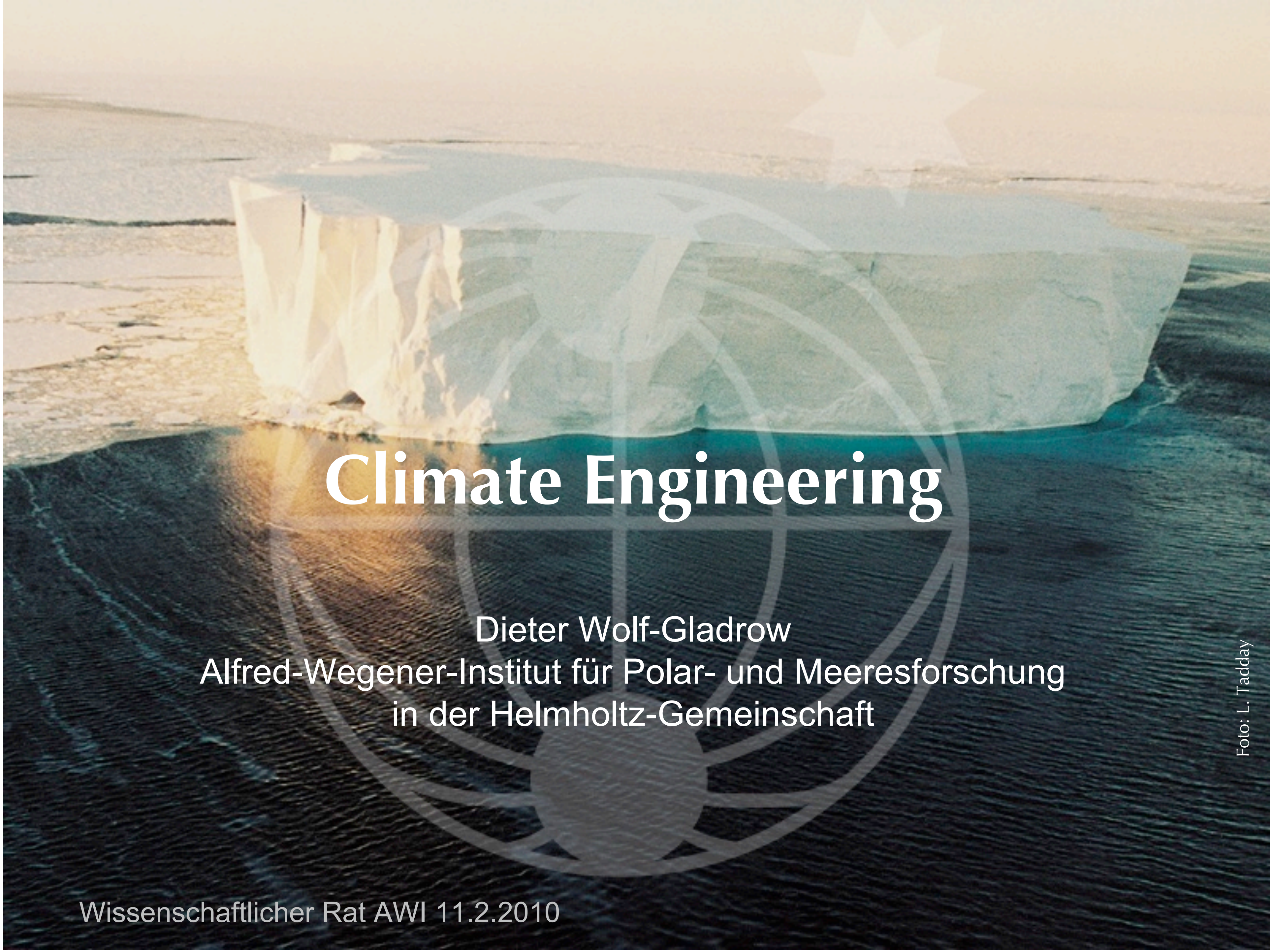


Foto: L. Tadday

Climate Engineering

Dieter Wolf-Gladrow
Alfred-Wegener-Institut für Polar- und Meeresforschung
in der Helmholtz-Gemeinschaft

Wissenschaftlicher Rat AWI 11.2.2010

CO_2 emissions: A large scale geophysical experiment (Revelle & Suess, 1957)

"Human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future."

