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Sustainable Management of Materials

- Applying Backcasting from Principles of Sustainability -

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Abstract

There is no such thing as a "sustainable" or "harmless" substance or material. From a sustainability perspective, the characteristics of materials must be evaluated in relation to the social, ecological and economic aspects by which they are extracted and used throughout the whole life cycle. Sustainable *management* of materials follows from the full context of sustainability. A framework for Sustainable Development, built on Backcasting from four Basic Principles of sustainability, is used to elaborate some guidelines for the sustainable management of materials. Without such a full systems-based approach and framework, it is difficult to…

- …ensure that all aspects of sustainable use of materials are considered from a full systems perspective,
- …enable decision-makers to assess current data and information on sustainability in a structure that is relevant for strategic decisions,
- …discover areas where more information is necessary – or unnecessary – for making relevant decisions,
- …focus problem-solving upstream at the source of problems, in order to design problems out of the system,
- …evaluate alternative materials solutions and visions from a strategic point of view, so that blind alleys can be avoided,
- …deal with tradeoffs in a strategic way,
- …build creative assessment and problem solving communities through shared mental models,
- …involve all aspects of business in a cohesive manner including: leadership, management, programs of activities, product-development, choice of materials, indicators etc.

The presented framework helps to imagine a future where the management of materials complies with the basic principles of social and ecological sustainability, followed by strategic measures and investments to arrive at that goal. Such strategies should build on a step-by-step approach, where each step provides the ground for the next, while bringing economic resources to the continuation of the process. The available possibilities are a combination of *dematerialization* and *substitution* of materials. There is a dynamic relationship between the two – dematerializations support substitutions and substitutions will prompt dematerializations. The opportunities are evaluated – under each of the four basic principles – by asking key questions. These key questions include meeting human needs in a social perspective, the relative scarcity of the respective materials in normal ecosystems, their biodegradability, the size of flows in combination with the degree of dissipative use, physical manipulation of ecosystems, and the costs for developing new and alternative methods in comparison to the costs for safe-guarding of traditional flows. All those aspects are allowed to interplay in a dynamic step-by-step changing process. There are many available checklists and manuals to monitor such transitions and to deal with the complexity and the trade-offs, but few have the added value of continuously keeping a valid definition of sustainability in sight.

1. Introduction.

CFCs eventually became doomed on the market. Ironically, they were initially introduced as environmentally perfect compounds due to their non-toxic and non-bio-accumulative nature.

There are many more historic examples of “safe” materials that have been launched large scale, followed by a late awakening and subsequent large costs to society and individual organizations. Examples are accumulation in biota of compounds such as PCB, DDT, and Methyl mercury, all causing negative biological impacts such as hampered fertility in mammals and birds. And there are examples that may be even worse through direct impacts also on humans, and that are now looming in the horizon – bromine organic anti-flammables in blood, endocrine disruption from plastic additives, antibiotic-resistant strains of microbes from antibiotics in biota, and hampered kidney function from Cadmium in foods – to mention just a few.

On the principle level, society is repeating the same kind of mistake over and over again. The industrial history of such events tells us a few things that should be kept in mind for future planning:

- Sometimes impacts occur through very complex interactions in the biosphere, and can generally not be determined before hand. At best, a certain impact can – after it has occurred – be clearly related to a certain activity or process. But even that is sometimes scientifically difficult, and the delay-times from the discovery of impacts, through scientific analyses, to legislation may be very long.
- These points *speak in favour of discovering principles by which management of materials can be determined upfront and upstream,* rather than after damage has already occurred downstream.

We have previously presented a framework for sustainable development[1,2,3,4]. The framework is built on (i) Backcasting from (ii) Basic Principles of Success.

(i) “Backcasting” means a planning procedure by which a successful outcome of the planning is imagined in the future, followed by the question: “what was it that we did today, that allowed us to get there?”
(ii) The term "Basic Principles of Success" denotes principles that:
- are general enough to cover the successful outcome (social and ecological sustainability) and to be independent of scale or field of activity,
- are concrete enough to guide problem analysis and creative solutions,
- are not overlapping, so that comprehension is supported, and so that metrics for the monitoring of progress can later be developed.

The methodology has been elaborated from “Backcasting from Scenarios”[5] – a planning methodology built on the envisioning of a simplified picture of success. A metaphor from games theory for this way of planning would be jigsaws by which a more or less specific picture guides the game and helps the player to deal with its complexity. To backcast from scenarios is a methodology that has some disadvantages for sustainable development. First, it is difficult to make many people agree on detailed descriptions of a successful sustainable outcome. Second, there is often a resistance to making very detailed plans in the light of the ongoing technical development that may subsequently change the conditions for the planning. Finally, how do we know if a detailed description of a sustainable enterprise or society really is sustainable? There is uncertainty. Therefore, we need basic principles for sustainability to scrutinize any scenario with regard to the complexity of its social and economical system dynamics.

To backcast directly from basic principles of sustainability resembles *chess* more than jigsaws. It is principles of success (principles of checkmate, or basic principles of sustainability) that guide the game. This is a dynamic way of planning, whereby each move takes the current situation of the game into account while at the same time optimising the possibility of winning – which can come about in many different ways. It is easier to agree on basic principles for success and some concrete steps that can serve as flexible steppingstones in that direction, than to agree on detailed descriptions of a desirable final outcome.

The basic principles of sustainability are elaborated as first order mechanisms – upstream at the first level of approximation – for ecological and social un-sustainability, followed by a "not" inserted in each principle. Finally, the principles have been put into a framework for sustainable development. Actions are launched – step by step – in a strategic way to serve as economically attractive steppingstones towards compliance with the sustainability principles. The framework is systematized as a manual for facilitation of brainstorming sessions and team-planning that is presented below (section 2.3, "A,B,C,D"- methodology).

