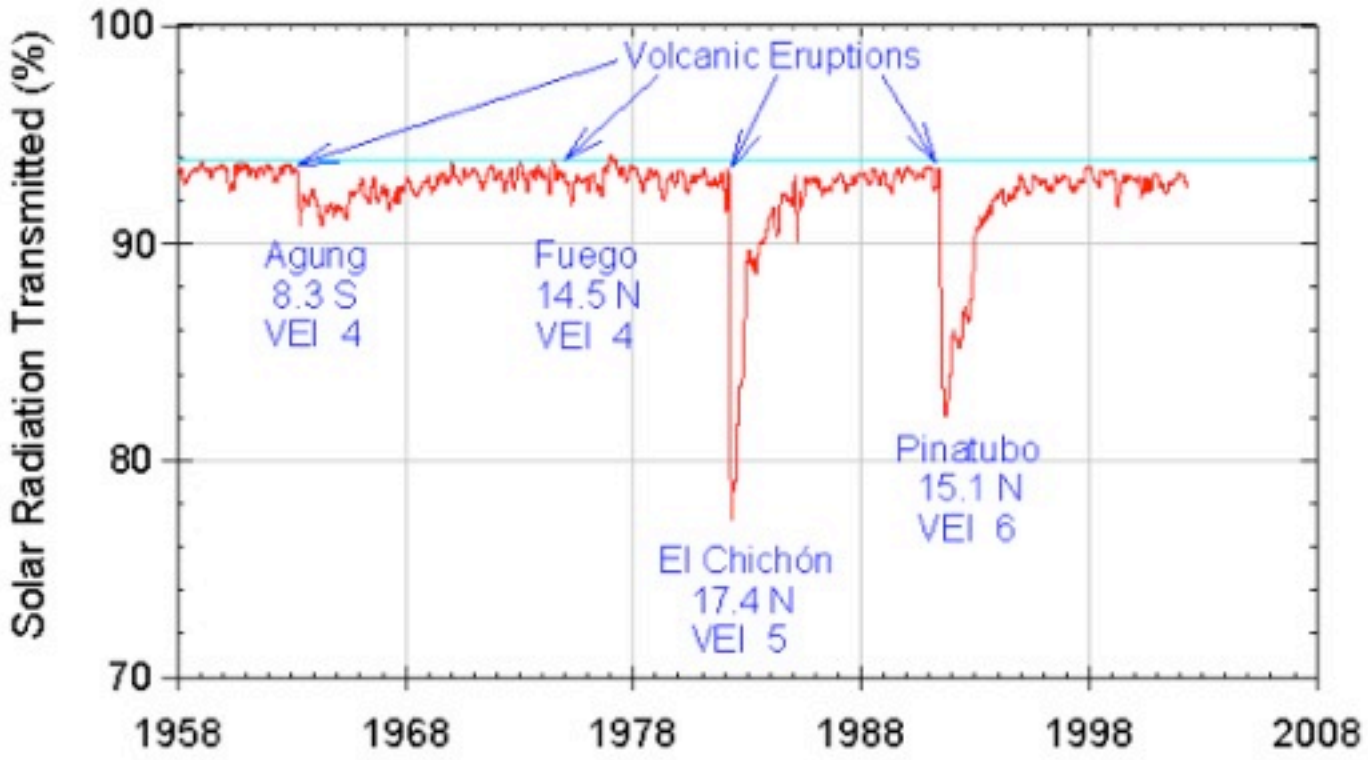

Ship tracks in the Atlantic (Courtesy of NASA)