Roger Revelle

Hans Suess in 1972

The 2°C warming target
CO_2 emissions: less than 205 Gt C until 2050

HELMHOLTZ ASSOCIATION

Greenhouse-gas emission targets for limiting global warming to 2 °C

Malte Meinshausen[1], Nicolai Meinshausen[2], William Hare[1,3], Sarah C. B. Raper[4], Katja Frieler[1], Reto Knutti[5], David J. Frame[6,7] & Myles R. Allen[7]

Limiting cumulative CO_2 emissions over 2000–50 to 1,000 Gt CO_2 yields a 25% probability of warming exceeding 2 °C—and a limit of 1,440 Gt CO_2 yields a 50% probability—given a representative estimate of the distribution of climate system properties.

Between 2000 and 2050: < 1000 Gt CO_2 = 273 Gt C
Between 2010 and 2050: < 750 Gt CO_2 = 205 Gt C
Current emission: ≈ 9 Gt C yr-1 -> ≈ 20 years

3.67 g CO_2 = 1 g C

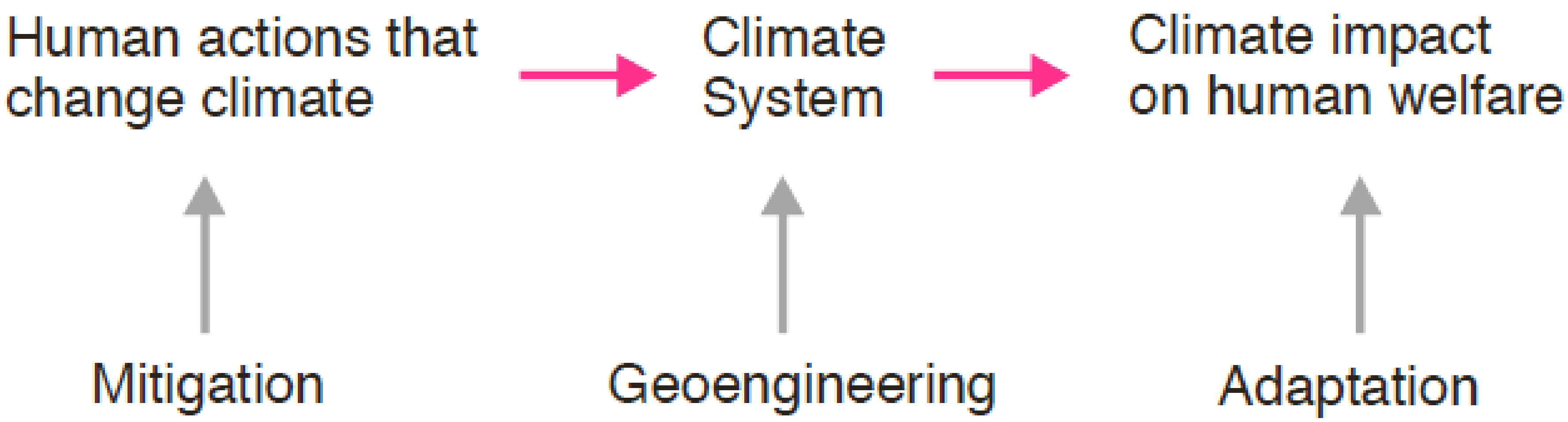
Outline

Motivation

Mitigation/Adaptation/Geoengineering (Climate Engineering)

Geoengineering: Report of the Royal Society (2009)

Mitigation/Geoengineering/Adaptation



(Source: David Keith)

Mitigation/Adaptation/Geoengineering

HELMHOLTZ ASSOCIATION

Mitigation: `activities that reduce anthropogenic emissions of greenhouse gases (particularly CO_2)´ (Lenton and Vaughan, 2009)

Adaptation: ... build a house against rain & storm ...,
... floating cities (for our Dutch neighbors) ...

Geoengineering: `large-scale engineering of our environment in order to combat or counteract the effects of changes in atmospheric chemistry´ (NAS, 1992)
+ ocean (acidification)

Adaptation

Adaptation "is crucial to deal with the unavoidable impacts of climate change to which the world is already committed" (The Economics of Climate Change: Stern Review, 2007)

Pielke Jr R, Prins G, Rayner S & Sarewitz D (2007). *Lifting the Taboo on Adaptation.* Nature 445, 597-598.

