Jeu-de-Joule: a conceptual earthly energy model

Anton W. Trijssenaar
Rijksweg 436, 2071 CT Santpoort, Netherlands
Tel: +31 23 5379153
E-mail: tryser@mac.com

Abstract

Present fuel prices trigger a renewed interest in the energy debate. The paper extends the debate beyond the present boundaries with a descriptive model that maps two parallel processes on earth: (1) the stocks & flows of energy, developing between the earth's main energy source: the sun, and its main energy sink: outer space, and (2) the accumulation of a collective memory on earth in the form of genetic information in living organisms (DNA), and in the increasing number of Bytes of information created by humans. The model makes it possible to "think through" the parallel developments of energy and information, and of the parallel growth of activities that goes with it. It also provides a tool to distinguish the stocks and flows of energy that drive the economic activities on earth. This may help the debate to go beyond the stage where all energy remains equated to non-renewable resources.

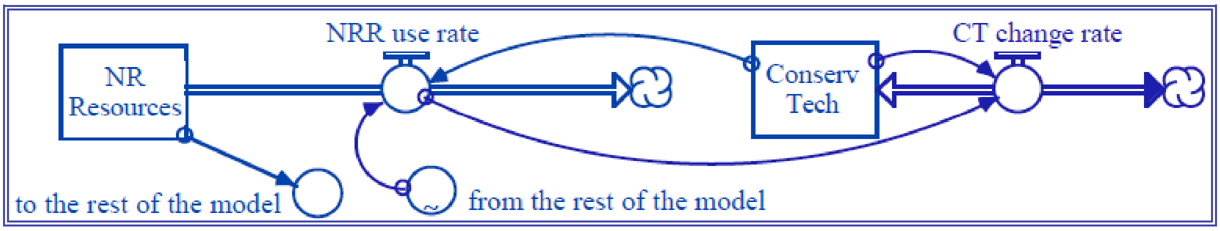
Limits to Oil Revisited

Developments of the last years have revived concerns about the limits of the world's oil reserves. The focus is now on the maximum rate of what can ever be produced. These are the "Peak Oil" questions that give further weight to the depletion theories of the nineteen fifties. At that time, the geophysicist Dr. M. King Hubbert predicted correctly that the oil production of the Lower 48 states of the USA would peak in 1970. (Deffeyes 2001, 2005)[1]

System dynamics communicates the Hubbert theory as a stock-flow process. (Radzicki 1997)[2] This method of conceptualising could further facilitate the discussion about peak oil and its repercussions. Yet a stumbling block is the way in which most models depict the conservation technologies. The World3 model (Meadows 1991)[3] is often referred to in peak oil circles. It depicts the conservation technologies as a stock that remotely affects the flow of non-renewables. With that, the energy that the earth receives from the sun remains equated to the non-use of non-renewable energy. This leads to the paradox that comfortable solar homes are called zero energy houses. And it feeds into the conventional mental model in which conservation leads to a zero energy economy and hence a zero growth economy.

Theories of growth

There is little common language with regard to a continued growth of (economic) activities. Sustainable development is widely associated with the report "Our Common Future" of the UN's World Commission on Environment and Development. However the report does not give a proven recipe for sustainable growth. Textbooks on macroeconomics maintain that there is no theoretical basis to guarantee that any economic optimum is associated with a stable ecological equilibrium. (Pearce and Turner 1990)[4] The single established basis for sustainable development is to be found in the micro economic theory on natural exhaustible resources. A review on the subject (Withagen 1984)[5] states that before 1970, modern economic theory showed almost no interest in exhaustible resources, and that it has been Forrester's book on World Dynamics that changed the theoretical interest in resource problems. It should be noted, however, that the World Model of Forrester's System Dynamics Group depicts the world as an *isolated* system in thermodynamic equilibrium: a system in which –in essence– neither matter nor energy is exchanged with the outside environment. The earth's influx of solar energy is represented in the model, not by the insolation itself, but by the earlier mentioned stock of conservation technologies.



