Early Recognition, Monitoring and Integrated Management of Emerging, New Technology Related, Risks
iNTeg-Risk
Grant agreement number: CP-IP 213345-2

Emerging risks in alternative strategies of CO_2 capture and storage

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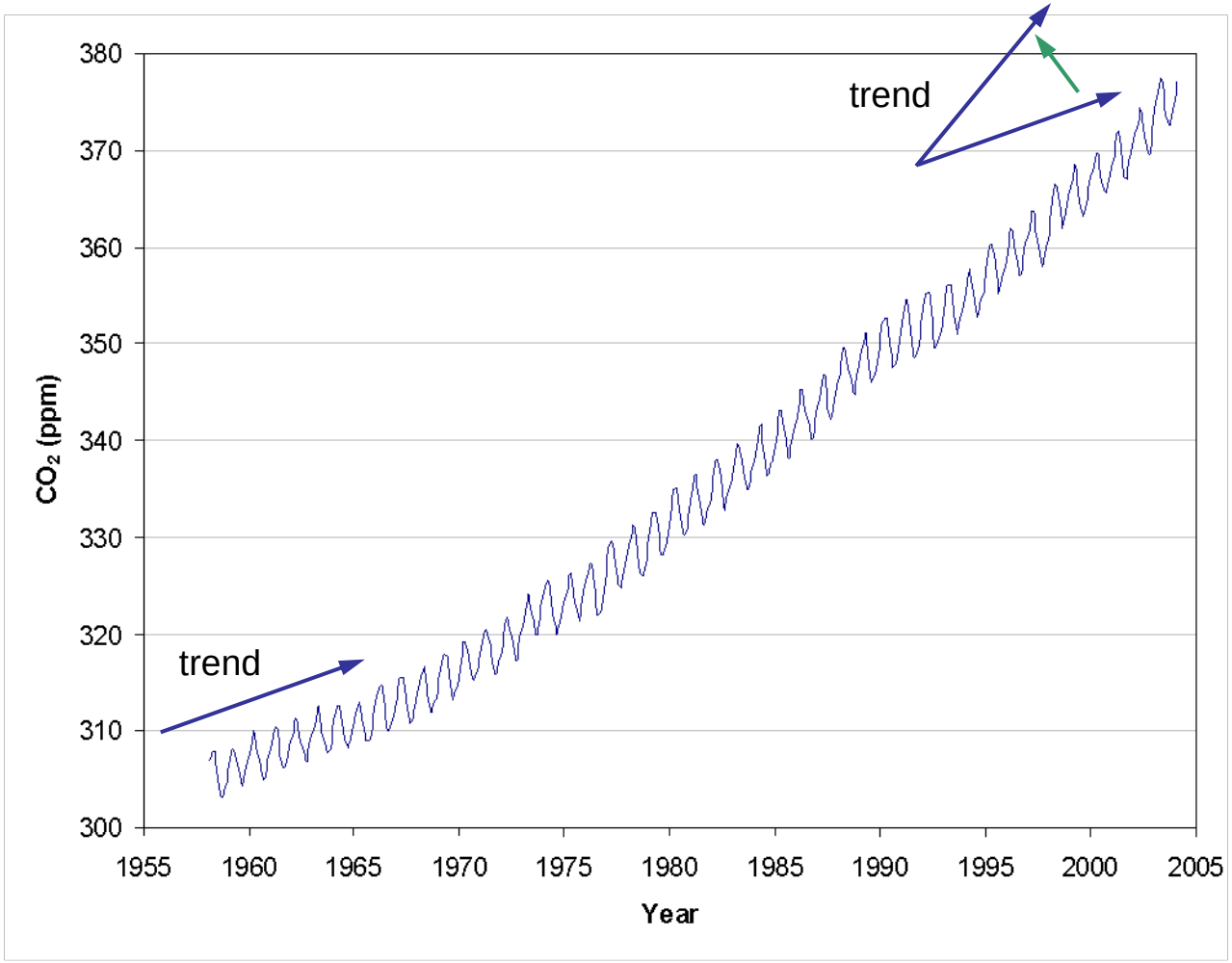
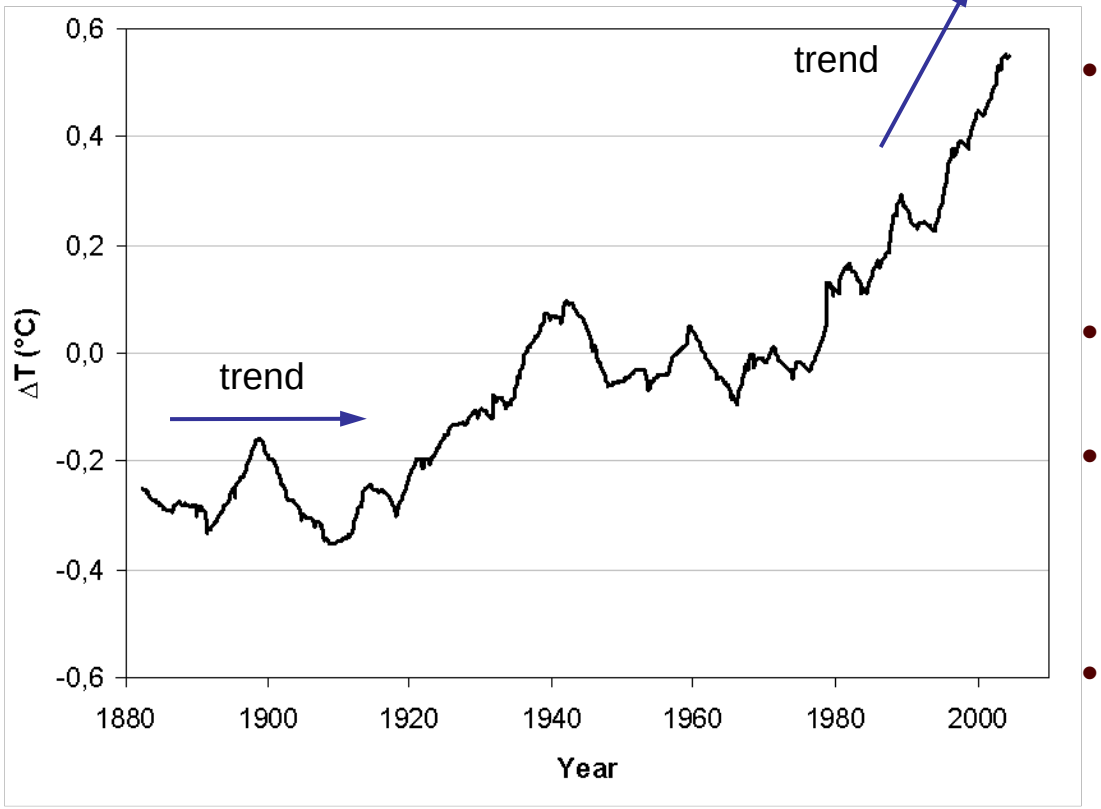
Introduction

