INTRODUCTION TO LIFE SUPPORT SYSTEMS AND SUSTAINABLE DEVELOPMENT

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Abstract – Present social metabolism is based on resource depletion and environmental destruction. This is a non sustainable situation. Sustainable development implies a new paradigm based on scientifically sound concepts as exergy and exergy based methods which are presented here. With these tools the present dilemma will be dissected into manageable components and an effective strategy can be developed and put into action. Present resource management may not look so pleasant with these tools. However, this approach is necessary if we are serious about sustainable development. The physical concepts and methods used are well established and recognized, thus, they can easily be brought into operation with present social management. This offers a new direction, a paradigm shift including moral obligations and scientific responsibility. This development will be in harmony with a sustainable ecological development. Fundamental physical limitations and environmental consequences will be pointed out. Tools suitable for a sustainable development will be presented and applied to real processes. The message to society is clear: meet the challenge ore die. Cultures that do not represent sustainable development will be replaced. By the use of proper concepts and methods the building of sustainable development will turn out to economic and social acceptable.

Content

1 INTRODUCTION

The future of life on our planet is a matter of increasing concern, as we are being confronted with several warnings about the growing fragility of the Earth's life support system. Expanding our understanding of the life support systems and of sustainable development are doubtless two of the most important issues humankind is presently facing. This issue challenges humankind, demanding that we critically reassess our objectives and our agenda, from a sustainability perspective. This re-evaluation applies equally to the all actors, particularly industry. Present industrial management is founded, to a large extent, on resource depletion and environmental destruction. It is precisely these activities which we know to be unsustainable. This implies tremendous efforts from industry, which gradually adopts the new situation. For most industries this relates to a complete change of paradigm. The new paradigm is based on corporate social responsibility. Industry is partly the problem as well as the solution for a sustainable development. A redesign into sustainable development needs physically and ecologically recognized concepts and methods. These concepts and methods must also have room for economic considerations and be effective operational tools. This makes the exergy concept and exergy based methods suitable in this redesign of a "green" industry.

This presentation introduces the exergy concept into life support systems, i.e. the flows of energy and matter in Nature. These are literally described and graphically illustrated to facilitate understanding. Life support systems further the life in a sustainable fashion, i.e. they provide all needs required for continuance of life. Thus life support systems encompass natural environmental systems as well as ancillary social systems required to foster societal harmony, safety, health and development. The one common thread in all of these systems is that they support life on the Earth and exergy is a suitable physical concept in the description and understanding of them. A general background to the development of life support systems is presented. This will start from the very beginning of time. It will indicate how the existence of space and time are linked, and why time has a specific direction. The concept of exergy is introduced; see http://www.exergy.se, as the fundamental driving force behind the global system including life itself. The ability and evolution of nature will be illustrated in physical terms. Sustainable development is regarded as an evolutionary state of a living system that cannot be modeled. Thus, vitality is a more suitable name for this than sustainability. The complexity of nature and the process of natural evolution are far above human imagination.

The use of natural resources in society is described by exergy (see Göran Wall, "The Use of Natural Resources in Society" in Our Fragile World, pp. 209-230)**.** Exergy offers a better understanding of Nature and natural processes. This makes it clear that the present industrial culture is based on resource depletion and environmental destruction which is truly not sustainable. Attention is addressed to the differences between resource use in nature and in society. Present focus must be on social responsibilities; between humans and with nature. Present culture is characterized by greed and violence fostered by arrogance and ignorance instead of friendship and compassion. This must change into a culture of peace. Peace within us, peace among us and peace with nature are essential for happiness, harmony and knowledge to flourish. We, the people of the world, are also children of Earth with a common goal to care for life itself. We were given intelligence, emotions and possibilities, but also responsibilities. With these gifts we have created a world of prosperity, but also of poverty. The world has brought us together, but also apart and away from Nature. We face a future of threats and limitations, but also possibilities. These challenges demand for careful and responsible actions from everyone based on a better understanding together with moral obligations which implies an increased corporate social responsibility.

Unexploited possibilities and resources will be presented together with on outlook for future scenarios By the use of proper concepts and methods the challenge of building a sustainable industrial metabolism may well turn out to become profitable business (a successful industrial enterprise) and to take a leading position in sustainable development in the society. Successful business and enterprise is characterized by an efficient and effective resource use. Management systems are characterized by Total Quality Management (TQM) principles, which will be introduced. Companies have to optimize act in a physical and economical environment.

Instead of being restricted by rules and standards or threats of legal actions the development must be based on sound concepts and methods that can be easily adopted into the operation of design and construction of "green" products. This process of development must be based on true understanding of existing conditions and be possible, in order to be successfully, to put into operation. This makes exergy and exergy tools into excellent concepts to be adopted.

Sustainable development as well as TQM is not about certificates, licenses or awards it is about new production processes based on better use of available resources. The main message of TQM is common sense and human respect. To be sustainable this common sense and respect must also include Nature and future generations. Moral obligations are thus an unavoidable task to meet. This implies responsibility for environmental impacts and prudent resource use together with environmentally sound design and manufacturing.

Our main problem is ignorance and arrogance. This causes unforeseen social problems in the long run, and will be presented with regard to sustainable development. So far, the way out of this dilemma seems controversial, unfeasible and very expensive. However, this is mainly due to our inability to see the real problems, the related solutions and unexploited opportunities. Industrial development is trapped in a situation of being pushed by legal restrictions and shrinking assets. New robust machinery is needed, that operates in harmony with the environment. This machinery must be built on a solid scientific basement, and the physical concepts and methods for this are presented here. This can be maintained and fueled by a paradigm based on morals, creating a basis of a successful strategy to be established and employed. When our present situation is highlighted from a physical perspective a clear picture of the problems will appear. This picture may not always be so pleasant, however, necessary if our intension is to meet a sustainable development. The physical concepts and methods used are well established and recognized, thus, the can easily be adopted by the technological and economical workforce and be put into operation. This will, offer a new direction, a paradigm shift, for the industrial and economical development. Economical development will be based on an industry in harmony with the environment. Fundamental limitations environmental consequences will be pointed out. Concepts and methods suitable for the industrial framework in order to meet the need of a sustainable development will be presented and applied to industrial processes. Unexploited possibilities and resources will be presented together with on outlook for future scenarios By the use of proper concepts and methods the challenge of building a sustainable industrial metabolism may well turn out to become profitable business, i.e. a successful industrial enterprise, and take a leading position in sustainable development in the society. Successful business and enterprise is characterized by an efficient and effective resource use. Management system is based on TQM and companies optimize there activities in a physical and economical environment.

2 PHYSICAL CONDITIONS IN NATURE

Nature is the only creature and holder of life, as far as we know. From our understanding there are some fundamental conditions that maintain this unique capacity of the Nature. These conditions are described below by physical concepts as simple as possible. Economics and industrial management must operate within these conditions to be sustainable.

2.1 Contrast, Motion, Exergy, and Time

In order for things to happen, i.e. motion to occur, there must be a driving force; something that can create action. Without such conditions nothing would happen; everything would look the same forever. It would be a completely frozen world, no life and no death. Time would not exist, or at least it would not have a meaning, since everything would always look the same. A force is created by a difference in space of some kind, i.e. a contrast. This is a physical quantity such as temperature, pressure or tension. When this force, due to a contrast, is acting, it also "eats up" its source of power. The depletion of power into action is the creator of time. Just as a watch needs to be powered to show us time. By allowing a contrast that is enclosed into the three-dimensional space to act, a new fourth dimension is created, i.e. time. The importance of contrast is well documented, e.g. in the concepts of yin and yang that originate from the Tao philosophy. Many religions call it good and evil or heaven and hell. The Native Americans expressed the source of life as "Mother Earth and Father Sun." In essence every human being experiences the contrast of life and death.

Exergy is the physical concept of contrast, which quantifies its power of action. A system in complete equilibrium with itself and the environment does not have any exergy, i.e. no power of action. Obviously, exergy can only be larger than or equal to zero. Exergy can be defined as work, i.e. ordered motion, or ability to perform work. In physics, work is a specific form of action, usually expressed as force time distance. If there is exergy then time can be experienced, however, only if exergy is destroyed. This is an irreversible process, which creates a motion in a specific direction, i.e. in the direction of time. Motion in a specific direction is often used to measure time, e.g. the pointers of a clock.

The limited speed of light is also of essential importance for the life support system. If light could move at infinite speed, the Sun could, in principal, release all its stored exergy immediately, thus, there would be no time for life to appear. The light from other stars in the universe brings also with it the history, due to the limited speed of light. When we look into the space, we look into the history of the universe. The border of the universe gives us its time of birth, or the so-called "big bang," perhaps the birth of time. However, if the universe is infinite, then also time would be infinite.

If there is no exergy destruction there will be no action, everything will remain the same forever. In the real world of space and time such situations do not exist. A continuous, forever ongoing process of change, as we know it, characterizes the real world. From this we understand that behind this changing process is also a depleting contrast. For the universe this may be a problem, but for the life supporting systems on the Earth this is not a problem, at least not for the coming five to six billion years, i.e. as long as the Sun–Earth–space system remains. Let us conclude that contrast is the source of action and that depletion of contrast is the creator of time.

2.2 Energy, Matter, Exergy, and Entropy

Energy and matter cannot be created, destroyed, produced or consumed. This is a fundamental law of nature. There are no sources or sinks for energy and matter. Energy and matter can only be converted into different forms. This occurs by the consumption of contrast, gradient or quality. Locally, the contrast can be improved, but this can only occur at the expense of an even greater deterioration of the contrast elsewhere. On the whole it is a question of continuous deterioration of contrast, thus, pointing out the existence and direction of time. This is also a fundamental law of nature. The situation is illustrated in Figure 1.

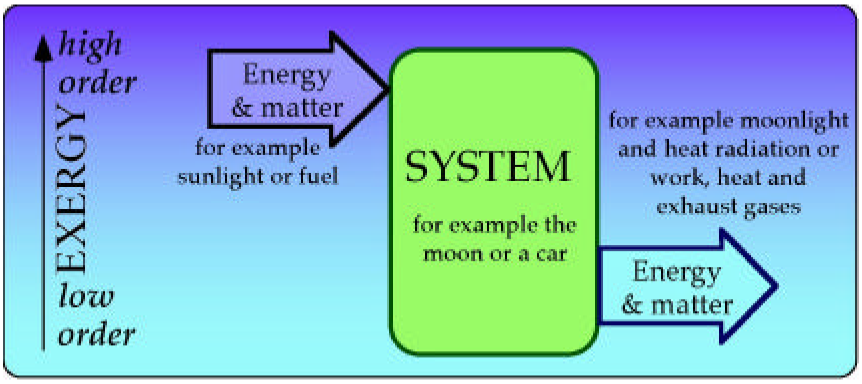

Figure 1. The flow of energy and/or matter through a system

Energy and/or matter flow through a system. This must be well defined with regard to space and time. The motive force of the flow of energy and/or matter through the system is the contrast or the level of order. From above we know that a part of this must always be destroyed in order to create action and time. The quality of the energy and/or matter constantly deteriorates in the flow passing through the system. The concept of entropy, or rather negentropy (i.e. entropy times –1), is a measure of the level of order. Energy and/or matter are falling from high order, i.e. low entropy or high negentropy, in the inflow into low order, i.e. high entropy or low negentropy, in the outflow. This is a necessary condition if the flow is to have a definite direction in space and for time to exist, as indicated above. This is also expressed as a destruction of exergy.

Energy and matter only serve as carriers of contrast, which is consumed when it flows through a system. When energy and matter flow through a system, a very small part of this may sometimes be stored in or removed from the system. If there is a balance between inlets and outlets of energy and matter, the system will remain unchanged, a kind of dead state that is described in Figure 1. Such dead state systems are the moon and a car. The moon offers us moonlight and a car is a mean of transport, however, the systems remain in principal unchanged. According to this way of looking upon flows of energy and matter it is wrong to say that energy and matter are produced or consumed. It is only contrast that can be produced or consumed. If an old car stands in the open air getting rusty, the material deteriorates in contrast but the matter still exists. It will combine with the environment in new chemical combinations, i.e. new chemical substances of less contrast to the environment. From a socio-economic point of view, we can say that the car and its material decrease in value and, as time passes, become of no value. In this case the energy and matter is removed from the system, and we have a state of decay.