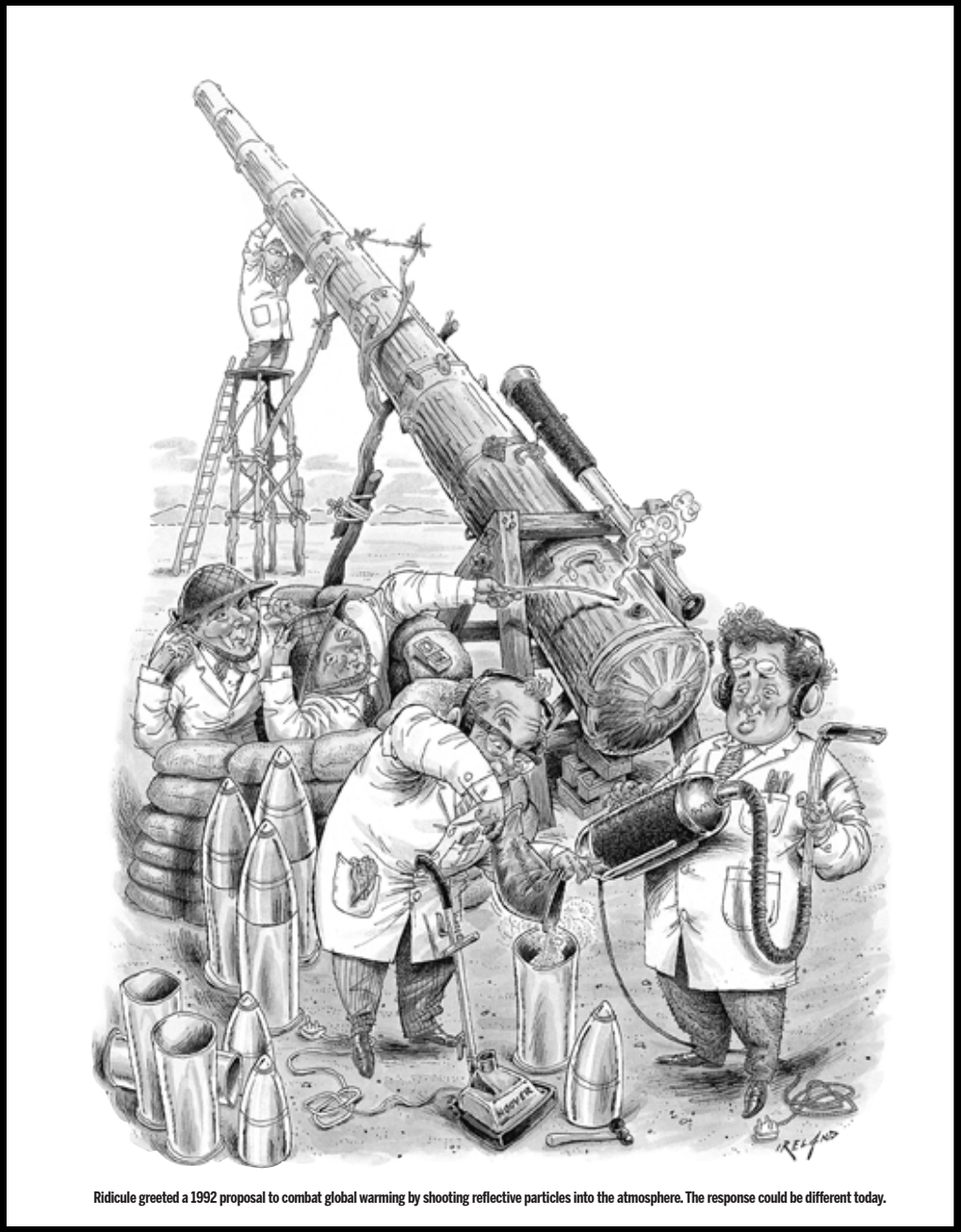
Courtesy Stephen Salter

Mt. Pinatubo, 1991

# Mauna Loa Observatory Atmospheric Transmission