HELMHOLTZ ASSOCIATION

Will it be effective?

The radiative forcing potential of different climate geoengineering options

T. M. Lenton and N. E. Vaughan

School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK

Tyndall Centre for Climate Change Research, UK

Received: 10 December 2008 – Published in Atmos. Chem. Phys. Discuss.: 28 January 2009
Revised: 10 July 2009 – Accepted: 24 July 2009 – Published: 6 August 2009

Atmos. Chem. Phys., 9, 5539–5561, 2009
www.atmos-chem-phys.net/9/5539/2009/

HELMHOLTZ
ASSOCIATION

Royal Society, London

Geoengineering the climate

Science, governance and uncertainty

September 2009

Membership of working group

The members of the working group involved in producing this report were as follows:

Chair	
Professor John Shepherd FRS	Professorial Research Fellow in Earth System Science, University of Southampton.

Members	
Professor Ken Caldeira	Director, Caldeira Lab, Carnegie Institution, USA.
Professor Peter Cox	Professor of Climate System Dynamics, University of Exeter, UK.
Professor Joanna Haigh	Head of Department of Physics, Professor of Atmospheric Physics, Imperial College, London, UK.
Professor David Keith	Canada Research Chair in Energy and the Environment, Director, ISEEE, Energy and Environmental Systems Group, University of Calgary, Canada.
Professor Brian Launder FREng FRS	Professor of Mechanical Engineering, University of Manchester, UK.
Professor Georgina Mace CBE FRS	Director, NERC Centre for Population Biology, Division of Biology, Imperial College, London, UK.
Professor Gordon MacKerron	Director, Science and Technology Policy Research Unit, University of Sussex, UK.
Professor John Pyle FRS	1920 Professor of Physical Chemistry, University of Cambridge, UK.
Professor Steve Rayner	James Martin Professor of Science and Civilization, Director, Institute for Science, Innovation and Society, University of Oxford, UK.
Professor Catherine Redgwell	Professor of International Law, University College London, UK.
Professor Andrew Watson FRS	Professor of Environmental Sciences, University of East Anglia, UK.

Two classes of geoengineering methods
Royal Society Report 2009

HELMHOLTZ ASSOCIATION

1. Carbon dioxide removal (CDR) techniques:
   remove CO_2 from the atmosphere.

2. Solar Radiation Management (SRM) techniques:
   reflect a small percentage of the sun's light back into space.
   Remark: SRM does not address ocean acidification!

2. Solar Radiation Management (SRM) Royal Society Report 2009

HELMHOLTZ ASSOCIATION

Increasing the surface reflectivity of the planet, by brightening human structures (e.g. by painting them white), planting of crops with a high reflectivity, or covering deserts with reflective material.

Enhancement of marine cloud reflectivity

Mimicking the effects of volcanic eruptions by injecting sulphate aerosols into the lower stratosphere (Crutzen)

Placing shields or deflectors in space to reduce the amount of solar energy reaching the Earth

GLOBAL TEMPERATURE STABILIZATION VIA CONTROLLED REFLECTIVITY ENHANCEMENT OF LOW-LEVEL MARITIME CLOUDS

Scientific Collaborators:-

University of Edinburgh: Stephen Salter, Tom Stevenson

Pacific Northwest National Laboratories – Phil Rasch

University of Manchester - Keith Bower, Tom Choularton, Hugh Coe, John Latham

University of Leeds – Alan Blyth, Alan Gadian, Laura Kettles Ben Parkes, Mike Smith