If energy and/or matter are stored in the system we may have a viable state, i.e. life may occur. Logic would suggest therefore that the existence of life and the evolution of life imply that energy from the Sun must be stored on Earth.

2.3 The Earth, the Sun, and Space

On the surface of the Earth, at many different levels of size and of time-scale, systems operate by involving many kinds of matter in a complex pattern. Energy and matter permanently flow through different systems on the Earth's surface. Many branches of science, e.g. hydrology, climatology, oceanography, and ecology, study this. It is impossible to fully understand how all these systems and flows of energy and matter cooperate. Figure 2 offers a model for all the systems of the Earth's surface simplified by a network of 5 spheres; atmosphere, hydrosphere, lithosphere, biosphere and sociosphere. It must be remembered that this separation of the Earth into five spheres is just a model and the distinction between the spheres are not always accurate. Also it is important to remember that the whole is always more than the sum of its parts. The model is not exact but a guide to better understand some global processes.

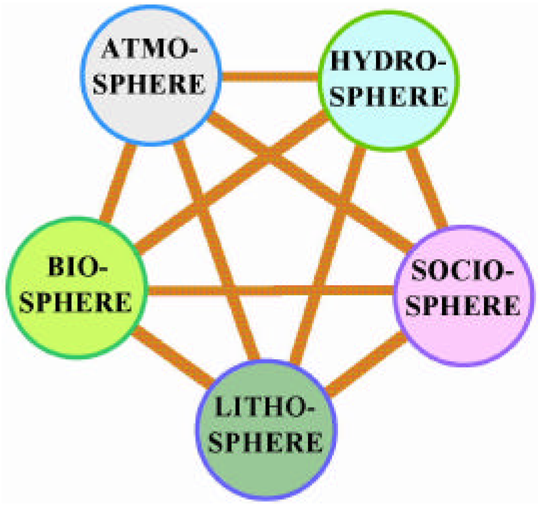

Figure 2. The Earth as five spheres in mutual interaction

The atmosphere contains about 78 percent of nitrogen, about 21 percent of oxygen, and the rest as argon, carbon dioxide, water vapor, ozone, and other gases. Water, mainly in the hydrosphere, appears simultaneously as ice, water, and steam, i.e. solid, liquid, and gas. Furthermore, water is an enormous heat reservoir, thereby balancing temperature variations both in space and time on the Earth. The lithosphere is the solid bedrock with all its minerals and salts, which by erosion is dissolved and becomes an important nutritive in the water. The biosphere consists of all living organisms on the Earth, except modern man, whose world constitutes the sociosphere, together with all the man-made systems. Plants and animals consequently belong to the biosphere, and buildings and machines belong to the sociosphere. Only so-called primitive people and their belongings are hosted by the biosphere. The exact definitions of these spheres are not essential for the discussion. Sociosphere and technosphere may be regarded similar. All these spheres interact with each other in a mostly constructive manor, e.g. the evolution of life, creation of free oxygen and fossil fuels from the living processes of the biosphere. Further examples are erosion to mineralize water and sedimentation to remove toxic substances from the biosphere. However this interaction may also be destructive, e.g. volcanic eruptions, hurricanes, ozone depletion, greenhouse effect, and an increase in DDT and PCB in the biosphere. Figure 2 illustrates the interaction as lines between the spheres. Exergy is consumed in the constant flows of energy and matter that go on within and between these spheres. The driving force is exergy, which mostly originates from the contrast between the Sun and space, see Figure 3.

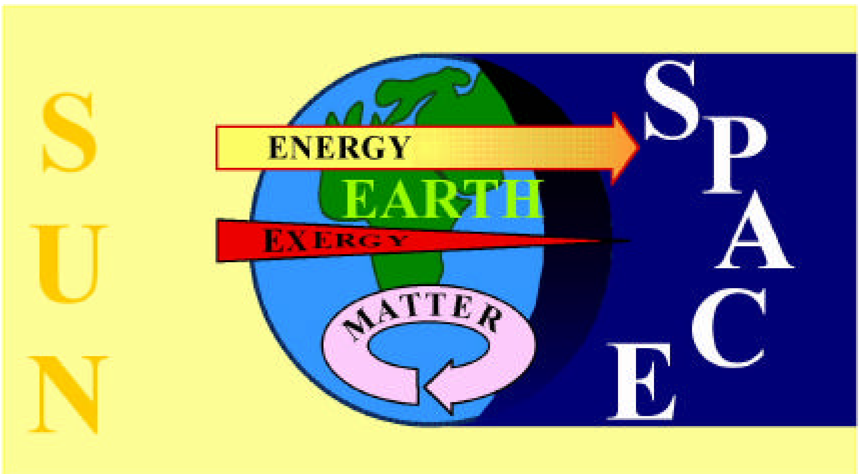

Figure 3. The Sun-Earth-space system

The source of exergy on the Earth is secured from the contrast between the Sun and space. The Sun is a star, i.e. an extremely compact and hot body that emits light, whereas space is the opposite, i.e. almost empty and cold. This is a system of extreme contrast. The life support systems on the Earth are equally dependent on both of them, but this is not enough. The Earth is the only planet in the solar system of suitable size and distance to the Sun for life, as we know it, to evolve. The size, which implies the gravity of power, is big enough to keep an atmosphere of gases such as oxygen and nitrogen to its surface. But, the size is not too big. On the Sun, the gravity of power is so big that it ignites the fusion of hydrogen into helium, which releases a huge amount of stored energy. This also makes it impossible for life to appear on its surface. The distance between the Earth and the Sun gives a suitable ambient temperature, which is perfect to simultaneously sustain ice, water, and vapor. On planets closer to the Sun, such as Venus, all water would be evaporated and on planets further away from the Sun, Mars for instance, the water would remain frozen. These are all important factors for a life support system. This makes the Earth the only carrier for the evolution of life in our solar system. The Earth is the only planet able to successfully capture the contrast of the "Sun-space" system. The Earth is provided with life support systems, which makes it suitable to host the living Nature, i.e. the process of evolution of life. This makes our planet unique, perhaps in the whole of the universe.

2.4 Sunlight and Life

The exergy of sunlight is on the average about 93 percent of its energy value. The incoming solar energy is equivalent to about 1.6×10^{17} W of exergy, see Figure 4. This is about 13 000 times the exergy that is presently being used as energy and material resources by the human society, which is about 1.2×10^{13} W or on the average about 2 kW per capita. However, this use is very unequally distributed among the people of the world, the average American uses about 10 kW whereas the average Chinese uses about one 1 kW and the people of India even less.

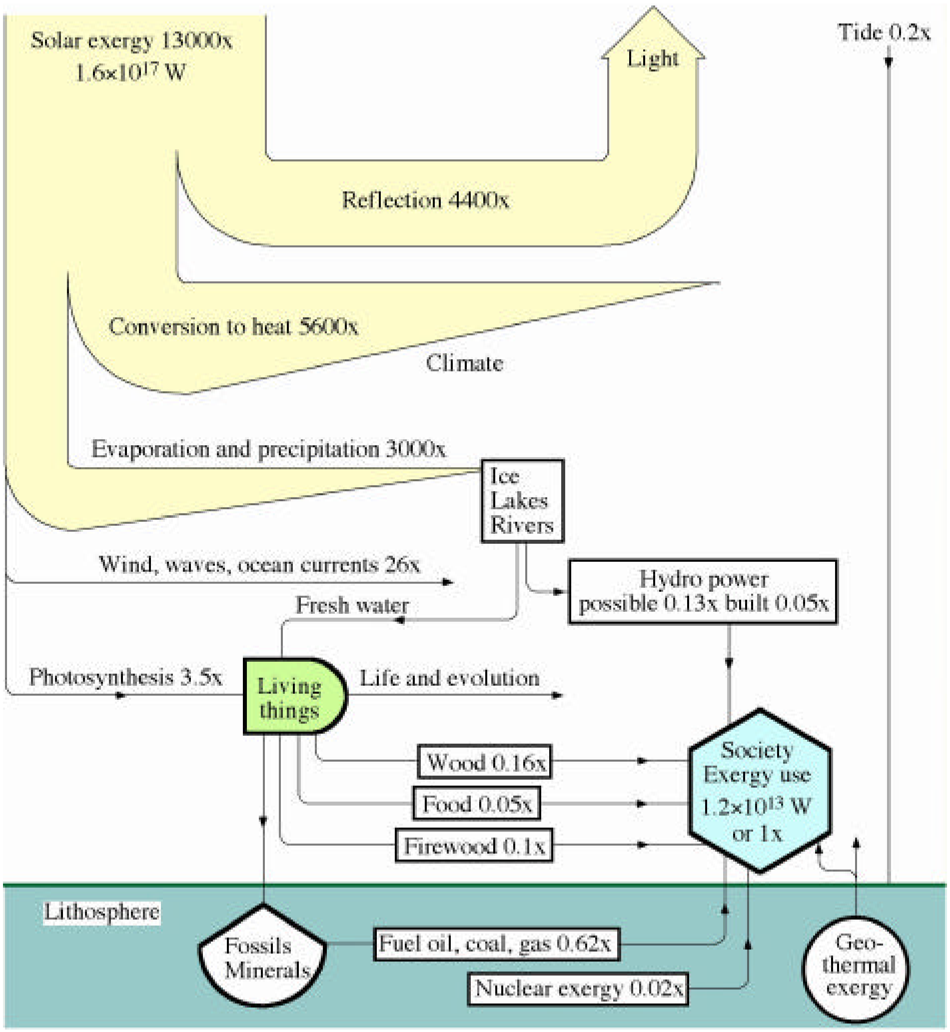

Figure 4. The global exergy flows on the Earth, where 1x is equal to 1.2×10^{13} W.

Almost all exergy used on the Earth derives from the Sun. Only small fractions of exergy originate from the Moon as tidal effects, geothermal exergy from the hot interior of the Earth and the use of nuclear exergy. About one fourth of the sunlight is reflected as light, which also implies that the exergy remains. This reflection is mainly as ultraviolet light, which gives the characteristic shimmering light to pictures of the Earth. The rest of the exergy is absorbed by the atmosphere and the surface of the Earth and is consequently gradually destroyed, but during this destruction, it manages to drive the water/wind system and life on Earth. The circulation of water, i.e. the evaporation and the precipitation, accounts for about 3000 times the use of exergy resources used by society. This circulation of water is also indicated as matter in Figure 3. About 400 000 km^3 of water evaporate annually and about one tenth of this water falls over land to create ice, lakes, and rivers. The enormous exergy wasted by these systems into ambient heat may seem extravagant but these processes establish a basis for a suitable climate of the Earth's life support systems.

Living nature, or the biosphere, is subject to three fundamental processes, namely: production, consumption, and decomposition. These maintain the circulation of matter by using the incoming solar exergy in a sustainable and evolutionary way, see Figure 5.

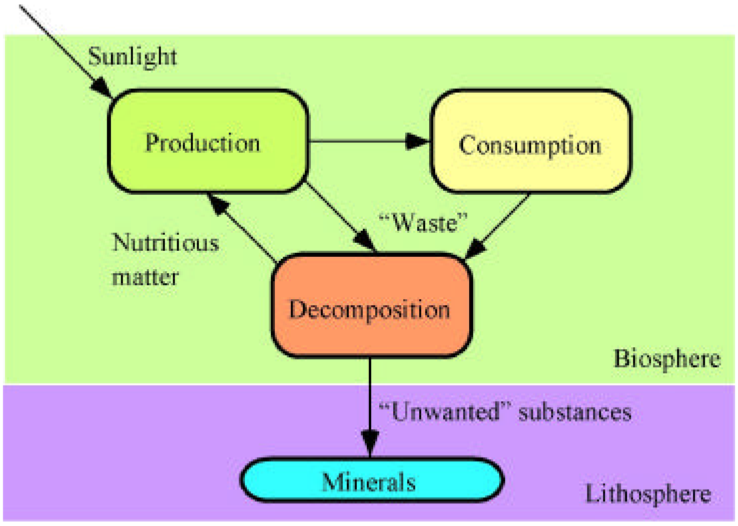

Figure 5. The circulation of matter in nature is powered by sunlight

Exergy is the "fuel" for living systems, that are sustained by converting energy and materials; e.g. a living cell, an organism, an ecosystem, the Earth's surface with its material cycles, or a society. The green plants, which represent the production process, convert exergy from the sunlight into the exergy-rich matter of biomass, via photosynthesis. The exergy as biomass then passes through different food chains in the ecosystems. At every trophic level exergy is consumed and decomposition organisms dominate the last level in this food chain. There is no waste. The main problem for nature does not seem to be lack of natural resources, such as solar energy, but how to make use of this immense amount of available exergy in a creative manner. This is not a matter of spending it, but the opposite, namely to capture it into new forms of contrast, i.e. to build ordered structures. This is a delicate problem far beyond the imagination of human beings. We just happen to be a part of this highly intelligent process of evolution. Exergy is captured by nature through structural and chemical changes on the Earth. This is shown as a net-flow of "unwanted" substances away from the biosphere and stored in fossils and minerals in the lithosphere, see Figure 5. Thus, a minor part of the incoming solar energy is stored on the Earth, which is a key element in nature's process of evolution.

