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EXERGY CAPITAL AND SUSTAINABLE DEVELOPMENT

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ABSTRACT
The Exergy Capital of Nature is defined and related to present use of natural resources in the industrial society. Possible future consequences with reference to natural evolution and the generation of new microorganisms are presented. To meet the need for a sustainable development the exergy capital must be restored or at least be conserved. This means an immediate stop of the use of non renewable resources.

INTRODUCTION
Exergy is often confounded with energy. Exergy is work, i.e. organized motion, or ability of work. Whereas, energy is motion or ability of motion, i.e. not necessarily work. Exergy relates to the second law of thermodynamics and the works of Sadi Carnot (1796-1832) in 1824 and of Willard Gibbs (1839-1903) in 1873. The term exergy was coined by Zoran Rant (1904-1972) in 1953 from the Greek words *ex* (external) and *ergos* (work). Exergy appear in physics as energy, matter and information and is of principal importance to the understanding of reality. A universe with energy in complete equilibrium would have no exergy, no contrast, no differences, no patterns and no structures. Also there would be no time since nothing could change. With structures comes exergy, and with interacting structures come exergy conversions and alterations. Energy is always conserved. If exergy was conserved everything could be returned to origin and changes would be reversible. Thus, time would have neither direction nor meaning. Changes must be subject to both exergy destruction and finite time, then changes become irreversible, time will have a direction and there will be meaning. With infinite speed of light the universe would turn into equilibrium instantly and time would never appear. Let us summarize: energy create existence, exergy create structures, and exergy destruction and limited speed of light create meaningful changes, i.e. time. The rest is evolution managed by Nature.

NATURE

Fig. 1. The Sun-The earth-space system.

Seemingly dead structures in space convert into non predictable self-reproducing structures as life and life forms, by means of converting and partly destroying exergy. Exergy feeds life. The earth is unique to life due to its size and position in the contrast between the sun and space, see Fig. 1. Nature creates a state far from thermodynamic equilibrium on the earth by an everlasting redesign of the environment mainly powered by the exergy from this contrast, i.e. sunlight, see Fig. 2.

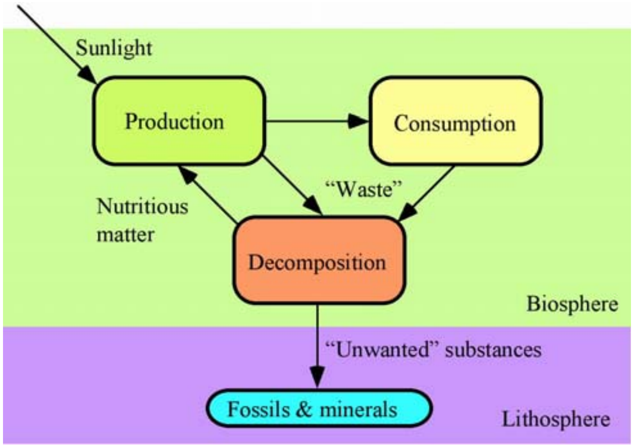

Fig. 2. Nature builds up an exergy capital as deposits of fossils and minerals in the lithosphere through the living system.

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. Green plants, which represent the production process, convert exergy from 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 the lack of natural resources, such as solar exergy, 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 Fig. 2. Thus, a minor part of the incoming solar exergy is stored on the earth, which is a key element in nature's process of evolution.

Sustainability in nature is not a static state, but rather a state of constant change or evolution. A fraction of the circulating material is constantly removed; thus creating a constant change in the environment; a redistribution of matter. The total amount of exergy as fossil carbon in the earth's crust is estimated to be about $6.6x10^{26}$ J which is equivalent to about 120 years of solar inflow to the earth. Simultaneously, the content of oxygen has increased in the atmosphere at the expense of carbon dioxide. Thus, exergy is being stored as increasing contrast, or a growing amount of so called natural resources in the lithosphere. This is the earth's exergy capital. When this capital is dispersed, e.g. by combustion of fossil fuels, this capital is lost for ever. Well ordered structures and concentrated substances are demolished and spread as pollutants in the environment. Thus, the process of creating order through natural cycles is being reversed by the industrial society. Nature redistributes material substances and reshapes its environment so that highly sophisticated structures can develop in order to make the evolution of life possible. Initially, material substances were organized into systems, which were able to reproduce themselves. This is the essence of life, see Fig. 3 The relation between exergy E and information I is simply $E=kT_0I$, where k is Boltzmann's constant and T_0 is the ambient temperature. (Ref. 1) The indicated processes of change, i.e. life and mind, in Fig. 3 should not be taken to appear exactly in time, this is just a simple model for the sake of understanding. Also, the exact meaning of life and mind defy precise definition.

