Escaping from limits to visions of space[1]

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Abstract Two discourses, each structured to a significant extent by a spatial conceptualization, are under consideration here: the discourse on nanotechnology and the discourse on sustainable development. Both of them refer to space as a resource and a matter of design, and both follow a scheme of oppositions, albeit the way they view these oppositions is completely different. Global limits to growth are contrasted with boundless spaces filled with possibilities for all humankind, and resource constraints with an excess of matter. This conceptualization coalesces in powerful visions of undiscovered, utterly unknown landscapes in the macro- and nanocosm. This visual and conceptual opposition of spatial limitation (*Be-grenzung*) and of spatial openness (*Ent-grenzung*) is a dominant feature in both the nanoworld and the green world of sustainable development. Both claims – for spatial limitation as well as for spatial openness – are continuously being reconfigured and readjusted in relation to societal, scientific and political issues. In this process the necessarily irreconcilable gap between recent configurations of epistemic and social facts and future possibilities is bridged with visions of space. Thus the spatial implications are of crucial importance for understanding both eco- and nanodiscourse. At the end of the paper it is argued that devoting more attention to the spatial implications of these discourses helps to rationalize and in a sense to restrain the excessiveness of nanovisions.

1. Ecotechnology and Ecoscience

In the following, the green world of sustainable development is subsumed under the umbrella of ecotechnology. In this general sense, ecotechnology principally develops local theories and practices and is referred to as applied research or "use-inspired basic research".[2] Good examples of this are restoration ecology, landscape ecology, and industrial ecology. Interestingly, explicit reference has been made to the latter in the context of recent activities around green nanotechnology. Industrial ecology is believed to afford a framework for sustainable development of nanotechnology.[3] This ecotechnology is contrasted with something that is tentatively called "ecoscience". Ecoscience is characterized by the development of more general concepts and theories, something that happens in, for instance, theoretical ecology, which generated the competitive exclusion principle, models about predator-prey relationships, as well as ecosystem theories.[4] Ecoscience also includes ecophysiology, parts of hydrology and geology, chemistry and physics, such as when it comes to the ecological study of ion exchange processes in soil or turbulent processes in running water. Ecotoxicological issues might also come under a more ecoscientific than ecotechnological perspective. In sum, one might say that ecotechnology is about developing

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1 Thanks are due to Ann Johnson for presenting a very first draft of the paper "limits to growth – limits of space" at the 2007 SPT conference in Charleston and to Alfred Nordmann, who helped to strengthen some arguments.
2 This is the so-called Pasteur's Quadrant presented in a book of the same name by Donald Stokes (1997).
3 In 2008, the *Journal of Industrial Ecology* offered a special issue on "what industrial ecology has to offer for an emerging technology and what that emergence has to say for the development of industrial ecology" (Clift/Lloyd 2008: 259).
4 Some of these theories and models originated from an applied context but evolved further and eventually followed instead the ideal of fundamental research.

tailored solutions and site-specific practices whereas ecoscience seeks to overcome the dimensions of case studies and instead to describe ecological phenomena in more general concepts, models and even laws.[5]

What do we gain by the conceptualization "ecotechnology versus ecoscience" and by the bracketing out of sustainable development?

First, it highlights the point that sustainability science is historically and epistemologically in line with other disciplines such as industrial ecology and bioengineering, as well as with space ecology or so-called cabin ecology. All of these are concerned with the role of space as a scientific object and thus with instrumentally and cognitively controlled space. Cabin ecology is a particularly interesting historical case. Although its heyday was in the 1970[6], it still comes up with spectacular projects from time to time, such as the Biosphere 2 project in the Arizona desert (1991), which is purported to be a simulation of Biosphere 1, "our blue planet". Originally the project was financed privately by multimillionaire Edward Bass and backed up scientifically by ecologists Eugene and Howard Odum. In scientific terms the project failed, because it was necessary to intervene to prevent serious harm occurring to the eight "bionauts" when the circular flow of elements did not function as expected. Although less well known, a third biosphere project, based in Siberia[7], exists in addition to Biosphere 1 and 2. It was built between 1965 and 1972 and still in operation. A simulated journey to Mars can be claimed to be an even more recent variation of the older cabin ecology program. The project has just been launched and is a joint effort on the part of the European and Russian space agencies.[8] The plan is to enclose a group of people in a cabin for about 520 days – safely buried beneath the Earth's surface. It is this kind of research which, even back in the 1960s, was "likely to draw more attention (and surely more money!) than biology", as the well-known ecologist of the time Margalef noted (Margalef 1968:1).