Such work does not depend solely on altruistic motivation, and/or on saving money and resources by higher modes of "eco-efficiency". There are major business benefits for taking the full scope of sustainability into account. Non-sustainable development can be perceived as society entering deeper and deeper into a funnel of declining potential for quality of life and strong economic performance of society at large, as well as individual organizations. Pollutants and gases inducing climate change are increasing, productivity of ecosystems is decreasing – meaning larger resource throughputs for the same harvest or catch. At the same time, we become more and more people on earth. Per capita, the resource potential for living prosperous lives is systematically declining – it's like moving deeper and deeper into a funnel of declining resources[1,2]. To be, step-by-step, 'part of the solution' i.e. staying on the cutting edge towards sustainability, inherently means relatively smaller risks of being hit by the walls of the resource funnel. Hitting those walls will mean increasing costs for resources, waste-management, tax, insurance, legislation, bad reputation, head-over-heal corrections when concrete negative impacts surface, and to loose market shares to those who come up with the solutions at the cutting edge. A common counter-argument for proactivity is that the timing for such negative events is difficult to determine. This argument actually works the other way around. The business risk as regards dead-lines for inherently non-sustainable practices on the market remains with those who are economically dependent on them. You cannot change your organization's dependency on energy systems, infrastructures, technologies, management routines, and image over night. What we do today, influences our chances tomorrow…

In line with the above, the theme of this paper is to put the future vision of material-management – for any organization, municipality or nation – within the constraints determined by the basic principles of sustainability, and then to elaborate some common-sense conclusions and guidelines.

In section 2, the approach is presented. It includes an abridged version of the framework, a methodology for applying it, and some overall conclusions as regards materials. In section 3, the framework is discussed more in detail in relation to the choice of materials. The discussion is built on experiences from applying the framework on a number of issues such as Sustainable Product Development[6] and LCA[7] and contains a general discussion on dematerialization and substitution. There is a comment on the traditional Life Cycle Assessment from its perspective of "choosing between negative impacts" to the Backcasting perspective "choosing between stepping stones towards sustainability". Finally, a few concrete examples from international industrial application of the framework are presented. The latter includes the development of a Consensus document for Sustainable Farming in Sweden[8], new production lines of Electrolux[9, 10, 11], management of trade offs regarding mercury in low-energy lamps at IKEA[12], and elaboration of sustainable PVC[13].

2. Approach.

2.1 Elaboration of the principles of the framework.

A framework for planning in complex systems should keep five essential hierarchal levels apart and not confuse them with each other[3] – (i) the System, (ii) Success in the system, (iii) Strategies, (iv) Actions and (v) Tool-box. "Renewable energy", for instance, belongs to the (iv) action category, not the (ii) success category. Changing to renewable energy may lead to deforestation and is therefore not in itself a principle for sustainability. However, if sustainably managed, renewable energy may comply with principles for sustainability.

At the heart of planning and cooperation is level (ii) – success. It should inform strategies, actions and the design of our tools. It occurs through backcasting from success-principles, i.e. imagining that the conditions for success are complied with, and then proceeding by asking: "what shall we do now to optimize our chances to get there?"

In order to arrive at a principle definition of (ii) success – in this case sustainability – we must know *enough* about the (i) system – in this case the biosphere and the human societies and the interactions and flows of materials between the two. Since the concept of (ii) *sustainability* becomes relevant only as we understand the non-sustainability inherent in the current activities of Society, it is logical to design principles for sustainability as restrictions, i.e., principles that determine what human activities must *not* do in order to avoid destroying the (i) system. CFC's where "harmless" yesterday. What compounds are 'harmless' today, but not tomorrow? In what principle ways could we destroy the system biosphere/society's ability to sustain us? The answer to this question should be looked for *upstream* in cause-effect chains, where basic errors of societal design trigger all the thousands of negative impacts that later occur downstream. To correct errors at this systems level, upstream in cause-effect chains, is the only way of creating comprehension and not only coming to grips with current problems, but also to avoiding new problems that are looming in the future. At this level, complexity is as low as it gets. The comprehension that follows from understanding this level – "the basic rules of the game" – makes it possible to ask the right questions and to structure all the details in a way that makes sense from a decision making point of view. With an added "not", such basic principles for destroying the system would be conditions for the whole system (Biosphere and Society) – "system conditions".

The negative impacts related to non-sustainability that we encounter today can – on the basic principle level – be divided into three separate mechanisms by which humans can destroy the biosphere and its ability to sustain society:

1. A systematic increase in concentration of matter that is net-introduced into the biosphere from outside sources.
2. A systematic increase in concentration of matter that is produced within the biosphere.
3. A systematic physical degradation.

The system conditions specify how to avoid the destruction of the biosphere. Together, these first three basic principles provide a framework for ecological sustainability that implies a set of restrictions within which sustainable societal activities must be incorporated. Sustainability of society also depends on the maintenance and robust functioning of social systems – formal institutions as well as the informal structuring of civic society at large. This is not only to sustain society, but also to comply with the three ecological constraints. This requires a fourth basic condition that takes social sustainability into account:

The Four System Conditions

In the sustainable society, nature is not subject to systematically increasing…

I …concentrations of substances extracted from the Earth's crust,
II …concentrations of substances produced by society,
III …degradation by physical means

and, in that society. . .

IV…people are not subject to conditions that systematically undermine their capacity to meet their needs.

2.2. The implications of the System Conditions for planning

I. The societal influence on the biosphere due to accumulation of lithospheric material is covered by the first principle.
The balance of flows between the biosphere and the lithosphere must be such that *concentrations* of substances from the lithosphere do not systematically increase in the whole biosphere, or in parts of it. Besides the upstream influence on this balance through the amounts of mining and choices of mined minerals – including the respective mineral's or metal's relative scarcity in normal ecosystems – the balance can be influenced by the quality of final deposits, and the societal competence to safeguard the flows through recycling and other measures. What concentration can be accepted in the long run depends on properties such as ecotoxicity, here taken in a broad sense to include effects on geophysical systems, and bioaccumulation. Due to the complexity and delay mechanisms in the biosphere, it is often very difficult to foresee what concentration will lead to negative impacts. A general rule is not to allow deviations from the natural state that are large in comparison to natural fluctuations. In particular, such deviations should *not be allowed to increase systematically*. Therefore, what must at *least* be achieved is a halt to systematic increases in concentration of matter that is net-introduced to the biosphere from the Earth's crust. Depending on the characteristics of the respective substances and the recipient, the critical concentrations differ. This must be taken into account when we consider flows and develop monitoring schemes (see Section 3).

II. The societal influence on the biosphere due to accumulation of substances produced in society is covered by the second principle. This mechanism differs functionally from the first, since *production* refers to the combining of elements into compounds, whereas system condition 1 reflects net-inputs of elements.
The flows of molecules and nuclides that leak out from societal activities must not be so large that they can neither be integrated into the natural cycles within the biosphere, nor be deposited safely into the lithosphere. The balance of flows must be such that concentrations of substances produced in society do not systematically increase in the whole biosphere or in parts of it. Besides the upstream influence on this balance through production volumes and characteristics of what is produced, such as degradability of the produced substances, the balance can also be influenced by the quality of final deposits, and competence to safeguard the flows through measures such as recycling and thermal treatment. As with metals, the complexity of qualitative differences amongst various compounds creates high demand for a subtle guidance as regards the respective flows and practices (see Section 3).