NCAR - Jack Chen, Andrew Gettelman, John Latham, Hugh Morrison

U of Washington – Rob Wood

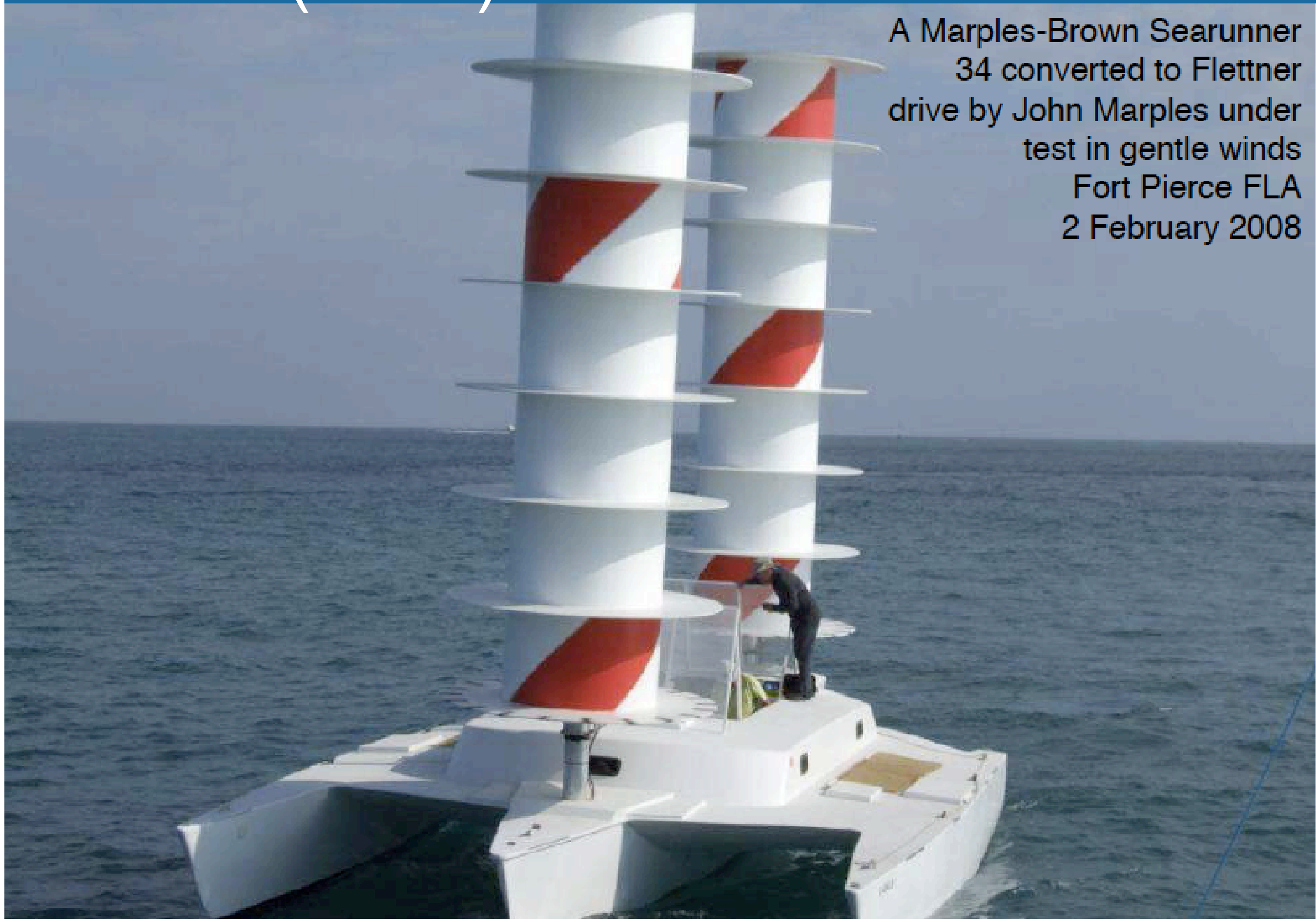
Unaffiliated – Armand Neukermans & Colleagues

(Latham, 1990, 2002: Bower et al., 2006: Latham et al., 2008: Salter et al., 2008)

Size matters: material is brighter at small size

smaller cloud droplets -> increased reflectivity

Seawater droplets -> increase cloud albedo Latham (1990)



CCN =
cloud
condensation
nuclei

Salter, talk in Hamburg, 2009

Possible Technique (Latham, 1990)
To disseminate sea-water droplets at ocean surface. These ascend via turbulence to cloud-base in sufficient numbers and with sufficient salt-mass to dominate as CCN, thereby enhancing N and increasing, in a quantitatively controllable manner, cloud albedo (Twomey, 1977) and longevity (Albrecht, 1989).