3 USE OF NATURAL RESOURCES IN SOCIETY

3.1 Exergy Accounting of Natural Resources

Exergy is the maximum amount of work that can be extracted from a contrast of any kind, e.g. a mineral deposit or sunlight. Exergy is often defined as the maximum work potential of a material or of a form of energy in relation to its environment, i.e. a reference state. Usually the reference state is the ambient temperature and pressure, e.g. 25ºC and 1 atmosphere. However, the Earth is not in a state of thermodynamic equilibrium; indeed it is far from an equilibrium state. The temperature varies from place to place. Pressure and chemical conditions also vary around the globe. Other important factors are the deposits of fossil fuels and the existence of oxygen in the atmosphere, as described above, which build up a huge thermodynamic potential. Thus, the Earth and the environment are in a state far from thermodynamic equilibrium. However, for the life processes the sustainability of this state is of essential importance.

The exergy content of pollution can be understood as its potential for doing harm, by driving uncontrolled reactions in the environment. In terms of a human-metabolic analogy, exergy embodied in wastes could be measured as the potential for causing indigestion. It is clear that exergy embodied in wastes can cause physical processes, such as climatic warming, as well as chemical reactions, such as ozone depletion.

Exergy is a fuel for all processes in the life support systems, both to sustain and destroy ecosystems (see Figure 2).

3.1.1 Exergy as a General Resource Concept

Energy and material substances appear in many forms and in different qualities. This is best described by the universal concept of exergy. When we use the word energy in everyday life we should, if we are precise, use the word exergy instead, since we are generally referring to the usefulness of the energy. To get a better understanding of what we mean by "exergy" here are some very simple examples in the context of life support systems and natural resources:

1. A system in complete equilibrium with its environment does not have any exergy. There is no difference in temperature, pressure, density etc., able to drive any processes. Thus, a waste flow, of any kind, with no exergy does not, by definition, influence the environment.
2. The more exergy a system carries, the more it deviates from the environment. Hot water has a higher content of exergy during the winter, than it has in a hot summer day. A block of ice carries very little exergy in winter but much more in summer. This fact was the basis of a very prosperous trade of ice in the nineteenth century, when ice was regularly shipped from North America to the West Indies, South Africa, and finally to Europe.
3. When a physical resource, i.e. energy, matter, or information, loses its quality, this means that exergy is destroyed. The exergy is the part of the resource, which is useful to society and therefore has an economic value and is worth taking care of.
4. Almost all energy converted in the biosphere derives from the Sun. When sunlight, which is rich in exergy, reaches the Earth, a lot of it is reflected by the ozone layer, mainly the harmful, ultraviolet light. Some of the energy, however, is absorbed, partly by photosynthesis in green plants it is then converted and ultimately leaves the Earth as heat radiation, with no exergy relative to the Earth. The net exergy absorbed by the Earth is therefore gradually destroyed, but during this destruction it manages to drive the water/wind system and thus, life on Earth. Green plants absorb solar exergy and convert it via photosynthesis into exergy rich substances. Part of this exergy then passes through different food chains and ecosystems. On every trophic level exergy is consumed, down to decomposing micro-organisms, which constitute the last level in this food web. There is no waste, i.e. all exergy is being taken care of and efficiently used by living nature.
5. A concentrated deposit of a mineral "contrasts" with the environment and this contrast increases with the concentration of the mineral. The mineral is thus a carrier of exergy. When the mineral is being mined, the exergy content of the mineral is kept constant, and if it is enriched the exergy content increases. A poor deposit of mineral contains less exergy and can accordingly be utilized only through a larger input of external exergy. Today this substitution of exergy relates mostly to exergy forms such as coal and oil. When a concentrated mineral is dispersed, the exergy content decreases, see (3). However, from an environmental point of view, this decrease might not be harmless. In many cases it has catastrophic effects to the environment, as described above.
6. A unique property of the exergy concept is that it depends on the conditions of the environment. By convention a "standard environment" should be given, with an agreed chemical composition, temperature and pressure, relating to a standard atmosphere, sea and bedrock, for instance. The problem however, is that these systems are not in equilibrium with each other. Sometimes therefore, one should use local standards depending on the season (see (2) above). This environmental link makes exergy a suitable ecological and environmental indicator.

Exergy is *the* "fuel" for dissipative systems, i.e. systems that are sustained by converting energy and materials; e.g. a living cell, an organism, an eco-system, the Earth's surface with its material cycles, or a society. The exergy concept could and should be used systematically to describe such systems scientifically.

The exergy concept has mostly been used within energy and power technology, where one works with thermal energy of varying qualities. The field of application can be extended to the totality of energy, material and information conversions in the society. This yields a uniform description of the use of physical resources and their environmental impacts. Also, there is a lack of a useful common scientific measure of substances, which is a serious problem in many environmental accounting methods practiced today, e.g. Life Cycle Assessment or Life Cycle Analysis (LCA), and environmental economics. (See Göran Wall, "Exergetics" in Our Fragile World CD.) Natural resources are traditionally divided into energy resources and other resources. This separation often can be only approximated. Oil, for example, is usually looked upon as an energy resource and wood is regarded as a material resource. This distinction is not very meaningful, however, because oil can also be used for producing useful materials and wood can be used as a fuel. It would be more appropriate to consider these resources together. The exergy concept, as a common resource measure, is able to provide that constancy. The exergy content of energy resources may be given by multiplying the energy content by a quality factor that applies to the energy form in question. In principle, a material can be quantified in exergy units just by multiplying its quantity with a transformation factor for the material. The unit of such a transformation factor could then be, for example J per m^3 or J per kilogram. This would be the beginning of expanded resource budgeting and a first step towards integrating with traditional energy budgeting.

Exergy per unit quantity is in fact the physical value of a resource relative to the environment. This can be compared to a price, i.e. the economical value, which is also partly defined by the environment through, for instance supply and demand.

Exergy can only denote *one* extensive physical quality of goods. The exergy content *does not* imply anything about intensive physical or biological qualities like electric conductivity, nutritive value, toxicity, or the like. However, when a material is used as an exergy converter the efficiency is then related to the quality of interest of the material. A material with bad electric conductivity gives a greater exergy loss than a material with good electric conductivity gives when being used as an electric conductor. In a similar way we may distinguish biological qualities with regard to their effect on the natural exergy conversions in the environment.

3.1.2 Exergy Factor of Some Common Forms of Energy and Material Substances

In Table 1 below some energy forms are listed in decreasing order of quality, i.e. exergy factor, which is the ratio between exergy and energy. The exergy factor ranges from 1 for potential energy, kinetic energy and electricity (which is pure exergy and thus can be totally transformed into all other forms of energy) to 0 for the exergy-lacking heat radiation from the Earth. The exergy factor of thermal energy varies considerably from 0.6 for hot steam to zero for heat radiation from the Earth. It must be noted that this factor is only approximate. When using energy we utilize the energy conversions along its way towards heat at environmental temperature.

However, it is not only energy-containing systems which carry exergy. If a system is deprived of energy and thus deviates in this way from the environment it carries exergy. An ice-block in an environment at room temperature is an example of such a system. Due to this, the ice represents negative energy content. When the ice melts, it takes energy from the surrounding air, but we can use the contrast in temperature between the ice and the surrounding air to extract work. This makes the contrast between the cold ice and the tepid air a source of exergy. In an analogous manner, an empty container, i.e. a vacuum, surrounded by air and at normal pressure, represents a source of exergy and can be utilized to extract work.

Analogous to the quality of energy, the quality of a certain material can be expressed as the amount of exergy (per unit) for the material in question. The purest form of matter is that with a known structure and consisting of only completely known elements, for which the entropy is almost zero. This may be a material of only one substance, e.g. a pure metal, or a material of a pure structure, e.g. a living cell where all the atoms are in precise places. Diluted and mixed matters have higher entropy, and therefore have a lower quality. The quality decreases with a greater extent of dilution or mixture. A concentrated mineral deposit has high exergy content. By mining the mineral deposit and distributing it in the environment, the exergy content decreases. In Table 2 different forms of material are listed in order of decreasing quality. It is difficult to specify the numbers as for the energy forms in Table 1. In any case, there is a clear difference between the upper part of Table 2, which can be considered as high ordered and the lower part, which can be considered as low ordered.

Table 1. The exergy factor of some common energy forms

Energy form	Exergy factor
Mechanical energy	1.0
Electrical energy	1.0
Chemical energy	About 1.0[1]
Nuclear energy	About 0.95
Sunlight	0.93
Hot steam (600 degrees Celsius)	0.6
District heat (90 degrees Celsius)	0.2-0.3[2]
Heat at room temperature (20 degrees Celsius)	0-0.2[2]
Thermal radiation from Earth	0

[1] May even exceed 1, due to definition of system boundaries and final states

[2] Strongly depending on the outdoor temperature

The quality of the material form is expressed by an index giving the approximate exergy content i.e., the amount of "elements in an ordered form," as a percentage of the amount of the material. The definition of the quality index is here analogous to the definition of the exergy factor for the energy forms in Table 1, where the quality index was the amount of exergy, i.e. work, as a fraction of the amount of energy in question. The exergy for a material is thus the amount of "elements in an ordered form" that can be extracted from a system in its environment without additional exergy inputs. Thus, from a given amount of material, only the part given by the exergy content can be refined into a pure form, provided that no consumption of external exergy occurs. As the exergy does not differentiate between energy with exergy factor 1 and "matter in an ordered form," there is here a clear connection between energy and matter. Accordingly, we can exchange extra superior energy for the same amount of exergy in the form of matter in an ordered form. This is what we do when enriching and refining a mineral deposit into a commercial product. We exchange, so to say, exergy in the form of energy for exergy in the form of a material substance. Einstein's relation between energy and matter, $E=mc^2$, where the energy is equal to the mass times the speed of light squared, is another more fundamental relation. From Einstein's relation only about 6 tons of matter would support the energy need of the whole world per year.

From Table 2, we see that the exergy factor ranges from 1 for absolutely pure and microscopically well-ordered materials, to almost 0 for materials evenly distributed in the soil or completely dissolved in seawater. The value of the exergy factor depends on the environment within which the exergy is estimated. In Table 2, the estimate of the exergy content of the different materials was made with the Earth's average combination of material as environment. This means that materials common on Earth are of a low exergy value. A comparison with energy forms in Table 1 can be made, where heat radiation from the Earth is considered as worthless.

Table 2. The qualities of different material substances

Form of material substance	Exergy factor
Matter in an ordered form[1]	1.0
Matter as commercial goods[2]	Almost 1
Rich mineral deposits[3]	About 0.5
Poor mineral deposits[4]	Almost 0
Mineral dissolved in sea water or soil	About 0

[1] e.g. carbon in the form of diamond or a living organism
[2] e.g. iron, gold, lead, steel, alloys or plastics
[3] e.g. bog iron (limonite) or sea nodules
[4] e.g. bauxite

Exergy available as chemically concentrated substances can be utilized in chemical-electrical cells of concentration type. In the biosphere there are ecosystems living from the concentrated hot minerals erupting from the so-called “smoke-stacks” in the deep sea, far below the reach of sunlight. These ecosystems are only maintained by the exergy from the contrast of chemicals in their environment, and they are completely separated from the solar powered ecosystem. At a river mouth, the exergy-rich fresh water literally flows into the sea. If the fresh water is made to mix with the saltwater in a controlled process, the exergy could be extracted. This is called osmotic exergy. For a river that flows into the sea this exergy may be equivalent to a waterfall at a height of over 200 m. The exergy content of fresh water is also illustrated by the fact that exergy is needed to desalinate seawater.

