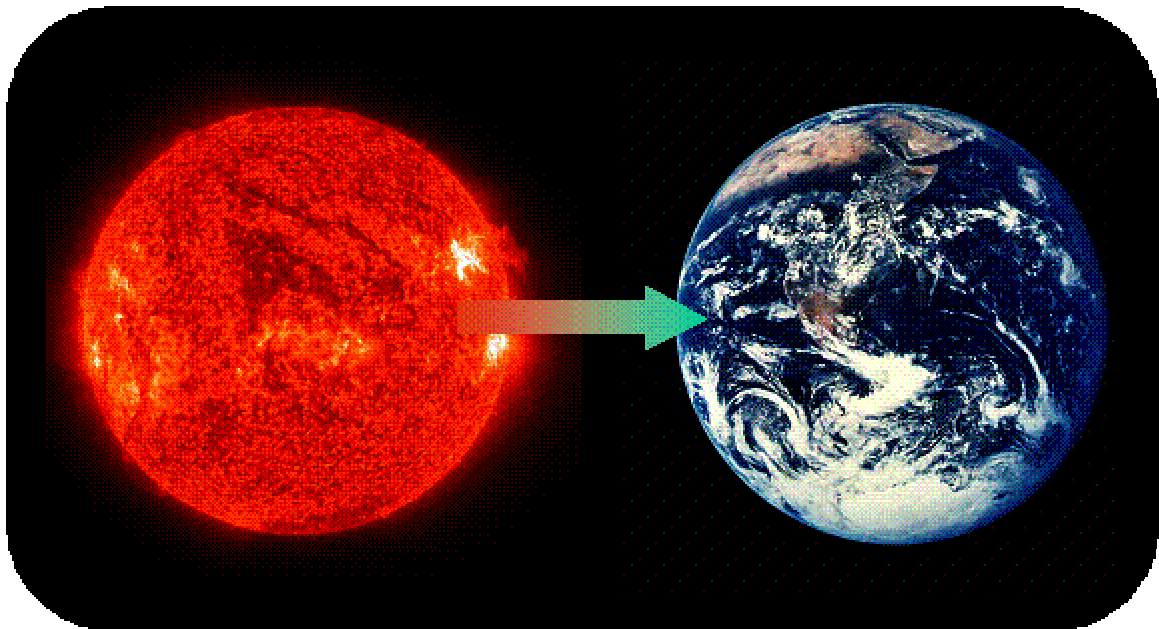


The

APOLLO-GAIA

Project



The Historical Background

The “Apollo-Gaia Project”

Historical Background

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The Apollo-Gaia Project
is Co-ordinated by David Wasdell as part of the Meridian Programme

It is hosted by the Unit for Research into Changing Institutions,
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The “Apollo-Gaia Project”

Historical Background

1: “Global Warning” and its Aftermath

In the early months of 2005, several scientists in the field of Climate Change and Footprint Overshoot were beginning to assert that political decision-making and effective action were not responding rationally to clearly presented scientific material. While some of the resistance and inertia could doubtless be attributed to the influence of vested interests and the political fear of losing electoral support, the intensity of the dynamics of denial pointed to powerful underlying social processes that were largely unconscious.

Drawing on three decades of consultancy-research focussed on the psychodynamics of social systems facing rapid change in conditions of low resource and high stress, I began to explore how best to consult to the process. A three-part paper entitled “[Global Warning](#)”, was prepared in order to begin to raise awareness of this agenda of social psychology. The document identified not one, but three, threatening waves of change currently facing humanity, namely:

- **Climate change**
- **Footprint overshoot (limits to growth)**
- **Psychodynamic response**

Even at that early stage of analysis it is fascinating to note that I was driven to conclude:

There is a critical point in the system at which the feed-back loops become dominant and render further increase in temperature independent of any reduction in human-generated greenhouse gases. **It is essential that this threshold should not be crossed.** As feed-back systems are activated even below the critical threshold, it becomes rapidly more difficult, and massively more costly, to bring the system back under control.

Time-lag between increased levels of atmospheric carbon-dioxide and the consequent stabilisation of appropriate global temperature, means that further global warming is already activated. **Rapid transition towards a low- or zero-carbon-emission culture is, therefore, now imperative.** That may not, however, be enough to halt the feed-back systems already triggered. It is doubtful if effective programmes of carbon-dioxide sequestration can be put in place and we may have to face the consequences of uncontrollable climate change.

“**Global Warning**” was produced as a background resource document for the G8 Summit at Gleneagles under the Presidency of UK Prime Minister, Tony Blair. Climate change was high on the agenda. It was published as an internet cascade by the [Meridian Programme](#) at the beginning of June 2005 and launched on the eve of the United Nations World Environment Day during a Symposium on Climate Change held in University College London. The Symposium was chaired by Sir Crispin Tickell, and keynote presentations were given by Richard Betts from Hadley, Simon Retallack of the IPPR, and Peter Bunyard of The Ecologist. In the ensuing discussion we arrived at a unanimous conclusion that further exploration of the feedback dynamics of climate change was now the most urgent and important research agenda.

The object of the “Unit for Research into Changing Institutions”, the educational charitable Trust which hosts the Meridian Programme, is defined as to conduct “**Research into ways to implement and advance the capacity of society and its associated institutions to adapt to change in a functional and realistic manner**”. If that task were to be carried out effectively, it was clearly essential to gain as clear an understanding as possible concerning the fundamental changes now facing society. From there on, Unit resources were focussed almost exclusively on the Climate Change agenda.

Initial literature search, correspondence and conversations led to an early approach to John Schellnhüber, the Director of PIK Potsdam. My letter was dated 1st July 2005, and contained the following:

Dr Richard Betts of the Hadley Centre urged me to contact you following our recent meeting and correspondence. There are two main reasons for my initiative. The first is to share with you the text of a paper entitled “Global Warning” produced as a resource to the G8 meetings. The second (and more urgent) issue is to explore current frontiers of modelling of the positive feedback loops in climate change.

I note that David King refers to them as important but unknown in their effects. Richard Betts (Director of Climate Change Research at the Hadley centre) claims that Hadley is now including four of them in its models and intends to concentrate on the feed-back issues over the next couple of years. In a private communication he also says: “The feedbacks do indeed have implications for our ability to stabilise at 2 degrees C above pre-industrial (or indeed any level)”. Aubrey Meyer (originator of the “Contraction and Convergence” strategy, and Director of the Global Commons Institute) asserts: “The most important set of issues in this area concern feedbacks. There are ... a number that are positive and capable of making the future much worse than the IPCC’s suggestions.” Or again: “Climate change is a survival issue due to the risk that positive feedback processes will magnify the initial global warming due to anthropogenic greenhouse gases”. He calls for a strengthening of research into Climate feedback in the GCI protocol proposal 2.14.

I can find no evidence that any significant progress has been made or is even underway in this vital area.

Earlier this month I wrote to Richard Betts as follows:

As I have monitored developments, six feed-back loops have come to my attention, and you may be aware of more. The ones I have picked up are:

- 1. Increase in sea temperature decreases CO₂ absorption**
- 2. Reduction in planktonic capacity to process CO₂ with rising water temperature and reduction in availability of rising nutrient-bearing currents (lowered density of surface water with rising temperature)**
- 3. Decreasing snow/ice surface decreases light/energy reflection**
- 4. Thawing of permafrost releases more methane**

These are already in action. They are obviously non-linear and difficult to model with current data, but must be the focus of research and model-improvement.

Two further feedback issues are subject to critical threshold triggers, namely:

- 1. CO₂ sink-to-source of land-based bio-systems (Peter Cox)**
- 2. Triggered start of release of methane-hydrate deposits (parallel to end of Permian period)**

What is the relative-effectiveness relationship between human increase/decrease in CO₂ emissions and the summed effect of the feedback loops, measured against rise in global temperature, and taking into account the time-delay between GHG release and stabilising of resultant temperature?

It looks as though there is a critical point in the system at which the feedback loops become dominant and render further increase in temperature independent of any reduction in human-generated greenhouse-gases. It is obviously essential that this threshold should not be crossed. Does the higher rate of warming in polar regions risk precipitating feedback processes even though the overall global warming is held at around the 2°C mark? Do the feedback loops put at risk the strategy of temperature overshoot and reduction currently being considered?