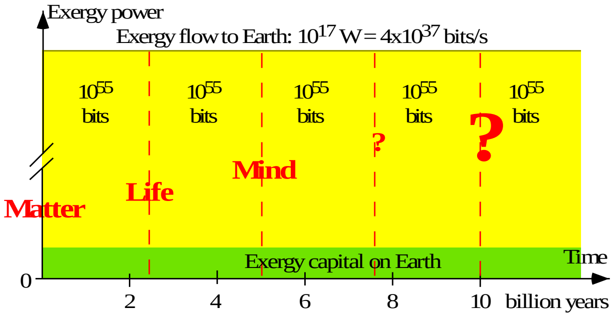

Fig. 3. A tiny part of the exergy flow from the sun to the earth is stored in deposits on the earth, while matter is organized into life and further into the mind, and further into …?

Apparently nature has the machinery to create highly sophisticated and ordered structures operating in space and time. Obviously, there is a strategy acting behind the scenes. Exergy capital on the earth is essential to the evolutionary process that characterizes living nature. Over billions of years nature has gone through an enormous process of change, which is so powerful that it has completely changed the life conditions on the earth. This story can be told in terms of exergy. An estimation of the exergy from the separation of carbon dioxide into carbon deposits, and oxygen into the atmosphere, is indicated by the green area in Fig. 3, where the size of this area is exaggerated in order to be visible. The relation between the yellow and the green areas are about 6 billion years to 120 years or 50 million to 1, see above. This build up of an exergy capital is of vital importance for life and for evolution on the earth.

Obviously, nature operates in a very intelligent way. By capturing huge amounts of exergy in the earth it creates an enormous contrast, which is able to generate life with very little effort. Look at a simple potato: the difference between whether it is dead or alive is not physically measurable. However, planted in soil the difference is undeniable. The interactions within this system, which give rise to life on the earth, are inordinately complex. Let us compare the situation with the creation of a piece of music on a violin. This needs a well-tuned violin, which resembles the deposits on the earth. A musician could then, with a small effort "bring life" to this wooden box. No one would ever imagine using the violin as firewood, especially not a Stradivarius. However, this is exactly what happens in the name of economic development, when mineral deposits are extracted at the current unsustainable rate. Keeping the genetic codes or the music sheets is meaningless if we also destroy the environment or the instrument, i.e. the capital.

If all exergy capital, i.e. funds and deposits on the earth, were used up this would mean that minerals of the lithosphere were oxidized and most of the oxygen in the atmosphere were depleted. Then most life forms, as we know of today on this planet would disappear. The earth would be brought back to a state similar to that seen at the creation of our solar system, i.e. some five billion years ago. From an ecological perspective the exergy capital on the earth resembles the value of the biosphere. When resource deposits are exploited and used this literally means that we deplete the life support systems, since the preservation of these deposits are essential for the support of life. Global exergy accounting of natural resources provides a good understanding of the present ecological crisis, pinpointing problem areas and maybe providing solutions. Also, this knowledge is an essential part of a new paradigm to guide science towards a sustainable development.

Life may be regarded as the organization of matter in space and time into living organisms, as mentioned above. Matter as specific molecules are essentially the "building blocks" of life. On Fig. 3 it is positioned at the first level on the evolutionary scale. Going up the scale life, or living organisms, advance and evolve towards the level of the mind, i.e. the state of being aware. This higher level of organization is "carried" in particular by intelligent life forms, i.e. species with large brain capacity. At this level living organisms are acting as the "building blocks" of awareness. Logically the next level must in some way involve awareness as "building blocks." However, it is just as impossible for a human being to predict future levels of organization as it is for an atom to describe the complexity of a bacteria or for a bacteria to explain the beauty of a piece of poetry. It is simply out of range of our imagination. In this regard, the human brain is far too "stupid" to grasp this enormous intelligence we call nature. We can only show respect and humility for the power and beauty of nature. Nature is so intelligent and immense that science will just go on creating new patterns eternally. Thus, the unknown will always be there. This knowledge is also an important part of a new paradigm. Science must always treat the unknown with highest respect, if not hubris may be its fate.