World3/91 as isolated system with a simplified sub-model of Non-Renewable Resources and Conservation Technologies

Despite criticisms that the World model contradicts thermodynamic theories, it still forms the basis of the theoretical arguments in the sustainability debate. In a thesis on depletable resources and the economy, further extension of this kind of modelling was supported because: "However much economic processes may look like physical processes, the application of the two fundamental laws of thermodynamics in economics can be no more than the application of useful analogies of these laws, since economics is fundamentally different from thermodynamics." (Heijman 1991)[6]

A prominent critic of the use of equilibrium models in economics is Nicolas Georgescu-Roegen. (1971)[7] He argued that equilibrium models reduce the description of economic activities to the terms of the first law of thermodynamics. Within this framework, only the depletion of resources can be described, not the overall degradation that economic activities inflict. Earlier on, Odum (1963)[8] modelled the "ecosystem ecology" with due consideration to the entropy within ecosystems. Daly (1977)[9] was among the first to actually use Odum's approach as ingredient for a theory on steady state economics. The broad thrust of this idea has subsequently been used in many circles to demonstrate the need for a zero growth economy. However, the thermodynamics, that Georgescu-Roegen, Odum and Daly apply, can only describe a deterministic evolution, going from order to chaos. The creation of new forms of self-organisation is beyond the scheme of this field of physics. "Processes that did not fit this scheme were taken to be exceptions, merely artefacts due to complexity, which itself had to be accounted for by invoking our ignorance, or our lack of control of the variables involved." (Nicolis & Prigogine 1989)[10]