Latham, talk in Hamburg, 2009

CONCLUSIONS

IF GCM ΔF VALUES ROUGHLY CORRECT, TECHNIQUE COULD STABILIZE EARTH'S TEMPERATURE FOR SOME DECADES

HOWEVER

1. UNACCEPTABLE RAMIFICATIONS MIGHT BE DISCOVERED.

2. MORE DETAILED LES STUDIES COULD DEMONSTRATE THAT OUR ΔF ESTIMATES ARE SERIOUSLY INFLATED

3. INSURMOUNTABLE TECHNOLOGICAL PROBLEMS MIGHT THWART SUCCESSFUL GLOBAL DEPLOYMENT.

ENCOURAGING OBSERVATIONAL/FIELD SUPPORT FROM:-

Quaas & Feichter (2008). Satellite cloud study. Global ΔF = - 2.7 W/m^2.

Platnick & Oreopoulos. 2008. Satellite cloud study.

Roberts et al. (2008). Airborne cloud/aerosol study. Local ΔF = - 60 W/m^2.

1. CO_2 removal methods (CDR) Royal Society Report 2009

HELMHOLTZ ASSOCIATION

Land use management to protect or enhance land carbon sinks

The use of biomass for carbon sequestration as well as a carbon neutral energy source

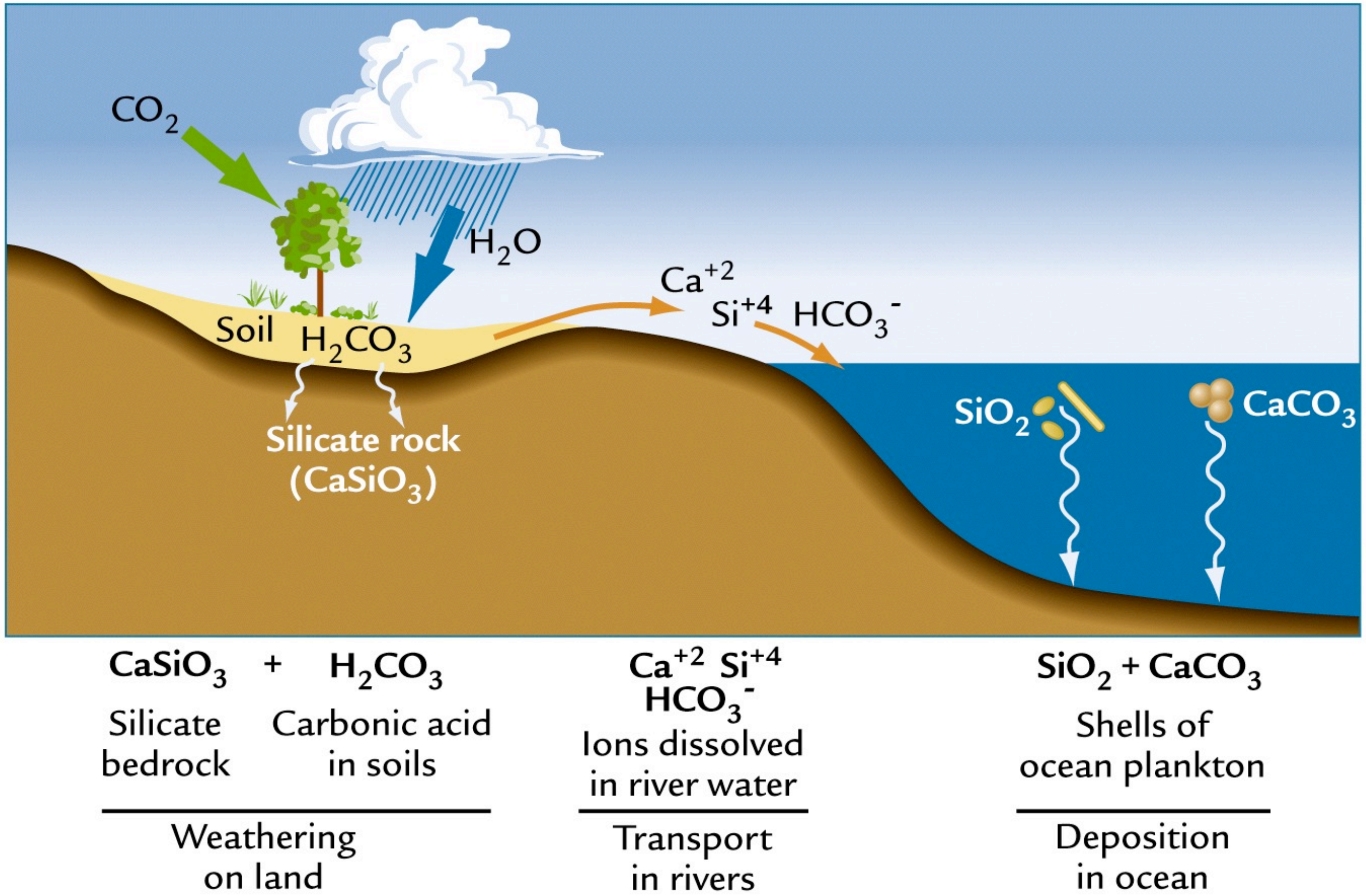
Enhancement of natural weathering processes to remove CO_2 from the atmosphere (dissolution of olivine)