Increase in atmospheric CO_2 ⇒ climate change ⇒ countermeasures



- Natural sources and sinks + significant human emissions
- Added impact by other greenhouse emissions such as methane, HFC, soot, N_2O…
- Potential consequences: global warming 2-6°C, flooding of coastal regions, widespread droughts by the end of the century?

Problems - challenges



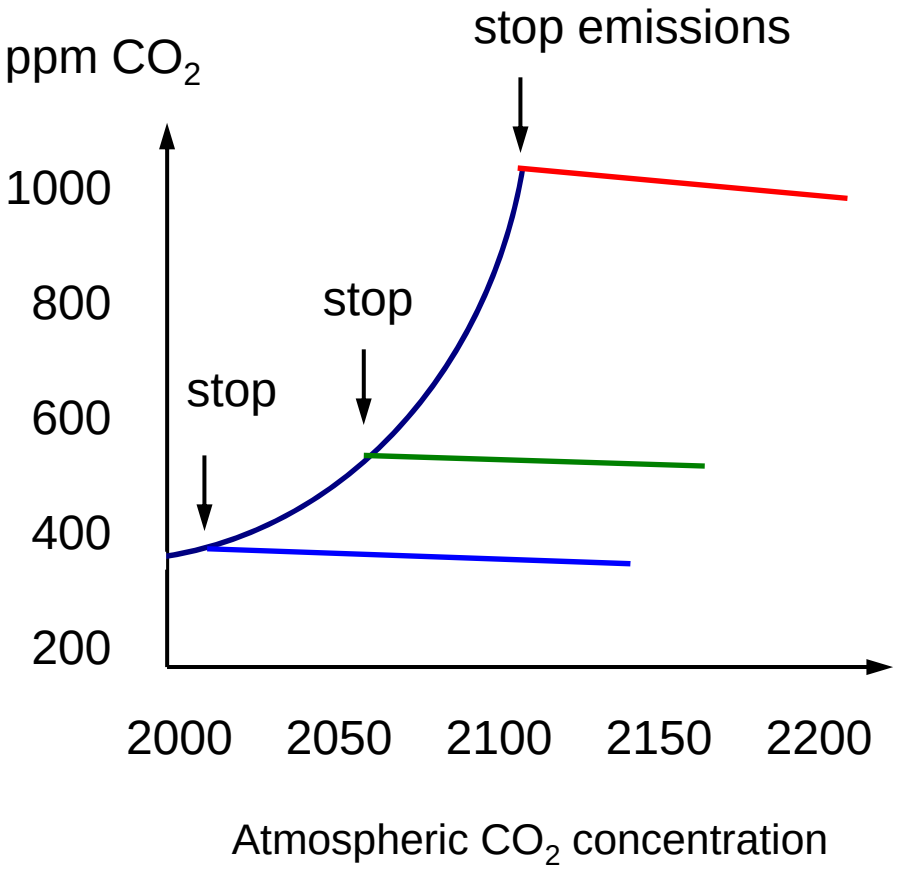
Mean change in world temperature

0 = mean of 1951-1980

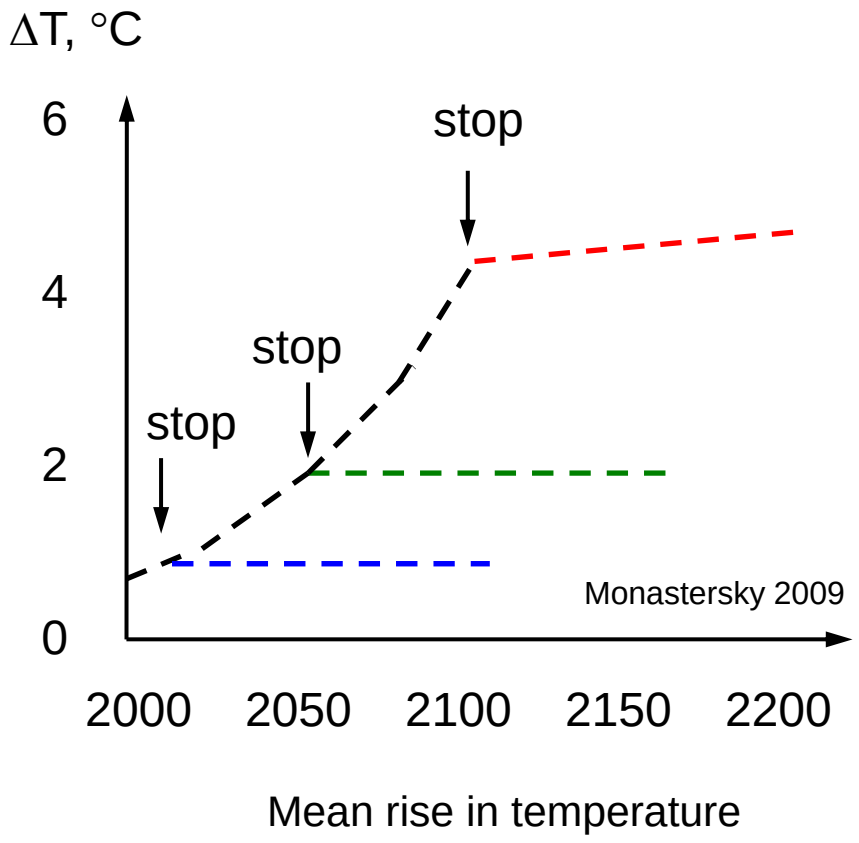
- Accelerating global warming:
  - interaction of factors, e.g. warming by CO2 will release methane from permafrost and (finally) ocean floor
- Sensitivity in climate models ⇒ uncertainty
- Calibration by measured and factored consequences:
  - trends in measurements
  - historical & other evidence
- Efficiency of countermeasures?
  - cost, timing, impact