Hadley models may already take all this into account, in which case please forgive my presumption! If they do not, then some conflation of "World-3"-type programming with the climate-change model might be appropriate.

As I see it, the issue of feed-back threshold is now the most critical research field, with urgent implications for current strategic decision-making for the world-community.

Since that correspondence with Richard Betts one further feedback loop has been identified, namely the decrease in oceanic absorption of CO₂ with rising acidity of surface water. The same phenomenon is also reducing optimal conditions for planktonic life and therefore further reducing plankton absorption of CO₂.

I have been looking at the topology of the equilibrium surface that determines the threshold at which the positive feedback loops can trigger a "runaway" process of global warming that then becomes independent of the precipitating signal. In other words, the threshold beyond which no intervention of emissions limitation (whether managed under C & C or not) can capture and reverse the warming process.

Jim Lovelock's study of stasis dynamics may help, but does not seem to be sufficiently detailed. Meadows, Meadows and Randers' development of the World 3 modelling (in "Limits to Growth, the 30 year update") has good programming for non-linear feedback processes but seems not to apply them to this specific area of climate change. Rees and Wackernagel in company with yourself appear to take the climate change models as given and apply them to footprint analysis and implications for response to effects of climate change respectively.

Are you aware of any other solid work being done on this, or have I come to "the shoreline of ignorance"? I would be very grateful for any leads or comments you can provide.

With best wishes,
David Wasdell.
Director, Meridian Programme

In his response, John pointed me to the Report of the 91st Dahlem Workshop on “Earth System Analysis for Sustainability”, and invited me to take part in the upcoming Berlin conference on Tipping Points in the Earth System Dynamic. It was the start of a very fruitful exchange.

2: “The Feedback Crisis in Climate Change”

As the G8 Summit at Gleneagles came to an end, I was putting the finishing touches to the first draft of the conceptual analysis of the feedback dynamic system. In contrast to the classical approach to climate modelling, I started with the thermodynamics of the earth system as a whole in its spatial context. Then, having established the macro-system perspective, the analysis moved down a level to delineate all the drivers of climate change at a global level, and categorise the various feedback processes that had been identified. I constructed a conceptual model using a systems dynamics approach. The third element was the development of a topological landscape to represent the dynamic interplay between positive and negative feedbacks as they leverage the transition between “attractor-basins” in the complex behaviour of the global climate system.

At this point I received an unexpected e-mail from Prince El Hassan bin Talal, President of the Club of Rome, to say that he was interested in what I was doing and wanted to support the work of the Meridian Programme. All members of the Club of Rome had received e-copy of “Global Warning” and it was to this that the Prince was responding. I talked over our present work with his executive assistant, and agreed to air-mail half a dozen copies of the initial draft of “[The Feedback Crisis in Climate Change](#)” to the Palace in Amman. Two months later I received an invitation to attend (as President’s guest) the next Annual Conference of the Club of Rome to be held in Norfolk, Virginia, at the beginning of October.

Meanwhile, I followed up an introduction to Prof. Peter Wadhams, previously the Director of The Scott Polar Institute, and currently working in the Department of Advanced Mathematics and Theoretical Physics at Cambridge University. As we went over the new analysis, Peter said: “I think you have put your finger on something that has not been addressed before, namely feedback-on-feedback, or second-order-feedback, with the potential to accelerate the processes of climate change which are the subject of current modelling”. He also undertook to introduce the analysis to the Scientific Committee of the European Environment Agency at their next meeting later in the autumn.

The rest of the summer, was taken up with an intensive programme of literature search, consultation with leading climate scientists around the world, and continuous revision of what now became “The Meridian Report: The Feedback Crisis in Climate Change”.

3: The Club of Rome

In his opening remarks, the President welcomed me and drew attention to the Meridian Report as being “Worthy of note!”. Introductions followed to some of the Members with expertise in systems dynamics, climate change and environmental sustainability. On the final morning I had the opportunity to give a brief (unscheduled!) [presentation to the conference](#), from which the following quotes are taken:

In systems analysis, the conditions and behaviour of a macro-system set the parameters and conditions for the behaviour of all dependent sub-systems. The sustainability of the global environmental and climate systems therefore determines the sustainability of the dependent sub-systems of the human species, be they social, political, economic, educational, developmental, health or military, which have been the subject of our discussions about sustainable development at this conference.

The Meridian Report “The Feedback Crisis in Climate Change”, outlines a new conceptual model of the complex, interactive set of positive feedback mechanisms which are already driving runaway climate change, initially triggered by the still-accelerating emission of greenhouse gases. The analysis indicates that there is a critical threshold beyond which the process becomes self-sustaining and can no longer be brought back under control by any reduction in GHG emissions. Should that threshold be crossed, the resultant “extreme event” in the climate system could lead to the extinction of life as we know it within the global biosphere.

This analysis has not yet been taken into consideration by the IPCC or the UNFCCC, nor could it be featured in the “Limits to Growth: the 30 year update” which Dennis Meadows so ably summarised for us yesterday. Climate feedback puts at risk any possibility of achieving a sustainable scenario as we seek to recover from the overshoot of our use of planetary resources. It also raises the possibility that future reality may be far worse than the most extreme “collapse and crash” scenario previously modelled by the “Limits to Growth” team.

We now need to address the issue of responsibility for action. In scenario 10 of “Limits to Growth: the 30 year update”, the authors explored what might have happened if the most sustainable solution had in fact been applied a decade after the original analysis was made public.... They concluded: “That future might have been possible once. But the world society of 1982 did not grasp the opportunity”.

I question the implicit assumptions about the nature of that “world society” which is apparently to blame for the non-implementation of effective response to the information made public in the original “Limits to Growth” analysis. It is a society which is assumed to act decisively, rationally and effectively on information supplied disinterestedly by the scientific community.... With hindsight we can recognise how naïve those assumptions really were.

Today we recognise that those in possession of the most accurate information share the greatest responsibility for ensuring its most effective application. Change agency and the catalysis of social transformation must go hand in hand with the conduct of the most competent scientific research.

We now face the problematique of the identification of the most appropriate locus of initiative. It seems to me that the most obvious institutions of the UNFCCC, the UNEP, and the IPCC are in trouble. The time-scale of their deliberations, the political control of their decisions, the power of vested interests to which they are exposed, and the absence of channels for effective implementation combine to make it very difficult for them to act decisively in the current situation. The national academies of science and other academic associations are not organised to take the required level of action on an international scale.

The Club of Rome, on the other hand, with its unique constitution, its history, its global connectivity and its reputation for the highest quality of scientific investigation and disinterested application, may well be best placed to take up the critical agenda now facing the global community. It is, however, not clear whether the Club of Rome currently has the capacity, the resources or the will, to shoulder the responsibility for the required leadership role.

I should like to conclude, if I may, by offering some brief suggestions as to the agenda which must now be addressed:

1. **Recognise that there now exists a state of global emergency.**
2. **Convene, with the utmost urgency, a global analysis and modelling capacity, in order to test the conceptual climate feedback model, to quantify the complex feedback system and to determine the time-frame of its behaviour.**
3. **Declare excess CO₂ to be an eco-toxin with potentially catastrophic impact on the global biosphere.**
4. **Develop and operationalise an emergency strategy to move our global society towards a zero or negative carbon economy within the shortest possible time-scale.**
5. **Develop and operationalise the most effective institutional instruments to manage the transition.**
6. **Take note of the appropriate developments in:**
 - i. **complexity science;**
 - ii. **dynamic cellular networking**
 - iii. **advanced learning systems**
 - iv. **psychodynamics of social systems.**

The address was described as “A call to arms for the Club of Rome”, and I was urged to consider preparing a formal Report to the Club of Rome, to accept the role of Active Member, and to take up leadership of the UK Chapter. More importantly the event signalled a revolution in the social role of science. It called for a far more active and responsible engagement in the application of scientific analysis to the realm of policy formulation and the achievement of appropriate social change.

The concluding comments spelt out the agenda for an action-research programme at a global level. It is that initiative which led to the proposal for the “Feedback Dynamics Research Project” which then merged with John Schellhuber’s call for a “Manhattan Project of Climate Science”, and has now evolved into “The Apollo-Gaia Project”.