Direct engineered capture of CO_2 from ambient air

Oceanic iron fertilization (OIF)

Ocean fertilization by increasing upwelling processes

The C cycle on long time scales: weathering of silicate rock



(Ruddiman, 2000)

The net effect of weathering can be summarized into the basic equation
igneous rocks + acid volatiles ⇒ sedimentary rocks + salty ocean

Artificially enhanced weathering of olivine

$Mg_2SiO_4 + 4\ CO_2 + 4\ H_2O \Rightarrow 2\ Mg^{2+} + 4\ HCO_3^- + H_4SiO_4$

HELMHOLTZ | ASSOCIATION

+ 2 Mg^{2+}: increase total alkalinity (TA)!

ENHANCED WEATHERING: AN EFFECTIVE AND CHEAP TOOL TO SEQUESTER CO_2

R. D. SCHUILING[1] and P. KRIJGSMAN[2]

[1]*Institute of Earth Sciences, 3508 TA Utrecht, The Netherlands*
E-mail: schuiling@geo.uu.nl
[2]*Groteweg 10, 8191 JW, Wapenveld, The Netherlands*

Requirements: small grain size (< 10 μm), high temperature, low pH
-> reactors or soils in tropical regions

Abstract. Weathering and subsequent precipitation of Ca- and Mg-carbonates are the main processes that control the CO_2-concentration in the atmosphere. It seems logical, therefore, to use enhanced weathering as a tool to reduce rising CO_2-levels. This can be applied as a technology, by reacting captured CO_2 with olivine or calcium-silicates in autoclaves. It can also be applied extensively, by spreading fine-powdered olivine on farmland or forestland. Measures to control the CO_2-levels of the atmosphere will be adopted more readily if they also serve some broader economic goals. An effective strategy for CO_2 control will require many parallel approaches simultaneously.

Potential for olivine dissolution

The geoengineering potential of artificially enhanced silicate weathering of olivine

Peter Köhler,[1] Jens Hartmann,[2] Dieter A. Wolf-Gladrow[1]

Consider olivine dissolution in catchment areas of Amazon & Congo.
1 g CO_2 sequestration ≈ 1 g olivine (-> huge amounts of olivine!)