Suggested countermeasures: CO_2 capture & storage

Challenge: slow recovery from warming



Atmospheric CO_2 concentration

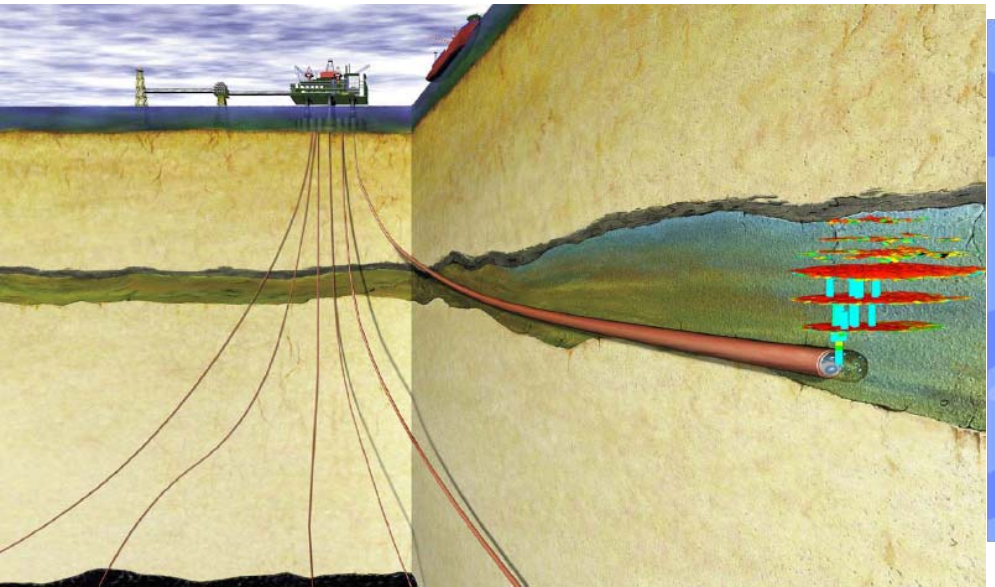


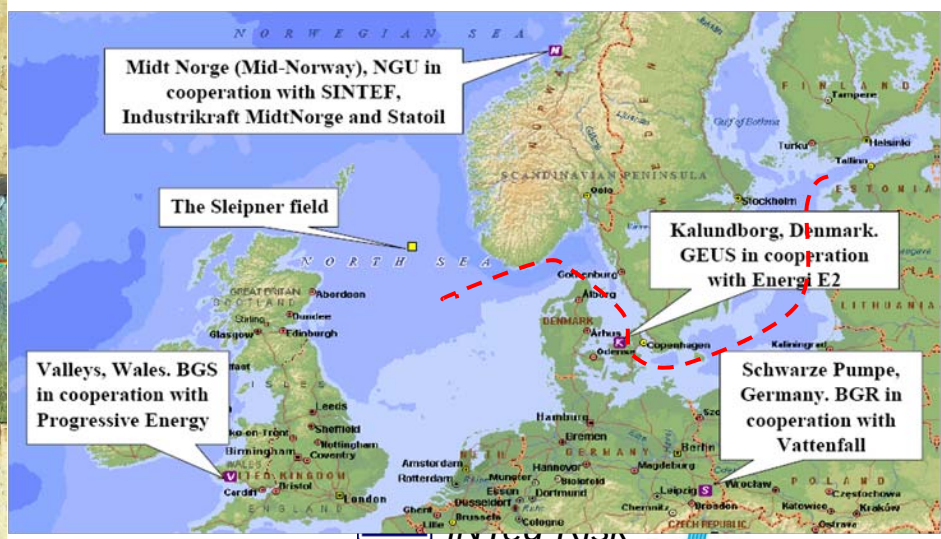
Mean rise in temperature

Capture at source + deep underground storage

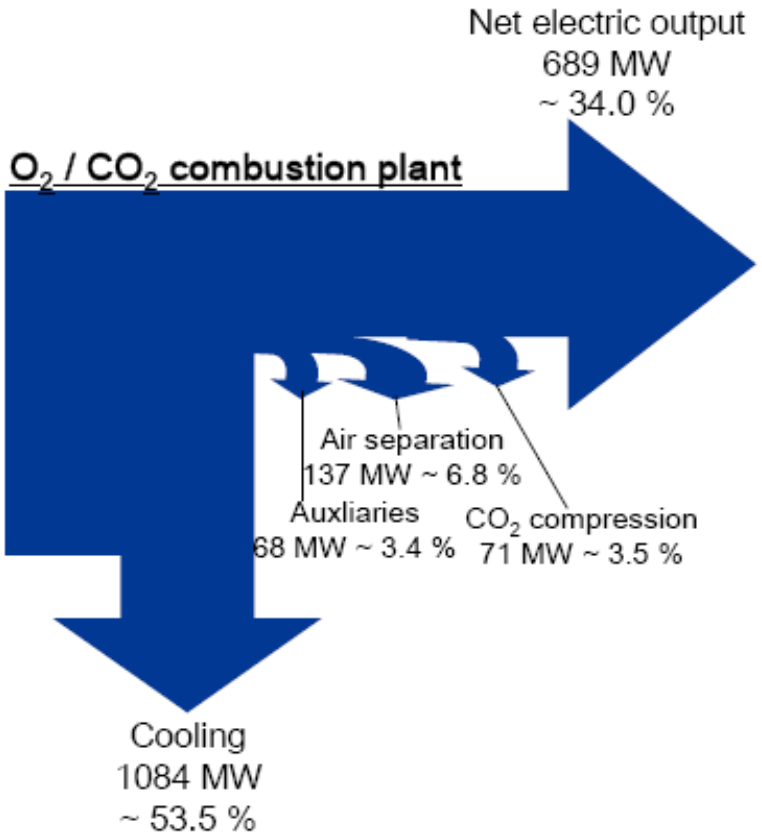
Intermediate storage & transport of CO_2, at additional risk/cost