Second, the bracketing of the sustainability discourse within ecotechnology makes it easier to move diachronically as well as synchronically within a discourse in which the notion of limits to growth is the central driving force, scientifically supported by the theory of carrying capacity. In the 1960s, this hitherto technical model of space for astronauts was turned into a macroeconomic model. Carrying capacity played a major role in the model, and the limited nature of space as a resource was expanded to include other resources: "[T]he earth has become a single spaceship, without unlimited reservoirs of anything, either for extraction or for pollution, and in which, therefore, man must find his place in a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy" (Boulding 1966: 34). This "economy of the coming spaceship earth" also underpins those models that provided scientific back-up for the concerns expressed in the Club of Rome report on the "Limits to Growth", published in 1972. As a complete world model that can be characterized – and supposedly controlled as well – by a few parameters, Planet Earth is a form of excess that likewise emerges from the idea of using space to exert control. Thus "space" is not merely one of numerous physical parameters but is itself an analytical baseline and scientific object itself in ecotechnology.

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5 This comparison of "*technoscience*" and "*science*" follows a rather familiar scheme (Carrier, Cartwright, Hacking, Nordmann etc.). However, what is unusual is its application to the field of ecological research, where ecotechnology is in keeping with a technoscientific framework and ecoscience with science conceived in a traditional sense. Whether ecoscience then copes with science from a traditional perspective of philosophy of science is another question.

6 See, for instance, the Preface of W. B. Cassidy's (ed.) *Symposium on Bioengineering and Cabin Ecology* (Tarzana, Ariz.: American Association for the Advancement of Science, 1969); see also Anker 2005.

7 See for instance http://www.permanent.com/s-bios3.htm.

8 Mars project of the European Space Agency (ESA) in collaboration with the Russian Space Agency, see http://space.newscientist.com/article/dn11529.

2. Probing the distance between different modes of space

In eco- as well as in nanotechnology "space" is used in a metaphorical as well as in a very literal sense. Literal and metaphorical practices overlap to a certain extent, which sometimes makes it difficult (if not impossible) to draw a distinction between them. Ecological modeling of our overcrowded world becomes a blueprint not only for the – no doubt – technocratic management of the whole planet but also for our perception of nature. At the same time, landscapes – which are the paradigmatic means for representing nature outside ("true nature") are used as visual tools in highly sophisticated data transformation processes in nanotechnology. Moreover, interestingly enough, eco- and nanotechnology are not only intertwined with respect to visual and conceptual representations but also to persons and institutions. In what follows I will begin by giving an idea of these ambiguous practices and offer some examples of the occurrence and use of spatial concepts, focusing on the nanoworld but at same time keeping ecotechnology and, with it, sustainability discourse within our field of vision.

The first example is a literal reference to space: "There is a whole lot of land, especially with nanotech to make it worth something. It also seems likely that we could make a lot of really nice new land, recognizing what we have here to make more beaches, or we could go into space" (Henson in Crandall 1996: 132). This vision comes from H. Keith Henson, an American electrical engineer, and was published in a book with the telling title "*Nanotechnology: Molecular speculations on global abundance*" (1996). Henson is related via several patents to Eric Drexler, one of the best known and most controversial figures in the nanoworld, and by several memberships in academic circles and societies, for instance in the National Space Society, to the celebrated promoter of space colonies Gerard O'Neill. O'Neill organized the Society's first conference at Princeton University in 1975. The title of the conference was "Space Manufacturing Facilities" and Henson, together with his wife Carolyn Henson, presented a paper on "Closed Ecosystems of High Agricultural Yield". The formation of this social network and the relatedness of scientific and engineering issues demonstrate rather well that the constitution of ecotechnological and nanotechnological space is intrinsically connected.

Turning now to more metaphorical uses, the next example is still located in the border zone where the metaphorical mixes with the literal and the fictional with the factual. On December 29, 1959 – shortly before the environmental threat of Spaceship Earth was diagnosed and in the midst of the Cold War, Richard P. Feynman delivered his famous talk at the banquet of the annual meeting of the American Physical Society at Caltech. Feynman's famous "There's plenty of room at the bottom" speech was at once provocative and unremarkable. It was often (and still is) cited as one of the most important papers in the nano field, and in some accounts of the origins of nanotechnology Feynman is even referred to as a founding father[9]. What was so provocative about this talk? "What I want to talk about is the problem of manipulating and controlling things on a small scale. As soon as I mention this, people tell me about miniaturization, and how far it has progressed today. They tell me about electric motors that are the size of the nail on your small finger. And there is a device on the market, they tell me, by which you can write the Lord's Prayer on the head of a pin. But that's nothing, that's the most primitive, halting step in the direction I intend to discuss. It is a staggeringly small world that is below. In the year 2000, when they look back at this age, they will wonder why it was not until the year 1960 that anybody began seriously to move in this direction" (Feynman 1960: 22).

