Terra Entropica

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Earth's entropic balance

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Content

Introduction

Never has mankind been as prosperous as today. Man has conquered the earth, lives at a high standard, at least in the more developed regions and multiplies rapidly. The success of the species has been connected with his intelligence. Using it, he has tamed the fire and has further strenghtened his position by detecting and exploiting fossile and prefossile burnable resources.

What, however, will happen if the burning materials are exhausted ? Today , there is no definite answer to that question. It is indicated, however, that man on the average behaves like an arbitrary species which suddenly finds a large amount of food : the population increases as long as these resources exist. Once they are used up, the population is drastically reduced to a lower level or vanishes completely.

Furthermore, since ever more individuals want to live at a high standard during the good times, production and consumption are heated up. As a consequence, the biological basis of mankind gets increasingly destroyed. Once the fossile energy resources are exhausted, probably also the regulative mechanisms of the food basis are destroyed, too, and thus a return to the old ways is impossible.

Global deforestation, poisoning of the water by salts and fertilizers, disappearance of the ocean algae does happen already today. On the other hand, survival in a self made completely artificial environment is impossible without abundant energy resources.

In this situation should one wait until the resources are used up and only then develop assembly lines on the basis of regenerative sources, which then would support the existing or a smaller population, or is action required already today?

Without premeditation one can expect catastrophies, famines and wars of an hitherto unknown scale and the population would be reduced to a lower level this disastrous way if the turning point is missed. Locally one already observes such scenarios today.

A contributing factor is provided by the value system of our growing society. This value system heats up the production and causes also the destruction of nature. Therefore, these values have to be changed already today although some still argue that this is unnecessary. The change has to be made in such a way that civilization can persist even without fossile fuels. This is one of the core problems : how to introduce additional rules in a consolidated society which does not want to change only because of a vision of the future. This book wants to contribute to the vision as well as in practical advice.

In this context, the most important element is a new evaluation of human activities, which is based on a thermodynamic principle: i.e. the principle of smallest possible entropy production. This scientific concept is to a very large extent compatible with many intuitively proposed environmental concepts.

1. Cost and Value

1.1 NATURAL SCIENCES AND ECOLOGY

Political and social development is today very much dominated by economical considerations. The "laws" of the "free market" subdue ever increasing parts of human life. These "laws", however, are based on value systems which are by no means as obvious as in the beginning of the technological development.

It appears rather straightforward to put a price-tag at a product which lies in a store; basically one has to look for competitive offers and the average salary of the potential customers. More difficult to evaluate are stocks and the various forms of primary energy, i.e. gas, nuclear fuel etc. This becomes apparent in the large fluctuations of the stock values even in times where there are no apparent changes in the particular company and in its economic environment.

The value of primary energy, for example, is the subject of endless discussions because evidently the costs for mining and distribution are only part of the total cost which occurs for society as a whole after the fuel is finally burned. Today one is well aware of these secondary costs which result from the use of these fuels, however, the amount of additional costs apparently cannot be clarified in our current economic system. Mostly the debate ends in a complicated taxation system which, however, contains a lot of elements which are foreign to the original problem. This then leads to globally inconsistent measures, i.e. the additional costs depend on whether a given fuel is produced in the Iraq or in Europe and if the fuel is used to drive cars or for home heating.

Obviously, here an unified approach is missing. Early attempts in this direction can be found in the ecological evaluation of the energy conversion chain, i.e. considering the efficiencies and also the emissions which occur when the fuel is burned. For a more consistent view one would like to have an evaluation which is based strictly on the natural sciences. At this point it is often argued that this would intervene into the realm of economics and politics, and thus disregard the well-shaped tools which were already developed in these fields. Indeed there is very strong doubt on the relevance of a purely scientific approach in these complicated fields and today only a minority believes that one can find criteria and a global vision in this sector.

This leads up to a provocative question : how important is the role of the natural sciences in ecological and economic discussions of today ? Is it really held possible that concepts ot natural sciences might be used to make decisions about or to find a vision to solve global problems ? Is it not thought today that the scientific method is only useful to solve very narrow problems in highly specialized fields.

Certainly, the importance of the natural sciences to solve sociological problems is considered low and this branch of activity is advised to concentrate of the consumer goods like cars, television sets and tamgotchis. Probably this has to do with our wish to see science and technology rather in the role of the conservator of our living standard as in the role of a social critique. Consequently, also the individual scientist should rather concentrate on small market oriented problems and not discuss information and power monopoles.

An exception are today the ethical aspects of genetic and nuclear techniques. This is evidently connected with the direct danger potential concerning the gene pool. Disturbingly, however, genetic technology is pushed into the same direction as chemistry and physics earlier. Fast marketing of the products of biology, biophysics and biochemistry is requested. Long term consequences are usually disregarded.

The success of the human species now seems to threaten him - like the sawtooth tiger who might have become extinct because of his altogether too successful hunting strategies which eliminated his food basis. In other words, both cases have in common a breakdown of the prey-predator cycle.

An extinction of certain species through evolution or external influence does not happen for the first time. In sober contemplation a catastrophic development is also possible for the human kind. The only hope is the rational approach to the problem: man is the first species to foresee such a development, who could avoid the trap of too much success. The natural sciences, as they are developing the industrial tools are often looked at as the source of this threatening development. Can science also tame the ghosts which it has created ?

In order to bring about an effective change, one has to obey the rules of today's economy while at the same time the ecomomic value system has to be changed in such a way that it is consistent with a sustainable society. A certain modification of the values of the free ecomomy is already effected by the tax and social redistribution systems. It restrains the "free forces" of the market, but it does not attack long term pollution problems. Although it is generally acknowledged that the values and conventions of the growth society of today will not hold in the future (Club of Rome et al.), these values have not sincerely been questioned so far. But what should the new or additional rules look like ? We submit that some of the concepts of science can be helpful, i.e. one should try to construct a value system for a sustainable development on the basis of scientific concepts. Why such concepts should be found in the framework of the natural sciences, which obviously created all those unwanted side effects of human activity might not be evident for the layman. This skepticism mainly results from a fundamental misunderstanding : the technology of today is often advertised as the only possible one and at the same time science is set equal to this technology. However, a technology is not identical with a law of nature. Physics of radiation or material flow is the same if it decribes processes in a solar collector, a coal power station or an combustion engine. Thus, in the hope to find universal rules for a future society, we look at the laws of natural sciences for a suitable lead.

1.2 ENERGY AND ENTROPY

Which of the many concepts is, however, the useful one ? The large consumption of energy and the pollution of the biosphere already shows first consequences such as global warming, pollution of the sea and the water table. Looking in a first step for just a description of these phenomena, one should approach a discipline which is part of physics as well as of chemistry and biology- i.e. thermodynamics. In choosing the dominant physical quantity in this context, we have to keep in mind that a positive value should be attachable to this quantity.

Just as physics is based on a few fundamental laws, thermodynamics is based on only three basic principles. The first law states, that the total energy is conserved in a closed system. As the energy can be distributed in many ways onto the elements of a system, we need a second law to describe just this distribution of energy. This second law of thermodynamics, however, only describes a tendency: in the end the energy is distributed evenly onto the elements, and as a consequence the disorder of the motion or element distribution always increases. The third law of thermodynamics states that the absolut zero of the Kelvin scale ($0\ \mathrm{K} = -273.15^{\mathrm{o}}\mathrm{C}$) cannot be reached. This asymptotic law is less relevant for our discussion, as life processes usually take place at and around the mean yearly temperature of the earth, $T_e = 288\mathrm{K}$.

One may coalesce the first two laws into a single statement:

"energy is conserved, but disorder always increases with time".

Disorder is often meant as disorder of motion; in this context one looks at the conversion of conservative energy forms like mechanical or electrical energy into thermal energy. Corresponding to the second law, thermal energy cannot be fully reconverted into the conservative energy forms. According to the same law, also the structure which converts the energy cannot be fully reconverted. Both statements apply to technical as well as biological structures : plants, for example, use photosynthesis for energy conversion but one can also look at power plants, solar collectors or even

electric razors. Also humans can be considered as an energy converting structure, which takes in energy rich compounds and disposes of energy poor (stable) materials, like CO_2; at the same time chemical energy is converted into thermal energy. We find that in all cases the processes are irreversible if one looks at the final energy form. Also , the structures which allow the processes to occur, decay with time. In a direct comparison, biological structures are far superior to the technical ones, in particular in respect to lifetime and reusability.

All this points to the importance of the second law. The basic quantity of the second law is the entropy. We abbreviate the entropy with the letter S; it is a measure for disorder as well as non-reusability. In contrast, energy is conserved, it cannot be increased or decreased, only converted. The energy is apparently less suitable to describe pollution or the decay of structures. In a combustion engine for example, the increase of entropy times the reaction temperature gives this part of the energy which is not converted to mechanical energy, but is waste thermal energy. Thermal energy thus is highly "entropic" and is generally less valued than equivalent amounts of mechanical or chemical energies (Joule).

We present two examples in order to further eludicate these relations:

It is obvious that the chemical energy which is stored in a gallon of gas counts more than the heat which is created on burning: one can choose to burn the gas at any time, while once the heat is created, one cannot do too much with it anymore. In principle one can drive a thermodynamic cycle using the waste energy, but according to the second law this engine can never completely convert the heat into a higher valued, mechanical or electrical, energy.

Another example in given considering two bottles, one of which is filled with a gallon of hot water and the other with a gallon of cold water. I can make coffee or warm myself using the hot bottle of water. If, however, I mix the contents of both bottles to create two gallons of lukewarm water, I cannot get warm or make coffee any more, unless I use additional external energy. We value the energy, which is stored in the hot water, higher than the same energy which is distributed onto the two gallons lukewarm water. The "loss in value" of the energy which occurs on the mixing of water can be calculated as entropy increase, which is defined as :

$$\Delta S = \Delta Q/T$$

here, T is the temperature at which the higher valued energy ΔQ is converted into heat. We will see a little later, that ΔS is well suited to evaluate an energy *conversion as well as, in a more generalized form, the creation of waste. For the latter one uses the concept of mixing entropy and not the above equation. For a comparision of elemental and thermal waste, however, one has to find a way to intelligently compare these two forms of disorder (see thermodynamic separators). Radioactive waste is a special case and will be treated separately.*

In order to illustrate the mixing entropy here we only give an example. Later this problem will be taken up in more depth.

We take again two filled bottles, but this time they have the same temperature. One bottle contains salt water, while the other contains drinking water. Again it is obvious, that by mixing one can easily obtain water with a smaller salt content, but in order to regain drinking water from this mixture one has to use external energy, for example heat to actuate evaporation. After the mixing, the total energy content is the same but the entropy has increased through the mixing. This kind of entropy increase is thus called "mixing entropy", it describes a substance disorder. In the appendix the mixing entropy as well as the entropy of motion are demonstrated in more detail by example.

A conversion of a high valued energy like chemical or electrical energy into a lower valued like heat, increases the entropy. A closed system does not exchange mass or energy with the outside world. Thus in closed systems the entropy always increases. In open systems, like sun-earth-space or a lifeform, such an exchange is allowed and the entropy can increase, stay constant or even decrease. In such open systems, in particular , we have a minimum of the entropy production. A large class of thermodynamic states, i.e. stationary and/or steady states obeys the rule of minimal entropy production. Stationary states are also characterized by its flows and forces which do not change in time. If one talks about a sustainable situation, one actually intends to come close to such a stationary state. Sustainability is a new trend word which summarizes closed material flows.

It is important to note that with stationary states it is not the entropy itself which is minimized, but its rate of increase. The principle of stationary states is to slow down the entropy increase as much as possible. Among other quantities, also the entropy should remain constant. Thus if entropy is produced within a stationary state, this also requires an entropy export.

Because of the importance of this principle, we summarize: complex systems, as lifeforms, are not in thermal equilibrium or ground state, but close to a stationary state. Such states exist only under the continuous influence of external flows and forces [1, 11] and therefore are subjects of irreversible thermodynamics. One of the laws of irreversible thermodynamics states that stationary and steady states are close to a minimum of entropy production [1]:

$$dS/dt = Min$$

Here, the entropy production dS/dt is the increase of entropy ΔS per time interval Δt. Is it possible and advisable to expand this law to a principle of action in the future?

Man itself, the most complex biological system, knows a minimum of the entropy production: the residual energy conversion of about 60 Watts, which are given away as thermal energy, divided by the internal body temperature 37.5°c = 310 K. This gives :

$$(dS/dt)_{min} = 0.2 \text{ J/sK}$$

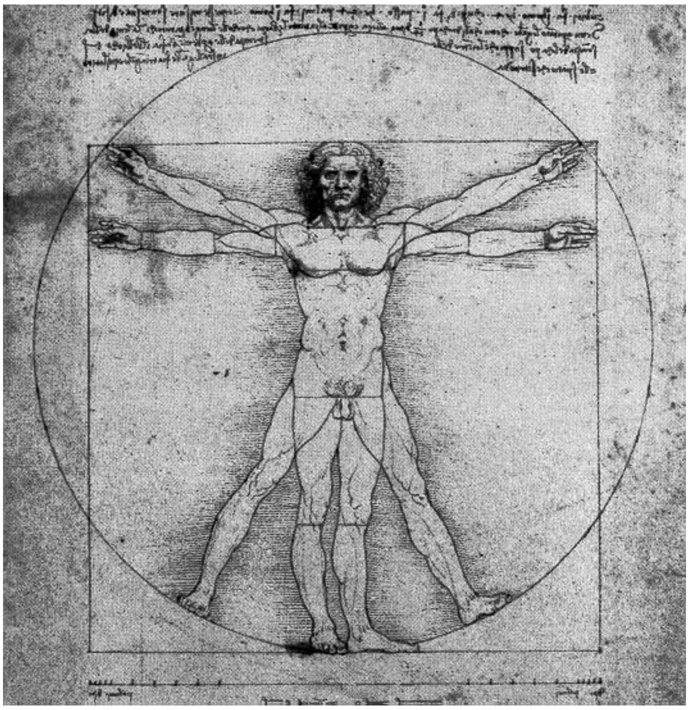


Fig. 1 : The human body in rest and action (Leonardo da Vinci)

Each activity increases the energy conversion and with it the entropy production. Of course, this cannot be considered a proof for the applicability of the principle but strongly suggests it. The low value, in particular, indicates that one is at least close to a possible minimum. The consequences would be twofold:

(1) We can link minimalisation of entropy production to evolution. Lifeforms might evolve using this principle.

(2) Is it possible to classify individual as well as collective activities in regard to their entropy production in the biological as well as in the technical regimes ?

1.3 NEW VALUES

A society which embraces the principle of minimalization of its entropy production in one of its survival strategies, has to reconsider the value system of today. First, we pick out a few examples which make us uneasy when we hold onto todays value system. Then we will outline that the necessary changes could be grave but are not impossible.

1.3.1 Consumption race

One of the modern plagues is the always increasing amount of money combined with a strongly non-recycling, i.e. "emitting" production of goods. In a more traditional view money is nothing but an universal stand-in for the exchange of ones goods and services in a society. It is a joker, who transformes own services and goods into those of others. Initially introduced for actuating the exchange of goods, today the money has developed a complex dynamics of its own. Many people consider it a value in itself, or even the only value left. Indeed, the money flow, left to itself, tends to destroy any other value system and fuels production and consumption.

Even the producers of high technology products mourn the ever increasing pace of the appearance of new models, which should be always better and cheaper as its precedessors. As a cause increasing competition is stated. Increasing competition reflects the fact that with an increase of manpower and money more and more groups (companies) are in a postion to offer these originally rare goods. As a consequence the period of use of the product is shortened; then,the producer argues, quality (lifetime)and recycability (reuse) can be less. In total , the entropy production is doubled. An extrapolation of these tendencies show : even new products would finally end up very shortly after acquirement in the dump, i.e. in the limit we would just produce waste. A cyclic production would be much better, as it can be speeded up or slowed down without increasing the waste pile (Chapter 4).