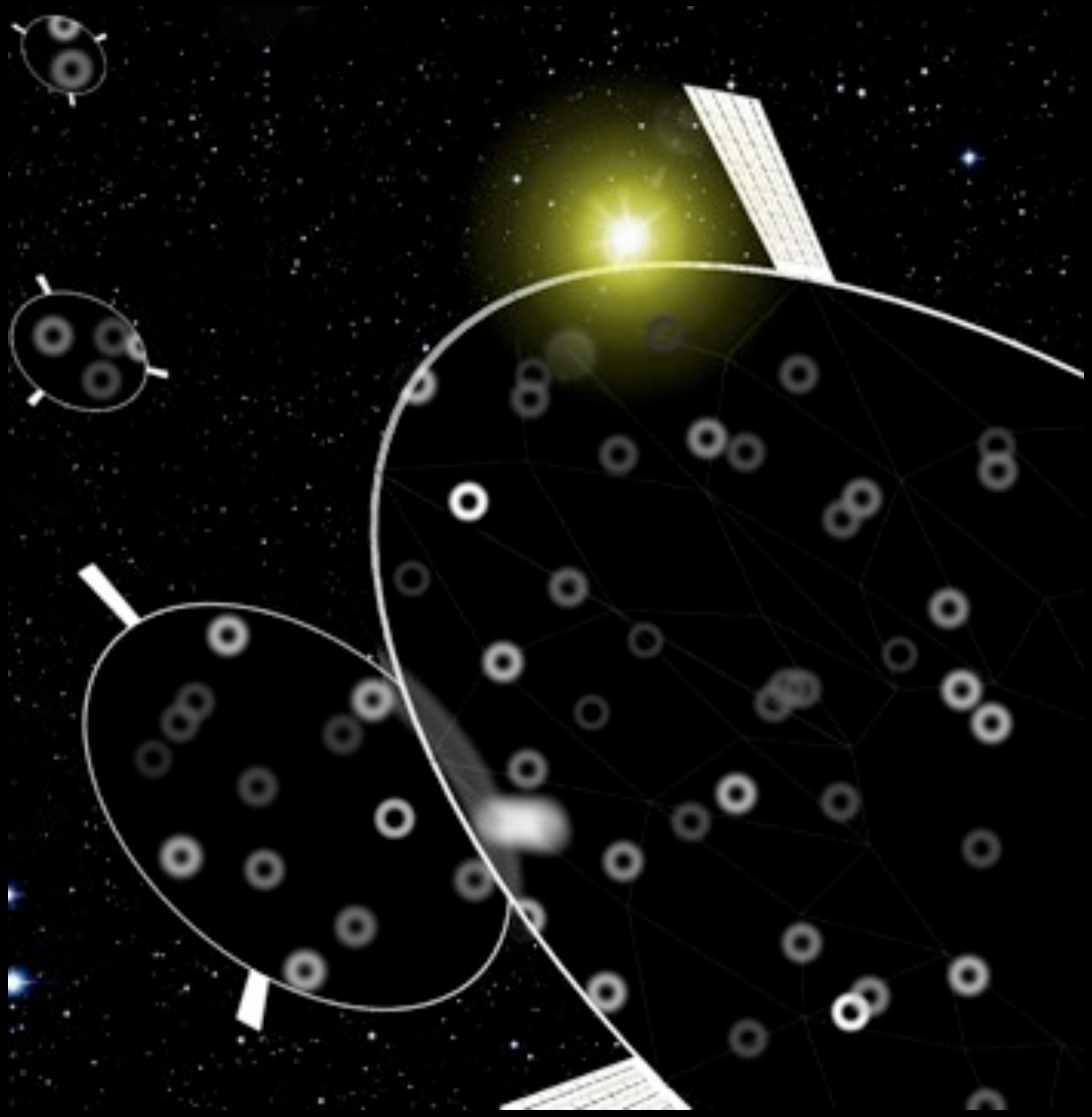



Source: Wikipedia/NOAA

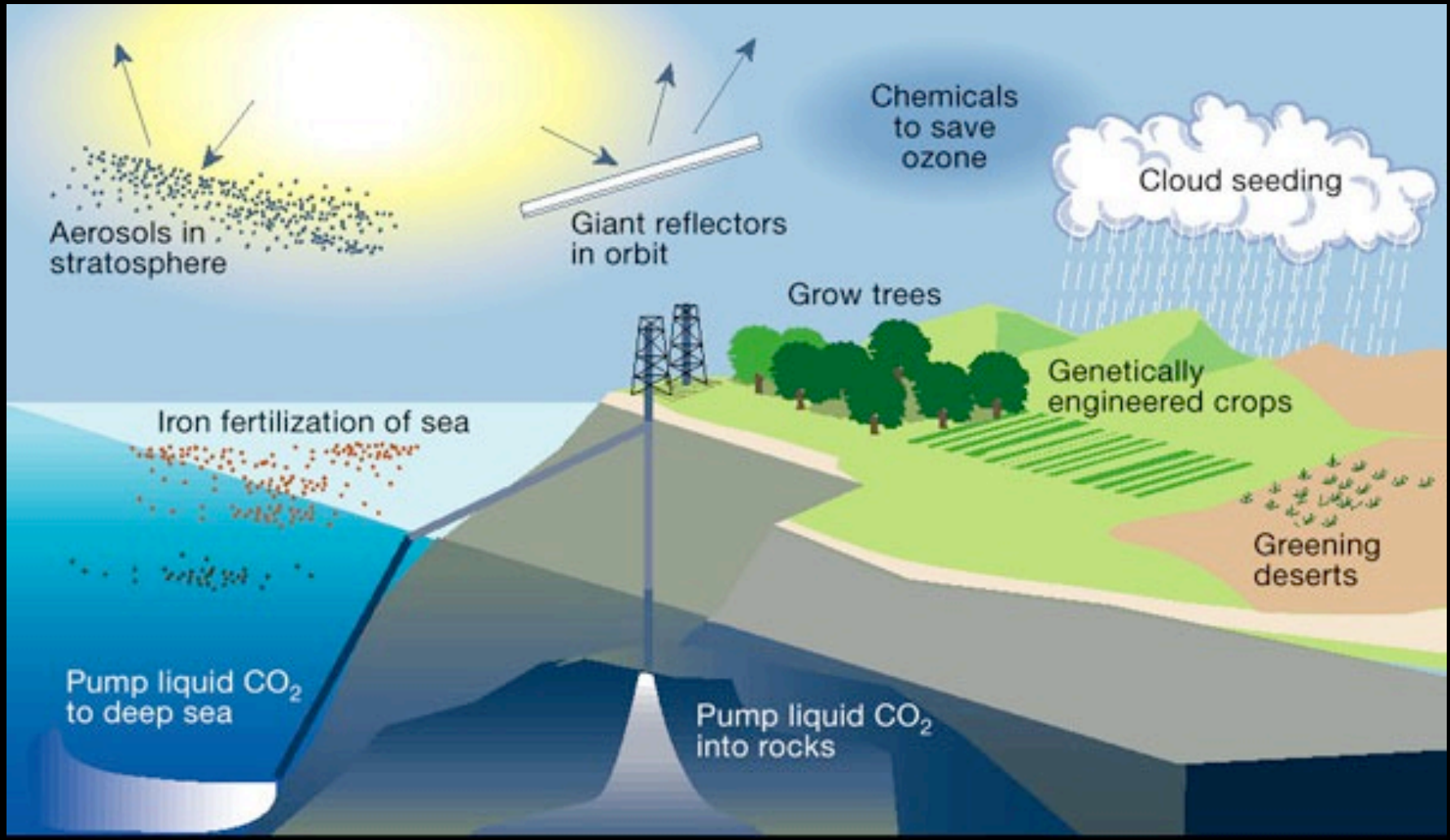



Ridicule greeted a 1992 proposal to combat global warming by shooting reflective particles into the atmosphere. The response could be different today.