3.1.3 Exergy of Emissions and Pollution

The more exergy an emission carries, the more it deviates from the environment. An emission of substances, that are common in the environment, e.g. steam or water, carries less exergy than emissions of substances that are less common, e.g. heavy metals or radioactive waste. Simultaneously, the exergy represents physical value, i.e. that a substance is technically useful and therefore should have an economic value and should be worth taking care of. Thus, emissions of high exergy substances should also be regarded as a misuse of resources. In this regard exergy also offers a useful concept as an ecological and environmental indicator.

3.1.4 Exergy as a Tool towards Sustainable Development

Exergy accounting of the use of energy and material resources provide us with knowledge as to how effective and how balanced a society is in the matter of conserving natural resources. This type of knowledge can identify areas in which technical and other improvements should be undertaken, and indicate the priorities, which should be assigned to conservation measures. In order to generalize the use of exergy accounting in the society, statistical data must be provided. Necessary steps should therefore be undertaken by national authorities to establish international agreements to facilitate the gathering and sharing of information. Making comparisons of this type between various societies throughout the world and studying the international system should also be of fundamental interest if we are serious in our efforts to work towards an equitable distribution of resources and a sustainable society.

3.2 Classification of Resources and Reserves

Resources and reserves are usually defined according to Figure 6. Resources cover a wide area, from hypothetical and speculative in the physical context to sub-marginal and unprofitable regarding the economic feasibility. However, reserves are only the known and profitable part of the resources, and in addition to this the sustainable reserves should also be specified, i.e. reserves that are ecologically acceptable. Ecologically acceptable parts of natural flows and funds could be regarded as sustainable reserves. Reserves originating from deposits are obviously not sustainable reserves.

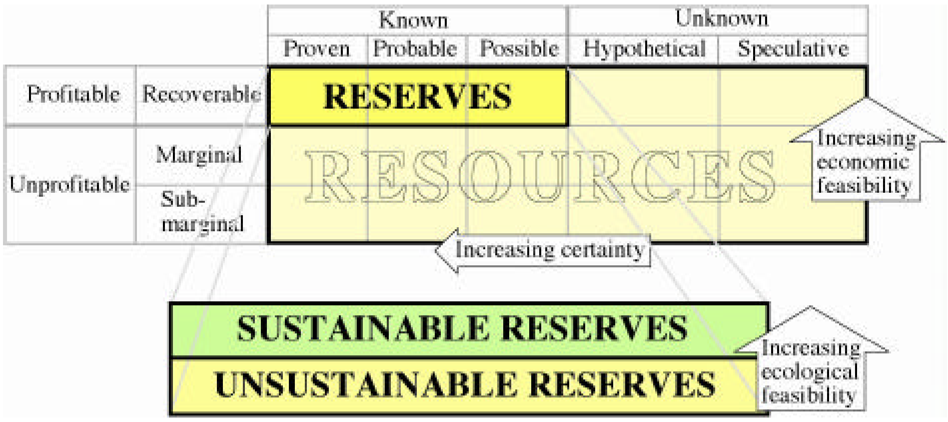

Figure 6. Definition of resources and reserves

Resources must also be classified in order to relate an analysis to the notion of sustainability, see Figure 7. Natural resources appear partly as *natural flows* and partly as *stocks*, which are divided into *dead stocks* or *deposits* and *living stocks* or *funds*. Solar energy, wind energy, and water flows are natural flows. A natural flow has a limited size, but usually lasts for a very long time. An ecosystem, such as a forest, forms a valuable stock. It is built up of natural flows of sunlight, water, carbon dioxide, and mineral substances. It gives rise to a flow of new biological matter and part of this flow, i.e. the yield, can be taken out of the system without decreasing the stock. Other stocks, such as oil deposits, have quite different characteristics. A deposit can only yield a flow if it is gradually depleted and dispersed. This is partly a time-based classification because the time of reproduction is the physical concept that is of interest here. Deposits and funds are defined with regard to the difference in the time of reproduction. Natural flows are renewable and deposits are non-renewable resources. Funds that are used in a sustainable way, i.e. the extraction is less than the growth, would be renewable, but if they are used in a non-sustainable way they cannot be regarded as renewable, e.g. the large-scale clear-cutting of forests.

We could also distinguish between deposits and funds by means of origin. Deposits originate from toxic substances, which are being removed by the ongoing recycling processes in the biosphere, and put into the lithosphere, see Figure 5. Thus, it builds up exergy on the Earth, which is of importance to the life support system, as was discussed above. Deflections of the substances, which are part of the cyclic processes in the biosphere that are powered by the Sun are instead funds. This will be further explained below.

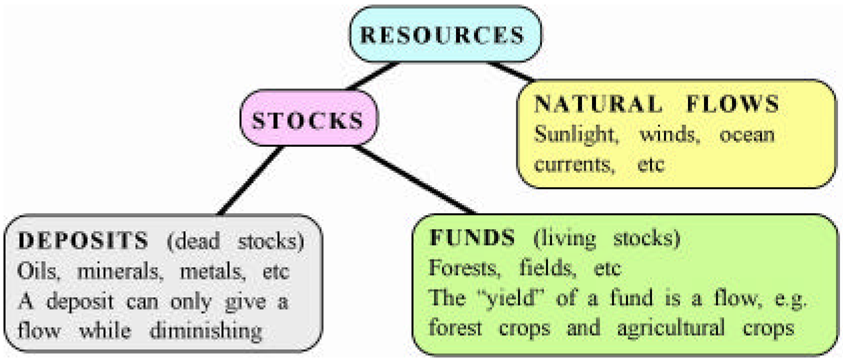

Figure 7. Classification of resources

3.3 Resource Use in Society

Present industrial society, is built on a non-sustainable resource use, see Figure 8. Substances, such as fossil fuels and metals that originate from deposits of fossils and minerals in the lithosphere are unsealed and spread in the environment, which is exactly the opposite of what is done by nature, see Figure 5. In nature these substances are instead being accumulated and stored as deposits. The present use of resources in industrial society is obviously not sustainable, at least not for a very long time. The situation is similar to a colony of bacteria living from a limited resource. The population may flourish and increase exponentially for a short period but after that it collapses from the destruction of its life support system. "Production" is the name of this activity in economics. But how can the relentless consumption of Earth's scarce resources be seen as a productive activity, either physically or biologically?

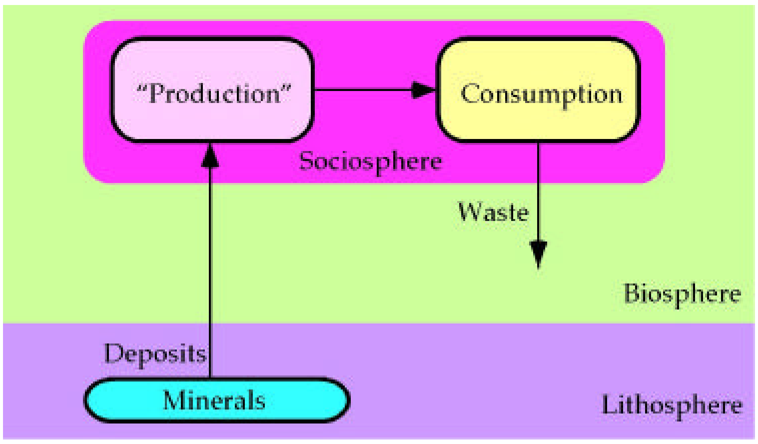

Figure 8. Society takes deposits from nature and returns wastes

There is another major trend in the use of natural resources by society that must be considered. Due to the ongoing use of deposits, the quality of the remaining deposits decreases (see Figure 9). Usually, mineral deposits of higher concentrations are used first. This implies that as time goes on more effort is required to extract the same amount of material, i.e. more exergy is needed per final product. In the early stage of operations the improvement of technology (the green curve of Figure 9) could mostly catch up with this increasing need, so that, in fact, exergy input was still reduced. This is demonstrated by the left part of the bottom blue curve. However, due to physical conditions the technological improvements are facing a theoretical limit to their efficiency. This is indicated by the dotted line over the green curve. For many materials, e.g. metals, this limit is already reached. Thus, further extraction of deposits can only take place at the expense of an increasing input of external exergy, thus, the total use of resources per amount of final product has to increase, as shown by the right hand side of the bottom blue curve of Figure 9. This is an unavoidable consequence from the use non-renewable resources.

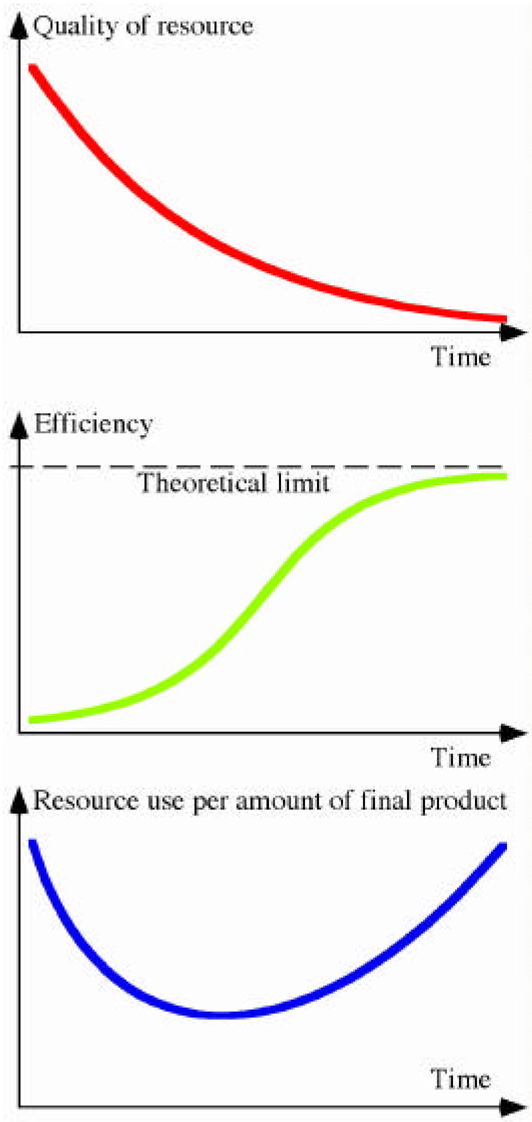

Figure 9. Major trends in the extraction of deposits

Figure 5 shows that the natural ecological system is in a state of constant change, i.e. the natural evolutionary process, and this process is now being heavily disturbed by the resource use of industrial society, described by Figure 8.

The present situation can be better understood from Figure 10, where resource depletion and environmental destruction are two sides of the same problem, i.e. the use of deposits. Toxic substances are carried by the inflow of so called natural resources, e.g. fuels and metals, from the lithosphere to the sociosphere. In a closed system, nothing disappears and everything disperses, i.e. the first and second laws of thermodynamics, which state that all substances that are extracted from the lithosphere will unavoidably end up in the environment, i.e. the sociosphere, the biosphere, the atmosphere and the hydrosphere. Living processes, however, that are powered by the inflow of sunlight may enrich substances in the food chains. So far only natural processes on the Earth have the capacity to concentrate material substances on a global scale from the use of an external exergy source, i.e. the Sun-space system. The situation will be further illustrated and explained below.

