Tyndall Centre for Climate Change Research

The Cambridge-MIT Institute

Tyndall Centre & Cambridge-MIT Institute Symposium : Macro-Engineering Options for Climate Change Management & Mitigation

The Tyndall Centre for Climate Change Research (www.tyndall.ac.uk) and the Cambridge-MIT Institute (www.cambridge-mit.org) convened a special joint Symposium on "Macro-Engineering Options for Climate Change Management and Mitigation" at the Isaac Newton Institute in Cambridge, England, from 7-9 January 2004. The purpose of the Symposium was to identify, debate, and evaluate possible macro-engineering responses to the climate change problem. These include large-scale Carbon Capture and Storage (sequestration), and more controversially, the possibility of adjusting the planetary albedo to compensate for global warming. The web-site for the Symposium is at www.tyndall.ac.uk/events/past_events/cmi.shtml.

Background

Many people now recognise that reducing global greenhouse gas emissions by the amount (say 50%, over the next few decades) which may be necessary to avoid excessive climate change, is going to be extremely difficult. If this is also to be combined with significant convergence internationally, which is increasingly likely to be necessary, it will indeed require the developed countries to reduce their emissions by much larger proportions than this, by (say) 90% (for the USA) and 80% (for Europe). It is far from certain, and perhaps unlikely, that such reductions can be achieved just by improving energy efficiency and reducing carbon intensity by using renewable sources of energy. Such conventional approaches may not be sufficient either in their magnitude**,** or the time-scale on which they can be achieved. Because of the urgency of implementing climate-change management, more innovative approaches to the mitigation of climate change are likely to be needed. Indeed, such new options may already be needed during the Second Commitment Period for the Kyoto Protocol. While potential low-carbon sources of energy, such as nuclear fission and fusion, do either already exist or may become available later in this century, there is quite likely to be a serious shortfall in the medium-term. Any alternatives which might help to close the gap, such as possible macro-engineering options for climate change management and mitigation, therefore need to be widely discussed and properly evaluated, as soon as possible, before they can be seriously considered for implementation.

Philosophy

The intention of the Symposium was to initiate an open process of exploration and evaluation of any possible macro-engineering approaches, so that suitable options may be identified and made available if possible, if and when it is decided that they are required. This process is envisaged as continuing for a number of years, before any firm conclusions can be reached. The range of approaches identified now will doubtless be incomplete, and any evaluations made will necessarily

be preliminary. Nevertheless, since the detailed evaluation and the actual implementation of any promising approaches may take several decades, it is important to start the process as soon as possible.

Although most of the macro-engineering approaches identified so far are not currently in the mainstream thinking in relation to climate policy, the mere fact that they have been conceived and proposed places an obligation on engineers, economists, and environmental and social scientists, working together, to explore their feasibility and evaluate their consequences and their wider implications. At the very least, such options may need to be considered as emergency policy options in the event of greater adverse climate change impacts than expected, or less effective carbon reduction measures than anticipated. The process of exploration, evaluation, development and (eventually) pre-operational implementation of such approaches should be regarded as at least an insurance against these eventualities.

Many of these possible options are highly speculative at present, and some may even appear to be quite crazy. However, that is precisely why they should be evaluated (and if necessary dismissed) as soon as possible. Otherwise, politicians may seek to use them as "Magic Bullets" either to postpone action, or as prospective solutions for actual implementation, once it becomes clear that the mitigation of climate change is going to be a major and very difficult task indeed...

The symposium therefore aimed to

- Consider all approaches identified, objectively, and without preconceptions
- Engage in an open, unbiassed, and visionary but still concrete discussion
- Disregard potential pressures in relation to political correctness.
- Employ a very wide range of criteria for a preliminary evaluation

Participants

The Symposium was attended by 34 invited participants who were known to have an interest in the subject, mainly from UK, European and North American institutions (see list attached). Whilst some of these were known proponents of particular schemes, most were uncommitted and many were quite sceptical about the viability of macro-engineering options. The group was however essentially only selected subjectively by the conveners, and so makes no claim to be representative of any community or formal scientific body.

Possible macro-engineering options

The macro-engineering options considered, and the person presenting each option to the symposium (but not necessarily advocating them) are listed below [see also the Symposium programme]. Links

to the individual presentations and to additional background papers can be found on the Symposium web-site at www.tyndall.ac.uk/events/past_events/cmi.shtml.