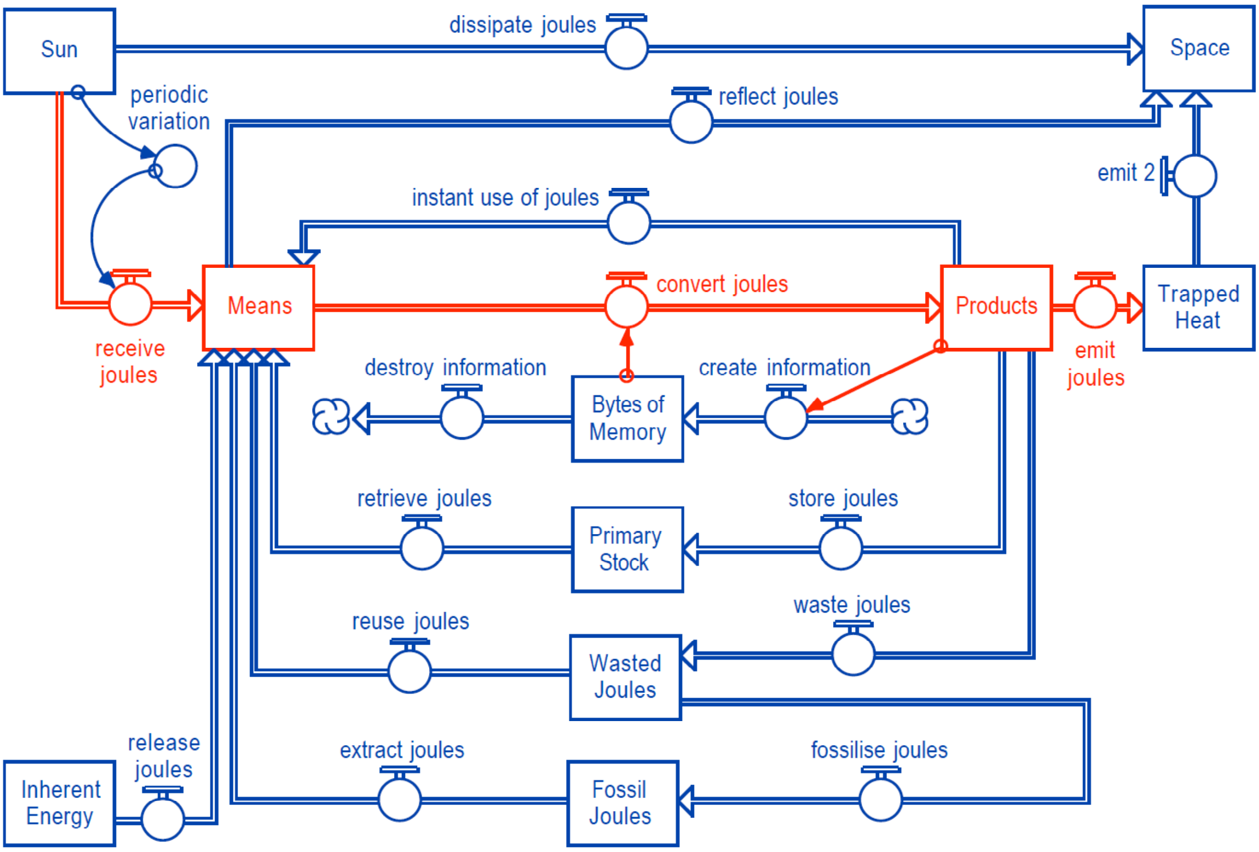
Evolution criterion of growth

Life on earth exists in a system far from thermodynamic equilibrium for which the theory of self-organisation in non-equilibrium systems applies. (Prigogine 1978)[11] Despite doubts about their validity, there are many adaptations of the theory outside physics and chemistry. Engelen and Allen (1986)[12], for instance, applied their version of the complexity theory to develop a regional energy policy model for the Province of North Holland, while at Prigogine's Institute for Physics and Chemistry in Bruxelles. In the planning stage of the project, in 1983, it was stated that: "The new concept emerging from the discovery of 'dissipative structures' by Prigogine in the physical science, offers us a new basis on which to understand complex systems, a basis capable of describing evolutionary change". Yet the model development only laid a necessary basis for further research. The *inherent* uncertainty in predicting self-organisation made the model as dependent on extrapolating the past as any other model, be it in a more sophisticated way.

At AD 2006, the theory of self-organisation in non-equilibrium systems is still confined to the chemistry labs. As a consequence, there is also no unifying theory of sustainable growth. Yet an "evolution criterion" that sufficiently explains the thermodynamic direction of life on earth seems the *principle of the least external energy dissipation*, as is, for instance, described in Thermodynamics of Biological Processes (Zotin (1978)[13]. It means that processes that emit the least energy for a given activity will have the most chance of survival in a common environment with roughly equal resources. Or, in other words, in the long run, evolution seems to prefer conversion processes with the highest overall energy productivity.

Jeu-de-Joule

The aim of this paper is to facilitate a meaningful discussion about sustainable growth, without having to use the physics of complex systems. To this aim, a conceptual model is made, called Jeu-de-Joule (with a wink to the French game "jeu de boule"). In a federation of energy models, Jeu-de-Joule (JdJ) would rank as the simplest possible model to describe the whole history of the whole earth. The model maintains a fair amount of conceptual integrity, so it can be useful on the global level, as well as on many local level situations.



Jeu-de-Joule: a descriptive conceptual model of the interplay between joules of energy and Bytes of memory on earth

Earth is a spherical shaped solar collector, just like the moon. Both receive an almost constant income of solar photons. The main difference is not the income, but the outflow of energy. At the moon, photons from the sun that are not directly reflected to space, will convert to heat, and those converted joules will almost all emit to space within 24 hours. The photons that planet earth receives travelled from the sun in 8 minutes and 19 seconds. About one third continues its journey directly as reflected photons. The remaining two thirds become part of a unique labyrinth of activities on earth: an energy / matter interplay like a giant pinball game.

What’s organising the self-organisation

To capture the self-organising act, the model will have to map the basic energy stocks & flows of the earth as a whole. In the model, joules on earth are either received from the sun, or released from the inherited joules in the earth itself, e.g. volcanoes, hot springs, and nuclear energy (or from other sources, e.g. gravitational force from the moon, which, for simplicity, are not taken into account, nor are incursions of mass out of space). Joules arrive at a mass/energy combination (*Means* of production) that is able to *convert* energy from one thermodynamic state to another. This process includes the direct reflection of sunlight. The conversion (or production in economic terms) leads to a subsequent thermodynamic state: *Products*. This conversion always involves the loss / reflection of joules to space. The remaining –productive– energy can go into different loops that end up again in the means of production, be it that some loops go via very long lasting storages. In the case of the productive part of electricity, for instance, there is an *instant use of joules*.

Means and Products store arbitrary large amounts of joules. Those amounts can be seen as energy plus mass equated to energy. They are basically immeasurable, and so is the actual rate of conversion. Yet the rate of the conversion activity can be approximated via other indicators if necessary. What is significant is what goes in and out of the different energy storages further down the system. These amounts will, somehow, have to be quantified in a follow-up phase of the modelling process. The same goes for the build-up of *Memory* on earth, but then of course somehow measured in Bytes of information. The basic premise of the model is, that growth cannot be modelled without a provision for the information build-up that governs the energy conversion activities on earth.