III. The societal influence on the biosphere by physical means is covered by the third principle. It covers all kinds of destructive manipulation, displacement and harvesting of natural capital and natural flows within the biosphere.
This condition implies that the resource basis for: (i) productivity in the biosphere such as fertile areas, thickness and quality of soils, availability of fresh water, and (ii) biodiversity, is not systematically degraded by over-harvesting, mismanagement e.g. through monocultures or introductions or disruption of ground-water flows, or

displacement such as asphalting productive ecosystems. Again, the complexity is high, and we need a subtle tackling of this complexity as is illustrated in Section 3.

IV. Social dynamics and the production of services for humans are covered by the fourth principle. The challenge is in contributing as much as possible to the meeting of human needs in our society and worldwide, over and above all the substitution and dematerialization measures taken in meeting the first three objectives (see 3.1). The term "human needs" is here not only defined as basic physical needs such as food and fresh water, but all constitutional needs that that must be satisfied for humans to stay also mentally and socially healthy – protection, affection, understanding, identity etc[14].

Taken together, the first three system conditions define an ecological framework for any sustainable society, and the fourth principle is the basic social condition. It interacts with the other three in a dynamic way. If the purpose of society is to meet human needs –worldwide today, and in the future, while conforming to the ecological constraints given by the first three principles – then the use of resources must be efficient enough. So, it will not be sufficient to strive for the dematerializations and substitutions needed to comply with the first three system conditions. Social sustainability implies that we also need improved means of dealing with social issues like 'equity' and 'fairness' from the perspective of *human needs* (see above), and population growth. It is an inefficient use of resources, from the perspective of humanity, if one billion people starve and lack access to safe drinking water, while at the same time another billion use more resources for low-value activities such as sitting in traffic jams. These issues could begin to be addressed by keeping the basic needs of humanity in mind – all people now and in the future – when decisions are made.

Considering these basic principles of sustainability also makes it easier to draw the conclusions upstream in cause-effect chains, at the source of problems. Considering the principle of conservation of matter, what is introduced into society has a tendency to eventually leak out into the ecosystems. Consequently, from a backcasting perspective, questions like "do we use persistent compounds that are foreign to nature?" or "do we pay social costs for the purchase of materials in the developing world?" opens up the mind to a wide-screen perspective and should have at least as high priority as "do we emit ecotoxic substances?" The latter question only covers those substances and activities that have already surfaced as problematic, whereas the first type of questions completes the picture on the basic principle level, helping us to avoid new problems that will otherwise surface in the future.

2.3. The Framework

As a first step for an organization that wants to take sustainability as the starting point for planning, the system conditions must be "translated" into objectives that are relevant to the individual organization (the System Conditions are basic principles for the whole biosphere). For an organization that does not want to be a problem in the system, a logically and ethically relevant way of translation would be to add 'our contribution' into the phrasing of the system conditions:

The ultimate sustainability objectives of our organization are to:

1. …eliminate our contribution to systematic increases in concentrations of substances from the Earth's crust.

2. … eliminate our contribution to systematic increases in concentrations of substances produced by society.

3. … eliminate our contribution to systematic physical degradation of nature.

4. …eliminate our contribution to the undermining of human's ability to meet their needs worldwide.

Each individual organization must draw its own conclusions from these basic principles as regards problems, solutions, goals and sub-goals. The framework provides a systematic way of guiding this intellectual process, "A,B,C,D":

(A) The framework, with the system conditions, the step-by-step approach to comply with them, and the business motivation to do so in a strategic manner, is shared as a mental model for community building amongst the participants of a planning procedure ("playing the game Sustainable Development by the same rules");
(B) Assessment of "today", i.e. listing of all kinds of current flows and practices that are problematic from a sustainability perspective, as well as considering all the assets that are in place to deal with the problems;
(C) Creation of solutions and visions of "tomorrow" i.e. applying the constraints of the system conditions to trigger creativity, scrutinizing the suggested solutions, and listing of those and
(D) Making priorities from the C-list and launching of concrete programs for change i.e. action planning.

The latter point – D – provides the framework with its strategic component. When suggestions from the C-list are prioritized to be launched relatively early on (to serve as stepping stones for further improvements, just like when moves in chess are scrutinized as regards their potential as stepping stones to eventually complying with principles of checkmate) this is made by searching for measures that respond "yes" to the following three questions:

(i) *Does this measure go in the right direction as regards all system conditions?* Sometimes a measure represents a trade-off, i.e. goes in the right direction as regards one of the system conditions, at the expense of some of the others. Asking this question helps seeing the full picture, and finding complementary measures that may be needed to take all system conditions into account.
(ii) *Does this measure provide a steppingstone for future improvements?* It is important that investments, particularly when they are large and tie resources for relatively long time periods, can be further elaborated or completed in line with the system conditions, so that they do not lead into dead ends. An example would be to invest heavily in a technology that will cause less

impacts in nature, but without being capable to later adapt into complete compliance with the system conditions.

(iii) *Is this measure likely to produce return on investment soon enough to fertilize the further process according to (ii).*

It is the combination of "yes" to all the three questions that provide the strategic element of the framework. Each suggested investment is scrutinized as regards its potential to reduce impacts, be possible to develop further towards sustainability, and bring money to that development.

3. The framework, applied for the sustainable management of materials.

This section discusses more in depth some issues that are particularly essential when Backcasting from System Conditions of Sustainability is applied to materials: (i) The dynamic interrelationship between dematerializations and substitutions (trans-materializations), (ii) the need to complete traditional Life Cycle Assessments on some selected impacts with a full social and ecological sustainability perspective, as well as with a business strategic perspective (i.e. regarding materials as not only a provider of negative impacts but also as stepping stones towards sustainability, (iii) a few words about how to make priorities on the detailed level within the constraints provided by the framework and (iv) some concrete example from industry.