1. CO_2 Sequestration (Capture and Storage)

- Geological disposal (liquid) [Julio Friedmann]
- Geological disposal (solid) [Klaus Lackner]
- Direct ocean disposal [Ken Caldeira]
- Atmospheric scrubbing [Klaus Lackner]
- Ocean fertilisation [Victor Smetacek]
- Enhancement of land carbon sinks [Victor Brovkin]

2. Insolation Management (albedo modification)

- Orbiting Deflection Systems [Lowell Wood]
- Stratospheric Balloons & Aerosols [Lowell Wood]
- Low-level Cloud Stimulation [John Latham]

In addition, the symposium also discussed in somewhat less detail some other large-scale mitigation and adaptation options, which do not directly address global climate management, including Land Surface Modification, Ocean-Current Stabilization by River Deviation, Sea-Level Stabilization by Freshwater Retention, and Large-Scale Migration Corridors for Biosphere Adaptation.

Evaluation

The symposium had intended to attempt a preliminary Delphi-type evaluation of the various possible options, according to a wide range of criteria [Feasibility, Effectiveness, Predictability, Reversibility, Environmental impacts, Ecological tolerability, Safety (potential for disaster), Cost, Social equity, Economic equity, Economic efficiency, & Public attitude], but was unable to complete this in the time available because there was so much energetic and constructive debate on the proposals presented, and it was decided not to curtail this. However, participants did complete a personal option evaluation form and the results of these will be analysed in due course, and should provide a useful basis for further debate.

Preliminary Consensus Summary

The Symposium was not intended to attempt anything more than a rapid and preliminary overview of the state-of-the-art with respect to macro-engineering options, and no attempt was made to debate or agree formal conclusions or recommendations at the meeting. However, a surprising degree of consensus did emerge, which was broadly supportive of further active and

systematic research & development of most of the options reviewed, and the following summary of the views of the symposium was subsequently drafted and agreed by e-mail exchanges:

1) The potential scale of global CO_2 emissions reductions likely to be required over the next 100 years is so great that all potentially feasible methods for mitigation need to be considered seriously.
2) Conventional methods to ameliorate or reduce per capita energy use, and to reduce the carbon intensity of energy, including energy conservation and the use of renewable and low-carbon sources of energy, will need to be deployed globally, and pervasively, throughout the economy. More extensive use of nuclear power is an option which may be needed as a low-carbon source of electricity.
3) It is however likely that in practice the extent and rate of deployment of such conventional approaches will be not be adequate to avoid atmospheric CO_2 concentrations and the consequent climate change reaching undesirable levels during the next few centuries. Additional large-scale "macro-engineering" approaches to the mitigation and management of climate change may therefore be required.
4) Some macro-engineering approaches operate by mitigating CO_2 emissions, whereas others seek to increase albedo and so reduce incoming UV & visible radiation slightly, to compensate for the consequential changes to the global radiation balance, without affecting CO_2 levels.
5) All of the less conventional macro-engineering approaches discussed at the symposium appear to be feasible in principle, and some may potentially be usable on a sufficient scale in due course, in addition to conventional approaches, to assist in closing the gap between what is needed and what is otherwise achievable.
6) By using more than one technique, there may ultimately be some scope for adjusting CO_2 levels and climate change separately.
7) In addition to their contribution to the greenhouse effect, increasing atmospheric CO_2 concentrations are already causing progressive and significant acidification of the surface waters of the ocean, with detrimental effects for calcifying organisms including corals, in addition to those of increased temperature, and this acidification will continue and eventually extend into the deep ocean. Both warming and acidification are likely to have ecological impacts. Albedo management could address the former but not the latter.
8) Change in ocean surface pH will probably also change emissions of other climate-relevant trace gases (DMS, organo-halogens), and may also alter the soft-organism biological carbon pump and so alter oceanic carbon dioxide uptake/release.
9) Substantial reductions of present and future CO_2 emissions, either directly or through CO_2 capture & storage, are therefore likely to be needed to avoid excessive acidification, even if it eventually becomes possible to manage climate change by adjustments to albedo.
10) These adverse marine effects must however be set against the associated possible benefits of probable increased biological productivity on land. Ultimately it may even be possible to decide on, and seek to attain, a desirable compromise target CO_2 level, since there is no reason to suppose that the current level (or even the pre-industrial level) should necessarily be regarded as the target.