Over the following months I explored the formation, history, dynamics, constitution and current capacity of the Club of Rome, corresponding with and interviewing members who had been closely involved with the organisation over many years. A memorable three hours was spent with Dr. Alexander King, who, with Aurelio Peccei, co-founded the organisation back in the 1960’s. Sadly, Alex has recently died (he was in his nineties when we met), but his insights and assessments were immensely valuable.

The perceived legacy of the Club of Rome is still closely entwined with the “Limits To Growth” report from 1982. There is little awareness of the subsequent 20-Year and 30-Year Updates, or of its many other contributions to the study of the “Global Problematique”. On several occasions, I was warned that if my ongoing work was involved with the CoR, “Nobody would touch it with a barge-pole!” The organisation appeared not to have the public confidence, the international position, or the internal resources required to act as host platform for the needed initiative, though its support and endorsement, as one among an ensemble of other institutions, would be immensely valuable. Limiting the output of the

Project to the format of a “Report to the Club of Rome” was also seen to be inadequate. Communication would need to be dynamic, multi-channel, and emergent in real time. It was also clear that it would be inappropriate to conduct the Project from the position of an Active Member of the CoR. Such a position would unbalance my relationship with other endorsing institutions. It was with reluctance that I eventually declined to accept the offered appointment. Close links are, however, still maintained with the Club which remains in full support of the Project.

4: The European Environment Agency and Beyond

Prof. Peter Wadhams introduced the Meridian Report to the Scientific Committee of The European Environment Agency in the late autumn. They noted the significance of the analysis and wished to spend more time on the Report at their next meeting scheduled for February 2006. Meanwhile the computer graphics of the three-dimensional topological landscape were completed and included. The text was continuously revised in the light of comments, criticisms and contributions from other scientists in the field. Not all responses were supportive! Some traditional climate modellers found it almost impossible think outside the box of multi-layered, cellular, coupled land-ocean-atmosphere platforms, and to relate to the top-down, systems-dynamics approach. One or two found it difficult to see the difference between a graph of increasing radiative forcing over time, and a cross-section through the topological landscape of adjacent attractor-basins. Others were still struggling with the distinction between positive and negative feedback!

In early January we developed PowerPoint presentation skills to include multiple layers and hyperlink activation, and assembled the visualisation of the [complex feedback model](#) underlying the analysis. Within forty-eight hours of publication I had received an invitation from Dr. Jacquie McGlade, Director of the EEA to deliver the guest lecture at the next meeting of the Scientific Committee. The presentation was duly made on 14th February. Jacquie, herself a Cambridge mathematician and founder-member of the “Resilience Alliance”, publicly endorsed the analysis, indicated that she wished the EEA to join in that endorsement, and would invite other appropriate bodies to do the same. She insisted that I should work as an advisor to Al Gore, whom I met for the first time at the end of March. She also offered to make introductions to other climate science specialists and institutions in Europe, the UK, and North America.

Working through the early hours in preparation for a final meeting with Dr. McGlade and her chief scientific advisor, I put together the first draft outline of the “Feedback Dynamics Research Project”, initially proposed at the Club of Rome. We worked together to expand the set of participating institutions and to identify the most gifted scientists, mathematicians and modellers who could be invited to be part of the “core team”. The design has since been subject to a process of continual evolution.

Bob Citron, the Director of the Seattle-based “Foundation for the Future” had invited me to take part in their workshop “Crossroads for Planet Earth” in early April. As I shared with him the emerging analysis, he changed my role and I found myself responsible for delivering the opening keynote to the event, and being introduced to a large public gathering as “the world’s leading expert on feedback dynamics in climate change”!

The “Feedback Crisis” Report was completely re-worked. Material was included from studies of the “Paleocene-Eocene Thermal Maximum” as we began to realise that the anthropogenic intervention in the climate system had the potential to trigger an extinction event way beyond the oscillations of the glacial/interglacial period. The presentation was eventually re-titled “[Beyond the Tipping Point: Positive Feedback and the Acceleration of Climate Change](#)” and sub-titled “Towards the Anthropocene Extinction Event”. The whole event was captured on video, and the beautifully produced proceedings will be published by the Foundation for the Future later this year. Just before returning to London, I was interviewed by the director of a local TV station who then obtained permission to use the recording of my presentation. The material was released as a documentary on cable TV towards the end of May.

The Seattle workshop afforded an opportunity to meet in robust dialogue with a group of experts and communicators from around the world. The experience contributed to the continuous revision of “Beyond the Tipping Point”, a process of learning that was even further enhanced over the next couple of months. I had been registered as an “expert reviewer” for the Intergovernmental Panel on Climate Change, 4AR, Work Group 1: Climate Science. The onerous task of working through some 1500 pages of draft text, visuals and references, enabled me to update the analysis of feedback mechanisms against the data-base of published, peer-reviewed literature. In my response to the Editors I noted:

Major omission: Specific feedbacks and their effects on specific parameters are mentioned at various places within the text. What is now needed is a section that addresses the complex and interactive feedback system as a whole. An introduction would bring together the complete set of currently identified feedback mechanisms and their specific impact on particular factors of climate change (much as has been attempted in the current Chapter 7). The section would then need to outline the (non-linear) secondary feedback dynamics (the composite effect that the outcomes of specific feedback processes have on the acceleration and reinforcement of other feedback mechanisms within the system). It would also be necessary to address the interaction between the feedback system as a whole and the dynamics of radiative forcing. Implications of this new section would have to be taken into account in the relevant sections of reports from the other Working Groups.

Incidentally the treatment of feedback dynamics was not significantly improved in subsequent drafts. It was almost completely elided (together with references to non-linearity and evidence of accelerated climate change) from the final text of the Summary for Policy-Makers. (See “[Political Corruption of the IPCC Report?](#)”)

5: EU Commission Workshop: Sustainability & the Science of Complexity

In mid-June, an inter-directorate initiative within the EU Commission led to the convening of a workshop to explore the possible contribution of emergent fields of complexity science to the task of decision-making. I was asked to act as one of the rapporteurs for the event. John Schellnhüber, the Director of PIK Potsdam was one of the participants. The night before the workshop we were able to arrange a small seminar in the Royal Academy of Brussels in order to explore the analysis of feedback dynamics in climate change. The event was attended by about a dozen other interested individuals, and gave John and I our first opportunity to meet and compare notes. John was also able to clarify some of the issues in response to queries raised by other participants.

Next day, the Complexity Workshop opened opportunities to take the “Feedback Dynamics Research Project” a step nearer to realisation. The three relevant paragraphs from the workshop report are quoted below:

From the “Expert” presentations:

With regard to the specific challenge of avoiding dangerous climate change, the goal must now be to identify potentially catastrophic effect of tipping points in the behaviour of both natural and human systems. For example, present scientific knowledge cannot rule out the possibility of entry into a process of “runaway” climate change, with consequences far beyond our ability to manage. This critical research agenda should concentrate global resources in a “Manhattan Project” style engagement. All other work on impact assessment, mitigation and adaptation depends on the outcome of this overarching issue.

From the Open Discussion:

The greatest priority was assigned to researching the possibility of a “tipping point” in the whole earth climate system. This would threaten runaway climate change over which we would have little further control. To have the highest chance of success, such a project (a “Manhattan” project for Earth life sustainability) must be boldly planned and involve all stakeholders from the outset. Only if all the key interests are invested in the project and committed to it will the results then be influential.

From Workshop recommendations:

The **outstanding research priority is to explore the possibility of a “tipping point” in the earth climate system as a whole.** We must assess the potential threat of runaway climate change with massive implications for all other dependent systems of the human enterprise. To do so, it is essential to establish the “Manhattan Project” of climate science (with a different name, of course) to focus on this specific issue. It was recognised:

- That the initiative would require the establishment of a virtual college of world-leading expertise
- It would involve the pooling of cross-platform modelling resources and the development of new software capacity for the analysis and simulation of the complex feedback dynamics involved
- That necessary funding for the Project must be mobilised as quickly as possible

That it is very unclear what kind of institutional platform is required, or what initiatives should now be taken and by whom.

At the close of the workshop, John invited me to visit Potsdam to give a day seminar for himself and his research team so that we could explore the issues in greater depth.

This was not the first occasion (nor was it to be the last!) on which John called for the establishment of a “Manhattan Project” to address the dynamics of tipping points in the earth’s climate system. James Lovelock had also made a similar proposal earlier in the year, and Martin Rees, the president of the Royal Society had called for “An Apollo/Manhattan Project” to drive a “crash programme to achieve the transition to a low-carbon economy”. During the Workshop discussion, John came under strong criticism for using the “Manhattan” label, and he offered “San Gimignano Project” as an alternative, and less offensive title.