3.1. The dynamics of dematerializations and substitutions

Each of the system conditions represents a basic principle for sustainability. To comply with those in the future for the management of materials, requires combined dematerializations and substitutions (trans-materializations)[4]. This means that when society is managing materials in a sustainable way, minerals and metals (S.C 1), chemicals, and unintentionally produced compounds such as dioxins or nitrogen compounds from too intensive farming (S.C 2) are not increasing in concentration in the biosphere any more (i.e. all compounds have ceased to systematically increase, not only the ones that are currently causing identified impacts). Furthermore, renewable materials and foods from ecosystems are not over-harvested any more and/or purchased from poorly managed ecosystems or from companies that are not restoring ecosystems after strip mining, and infrastructures for transport are not growing systematically on behalf of productive ecosystems (S.C 3). Finally, materials are not wasted and/or made un-accessible by other means to people in less affluent areas of the society. Nor does their extraction, manufacturing, transportation, warehousing and marketing contribute to social behaviour or abuses which undermine peoples' capacity to live a fulfilling life (S.C 4). In turn, from an industrial perspective, this requires:

(a) *Dematerializations* by means of higher resource productivity and less waste. Dematerializations, such as recycling or improvements of design that allows higher material performance per utility unit, are not only helpful to avoid accumulation of waste (S.C 1 and S.C 2) and to reduce the pressure on productive ecosystems (S.C 3). To increase resource productivity and reduce waste is also a way of creating enough resources for people on the global scale (S.C 4).

(b) *Substitutions* i.e. many of the currently used materials and management routines are so problematic from a sustainability perspective, that it will be too expensive to safeguard them within the constraints provided by the system conditions. Consequently, dematerializations will not be enough to reach sustainability. Examples of such needed substitutions are some heavy metals that are normally very scarce in ecosystems like cadmium[15] (S.C 1), some chemicals that are relatively persistent and foreign to nature like bromine organic anti-flammables (S.C 2), and materials such as wood from poorly managed ecosystems or from a mining-industry that doesn't restore natural systems after strip-mining (S.C 3). Such flows should not only be dematerialised (which is necessary during a transition period) but in the end be phased-out and therefore substituted for by other materials and practices. Such new materials should be selected in a way which maximizes the benefits for a global society and presents such opportunities for future generations that will be easier to adapt within the constraints of the system conditions. In turn, this means that the flows of certain other materials may not be dematerialised, but in fact be *increased* in relation to today to arrive at a sustainable society. Still other materials may be scarce and foreign to nature, and yet their respective flows may be essential for sustainability and consequently need to be *increased* in a sustainable way i.e. safeguarded by extraordinary societal means and 'closed-loop' processes. Examples could be scarce metals in thoroughly recycled photovoltaic cells.

It follows, that the terms *Dematerialization* and *Substitution* are not only important one by one. They are also interrelated in a dynamic way that should be utilized for planning. The less degradable a material is, that is relatively scarce in natural systems, the more it must be safeguarded and/or dematerialised within the technosphere, since the leaked amounts that can be assimilated in natural cycles are so small. For scarce metals the assimilation is slow and occurs as sedimentation and biomineralization. For chemicals that are relatively persistent and foreign to nature, assimilation occurs also as degradation with relatively long half-life-times.

There are also economic relationships between the two. When very profound dematerializations are not enough, perhaps because materials are so relatively non-degradable and/or impact-levels in natural systems are already trespassed (e.g. CFCs or PCB's), substitutions may be relatively expensive early on. This is because the early production-volumes of the substitutes often are relatively small. Furthermore, they often require investments in new infrastructures. An example is the development of new coolants in refrigerators substituting for CFCs, as well as new refrigerators that fit those new coolants[9]. To make the *substitutions* affordable, the implementation of new technologies is often supported or made possible through various kinds of *dematerializations*, i.e. higher resource productivity and less waste within the new and more expensive production lines and products[4,6]. *Dematerializations support substitutions, and substitutions will prompt dematerializations*.

3.2. Life Cycle Assessments from a Sustainability perspective

Most industrial processes involve a whole series of events from the extraction of raw materials through transport, production, use of products, to eventually the disposal of the product itself. The picture gets even more complicated when socioeconomic aspects, such as the distribution of resources, wealth, and social impacts are included into the picture.

The term Life Cycle Assessment, LCA, denotes the sound objective of evaluating impacts of products and services from the "cradle" (resource extraction), through transport, production, and use, to the "grave" (deposit of waste). It is obvious that this leads to a more comprehensive view of the full impact than if only the product or service itself is evaluated. However, it is important to realize that the term LCA in itself doesn't say *how* the evaluation is done, or for what *purpose.* The most commonly applied forms of LCA are focusing on a selected number of ecological impacts that are accompanying a product or service from the cradle to the grave – e.g. "use of energy, and emissions of compounds causing green-house effect, acidification and eutrophy" – in order to compare different alternative products or services as regards their respective impacts. The purpose can be to market one product before another, or to try to foresee the impacts of alternative investments.

The ultimate applicability of LCA would be to support *sustainable development.* However, a recent Swedish study on the implementation of environmental management systems in Swedish companies, concluded that only 10% of corporations have allowed the results from LCAs to influence the measures taken[16]. The study didn't give any explanations to this, but it is possible already from a theoretical point of view to discover some presumptive reasons for a relatively low use of LCA amongst decision makers in business:

- The results from LCA, performed by scientists to evaluate a scientific question, may be too complex to interpret from a business perspective.
- Efforts to aggregate information on different categories of impacts into simplistic figures in order to approach the decision maker may be perceived as flawed.
- The impact-perspective may be too narrow, i.e. missing important aspects of sustainability such as social aspects, non-sustainable management routines of ecosystems, and non-sustainable emissions of compounds with not yet discovered impacts.
- Business-strategic points of view are lacking all together.

In conclusion: it cannot be excluded that the relatively low impact of LCA on business decisions is not only related to a relatively low *use* of the method by decision makers in business, but also to a relatively low *relevance* of traditional LCA for such purposes.

Many authors have discussed the complexity of, and difficulties related to, the assessment of sustainability impacts from industrial activities. Efforts have been made to streamline LCA to make the results easier to interpret[17] [18] [19]. However, there is a lack of a generally accepted framework for discussing impacts from a sustainability perspective[20], and there is a great need to apply a systems view to tackle the problems from a large enough perspective[21].

A methodology of LCA that builds on a sustainability perspective has previously been suggested[7]. It utilizes basic principles for sustainability as the guiding norm for the impact-assessments of the LCA. This paper also states that this perspective would open up for a more strategic approach of the LCA, but doesn't elaborate this idea.