1.3.2 Realization and financing

We point at the money pile, but what represents the amount of money? Capital, i.e. a certain amount of money, can stand for a natural resource like coal or copper, but also for the services of a work force, which might be needed to carry out a project , i.e. a potential service. For a potential service, we use the word (human) capital. Like with (money) capital, it is not necessary to assemble the workforce beforehand ; it is only necessary to show that the planned project is feasible and then its financing can be done before, simultaneously or after the project is finished. In a growth society in particular, the necessary spaces and building materials are considered granted; already existing societies will basically hail the advent of the new group, whose existential basis should be served by the project. Repeating this procedure many times is called a consume-consumer staircase.

However, this approach obviously works only as long infinite space and resources are offered. It is dubious that it will work in the future; feasibility and financing alone will not suffice as criteria for social decisions.

At that point usually another criterion is named, in particular in connection with really large projects : " a project is o.k. if it benefits the largest group ". This, however, will not suffice. Because of the large monies of today, one can invent many projects. Is a project completed, initially only a certain group will profit by it, others will loose. Later, the loosers will, however, join the large and successful group and this additional criterion will become meaningless. The benefit of the largest group is thus not suited as a controlling principle as it only leads to the disappearance of group boundaries (see also company mergers). A consequence of such mergers is that the exploitation of resources goes on unhindered, although that is certainly disadvantageous for us all.

Increasing money flow, a successful concept in a growth society, is insufficient and even dangerous on the road to a stationary society. In fact, it is a classical example for the conversion of quantity into quality :

> *If, after some time, in a small community a large project is advanced, usually this is welcomed by the majority - jobs are created, the turn around increases, everybody takes action, critics are done away as fossils of the past. If, instead say 3 projects are advanced at the same time, resistance is called to the fore. Real or construed conflicts are discussed, the wealth and power of the banks are critized, citizens initiatives pop up and the call is for additional criteria for the projects to go or eventually to abandon them. The switch from aggreement to rejection (quality) appears here already between the numbers 1 and 3 (quantity). Of course, the number of people involved, the money flow and the used services can be significantly different from 1 and 3, and these larger number may not be accepted by the community any more.*

The concept of minimalization of the entropy production can give a contribution here, as it offers a new basis for the comparison of competing projects and with it a new value scale. Although we deal with a measurable physical quantity, one still has to define goals, but not only in terms of feasibility and financeability, but also in terms of follow up loads which reach far into the future. This approach would probably hinder extreme consumption and the loading of environmental problems onto future generations. The concept works also locally and therefore not only communities but also individuals can adopt and work with this new principle as well. The possibility to apply the principle locally is a big advantage as compared to advertised world models, as it approaches the individual directly. Of course, at the end particular solutions have to be welded together into a global solution.

1.3.3 Entropy production as alternative currency

One can even go a step further and project a weighted entropy-production as a basic currency.

Traditionally, property, real estate and currency are connected with material bodies; in the physicist's languange, with the mass of certain materials. However, from the beginning, this was always problematic. Both energy and mass are conserved, and therefore exist in a time independent quantity. You can only change its distribution or habitus. Take for example gold as "precious" metal: there is a certain limited amount of it on earth, which does not present a value in itself. The value is obtained through the capability of man to concentrate this metal, to hoard it and to assign a value to it. Gold has physical properties which make it indirectly useful to man. Gold does not corrode, can be formed easily, cannot be faked , and exists in a limited amount only. Thus, historically its value was located in its usefulness to make coins which then should represent the exchange of goods. Because of its limited amount, however, later less noble but more abundant metals have been used. Today even paper money, because it became more and more obvious that one can use arbitrary representatives for a currency basis, once everybody agrees. Of course, a limited amount should be set to represent the real exchange of goods. If the participants of the currency flow stop believing in this representation, the jokers will be abandoned and everybody returns to barter trade. The value of a currency thus is not so much based on a representative material (like gold), or its scarcity, but on the capability of the acting humans to produce goods and trade in organised ways.

Which goods or services are to be offered is not really defined by the trade mechanisms. Here we need a product evaluation, which culminates in the setting of a multiple of the currency unit: the product gets a price tag. The same procedure is applied to services. In an open society [40] this value system, which might have arisen from rather obscure beginnings, is, however, rather flexible. Both individually and socially set values are not invariant to time. There is always room for change.

If one now proposes a reduced entropy production as a value, at first sight one turns to a completely unusual quality. It is not a conserved quantity, like mass (for example gold) or energy (for example fuel), but rather represents a principle of minimal destruction.

Obviously, if one suggest to a social group to consider a reduced entropy production a positive value, one suggests that the group should refrain from acts, which lead to a high entropy production. At first sight this completely contradicts individual wishes and also group dynamics. On the other hand, there are many examples where one faces exactly the same problem: one values positive the activity of the police forces, i.e. the control of violence inside a group. The same applies to the defensive forces, which are supposed to control armed violence between different groups. This judgement is based on the idea that prevention is often better than to live through a catastrophical event.

The situation is similar with entropy production. As we will discuss in more detail later, primarily the reduction of entropy production creates food and fuels, but it also represents a service, which is apt to prevent big catastrophies in the future. To achieve this goal, significant changes are requested in the "cost" evaluation of products and services, which at the end will also reflect on the assembly lines.

As a first example we evaluate the value of a barrel of oil. Today , only the stored chemical energy is considered a value. Converting this energy in a big scale through burning brings to the fore one of the more well-known environmental problems. Burning oil (or coal), at the end we obtain a mixture of carbondioxide (CO_2) and water (H_2O); the CO_2 mixes with the standard atmosphere and ultimately leads to the green house effect. This secondary entropy production is not considered at all in the classical view. Our evaluation is different: first, chemical energy is converted into heat, i.e. a highly entropic energy form (first cost contribution). Second, from the exhaust, CO_2 is released into the atmosphere; this gives mixing entropy (second cost contribution). Third, the emission capability of the earth is reduced (green house effect or reduced entropy export: third cost contribution). At combustion, also water is created and distributed- this entropy source is practically without negative effects, as we already have an atmospheric water cycle. Here we discover an important point: as a species we have to define a weight- or value factor to a given entropy production, whether we stay neutral, benefit or suffer from that entropy production. A second important point is the secondary entropy production: it is not the combustion itself, which creates the biggest problem but the blocking of the infrared emission. This urges even more to consider entropy increase as the relevant cost and not just energy conversion.

Before burning, the barrel oil represents a value also in our new counting procedure. The oil contains stored negative entropy production, based on *photosynthesis during a bygone era. During this time period, a small part of the incoming solar energy was stored, i.e was not emitted at a lower temperature, and such taken out of the global entropy production. This corresponds to a saved capital.*

If one thus takes as gain simply a negative entropy production and as cost a positive entropy production, the radiation equilibrium sun-earth-space would give us a finite amount of "money" to spend or gain per day or equivalently there would be a daily world "financial" frame .

Within this concept, money growth is limitited

Our current system, by applying "consumer want" price tags on everything, does not recognize such a limit. This entropy related financial frame is equal to the daily entropy export, i.e. the entropy which is exported during 24 hours through infrared radiation. Moreover, this "money" exist only potentially, it is not yet "earned". For that we have to install entropy reducing measures like photosynthesis. If we can convert from the solar energy a part ΔE to say chemical energy in the time Δt, then $\Delta E/\Delta t T_e$ are the earnings (T_e : mean surface temperature of the earth). The fossile reserves were created just this way. The maximal daily earnings of mankind would be reached, if all of the sunlight is converted into storageable energy - a gigantic sum. This vision is not too far from a future reality, because, disregarding nuclear energy for a moment, we can only store as much as the sun and our natural (plants) and artificial converters allow.

Aside from this perspective, we recognize already today what happens if we do not balance our ”costs” and ”gains” or entropy production correctly. The atmosphere and the seas suffer from the mixing of reaction products and creation of waste. As we see the coming problems already today, still the consequences are shifted into the future. This shifting of ever increasing costs into the future is another fatal weakness today's system, which we all still hold on to.

1.3.4 "Interest rates"

The increase of the money pile in our present economy mainly stems from the trading with money itself. One uses loans, stocks and bonds, which apparently represent some share in ownership or a promise to pay later. Trading with money requires some initial seed money, i.e. capital. A skilled trader is supposed to increase his capital. For that, he has to "invest" his money, that is one has to find a person who wants to build something of value or who is in a position to exploit some resources if given some seed money or "loan". This person, the "entrepreneur", is supposed to be capable to pay the loan back and also some excess money, which is called "interest". "Interest " and the setting of interest rates are one of the main driving forces in trade. While loans will stimulate growth (and exploitation of nature), they contain, however, also a regulatory measure: because of the interest, people who need money will be reluctant to loan more than it is necessary.

Do we rediscover this very efficient trade tool in the new value system or is it gone forever ?

At first sight, a physical quantity like entropy reduction does not lend itself to an automatic increase with time. On the contrary, if one is not careful, the costs, i.e. entropy production, automatically increase. Morever, it appears that even if one decreases entropy production, say by converting sunlight into a certain amount of stored electricity (battery), we can at best get the same amount back- by converting the electricity to thermal energy at a later time. Even this is possible only in part, as we will have storage losses. Disregarding prefossil fuels like uranium and deuterium for a moment, this is a fact as soon as the natural "capital", the fossil resources are exhausted. An observer from outer space would realize, that our current economy rules are based on quicksand, i.e. cannot survive the limits of growth.

How can a new economy survive without the incentives of capital and interest ? Without them, nobody would save, capital would not build up and investments cannot be done. Everybody would immediately disperse any gain and even try to loan money indefinitely. This runs against the principle of minimalization of entropy production and therefore we expect to rediscover capital and interest in the new value system. One difference, however, we have already stated: we cannot go beyond the daily world finance frame, which was defined by total daily conversion of the sunlight. As long as we do not have the corresponding maximal amount of converters, investment and interest are still possible. Savings and capital would, however, always represent a countable conversion of sunlight into storageable energy, i.e. a build-up of resources. "Saving" would mean a reduction or a delay of an entropy production. Both is of "value" also in the new system, as we will see below, but first let us give an example about interest in the new accounting:

Assume that Mr. A's solar appliance in the summer of 2006 has converted so much light into say methanol, that he and his family do not only survive the winter, but have an excess of one barrel to give away. This excess he offers to the central storage facility i.e. to the local "bank" B. The bank gives him credit points minus a deduction "accounting cost", because also the central storage facility has to be maintained and some of the methanol evaporates. The "payed in" methanol, together with other barrels will now be given to the entrepreneur C, who takes a loan from the bank in order to build a new light converting *facility, which again converts sunlight and some basic materials into methanol. At the end of 2007, the barrel from Mr. A has doubled. In the sense of -dS/dt a capital has been created- considering the sunlight free, the gain has been made by delaying the conversion of sunlight into low temperature (300K) thermal energy. To whom does the capital belong to ? To be fair, the gain has to be divided between the builder of the new appliance, C, the saving customer, A, and the bank, B. Thus, interest can be paid out. The total money frame is conserved automatically, as investments of this kind can only be effected as long as new converters can be physically installed.*

Stock markets and even speculation would still be possible inside the given frame. Artificial fluctuations of the amount of money would still be possible. However, we would always have a means to correct those fluctuation by looking at and quantifying the real situation on the ground. This is different from the system of today, where some rather undefined "want of the customer " seems to be the dominant force to define the price tag. We will see later that we cannot and will not try to remove the free decision of the customer to define the value of a product or service, however, we can offer him an additional and universal boundary condition.

At least there are big inconsistencies in the current system; for example, it is not evident why the total capital increases faster than any represented value, no matter if one views that value in terms of products per person or in "quality of life". Taking a measurable quantity like entropy production into the economic system might even help to avoid inconsistencies and to divide the capital in a fair way.

1.4 SUN, EARTH AND RADIATION

The sun’s radiation onto the earth gives us our economic frame. This suggests to look a little closer into our stellar sitution, that is the so called radiation equilibrium between sun, earth and space:

Part of the solar radiation falls on earth and heats it up. Because of the earth's rotation ant the atmospheric cycle the produced heat is almost distributed evenly on the surface. Because of $\Delta S = \Delta Q/T$ we discriminate the value of thermal energy ΔQ by the temperature T where it is held. Equal amounts of heat are valued higher at higher temperature as the entropy is lower. Thus, although the total light energy which falls onto earth equals that which is later emitted, solar radiation is of higher value than earth radiation because of the higher radiation temperature (5800^{o}C). For the complete system sun-earth-space, the radiation temperature decreases from 6100 K to 287 K to almost 0 K. As the IR-radiation is send into space and if one considers the universe as closed system its entropy increases. At the surface of the earth also every day a large entropy production occurs, as the solar radiation, which is equivalent to heat at the surface temperature of the sun, is converted into heat at the much lower surface temperature of the earth. The temperature of the earth would continuously increase if there were not for that entropy export into space via infrared radiation. In other words, the partial system sun-earth exports entropy (space cooling). Because of the rotation we have also a periodic (night and day) temperature oscillation. Only averaged over this period, we have a radiation equilibrium. Then the complete system is not only at a minimum entropy production ($dS/dt = Min$), but for the partial system sun-earth the total entropy production vanishes , $dS_T/dt = 0$. Entropy production during the day (heating) is exactly balanced by entropy export during night and day. From that balance and if one takes astronomical data only, one calculates 276 K which is close to the actual 287 K. The difference is ascribed to particular properties of the radiating surfaces and of the earths atmosphere (albedo, green house gases, etc.).

Plants and animals also give a contribution. From this it follows that the lifeforms, while they had to adapt to the initial earth surface temperature and its variations, with increasing proliferation they actively participated in changing this temperature, both via changing the surface absorption and reflection properties (plant- and algae cover) and by changing the original atmosphere itself (CO_2-cycle, methane, etc.). By keeping the biomass constant, we actually finetune the earths temperature.

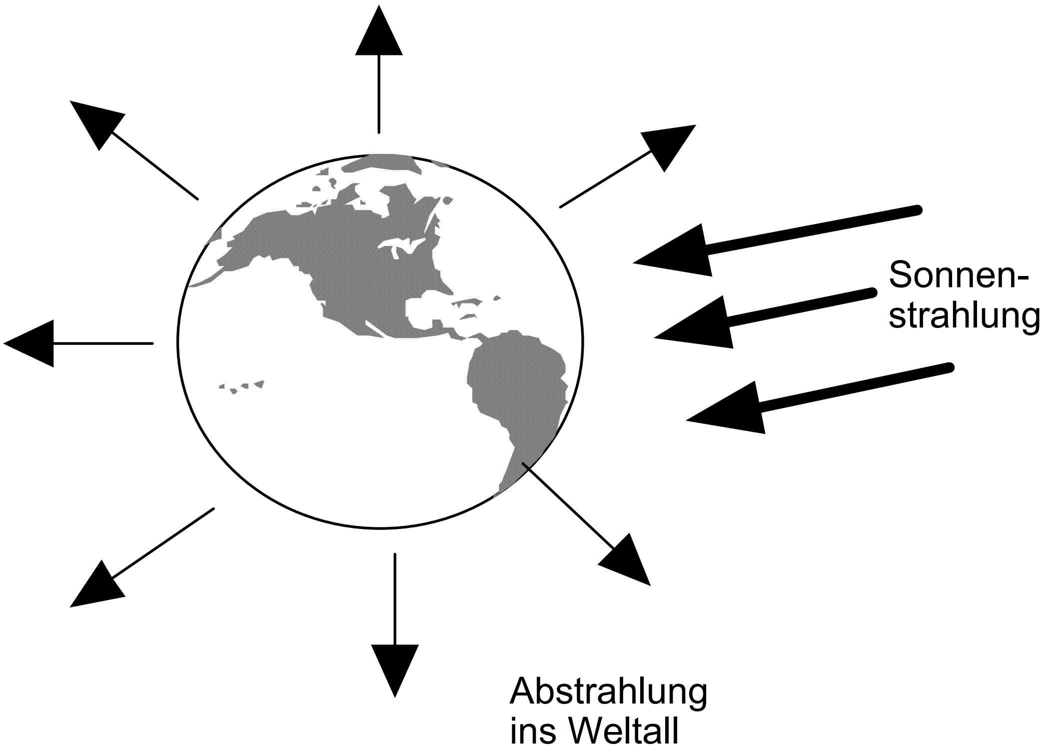


Fig. 2.Radiation equilibrium earth/sun/space.