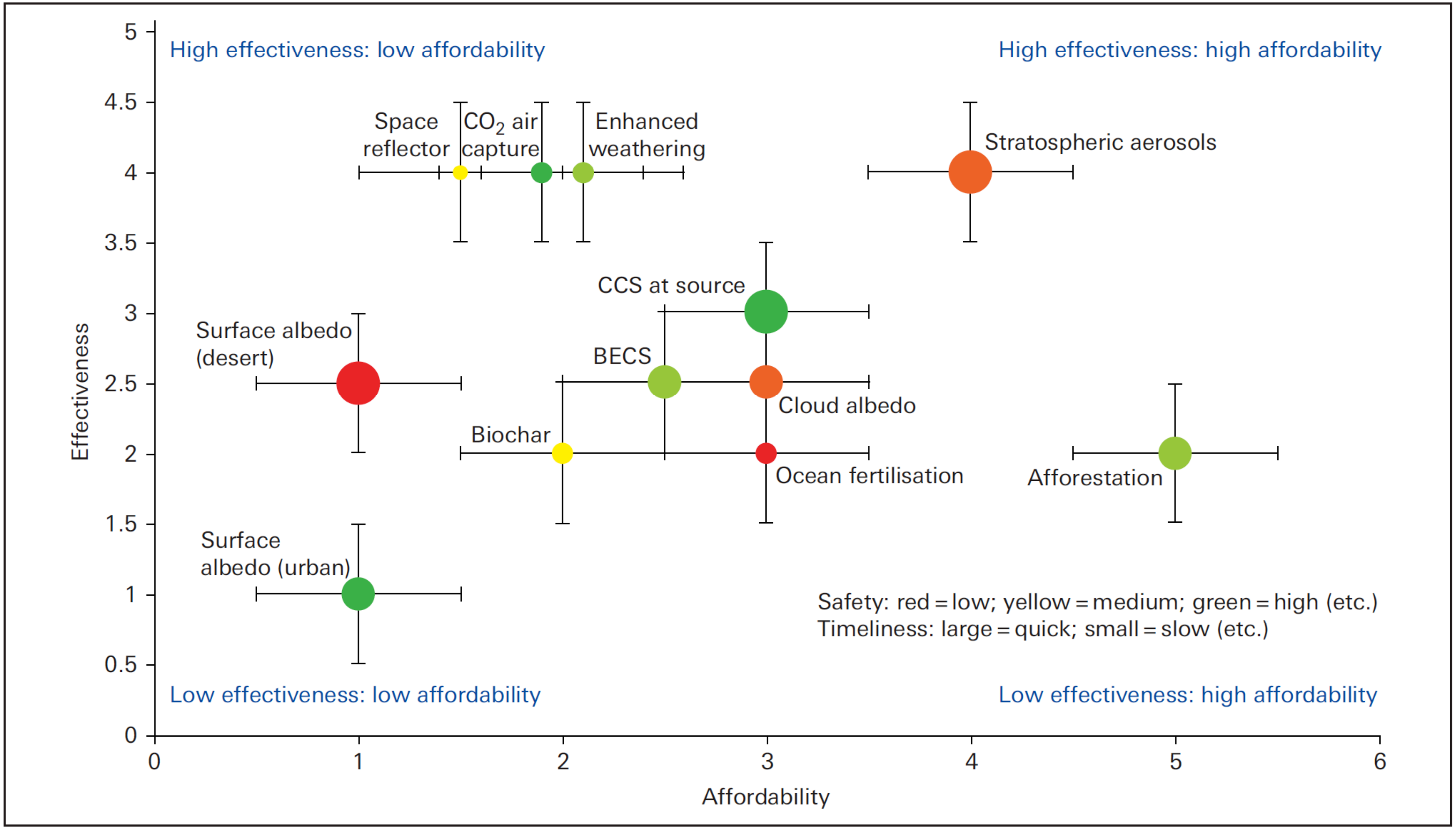
Problems:

1. Increase of river pH from below 7 to 8 or 9 (‘river alkalinization’).
2. Dissolution of silicic acid would limit potential to < 1 Pg C yr^{-1}.