The A,B,C,D methodology presented in Section 2.3 could be applied for "Strategic LCA":

A. <u>Overall idea</u>. Rather than comparing selected impacts during the life cycle of various alternatives, the perspective is to evaluate the alternatives from a strategic point of view: "how can these alternatives – technically and economically – be applied as strategic stepping stones towards sustainable practices"?

B. <u>Determining the current situation</u>. The previously described basic principles for sustainability are used as a "lens" through which today's impacts of the tested alternatives are determined. This will create a list of critical flows and routines under each of the four principle conditions for sustainability, and under each of the stages of the Life Cycle – from extraction of raw materials to disposal of product after end use. Together, these lists will comprise a pattern of qualitative "sustainability" impacts.

C. <u>Brainstorm, imagining a successful tomorrow</u>. Possible "solutions" to each of the critical practices listed in step B are estimated and listed. At this point, only theoretical restrictions are allowed to influence the flow of ideas – economical aspects and other aspects that determine what is "realistic" or not will be covered under D.

D. <u>Prioritizing of alternatives</u>. Various investment alternatives from C are now compared with reference to their potential to (i) serve technically as stepping-stones towards compliance with the four principles for sustainability, and (ii) give good return on investment, or at least being "economically feasible". The strategic thinking is given by the combination of those qualities.

This type of life-cycle perspective on materials and products would be "feasibility to develop towards sustainability" rather than "current impacts". It would complete traditional LCA with three added values: (i) the full sustainability perspective – including the social dimension – is taken into account, (ii) the strategic business perspective is taken into account, and this means that (iii) the businessperson is naturally made intellectual partner of the process (leading to a natural recruitment of responsibility in the business community) and (iv) data on various kinds of impacts – e.g. "waste of energy" and "emissions of green-house gases" – are not aggregated into simplistic figures that are difficult to defend from a scientific point of view. Experience shows that the business community has already started to make substantial progress as regards "win-win" solutions on the discovery of new materials that are ecologically less harmful from a LCA perspective, and we are currently designing a study to elaborate a systematic methodology based on the reasoning above[22].

3.3. Making priorities on the detailed level

On an overall level, the guidelines for selecting steps towards sustainable management of materials follow from the presentation above. Through the life cycle of materials – from resource extraction through transports, processing, use and disposal – the four system conditions can be used as a checklist to discover flows and management routines that are critical from a sustainability perspective. All critical aspects are listed, including questions when more information is needed (question-marks are also listed as "critical" aspects until there are answers) – for instance whether a substance is persistent and foreign to nature or not. Solutions are looked for in combinations of dematerializations and substitutions of each critical flow. When new products are planned, this way of thinking can inform all stages of a traditional product design cycle – from investigation of needs, through principle product, prototype, production and marketing[26]. Together with ten small to medium-size companies, we are currently developing this way of planning into a concrete tool for sustainable product development. An essential aspect of this study is to identify hierarchies of relevant questions under each system condition. Examples of such questions where given in section 2 and 3, and a more complete sample of relevant questions under each system condition is presented below in section 4, "Conclusion".

Sometimes there are many possible choices of materials that fit the presented framework, i.e. can serve as strategic steppingstones towards compliance with the System Conditions. How can we make priorities on an even more detailed level amongst those? *Is it doable to come up with checklists or manuals to support decisions beyond the overall framework with its guidelines for dematerializations and substitutions throughout the life-cycle of materials?* Given that complete compliance with the system conditions is the ultimate goal, on what grounds can trade-offs during the transition be managed, and how are uncertainties as regards compliance with the principles dealt with?

From other complex systems, such as chess, a couple of essential conclusions can be drawn in this respect: (i) Once basic rules are clear, the individual's potential to deal with trade-offs and to optimize chances in multidimensional and complex situations is very large, (ii) one of the most essential elements to utilize this potential of the individual, and to become 'professional', is *learning*, i.e. "getting experienced" and (iii) beyond a certain level of specificity, checklists confuse more than they help. This means that it is unlikely that very detailed checklists or manuals can replace any of the time-consuming training it takes to be a professional planner in a complex system. The reason is that when we prioritize between various strategic options for sustainable development, there are so many categories of criteria that are simultaneously in play, and that present themselves as "gray-areas", that each situation has a tendency to be "unique". Or in other words – attempts to come up with very detailed hands-on manuals that are layered on top of a framework of basic principles and their respective guidelines, have a tendency to result in so many feedback loops and footnotes and exceptions to the rule that they risk to confuse more than they help. A few of the most obvious and important categories of such criteria are listed:

1. Certainty of current data and information. This category varies between no knowledge about risks, or even about the very existence of a material or compound (meaning that there is zero influence on decisions) – to certainty, when the rest of the categories below are allowed to determine the outcome of planning. Between those extremes, a gray-zone will influence decisions in a relative manner. The "precautionary" principle has been launched to deal with this gray area, and is further informed by the categories 2 and 3 below.
2. Seriousness. This category is directly communicating with the first. Full knowledge on very serious social and/or ecological impacts provides one extreme, whereas full knowledge on completely benign impacts provides the other. Between those, we have the gray-area again, this time expressed as "degree of potential danger". The greater the seriousness of the considered impacts, the smaller the certainty needs to be to provide a rationale for undertaking proactive measures.
3. Urgency. The combined result of the first two categories is now integrated into the time-perspective. The extremes are: certain information on very serious impacts that will occur very soon on the one hand, vague information on very benign effects that might occur in the distant future, and the gray-area again – that has now become *multidimensional* – between those.
4. The individual player's relative contribution to the problem. This category reflects the moral dilemma. The greater an organization's contribution to a problem is, the greater are the ethical demands to do something about it. By natural reasons, this contribution is often determined somewhere on a gray-area. (Uncertainty here should not be used as a means of dodging responsibility. We are dependent on the system 'Society in the Biosphere' and should be prepared to be held accountable for the impacts we are inflicting on it).
5. The efficacy of possible solutions. This category can be subdivided into two interrelated categories:

- Technical potential of doing something about the situation. An actor may have access to effective means to deal with a problem, or not. The potential of providing a substantial contribution to a solution of a problem is a driver for activity, and vice versa. Needless to say, reality often presents itself somewhere on a gray zone again.
- The economic potential of doing something about the situation. Even if very effective measures exist, it is not certain that effective contributions to solving the problem are particularly attractive or even doable from an economic point of view. The extremes are net-incomes from the measures (when there may need to be no other drivers at all) vs. pure costs that are so large that the measure is not within the realm of a realistic budget.