The continuous reproduction of life forms, like plants, animals and humans or in more general terms the stationarity of selforganising structures, is according to thermodynamics possible only if at another location disorder is created of at least the same magnitude. Selforganisation exists on earth since the first protolifeforms came into existence. This local reduction of disorder, which is the basis of our existence, is possible only because of the energy flow originating from the sun and because of the export of entropy into space also from the subsystem biomass. A stationary state of self organisation on earth is reached, when the entropy of biomass is constant, i.e. when plant entropy production and entropy export (plant infrared emission) balance. Here we notice again, that energy is not the correct criterion but entropy. One understands also that by taking away from the entropy balance, one can construct highly organized (low entropy) lifeforms. Lifeforms can develop only if they block part of the direct conversion of light into heat. They use the higher valued light energy to support their organisaton structure and their materials conversion cycles.

The apple tree is a straight forward example: The light energy is used vis photosynthesis to build up an organized structure (stem, root, leafs); at the same time chemical energy is stored (wood, fruits). The material flows needed for that are all closed.

If one would apply the principle of minimalization of entropy production on earth disregarding lifeforms, in order to reduce the entropy production as much as possible one should thermally isolate the world such that it reaches the temperature of the sun. Then, of course all lifeforms would be destroyed. Obviously, for the lifeforms to benefit from the principle we have to install boundary conditions, which are helpful for the species to survive. As evolution has adapted us to the average earth temperature and its variations, the goal would be to keep this temperature a constant while minimizing the entropy production on that level. Indeed a small increase in the average temperature may melt down the polar ice. As a consequence low lands will be flooded and the equitorial desert areas will be increased. Also, atmospheric turbulences will lead to flood and storm disasters while the new eqiuilibrium is installed. Obviously, we cannot let the entropy balance drift away.

1.5 THE FORGOTTEN ENTROPY CONTRIBUTION

How does it happen that the burning of fossil fuels pays off in economic terms, but that at the same time large environmental problems appear which nobody seems to be accountable for. One has to suspect that our cost-gain calculations are wrong. Indeed, if one considers entropy-productions as costs, the burning of fossil fuels would be more costly and one could afford to do it in a much smaller scale only. Why the current costs are much too low, come to the forth very easily using the concept of entropy production: if one considers only energy conversion - and this is still done even if one rises taxes on energy and gives out emission privileges - in terms of the production of entropy one considers one term only and that is the thermal entropy. If one takes the concept literally, however, one has to add mixing entropy. This important contribution, which very often creates important secondary entropy productions which are in turn responsible for most of the environmental problems, is simply omitted today.

For a more detailed elaboration we take up an example. Assume that a gallon of methane is converted into carbondioxide (CO_2) and water (H_2O). Part of the entropyproduction is related to the heat of reaction, which is useful for us and thus is considered a positive value. Another part, however, is the mixing entropy which occurs when the reaction products are emitted into the atmosphere. These two contributions, thermal and mixing entropy, have to be weighted differently in general as thermal entropy can be exported into space, while the mixing entropy cannot. The mixing entropy can only be reversed through a filtering system, which in its operation should only produce thermal, i.e. exportable, entropy (see thermodynamic separators). After cooling, the reaction products down to the earth temperature T_e, the CO_2-gas should be *collected again, as it is a hothouse gas, while the water can be released into the already moist atmosphere withour further efforts. We notice here that the dispersion of different chemicals from our perspective have different entropic weight factors, depending on whether they are harmful or harmless for us (see species-specific weight factors). Thus, in particular the costs for collecting harmful or even toxic chemicals (waste) can be very high, but so far this is not been considered in a direct way in our economy, but rather as an afterthought.*

The burning of methane could also be done in a closed system, i.e. without emission of the reaction products. Certainly, if we only convert the chemical energy into thermal energy and collect the reaction products where they are created, we obtain a much lesser entropy production. This lower value would only consider the difference in quality of the energy forms involved, and the lower one (thermal) could be exported. However, such engines probably would have a significantly smaller power output. A (combustion) engine which gives a higher efficiency today, has to be paid by future generations, because these would have to struggle with the direct and indirect effects of the emissions. A cost calculation based on entropy production not only would unveil this questionable behaviour, but would also stimulate the production of "entropy efficient" appliances.

Products of this kind should be optimized not only in respect to a smallest thermal entropy production, as it is done today by looking at a figure of merit or conversion efficiency, but the optimizing should always consider the total entropy production.

The definition of mixing entropy as well as simple models for the distribution of toxic substances over the earth, sea and atmosphere can be found in the appendix.

1.6 THERMODYNAMIC SEPARATORS

The above examples show, that numerically equivalent parts of thermal and mixing entropy are not equivalent in terms of emission problems. The reason for that is that thermal entropy can be exported into space while the materially bound mixing entropy cannot. Thus we have to look at the conversion of mixing into thermal entropy.

In order to determine how large the thermal equivalent of a mixing entropy is, we have to design an engine which separates the mixed elements again. This engine ("thermodynamic separator") runs only with external energy and therefore certainly creates waste heat. The mixing entropy, however, will be reduced at the expense of thermal entropy. We now ask for a construction which, except for the emission of heat, does not have any material emissions. If we have found such a mechanism, we have found such a separator. The separator now has a measurable thermal entropy production per unit of reversed mixing entropy. As entropy always increases, the thermal equivalent is at least a large as the mixing entropy under consideration.

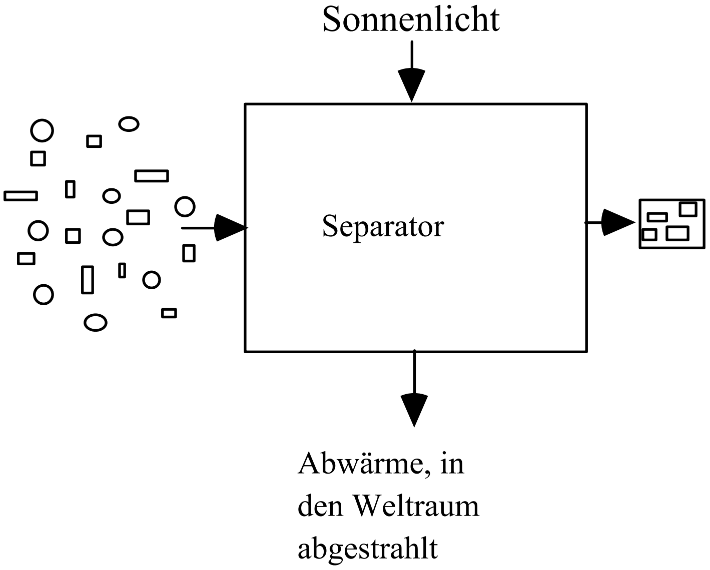


Fig. 3. A thermodynamic separator runs with sunlight as primary energy and emits only waste heat. It reverses the mixing entropy by selecting one molecule species (right) from a mixture of two or more species (left) and concentrating them.

If one has found a thermodynamic separator for a family of distributed materials or a single one, not only the total thermal entropy production but also the amount of primary energy which runs the separator can be determined. The end result is depends on the quality of the separator. The same , however, is also true for pure energy conversion, i.e. the conversion of higher valued energy into thermal energy.

Only if one reverses the mixing, one obtains a reasonable estimate of the "costs", in terms of heat production, i.e. exportable entropy. This consideration is in particular important for toxic waste. A thermodynamic separator which is well-known to all of us, is the atmospheric cycle: saltwater evaporates under the sun's radiation; during this process it is stripped off the salt content. The desalienated water vapor later condenses and falls to the ground as rain. The soil takes up the water and minerals are extracted. At the end we obtain drinking water. The atmospheric cycle is also a self cleaning mechanism, i.e. a separator who gets its primary energy directly from the sunlight, without our intervention. Such self cleaning mechanisms not only constitute an example for technical separators which clean out other chemicals, but may also be viewed as an example for a local reduction of the entropy over a certain time, here driven by the sun's radiation.

Today, with the large number of chemicals which are already dispersed in the waters and the atmosphere it is impossible to rely solely on the selfcleaning mechanisms of nature. Future cost calculations should consider this. In a first step, technical separation techniques which are already in use, like falling out of solution, sedimentation, density separation, electrolytic separation and others, are to be evaluated in terms of their total thermal entropy production. Such as comparison should of course also consider secondary entropy sources. For example, if separation techniques spoil large quantities of water or use very large amounts of primary energy, one should make efforts to look for alternatives, or if this is impossible, one should take the specific material out of the global cycle. Obviously, this is in particular relevant for toxic materials used in certain processes. Then the whole process will be in question. Very good marks will be given to processes which create no secondary mixing entropies at all. In a global outlook, one expects to finish with far less materials as compared with todays circulation. First steps in the sense of this evaluation are already taken, when one looks at the rules for chemical exposure of humans. For automatic production processes, these criteria are usually neglected, i.e. are left to the community. However, a comparison of technical and biological processes and products is only possible if one compares the productivity of entropy. Biological products would probably get good marks because of the biological decomposition chain. Biological structures also have an advantage in using rather few material flows, i.e. C,O,H - N,S,P -K,Ca-Mg,Fe. Biotopes like the rainforest, aside from these material flows, use only sunlight and offradiation of heat. The root-and leave- a capillary arrays contain the thermodynamic separators. Obviously, nature follows the principle of minimalisation of entropy production, while human products are still far away from that.

In the future, the "thermal" cleaning, i.e. the reversal of every emission should be included in the cost calculation. This calculation is based on a thermodynamical machine which reverses the mixing entropy in question. It is important to follow this path as only thermal entropy can be exported into space, not material mixtures. Today optimizing efficiency is equivalent to optimize only the thermal entropy produced in a process. This is not sufficient. The traditional separation of efficiency and emissions in appliances and processes has to be abandoned.

1.7 MINIMALIZATION OF ENTROPY PRODUCTION

If one argues in big dimensions in space and time, i.e. globally and historically, for the individual it is difficult to define a plan of action. As a consequence , the solution of global warming or pollution of the seas and the atmosphere are put into the hands of a future world government. Better would be to spell out rules for individual action. In what follows we therefore focus on the local and individual applicability of the principle of minimalisation of entropy production. As we deal with a principle here and not a law, there are virtually no limits to creativity. From different proposed solutions, however, the one which produces the lowest entropy per time interval has to be taken.

For an individual approach, some more specific rules which of course originate from the principle would be helpful. These do exist indeed. They mainly result from the fact that entropy production is a rate and thus embraces the course of time.

1.7.1 The "greek elements"

Generally, the increase of entropy is much larger in the mobile media air and water as in soil. We do conclude that from the ever increasing worsening of the quality of air and water, while poisoning of the soil is a more local phenomenon. For our theme we therefore may use the greek elements, i.e. air, soil and water for a classification. Although they have no deeper scientific meaning, for a summary or rules they are better qualified as the chemical elements or the elementary particles. The fourth greek element, fire, however, plays a special role which we will discuss later. First, with the element air we equate the clean atmosphere and will consider entropy production in its volume. How do you calculate entropy production, if there is emission of a foreign gas on a certain locality on earth? How large is the entropy production for this emission in a global view? For that one has to determine the mixing entropy- we have already seen that a foreign material B (gas) increases entropy when brought into a larger volume of a pure material A.

As we calculate in the appendix, the average global entropy production in the troposphere is proportional to the amount of emitted material and the average wind velocity, if one assumes that on the average, the winds blows from all directions. Also one has excluded vertical, i.e. up- and down winds. Upward we assume material diffusion only, which might be justified because of the relatively small height of the atmosphere. The result is evident : one should refrain from emissions as much as possible if one wants to minimize entropy production. The fact that the winds carry away pollutants is very convenient and is widely used in profit making ("high chimney policy"). However, emissions only shift the problem to some other region, and if everybody joins in, at the end we will have large atmospheric changes, at other places and at other times. This shifting of problems into the future gets even more evident if one considers the layer stucture of the atmosphere : after the foreign material is evenly distributed in the troposphere, we have reached the maximal entropy in this atmospheric layer and then its increase in time, i.e. entropy production is finished. However, the foreign material will now penetrate into the stratosphere through diffusion. This opens another source of entropy, which is proportional to the amount of foreign material and its diffusion constant. In the stratosphere we rarely find selfcleaning mechanism; that means that the foreign substances remain there for a long time. If the pollutants have properties which change the screening properties of the stratosphere, we will have created large secondary problems. FCKW's , which are thought to create the ozone hole, are the best known example. Even if one were able to repair the damage, this would be very costly in any counting. Damages of that kind are created but slowly, but as they persist a long time , we have taken up a loan which has to be paid back by future generations, if that is possible at all. Pollution prevention in the sensitive atmospheric volume therefore has the highest priority.

Now we turn to the next greek element, the water of the oceans. Here we have a similar picture as we find a layer structure here,too. Near to the surface we find convective flows. The calculation of the entropy production connected with the distribution of foreign material in water follows that in the atmosphere.Instead of the wind velocity one has to use the average flow velocity of the waters. In the surface layer of the oceans material distribution is very fast. One often cites the single tear which falls into the water and whose molecules are found only after weeks in all oceans of the world. Considering the layer structure of the oceans, i.e the surface flow belt and the deep sea, we again observe a slower material distribution in the deep sea. If , for example, we deposit nuclear waste in the deep seas, diffusion and with it entropy production is initially small. At first sight the waste problem seems to be solved. Pollution, however, is only stretched over a longer time. Again future generations face grave problems.

At this occasion we bring an example, the meander effect :

Another example for a mixing entropy which we already have refered to is the cycle of surface water, from which we derive our drinking water. The cycle begins with the desalienation of the saltwater through evaporation.Later this water rains down on the land masses. The rainwater returns to the sea via the river beds. At desalienation the mixing entropy got reduced : sweetwater contains significantly less salt then salt water. A minimal entropy production we have in the cycle if we hold back as much sweetwater as possible over the longest period possible. Thus, a meandering river, with a great length and low flow velocity is to be favored against a fast flowing, straight river. Alternatively, however, one can build a reservoir to keep the sweetwater for a long time. In both cases one has to observe secondary entropy productions : if one uses very flat reservoirs, one looses a lot of landmass- alternatively, if one *installs to many obstacles to a river flow, one risks flooding. One always has to watch for secondary effects.*

Now we turn to the third greek element, the soil. Here, the entropy increase is determined by diffusion, which is generally small in a solid. Thus direct entropy production is small. Accordingly, it is better to find waste sites on the continents. However, there is always an interaction between the greek elements, i.e. the dissolution of gases and solids in water, the emission of solid dust particles in the atmosphere or waste fires. Because of those interactions the deposition of waste on soil is also not a final solution- while relying on it, one should at least shield both the water table (avoid its poisoning) and the atmosphere (avoid waste burning). A long term solution, however, can only be found if we look into the mechanisms of waste production and into possible recycling strategies (Chapter 3). The fourth greek element, the fire, of course has a special status. It is a strange coincidence that it also plays an important role here. This stems from the fact that the discovery of the use of fire initiated human predominance on this planet. With the relatively small populations of the ancient world, however, the additional CO_2-emissions from fires were certainly negligible, i.e. they could be taken over by the regulatory mechanisms of the biomass. Today we have too many and too intensive "fireplaces". The regulatory mechanisms, mainly provided by the single cell algea of the seas (phytoplancton) and the plant cover are overloaded by these additional emissions. Although a high CO_2-content (up tp 1%) does not damage the plants directly, secondary effects of these emissions are much more harmful. The large industrial CO_2-emissions in a period of time which is small against the time of the accumulation of the fossil resources are a typical case of a too large entropy production, which leads to a thermodynamic imbalance as it ignores the regulatory measures of the plants. Because of the permanent hothouse effect of CO_2 this imbalance may well develop into a catastrophe. The physical recycling of CO_2, i.e. binding into carbonates, is far too low. The installation of technical CO_2-condensors on the other hand, is considered as much too costly. however, many of our economic concepts and calculations would not stand up, if one would face this problem today. Instead we take up loans which conveniently have to be paid back by future generations.