It is not "the importance of space" that makes Feynman's vision for future research stand out. This was a rather common figure in science and technology writing at the time, as will be

[9] A critical discussion of this historical reconstruction and its perception is given by Toumey 2005. The paper was published in the same journal (Engineering and Science) as Feynman's seminal paper.

shown in section four below. What is remarkable is the direction he proposed, namely, the move into a "staggeringly small" world of atoms and molecules and the search for the endless space there - rather than in the popular macroworld of outer space.

Going on from Feynman to talk generally about an open space of unbounded possibility as we find it much of the nanotechnology discourse puts us on the side of metaphorical practice: it is about the potential of building everything. Take, for example, this quote from chemist Roald Hoffmann: "Nanotechnology is the way of ingeniously controlling the building of small and large structures, … it is the way of the future, a way of precise, controlled building, with environmental benigness built in by design" (NSTC 1999: 4, emphasis added by A.E.S).

This leads to more specific visions of nanotechnological research that simultaneously distance themselves from and yet continue to embrace the notion of bottom-up manufacturing, which "should require less material and pollute less" (NSTC 1999: 8). The nano-constructed bottom-up world is said to be even more sustainable than the traditionally constructed top-down world ever could be. This is precisely one of the key messages of "Shaping the World Atom by Atom", a brochure published in 1999 by the U.S. National Science and Technology Council (NSTC), chaired by Mikael C. Roco and commissioned by President Clinton. It has been argued that this report would create a heuristic and rhetorical framework for the pursuit and perception of nanoscale research. However, two years later, in the NSET workshop report "Societal Implications of Nanoscience and Nanotechnology", Roco and his co-author Bainbridge support this view, saying: "…if the oceans could be used for growing biomass fuels or harvesting energy through nano-biotechnology advances, significant increases in global energy supplies would result. Systems life cycle thinking is particularly important in addressing the energy issue because of the coupling of energy and the environment. For example, if artificially engineered plants that produce ready-to-use energy become possible, at an early stage we will have to address issues akin to those now arising from the field of genetically engineered foods. But, properly designed, systems using such technologies as photovoltaics, engineered photosynthesis, factory process heat re-use, or agricultural fuel production could lead to a world of sustainable energy, agriculture, and climate" (Roco/Bainbridge 2001: 40).

Again, nanotechnology is presented not only as a crossover technology but in particular as an all-enabling technology. Interestingly enough the report speaks here of an "open system biosphere", which is a noteworthy rhetorical turn because it is, strictly speaking, an oxymoron: the biosphere is by definition a closed system in terms of resources such as raw materials or space – it is open only with regard to energy input (solar) and output (warming). That the authors choose this wording – it appears just once and without being specified – might be taken as an indication that they too are struggling with a conceptualization of nanotechnology as sustainable, given that this inevitably involves an antipodal conceptualization of nanotechnology and ecotechnology. The latter is portrayed as a preserving technology which has a vocabulary and various models of limitations (such as "limits to growth" or "carrying capacity"); this is quite unlike the former which, as already shown, offers more or less literally open spaces and endless possibilities.

3. Wrapping up the phenomenon "green nanotechnology"

Today, one might say that the 1999 NSTC report was successful in creating a heuristic and rhetorical framework. This is especially true of the claims of identifying nanotechnology with the objectives of global sustainability or environmental claims in general: Nano is definitely sold as an environmentally beneficial or at least neutral technology. Reports such as "*Nanotechnologies for Sustainable Energy: Reducing Carbon Emissions through Clean*

Technologies and Renewable Energy Sources" abound, in which the impact of nanotechnology on the road to sustainability is examined. In this report two points in particularl might be highlighted: “Over the next seven years, the highest growth opportunities will come from the application of nanomaterials to making better use of existing resources, rather than generating new forms of renewable energy.” And: “Current applications of nanotechnologies will result in a global annual saving of 8,000 tons of carbon dioxide in 2007, rising to over a million tons by 2014.”[10]