6. Market Visibility. This category naturally varies between large and low visibility respectively. It also has a complex ethical dimension. If negative impacts are

considered, and if measures are not undertaken because of a high chance to avoid being caught, this is an unethical and ultimately flawed decision. The same may go for "lip-service" and "showing off" without any greater engagement in the real cause. If – on the other hand – high visibility of very good actions is allowed to influence decisions out of marketing reasons, it may be a good thing for not only the marketing, but also for the creation of role models and leaders within society.

7. Clustered risks. The list above is complex enough. Yet, it deals with the risks of only one identifiable material. In reality, sustainability-risks that are linked to individual materials and products present themselves as clustered risks in the whole Life Cycle Perspective – from resource extraction to end-use and disposal of products.

The conclusion is clear: it is not possible to create upfront comprehensible and easy-to-handle and very detailed checklists or manuals for the management of complex systems. Problems are generally multi-dimensional, and each dimension presents itself as gray-areas. Instead, the overall recommendation would be to (i) make principles for success very clear upfront, as well as (ii) smart overall strategies and guidelines to approach those principles (i.e. to apply a framework for decisions as a shared mental model amongst team-members), and then to (iii) get on with the learning, i.e. "playing the game" and getting experienced in seeing the large picture of the goal and selecting stepping stones in that direction. (iv) As the game unfolds, and the marginal costs in relation to utility and profit decreases (as more and more "low hanging fruit is picked"), it is likely that a need for more sophisticated tools will evolve. Examples are Management systems such as ISO 14001, LCA, Tools for Product Development, Purchase manuals etc. Those tools should be informed by the same framework as is informing the business program – (e.g. LCA, see section 3.2).

3.4. Three concrete examples from industry

Electrolux

An example from business is the way by which Electrolux phased out CFC:s. Introduction of HCFC would have meant an improvement in relation to CFC as regards effects on the ozone layer. However, Backcasting from the System Conditions led to the following questions: can we trust that HCFC will be used large scale in the future, and if not, would the developed technology for HCFC be able to apply for other substances that would be less problematic from the System Conditions point of view? The questions led to a completely different strategy towards sustainable use of hydrocarbons, using R134a as a flexible platform – or stepping stone – towards compliance with the system conditions, mainly the second system condition[9]. Though this compound has a relatively low degradability and doesn't fit the long-term goal in itself, it could be used as an incremental step in a new type of white ware. This white ware was designed – already upfront – to be adaptable to the next generation of degradable hydrocarbons that Electrolux developed thereafter. Electrolux was first in launching a whole family of freon-free refrigerators and freezers. The result was increased market shares in several important markets. They also presented a new overall business strategy, based on the system conditions[10]. It came to encompass a subtle balance of strategically chosen *dematerializations* and *substitutions* – for a number of production lines – under each system condition.

IKEA

An example of systematic planning of this type is the methodology by which IKEA introduced their particular brand of low-energy lamps on the market. The tradeoffs between wasting energy on the one hand and increasing pollution with mercury on the other, have different dimensions, and cannot be compared with each other by scientific means. The problem was dealt with through backcasting: in the future, lamps are very energy efficient, yet don't contribute to increasing concentrations of mercury *or any other pollutant*, yet make perfect business sense – also for the customer with the thin wallet. How could IKEA produce a flexible platform to arrive at this point? The story is presented by the head of environmental affairs at that time, Russel Johnsson:

"Replacing an incandescent lamp with a CFL will give considerable savings in energy consumption and electricity costs (roughly a factor 5) and a considerable increase in product life (factor 8-10). But the high price has been an obstacle for the private households to dare to prove these facts to themselves in practice. The typical price level in Sweden at the time was 120 SEK (15 USD) for a 11 W CFL (corresponding to 60 W incandescent lamp). The reason for the high price has evidently been that the lamp manufacturing giants have large production facilities for incandescent lamps and don't want to compete with themselves by marketing CFL's at low prices. The problem is even more complex, since CFL have higher mercury contents than incandescent lamps.

The trade off problem is between higher use of mercury (System Condition 1), lower expenditure of energy (mainly system condition 1 and 2), and higher costs for the lamps lowering their availability to the public (system condition 4). A more creative methodology than trying to estimate if the impacts outweigh the benefit, is to start the planning procedure from a point where the tradeoffs don't exist – backcasting from the system conditions to find a strategy to comply with them. In short, these were the moves that followed from this planning process:

1. We identified a producer who could provide a good enough combination of the listed criteria to serve as a platform. We wanted a good reliable CFL with max. 3 mg Hg (mercury)/lamp, which can be compared to the requirements in the European Union environmental labeling system for such lamps which is max 10 mg on the global market (factor 3). A Chinese manufacturer, outstanding both from product design and production technology points of view, could meet those requirements in the same time as he was competitive enough on price.
2. We let this producer, and his competitors, know that as long as he would be ahead of his competitors as regards price, energy expenditure and mercury contents, he would continue to make business with IKEA.
3. We also visited the supplier's RD&E department and discussed possibilities for further reducing of the mercury content and other potential environmental

improvements. We documented our visit on video – edited video cassettes were later distributed to all our Swedish stores.

4. We informed customers about the very serious environmental dangers with mercury and offered them to take back (free of charge) all their used light sources containing mercury to the IKEA stores. We made a contract with a major recycling company (RagnSells) to take care of all such returned light sources with mercury including all those we generate ourselves in stores, warehouses and offices. 98-99 % of the mercury is recovered by a specialist company in Germany. Together with SSNC we made a thorough review also of this company and documented also this on the video cassette mentioned above.
5. As a result of this campaign the private household sales of CFL's in Sweden have increased considerably. The competition had to decrease their prices. Our CFL sales have increased. We think that our campaign has been good for everybody – for the customers and for the country (we need to save energy in order to close down nuclear reactors) – except the manufacturers and importers of incandescent lamps. We calculated that, if every Swedish household replaced 20 pieces of 60W incandescent lamps with 11W CFL's, the resulting yearly energy savings would equal the production of one of the Swedish nuclear reactors.

Hydro Polymers

PVC has been the target for serious attacks from NGO's during at least two decades. It is often perceived as inherently non-sustainable due to mainly pollution throughout the whole Life Cycle of the material, but also as regards its contribution to the green house effect. Top management of Hydro Polymers, one of the leading manufacturers of PVC in Europe, decided to take on the intellectual challenge of scrutinizing PVC from a sustainability perspective. They are now pioneering a major sustainable development programme for the plastics industry using the TNS framework[13]. The report, entitled 'PVC - An Evaluation Using the Natural Step Framework' have been published jointly by The Environment Agency and The Natural Step in the UK[23].