Effectiveness versus Affordability
Royal Society Report 2009

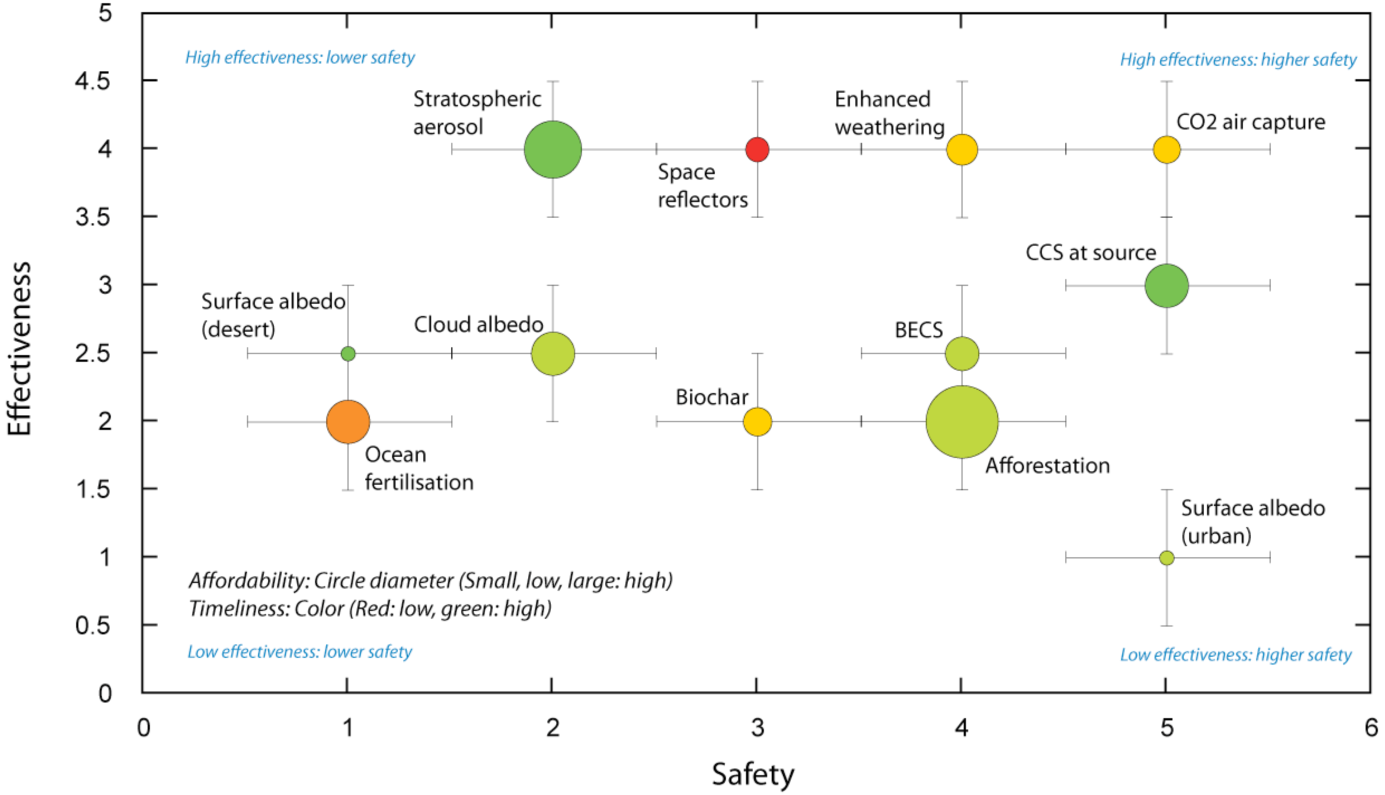
HELMHOLTZ ASSOCIATION

Figure 5.1. Preliminary overall evaluation of the geoengineering techniques considered in Chapters 2 and 3.



Effectiveness versus Safety

http://2020science.org/2009/09/01/geoengineering-options-balancing-effectiveness-and-safety/



Displaying estimated effectiveness versus "safety" for twelve geoengineering approaches. Based on data in the Royal Society Geoengineering the climate report

Final remarks

HELMHOLTZ ASSOCIATION

Large scale experiment (Revelle & Suess, 1957): anthropogenic CO_2 emissions & climate change & ocean acidification

Finish this experiment (mitigation) or adapt to the consequences or counteract/combat the effects (geoengineering)

Some geoengineering methods (iron fertilization, enhanced silicate weathering) have the potential to sequester large amount of CO_2 in the ocean (order of 1 Pg C yr^{-1}).

These methods have (not well known) impacts on marine ecosystems (general problem for CO_2 sequestration in the ocean).

Geoengineering: trade-off or torture?

Sustainable development

AWI & Climate-Engineering (CE)

HELMHOLTZ ASSOCIATION

AWI hat sich gegen bestimmte CE-Maßnahmen ausgesprochen (z.B. keine großräumige Eisendüngung).

CE könnte in Zukunft Teil eines Gesamtkonzeptes zur Verhinderung/Verringerung von unerwünschten Klima-veränderungen werden (zusammen mit Mitigation & Adaption).

Grundlagenforschung (z.B. kleinskalige Fe Düngung) kann dazu beitragen Potential & Risiko von CE abzuschätzen und damit einen fachlichen Beitrag zur Beförderung von politischen Entscheidungen liefern.

DON'T BE HUMBLE!

Humble is a small town in Texas.
Enco: now they call themselves Exxon.
From Life Magazine 1962.

(thanks to Stephen Salter)


Thanks for your attention!

Title

HELMHOLTZ
ASSOCIATION