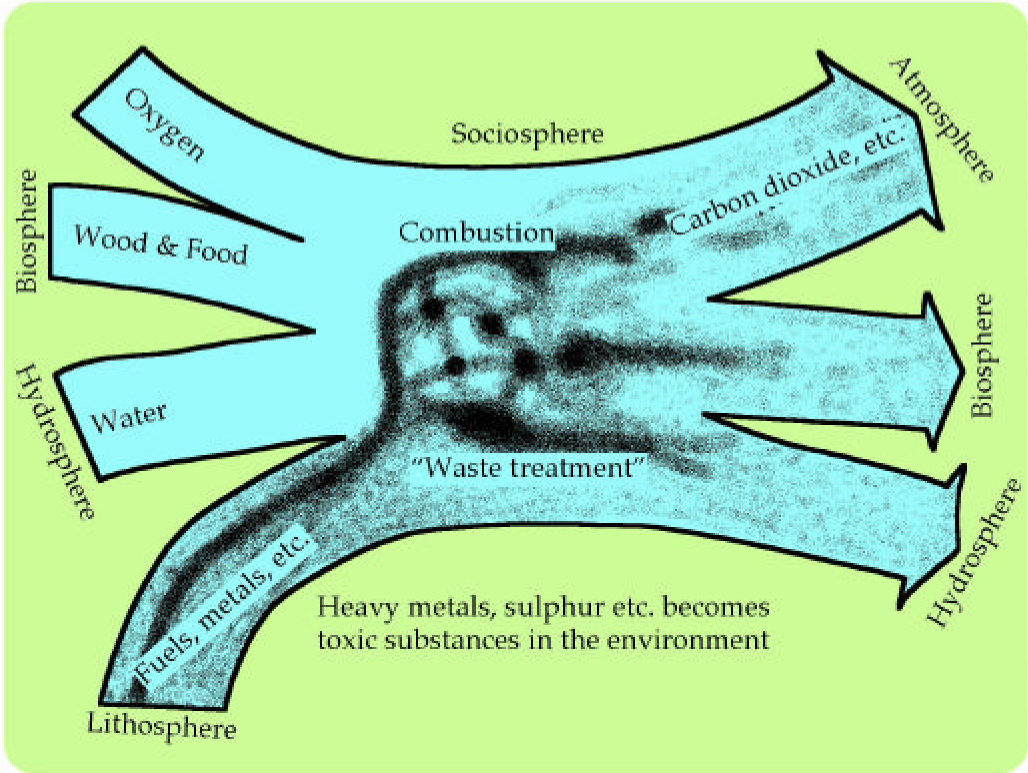

Figure 10. Resource depletion and environmental destruction are two sides of the same problem

In Figure 11, we see how the exergy flow through the society is maintained. The greater part of the exergy requirements are utilized from the terrestrial exergy stocks, i.e. funds and deposits. Human only uses a very small part of the exergy flow from the Sun, e.g. in agriculture and forestry. Through society therefore we see an almost continuous exergy loss. Some exergy flows, such as flows of ores, initially increase their exergy when passing through society. However, other flows decrease their exergy all the more. A tank, which contains the funds and the deposits, indicates the limited amount of exergy stocks on the Earth. As long as the levels are kept stable, i.e. the output of resources does not exceed the input from the Sun and the biological processes, and then we have a sustainable situation. However, if the level is dropping, i.e. the level of stocks is depleting then we have a non-sustainable situation. This is the case for the current industrial society. There is either no re-circulation of material substances, or very little indeed. Instead matter is being moved from deposits as minerals, or natural resources as they are often called, into the environment as emissions or waste dumped into the wider environment. If the level of deposits is dropping, then substances will also be contaminated in the environment, as shown in Figure 11. As long as these substances are under control, i.e. within the sociosphere, this may not be a serious problem. Large amount of substances are accumulated in the sociosphere as constructions, e.g. buildings and machines, and, as long as these remain, their substances may not effect the environment. However, when they are allowed to decompose they may pose a serious threat, e.g. old nuclear, chemical, and biological arms that are not properly stored or destroyed. This also relates to harmful substances that are accumulated by a purification system. However, human constructions and buildings will not last forever. Sooner or later they will deteriorate and their substances will end up in the environment. Thus, environmental pollution is an inevitable consequence of the use of deposits. The depletion of the resource may not be the most serious problem, but rather the emission of toxic substances into the environment. Thus the focus must be directed away from an eventual lack of non-renewable resources and instead be directed towards the environmental impact and its consequences. Presently, only nature offers the machinery to put these substances back into the lithosphere, see Figure 5. However, the present damage may take nature millions of years to repair, and in the meantime there will be a serious impact on the living conditions for humankind as well as for other forms of life.

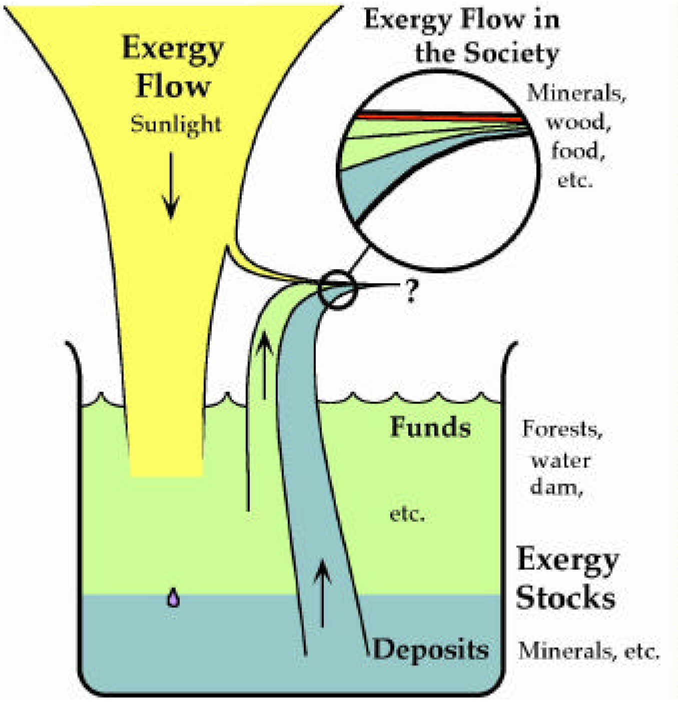

Figure 11. The exergy flow from the Sun, and the exergy stocks on Earth create the resource base for human societies on Earth

The use of energy and material resources in society can be expressed in exergy by the use of exergy flow diagrams. These diagrams offer a unique insight to the use of natural resources in society; see Figure 12 and Göran Wall, "The Use of Natural Resources in Society" in Our Fragile World, pp. 209-230**.** Using this technique, the current misuse of resources becomes more apparent, and with this also the urgent need to improve this use. Consequences of this misuse are further elaborated in a separate article (see Göran Wall, "The Life Support Systems and Sustainable Development" in Our Fragile World CD).

Figure 12 shows the main conversions of energy and materials in Swedish society in 1994, based on data from official statistics. The flows of resources go from left to right in the diagram, i.e. from the resource base to the consumption sector. Thus, the diagram basically represents the resource supply sector where resources such as crops and minerals are turned into consumer goods such as food, transport and thermal comfort. The width of the flows is defined by their exergy content and the unit of the flows is J. The accuracy of the flows varies a great deal between the different areas. For the electricity system the accuracy is quite high, whereas for sectors related to agriculture and forestry we have, for obvious reasons, a different situation. In order not to make the diagram too complicated, only exergy flows exceeding 5 PJ are included. The inflows are ordered according to their origins. Sunlight is thus a renewable natural flow. Besides a minor use of wind power, far less than 5 PJ, this is the only direct use of a renewable natural flow. Harvested forests, agricultural crops, and hydropower are renewable exergy flows derived from funds, which of course are founded on the renewable natural flow of sunlight. Iron ore, nuclear fuels, and fossil fuels are non-renewable exergy flows from deposits, which are exhaustible and also carry with them toxic substances. The unfilled boxes represent exergy conversions, which in most cases represent a huge number of internal conversions and processes. The resources actually demanded in society appear as outflows on the right side of the diagram. The total inflow of resources during 1994 amounts to about 2720 PJ or 310 GJ per capita and the net output becomes 380 PJ or 40 GJ per capita. Thus, the overall efficiency of the supply sector can be estimated at less than 15 percent, which must be regarded as poor. As we can see, some sectors are extremely inefficient. Some resource conversion systems have a ridiculously poor efficiency. For nuclear fuel to space heating through short circuit heaters the utilization becomes less than 0.025 percent.

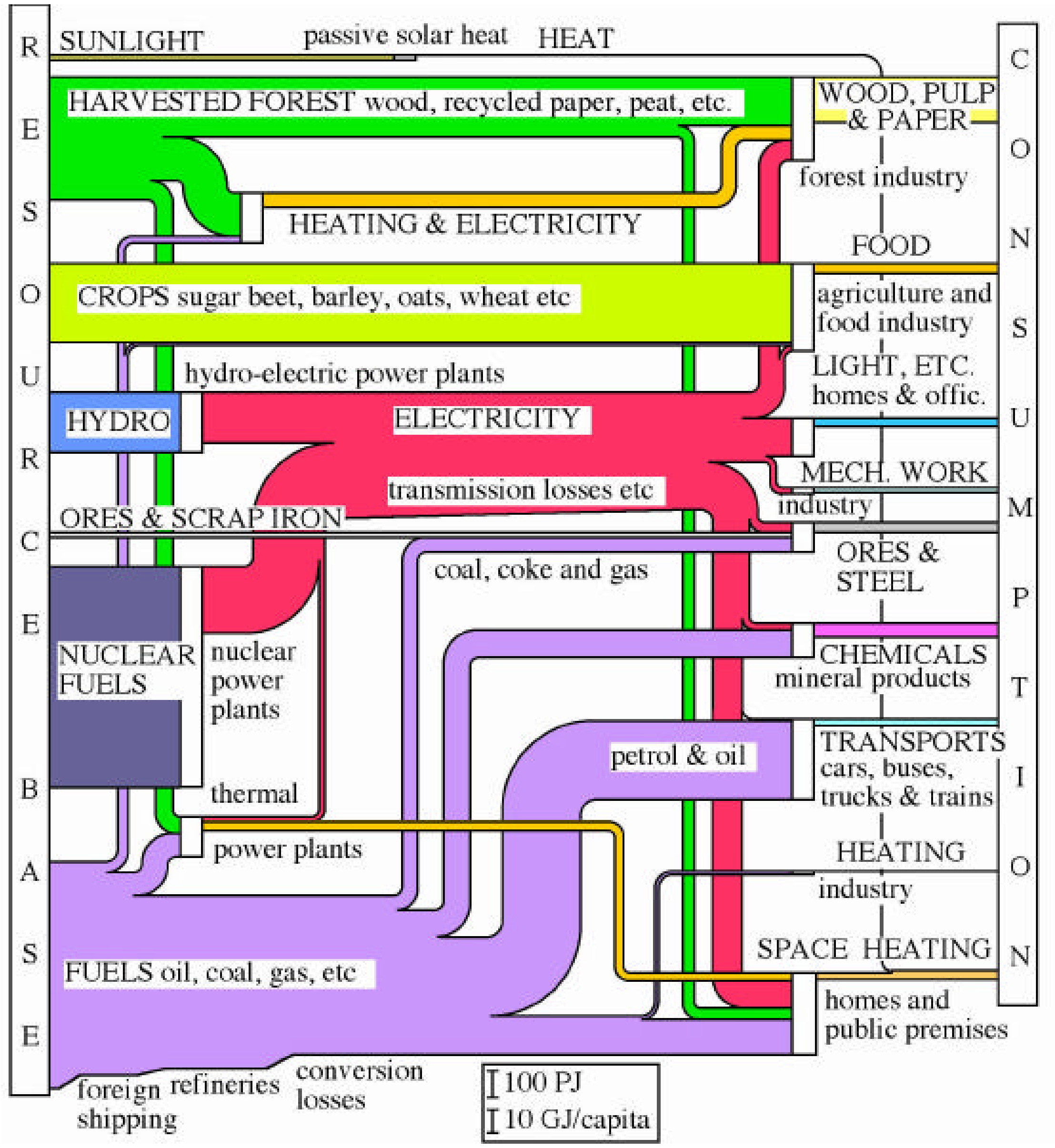

Figure 12. The exergy conversion system in the Swedish society in 1994. Total input about 2720 PJ or 310 GJ per capita and output about 380 PJ or 43 GJ per capita.

Further information on this diagram and other similar studies for Italy, Japan and Ghana are found in Göran Wall, "The Use of Natural Resources in Society" in Our Fragile World, pp. 209-230 or in Göran Wall, "National Exergy Accounting of Natural Resources" in EOLSS On-Line, 2002.

By calculating the exergy loss, i.e. destruction and waste, we can visualize possible process improvements. In engineering energy flow diagrams are often used to describe this, see Figure 13. This shows a power plant, its main components and the energy and exergy flows of the plant. The exergy flow shows losses both as destruction and emissions to the environment, which is important information for estimating environmental effects. It also gives a hint about the possibilities to improve the process and where to direct the efforts of improvement. In the energy flow diagram energy is always conserved, as stated by the first law of thermodynamics. The waste heat carries the largest amount of energy into the environment, far more than is carried by the exhaust gases. However, the temperature of the waste heat is close to ambient so the exergy becomes small. The exergy of the exhaust gas and the waste heat are comparable. Energy and exergy losses from friction have little direct impact to the environment.