Source: Fleming (2007) *Wilson Quarterly*



Courtesy or Roger Angel




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

From Keith (2001) in *Nature*

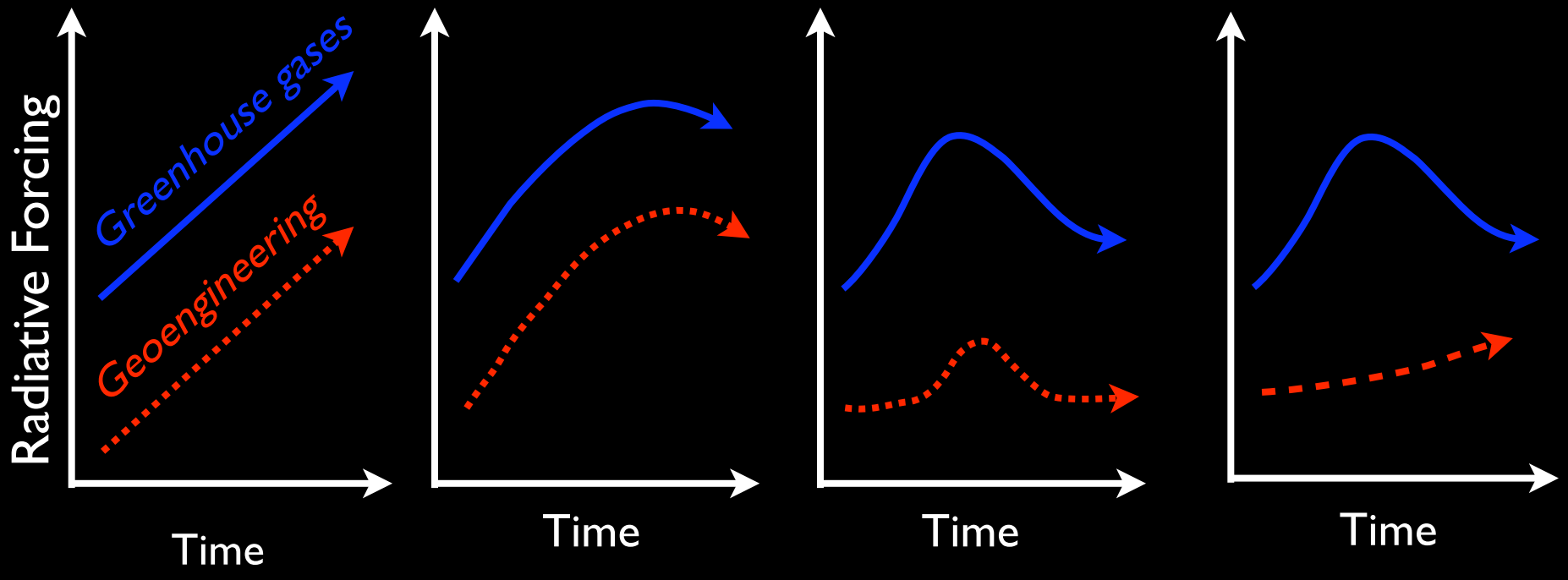
# Modes of Geoengineering

Geoengineering as an alternative to mitigation

Geoengineering to "buy us time" to allow delayed mitigation

Geoengineering to reduce peak impacts as mitigation is implemented

Geoengineering to avoid serious long-term impacts




Modified from Keith (2007)