The "B" and "C" analyses in the A,B,C,D of the framework – see section 2 – displayed a very wide window of opportunities. On the one hand, PVC has currently a number of positive qualities, also from a sustainability perspective, the most important of which are its long lifetime, lightness, weather resistance, low flammability, and the fact that it requires little maintenance and is easy to mould and colour. In turn, those aspects are built on the chlorine and the additives that make PVC currently the subject of heated debate. Backasting from compliance with the System Conditions made Hydro Polymers endorse the following challenges:

- The industry should commit itself long-term to becoming carbon neutral (System Condition 1 – plastics are currently produced with petroleum and natural gas as raw materials which amount to around 3% of the total use of these fossil raw materials).
- The industry should commit itself long-term to closed-loop system of PVC waste management. (System Conditions I-IV – in relation to a back-casting perspective,

today's use of PVC in society is highly wasteful, with around 50% ending up on land-deposits).

- The industry should commit to ensuring that releases (emissions) of persistent organic compounds from the whole lifecycle don't result in systematic increases in concentration in nature. (System Condition II.).
- The industry should review the use of stabilizers and additives consistent with attaining full sustainability, and especially commit to phasing out long term substances that can accumulate in nature or where there is reasonable doubt regarding toxic effects. (System Condition I – such compounds include heavy metals as stabilizers, and System Condition II – a number of organic additives that are persistent and foreign to nature. The latter are a matter of concern, because they might migrate out of the plastic into the environment; the additives are not chemically bound to the polymer but instead form an intimate physical mixture. PVC in itself is a stable matrix that doesn't shed PVC or other persistent brake-down products to the environment).
- The industry should commit to the raising of awareness about sustainable development across the industry, and the inclusion of all participants in its achievement.

The "D" part of the analysis, i.e. some early flexible steppingstones, can be exemplified by a number of "”low-hanging fruit" that are already picked and related to the long term goal:

1. Education of personnel throughout the Hydro factories in Europe, making A,B,C,D analyses part of the education and training, as well as a source of new ideas to top-management.
2. Dematerializations of flows, for instance making exothermic processes endothermic and utilizing scrap as raw materials.
3. Hydro is actively working to develop a new paste process involving a particle distribution that means less plasticizer needs to be added, and in which new types of plasticizers can be used (flexible platform). Hydro is also involved in international research on new PVC production methods and the development of new PVC materials.
4. Over the past few years, Hydro Polymers and the PVC processing industry have, in cooperation with stabiliser manufacturers, developed new, modern calcium/zinc stabilisers. A few product areas, such as cables, have already changed from using lead stabilisers to using calcium/zinc ones. (In the long run, as revealed by a backcasting analysis, also zinc is a doubtful stabilizer because it is relatively sparse in ecosystems in comparison to the societal flows of the metal[14]. This is a particular issue since zinc is purposely used by society in a dissipative way to protect iron from oxidizing, i.e. 'not contributing to materials from the Earth's crust increasing in the Biosphere' has made Hydro consider the calcium/zinc stabilisers as a platform for other solutions).

4. Conclusions

The theme of this paper is to put the future vision of material-management – for any organization, municipality or nation – within the constraints determined by basic principles of sustainability, and then to elaborate some common-sense conclusions and guidelines. Backcasting from Basic Principles of Sustainability is (A) a framework that covers relevant aspects of how to plan ahead in the complex system "Societies within the Biosphere". It brings a sustainability perspective to (B) analyses of current practices and materials, to (C) suggested solutions and visions, and to (D) the strategic evaluation of various solutions and paths to arrive at sustainability.

> A framework for Sustainable Development is neither an alternative to various kinds of facts and actions around sustainability, nor to various kinds of tools and concepts to deal with such facts and actions. All these things are as essential. A framework stitches it all together, creates comprehension, and provides direction to the planning. Without a full systems-based approach and framework, it is difficult to…
>
> - …ensure that all aspects of sustainable use of materials are considered from a full systems perspective,
> - …enable decision-makers to assess current data and information on sustainability in a structure that is relevant for strategic decisions,
> - …discover areas where more information is necessary – or unnecessary – for making relevant decisions,
> - …focus problem-solving upstream at the source of problems, in order to design problems out of the system,
> - …evaluate alternative materials solutions and visions from a strategic point of view, so that blind alleys can be avoided,
> - …deal with tradeoffs in a strategic way,
> - …build creative assessment and problem solving communities through shared mental models,
> - …involve all aspects of business in a cohesive manner including: leadership, management, programs of activities, product-development, choice of materials, indicators etc.

Applying the framework on materials shows that there is no such thing as "sustainable" or "harmless" substances or materials. An example is that one of life's basic building blocks – CO_2 – is currently threatening the world through climate change. The characteristics of materials must be evaluated in relation to how materials are *used* throughout the life-cycle. Sustainable *management* of materials follows from the full context of sustainability, and strategic measures and investments that are launched to arrive at sustainable management of materials should not only have focus on "side-effects of the current management of materials", but also on "future sustainable management of materials". In fact, both aspects should be simultaneously taken into account. Today's full knowledge on impacts and down-stream effects should influence the planning[24], and the same is true for the ultimate goal and each measure's ability to serve as a platform in that direction. To that end, the basic principles of future success for planning – sustainability – can be translated into basic objectives of any societal activity or organization at any scale, and those objectives can be arrived at through a combination of *dematerializations* and *substitutions*. There is a dynamic relationship between the two – dematerializations support substitutions and substitutions will prompt dematerializations. The bullet list above is covered by a number of hierarchically dependent questions that are exemplified under each objective below[25]:

The ultimate sustainability objectives of this organization are to…

I…*eliminate our contribution to systematic increases in concentrations of substances from the Earth's crust*.
Relevant questions are:
"Does our organization/project/ process/product systematically decrease its economic dependence on fossil fuels? Is our organization/project/process/product economically dependent on matter from the lithosphere? Can the same human service be delivered by less resource demanding means? Are any of the lithospheric materials, or their brake-down-products, currently increasing in concentration anywhere in the Biosphere? Regardless if we have data on accumulation or not, are the materials abundant in nature (for instance aluminum, titanium, iron) or scarce (for instance cupper, zinc, cadmium)?[14]. If we are dependant on scarce elements, are there alternative methods by which we could phase them out, or is complete safeguarding of the substances inherently a more realistic alternative for the future? Are resources containing mined materials saved throughout the life cycle or are materials used in a dissipative way? Are they recycled on a maintained quality level?