11) Different macro-engineering approaches have different features, for example
    a) Albedo adjustment techniques affect climate but do not directly affect atmospheric CO_2 concentrations.
    b) CO_2 capture & storage methods are well adapted for implementation at large fixed installations, but not for diffuse sources (e.g. transportation), although they can be used (e.g. in conjunction with coal gasification & liquefaction) to generate low carbon fuels including hydrogen for transportation applications.
    c) CO_2 capture from ambient air (& subsequent storage) does have the potential to address the problem of emissions from diffuse sources, and can potentially be implemented in any location. . However, it must still be paired with some actual method for sequestration (e.g., geologic, mineral, dissolved limestone etc).
12) It is therefore conceivable that a ***portfolio*** of different conventional and macro-engineering methods could be constructed, in order to address different aspects of the anthropogenic perturbation to the Earth System due to fossil fuel use. This could be extremely important, given the magnitude of the problem and the uncertainties involved, and in financial terms this could create alternative and potentially valuable options that can be exercised later. Within any such portfolio, least regret options should be considered first.
13) The risk of enduring doubled (or higher) CO_2 concentrations, together with a small reduction in insolation, is potentially less than the risk of doing so without such a reduction in insolation. Further research to quantify the risks in this trade-off is required.
14) It will be necessary to undertake extensive further research, development and political, ethical and socio-economic analysis of all the unconventional options considered, including especially albedo modification, and any conceivable environmental impacts of them, before they could be considered seriously for large-scale implementation. Such studies, involving discussions with representatives of all groups impacted, should be encouraged and funded at realistic levels.
15) Any deliberate attempts to modify the environment should however be subject to the modern (medical) ethical principle "First, do no harm". All of the options considered will require large-scale tests with extensive ("broadband") monitoring, in order acquire a better understanding of the likely near- and far-field effects. Basic research should be combined with large scale pilot experiments to maximize the learning outcomes from any specific endeavour.
16) In the short-term we should therefore establish, for each of the options to be considered further, not only the necessary R&D programmes, but also inter-disciplinary working groups to study very carefully all the possible ramifications of the proposals (including that of any pilot experiments) on a regional and global scale.
17) The macro-engineering options need sufficient R&D support in order that we may have the option of implementing them in the future, if necessary, and if they prove to be feasible and acceptable. However, it is essential that the existence of research into such potential future options is not used as a reason for delaying the implementation of known existing options, or for avoiding the tough decisions that need to be made now to get us on a path to stabilisation.

Comments on specific options

A. The potential effects of albedo adjustment on air quality (through changes in atmospheric chemistry, particularly effects on oxidants such as OH) need to be addressed early on.
B. CO_2 capture from ambient air has the unique feature that it can in principle be used to permit continued use of carbon-based fuels for transportation applications, if it were combined with hydrogen production (from a carbon-free source), and so used to produce a wide range of gas & liquid fuels suitable for this purpose
C. While biological sequestration techniques (including both enhanced land carbon sinks and ocean fertilisation) are ambient air capture methods, they have relatively limited potential, as the maximum scope for mitigation is probably less than 1 GtC/yr, and the impacts on the terrestrial and marine ecosystems are difficult to predict but may be large.
D. Land carbon sequestration might nevertheless be useful in a portfolio of methods, since both soil conservation techniques and afforestation of former agricultural land in snow-free temperate regions move both the climate and the carbon cycle back towards the pre-anthropogenic state. Terrestrial ecosystems are also much better understood than marine ones, due to long-term experience in agricultural and forestry practice.
E. Sea level rise can best be addressed by dealing with the causative factors, rather than by trying to sequester water on the continents by artificial impoundment, which is unlikely to be feasible or effective on the scale required, and could have major terrestrial & social impacts.

Next Steps

The Symposium participants agreed that further discussion and evaluation of macro-engineering options needed to be brought into the main-stream of the debate on possible responses to climate change, and agreed as individuals to promote this development. There are few institutions with the appropriate remit and range of expertise, but the Tyndall Centre may be able to take a leading role in the UK. The debate could now usefully be re-envigorated in North America, where a way is needed to build further on the 1992 NAS report (see Chapter 28 of www.nap.edu/books/0309043867/html/). Finally, funds should be sought for further design and (where appropriate) pilot-scale studies of the most promising macro-engineering options.

Additional Note: An IPCC Special Report on Carbon Capture and Storage is being prepared during 2004 and should provide a much expanded and authoritative information base for these options.