6: Seminar in PIK Potsdam, 8th – 10th August 2006

The Potsdam Institute for Climate Impact Research is located in the focal point of the “Wissenschaftspark Albert Einstein”, and housed in the buildings of the German Royal Astronomical Observatory which was moved to Potsdam from Berlin when air and light pollution reduced optimal conditions for observation. Architecturally, the site is laid out as a cathedral of astronomy.

The great refracting telescope in the central free-standing observatory was the second largest in the world when constructed, and is still ranked fourth.

In the past, the complex has been the centre for astrophysical research and has seen the most prestigious line of directors. Here Albert Einstein directed the institute, following on from a series of brilliant predecessors, some of whom are buried around the Refractor building. The Michelson-Morley experiment on the velocity of light was carried out here. Mathematical advances laid the foundation for Einstein’s work on the special theory of relativity and opened the portals on the nuclear age. PIK sits in the matrix of the bomb.

All astronomical equipment has been removed from the observatory dome in the centre of the main building and the rotunda has been transformed into a state-of-the-art seminar and presentation room. Here in the “navel” I delivered the presentation: “Beyond the Tipping Point: Positive Feedback and the Acceleration of Climate Change” to a packed audience of PIK staff.

As in Brussels, John Schellnhüber affirmed the critical importance of establishing a “Manhattan Project” (or “San Gimignano Project”) of Climate Science to address the agenda raised by the presentation, namely the potential existence of a “Tipping Point” in the whole earth system that could precipitate uncontrollable, runaway climate change. He also noted and amplified the comment that the new analysis reversed current economic cost-benefit assessment of mitigation interventions, rendering future discounting an irrelevance and confirming that immediate intervention would be the cheapest and most cost effective strategy.

I was, however, left with some serious concerns about the development and naming of the proposed research programme. In our discussion before the seminar John had shared in confidence that, the previous evening, he had been invited (by the Chef de Cabinet of the President) to act as the chief scientific advisor on Climate Change to the President during the German leadership of the EU and G8 next year. He would have major responsibilities for developing the Climate Change agenda for both bodies. His work pressure was already well-nigh overwhelming, with his ongoing research, administrative and personnel responsibilities as Director of PIK, his present advisory role to the German Government, engagements with the EU, IPCC and numerous overseas engagements. The new duties would leave him little time and energy to devote to the proposed “Manhattan Project”.

The name itself was initially used as a symbol “tag” to indicate the gathering of the best available scientific resources to focus on the research agenda and drive it through to application. The proposed form was that of a virtual team or meta-net with high learning profile, distributed and parallel processing, and strong competition/collaboration and coordination.

In the 1940's, "Manhattan" was used as a code name to mask the identity of the American wartime project to develop an atomic bomb. It is an offensive association and quite inappropriate to our proposal. We need no code word to disguise the real import of the programme which clearly and openly concerns "Feedback Dynamics in Climate Change". My seminal presentation in PIK was merely the prolegomenon, asking the questions and setting the agenda. Yet John persistently introduces the "Manhattan" tag and then mystifies the encoding further by displacing the association to the "San Gimignano" project. In support he notes that San Gimignano is known as the "Manhattan of Tuscany". It is a small medieval hill-top town ("a village crystallised in the 14th century") dominated by a set of ecclesiastical, civil and commercial towers, (some 14 of the original 72 still remain intact). The skyline bears some resemblance to the profile of Lower Manhattan Island.



The associated reference is regressive, obfuscatory and irrelevant. It has no resonance with the problematique of contemporary global civilisation. It is intensely European and the reference is meaningless without detailed explication. It adds nothing except confusion to the task of communication. It only emerged in the Brussels "Complexity Science Workshop" as a means to diffuse the conflict between John Schellnhüber and another participant.

It was time to seek a new title.

7: From “Manhattan” to “Apollo-Gaia”

A few days after returning from Potsdam I travelled down to visit James Lovelock in his West-country hideaway. Jim is the father of the “Gaia” hypothesis, the understanding of the whole earth system as an inter-active, co-evolutionary web of complex-adaptive bio-geo-chemical sub-systems that cohere in a life-supporting dance. Our conversation ranged over a number of issues:

1. That there is no example for the current situation in the contained glacial/inter-glacial oscillation period.
2. That the Paleocene/Eocene Thermal Maximum offers the best geological antecedent for the anthropocene intervention in climate change. The peak CO₂ concentration of the PETM was about 440 ppm, and that was enough to trigger the major extinction event.
3. That inclusion of CO₂ equivalent concentrations of all anthropogenic greenhouse gasses puts us at a current concentration of 421 ppm and accelerating.
4. That the CO₂ concentration in the PETM appears to have levelled out at about 440ppm, but we are approaching that figure with an accelerating upward path destined to go far higher in the business as usual scenario.
5. That the pace of the Anthropocene intervention is some 30 times faster than the events of the PETM, making biological adaptation to the event very much more difficult.
6. That biological modification to global resilience due to human change in land use is at least as significant as the increase in CO₂ concentration.
7. That change in land use is damaging Gaia’s immune system and accelerating the weakening of the capacity of the whole earth system to cope with the effects of climate change and to evolve appropriate biological responses to the crisis.
8. That the production of aerosols from forest fires (as well as anthropogenic aerosols) provides a mask of the true nature of global warming, while carbon release from burning bio-mass adds significantly to the increase in greenhouse gas concentration.
9. That the scale of changes in human behaviour required to prevent the Anthropocene Extinction Event (hot-earth solution) is now so massive as to make the catastrophe virtually inevitable.
10. That bio-fuels are not a solution. Too much land would be required to produce the fuel to serve even present usage. That would degrade even further the resilience of biological systems to the crisis. It would also divert essential land resources away from food production at a time when we would be encountering major shortfall in food production. In ethical terms, the survival of the poorest and most vulnerable would be put at risk while the rich and most powerful attempted to sustain their life-style as long as possible.
11. We affirmed that the inclusion of human activity in Gaian dynamics opened up a new level of response. For the first time in geological history biological feedback systems could now call on information and communication as an agent of responsive change in addition to bio-geo-chemical adaptation and evolution.

12. Reflecting on the contribution of Complexity science, we noted that the dynamics of the overarching earth system set the contextual parameters within which the co-evolutionary development of bio-geo-chemical subsystems took place. It was inappropriate to treat the macro system simply as an emergent higher-order level of complexity.

Together we reflected on the fragmentation of all science (including climate science) into shattered micro-disciplines. Each micro discipline tended to exist in a niche of its own, out of significant cross-disciplinary communication with even its closest relatives. Jim reflected on his visit to the Hadley centre and his discovery of the lack of inter-group information-flow and integration and the absence of any over-arching view of the subject. We noted the drive towards niche-specialisation in academia stemming from the search for projects that could yield Doctoral honours. We also hypothesised that such fragmentation served the purpose of defending academics from the anxieties generated by seeing systems as wholes (levels of complexity) and in particular from looking at the implications of the overall behaviour of the whole earth system. The fragmentation also preserved the dissociation of “pure” science in its stance of taking no responsibility for the practical (and political) application of emergent knowledge to social systems.

Jim’s experience of Hadley led him to convene (around February 2006) a gathering of all departments at Dartington in an attempt to catalyse a more integrated approach. It was here that the idea of a possible global tipping point became clear. As a result Jim called for the establishment of a “Manhattan project” of climate science to explore the critical issue and to apply its findings to the whole field of human response to climate change. The idea was to bring together the best available minds in an applied science project. The proposal has been repeated by several people present at or influenced by that particular gathering (including possibly John Schellnhüber). We had some light hearted exploration as to whether my proposal to the Club of Rome in October 2005 preceded his suggestion, before recognising that the idea was emerging synchronously from a variety of sources across the world.

Leadership style of any such initiative was seen to be critical to its success. Jim insisted that a “benign dictatorship” was essential, with the director having the right to make the final decisions (Openheimer style). His American wife, Sandy, questioned whether such an approach was possible within a democratic world. We noted the need for distributed processing, web-based communication resources, intense inter-activity and supported creativity. I contributed the idea of task-based, catalytic facilitation and the development of the project as a learning system.