The enormous flow of solar income is not in itself sufficient to explain the growth that can be observed during the existence of earth. It is the ability to store and retrieve solar energy for various periods of time, that make-up the uniqueness of planet earth. The main physical enabler of this phenomenon is the earth’s mass, and especially its mass of water. Its influence is extensively studied in the present-day climate models. In the model, mass as such is not discussed, since energy conversions do not change the amount of mass on earth in a significant way. The amount of *Bytes of Memory*, on the other hand, does change significantly over time. The two sources for the memory build-up on earth are the genetic information in living organisms (DNA) and the replicable information produced by humans. The model enables to map the parallel development of Bytes of information and joules of energy. The assumption is that the memory build-up will proof to be the simplest possible indicator of the organisation of the self-organisation of energy processes on earth.

Convert joules means the activity that encompasses all the energy conversions on earth in whichever timescale and on whatever aggregated level. In the model it is assumed that each and every conversion (production activity) triggers a change in one or more of the stocks & flows of joules and memory. Equally, there are also links assumed between those stocks & flows and the conversion process. However, mapping all these links would not be helpful in this phase of the discussion. Instead we may, at first, just “think through” the causalities while walking along the geologic time line of the interplay between energy and memory.

The *periodic variation* of the earth’s solar income is included because of the time the model should be able to cover and the eras of glaciations that have occurred during that time. These variations are of particular interest since the intriguing observations about the human influences that may or may not have countered the effects of the present variation cycle. (Ruddiman 2005)[14]

The parallel storage of joules and DNA

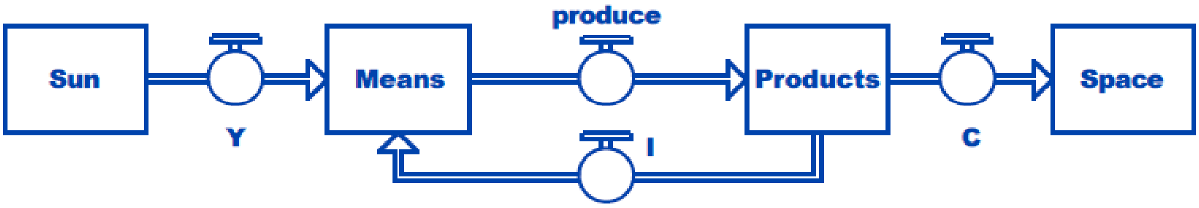
The earth's most basic storage capacity of solar joules is its mass of water. About 3.5 billion years ago this mass levelled off to a temperature in which the earth's organic evolution could start. From that time on the thermal energy in water (and air), maintained most of the primary (short to medium term) stock of joules of the earth. Based on the favourable water mass, a complex capacity arose in organisms that convert sunlight into hydrocarbons through photosynthesis: plants, algae, and some bacteria. This evolution of photoautotrophs manifests itself in mazes of layers of different niches, all resulting in more solar joules being trapped more productively. The basic designs for those energy-trapping activities rest in the DNA of the photoautotrophs, which collectively formed the sole content of the earth's memory till the era of even more complex life forms.

Some 2.5 billion years ago, the plant kingdom came against their limits to growth as a consequence of their waste product: oxygen. The result was the Oxygen Catastrophe[15]: a crisis that would be noticed in dramatic changes of the amount of stored memory and stored joules.

The oxygen catastrophe is an example in the earth's history where the amount of memory, encapsulated in DNA, increased the probability of a carrying capacity crisis. Yet at the same time the memory volume raised the probability of a DNA pool that –eventually– could overcome the crisis. In this case, that memory pool enabled the creation of species that use oxygen (and hydrocarbons), and produce carbon dioxide as a waste product that can again be used by plants. So it seems that more memory means a greater probability of both a carrying capacity crisis *and* a solution of that crisis. Bridging the two is of course the difficult part.

After the oxygen crisis, the synthesis of plants and animals triggered a renewed growth in the stocks of memory on earth. It also led to ever increasing stocks of joules, including the stock of fossilised joules. However, such fossilised joules could not be reused by the then living organisms and were in fact lost as a means of production in the conversion cycles. They became unused investment (dead capital), because no large-scale extraction by living organisms could take place. Such savings decrease CO_2 levels in the atmosphere, and the resulting loss of *Trapped Heat* would probably contribute to global cooling if this accumulation of fossil joules had continued. (Ruddiman 2005)

The process of excess savings has strong similarities with the world economy of the nineteen twenties and thirties. The model below has Keynes' model of renewed growth of the thirties (Y=C+I) converted into a mini JdJ model with all energy and information stocks crammed into the Means. Of course only after human civilisation started was there a memory pool that enabled the gradual use of the excess investments.