Another, certainly more sustainable, example is the Green Nano Initiative launched by the Woodrow Wilson Center (WWC), an American think tank[11] which, in April 2007, published the report “*Green nanotechnology: it’s easier than you think*”[12]. In the report’s introduction, Project Director D. Rejeski writes about emerging technologies thus: “As *instruments of sustainability* nanotechnologies can only develop further if we promote the dissemination of green nano practices and technologies on a broad basis” (Rejeski in Schmidt 2007: 3, emphasis added by A.E.S). At another point in the report, there is a quote from chemist J. E. Hutchison from the University of Oregon, who is also Director of the Oregon Nanoscience and Microtechnologies Institute’s Safer Nanomaterials and Nanomanufacturing Initiative: “Green nanotechnology is a terrific way to do nanotechnology responsibly” Hutchison in Schmidt 2007: 6). The linkage between green chemistry and green nanotechnology comes through clearly at several points in the report – not only in the form of institutional initiatives and individuals involved in both areas, but also in references to certain issues, such as the transfer of precepts from green chemistry to nanotechnology. Here, a model that has already been tried and tested – and in some respects successfully established – in society is transferred to a technology of the future. In the process, the latter is not only provided with a matrix for ‘responsible innovation’, as the phrase goes, but also benefits from being placed on the solid ground of proven experience. In this way the already existing technology, which can be recognized and exerts effects in society, is integrated into the “immanence of the discourse of the present” (Grunwald 2006: 61).[13] Just as discourse about the future is always simultaneously discourse about all things present, so too expectations and fears of the future, in other words “visions”, are a crucial factor in decisions made in the present.

So far it has been shown that activities framed as “green nanotechnology” are numerous and the distance between the rationale for sustainable development and the one for nanotechnology seems to diminish more and more. Nano fits perfectly into the sustainability discourse by revisiting the boundaries between science and society, respecting the limitations of natural resources and the scarcity of environmental goods. Nano promises to eradicate poverty by providing material goods – pollution free – to all the world’s people, to cure diseases, even to reverse global warming, and finally to solve the energy crisis.

Both - nanotechnology and ecotechnology - basically refer to the same concepts. But do they really tell us the same stories?

At first sight we would be inclined to expect completely different stories: Whereas sustainability discourse relies and insists on the scarcity of resources, including space, nano tells us a story instead about possibilities of avoiding – in a sense ignoring – the limits and

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10 See http://www.researchandmarkets.com/reports/c68307 (last accessed 04/06/09).

11 One part of the initiative consisted in organizing a series of workshops in 2006 and – in collaboration with the American Chemical Society – the “Nanotechnology and the Environment Symposium”.

12 The Center was established in 1968 by the American Congress as an ”international institute for advanced study, symbolizing and strengthening the fruitful relationship between the world of learning and the world of public affairs” (Schmidt 2007: 33).

13 Barack Obama’s election campaign is perhaps a good example of this kind of embeddedness, particularly in terms of ecological and social visions. The title of the campaign was, telling enough, “Building a 'green collar' economy via nanotech manufacturing climate solutions” (posted in November 18 2008 by Garry Golden (http://www.memebox.com/futureblogger/show/1307-barack-obama-building-a-green-collar-economy-via-nanotechnology-for-cleantech-energy-storage-and-electric-vehicles).

scarcity of this seemingly overcrowded world. Nano proposes a whole new world with visions that offer us "plenty of room" in which we may manipulate and even reconstruct nature's materiality – without being restricted by scarcity but rather by producing an excess of materials that are then to be tamed. The vision of an empty world is clearly at odds with the vision of an overcrowded tormented world, prompting many promoters of nano to claim the importance of nanotechnology for global sustainable development. This conceptual tension already came to light with the notion of the "open biosphere" (see above).

It seems that the limits of a bounded world with scarce resources celebrate their own excess when they are taken up by nanotechnology. This is an excess that lies in the endlessness of space as well as in the endless possibilities of recombination and control on the atomic or molecular level. This rather complex argument will be elaborated separately in section eight below. In the following, the ambiguity of spatiality in nanodiscourse will be discussed further in the context of an historical reconstruction.

4. Mediating space

What exactly was the provocation contained in Feynman's paper that prompted historians and scientists alike to make it the starting point of an "apostolic succession"[14] and Feynman the founding father of nanotechnology? Feynman claimed to see a "new field of physics", as he stated in the paper's subtitle. However, the really crucial claim contained in the paper was the existence of an empty and as yet unexploited space: he mapped out a vision of a "staggeringly small world that is below" (Feynman 1960: 22), exploration of which would dramatically transform not only scientific but also everyday life.