At this point one should observe, that while there is a generations treaty such as that each following generation carries the last, for longer period of times, say beyond 50 years, there is no premiditation. It is, however, evident that we cannot indefinitely increase these long-term loans. At some point in time a certain generation will not be able to cover these loans anymore. Thus, one should act early. The evaluation of products and services via the entropy production measure can help here, as it not only opens the eyes for the problem of longterm preservation, but also asks to average the total entropy production (costs) to zero over shorter periods of time.

There are two principle strategies to reduce the entropy rate. One is to stretch consumption over a longer period, the other is to reduce consumption. We will now shortly discuss the gist of these two approaches.

1.7.2 Reduced entropyproduction

Light, i.e. electromagnetic radiation, is a high value, low entropy form of energy which should not be converted immediately into thermal energy. If one has found a way to convert it into another form of energy, which also can be stored , i.e. for example chemical energy ΔE during one day d, the total entropy production is reduced by $\Delta E/(T_e d)$. At night, however, emission is as strong as before and as a consequence the surface temperature will decrease a little. If one continuous to do so, a new radiation equilibrium is finally installed. Evolution, however, has adapted us to T_e. There is of course also the possibility to store that energy and still keep the surface temperature constant. For that one has to reduce the emission also by ΔE, for example through increasing the content of the green house gas CO_2 in the atmosphere. In total, we then have the balance in incoming and outgoing energy ΔQ:

$$\Delta Q = \Delta Q_0 - \Delta E = \left| -\Delta Q_0 + \Delta E \right|$$

The plant cover already uses this principle. The O_2/CO_2 balance is mainly governed by the sea-algae. The plant cover reduces the daily entropy production via chemical storage and at the same time reduces the night and day entropy export by its CO_2 production in such a way, that the earth's mean surface temperature does not deviate much from that of the prefossil earth. Keeping the temperature constant while covering the planet, the plants definitely have installed an evolutionary advantage

Mankind should learn this lesson. It does not make sense to increase the CO_2-production by burning fossil fuels and at the same time to cut down the forests. On the contrary, for each excess gallon of CO_2 which is released into the atmosphere, an equivalent increase of green surface should be installed. Technical regulators, for example CO_2 -condensors, which would also cool - off the earth, could be used alternatively; instead of green areas, solar-chemical converters ("artifical plants") would be in order, too. All of this is not even in a planning stage.

1.7.3 Delayed entropy production

Not only the reduction of an entropy increase ΔS over a certain time reduces the entropy production, but also a delayed increase would reduce it. This stems from the fact that we have to consider a rate, ΔS/Δt. One example for a delayed entropy production we have already seen when we discussed the meander effect. If one, for example delays the use of a certain quantity of fuel, one has also reduced entropy production: this is widely known as "saving" of energy. Again., the use of the term entropy instead of energy is superior, as it allows as to include emissions into energy supply strategies, as well as to evaluate storage strategies.

Generally speaking, if one delays a given constant entropy production by a time t_1 inside a larger time interval Δt, for example via chemical storage, the mean entropy production in the larger interval is reduced. If after the time interval Δt, one reduces the stored energy to thermal, in the larger interval Δt' which includes the conversion, entropy production is up to the initial value. At first sight it looks as if one only has shifted the solution of a problem. However, one has now the advantage to use the stored energy at another time or place, i.e. when it is needed most. This also bears dangers; planned or unintentional energy storage- the latter relating to our present day fossile fuels- may lead to an immense entropy production over a short period at a later time. This may even destabilize the "radiation equilibrium". Such a delayed entropy production apparently occurs today, as the fossil resources are burned away in a time interval which is too short against the time span of its creation. As we said in the last chapter, one can in principle balance that production by an increased entropy export into space, using cool off-converters, i.e. strongly IR-emitting surfaces and technical or biological CO_2-condensors, or by cooling off the earth by increasing the amount of solar light converter and storages, technical or biological.

In this context often it is asked if one should use fossile energy to build solar cells or windmills, as long as those elements are not effective enough to carry themselves in a regenerative economy. In other words, if they produce more entropy during their lifetime as they reduce. The answer is yes. We have always a reduction of the entropy production if the time interval of the use of primary energy is prolonged. One could have used the fossil fuel which is needed for the construction of a solar cell or windmill directly and for other causes, thus creating a high entropyproduction (burn it now !). Again there might be the argument, that in the end all solar radiation is converted into thermal energy and that thus the kind and quality of energy storage is irrelevant. This is not the case with our concept: if one reduces the quality of energy storage, the storage time is reduced, the refilling cycle is shortened and the overall entropy production is increased. If we consider a given energy storage as an stationary state, although the input and release of energy is switched on and off during a cycle, then the minimum of entropy production is higher for a storage of a smaller cycle period. The optimal period of energy storage, however, is not the same over the globe, it differs depending on geographic location. This geographic optimization we find also in plantlife, but far less in our global economy, where it is implicitely assumed that the " best product" is the "best product" everywhere (selling refrigerators to the eskimos). We give one example concerning geographical energy storage:

If we have a continuous warm climate over the whole year like we observe approximately with tropical islands, we find no necessity to store energy over a longer period of time. The power from a solar cell, for example, can be used immediately. The storage cycle period is very short in this case (microseconds) and the entropy reduction provided by the solar cells conversion of light into electrical energy is too small to count, because the electrical energy is converted into Joule heat inside the same time interval. If we now look at a solar collector in the subtropical region, during the summer we could convert more energy than we use , and the energy has to be stored for the winter, the storage cycle period then being one year. Averaged over the whole year, we have the same entropy production than on the tropical island. However, if we now store the energy of one summer for more than a year, say for 2 years, the yearly entropy production is reduced by one half - this is an example of a "delayed entropy production".

If one considers a lowest minimum of entropy production over as long as possible a period of time as a positive value, a storage facility with a long cycle time and a long lifetime is also valued positive, at least in the subtropical belt. In fact, lifetime and cycle time are not the only parameters to be observed: entropy increases associated with production, installation, maintainance and disassembly of a storage facility all have to be considered simultaneously. We go into that in more detail in the following chapter.

1.7.4 Time interval of cost consideration

As we have seen in the case of thermodynamic separators and in particular with the desalienation process, entropy can be reduced if external energy is provided, in the particular case solar energy. Using a primary energy means conversion of a low entropy form into a high entropy form, which results in a positive entropy production. In evaluating such a process, we always have to consider the total entropy production, but what is the time interval to be used? For every entropy producing process one can find a characteristic time period T_Z, for lifeforms this is the lifetime and for repetitive technical processes the cycle time. Processes, which we consider continuous usually just have a very long cycle. The entropy production now has to be summed up over T_Z , to give the mean value, $(dS/dt)_{mean}$; in symbols :

$$(dS/dt)_{mean} = (1/T_Z)\ \Sigma\ (dS_i/dt)dt = \Delta S/T_Z$$

Actions which reduce or delay the entropy production of a process, are equivalent to a prolongation of the cycle time T_Z. If one misjudges T_Z, an important part of the entropy production could be missing. This is shown in fig.5. There, a product cycle is shown schematically over a time interval $\Delta T = T_Z$. It includes construction $(dS/dt)_H$, maintainance $(dS/dt)_B$ and dismanteling $(dS/dt)_E$. The first term also includes the necessary raw materials. In total:

$$(dS/dt)_H + (dS/dt)_B + (dS/dt)_E \ \text{-->}\ \text{MIN!}$$

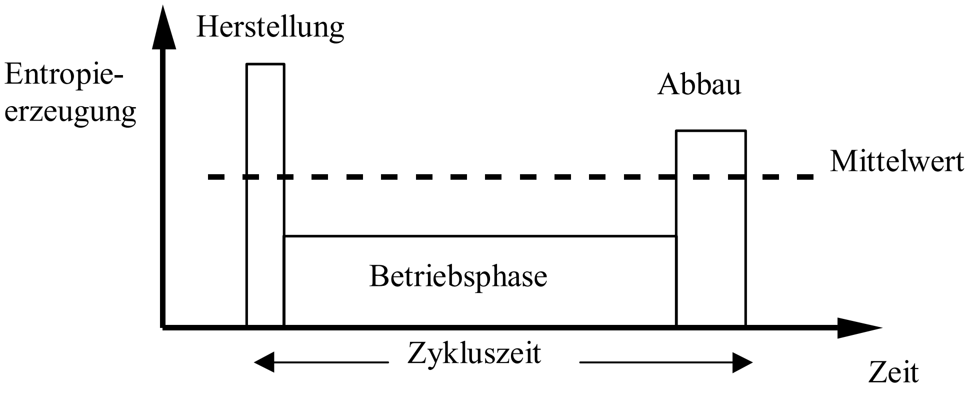


Fig. 5 Total entropy created during the life cycle of a product

This is equivalent to what is known as eco-balance of a product over its lifetime. If, for example, one compares cars only in regard to their gas consumption, one basically compares the maintainance entropy-production only, $(dS/dt)_B$, summed over the cars lifetime. Pollution which occurs during production or recycling are not considered, if one does not take into account the whole cycle, which might well have significant peaks at the beginning and at the end.

There are, however, product cycles which are significantly longer than those of cars and extend beyond the average human life span or even beyond many generations. This applies to buildings, but also for products with designed short lifetime, which, however, have a long destruction phase, as plastic or nuclear material. If one affects climate changes with one's products, one has to take even longer cycle times, for example those of ice ages. The problem of taking the correct time interval or "calculation depth" is always with us. In a given case we will always have to look for hitherto unknown secondary entropy sources. At this point the argument is heard that since all processes on earth are connected in a supercycle, it is impossible to account for all of them, and we might as well give up our entropic efforts, or, because we have to interrelate all of them on a supercomputer, all we can hope to achieve again is a world model. However, as we have said before, world models, because of their complexity, make it difficult to use them for the evaluation of a simple act or as a basis for an everyday decision.

It would be more helpful if we invert the problem, i.e. start with systems of low complexity and then combine them to larger units. We forward a systematic approach in Chapter II. The point of orientation will always be the minimum of entropy production and that also small groups, sizing down to the individual, can derive answers for their actions inside their time and life sphere.

2. Ways into a global stationary state

In this chapter we investigate if general rules exist how to combine local minima of the entropyproduction to a global solution. Initially one has to assume that the sum of local and particular solutions which are worked out by individuals and smaller groups, are not necessary the global optimum. This , however, should not be used as an argument for a regulation of all human activities or for a complete control over the whole world population (H.G. Wells)

The correct way is to combine individual solutions in such a way that the optimum is approached.

Only this way we can hope to preserve an universal adaptability to environmental or social changes inside the society comparable to that which is characteristic for the individual. For the connection of particular solutions one has, however, to provide an algorithmus, i.e. an iterative strategy which connects two optimal singular solutions in such a way that the new combination is even better [11]. Such a strategy can be worked up to systems of arbitrary complexity. In what follows we sketch the structure of such a scheme.

2.1 ACTIONCOORDINATES AND TARGETPARAMETERS

In a first step we try to generalize the stationary state, sometimes also called flow equilibrium such that is describes higher activities in a quantitative way. As before, the evaluation of the activity will be its entropy production , dS/dt. This may depend on various variables. For demonstration we chose one variable , the action coordinate A .

First, we assume that a state with a minimal entropy production, (dS/dt)min, exists at Ao. This we justify by assuming lifeforms to be close to the stationary state. For humans we have adopted the basic energy conversion as minimum, i.e. (dS/dt)min = 1/5 W/K. Each human activity increases the entropy production. The action coordinates Ai are then a generalisation of the thermodynamic forces which generate the thermodynamic flows, for example the entropy flow dS/dt.

A flow equilibrium can also be compared to a static equilibrium, for example a ball in a bowl. The minimum of the potential energy is at the bottom of the bowl. The ball is at rest only at the bottom, i.e. at the minimum . It is necessarily in motion at all other positions. Instead of a bowl one can also take a hollow sphere or a paraboloid. Now what about a minimal entropyproduction. Can it also be represented by a bowl depicted in a coordinate system? The ordinate would have to be dS/dt, but what is the abscissa? We call this variable an action coordinate A, as each activity enhances the entropyproduction. A dS/dt increase is then represented by an uphill motion (Fig. 5)

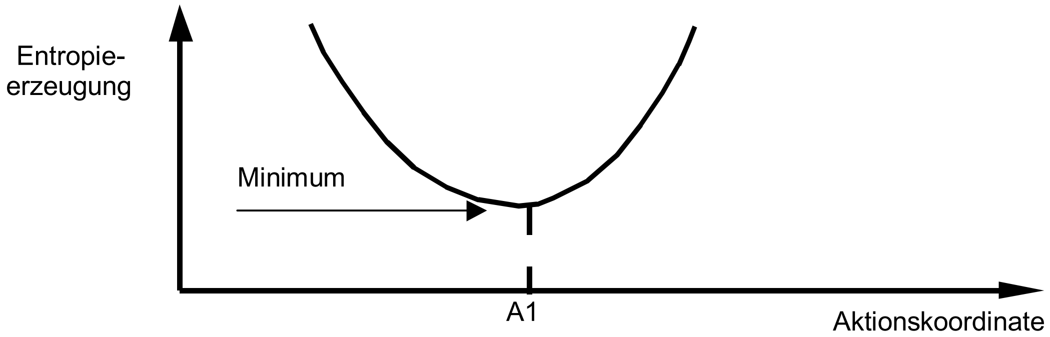


Fig. 5. Illustration of the action coordinate

The minimum of the parabola corresponds to the activity at rest A_o and at the same time announces -on the ordinate- a minimal entropy production $(dS/dt)_{min}$. Going away from A_o to either side we always leave the minimum. But what is negative Activity ? Obvious it is not passivity, because this characterises the minimum. Indeed, we apparently have a case of a bipolar activity. Both ways we increase entropy production.

> *Lets take up an example: rolling motion of a car can be changed by either accelaration or braking. Braking produces heat out of the high value energy of motion, i.e. entropy gets increased. With acceleration we increase fuel consumption, i.e. we increase heat production and mixing entropy (emissions). The rolling car indeed has the lowest entropy production, the residual production being connected to the rolling friction. We also find the bipolar pair of action-coordinates:*

"acceleration-braking". In contrast , "rest-motion" represents an unipolar activity, but coming out of a minimum. This actually suggests to set $A_o=0$, and asks about the meaning of a negative activity in case of unipolar activity. As negative activity cannot be accomplished by a single individual, actually negative activity might be activity done on the individual, which also requires an increase of the total entropy production considering both individuals. For example, a sick individual would require care, which can only be done by another person. This ties in with the idea that an offset minimum and with it a true biploar activity generally comes about because of two opposing effects.

The action coordinate is expected to get more and more complex with increasing complexity of the system considered. This means also a hierarchical order of activities. There are indeed activities which embrace more than the examples given before, for example by the pair

" creation-destruction". More complex activities can usually created through a combination of several lower activities. The combination should be chosen such that a new minimum of the entropy production is reached; only this is in the sense of progressing from local to more global units.