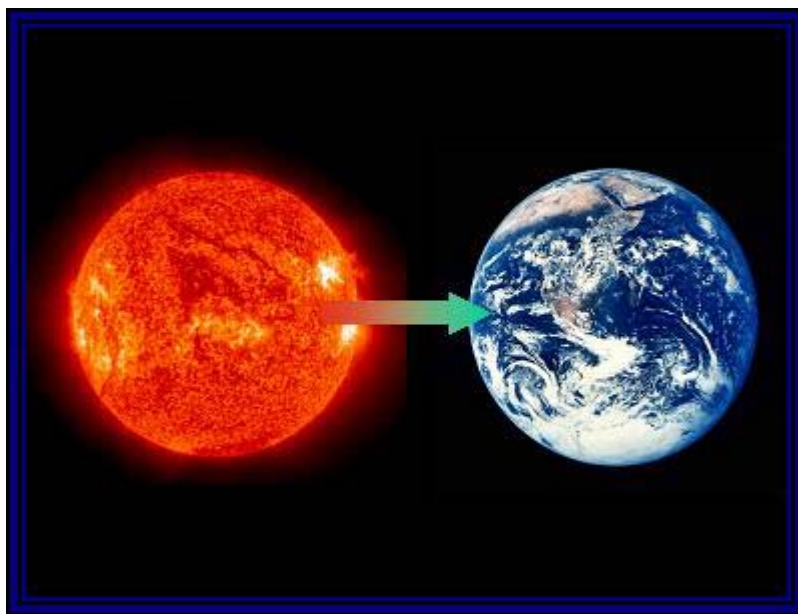
At one point Jim launched into an attack on my failure to use the concept of “Gaia” in my work. He was responsible for formalising the hypothesis and deserved to be given credit for it. The word had been suggested by a Nobel Laureate as giving full meaning to the living characteristics of the whole earth system. Opposition to the term by the scientific community had demonstrated their rejection of the hypothesis.

I tried to explain my reservations about the term while endorsing his hypothesis as an insight of genius. The mythological connections left him wide open to co-option by new-age mystics and the projection of animistic associations which had nothing to do with his theory. The use of a classical Greek myth was culturally biased and limited in its power to communicate with those who did not share the tradition or educational background.

“Gaia” is a pre-Copernican anachronism. On her own the Earth is barren. Gaia did not give birth to the heavens, the moon, the sun and the stars. There is no father for her children without the Sun. The earth system is devoid of life in the absence of solar gravity and radiation, the regular stirring of the lunar tides and the stream of emitted energy returning to the cold void of space. To be sure, living systems emerged in a co-evolutionary dance within this neg-entropic pocket of interstellar debris. But Gaia on its own is an inadequate and misleading symbol for the whole earth system on which we depend, whose complex environment we have put at risk, and for whose future sustainability we are now responsible. In contrast to geo-centric mythology, Gaia depends on Apollo for her life.



APOLLO-GAIA



So “Manhattan”, the symbol of war, was replaced by “Apollo-Gaia” as a symbol of life. We still had a problem with the associations of “Apollo”. For most people Apollo had nothing to do with the sun and everything to do with the American Apollo Programme, launched by President J. F. Kennedy as a symbolic demonstration of American technical superiority at the height of the cold war. The phallic power of rocket launch, and the triumphalist “giant step for mankind” as the first human set foot on the moon, are etched in our collective memory. It was the wrong image. Not as bad as Manhattan, but still the wrong image.

Within the Apollo Programme, however, it was the epic near-catastrophe of Apollo 13 that stood out with most intense emotional associations. The original events had been represented in the Tom Hanks quasi-documentary, “that tells the true and remarkable story of courage, faith and ingenuity in a race to bring a group of heroic astronauts home when their spacecraft was damaged thousands of miles from Earth”.

Jim Lovell’s laconic message: “Houston, we have a problem” signalled a technological failure that led to the abandonment of mission objectives. The moon landing was aborted. The priority was now survival at any cost. Life-support systems were at risk. Energy use had to be cut to a minimum. Carbon-dioxide levels went into danger levels and sequestration capacity had to be invented on the go. Course alterations had to be negotiated with inadequate computer control. There was no precedent, no manual, no set of pre-tested solutions. Intense creative team-work, physical and emotion support, mobilising of technological solutions to problems as they emerged, suspension of “cost-benefit” economic analysis, all combined with the driving imperative “Failure is not an option!” reiterated by Gene Kranz, the Mission Controller at the Houston Centre. The outcome was in doubt right up to the last moment, but they made it, and survived to tell the tale!

Here was a symbolic saga with which all could identify. As life on spaceship Earth faced its crisis of survival, Houston expanded to involve the whole of our global civilisation. Truly, Apollo-13 was a parable for our time.

8: From Washington to Brussels

Earlier in the summer, Sir Crispin Tickell had insisted that I should attend and present at the “Washington Summit on Climate Stabilization” to be hosted by The Climate Institute in mid-September. Crispin had been the Founder and first Director of the Institute while he was the British Ambassador to the Security Council of the UN. The current Director reviewed my proposal and sent a laconic e-mail to the effect that “unfortunately he agreed with the analysis” but that the programme was full! Eventually I was able to negotiate a 20 minute slot to introduce “[The Apollo-Gaia Project](#)” and its underlying analysis at the end of the final workshop of the Summit.

Preparation was intense. “Beyond the Tipping Point” was revised and updated to include new research and contributions from the Potsdam Seminar and the input from James Lovelock. The detailed design work on the original “Feedback Dynamics Research Project” was re-drafted and up-graded to lay the technical foundations for the operation of “Apollo-Gaia”. A new introductory presentation was developed from scratch using beautiful original photography from the NASA archives of the Apollo 13 Mission.

While in Washington I also had the opportunity to present “Beyond the Tipping Point” and the “Apollo-Gaia Project” to John Petersen and his staff in the “Fusion Centre” of the [Arlington Institute](#), as well as to Karen Coshof, Director of Stonehaven Productions. Karen was the Director of “[The Great Warming](#)”, a triple-length documentary on climate change. We had first met at the London premiere almost a year before.

Reception and endorsement of both analysis and project proposal, were profoundly encouraging. There was one exception. At the end of the presentation at the Washington Summit, I came under strong attack from the Chief Scientific Officer of the Climate Institute which had convened the event. He argued that temperatures and CO₂ concentrations were much higher in the Cretaceous Period than at present, so there was no real problem.

The Washington Summit on Climate Stabilization was designed to "**convene a group of world-class experts to assess the likelihood that we are tipping toward abrupt and highly disruptive climate change**". In his lead article preparing for the Summit in the current issue of Climate Alert, John Topping (The Director of the Climate Institute and Summit Chair) noted: "**We will need something far more ambitious than the Kyoto mechanisms if the world is to meet the climate change challenge..... It may well be that we are already experiencing positive feedbacks as warming begets more warming..... There is a real chance of the rapid climate change underway spiraling out of control with devastating implications for humanity and countless other species.**"

It transpired in subsequent correspondence with the Chief Scientific Officer that the Summit had in fact been conducted on the premise that: "**The challenge in the US is to push, but not so far as to be dismissed as way out of bounds**" and "**We wanted to go beyond IPCC, but not so far as to be dismissed, even if this might not portray the full risks**".

I responded strongly:

I deeply appreciate the political, economic, and national-security context in the USA, but find it absolutely unacceptable that boundary constraints imposed by that system should be covertly imposed on a scientific conference at this level. The conference was not convened to “push” the limits of what is acceptable to the Washington administration, but to assemble world-leading expertise to address the most serious issues in the dynamics of climate change at the highest possible level of competence.

The situation raises several critical issues. Strategically, if the scientific community fails to hold its ground, and waters down its understanding of reality to a level that is politically and economically acceptable, then it fails to provide any context in which significant learning can take place. It removes the tension between the skeptics’ defense of vested interests and the scientific delineation of a reality that demands significant change. In so doing it colludes in repressing evidence of system boundaries and constraints within which economic, technological, social, cultural and political decisions must be kept if environmental sustainability is to be achieved. The pressures to compromise are immense, and the costs of sustaining scientific integrity can be very high, but we do our civilization a great disservice if we abdicate our responsibility at this juncture.