However, in a certain sense the title was also unremarkable, insofar as it drew on a notion of space as already mentioned in section two above. The same issue of the journal "*Engineering and Science*" that featured Feynman's essay presented a lead article on "the importance of space" and numerous advertisements such as the one by the "Lockheed Missiles and Space Division", which announces Lockheed's intention to "expand the frontiers of space technology". Thus "space" was a popular topos at the time, especially the colonization of space. Visions of constructing entire colonies in orbit or even colonizing Mars were not regarded as a subject for science fiction authors but as an explicitly scientific and widely discussed public program that gave rise to utopian projects on the future of Martian societies. In an age of an impending population explosion on Earth and a Cold War between the USA and the USSR[15] in outer space, the space program was similarly a highly competitive issue for politicians, military, scientists, and engineers.

Many areas of physics, the engineering sciences and even ecology were involved in the bustling research and development activities initiated by the space program, in which many companies were also involved. This omnipresence of hotly contested space is mirrored not only by the textual but also by the pictorial environment of the Feynman paper. The following analysis focuses particularly on the mutual semantic interaction between images and surrounding text.

The journal "*Science and Engineering*" in which the Feynman paper was published can clearly be regarded as one of the most prestigious and also most representative organs of the community. The visualization of visionary statements is a major ingredient in the

[14] "Apostolic succession. Does nanotechnology descend from Richard Feynman's 1959 talk?" asks Toumey (2005) while tracking the migration of Feynman's talk through nanotechnology's literature.

[15] Sputnik, the first ever satellite, was launched on October 4, 1957. This was an event that generated considerable fear as well as jealousy among the American public and within the government (for more details, see the book and film by Deborah Cadbury: *The space race. The battle to rule the heavens*. (Harper Collins 2006). However, the "Sputnik Crisis" was the catalyst for the space race and resulted in excessive expenditure and extravagant technology programs on both sides – a veritable Bataille representation.

advertisements that are contained in the journal and are even inserted at various points within the pages of Feynman's paper. The images are generally accompanied by aggressive slogans, where a play of words involving conquest and colonization is extremely prominent. The publicity for Lockheed's missiles and space division comes up with visionary sentences such as "(e)xpanding the frontiers of space technology" or "(s)uch programs (human engineering, man in space, space communications, space medicine, space physics etc) reach into the future and deal with unknown and stimulating environments" (Feynman 1960: 33).

Most of these statements are complemented and underlined by a quite explicit visual language. For instance, a text in which Western Electric describes a space program involving missile technology as well as miniaturization and automation technologies is accompanied by a photo collage showing the curved surface of the moon traced precisely by the trajectory of a brightly shining rocket. And we are told that NASA is leading "US ventures into space": "Through the resulting of the new knowledge and supporting new technologies we will gain a deep knowledge of our earth and nearby space, sun and the planets, and ultimately, planetary space and the distant galaxy." (Feynman 1960: 41).

Sikorsky Aircraft (Stratford, Connecticut) announces the "Space age challenge - It's literally all around you!"[16] and then moves from abstract space to a very earthbound issue, turning in a certain sense against the euphoria of outer space: "The word space commonly represents the outer, airless region of the universe. But there is quite another kind of 'space' close at hand, a kind that will always challenge the genius of man. This space can easily be measured. It is the space-dimension of cities and the distance between them … the kind of space found between mainland and off-shore oil rigs between a tiny, otherwise inaccessible clearing and its supply base, between the site of a mountain crash and waiting ambulance – above all, Sikorsky is concerned with the precious 'spaceway' that currently exists between all 'earthbound places'."[17]

This is one of the rare examples where the boom around outer space is bent over and re-centered on earth with the aim of trying to redefine and transform the concept of space – or at least to occupy it locally. Feynman worked a similar kind of transformation while occupying the "room at the bottom".

5. Space biology and cabin ecology

Amazingly, biology and, in particular, ecology (as the science that studies ways of controlling and managing the environments of living organisms) were at the center of this space program. This is documented by numerous activities in which ecology and space flight were blended together. Examples include a number of publications written in the style of the book "Space Biology. The Human Factors in Space Flight" (published in 1960[18]), numerous papers in journals[19], as well as several conferences dedicated to the theme of "*Human Ecology in Space Flight*" – this being the title of a conference organized by the distinguished Ecological Society of America in cooperation with NASA and others (Calloway 1963-65).

Now, why did engineers, policy makers and the military suddenly turn to ecology and what were their expectations?

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16 L.c., p. 57.

17 Ibid.

18 The serious tone and nonfictional deliberateness of the book (edited by James Stephen Hanrahan and David Bushnell) and the whole project may be underlined by a recent slogan that appeared on the publisher's website: "A New York based publisher dedicated to producing *serious nonfiction* by leading intellectuals, academics and journalists." (highlighted by A.S.).

19 Including the American journals Missiles and Rockets, Astronautics, American Biology Teacher or the British Interplanetary Society Journal.