The increase of exergy capital on the earth is of essential importance for life to evolve. However, present industrial civilizations exploit and destroy this exergy capital in an unsustainable manner that inevitably leads to an ecological and social catastrophe.

SOCIETY

Present industrial society, is built on a non-sustainable resource use, see Fig. 4. The exergy capital of nature is exploited and 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, see Fig. 5. The present use of resources in the 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 the earth's scarce resources be seen as a productive activity, either physically or biologically?

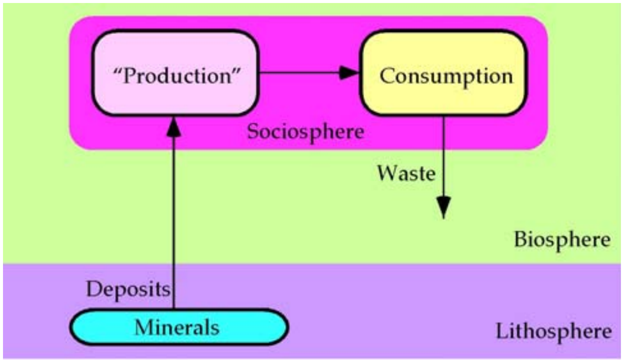

Fig. 4. Society exploits the exergy capital of deposits and dump the waste in the environment.

Figures 2 and 3 show 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 Fig. 4.

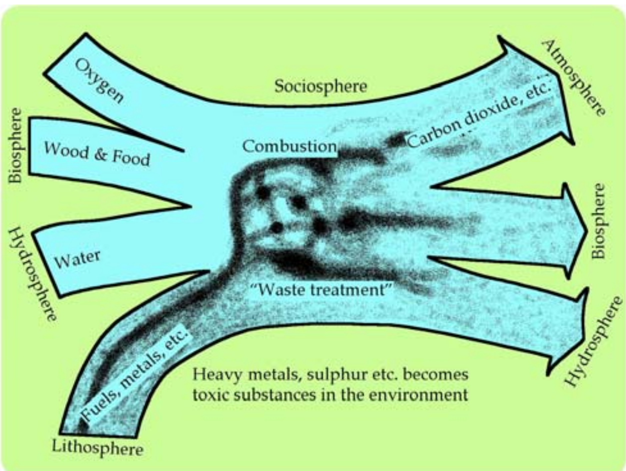

Fig. 5. Resource depletion and environmental destruction are two parts of the same problem

The present situation can be better understood from Fig. 5, where resource depletion and environmental destruction are two parts 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. 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. This 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, see above.

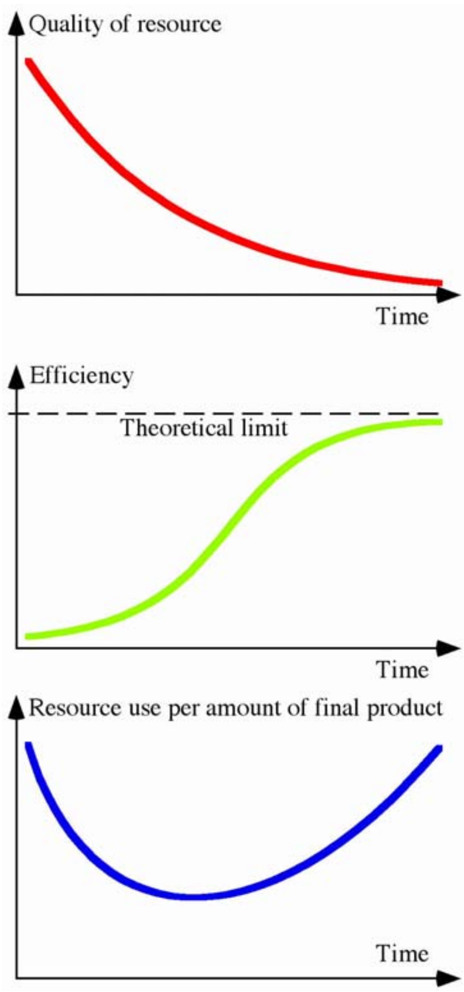

Fig. 6. Major trends in the extraction of deposits.