At this point we want to stress that here we only measure the entropyproduction created through a specific human activity. This is a basis for a new cost evaluation and does not contain a moral or political

judgement of these activities. Judgement is a matter to be taken up by society. A single high entropy production in the frame of a larger project

can indeed make sense for the group given a certain situation.

2.2 INCREASE OF COMPLEXITY

2.2.1 Coupled systems

Now we look closer into the increase of complexity, which runs along with a combination of local units into a global picture. As A_O stood for a large number N of simple activities, i.e. all lifesustaining physiological processes, fig.8 has to be viewed as a parabola in an N- dimensional space. Such a concept appears to be unpractical from the beginning. It is therefore a prerequisite to increase complexity in a controlled fashion, this means that we have to find a transparent algorithm. In order to make a choice we first formulate two simple principles :

1. one obtains correct answers with simple systems which can and have been analysed using other methods.
2. One should state in general how two initially independently optimized systems are combined to a more complex optimized total system.

The combination of two formerly separated systems should start with the definition of a joint activity coordinate. Thus, two systems which might have certain minima of entropyproduction versus certain activity coordinates individually, should have at least one coordinate in common. This joint coordinate is the basis of a potential coupling of the two systems. The ordinate is the entropyproduction per mass or volume unit, dS/dt, as before. Thus , in the same graph one can now find three minima, two representing the individual systems, the third representing the combined system (fig. 6).

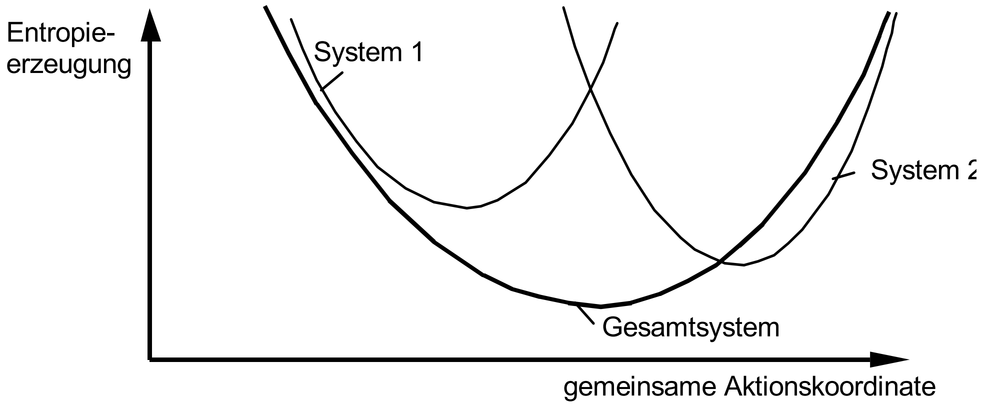


Fig. 6. Illustration of combining two formerly independent system into a coupled system with common action coordinate.

Next, we look at the optimization of a thermal solar collector system. Here, there is already a lot of work done and we can compare with these results. In such a system one usually finds two components: (1) the solar collector, which converts the influx of light (electromagnetic energy) into heat (thermal energy) and the heat reservoir, which should store this energy as long as possible. Both components are connected by a coupling element, the heat exchanger (fig.7).

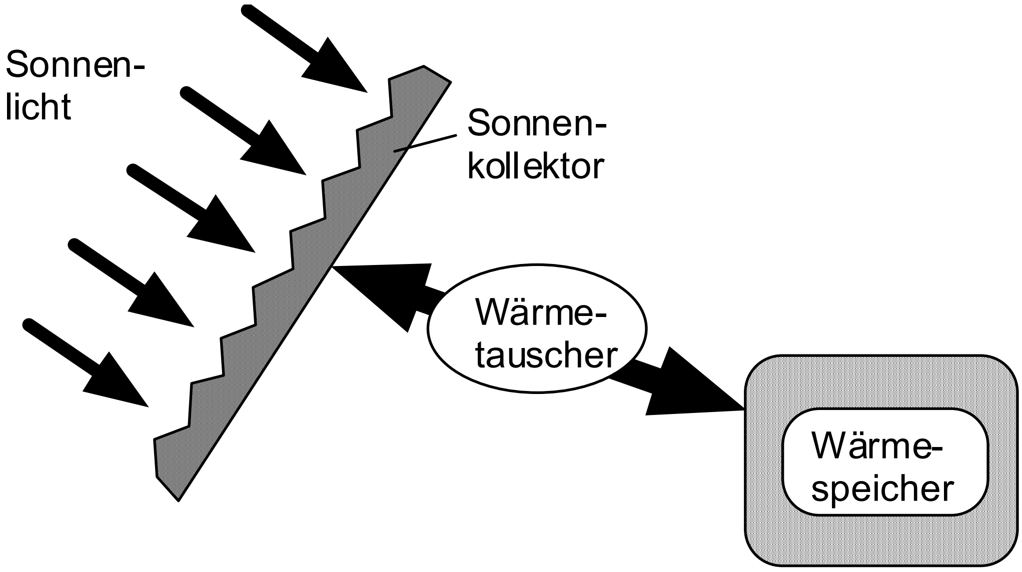


Fig. 7. Coupling of the two systems „heat storage“ and „solar collector“ by heat exchanger.

In the course of investigating the coupling in this particular example, we first look at the individual components. For the collector, we consider the incoming and outgoing radiation only; heat diffusion losses are excluded as they can be considered together with the heat exchange.

For optimization, one should control the two light fluxes. Which thermodynamic forces, or in technical language, which pumps and valves determine and regulate these light flows. The incoming light flux results from the temperature difference sun/earth and is constant. The valve for the incoming flux of visible light therefore has to be kept fully open, the valve for the outgoing infrared flux to be kept fully closed. For the construction of the collector one may use the fact that the solar radiation lies in the visible spectral range and is oriented along the line sun/earth. The offradiation on the other hand lies in the infrared spectral region and is goes in all directions. The inputvalve we thus (1) construct as a geometrical light trap by using an oriented structure as surface which has a characteristic dimension equal to the visible light wavelength. The material is selected such as to absorb optimally in the visible. This way the input valve is wide open. For the infrared radiation with a much larger wavelength such a surface appears "optically flat". According to Kirchhoffs radiation laws, the strong absorption of the surface usually means a strong emission, too, i.e. the output valve would therefore also be wide open. the trick is now to chose a material which absorbs well in the visible and poor in the infrared . Thus, as the surface can be chosen practically "black" in the visible and "white" in the infrared, both conditions can be met, ie, the input valve open and the output valve closed. This way, the temperature of the collector lies between T_e and

T_S. The higher the collector temperature, given a certain influx of energy ΔQ/Δt, as lower is the entropyproduction as $\Delta S= \Delta Q/T$. A high collector temperature is therefore consistent with the principle of a low entropyproduction. Today, solar collectors without radiation density enhancement can reach temperatures up to 600 °C.

The second component is the heat storage unit. Here, one has to control two fluxes, too: the incoming heat flux, which could come from any heat source, and the heat flux which should go to the consumer. The incoming flux is connected with the heat exchanger between source and storage. The input valve is to be held open as long as the heat source exists, the valve which gives heat to the consumer is to be kept closed at the beginning. Thus initially the same rules apply as were observed for the collector: a given quantity of thermal energy means a lower entropy-production, if kept over the same distance Δt at a higher temperature. The heat storage, disconnected from the consumer, should therefore be run at the highest temperature possible.

Adding a user (3rd system), the picture changes. If , for example, the user wants to average out the day and night cycle, collector and storage are to be manipulated differently (see appendix).

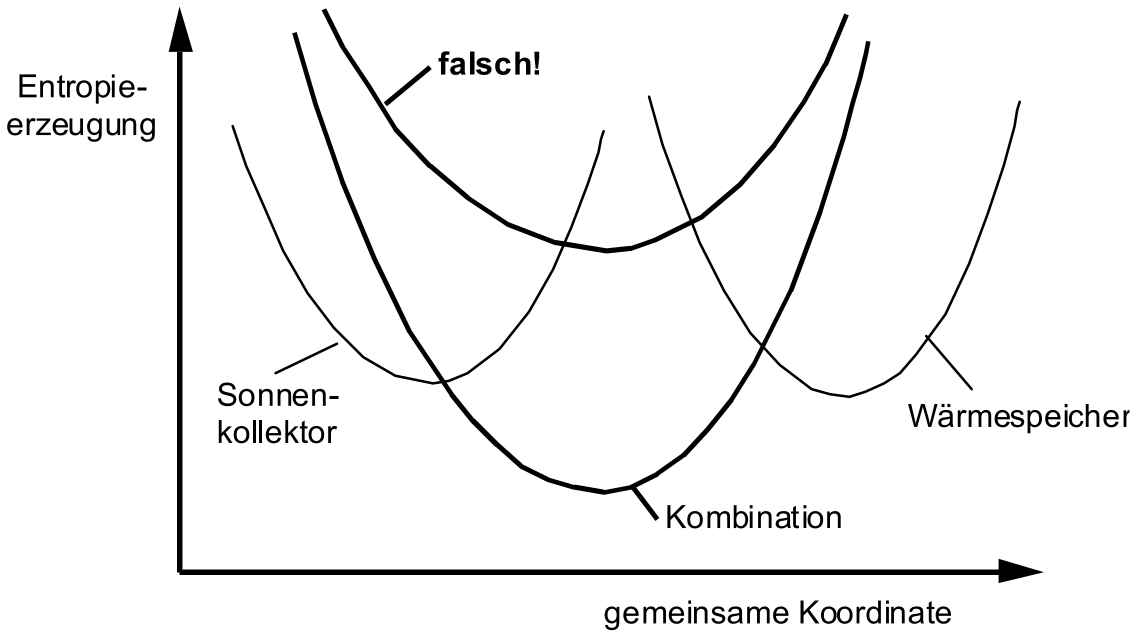


Fig. 8. Scheme of the combined system on a common action coordinate.

We now try to generalize; however, not to go astray we identify the collector with system 1 and the storage with system 2. For the combination of the two systems we need a coupling unit. More specifically, we read from the general rule that we have to find a a joint action coordinate Ak , then we can draw a minimum in the plane S/Ak.(Fig. 8). Obviously, here the couplig element is a heat exchanger, i.e. we can chose the pump , which guarantees that the heat loss of the collector is equal to the heat flow into the storage, as the joint action coordinate. If we have an intermittend inident light, we have to control the valve of the heat exchanger correspondingly. During the day the heat exchange should be open, at night it should be closed. At the same time heat should be given from the storage to the user. This leads to an adaptation of the temperatures of collector and storage, which are not the highest possible, as it was the case with the optimization of the single units. Thus, we do not only find a new combined minimum for the entropy production, but with it come also changes in the single components, adapted to the new conditions.

Already here we can further amplify on what we mean by species-specific target parameters. While for mammals at night stored heat is important to reduce the burning of food, a reptile, which is hunting only during the day would need a less efficient heat storage only, i.e. one which would average out a short break of the incident radiation (e.g. a cloud). If one simply takes a (quadratic) piece of rock with one shady and one sunny side, this can be viewed as a heat storage with a fast heat exchange period which is more or less useless for humans. A lizad, however, clinging to the rock could use it as a temporary heat source during the shadow period. Thus , even the characteristic time of a heat storage is species-specific. Our target parameter would be a daily storage time, the lizard's half an hour or so. This example shows , that even on a local basis the minimalisation of the entropy without target parameters does not make sense (see in particular the chapter about toxidity). Also, we find that the same target parameters may indeed benefit a whole group of species (warmblooded animals).

Moreover, as the average period of sunshine varies with the seosons and the geographical latitude, a solar heat storage has to be optimized seosonally and regionally, just as are plant strategies. Here evolutionary features appear again.

The coupling of a solar collector with a steam power station shows how the system components are changed also when the coupling strategy is changed. Originally using flat mirror systems one has concentrated the radiation in order to achieve the highest possible temperature for a later heat engine cycle. Later one has situated the heat exchanger directly into the focus of a series of konkave mirrors, which proved to be even more effective. This shows that the method chosen to combine two formerly individually optimized systems really makes a difference. There appears to be still a lot of room for ingenuity if one works around a principle instead of a law. Also, new optimums can apparently be achieved with increased complexity and stronger coupling.

As long as one considers nonemitting thermodynamic engines, an evaluation via entropyproduction should be equivalent to the classical treatment , which considers the efficiency of cyclic engines. Electric solar generators work without emissions and solar steam generators with non-toxic emissions, in both cases we expect to verify the standard results(see Appendix). In evaluating emitting engines (combustion engine, batteries) and chemical separators on should certainly use the more general minimalisation principle.

2.2.2 *Action guided twin systems*

A large class of coupled objects are twin systems. They can also demonstrate the coupling and the increase of complexity. While the collector-storage system combines two quite different objects, twin systems have a comparable functionality. However, the are weakly or strongly coupled using a to be defined joint action- (Ag) or coupling coordinate.

The first example for a twin system is what is generally called a "back-up" system. A back-up system is supposed to prevent the breakdown of an important service, for example of medical or military type. Back-up systems thus mainly represent a safety aspect and are switched off, except in cases of emergency. Usuallt the back-up sstem is switched on automatically if the main system fails; this way the two systems are connected. The lifetime of the total system is extended this way, because DS/Tz is smaller and as one system- the non-active one - always is on dSB/dt = 0.

A back-up system can be an identical unit, which is switched on when the main system fails, but both systems can be different, while serving the same function. If the main is a windwheel providing electrical energy and the back-up a solar fed battery, one can make the switchover not at failure but if the main systems energy level falls below a certain critical level. Alternatively, the back-up system could have a sensor which measures the wind velocity directly. Thus, we can think of different joint action coordinates Ag between the two systems.

The switching mechanisms used should be thermodynamic, i.e. should operate using a larger (molar) number of particles and not using the micro- or even nanoampere current of computeraided systems. This way a small thermodynamic number system controls a large number systems, which might lead to security risks as electronic shock scenarios or computer virus (millenium bug etc.). If electronic regulators and calculators of a whole region goes into failure, the resulting costs could be quite high. Thermodynamic switching thus can be viewed as a security measure against malfunctions. Failures can mean a high secondary entropy production, as the exchange of failing advanced units means large production costs $\Delta S_H/dt$.

As an example for a thermodynamic activation we look at a water collecting system, which is opened only if a certain amount of rain drops is assembled. This would need a larger area or volume for activation as compared with a localised electronic sensor, which could be acxtivated also accidentially. If such a thermodynamic activation is impossible, a distribution of many electronic semsors over a larger area would be a compromise.

Another example for a twin system is a combination of a support- or starter system with a main unit. The start-up system would have a similar function as the main system and would initially support it. An example for a technical startersystem is a small windelectric generator which is used to activate a larger unit of this kind even if this larger unit singly would not be able to operate.

> *Let us look at a pair of windmills: a starterwheel which needs only low wind velocities and a larger unit which is constructed such as to operate at winds up to storm values. At soft winds, only the small wheel will rotate. The larger wheel will, with its larger friction, will not rotate. As soon as the energy supplied or collected by the smaller wheeel is sufficient to undamp the larger system, for example via levitation of the rotating shaft, friction in total is reduced and with it the lifetime increased. Once the larger wheel works, it can protect the smaller wheel against too strong winds, for example via the reduction of the air-inlet . This way a mutually beneficial relationship is established, very similar to a symbiotic relationship. units can be continuously added, if necessary, whereby always consecutive units support each other.*

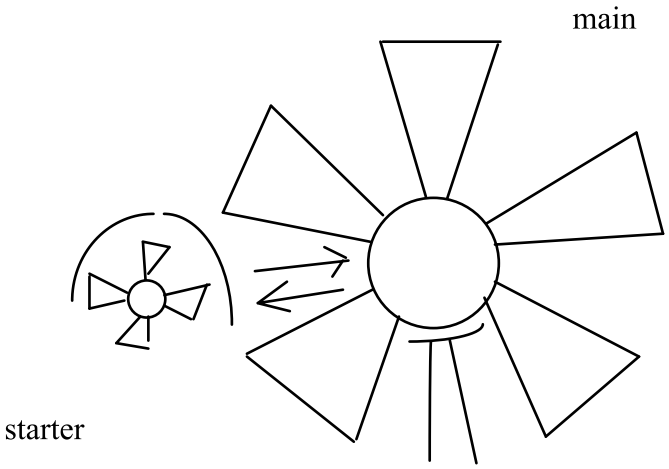


Fig. 9 Wind turbine twin system with main and starter rotor

Twin system of this kind primarily reduce friction and second increase lifetime, while the pair main-plus back-up system primarily increases lifetime and reduces energy dissipation second.