- **even a modest source (pp) ≥ million tonnes of CO_2 per year**
- **max ~100 000 ton / ship**
- **alternatively large network of pipelines > 1000 km min**
- **large intermediate storage sites**



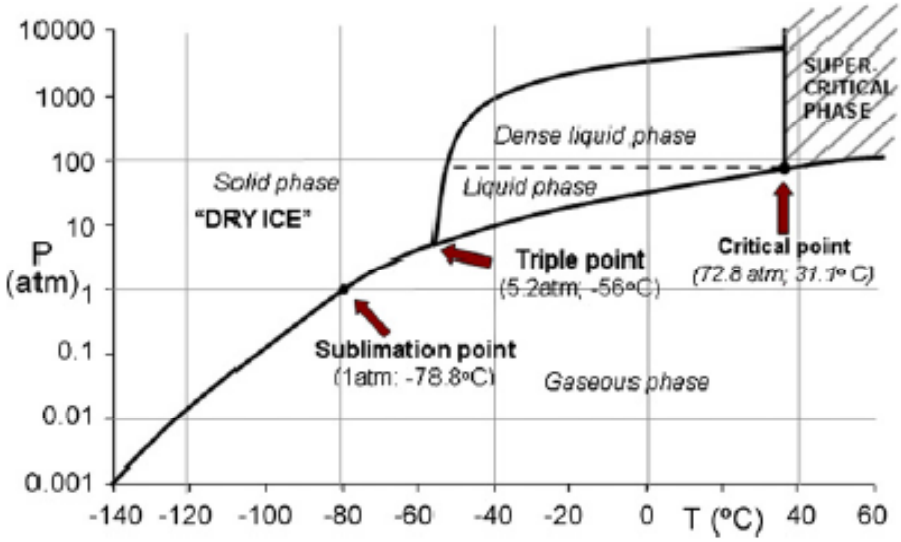


Capture at source + deep underground storage



CCS for coal firing:

- **Pre- or post-combustion capture, e.g. with gasification (IGCC) or oxyfuel processes**
- **Oxyfuel plant for conversion to carbon dioxide (and water)**
- **Transport to final storage by pipeline/shipping**



Capture at source + deep underground storage

CO_2 geyser = leaking geological storage

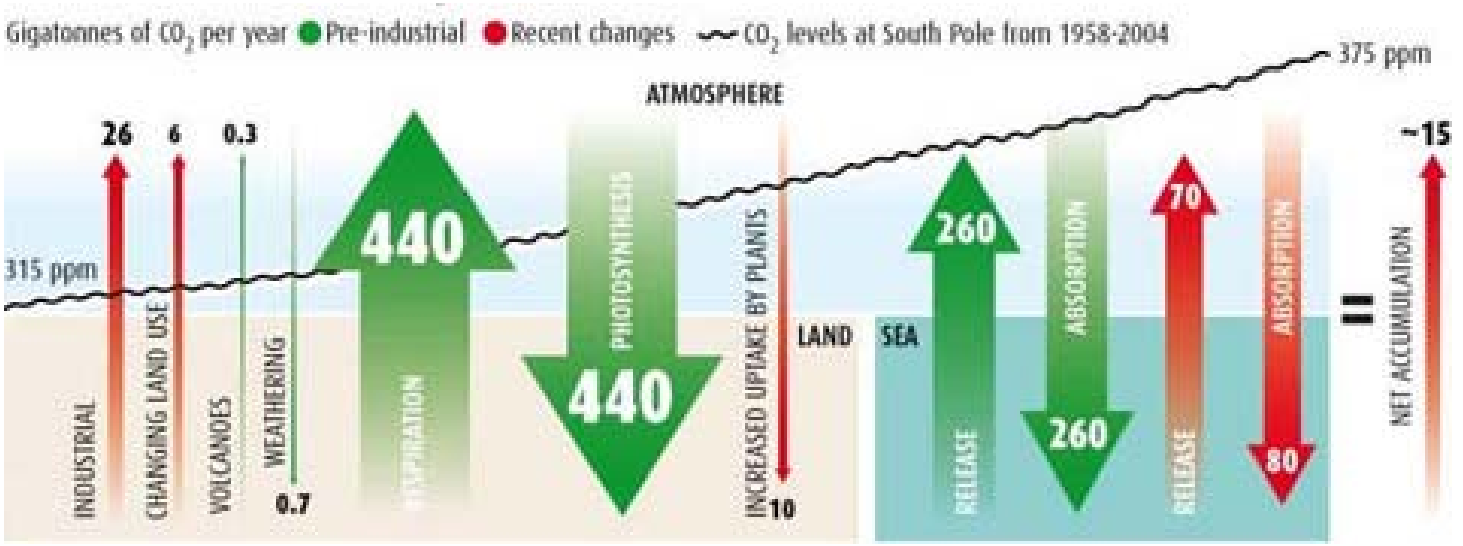
Aeschbach-Hertig 2009

Emerging risk issues:

- Ineffective capture
- Incomplete or no mineralisation, poor sealing layers
  $\Rightarrow$ leaking storage
- Threat to human life:
  - natural analogies in Cameroon, Europe
  - industrial leaks

Biological capture + storage as char

- pre-industrial CO_2 sources balanced by sinks
- nearly 500 Gt of CO_2 per year in atmospheric circulation on land
- bound to biomass, large potential (volume in nature)



Biological capture + storage as char

Capture by pyrolysis of biomass:

- CO_2-neutral to -reducing
- provides fuels for e.g. transport
- remnant carbon as char to improve agricultural soils (stable > 10^3 yr)
- applicable on individual farmer level and in larger scale plants

Emerging risk issues:

- expansion by a diffuse process
- implementation to sufficient extent on time for significant impact
- application in conservative societies

Geological/mineral capture + storage

Natural peridotite: mainly olivine $(Mg,Fe)_2SiO_4$ & pyroxene $(Ca,Mg,Fe)_2Si_2O_6$

Reaction with carbon dioxide to form solid carbonate/silicate products: e.g.

$$Mg_2SiO_4 + 2CO_2 = 2MgCO_3 + SiO_2$$

$$Mg_2SiO_4 + CaMgSi_2O_6 + 2CO_2 + 2H_2O = Mg_3Si_2O_5(OH)_4 + CaCO_3 + MgCO_3$$

Features:

- **facilitates storage on surface, reduced transport distance**
- **carbon "permanently" bound**
- **larger mass to transport/storage than with gaseous/liquid CO_2**

Risk issues:

- **leaks at the site of capture (or in transport / reaction site)**
- **cost of surface storage (large landfills)**
- **high volume of transport (reagents & reaction products)**

Other proposed approaches

Geoengineering:

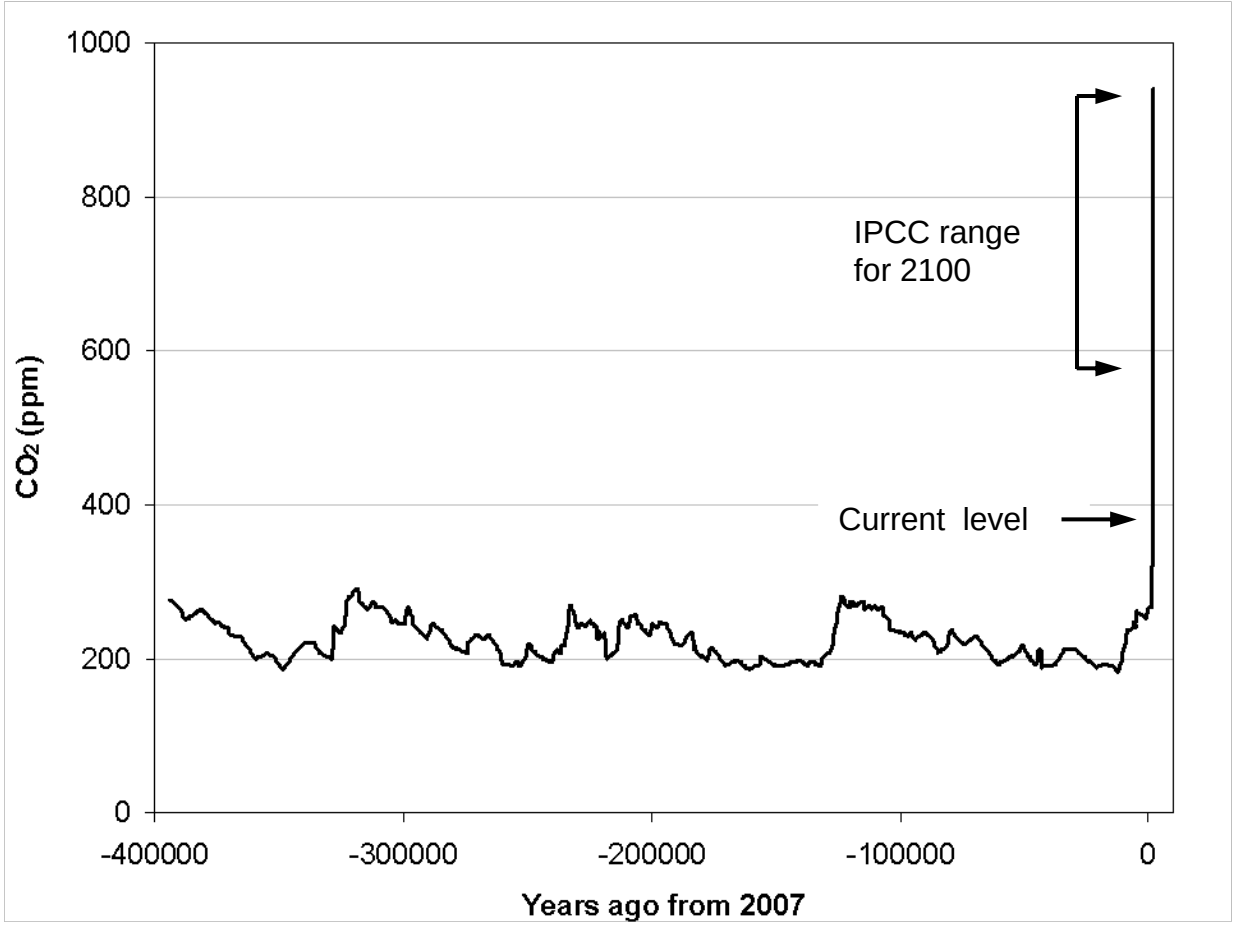
- manipulation of Earth thermal balance (solar reflectors, feeding of ocean algal blooms, etc.)
- manipulation of precipitation: cloud seeding, forest planting etc.
- chemical trapping of CO_2 directly from the atmosphere