There is another major trend in the use of natural resources by society that also must be considered. Due to the continuing use of deposits, the quality of the remaining deposits decreases, see Fig. 6. 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 middle curve of Fig. 6) could almost 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 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 middle 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 curve of Fig. 6. This is an unavoidable consequence due to the use of non-renewable resources.

In Fig. 7, 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 even more. A tank, symbolizes the exergy capital, which contains the funds and the deposits 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, the situation is sustainable. However, if the level is dropping, i.e. the exergy capital is depleting, and 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 if there is, very little. 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 Fig. 6. 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 Fig. 2. 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, see below.

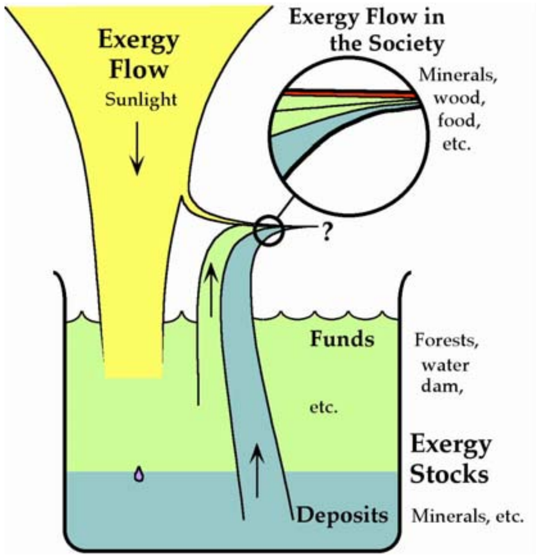

Fig. 7. The exergy flow from the sun, and the exergy stocks on the earth create the resource base for human societies on the earth.

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 Fig. 8. (Ref. 2) Using this technique, the current misuse of resources becomes more apparent, and with this also the urgent need to improve this use.

Figure 8 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.

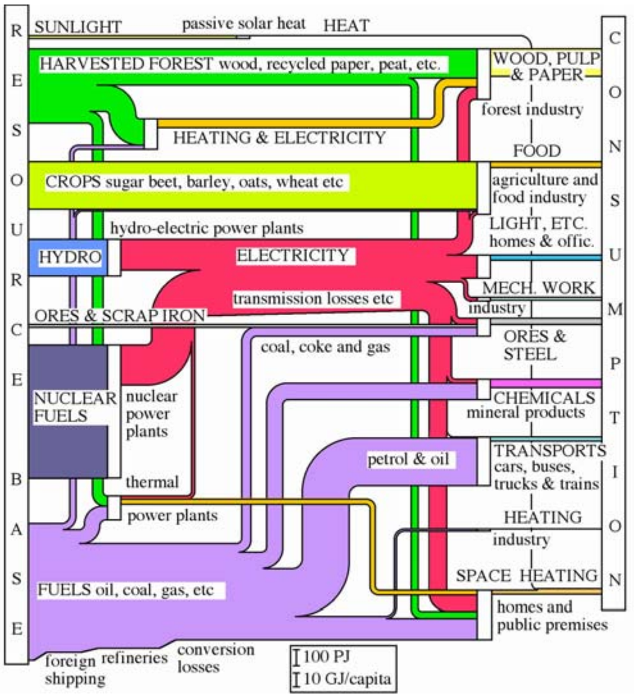

Fig. 8. The exergy conversion system in the Swedish society in 1994. Total input about 2720 PJ or 310 GJ per capita and output about 380 PJ or 43 GJ per capita.