It was my first dynamic encounter with the constraints experienced by leading climate scientists working within the limitations imposed by the current US Administration. It alerted me to the processes that were later to emerge in the political suppression of leading

edge science in the [wording of the Summary for Policy Makers](#) of the IPCC 4th Assessment Report: Work Group 1 (Climate Science).

Shortly after returning from Washington, I had the honour of delivering the same presentation as the “Aurelio Peccei Lecture” to the European Chapter of the Club of Rome in the Royal Academy of Brussels.

9: Convergent Ideas in Parallel Worlds

As colleagues alerted us to new research and recent publications, the structures and content of “Beyond the Tipping Point” were continually revised. A series of subsidiary papers, working notes and video mini-lectures were also produced:

- Exploring a new approach to [Climate Sensitivity](#) based on analysis of the Vostok ice cores
- An examination of [Malte Meinshausen](#)'s risk analysis of the policy goal of keeping global warming to a maximum of 2°C above pre-industrial levels
- A private paper alerting the Al Gore team to new issues in climate change that required attention beyond “An Inconvenient Truth”
- A working note was produced following a Faculty briefing for the Cambridge Programme for Industry with John Schellnhüber
- Contributions were video-recorded for inclusion in the All Party Parliamentary Group on Climate Change DVD for circulation to all members of Parliament and beyond
- Eight video mini-presentations were recorded and published via [YouTube and Big Picture TV](#)
- A detailed interview was recorded for a new Canadian climate documentary
- A working memorandum was produced following the European Corporate Leaders Group meeting in Brussels with John Schellnhüber, just in time to feed into the EU consultation with Heads of State
- A [summary of leading edge climate science](#) was produced as a resource for the Al Gore Training event in Cambridge
- An analytic note was submitted to the London Accord alerting the organisation to the implications of accelerating climate change for the institutions of the City
- A new approach to Climate Stabilisation based on radiative forcing rather than CO₂ emissions or concentration was submitted to the EFRA Committee to support its revision of the Climate Bill currently before the UK Parliament
- On the opening day of the G8 Summit in Heiligendamm I led the team giving the Presentation on Feedback Dynamics and the Acceleration of Climate Change to the meeting of the APPGCC in the House of Commons at Westminster, full proceedings of which will be widely published before the second reading of the Climate Bill in the early autumn.

Design, development, and activation of the Apollo-Gaia Project continued unabated through this time, and mid March saw a major revision of the whole structure. (Of which more in the two sections below).

As if working convergently in a parallel world, and in spite of his immense additional work load as Climate Science Adviser to President Angela Merkel in her leadership role with the EU and the G8, John Schellnhüber continued to use every opportunity to call for the

establishment of the “Manhattan Project of Climate Science”. One of his clearest expositions came in the video [interview for Big Picture TV](#) which he recorded in London on 6th December. The following is a transcript of the relevant sections:



Ten or fifteen years ago if you had mentioned this word of “runaway greenhouse effect”, people would have kicked you out of a meeting, particularly if had been a scientific meeting.... But very concrete scientific underpinning of all these ideas is that we clearly have identified on this planet now what we may call a “tipping point”. A tipping point is a large-scale region of the planet which could be flipped into a different state, a different mode of operation, by human interference.

So for example, the Amazon rain forest, according to one of the leading climate models in the world, operated by the Hadley Centre, will collapse by the year 2080 under human interference, under climatic change, if we stay on our unsustainable path.... Now if the Amazon rain forest breaks down, that would release a lot of extra carbon into the atmosphere. That means it is a self-amplifying global warming.

There are other effects, for example, ocean acidification. Because we pump so much CO₂ into the air, it goes into the sea water. It is like adding CO₂ to water to produce sparkling water – that is what is happening at a gigantic scale on this planet right now. This will deeply change the biological dynamics in the sea. It may for example mean that in the end less carbon can be taken up by the oceans. That would also be a so called positive feedback: the perturbation is amplifying itself.

Other things, the Indian Monsoon may change through global warming and through air pollution, that may have a major influence on the texture of the landscapes, and that may create some feedback effect. And if you now in a “thought experiment” put all these interactions and tele-connections together, and add them up, you could imagine a worst-case scenario where you would get a global warming that goes far beyond the five or six or seven degrees. That would create really a different world.

As I said, nobody has ever put that into a model and tried to calculate seriously the probabilities. My gut feeling is it certainly would not happen in the next decades. The question is whether it would happen in the next century. I still think the possibility is very, very small. But it is, you see, the biggest imaginable accident in the world system, like the biggest imaginable accident in a nuclear power plant. Unless we have analysed this probability, it is absolutely irresponsible to just go on doing what we are doing.

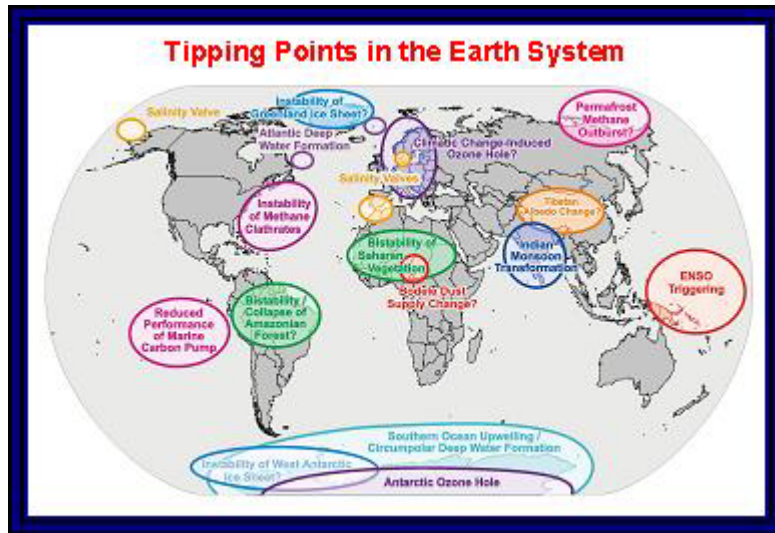
Science would have to analyse that immediately. Over the next five years we would need something like a “Manhattan Project”. Not for building a bomb, but for finding out whether this probability is zero. If it is not zero, if the probability might be just one percent, it would be absolutely scary and we would have to accelerate our efforts in order to abate global warming. This is the biggest question-mark.

We do, as scientists, a lot of detailed studies, of how certain farmers will be impacted by global warming. Whether they will have to switch from winter wheat to summer wheat, whether they could lose 10% of their income. But the biggest question of all, whether we could destabilise

the earth system as a whole, and that would be irreversible for ten thousands of years, this question we do not address yet. That is a crazy situation.

A week later John gave a masterful overview of the subject at the CPI Faculty briefing in Cambridge under the title: “Climate Science and the possibilities of Abrupt Non-Linear Change”.

He illustrated the set of local tipping points in sensitive sub-system behaviour, together with some of the accelerating feedbacks.



The cumulative effects of their interconnections drive an unstable scenario of complex unpredictability.



To me the great strength of John’s presentation lay in his illumination of the way the cumulative interactivity of local or sub-system tipping points pushes the global climate through the chaos window, past the chaos point and into a state of turbulence and unpredictability. The mounting stress on a set of human systems already close to breakdown would drive them beyond the limits of resilience with catastrophic implications.

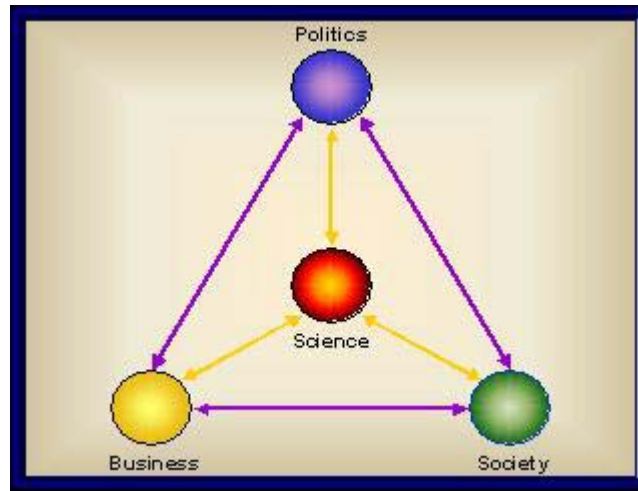
However, at another level, I found his presentation somewhat conservative. He appeared to take as given, the “policy goal” of attempting to keep average global temperature rise below 2°C, even though that near tripling of current temperature increase would push us well into the domain of dangerous climate change. His support for an eventual ceiling of CO₂ eq. concentration at 400ppm did not take into account mounting unease with current modelling of climate sensitivity which indicates the possibility that such a concentration might lead to an equilibrium temperature rise of up to 6°C and could not defend against runaway global warming. He did not appear to take sufficient account of the accelerating and mutually reinforcing impact of some of the major positive feedback dynamics. Taken together these reinforcing feedbacks are already accelerating climate change at a global level. They will eventually out-perform the limited damping capacity of reduction in anthropogenic greenhouse gas emissions. That is the critical threshold beyond which human ability to contain the effects of global warming is overwhelmed. All naturally occurring negative feedback mechanisms have already been neutralised.