Risk issues:

- limited technology, slow to implement or unknown impact
- unequal distribution of benefits and cost
- political/societal acceptance in different countries/regions

Status

Atmospheric CO_2 now higher than for millions of years



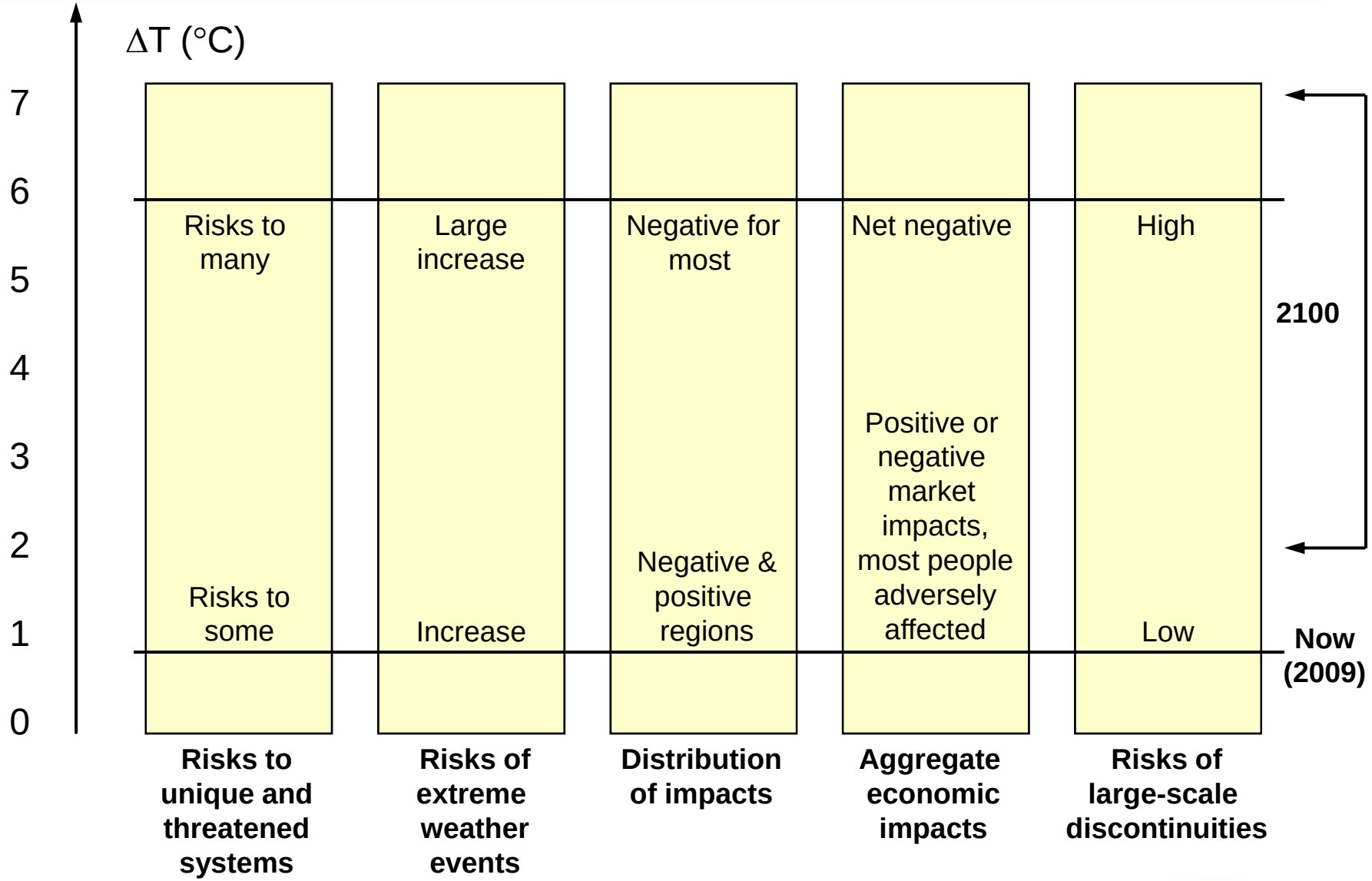
Advantages:

- warmer in Finland
- no new ice ages (before CO_2 ~ 250 ppm)

Disadvantages:

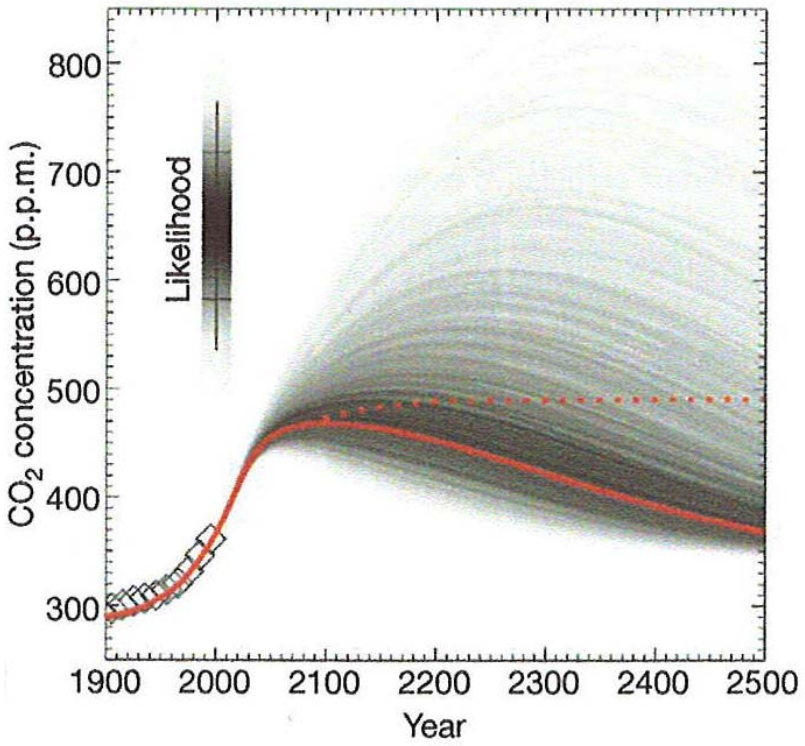
- lowland/coastal flooding
- deserts spreading
- loss of agricultural land
- high cost of intervention
- only slow recovery after mitigating action

Risk issues in climate change: current view



IPCC 2001; Smith et al. 2009

Risk issues in climate change: current view



Allen et al. 2009

- Assumed mitigation by 2020-2050 (?)
- Serious concern on regional agreement
- Difficulties to accept global vs. regional benefits and cost
- Difficulties to accept the time lag between mitigating action and its measurable impact

Summary: emerging risk in CCS

- **Capture at source + deep underground storage:**

  - carbon permanently stored in appropriate sediments (if not leaking); but
  - no mature technology or large scale implementation before 2020-2030
  - risks in storage and transport due to unprecedented scale

- **Biological capture + storage (char):**

  - inherently safe for thousands of years, added benefit in soil management
  - distributed (local) effort, probably slow to implement globally

- **Geological/mineral capture + storage:**

  - only surface depository needed, carbon ~permanently stored
  - even larger scale mass transport than as CO_2

- **General aspects:**

  - any widely distributed (local) mitigation process can be slow to implement
  - unequal regional benefits of mitigation
    $\Rightarrow$ slow or reduced response, multiple methods necessary
  - urgent action needed if “safe” level of CO_2 ~ 350-450 ppm