The Keynesian version of Jeu-de-Joule, where Y is the earth's income of solar insolation, C (consumption) is the rate of energy emittance to space, and I is the investment of energy back into the storage and conversion systems of the earth.

So, here again it seems, that the build-up of memory in DNA goes in lockstep with the build-up of a carrying capacity crisis. It is true that global cooling did occur during the earth's history as a result of periodic variations in the position of the earth versus the sun. Those cooling periods were exogenously induced. However, if the net accumulation of fossil joules had continued, it could have resulted in an *indigenously* induced global cooling because of the reduced CO_2 levels. The solution to this potential crisis came out of the human memory pool: out of human DNA at first, and later and more importantly, out of the build-up of human information.

In his book about "ploughs, plagues & petroleum", Ruddiman goes one step further. Here, he claims that the earth is at present in a period of low solar influx. He then poses the intriguing observation that this would have brought the earth into an era of global cooling, were it not that long-term human influences have counteracted this natural trend. So, in other words, humans started to consume excess savings of joules, with the unintended consequence that earth has not lost living organisms (and joules & memory) due to another ice age. For that to bring about, at least halve of the easy to extract fossil joules have been used. Such an amount of spending out of accumulated savings seems counterintuitive to the principle of energy productivity. Yet this view changes if we are indeed in an era of lower solar influx where the effects are being offset by human activity. Nonetheless, also Ruddiman has no doubt, that Earth Inc. is now vastly overspending the solar savings of the past, "leading eventually to levels of warmth not attained on earth for many millions of years".

Joules & memory

Before human civilisation, the memory stock of planet earth mainly consisted of DNA in living organisms, plus whatever memory there was in the living brains of those organisms. The knowledge about DNA surfaced only recently. The first Nobel Prize in the field was awarded to Crick, Watson and Wilkins in 1962. With that knowledge, the stock of DNA information now becomes more and more retrievable by humans, even after the original organisms are long dead.

Human civilisation itself started more than ten thousand years ago with the storage of reproducible information via written symbols. With it began a positive feedback between information and carriers of information. Paper, the printing press, film, radio, television, and now computers and computer networks, all created new generations of memory accumulations. This could happen because retrievals of bits/Bytes of information mostly end up as additions to the amount of memory that is already stored. Each successive generation of information-carrier produced a quantum leap in accelerating the rate and efficiency of this information replicating and memory generating process. These developments raised an astronomical stock of memory, which seems to grow at ever accelerating rates. Of course, Bytes of memory do not necessarily reflect the quality of the information that those Bytes contain. But that restriction has also been true for the amount of information in DNA in the past. In that past, carrier capacity crises developed at the tail end of a long build-up of (DNA) memory. Yet the expanded memory pool also provided the vital information to renew the self-organisation in a completely different direction. Now we witness an unprecedented step-change in the earth's stock of memory. This growth has initially been in lockstep with the rate of use of fossil fuels via a positive feedback between the accumulation of information (on how to use fuels) and the rate of usage of the fuels itself. At present, the growth of information is far greater than the growth in the use of fossil fuels. Still, the carrier capacity crisis, because of fossil fuel use, now becomes apparent in climate change and peak oil.

Use of the model

In a federation of energy models, Jeu-de-Joule would rank as both galactic, and minimalistic. It is an apparently all-encompassing model, yet without the structure or data to simulate the past or the future. But even in its present form, it already helps to provide a simple structure to tell the *story* about the parallel development of joules and memory during the earth's past. The model can help to think-through the parallel development of (1) the main energy stocks and flows of successive ecological and socio-economic periods in the earth's history, and (2) the growth of the amounts of Bytes of memory, both in the form of DNA and in the form of human information. The parallel tracks can then be used to distinguish a recurring relationship between the growth of memory and the crisis and subsequent solutions in the energy stocks and flows of the past.

Present developments show an astronomical growth of information accumulation on the one hand, and on the other a potential carrier capacity crisis from the overextended use of fossil fuels, and especially from the "addiction to oil". The lessons from the past indicate that self-organisation will –probably/eventually– lead to a more energy productive system. The past also indicates, that the core memory of the renewing system already exists in the present information build-up. Given that self-organisation is inherently difficult to predict, then the present memory pool should at least be regularly searched for the most energy productive pattern that is emerging.