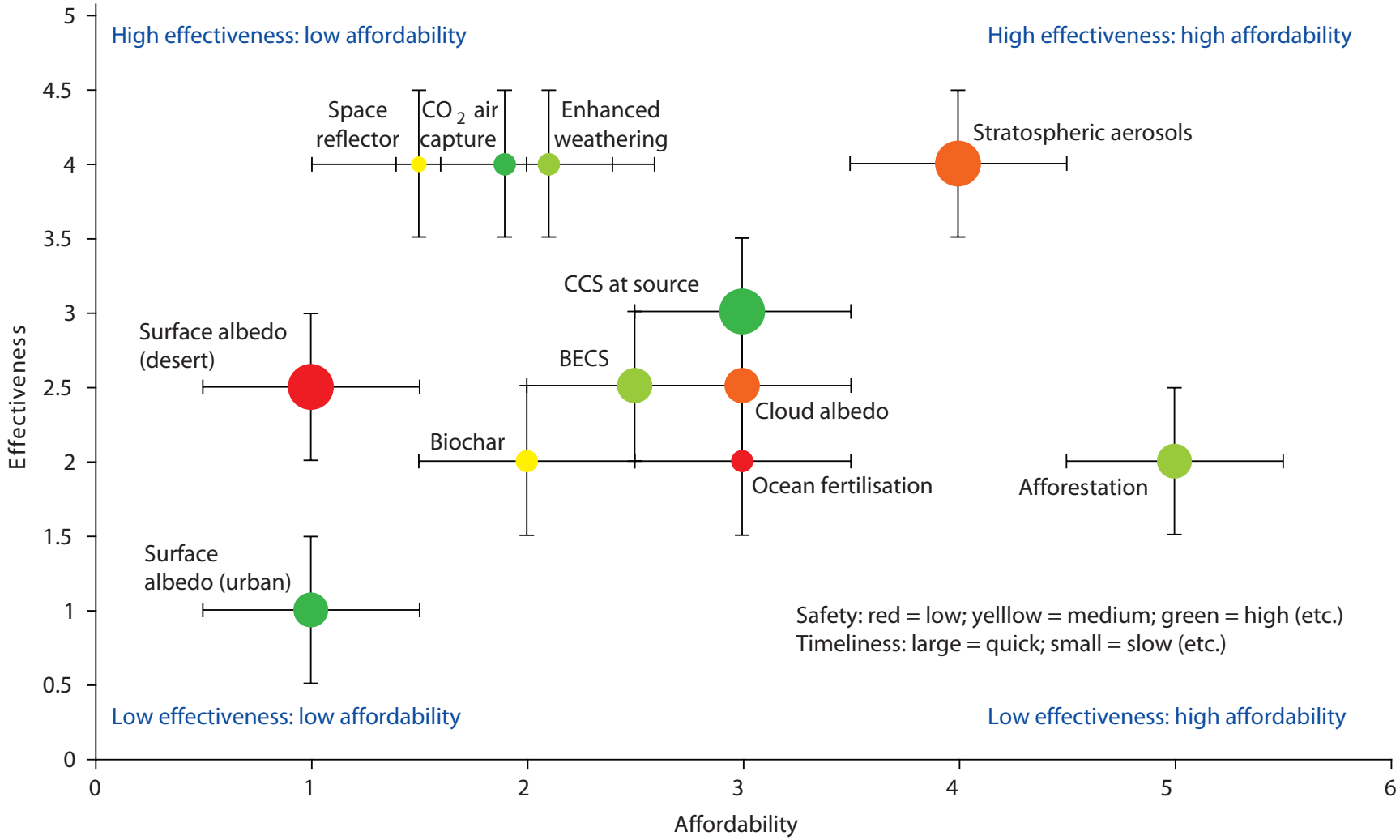
# Risks of Geoengineering

- Ozone depletion (suphate aerosols)
- Atmospheric chemistry (GHG lifetimes)
- Reduced direct radiation / increased diffuse radiation (biosphere impact, solar power)
- Possibility of a hazier (less blue) daytime sky
- Impacts on hydrological cycle
- Would not reduce (and could exacerbate) ocean acidification
- Ecological impacts (particularly for ocean fertilization and forestry-related schemes)

# Risks of Geoengineering

- Risk of rapid climate change
  - due to technological failure or abrupt removal
- Political and legal concerns
  - covert/unilateral geoengineering
  - potential of aggressive military application
- Possibility of increased emissions
  - if used to generate carbon credits
  - due to a perception of success
  - *more long-term warming ...*

# Summary of the effectiveness, affordability, timeliness and safety of various geoengineering proposals




from Royal Society report: *Geoengineering the climate*

# Concluding thoughts

- All geoengineering proposals are NOT equal
  - some are much more dangerous than others
  - they must be considered individually
- Geoengineering will have undesirable impacts
  - will net impacts be better or worse than climate change alone?
  - certainly not a substitute for mitigation!
- Climate change impacts will increase, and will likely last for many centuries
  - strategies to remove and *permanently* sequester $CO_2$ may help avoid some long-term impacts