It is again the desire to colonize Mars that paved the way: biologist James Lovelock (inventor of the Gaia hypothesis) was invited by NASA to participate in a scientific research program dedicated to searching "for evidence of life on Mars". His job was to design instruments capable of detecting the presence of life which could be sent on a spacecraft to Mars. This linking of outer and earth-bound space turned into a very successful research program – and remains so, given the Biosphere 2 project in the 1980s and the recent Mars mission launched by the European Space Agency, to name just two examples. Cabin ecology took off in the late 1950s with the aim of describing and constructing the environment inside a space vehicle. The idea was to build closed and well-defined spaces in which the environment found on the Earth's surface could be simulated. A legion of scientists and technicians worked on developing systems designed to ensure the circulation of air, water, and food. Ecologists were represented prominently in these projects. Eugene Odum, for instance, an influential scholar of ecology at that time, claimed that space exploration was "one of the most exciting new areas in science" generating necessary "*lebensraum*" for human evolutionary exploration (Odum 1971: 498). Ecologists thought that in order to build space cabins, all that needed to be done was to take "a little piece of this biosphere …" and try to build a wall around it. The elaborate design of this cabin would then be to construct a steady state ecosystem with a so-called "carrying capacity" for a few astronauts. The space cabin was to be a self-sufficient and stable ecosystem.

In the late 1960s the image of the Earth as a giant space cabin sailing through space with human astronauts on board came to dominate ecological debates. The visual representation of Earth as a space cabin was mainly inspired by the Apollo missions that took the first photographs of "our blue planet" from outer space. The discourse began to shift: the cabin model was no longer framed by the outer space program, but increasingly claimed by the environmental movement. By applying the space cabin model to the whole planet, the concept of Earth as a closed space came to the fore, together with all the other now familiar modeling parameters such as carrying capacity, stability, and closed chemical circuits. The space cabin became a rational and scientific means of managing the entire globe – a conceptualization in which humans had suddenly become a serious nuisance, polluting their cabin with carbon dioxide and producing unrecyclable waste. Humans became a form of "pollution" that was spreading "like a decease" and threatening to kill Gaia, as biologist James Lovelock puts it. In the 1970s the blue planet had become an overcrowded cabin and space therefore a scarce resource.

6. Brief note on the carrying capacity concept

The term "carrying capacity" was first used as far back as 1883 by engineer Mark Twain – better known as a novelist – to describe the maximum loads of people and goods on a steamboat (quoted in Anker 2007: 3). In the 1950s ecologist Eugene Odum used the term in a similar way to articulate a spaceship's ability to support a given number of astronauts. Economist Kenneth Boulding applied cabin ecology to macroeconomics and juxtaposed an unruly "cowboy economy" with a "closed" economic system. In the "*Economics of the Coming Spaceship Earth*" (1966) the concept of "carrying capacity" is of central importance and the idea of scarcity of space is now broadened to include other resources: "… the earth has become a single spaceship, without unlimited reservoirs of anything, either for extraction or for pollution, […] therefore, man must find his place in a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy." (Boulding 1966:34).

Boulding's concept of a closed economic system, also based on the concept of carrying capacity, became prominent in the famous report "The Limits to Growth", published by the

Club of Rome in 1972. “Spaceship Earth” was transformed into a model of the world in which a couple of variables characterized the totality of the planet. Environmental pollution, availability of raw materials, industrial production per capita and other easy-to-calculate variables all entered into the model. The report had an enormous impact on the political arena. Eric Drexler, well-known propagandist of tiny nanomachines, explicitly referred to the impact on his ideas exerted by the “limits to growth” notion. “*Unbounding the Future*” (1981) contains a very explicit discussion of environmental issues.

However, nano is not the first new and supposedly innovative technology to claim environmental benignness: current references to a “smokeless industry” bring to mind the “paperless office” argument which featured prominently in early discourse on the digital/information revolution – as part of a much larger argument that more efficient data processing and a general smarting up of all production and consumption would vastly increase efficiency and eliminate many forms of wasteful and excessive use of materials, transportation etc. And again, the timing is important, as is the close link between nano and the rise of environmentalism and sustainability discourse. This evolution from the conception of cabin ecology – being ready to explore outer space, spread plentiful resources and build new biospheres – to ecosystem ecology in the 1970s, where the concept of carrying capacity is extended to encompass Spaceship Earth so that *all* resources, including space, are scarce, raises questions concerning the relationship between the limits to growth, the availability of space and the excess of matter.

7. Deeper layers of the limits to growth

At this point Georges Bataille may be of help in further exploring how the notion of a limited Earth moves between and within ecology and nanotechnology, and how it can imply the transcendence of this limitation.