The model could help to narrow the search field for the emerging options. With the model, it is easy to imagine that a direct, instant use of solar joules is by far the most energy productive option. Here, there is no long-term storage required, nor are transportation losses a big factor as long as the conversion processes are in close proximity. Plant leaves produce sugars that way, and are as such a very early example from nature. The Romans did it by using direct passive solar gains for home heating purposes. But only in 1954 arrived the first photovoltaic (PV) cells that could instantly convert sunlight into electricity for practical use. It is the youngest ready-to-use energy conversion technology on the planet, and it still has an enormous space for development ahead of it.

Using the model to select a range of options, one could, for instance, choose to apply the principles of passive solar urban design, not only for daylighting and thermal comfort in the homes, but also to provide the rooftops for PV when the technology is ready. (Trijssenaar 1997)[16] In the same range, one could choose to design homes and urban spaces as mobile work friendly as possible in order to bring solar electricity closer to productive usage.
The model helps in this respect, because it invites to think-through the accumulation of information in relation with solar electricity. The present build-up of information is driven by cramming more components onto integrated circuits (Moore's law). The worldwide proliferation of information and telecommunication technologies (ICT) redouble even faster since fibre optics and wireless technologies follow more or less the same Moore's law as computer chips do. With this proliferation, ICT is servicing a growing share of the human activities, be it work, learning, play, or care. Present options for mobile work mean that office jobs can now be done at so many places outside the formal buildings that it becomes feasible to shrink offices, or even to create officeless enterprises. Using wireless ICT in order to (tele) work will further granulate the world's information stocks and flows. It also spurs innovation into smaller and energy thriftier devices. This in turn, could bring the devices within reach of PV options. And as wireless ICT and solar electricity come closer together, so are the chances that their technologies profit from breakouts of Moore's law into nanotechnology.

References

---

[1] Deffeyes KS. 2001. *Hubbert's Peak: The Impeding World Oil Shortage.* Princeton University

Deffeyes KS. 2005. *Beyond Oil: The view from Hubbert's peak.* New York: Hill & Wang. Also: http://en.wikipedia.org/wiki/Peak_oil

[2] Radzicki MJ. 1997. *Introduction to System Dynamics.* http://www.systemdynamics.org/DL-IntroSysDyn/inside.htm

[3] Meadows D. 1991. *World3-tech.* Apple Macintosh Stella/iTink software version of the World3 model. Lebanon, NH 1992 by Barry Richmond, HPS/ISEE Systems, Inc.

[4] Pearce DW, Turner RK. 1990. *Economics of Natural Resources and the Environment.* 24, London: Harvester

[5] Withagen C. 1984. *Economic theory and international trade in natural exhaustible resources.* Tilburg University

[6] Heijman WJM. 1991. *Depletable Resources and the Economy.* (p.22) Wageningen: University of Agriculture

[7] Georgescu-Roegen N. 1971. *The Entropy Law and the Economic Process.* Harvard

Georgescu-Roegen N. 1976. *Energy and Economic Myths.* New York: Pergamon

[8] Odum PO. 1963, 1975. Ecology: *The Link Between the Natural and the Social Sciences.* Holt Rinehart and Winston

[9] Daly HE. 1977. *Steady State Economics: The Economics of Biophysical Equilibrium and Moral Growth.* Freeman

[10] Nicolis G, Prigogine I. 1989. *Exploring Complexity; An Introduction.* New York: Freeman

[11] Prigogine I. 1978. *Time, Structure and Fluctuations. (Nobel lecture)* Science, Vol. 201, No. 4358

[12] Engelen G, Allen PM. 1986. *Modelling the spatial distribution of energy demand for the Province of Noord Holland: towards an integrated approach.* Sistemi Urbani, 2/3, 1986, 241-261

Trijssenaar AW: project's co-ordinator for the Province of North Holland

[13] Zotin et al. 1978. *Theoretical Basis for a Qualitative Phenomenological Theory of Development.* In *Thermodynamics of Biological Processes.* Editors: Lamprecht I, and Zotin AI. 85-98. Berlin: Walter de Gruyter

[14] Ruddiman WF. 2005. *Plows, Plagues, and Petroleum: How Humans Took Control over Climate.* Princeton: University Press

[15] Wikipedia, February 2006. http://en.wikipedia.org/wiki/Oxygen_Catastrophe

[16] Trijssenaar AW. 1997. *Project MainVille 2000: Final Technical Report to the European Commission.* Project Reference Number: SE/254/92 NL