John focuses strongly on the sub-system tipping points. They are comparatively local in effect and represent energy-redistribution dynamics. They are co-evolving complex systems responding (sometimes quite abruptly) to climate change at a global level. A higher order of system behaviour is, however, persistently missing or underplayed in his analysis, namely the thermodynamics of the global system taken as a whole. Non-linear change at this level provides the context within which the dependent subsystems are activated. In the video interview in particular John tends to lump together tipping points and feedback mechanisms. It would be clearer if sub-system tipping points could be distinguished from the threshold or tipping point of the whole earth system. Feedback processes (some of which are activated by the sub-system tipping points) combine to accelerate climate change at the global level, and in so doing drive the interactive set of lower-level changes.

Three months later John developed his presentation at the Brussels meeting of the EU Corporate Leaders Group. With a backdrop of images from the Second World War, he stated the need for the development of a culture of innovation like that in a total war mobilisation. Then, in later discussion, he added a slide from his recent presentation to the AAAS congress suggesting the establishment of “A Global Manhattan (or Apollo) Project”, to initiate the process of guided self-organisation.

John’s thinking had evolved from a suggestion for a scientific modelling capacity to test an hypothesis with low probability, to a call for global action to avert anticipated catastrophe. What was still unclear from his presentation was the mode by which such an initiative could be mobilised. To whom is the “call” directed? What institution (and under what circumstances) has the power and authority to launch the Project? Who should take responsibility to act in such a situation? There seemed to be assumptions about the ability of international institutions to act effectively and decisively to mobilise global action, which were palpably unsubstantiated. The initiative was caught in a “catch 22”.

Later in the same meeting, participants affirmed that: “It is absolutely essential that leading-edge science be effectively connected to the decision-making levels and action-generating initiatives in all three domains of business leadership, civil society and political policy-making. There is a need to develop a Master-plan to link leading climate change research directly to action and implementation.”



They went on to conclude that:

- The task is so great that global collective action is required.
- There is a very great challenge, but it is possible to make a difference.
- Need to establish a culture of innovation similar to that generated in a time of war if we are to push past the tipping point into systemic sustainability powered by renewables.
- Must now consider ourselves on a War Footing, with implications for industry and the civil society. There will inevitably be winners and losers.
- Need to launch a Global “Manhattan Project”, characterised by guided self-organisation.

Thinking might have been proceeding in parallel worlds, but it was now clearly coherent and convergent. It was time to move from consultation and planning to capacity building and action.

10: Evolution of Project Design

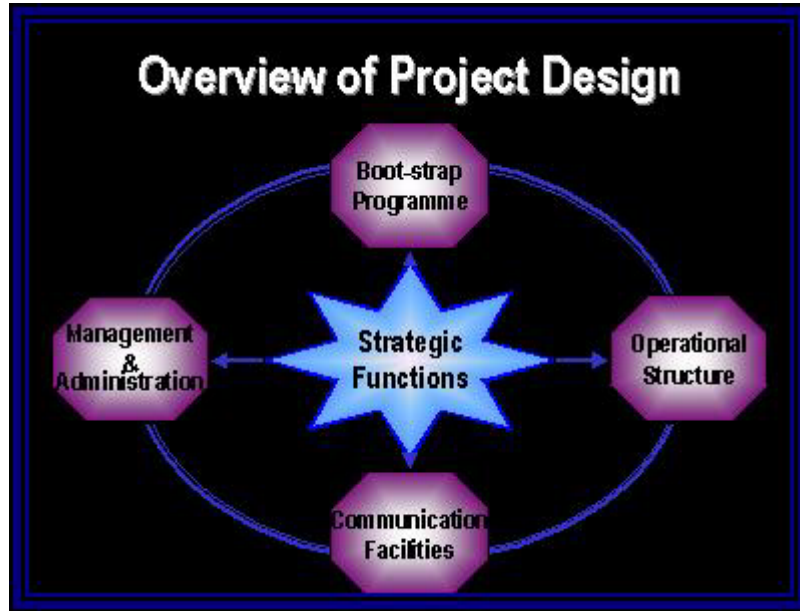
The twelve months following the EU Workshop on Complexity Science saw intense work on the design, organisational structure, functional delineation, and capacity-building of the Apollo-Gaia Project. A multi-layered, hyperlinked, PowerPoint system was developed to ensure that the file structures could cope with the process of continual emergent revision.

The “Mission Statement” was drafted, tested and worked through a series of revisions. The current version reads

To Avert the Impending Mass Extinction Event

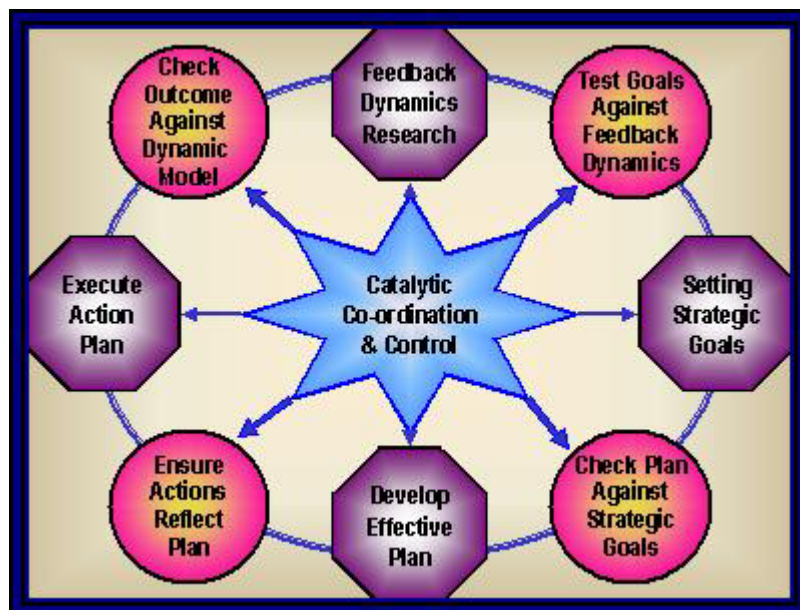
- To re-stabilise the climate system
- To limit increase in global temperature
- To minimise catastrophic climate change
- To optimise adaptation to unavoidable effects
- To sustain maximum bio-diversity

The **Institutional Design** raised exceptionally difficult issues. It was eventually decided that the situation required a high-level entrepreneurial initiative, that would then seek endorsement and support from a wide range of international institutions. The fundamental culture would be that of applied science, or action-research. The major features were co-ordinated to provide the **Overview of Project Design**.