Georges Bataille was one of the first philosophers to take up the biosphere[20] concept and give it an important role in his philosophy namely in *La part maudite* (the accursed share), a text published by Bataille himself in the book series *L'Usage des Richesses* (The use of riches) in 1949. “Mais la sphère terrestre (exactement la biosphère qui répond à l’espace accessible à la vie) est la seule limite réelle” (Bataille 1949: 36).[21] Because Earth is exposed to a permanent input of solar radiation, there is always an excess of energy. As long as living organisms grow and proliferate, excess is minimized. This situation changes once the limit of growth is achieved: “La limite de la croissance atteinte, la vie, sans être en chaudière close, entre du moins au ébullition: sans exploser, son extrême exubérance s’écoule en un mouvement toujours à la limite de l’explosion” (Bataille 1949: 37).[22] “J’insiste sur le fait qu’il n’a pas généralement de croissance, mais seulement sous toutes les formes une luxueuse dilapidation d’énergie!” (Bataille 1949: 39).[23] In fact man has succeeded in extending the

[20] This concept was already in the 1920ies put forward by the Russian biogeochemist Vladimir Vernadsky, but remained widely unknown. In a footnote Bataille references explicitely Vernadsky’s book “La Biosphère” from 1929. This is all the more remarkable as the first two parts of the book are very poor in footnotes or bibliographical indications in general.

[21] ”Aber die irdische Sphäre (genauer die Biosphäre[7], d.h. der Raum, in dem Leben möglich ist) ist die einzige tatsächliche Begrenzung.”(Bataille 1975: 54). The original citations in French are always also given in a German translation in the footnote (Bataille, Georges: Die Aufhebung der Ökonomie. München: Rogner & Bernhard, München 1975). We decided to proceed this way, because most part of this book is written in German. At this point I wish to thank the editors to make this rather unusual translation game possible.

[22] “Ist die Grenze des Wachstums einmal erreicht, verhält sich das Leben zwar nicht wie Wasser in einem Wasserkessel, aber es gerät doch in Wallung: ohne zu explodieren, verströmt sich seine Überfülle in einer Bewegung, die sich immer an der Grenze zur Explosion befindet.“ (Bataille 1975: 56).

[23] “Ich insistiere auf der Tatsache, daß es, allgemein gesehen, kein Wachstum gibt, sondern nur eine luxuriöse Energieverschwendung in vielfältiger Form!“ (Bataille 1975: 59).

limits to growth by investing labor and technology, but at the same time he also has the greatest power among all living beings to consume the excess of energy intensely and luxuriously. These are the assumptions for further developing the role of richness and excess in his general economy. For Bataille the "limit to growth" is intimately connected to excess, which is an unavoidable aspect of all production. The question is ultimately less one of growth in a linear, extensive sense but more one of development and whether it is possible to have development at all without waste, excess, and abjection or whether these are inherent, inevitable aspects of all transformations of matter.

The centerpiece of Bataille's theory is a plea for the rehabilitation of richness: "Dans les conditions actuelles, tout concourt à obnubiler le mouvement fondamental qui tend à render a richesse à sa fonction, au don, au gaspillage sans contrepartie."(Bataille 1949: 44).[24] These practices of gift giving are part of a sovereign form of life[25]: this is how the excess of matter, and therefore richness, can be turned into acting liberally. However, because we are afraid to acknowledge the tendency towards excess in ourselves – something that is even embodied within us – we tend to counterbalance this unease by masking liberty with, say, demands for justice in the distribution of wealth. But the demand to raise living standards is not a question of justice, but of liberty. "Sous le masque de la justice, il est vrai que la *liberté* générale revêt l'apparence terne et neutre de l'existence asservie aux nécessités: c'est plutôt une réduction de ses limites *au plus juste*, ce n'est pas le déchainement dangereux, dont le mot a perdu le sens." (Bataille 1949: 44).[26]

Although we cannot pursue this theory further here, we should keep in mind the suggestion – especially with a view to the global sustainability debate – that it is appropriate to speak of liberty rather than of justice.