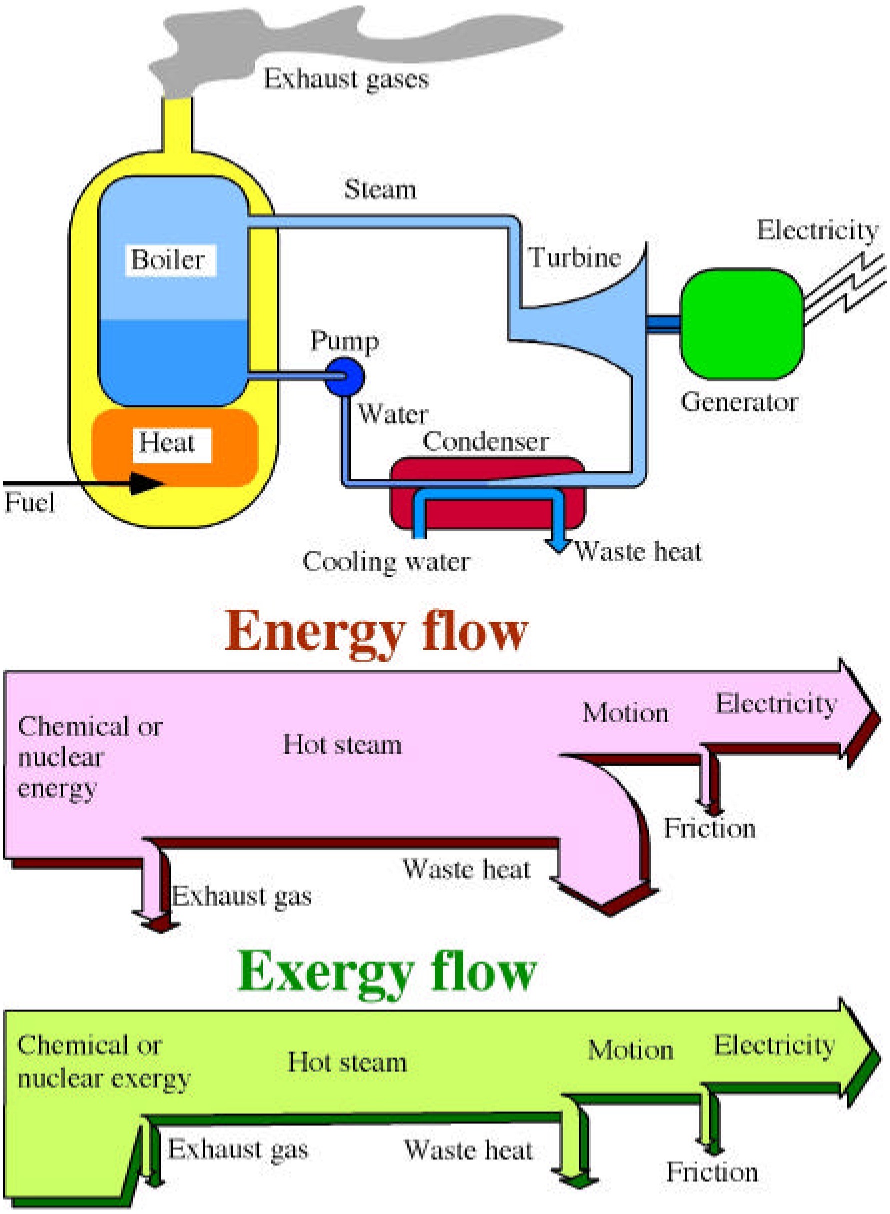

Figure 13. Energy and exergy flows through a condensing power plant.

4 EDUCATION TOWARDS SUSTAINABLE DEVELOPMENT

4.1 Sustainable development

There are more than hundred definitions of sustainable development, however, the most widely-used was coined in 1987 by the Brundtland Commission in their report, *Our Common Future*: "*to meet the needs of the present without compromising the ability of future generations to meet their own needs.*" This may sound very attractive since everyone will get what they "need", now and forever. However, this does not free the rich from dealing very concretely with the problems associated with redistribution of current wealth to those who are in greater need. Still, need must be treated with global justice to remain its meaning. The fact that the 225 riches people of the world have more assets than the poorest 3 billion people is not sustainable. Sustainable development must not become a mantra used as an excuse and justification to sustain economic growth at the expense of continued human suffering and environmental destruction. Thus, it must incorporate explicit and well-founded notion of the globe's carrying capacity and an awareness of the consequences of exceeding this. However, since the Brundtland report was presented, resource depletion and environment destruction have only proceeded and worsen. The poor are still ignored and left out with a catastrophe. Thus, the time of lip service must be replaced with action and true change. This implies the fulfillment of moral obligations concealed for generations.

From a sustainable development point of view, present industrial resource use is a dead-end technology, leading to nothing but resource depletion and environmental destruction in the long run. Deposits are exploited, used and become waste in a one-way flow, see Figure 8. Instead we need to develop a vital and sustainable society, similar to what is practiced by nature. A society that feeds from deposits also works against nature, which by storing exergy as deposits creates the essential conditions for natural evolution, see Figure 5.

Nature has so far generated life and awareness by means of natural evolution. Present social evolution is instead governed by increased wealth in terms of money, often indicated by Gross Domestic Production (GDP). This is when asphalt, smokestacks and color TVs replace rain forests, or when rice fields, cultivated for more than 5000 years, are converted to golf courses. This myth of progress must be questioned if we are serious in our efforts for sustainable development. At first we must find the roots to the problem. Then, we must work for a change through education, true actions, practical exercises, and precaution. Finally we must secure a guidance based on morals and responsibility.

4.2 Creativity and quality instead of empire building

The present empire building mentality that characterizes the society has a paralyzing impact on creativity and development, particularly sustainable development. The situation was well described by John Lennon already in 1970 (*Working Class Hero*):

As soon as you're born they make you feel small
By giving you no time instead of it all
Till the pain is so big you feel nothing at all
They hurt you at home and they hit you at school
They hate you if you're clever and they despise a fool
Till you're so fucking crazy you can't follow their rules
When they've tortured and scared you for twenty odd years
Then they expect you to pick a career
When you can't really function you're so full of fear
Keep you doped with religion and sex and TV
And you think you're so clever and classless and free
But you're still fucking peasants as far as I can see
There's room at the top they are telling you still
But first you must learn how to smile as you kill
If you want to be like the folks on the hill
A working class hero is something to be
If you want to be a hero well just follow me

The empire building mentality manifests itself in almost every organization. The organization of most Western companies is described in Figure 14. In the top is the CEO and in the other end the union leader - two "emperors" with a common goal - power, in which the workers and the objective of the company often are lost. Note the missing heads of the workers. They are not supposed to make decisions but to follow orders. The organization is strongly hierarchic and is based on complete control and obedience.

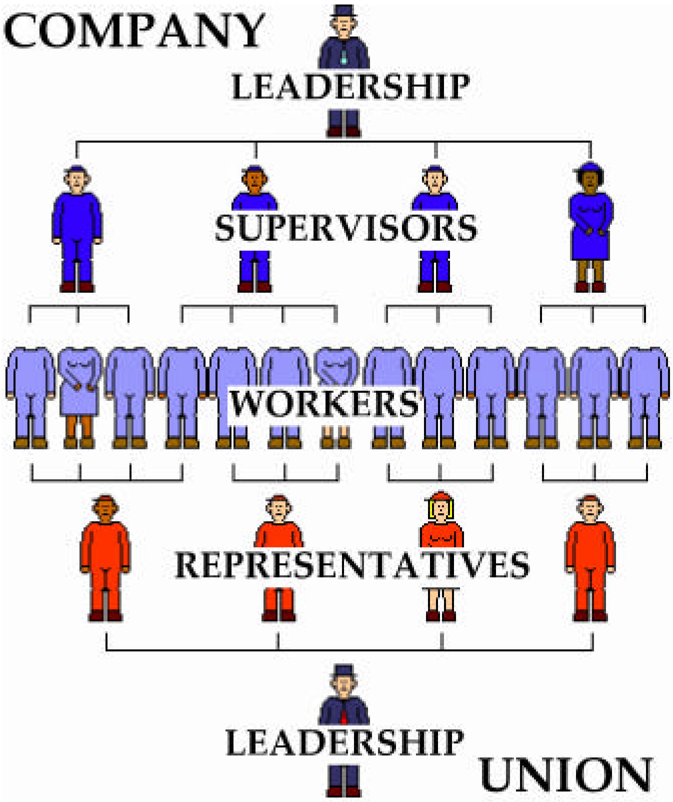

Figure 14. Empire mentality as two leaderships in a company

An obvious, risk of centralizing decisions and reducing the workforce to act on command is its impact on creativity, competence and competitiveness. Many companies competing on a free and unpredictable market have faced bankruptcy. Creativity is essential to the quality, development and greening of industry. This has successfully been met by employing total quality management (TQM) measures and more of democracy and anarchy, i.e. increased influence and responsibility to the workers. W. Edwards Deming has summarized 14 rules for quality management:

1. *Create consistency and continuity of purpose.*
2. *Western management must awaken to the challenge, must learn their responsibilities, and take on leadership for change.*
3. *Eliminate the need for and dependence upon mass inspection.*
4. *Reduce the number of suppliers. Buy on statistical evidence, not on price.*
5. *Search continually for problems in the system and seek ways to improve it.*
6. *Institute modern methods of training, using statistics.*
7. *Focus supervision on helping people to do a better job. Provide the tools and techniques for people to have pride of workmanship.*
8. *Eliminate fear. Encourage two-way communication.*
9. *Break down barriers between departments. Encourage problem solving through teamwork.*
10. *Eliminate the use of numerical goals, slogans, posters for the workforce.*
11. *Use statistical methods for continuing improvement of quality and productivity and eliminate all standards prescribing numerical quotas.*
12. *Remove barriers to pride of workmanship.*
13. *Institute a vigorous program of education and training to keep people abreast of new developments in materials, methods, and technologies.*
14. *Clearly define management's permanent commitment to quality and productivity.*

By establishing a creative and engaging atmosphere knowledge and competence will increase. Its impact on competitiveness is one of the major factors behind Japan's economic "miracle". A quality based industry management is not hierarchical, but flat, see Figure 15. Many companies also recognize the importance of the customer.

Figure 15. A company with a flat organization based on total quality management

Successful results from applying quality measures and increased democracy and anarchy in organizations should be further elaborated and adopted to a larger extent in the society. Adopting TQM principles together with engaging and educating the workforce on environmental issues are essential steps in the greening of industries. The message to industry is clear: meet the challenge ore die. Leadership is not a social class but a social task. Industry leaders that do not represent sustainable development will be replaced.

4.3 Education

Children should come to school to develop their unique personality or their unique skills and character, however, school is mainly disciplin, loyalty and obedience. The situation is well captured in the writings of a Swedish student: "*first you enjoy it, then you become bored and finally you get used*." Surrender and submission is a key to minimize the pain, as John Lennon expressed it. Unfortunately, education is poor on teaching learning as well as unlearning. Too many young people leave school with a fear for knowledge. Education must rather concentrate on how to learn, a process that is unique for everyone, just as other qualities mentioned above. Instead learning must be joyful and foster creativity. The care and training of the young generation in the world is partly left to commercial interests, and their messages differ completely from that of most parents (see Table 3). In short, the messages are: "Think and act!" versus "Act and don't think!" One tragic success of the commercial educational system is the increasing number of teenage smokers, particularly girls, all over the world, which of course brings further profit to the tobacco companies. The education of the rising generation must be of major concern within the society if we are serious about a sustainable development as well as the health of our children.

The essence of bringing up next generation has been made explicit by Astrid Lindgren: "*Give children love, more love, and even more love, then common sense will come by itself.*" However, love is a rare commodity in the world, particularly for children. Also, who will support the education of people that puts love, common sense and sustainable development in front of the national and commercial interests? Indeed, directing education towards sustainable development will challenge nationalism, materialism and consumerism. Thus the educational establishment has to clash with political economy within which it is embedded. However, if they succeed it may lead to a world of social justice, equity and ecological balance. Within the school this would mean that democracy, responsibility and morals must be practiced together with "joy in learning".