It is interesting to look at todays solar collectors in this view. Strangely they do not have light activated starters nor protective measures. This is not optimal in terms of the secondary entropy production; the missing protection invites cleaning costs, reduces lifetime and thus invites early replacement. On top of that the direct conversion into fast dissipated electrical energy has a smaller entropyreduction as chemical storage.

Finally we compare with nature. Here, we find a large amount of actionguided processes, which are often coupled with each other: the unfolding of the leaves in spring and their fall in autumn; the opening of flowers, variable water evaporation with desert plants etc. These phenomena support the energy- and material conserving processes of the plants as well as their security. As one observes these measures with plants, one is tempted to link them to low-energy systems only. This is unsupported; high energy level need these strategies even more as higher costs are at stake.

2.3 EVALUATION FACTORS AND BASIC SOCIETY

A mixing entropy can be valued positiv or negative, depending of its use. A physiological salt solution, for example, is valued positive as infusion while as drinking water it is useless. The evaluation of the mixture is based on the effect on humans. Equally, the emission of toxic gases into the atmosphere or toxic liquids into the water table is unquestionably negative, while the distribution of water and oxygen is valued positive. Obviously materials which are important for plants and animals are almost evenly distributed over the globe, while other, neutral or hazardous materials better be non-distributed. There is, however, a grey zone where one has both positive and negative effects, for example with pestizides and fertilizers.

Thus, even if we single out a certain species the evaluation of a given mixture is far from being objective. As with any other human values an evaluation of human activities via entropyproduction is not absolute. Society has to find an evaluation factor which is to be multiplied with a given entropy production. One sets the factor such as to benefit humans. Then, the other lifeforms are evaluated according to their usefulness to humans. One can specify the evaluation factors gi a little closer: they should primarily protect life and reproduction of the species. Thus, the distribution of toxic and radioactive materials and their persistence in water and atmosphere should be avoided and competing and parasitic populations should be held at bay. The weighted sum of all relevant entropyproductions we call the entropyproduction of a "basic society", as it might not include all wishes and addictions of human beings. Written as an equation, the total weighted entropy production (dS/dt)w follows from the summation of single entropy productions (dS/dt)1, (dS/dt)2,... with factors g1,g2 ... :

$$(dS/dt)w = g1(dS1/dt)1 + g2(dS2/dt)2 + ...$$

The evaluation factor g has other uses, too. As elaborated before, a mixing entropy can be valued positive or negative. for humans, the entropyproduction which is connected with the pollution of the seas and the salting of the water table is harmful. In other cases, entropy production can be useful for us such as the emission and distribution of oxygen by the plants or the distribution of water on agricultural areas. This can now be written as a value using a nagative evaluation factor, for example $g(O2) < 0$. The secondary effects of one and the same material distribution can be both positive and negative, for example, the use of fertilizers is wanted because of increased food production, but the simultaneous pollution of the water table with nitrates is not. In our sum , this would be weighted by sign and magnitude of the gi of the secondary entropy productions. In such conflicting cases one should attempt a separation. The structure of the equation also hints the kind and venue of the evolutionary changes which might result from its acceptance:

Today’s civilisation has already implicitely set many of the evaluation factors gi which are connected with various entropy productions dSi/dt.

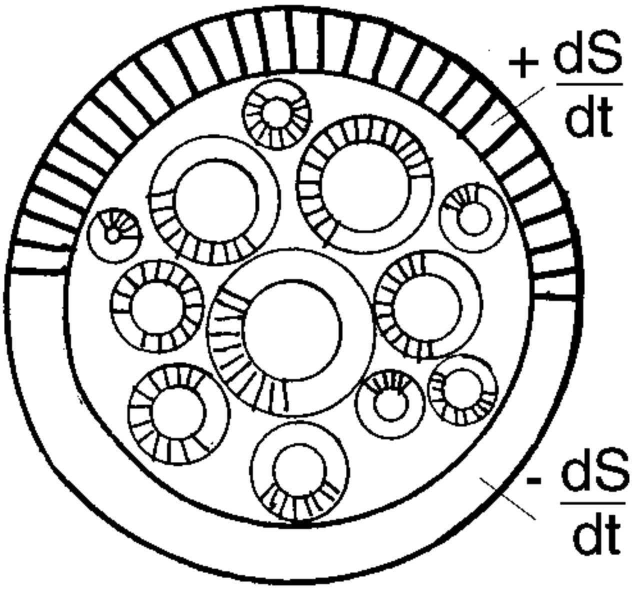


Fig. 10. The weighted Entropy contributions $G_S dS/dt$ of the single species-related subcycles add up to the global cycle.

For example, if one announces the right of life for every person, then it is unnecessary to evaluate his basic consumption, g(GU)=0. With mans various higher activities it is certainly different. CO2-emissions are not explicitely counted today, which would mean g(CO2) = 0. Indirectly, however, it is considered as society calculates "energy costs". If one reduces 'energy consumption' one indirectly also reduces emissions. This is equivalent to set g(CO2) > 0. According to our considerations, this value has to be reconsidered because of the secondary entropy production. Todays "admissible" concentrations of toxic materials in air and water, highest possible radiation exposure, limitations of noise and light can be considered nuclei of a more systematic evaluation on the basis of entropy production, including the weight factors gi. This can be observed in particular with chemical emissions : limitations are only imposed if the considered materials are to be distributed. In total, a matrix gik (k: given entropy production, i : all secondary effects).

Contrary to today's procedure, in the future we systematically have to change the matrix so that the total entropyproduction is minimal or even zero. This should work as follows: let g1 be the weight factor of a selected entropy source S1. If g1 is large, it should not arbitrarily set to zero, but the corresponding entropy source should be removed:

If for example the soil around a battery producing plant is loaded with lead, setting g(Pb)=0 is equivalent to ignore this fact. The health of workers and their families as well as that of other residents is, however, endangered. That is why *g(PB) should better be set large, which at the end would lead to the elimination of this toxic source.*

If one adds the negative entropy productions only, $-dSi/dt < 0$, instead of the total costs, one obtains the total "values" of the society in the new cost calculation. What are they ? These are the contributions which are taken out of the entropyproduction caused by the solar radiation on the prefossile earth, i.e. life preserving structures (forests, buildings etc.) and fuels (food, gas, etc.) . A society which traditionally values energy and not entropy reduction, will also acknowledge these items as values, however, in that case always inconsistencies : lifeforms including humans contain mostly water and the amount of carbohydrates is small, giving a small fuel or structural value. Nervertheless humans have a high priority.

Looking at entropyreduction instead of energy, these inconsistencies tend to disappear. For example, every lifeform as a highly ordered structure ($-\Delta Si$) already represents a large basic value, $\Delta Si/Tg$, Tg beeing the reproduction time. Next, this basic value can assigned a species specific g-factor. Man, as the lifeform with the highest degree of organisation and also as the judge, would probably choose a maximal value. However, other lifeforms would now have a comparable basic values. The structural entropy of organisation is evaluated in more detail in the appendix.

The negative entropy production connected with (self-) organisation thus representing a value, so far we have always evaluated the exportable thermal equivalent of this structural entropy form, in other form, the overall "production costs". The ratio between a structural entropy and the thermal equivalent will give an efficiency factor.

For this efficiency it is important, if the "development cost" are already included or if they have to be newly initiated. Blueprints of structures or DNA-charts of lifeforms are either existent or extinct. The latter significantly reduces the efficiency. If a lifeform vanishes, the efficiency for this particular blueprint goes to zero and the "development costs" go to infinity, as nobody can recreate this biological product without the DNA-chart. Thus, all the stable lifeforms created by evolution probably represent quite large values, even for us. And this does not only apply to plants and animals which are considered useful today, but also to lifeforms of so far still unknown use.

After inclusion of species specific evaluation factors we obtain a basic value scale for our acts which is based not on conserved quantities as energy ao mass, but on entropy production as not conserved, but still measurable and balancable quantity.

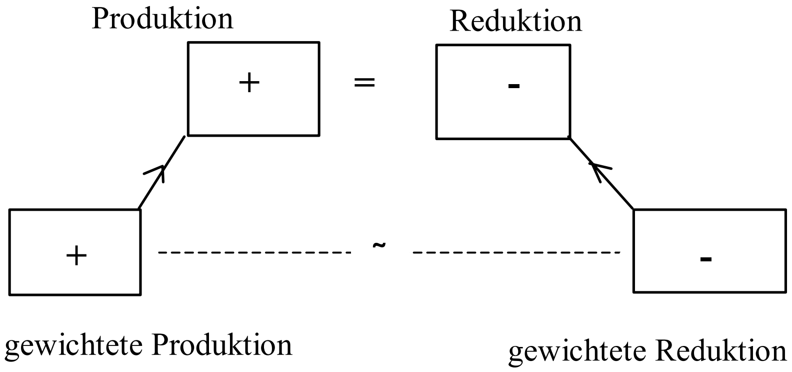


Bild 11. Entropy balance of a species and weighted balance

2.4 VALUE OF INFORMATION

In our society, information is considered a value, and rightfully so. The increasing experience in life is valued positively in general. Again, if one values energy primarily, the programming of our associative memory would be of marginal or arbitrary value. Information, however, is connected with entropy (v.Neumann, Shannon). We may interpret our knowledge as a structural organisation of the brain and thus consider as a reduction of entropy , - ΔS, versus a random or unprogrammed initial state. The konowledge might be acquiered over a learning period Tl. Thus, the learning speed -ΔS/Tl can now be considered an entropy reduction. We can also introduce an evaluation factor, which defines itself by the part of knowledge which is important for survival.

Information can also be viewed as negative entropy . In statistical themodynamics the entropy can be derived from a binary information system, such as two spin states (-1,+1). The binary number system of digital electronics also has only two digits (0,1). Choosing one of the values we specify information. The unit of this information is one bit. This gives also the smallest information in a binary system , Io = 1 bit. For the connection between entropy and information, we look first at Boltzmann's definition :

$$So = k\ln w$$

w is the number of possible states of the system which can be installed. k is Boltzmann's constant, which here serves to transform inform,ation into entropy. As with binary information we have two possibilities only, the entropy connected with on bit is :

$$So = k\ln 2$$

If we set the bit, information is stored and the physical state is determined; if only one state is possible, w = 1, the entropy is zero as ln1 =0. Entropy is reduced by one unit So, when we set one bit.

The concept of minmalisation of entropy production dS/dt values the increase of information positive. However, the corresponding information- or baudrate has to be weighted according to its elements which are relevant for survival and reproduction.

It is certainly not to be expected, that the production of silicon chips itself will solve the environmental problems. Information processing installations primarily contain structural entropy, i.e. negative entropy which is located in hardware and not only in the stored information. As is the general rule for products, not only the entropyreduction which in contained in the complex structure, but also the entropyproduction caused during its creation is to be counted. Thus, we always have to consider the exportable thermal energy which is to be paid for the installation of technical or biological information processing at the end. Intelligent lifeforms are lowentropic and thus their calculators are probably more efficient as todays technical computers. This can be estimated as follows : when we construct a technical information storage, the volume needed for the storage of a bit is limited to about several nanometer cube in size, which means that at least several thousend of atoms are involved. In contrast, biological information storage works already at a molecular level.

That means also, that a simple pollution on a molecular level corresponds to a much larger entropy increase as could be eventually compensated by the entropy decrease connected with technical information storage. Information technology, which certainly has to be praised for possibly avoiding secondary entropy production (see next chapter), can only give a small direct entropyreduction.

2.5 THE EXAMPLE OF A SUCCESSFUL EARTH POPULATION

Plants live successfully on this planet although they are basically localized . They did change the surface and the earth's atmosphere during their existence. Photosynthesis determines the composition of today's atmosphere, in particular its O2 and CO2-content. Through their surface cover plants changed the conditions for incident and emitted light and thus help to globally finetune the earth's surface temperature. They obviously observe strategies leading to an entropic balance : at night they prominently radiate heat, i.e. export entropy. For the non-exportable material flows they create cyclic flows, which they entropically balance individually through reducing the mixing entropy in their effective chemical separator systems, i.e. in their root and leaf systems. Photosynthesis also brings about energy storage, i.e. reduces the potential entropyproduction connected with unchanneled light conversion.

The 'higher' mobile lifeforms, i.e. humans and animals, have so far contributed little to the entropic balance of the earth. Viewed from the perspective of the successful sustainable populations of plants, funghi and microorganism, they have a parasitic, at best a symbiotic function. The latter in their role of contributing to the spread of plant life. If we choose to live on a future selfmade desert planet earth, we would have to artificially replace all the regulatory measures of the plants and their large variety. A gigantic task. If mankind would really decide to make this effort, a real desert planet like the moon or mars would be better suited. One may have theories about the roots of our strange behaviour, for example one may point to our genetic construction as predator, but if we cannot change our collective behaviour either through evolution or through the intellect, we will be just an episode of evolution. The hope is that each generation will learn from the accumulated knowledge of former generations and at the same time develop the necessary changes in the collective survival strategies.

3. New ways of production

We have seen that the concept of minimalisation of the entropy production does not question or replace the democratic and ecomomic structures of today : it proposes a shift of the values inside these institutions. The same is true for todays industrial production. The most remarkable difference between our production cycles and that of the plants is that our production creates large quantities of waste in form of gases, liquids and solids which is then distributed rather carelessly into the biosphere. Thus, the basic conditions of life , air, water and food get increasingly polluted. The material cycles of the plants do not create such problems, however, adopting the strategies of the plants appears to be difficult for us.

Although the principle of minimalisation of entropy production attaches high "costs" to pollutants, at first sight it cannot say anything about how to avoid them. If one looks more closely, astonishingly, we can derive guidelines even for that. This comes from the definition of entropy and its application to cyclic processes. That is why we now go back to classical thermodynamic cycles and then try to generalize them onto real product cycles. The theoretical prouct cycles that we obtain this way can be discussed in terms of better performance, but can also be compared with the production cycles of the plants. based on this comparison, we try to find general rules which might be applied to the technical production in the future.

3.1 IDEAL PRODUCTION CYCLE

3.1.1 Thermodynamic cycle

The term reversible stems from thermodynamics and means that a change of state can be reversed without increasing the entropy. Thus, along a reversible change of state course, the entropy production is zero, too. This is an idealized situation. If one connects several reversible changes of state such that the branches open a finite area in a phase diagram, we speak of a thermodynamic cycle. Then, the whole cycle is reversible. In order to depict such a cycle one usually chooses a pressure-volume diagram or an entropy-temperature diagram. In both cases the enclosed area measures a (mechanical) energy A. A is a high valued energy which is won after the cycle is completed once. Fig.13 shows in particular a cycle between two temperature reservoirs. In that case the upper reservoir provides heat, while the lower one accepts heat. The (mechanical) work may be used for some form of entropy reduction, i.e. either an ordered structure (building or lifeform) or an energy storage (fuel- or waterstation). In both instances we can also speak of obtaining biological or technical products.