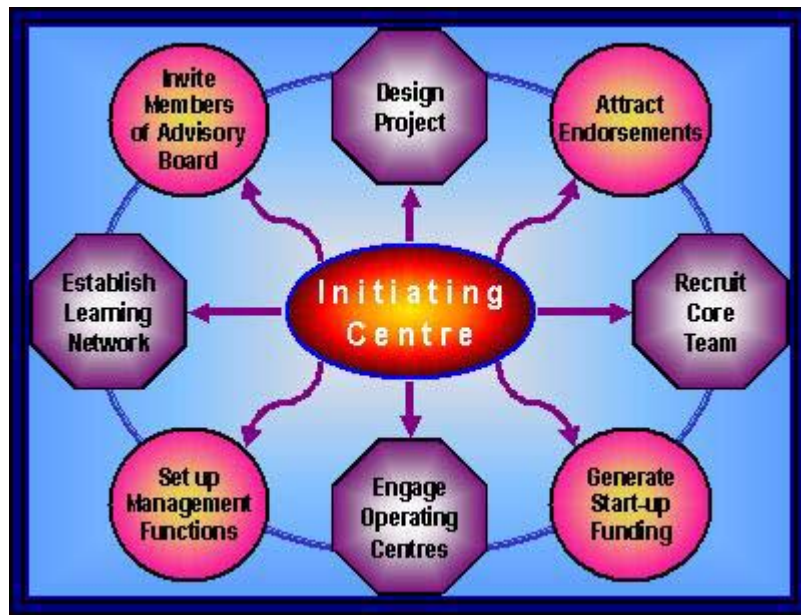
Overview of Project Design

The Project would be driven by the **Strategic Functions** required to execute the mission statement. The integrated assessment platforms underpinning the Feedback Dynamics Simulator would provide the “engine room” of the Project. The leadership style would be one of catalysis of an emergent complex learning net



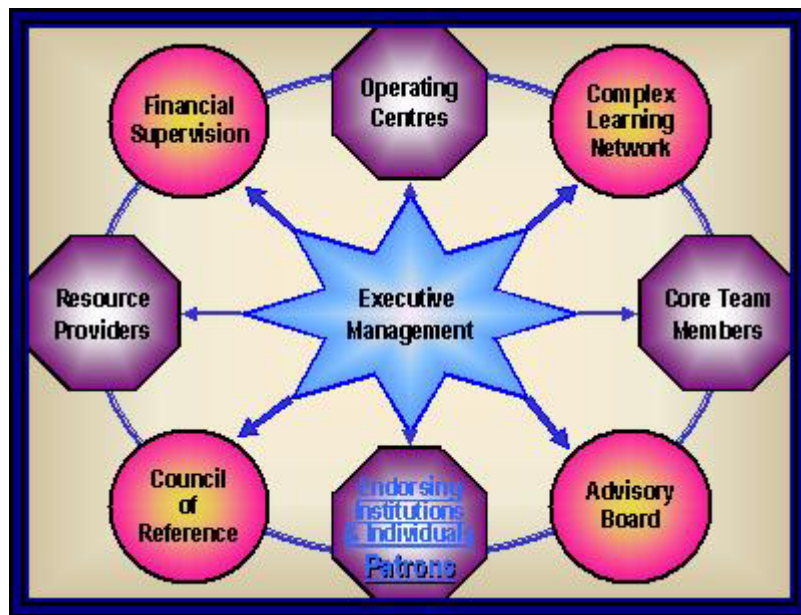
Set of Strategic Functions

A “Bootstrap Programme” was designed to trigger the required singularity in social space.



The Bootstrap Programme

The elements of the **Operational Structure** were assembled.

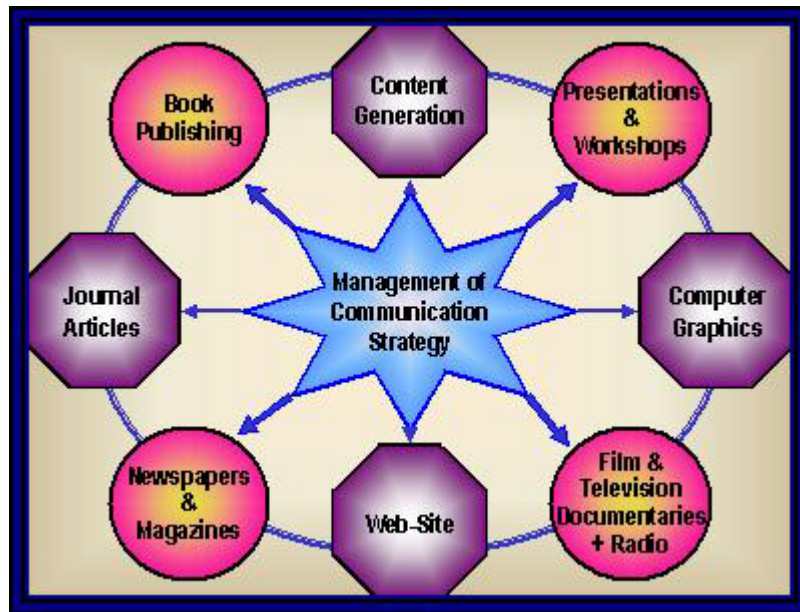


The Operational Structure

The working capacity of core team and set of participating institutions would be enabled by the provision of dynamic, web-based resources of a complex learning network.

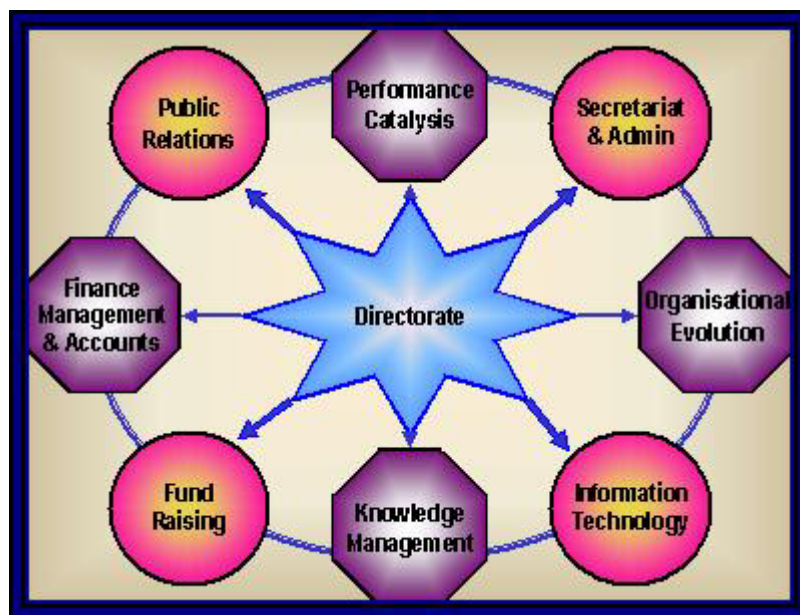
The structure of Patrons, Endorsing Institutions, Council of Reference and Advisory Board, serves to provide an enabling framework for the optimal execution of the Project task.

Task performance is also supported by a platform of **Communication Facilities**.



Communication Facilities

Finally the minimal but essential **Management Functions** were delineated



Management and Administrative Functions

The fine-structured detail of the various elements of the Organisational Design are the subject of a separate working paper.

11: Towards the Next Generation of Integrated Assessment Modelling

A strong working relationship was built with “[WhatIf? Technologies](#)”, the Canada-based systems modelling group whose experience, track record and software solutions offered the best available platform for the development of the “Feedback Dynamics Simulator” at the heart of the Project. The web-based protocols would enable active involvement by the international ensemble of participating institutions. It would provide an integrated environment for dynamic simulation of both natural and human systems. Focussed around the feedback dynamics in the bio-geo-chemical climate domain at a global level, it will also include the interactive responses of the human system, and relate to fields of population, energy, resources, manufacturing, transport, pollution, health, politics, economics and conflict. Information-flows, communication patterns, changing value-systems and psycho-social dynamics all need to be engaged in the emergent simulation environment.

Obviously no single institution can possibly have the resources or the multi-disciplinary expertise to carry such a programme. That is why the solution of an independent integrative hub has been adopted. The function will provide catalytic support to a distributed complex learning network of institutions, centres, teams and individuals, engaged in massively parallel processing in a culture characterised by both collaboration and competition. As the complexity, interconnectivity, interaction, resilience and redundancy of the Project evolve, it is to be expected that it will generate co-evolutionary characteristics, networked-creativity, self-organisation and high-level accelerated learning. The “chaordic” system is held coherent by commitment to the overall task of climate stabilisation, the avoidance of catastrophic climate change and the minimising of the most dangerous impacts.

It is hoped that the resources of Microsoft Research will be joined with those of leading graphical animators to generate a multi-dimensional visual user interface. This will combine with “user-friendly” interactive functions that will enable a wide range of stakeholders to test out practical and strategic actions and explore their consequences in real time. Feedback between users and developers will further accelerate learning within the system.

Delineation of the “Straw-Man” structure of required modelling elements is well advanced, and the initial operating budget has been estimated. The next step is the convening of a “Scoping Workshop” involving the staff of WhatIf? Technologies with the core team of leading specialists, mathematicians and modellers from the set of participating institutions.

David Wasdell
Director of the Meridian Programme
18th June 2007