Table 3. The messages to children from most parents versus that of commercial interests

What most parents wish	The commercial message
Care, understanding, and respect	Ruthless, violent, and selfish
Honesty	Being "smart"
Generous and pleasant	Demanding and self-centered
Deeply rooted	Rootless
An interest-free economy	High interest rates
Planning far-ahead	Living for the moment
An interest in nature	Worshiping Metropolis, CNN, and MTV
Enjoying peace	Action and high-jinks
A sense of nature conveying security	Nature seeming intimidating
Thoughtful and careful	Ventures and daring = winning
Looking for true values	Looking for action and easy money
Giving in love	Sexually demanding
Being oneself	Being artificial, and fashionable
Skeptical of motorism	Worshiping motorism
Do it yourself (DIY), saving, and repairing	Consuming, throwing-away, and buying new
Regarding oneself as a part of all	Regarding oneself the "be-all"
Avoiding tobacco, liquor, and drugs	Using tobacco, liquor, and drugs
Putting the children before the career	Putting the career before the children

4.4 Possible practical steps towards sustainable development

Most of the present activities in modern industrialized societies or products on the market do not belong to a "green" society. This is a problem, since it also interferes with traditional economic interests. These interests must be replaced to fit into a sustainable development just as traditional management has been successfully replaced by TQM. So far sustainable development mainly involves addressing some general principles or establishing often costly certificates, e.g. ISO 14000, or "green labels" to put on products, whereas legal means or effective concepts and methods are absent. Too much of environmental work is dedicated to greenwash and massive propaganda to give people a false sense that the situation is improving. In the long run this only prolongs a necessary and thus more costly change towards sustainable development. The sooner we realize that future has no room for fossil fueled cars and other resource depleting and environmental destructing products the better.

Ecotechnology, ecological engineering and ecological design are new promising methods to minimize the costs of measures and their harm to the environment. These methods will be successfully marketed by future industries. Ecotechnology should not manipulate the genes, but respect nature as a self-designing system, thus, ecotechnology is working on a higher level of complexity than biotechnology. This self-designing capacity is a significant feature, because nature will do some of the "engineering." Ecological engineering is like gardening that is able to make the best sustainable human use of nature. This involves complex problems of complex systems that will require a deep ecological and engineering knowledge to understand. Thus engineering together with ecology becomes a foundation of ecotechnology. An "ecoengineer" must be able to manage the metabolic processes in both society and nature in a sustainable way, thus to master exergy and exergy based methods are essential. At first "ecoengineering" must develop new technical solutions towards sustainable development that are applicable to existing systems. Priority should be given to systems that easily could be redesigned to reduce resource use and environmental destruction without serious social implications. Two such examples are building design and farming, which will be further described below.

A very promising novel scientific and technological project on ecotechnology was recently launched by Japan National Institute of Resources and Environment (NIRE), see http://www.nire.go.jp/eco_tec_e/index-e.htm. NIRE attempts to conduct fundamental research toward the development of ecotechnology, which is classified into; (1) Minimum Environmental Impact (MEI) and Maximum Energy and Resources Utilization (MERU) technologies, (2) environmental behavior of offensive substances, and (3) evaluation of environmental, energy and societal safety. MEI technologies include generic processes that emit less pollution, recover and detoxify pollutants, and remediate the polluted environment. MERU technologies are related to energy and resources conservation, and the development of renewable resources. The second category is exemplified by source inventories of environmentally offensive substances, and the elucidation and modeling of their behavior with respect to transportation and transformation in the environment. The third category relates to the construction of a system for the evaluation of environmental impacts, energy usage, chemical materials safety, and the hazards to society. In pursuit of human progress through advances in science and technology, NIRE has contributed to energy and resources development, and environmental protection. In view of creation of ecotechnology to ensure sustainable development, NIRE will endeavor to make further progress in research and development to unify industrial technologies with environmental technologies.

From the description of the use of energy and material resources in society, it is obvious that the use of deposits must reduce. This could be achieved through a more efficient utilization of resources. It is also of essential importance that resource use is changed to more renewable resources. Possible steps in this direction are already available just by starting from the design of many buildings. An ordinary house in most parts of the world with winter seasons, e.g. North America, Europe and Northern Asia could be built or modified as in Figure 16. I have rebuilt my own house in Sweden originally built 1922 accordingly, with all energy used for heating and other purposes supplied from wind power, and the result is very encouraging, see http://www.exergy.se/goran/swedish/artiklar /hus.html. A typical apartment house in Sweden rebuilt according to Figure 16, would easily become self sufficient with energy for space heating. This implies additional insulation of the construction and better windows, measures that are suitable to take similar with regular renovation. These measures will also offer jobs for people where they live. In addition, equipped with photovoltaic cells to generate electricity from sunlight, roofs could make a considerable contribution to the electricity production. The total yearly inflow of sunlight to a typical house in Sweden accounts to about 100 times the exergy needed for space heating of the same house. Wind power is another example of an ecotechnology that presently is increasing by about 40 percent every year. Thus, the opportunities for ecoengineering when it comes to improving house design are enormous. In addition, the local environment in most housing areas is poorly utilized. There are often suitable areas available for small farming and production of fruits and greens. This, may also engage people in meaningful activities, bring them together and create a suitable atmosphere for further learning about sustainable development. Areas for common use should be made available as is indicated in Figure 16. A greenhouse, which will offer fresh vegetables, is also an excellent way of bringing people together in a creative way. The house design should as much as possible be done together with the people it is suppose to host. Eventually part of the final design can be left for people to decide themselves. This will encourage engagement, imply responsibility by making them response-able, and support local democracy, all important parts of the social dimension of sustainable development. Doubtless, people also has a lot to offer of knowledge and experience for the ecoengineer to learn from. Ecoengineering must work together with both the local environment as well as the people involved.

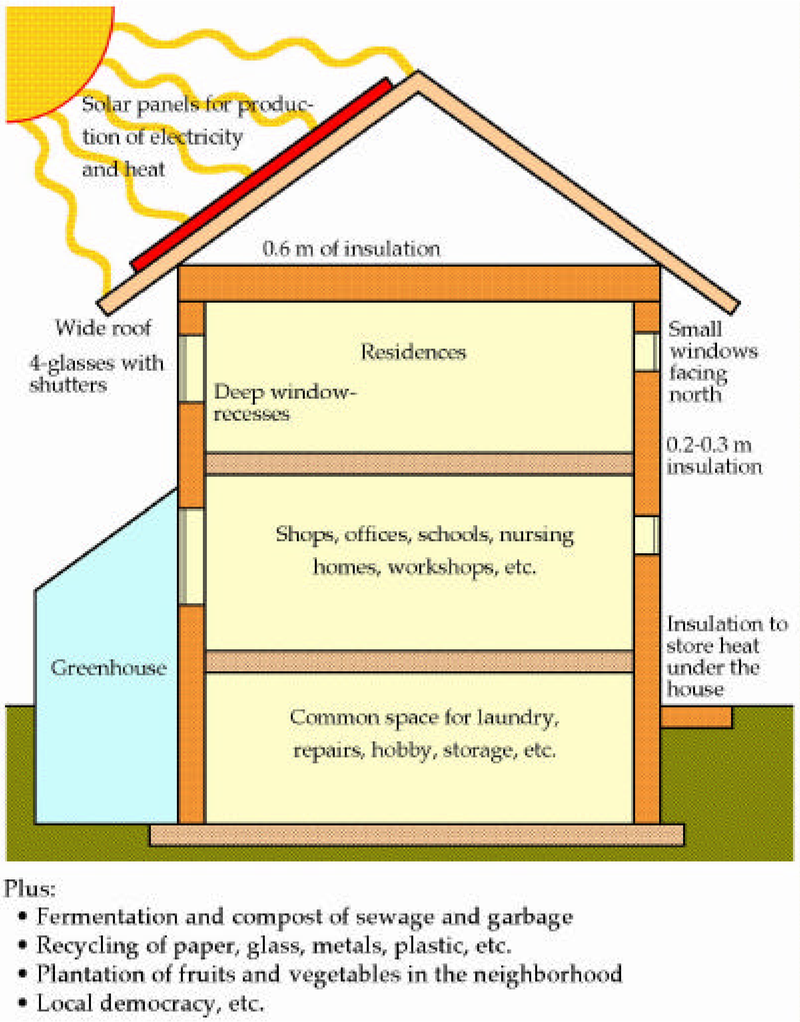

Figure 16. An ordinary house made more sustainable

Most resource use in modern society is linked to poor management of housing and transportation. Modern city planning suffers from a tendency of elephantiasis. By concentrating social functions such as living, working and shopping into separate big units distances increase and transportation becomes a necessity. Efficiency decreases. This in turn increases the production of cars, gasoline, roads, etc, thus, increasing the environmental impact. This, transformation also has a negative impact on the social life of modern cities, e.g. the suburbs becomes ghost towns in the daytime and the city centers are crowded with people and cars. An unpleasant, unhealthy and dangerous lifestyle characterizes most big cities. The social consequences are equally tragic. Family members are kept separated most of the day. It is not unusual that people spend several hours every day just for transportation—truly unproductive, unhealthy and environmentally destructive. By making better use of our houses and their surroundings, during the whole day and night, we could reduce both time and resources spent on space heating and transportation. There is nothing that prevents most houses to be used both for living as well as for working activities. Many cities used to have houses holding a small shop facing the street, a small factory on the backyard and living premises on the second floor. A walk through older parts of most cities in the world will visualize this as. With today's fast and efficient communication technology there is less need to transport goods and people. Thus, houses should be designed to host residences, shops, offices, schools, nursing homes, workshops, etc. Also, this would have a positive impact on most people's social welfare as well as on environmental pollutions. Figure 16, offers a simple exercise to further elaborate and develop to meet local needs for global sustainable development, i.e. think globally and act locally.

Sustainable development does not mean that we have to work more. Instead we have to work less, but cleverer, i.e. make better use of natural resources and time. The present inefficient use has tragic direct effects also on people. Sudden-adult-death or *karoshi* as it is called in Japan is today becoming a world phenomenon. Many people suffer from an unhealthy work load. This also implies a more careful design of our working conditions.

Besides, solving the problems of energy supply through better housing and less transportation we must also develop techniques of recycling. Paper, glass, metals, plastic could be separated in the households in order to facilitate further treatment towards recycling. It is also important that producers improve and simplify the recycling of packing materials in a profitable manner. The nutritious materials in food must be brought back into agriculture, similar to the recycling of nutritious matter in the biosphere, see Figure 5. How to maintain and sustain fertile topsoil to produce healthy food is probably the most serious problem humankind faces. In traditional farming all substances that are brought from the soil, as foodstuff, are carefully returned as fertilizers, see Figure 17. In this way humans are natural consumers in the local ecological systems, see Figure 5. Essential substances of nitrogen, phosphorus etc. are used in a sustainable manner. The maintenance of the fertility of the topsoil is of utmost importance for a sustainable society. Farm lands in China, which have been in use for more than 5000 years, provide an efficient, sustainable model. Fertile topsoil is a most precious resource for a sustainable culture. This is the lesson to learn from many fallen empires in human history.

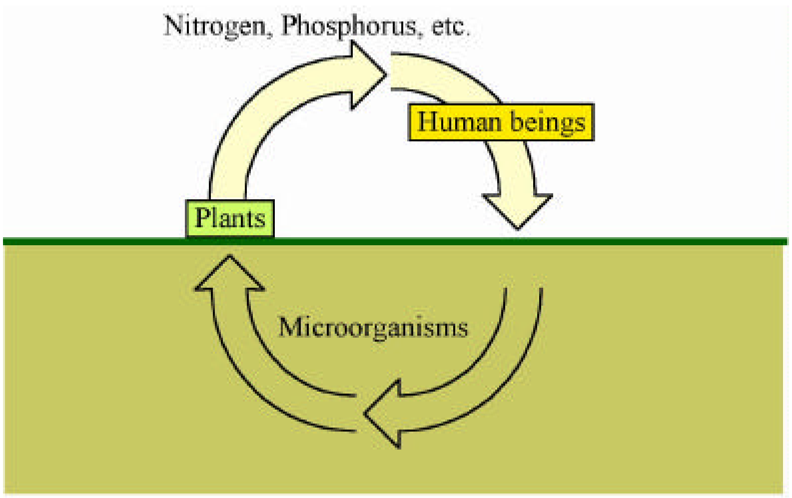

Figure 17. Traditional farming with recycling of matter in order to be sustainable

With industrialization came the industrial farm, characterized by use of artificial fertilizers, pesticides, and heavy machinery, driven mostly by fossil fuels. Improvements were measured in terms of increasing yield per land area and decreasing input of human labor, as well as a shift away from vegetables. With artificial fertilizers human waste becomes a disposal problem, and the water closet is introduced as a solution to this. However, this made the problem even worse, see Figure 18. From mass conservation principles, all substances that cross the dashed line must balance. Thus, the added fertilizers together with the human waste end up as additional nutrients in the adjacent environment. The pitfall is the water closet. Since the amount of fertilizers well exceeds what the plants assimilate, this will also add to the outflow. The total outflow of nutrient then instead creates heavy damage to the ecological system where it ends up. The natural microorganisms are also wiped out from the fertile topsoil. For the traditional farmer these organisms are essential, but not to the industrial farmer. Future agriculture must learn from this to be sustainable by adopting ecological engineering, e.g. permaculture. However, the situation is even worse than this.