II… *eliminate our contribution to systematic increases in concentrations of substances produced by society*.
Relevant questions are:
"Is the organization/project/process/product today economically dependent on substances that are either produced on purpose, or unintentionally as pollutants? Are those substances, or their brake-down-products, currently increasing in concentration anywhere in the Biosphere? Regardless if we have data on accumulation or not, are any of the substances persistent and foreign to nature? If so, are their alternative methods by which we could phase out our dependency on such compounds, or is complete safeguarding of the substances inherently a cheaper alternative for the future?" Are resources containing chemicals saved throughout the life cycle or are materials used in a dissipative way? Are they recycled on a maintained quality level?"

III… *eliminate our contribution to systematic physical degradation of nature*.
Relevant questions are:
"Is the organization/project/process/product today economically dependent on activities that mismanage productive parts of the Biosphere, or infrastructures that require unnecessarily area-consuming transports such as long road-transports? What are the long-term possibilities as regards meeting the same human needs by less area-consuming and/or less biodiversity damaging alternatives? Are resources

from productive ecosystems saved throughout the life cycle or are materials used in a dissipative way? Are they recycled on a maintained quality level?"

IV*…eliminate our contribution to the systematic undermining of people's ability to meet their needs worldwide*.
Relevant questions are:
"What human need is addressed through this material choice? In what way is the organization/project/ process/product today economically dependent on using a large amount of resources in relation to added human value? Can this need be addressed in other ways, e.g. substituting products for services? Are social costs paid for throughout our value-chain, also amongst suppliers from developing countries? Are human rights violated at any region or site where we have a direct or indirect influence? Can this influence in any way be turned into long term opportunities to meet the same human needs by much smarter and more sophisticated methods? Are resources saved and recycled throughout the life cycle to increase the chances for economical availability in a large enough perspective in space and time – globally now and in the future? Do our activities support, directly or indirectly, regimes or social organizations whose activities undermine the health and well-being of others? Will our actions damage the cultural diversity of society? Are we helping or hindering other people to act sustainably?

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References

1 Robèrt, K-H. **Den Naturliga Utmaningen**. ("The Natural Challenge"; In Swedish, Translated to Japanese) Book. Ekerlids Publisher 1994.

2 Holmberg, J. and Robèrt, K.-H. 2000. **Backcasting - a framework for strategic planning**. Int. J. Sustain. Dev. World Ecol. Volume 7 (4) 2000, 291-308.

3 Robèrt, K.-H.2000. **Tools and concepts for sustainable development, how do they relate to a framework for sustainable development, and to each other?** The Journal of Cleaner Production. Volume 8 (3) 2000, 243-254.

4 Robèrt, K.-H., Schmidt-Bleek, B., Aloisi de Larderel, J., Basile, G., Jansen, L., Kuehr, R., Price Thomas, P. Suzuki, M., Hawken, P., and Wackernagel, M. 2001. **Strategic sustainable development – selection, design and synergies off applied tools.** The Journal of Cleaner Production, 10 (2002) 197-214.

5 Robinson, J.B., 1990. **Future under glass — A recipe for people who hate to predict**, *Futures* October 1990.

6 Byggeth, S.H. Karlskrona univ. And Chalmers univ., Göteborg: **Integration of Sustainability Aspects in Product Development**. Thesis for the degree of licentiate of engineering. Göteborg univ. 2001. ISSN 0280-2872.

7 Anderson, K., Høgaas, E.M., Lundqvist, U. And Mattsson, B. **The feasibility of including sustainability in LCA for product development.** J. Of Cleaner Production 6 (1998) 289-298.

8 LRF, 1997. Environmental report for Swedish Agriculture 1996/97, Federation of Swedish farmers and Statistics Sweden, Stockholm, Sweden.

9 Robèrt, K.-H., 1997, **ICA/Electrolux – a case report from 1992**, Presented at: 40th CIES annual executive congress, 5-7 June, 1997, Boston.

10 Electrolux 1994. **Electrolux annual report** 1994.

11 Leif Johansson, Electrolux CEO at the time, personal contact.

12 Russel Johnsson, IKEA Head of Environment at the time, Personal Contact.

13 www.hydropolymers.com

14 Cook, D; Oldmark, J; Willis, P; Robèrt, K-H. 2002. **Strategic Planning for Social Sustainability.** GIN 2002, Corporate Social Responsibility - Governance for Sustainability. June 23-26, Gothenburg, Sweden.

15 Azar, C., Holmberg, J., and K. Lindgren, 1995. **Socio-ecological indicators for sustainability**, *Ecological Economics*, **18**, 89-112

16 Zackrisson, M., Enroth, M. abd Wilding, A. 1999. **Environmental Management Systems – Paper Tiger or Powerful Tool (In Swedish)**. IRIS-Miljö. ISSN 1402-5361.

17 Graedel, T. E (1998) **Streamlined Life-Cycle Assessment**. Upper Saddle River, NJ: Prentice Hall.

18 SETAC (1997) **Simplifying LCA: Just a Cut?** Brussels, Belgium: Society of Environmental Toxicology and Chemistry – Europe.

19 Todd, J. A. **Streamlining Environmental Life-Cycle Assessment**. New York, USA, McGraw-Hill. 1996, pp. 4.1-4.17.

20 Brattebø. 1996. **Industrial Ecology and Sustainable Product Design**. Presented at Norwegian Academy of Technological Science Seminar, 1996.

21 Bucciarelli, L. 1998. **Project oriented learning as part of the curriculum development**. NTVA seminar: Industrial Ecology and Curriculum, 15-16 October 1998 . (Norway: The Norwegian Academy of Technological Science).

22 Professor Yamamoto, Tokyo University, personal communication

23 PVC - **An Evaluation Using the Natural Step Framework**, http://www.naturalstep.org.uk/2020_top.html

[24] Geiser, K. 2001**. Materials matter**. Book, MIT press, 311-312.

25 Byggeth, S.H. Karlskrona univ. And Chalmers univ., Göteborg: **Integration of Sustainability Aspects in Product Development**. Thesis for the degree of licentiate of engineering. Göteborg univ. 2001. ISSN 0280-2872.