However, all this is suggestive of stronger parallels between the sustainability discourse in ecotechnology and nanotechnology: it is clear that nano-discourse does recognize physical limits to growth. What it does do, though, is open up new worlds beyond those limits. Also, both eco- and nanotechnologies seem to share a sense of the necessity (and possibility) of monitoring and eventually controlling every input and output of the production system, thus pursuing the impossible dream of production without waste, excess, or abjection – one that opens up new possibilities of guiltless consumption and abundance.[27]

"Le sentiment d'une *malédiction* est lié à cette double altération du mouvement qu'exige de nous la consumation des richesses. Refus de la guerre sous la forme monstrueuse qu'elle revêt, refut de la dilapidation luxueuse, dont la forme traditionelle signifie désormais l'injustice. Au moment où le *surcroît* des richesses est le plus grand qui fut jamais, il achève de prendre à nos yeux le sens qu'il eut toujours en quelque façon de *part maudite*."[28]

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24 "Unter den gegenwärtigen Bedingungen ist alles dazu angetan, die grundlegende Tendenz zu verschleiern, die darauf abzielt, dem Reichtum seine eigentliche Funktion, das Schenken, die Vergeudung ohne Gegenleistung, wiederzugeben." (Bataille 1975: 64).

25 For more details about the role of the gift in Bataille's reading see Kämpf (1999).

26 "Unter der Maske der Gerechtigkeit nimmt die allgemeine Freiheit allerdings das öde und graue Aussehen der den Notwendigkeiten unterworfenen Existenz an: es ist eher eine Reduktion ihrer Grenzen auf das rechte Maß, nicht die gefährliche Entfesselung – eine Bedeutung, die der Begriff verloren hat." (Bataille 1975: 65).

27 Indeed, it does more than this – for it holds out the possibility of recalling and reordering the waste/abjection of less efficient/more "primitive" industrial production.

28 „Das Gefühl einer *Verfemung* ist an diese doppelte Abwandlung der Bewegung gebunden, die die Verzehrung der Reichtümer von uns verlangt: Ächtung des Krieges in der skandalösen Form, die er annimmt, Ächtung der luxuriösen Verschwendung, deren traditionelle Form fortan Ungerechtigkeit bedeutet. In dem Augenblick, wo der *Überschuß* an Reichtümern größer ist als je zuvor, nimmt er in unseren Augen endgültig die Bedeutung an, die er in gewisser Hinsicht schon immer hatte, die Bedeutung des *verfemten Teils*." (Bataille 1975: 65).

8. Limiting or transgressing?

Drawing attention to the spatial implications of nanotechnology might help to rationalize and in a sense also reframe the debate about nanotechnology. It is the spatial conceptualization of nanotechnology in particular that makes it a field of technological and social innovation open to broader scrutiny and understanding. It is here that science fiction and science fact merge and coalesce in a border zone of inseparable practices, conceptualizations and visions. This border zone is as indispensable for the production of novelty and innovation as it is vulnerable to seduction by hype and hubris – it therefore needs to be observed attentively. Disentangling seeming necessities (cf. Nordmann 2007; Nordmann/Schwarz 2009), such as economic growth and technological innovation or global competition and local development, might be a strategy to accomplish these needs for more transparency and also for more democratic practices in political decision making about ways to inhabit nanotechnological spaces – in the present rather than in the future.

Looking at the history of space in ecotechnology reveals that there are parallels in the conceptualization of space in eco and nano: each contains an inherently built-in colonialist agenda and each started out with the goal of pushing back frontiers that had been taken as given: ecotechnology by taking flight into outer space and nanotechnology by finding its way into the room at the bottom – the inner space of matter.

Regarding the material excess of nanotechnology and the issue of growth, nothing new seems to have entered the stage with nano in terms of the dynamics of technical evolution since the European Industrial Revolution in the 19th century. Following Bataille's suggestion, excess is an unavoidable aspect of all production. It is business as usual in a more or less successfully implemented capitalist economy.

Equally, however, it might be worth taking the parallels between nanodiscourse and sustainability discourse as not just a rhetorical or even cynical game of becoming the best and fastest growing economy in the global race, supposedly for welfare and peace. Taken seriously, the two discourses seem not only to share a sense of the necessity – and possibility – of monitoring and eventually controlling the input and output of the production system, in short, the dream of wasteless production; rather, they both also refer to this necessity in the sense of a moral obligation to avoid waste and to limit excess. From this perspective it might be worth granting some credibility to the activities pursued under the banner of sustainable and "green" nanotechnology: it is a success of readjustment of values in science policy circles.[29]

Supporting the transformation from a "totalizing nano-space" to an "eco-techno-nano" space might help reduce the ambitious visions and lofty expectations associated with nanotechnology and might thus help gear the rhetoric of nanotechnology toward ecotechnological and therefore also sustainable development.

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29 STS scholar Andrew Jamison expresses this in the name of his ambitious program of "turning nano green": his agenda includes conducting research and educational projects that relate nanotechnology to social and environmental problems and that build bridges between nanoscientists/ engineers and environmentalists.

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