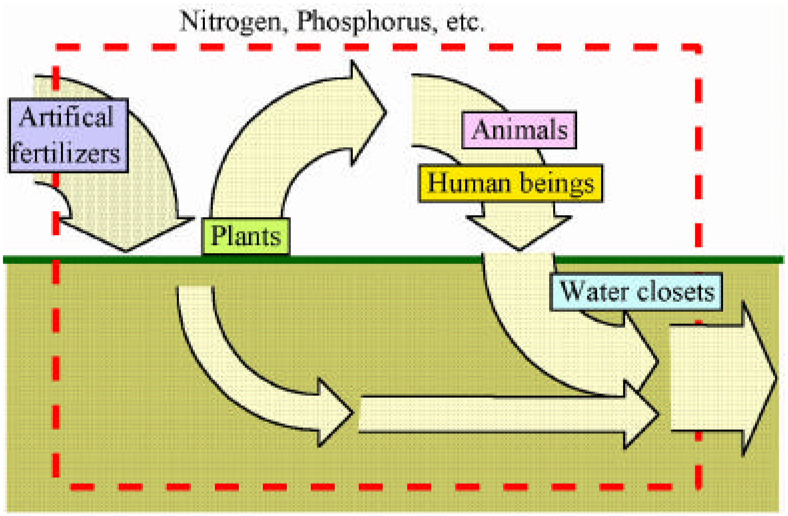

Figure 18. Modern industrial farming with artificial fertilizers and water closets

Artificial fertilizers not only bring nutrients to the soil, they also carry unwanted substances such as heavy metals, e.g. cadmium and lead. This is indicated by dots in Figure 18. These substances accumulate, thus, contaminating both the topsoil and food. This is a most serious growing problem in many parts of the world, particularly, in the developed world. Acid rain adds to this problem. The problem can only be solved by terminating the artificial input of fertilizers and safely returning natural human waste to the topsoil, see Figure 17. This change also goes hand in hand with the increasing demand for ecologically-sound food products—which is also a sign of demand for sustainable development. Modern industrial farming with artificial fertilizers and water closets without recycling of nutrients, withholds the ecological system, i.e. the farmland its necessary nutrients. The task for ecoengineering is to bridge these two misuses of resources in order to solve two problems with one solution that in addition will offer the consumers a better food and health. Future "green" agriculture industry will solve these problems in a sustainable and profitable way.

The technical solutions indicated in Figure 16 are all available on the market, but, traditions and institutional barriers often prevent these improvements from being realized. Sewage treatment systems that do not safely return natural human waste to the top soil must be avoided.

4.5 University Inc. and Morals Ltd.

The present situation for humankind is clear. With present direction we are heading towards a catastrophe, just like the glorious "unsinkable" M/S Titanic. One may argue about details, such as how or when, but not that a culture based on resource depletion and environmental destruction is doomed. So, why is nothing done? Present science is mainly busy measuring how the catastrophe proceeds or busy glorifying itself. It also lacks perspective, scientists work inside "tubes", without connection to other "tubes". The outside world is often regarded as non-science or of no interest. Pirsig calls it a "*cultural immune system … First you say things our way and then we'll listen to you*". The scientific society is somehow also caught in a situation of continuous apply for funding—survival—from governmental or industrial establishments. A paramount consideration for most scientists is funding, just as reelection is for most politicians. The situation is also dangerous for science itself because science is ruled by non science. Science becomes often valued by the size of the budget and managed by loyal "dollar scientists". What government or institutional establishment will support critics? Very few, I am afraid. Too much of science is also engaged in awarding and decorating each other. Nature is hardly impressed by Nobel prizes and when fuel oil companies or car manufactures offer multi million dollar green awards. These activities of party games for the sake of mutual admiration or "bribery" should be avoided. The situation inevitably brings prostitution to mind. Still, neither Darwin nor Einstein would have been funded by the academic establishment. This is a serious problem. Few consider the reality. Morals are banned by science, or as Pirsig (1992) expressed it "*morals have* *been declared intellectually illegal*". Morals are lost in politics and revealed from economics. The famous joke by Alan Sokal, professor of physics at New York University, exposes existing serious weaknesses in the scientific society. A leading journal of cultural studies may publish rubbish if it is academic mumbo jumbo and it flatters the editors' ideological preconceptions. All this creates an excellent environment for myths and fallacies to flourish in society. And even worse, forces and interests that gain from this. When a journalist recently asked one of the major universities why they practiced so high salaries for some professors, the answer was that the they will bring so much funding to the university, i.e. University Inc. This will gradually corrupt the whole idea with the university.

Limited company, i.e. Ltd. and Inc., is a company whose owners are responsible only to a particular level for the money that it owes. This may be a way for individuals to become extremely rich without any moral obligations, i.e. without being responsible for their actions. A tragic consequence of this is illustrated by the following example. The lobbying and PR company Mongoven, Biscoe and Duchin in 1993 made the following degrading characterization of environmentally concerned and committed people. First they categorized environmental activists into four groups: radicals, opportunists, idealist and realists. "*The radicals are difficult to handle. They work for social justice and for public control of industry, and their response to corporate overtures is impossible to predict. Opportunists work in the environmental movement mostly to be seen and to promote their career. They are often satisfied with some kind of partial concession. The idealists cannot be bought, but they can be backed into harmless positions with the help of realists, namely, those working towards pragmatic agreements with industry. The strategy to undermine the environmental movement is, therefore, to negotiate with the realists, neutralize the idealists, and isolate the radicals. Then, the opportunists just follow along.*" Besides, exposing ignorance and arrogance it explains the increasing practice of lip-service and greenwash. As long as greenwashing can serve the capital interests the same purpose as real actions and at a lower cost, there seem to be no moral obligations to prevent this. This becomes a human tragedy, when we consider that the future of this world is mainly in the hands of these multi-national companies with limited responsibilities. However, this should not be a surprise to anyone. Textbooks on business economics and management are not about moral issues, it is on the making of profit by any means as long as they are legal. Economic corporations as Inc. and Ltd. are legally sanctioned institutions legally released from moral responsibilities and obligations. Actually, a CEO that acts from moral obligations might be irresponsible to the shareholders. Thus, the legal conditions for these institutions must be revised to meet moral obligations. To wait for this to occur by itself is to wait in vain. It is equally important to limit the commercial influence on education and research at universities. The independence of these knowledge centers is essential for the development of true and independent science. Science in the hands of military interests is responsible for "monsters" like the neutron bomb and the landmine. Thus, commercially controlled science would be a disaster for humankind. Instead, science and scientist must act with greater responsibility and adopt moral obligations. The social construction of Ltd. must be replaced by organizations that can guarantee a moral behavior and sustainable development.

4.6 Culture of Peace

A most common believe that is generated from empire cultures is that humans are inherently evil and that it is only from discipline and obedience this can be fought. Thus, this culture of evil or violence acts to support the empire. Violence is a natural and entertaining part of modern culture. 10 minutes with CNN or any other news media is enough to proof this. During childhood most children are exposed to countless number of carefully committed and depicted acts of murder. There is no scientific evidence that human by nature is evil. Still, this tragic believe is deeply rooted among many people. Thus, to realize a culture of peace will be a most challenging and revolutionary experience, however, essential for sustainable development. It will be a complete turnover of the present paradigm.

It seems that industrial technology freed from moral obligations and justified by economics has given virtually free rein to material greed, no matter the consequences. The need of a moral approach to meet this culture of greed or self-interest towards self-destruction is obvious. Even the most sophisticated genetic engineering cannot meet this problem. There is no gene for greed. Many representatives of indigenous cultures have expressed the necessity of governing a society by morals in order to be sustainable. This has also been stated by many prophets and philosophers as well as in many old writings. For instants, the Seven Deadly Sins: arrogance (*superbia*), greed (*avaritia*), voluptuousness (*indivia*), gluttony (*gula*), anger (*ira*) and ignorance (*acedia*). These well known ethical rules with equally well known consequences are simple rules to practice in every persons live. They offer very simple easy to understand guidelines that are essential for sustainable development. These must be declared immoral by the society, and the opposite must be practiced in a sustainable society.

If we consider the potential happiness that our world is able to create, instead of the prevailing injustice and poverty, then we live in a tragic era of humankind. Never before in the history of human have the possibilities to establish a decent and peaceful life for everyone been so great. The total amount of food and other assets are more than enough for everyone's need, i.e. a decent life. Still a human starve to death every four minute. The case of Cuba is interesting to address in this regard. This is a unique example of how a country almost completely isolated from the rest of the world in terms of medicine, food supply, economic aid, etc, still, is able to offer its people good health and education. By some regarded best in the world. A key to this may well be the fact that the Cuban Constitution places children as the number one priority. Probably, the rest of the world has a lot to learn from Cuba on sustainable development.

I am the first to regret that part of this presentation is not a pleasant reading. However, this does not make me a pessimist. I am a true optimist when it comes to the survival of humankind, but a sustainable future will have no place for cultures based on resource depletion and environmental destruction. They will become the "dinosaurs" of the future, and the guarantor for this is nature itself. A main problem as author is to address issues of injustice and violence without making anyone feel accused. We are all victims. This is not the time for accusation. So let us join hands in a spirit of friendship and peace. Let us share the wealth of the world as sisters and brother. There is more than enough for everyone. Let us go together to meet Nature for a sustainable development and to establish the social structures that support this. These structures are based on an education committed to sustainable development. This vision of a better world and how to reach it is poetically captured by John Lennon in his poem *Imagine* from 1971. This is a vision for all of us to meet with the best of our abilities:

Imagine there's no heaven
It's easy if you try
No hell below us
Above us only sky
Imagine all the people
Living for today...

Imagine there's no countries
It isn't hard to do
Nothing to kill or die for
And no religion too
Imagine all the people
Living life in peace...

Imagine no possessions
I wonder if you can
No need for greed or hunger

A brotherhood of man
Imagine all the people
Sharing all the world...

You may say I'm a dreamer
But I'm not the only one
I hope someday you'll join us
And the world will live as one

5. CONCLUSIONS

Time to turn is here. Time to learn and time to unlearn has come. Education must practice true democracy and morals to enrich creativity and knowledge by means of joy in learning. Culture of peace must replace cultures of empire building, violence and fear. The torch of enlightenment and wisdom carried through the human history must be shared within a spirit of friendship and peace. This must be based on a true understanding of our physical conditions. Exergy is a concept that offers a physical description of the life support systems as well as a better understanding of the use of energy and other resources in society. Thus, exergy and descriptions based on exergy are essential for our knowledge towards sustainable development.

Exergy is a better concept than energy to describe the use of energy and material resources in the society and in the environment. A society that consumes the exergy resources at a faster rate than they are renewed, is not sustainable. From the description of the conditions of the present industrial society, we may conclude that this culture is not sustainable. One may argue about details, such as how or when, but not that a culture based on resource depletion and environmental destruction is doomed. The educational system has a crucial role to play to meet this change towards sustainable development.

Acknowledgments - This paper partly origins from my work in UNESCO's Encyclopedia of Life Support Systems, see http://www.eolss.net, which is hereby gratefully acknowledged. This encyclopedia is unique since it is a humble invitation to share present knowledge towards sustainable development. Feedback from readers will be integrated into a continuous revision of "EOLSS On-Line" to create a **living body of knowledge - a living encyclopedia**.

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