Certainly, the reversible cycle is an idealized situation, because a "reversible" production would be one in which the build-up of a product and its dismanteling could be reversed at any stage. That is clearly not so with real production cycles.

Fig. 12 in particular shows a cyclic expansion and contracting of an (ideal) working gas, with thermal energy taken out of a hot reservoir and less thermal energy given back to a cold reservoir. the difference in energy is converted into mechanical energy A using a directed gas expansion.

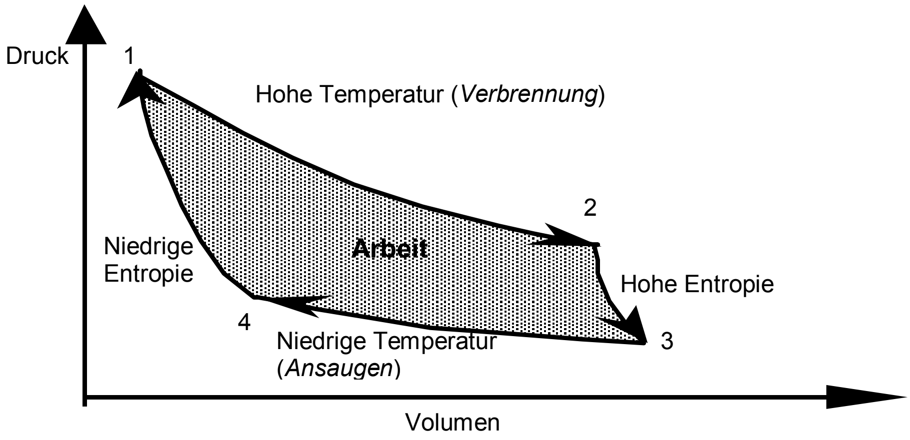


Bild 12. Carnot-Cycle, illustrated as pressure-volume-diagram.

3.1.2 Cyclic separators

Cyclic emission and separation is found in the prefossile earth as well as in the biosphere (sweetwater/saltwater cycle or CO_2-cycle respectively).

In order to prevent that large quantities of toxic waste, hothouse gases etc. are deposited into the atmosphere and the oceans and at the same time to control the global material flows in the future, we need a new kind of technical appliances, the socalled "thermodynamic separators" (Ch.1.6). These machines are supposed to run with primary energy and emit only waste heat, just like the work producing thermodynamic cycles, i.e. they should run emissionfree. These separators one can also use if one attempts a cyclic concentration and distribution of materials. Because of the special form of the mixing entropy, which runs over a maximum when the concentration c is increased (c : concentration of material B in matrix A) one can depict a rather fundamental cycle (fig. 13), Obviously, with a mixture AB, if A is concentrated, B is concentrated as well, i.e. two symmetrical cycles would always run in parallel. If we start at location 1, we have no ideal mixture in the beginning, but rather a granular material : there are regions which have a higher concentration of A (can be read from point 2) and an equal volume fraction having a higher concentration of B. Going from 1-2 (and simultaneously from 1-2') means a (mechanical) separation of the differently concentrated volumina; this way A as well as B gets enriched (per volume).

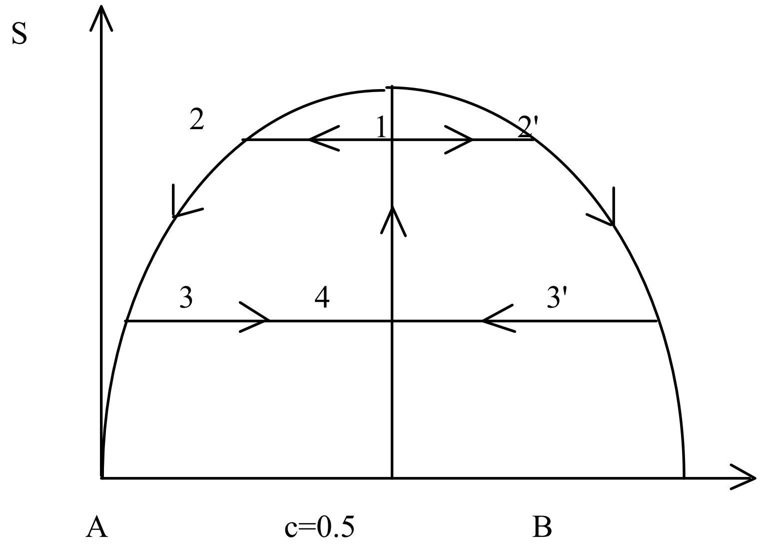


Fig 13 Ccyclic separation.

An example would be a mineral's separation into rich and dead material. Going from 2-3 is designed to further concentrate A. here, we have to use a difference in the molecules A and B, i.e. specific weight, size or bonding tendencies. Accordingly one knows density separation, molecular sieves or chemical pocesses. As one arrives at 3 one has almost pure material A (and B) which now can be stored (delayed mixing) or mixed again. In the latter case we go from 3 to 4; on this route we only bring the materials in close contact again. The molecular (though incomplete) mixing occurs on going from 4 to 1. For all action path's one needs primary energy (for example 4-1: stirring, heating to increase diffusion). If one can start from an ideal mixture, say an electrolytic solution A^+ and B^-, we do not need the segments 1-2 and 1-2'. However, with electrolytic separation two complementary cycles obviously run in parallel and the total volume gets separated in two halfs again, because the concentration of A (and B) occurs at the electrode(s)(1-3 and 1-3'). In order to increase the purity one is tempted to lower the section 3-4 down to the ordinate, where $S_{mix} = 0$; however, this is impossible because we can only asymptotically reach absolute purity. Cycles of this kind will always use primary energy as it runs between states of different structural entropy. In other words, there will always be a finite thermal entropy production $dS/dt > 0$, connected with such mixing/concentration cycles. The plants have integrated these "costs" into their entropy balance. In contrast, the mining of materials and fuels done by man, is primarily pointed to molecule concentration only (segments 1-3). A recovery of molecules out of strongly diluted mixtures is not attempted generally. With increasing exploitation of the natural cycles and the exhaustion of the richer mineral deposits, civilisation has to take measures also in this direction.

3.1.2 Production cycles

We now attempt to generalize the thermodynamic cycle such that it can be used to design a real production cycle. First, we submit that thermodynamic terms can be used, as in the end all production and recycling appliances run on high valued energy and create waste heat. If mixing entropy is created within a given production cycle, we have to add a thermodynamic separator, which also can be operated in a cycle, i.e. a subcycle is to be added.

The Carnot cycle suggests a free choice of the high and low temperature reservoir, but this would be true only for local subcycles. Globally these reservoirs are fixed, i.e. the hot reservoir is the sun (T_s) and the cold reservoir is the earth (T_e). A local example for a cycle using T_s and T_e is the solar cell (producing electrical energy). In this case we can show numerically (see 7.7), that the use of solar radiation here on earth is equivalent to direct coupling to the temperature reservoir sun, $T_s = 5800^oC$, while the lower temperature reservoir is $T_e = 15^oC$.

Also, if we use fossil fuels in a cycle, we recognize that we use these reservoirs, only delayed in time. With the exhaustion of the fossile reserves, more and more cycles will couple directly to the sun's radiation.

Products are created on earth if one uses high value energy to redistribute certain molecules - usually towards a higher concentration. In particular, concentration of uniform molecules into a pure liquid or solid of this species constitutes a high degree of order which reverses a molecular distribution. If this condensed state contains chemical energy it is specifically called a fuel, if not it is called a product.

Fig.14 now shows a general diagram, where a high value energy **A** is created between the sun's and earth's reservoirs, at T_s and T_e. **A** might be a mechanical or electrical energy. We might use it, for example, to concentrate a metal by running an electrolytic separation unit. Alter-natively, if we look for storage of the energy **A**, we may create high energy chemical compounds or lift water into a reservoir.

Later, when we use the stored energy we produce waste heat , which in the end is offradiated into space.

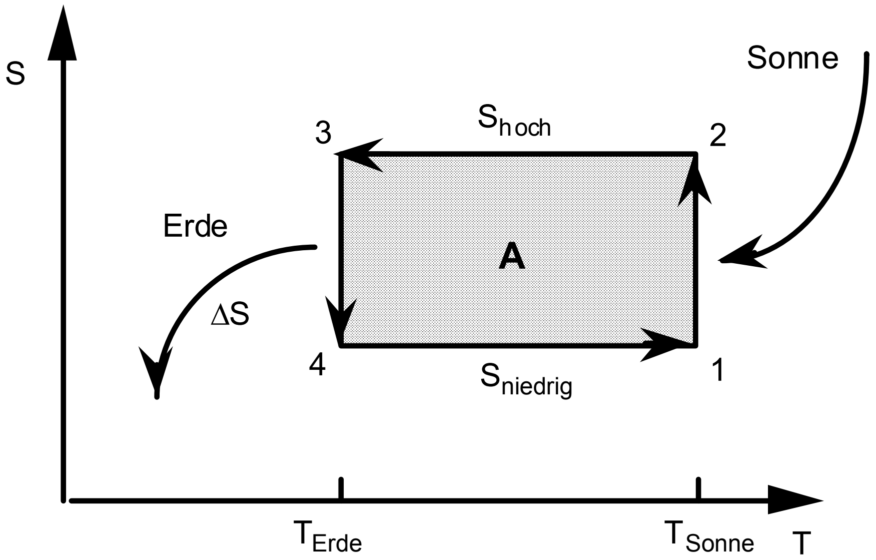


Fig. 14. Thermodynamic cycle between sun and earth, with export of heat and enropy into outer space.

As we already know that a reversible cycle is an idealisation, we cannot avert entropy production in any given cycle. Still, real (technical) cycles can be constructed, but usually they are run in one direction only. This unidirectionality is again connected with the second law, which can also be read that a finite entropy production $dS/dt > 0$ defines the direction of time. As we cannot avoid the second law, we also cannot avoid production cycles which work in one direction only. However, they should still run most close to reversibility, i.e. all branches of the cycle should observe a minimal entropy production. Optimizing efficiency for non-emitting and emitting engines is thus equivalent to minimize entropy production in their respective cycles.

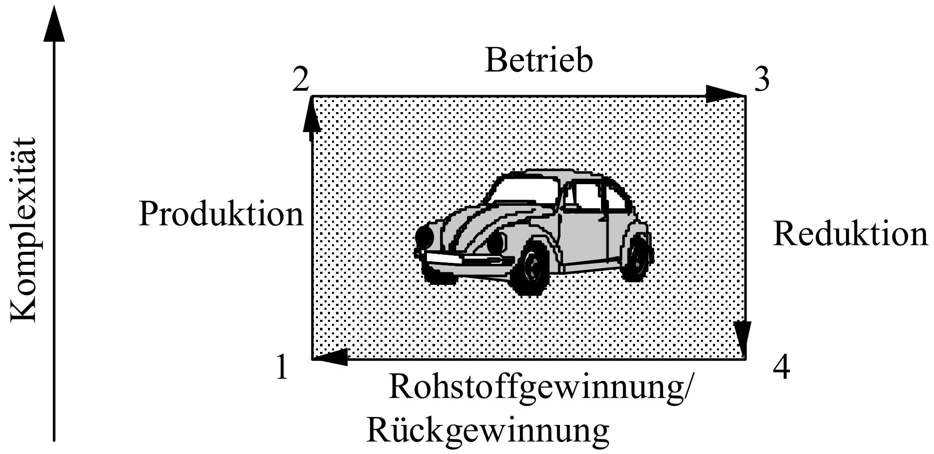


Fig 15. A production cycle should be closed and obey the principle of entropy minimization. With increased complexity, entropy is lowered.

Like the day&night temperature cycle of earth, a production cycle can be viewed as an intermittend stationary state, and therefore dS/dt = Min should hold. The same argument can be made in another way: if one constructs an ordered structure, the entropy is reduced by the same amount as it is increased when the structure is dissolved, minus certain heat and mixing losses. These losses are to be kept minimal. Again, this calls for a production cycle to stay close to reversibility.

This near reversibility should be the guiding concept for future reduction appliances, too (recycling): ideally, they should be combined with production plants to form a cycle locally and thus running backwards, exactly as the wordpair production/reduction indicates. Because of the unidirectionality of the complete cycle, however, they have to be separate units.

Today's production of goods is largely non-reversible and thus also very entropy productive. We call it shortly an "emitting" production. Most of the products are not reusable neither in the whole nor in parts and thus end up as waste in a short time after their production. Even the use of old, still functioning appliances, often is waived because of modernisation pressures ("panic mode"). Thus our production becomes even excessively irreversible.

Throwaway products, i.e. products with a small lifetime, are only successful as recycling is not even attempted. Avoiding or delaying recycling, however, is cost cheating at the expense of future generations.

Although from the principle of entropy minimalisation it follows that a quasi-reversible production should be attempted, from drawing a cycle diagram it still does not follow, how this aim should be reached in detail. Of course, in a first step one should discriminate and discuss the four branches of the cycle (recycling) : (1)

construction or production branch, (2) operation branch, (3) dismanteling or reduction branch, (4-1) molecular separation (fig.15).

We submit that in order to keep the total entropy production a minimum, the cycle time should be as long as possible. However, it is not necessary to go through the different segments at the same speed. The operation- or lifespan should be comparatively long. Consequently, the entropy production should be very low in this phase, while for short production and reduction phases the entropy production may be a little higher. Indeed, a good product should last long and should be saving energy during operation, while at construction one could eventually invest more. In total, however, the mean entropyproduction, $\Delta S/T_Z$, should be kept as low as possible over the cycle time T_Z.

In the search for further rules one might be guided by concepts of biological generation and reduction, because during evolution certainly entropy minimizing concepts have been developed. At first sight, a translation of biological strategies appears to be straightforward, however, with human technology one often has to deal with materials which are not based on carbohydrates.

In this context we compare a mobile biological unit (human or animal) with a mobile technical unit (car). Already here symptomatic differences and similarities are observed.

3.1.3 Biological Cycle

Fig.16 shows schematically a biological cycle. At the production branch side we observe smaller subcycles. They represent elements of the food chain, i.e. animal or plant lifeforms. With the reproduction of storks, frogs (subcycle) are eaten. This subcycle has to run faster as the main cycle , i.e . the stork has to live significantly longer as his prey, the frog, and the frog in turn lives longer as its prey, the fly. This slowing down of the cycles towards the main cycle is typical for biological cycles. An important difference between biological and technical cycles becomes apparent already here : while the biosphere knows only individuals as subunits, in a technical cycle each part is uniquely dedicated to the final product. There are modular subunits also in the technosphere, but the strict association of a module to its target product becomes visible at least in the operating phase, usually already in the production phase. In the biological system the subunit can also be used by a competing cycle: the frog is also food for the grey heron and the snake. Also, the subunit is not necessarily completely consumed: if the subunit, for example, is a food plant, it is sufficient to eat the fruits.