A FRIGHTENING FUTURE

The emission of toxic substances from the industrial society is likely to produce diverse and unpredictable consequences for life support systems on the earth. Probably, It will effect nature's evolutionary processes. New microorganisms may develop, that are better adapted to new environments, altered through the dispersal of huge amounts of toxic or exotic substances, see Fig. 9. Existing microbes or microorganisms, i.e. bacteria, fungi and viruses, provide the conditions on which present life is founded. They are the living foundation of the life support systems on which all other forms of life are depending. Each human being carries about 2–3 kg of bacteria in the digestive system, and we all know the importance of keeping this system in balance. All forms of life are built on the existence of a specified mixture of certain microorganisms.

The incredible power of these tiny organisms must not be ignored. One single bacterium could in theory fill out the entire solar system within a few weeks if it were able to multiply without limitations. This describes the power of the living foundation of the life support systems, which is solely under the control of nature, and the danger of interfering with these processes. However, by changing the physical environment in terms of chemical composition, etc. we create an environment that is unfavorable for existing microorganisms as well as higher forms of life. This may be recorded as a reduction in the number of species. However, the new physical environment that is offered will also encourage new forms of life to appear, initially by modification and creation of new microorganisms that are better fitted to the new conditions, e.g. bacteria that develop immunity to antibiotics. Later, new insects or insects with new characteristics will appear, such as the malaria mosquito that is resistant to DDT. This is what Darwin expresses as "the survival of the fittest." Microbes can withstand the most extreme physical and chemical conditions including high or low temperature, high or low pH, high pressure, high salinity, and toxic substances or radiation, as long as there is liquid water and exergy available. Toxicity is a condition that can be reversed when transferred to different biological systems or exposed to new forms of life. Microorganisms have an incredible ability to adapt to the most extreme environmental conditions. (Ref. 3) A toxic substance is of course harmful for some organisms but at the same time it offers a new ecological niche that soon will be occupied by new organisms. This is an unpredictable and dangerous consequence of environmental pollution that unfortunately is seldom mentioned. Furthermore, the current huge investment into genetically modified organisms such as bacteria and crops may well add further potential danger to this.

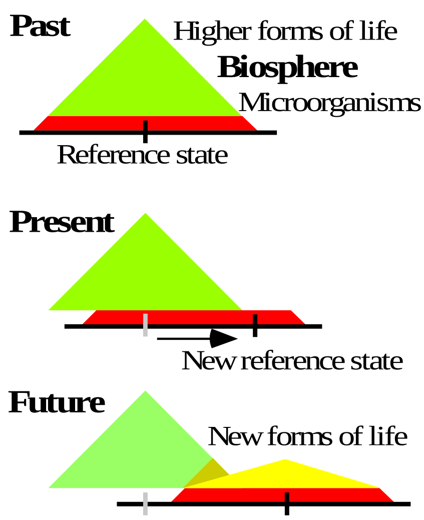

Fig. 9. "The Survival of the Fittest" or the driving forces behind the natural evolution

Thus, industrial society may nourish its own extinction by degrading the biological foundations of human existence. It would be very naïve to believe and rely upon that new microorganism will only have a positive impact on present higher forms of life. The immediate signs of the opposite are the appearance of new diseases and less resistance against existing diseases due to a weakened immune system. Persons with chronic wounds comprise a large number of patient populations. Also the increasing rate of chronic allergy and signs of listlessness among children, particularly in the developed countries, may be signs of this.

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. United Nations Development Programme *Human Development Report* has stated that the annual income of the poorest 47 percent of the earth's people is less than the combined assets of the richest 225 people in the world. Given this obscenely unequal distribution of wealth and income, the top fifth of the world's people consume 86 percent of all the goods and services while the bottom one-fifth must subsist on a mere 1.3 percent. 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. The exergy capital is used and become waste in a one-way flow (Fig. 4). Instead we need to develop a vital and sustainable society, similar to what is practiced by nature.

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. The reason for our failure is a consequence of our deep-rooted weakness of building empires. The so-called human civilizations appearing some 10,000 years ago may be characterized as the beginning of an empire builder era of humankind. This empire building era must come to an end in order to reestablish a sustainable development. 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.

CONCLUSIONS

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. 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.

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.

ACKNOWLEDGMENTS

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