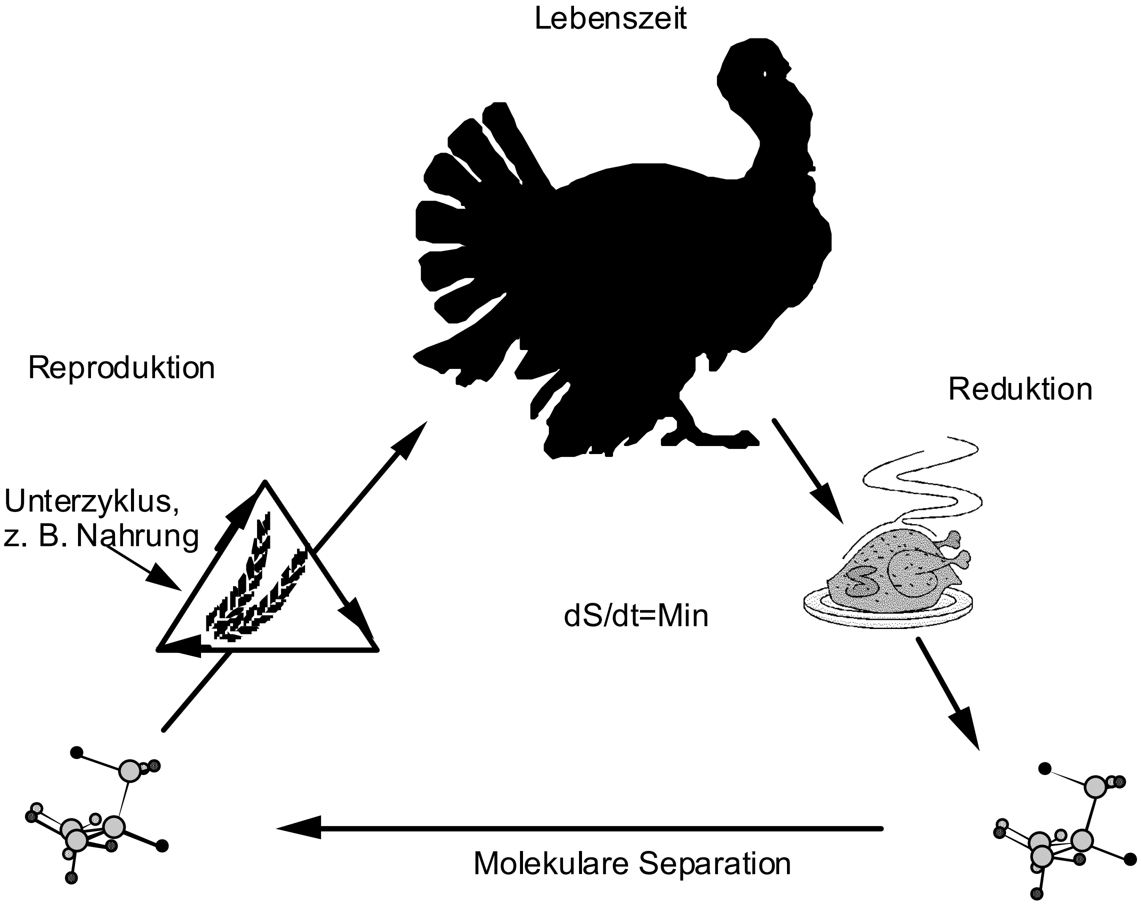


Fig. 16. Biological cycle. The comparison shows the multi-function of a biological subsystem.

Because of the individuality of the subunits in the biocycle there is no waste production due to unused"products". The total of all subcycles, the global biocycle contains the total living and decomposable matter, which is generally know as "biomass".

In the operating phase the differences between technical and biological cycles are not that large: in both cases fuel (food) is converted and waste products appear. It is obvious, however, that while biological waste is funneled into the intricate natural reduction system, which is also used by man in sewage plants or biowaste, this is not so for technological products. However, biological waste, ammassed in large quantities like in animal mass production, can be hazardous. If larger quantities of methane are produced it can add to the hothouse effect directly, or if reduced to CO_2 by methane bacteria, indirectly. This might possibly put strain on the CO_2-regulation, however, the biological reduction is the only one which is part of a true cycle.

At the beginning of the reduction branch, again we find secondary cycles. In nature these cycles run opposite to the technical ones, i.e. if we consider spare part recycling as subroutines - in nature the use of spare parts is practically excluded.

The reduction food chain supports individuals of other species, like predators or microorganisms. Single parts of the prey animal or plant are generally not reused, but in the digestion tract high molecular number substances like fat, proteins and sugar are extracted, i.e. the reduction goes directly down to the (large) molecular base.

Arguing that evolutionary strategies are superior because tested, evidently the direct reduction down to the molecular base is entropically favorable.

At first sight this seems to be a paradox , as the mixing entropy always increases with the number of individual units. Considering, however, that the high molecular weigth compounds are not distributed, but are directly used to support the organisation (high order) of other lifeforms, the potential entropy production does not occur at all.

We also learn from that fact, that generally the reduction should occur exactly at the place where the respective basematerial is to be used again.

The same principle is used with microecologies or on the lower levels of the reduction chain (microorganisms) : even the waste from the higher lifeforms usually contains some chemical energy. Its fast distribution is usually avoided in nature (see manure bug etc). At the end only CO_2, N_2, O_2, H_2O and several other compounds are distributed in the atmosphere through breathing, photosynthesis, ground bacteria, funghi etc.

3.2 TECHNICAL CYCLE

The basic concept of the technical cycle is shown in detail in fig.17:

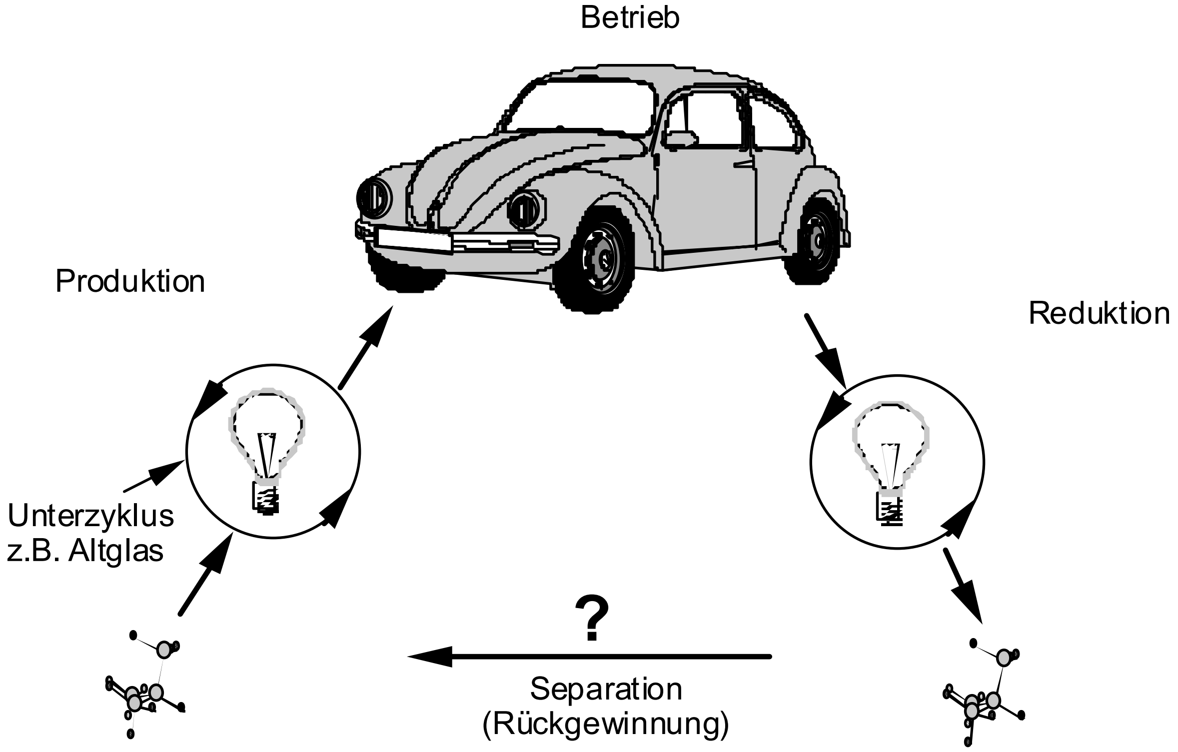


Fig. 17. Technical "cycle". In reality, however, only production and operation are existing, and evenfor these we are far away from minimized entropy production.

We start with the production branch. Here we again observe small subcycles. They represent individual parts, which in the end are used within the main cycle. The parts are themselves subject of a cycle. In contrast to biological cycles the part of a technical cycle is uniquely dedicated to the final product and therefore can be used only unifunctionally. The entropy produced during the making of the product is not used if the final product, for some reason, is not finished or not used. If the final product or a part of it is not used, its active lifetime is equal to zero and immediately it joins the irreversible , i.e. non reusable waste. In biological cycles there are rarely unused parts, because the biological reduction chain immediately starts operating. The figure also suggests, that subcycles and main cycle should be synchronized. This means that the lifetime of the part should be fitted to that of the complete product ("lifetimeadjustment"/ H. Ford). This makes sense. However, it is possible that a certain subcycle is faster. In that case one talks about a wear and tear part; for example, the car as depicted will certainly use several light bulbs during its operation time.

The production phase is followed by the operating phase. Here fuel is used and waste products like rubber/metal composites (old tires), dirty machine oil and exhaust fumes are created.

At the beginning of the reduction phase again secondary cycles are observed. In the technical cycle these represent the reuse of still functioning parts or subgroups of parts. For example, a headlight or a light bulb can still be build into a still functioning car who lost one of these. The increasing use of integrated functional groups of parts, however, work against this, reducing the average life expectancy of the subpart. Another wellknown problem with the technical reduction is the use of composite materials. These are usually designed to improve the functionality and the lifetime and indeed do so: however, their reduction generally needs more complex reduction stategies, so that one can easily obtain a higher total entropy production compared to the case where simple parts were used. We remember, in technical waste deposition or waste burning the largest danger lies in molecular emissions into the waters and the atmosphere.

The reduction down to the molecular level which is very well developed in the biosphere, is very rudimentary in the technosphere. This is evident from the ever increasing waste piles. If, however, the reduction phase of a cycle is too weakly developed, one observes a bottleneck effect. This limits the flows in the other branches, too. Thus, with no efficient reduction branch for cars, the filling up of the highways by cars in their operating phase may finally limit their production. If an efficient reduction branch would exist, it would be permitted to change design and comfort of cars and put new models on the streets. If not, the new models artificially reduce the lifetime of still functioning units and thus the total entropy reduction is increased.

3.3 GLOBAL SUPERCYCLE

Our demonstration of selected production-reduction cycles are set such as to underline certain aspects and to suppress others- for example, we could have taken out a specific subcycle and discuss it as a main cycle as well. One knows in particular from biological cycles that they are intimitely connected and form a supercycle (fig.18). The whole biomass is contained in that cycle. The fossile "resources" have a special status, as they are parked outside the cycle and constitute storage depots of the biological supercycle. These depots, which one also might consider as waste products amassed in earlier times, still constitute a large quantity of high value chemical energy.

Here we discover again a marked difference between technical and biological cycles :

While technical cycles are generally highly entropy-productive, as they convert high value energy into heat while also producing scondary entropy through mixing of materials, biological cycles produce such low entropies that even their "waste" is a high value energy.

In the future the technical cycles should be improved such that they can be combined with this still active and well performing biological supercycle. In principle already today the biological supercycle contains the technical cycles. However, the technical cycles rather destabilize the supercycle as they are not yet sustainable. Depicting the supercycle as an interlocking chain one immediately discovers that a particular subcycle may well be influenced by a disruption in a rather far away region. This is often used as an argument against individual and local environmental solutions. However, in a coupled system one can also argue exactly opposite : if one has found a new optimized solution for a certain segment of the chain, its positive influence will spread over the whole chain.

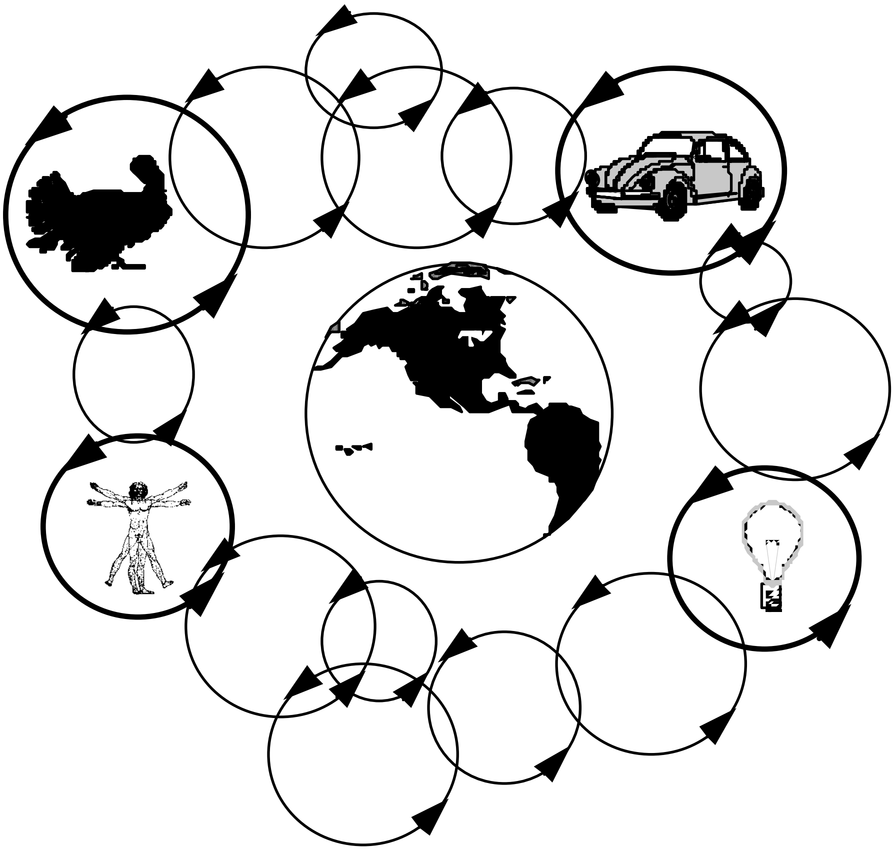


Fig 18.Global supercycle

3.4 RECYCLING

What can we learn from a comparison of biological and technical cycles; what do we wrong in particular in the reduction phase of our technical cycles ?

For that we first look at the mechanism which are used in the technical reduction phase and try to evaluate them:

(1) Export of waste to other regions of the earth. That is a much favored, but extremely shortlived bypass of a real reduction branch.

(2) There is a separation in the collection of biological and technical waste already today, apparently based on the understanding that here we have reduction of very different quality. This is well within the spirit of entropy reduction, as the interprenetation of two differently competent procedures inhibits the functioning of the better one.

(3) glas, paper, plastic and metal meanwhile are separated and collected independently. Then one tries to reproduce simple goods from the collected waste. This "downcycling" has not been very successful. Indeed, nature takes another venue here: there exists independent species specialised on the reduction(biological reductors), however, in their digestive system a large reduction jump down to the molecular basis takes place. The recycling of materials with plants and animals is different from our todays recycling. This suggests that the different approach is also the reason for our limited success in re- and downcycling.

(4) The restauration on the molecular basis, i.e. the element concentration or the reversal of the mixing entropy, is also superior in nature. After reduction to elements and simple compounds, for example plant leaves concentrate high molecular compounds, while the roots separate mineralised water. Our element-separation and -concentration methods are comparatively energy- and efficiency-wasteful.

Now we look at the possible reasons for the advantages found in the reduction processes of nature's ecosystems :

(a) biological systems use identical high molecular subunits for all species (products).

(b) effective reduction procedures down to the molecular basis already exist even for highly complex lifeforms.

Obviously, the biosphere does not even qualify between resources and waste. This difference in quality of the technical and biological reduction processes can be circumscribed also by asking certain questions:

(1) are technical products modular, i.e. are building blocks used ? - yes !

(2) are they modular and regenerative ? yes, as long as there are spare parts !

(3) are they modular, regenerative and are their parts multifunctional ? - no !

(4) are they modular, regenerative, multifunctional and cyclic reducable - no !

For products from the biosphere the answer is always yes. Possibly,we can approach a recycling of equal quality in different ways. One venue would be the exclusive use of plant and animal products. However, there are limits to that approach, as we cannot hope to live like indigenous people today.

Therefore we have to look for alternatives. As a rule we should transfer the strategies of the plants onto our industrial production. In particular, the product reduction should become similarly efficient. The production unit should just be a part of the production-reduction cycle but definitely not the only one. The producer should have the responsibility and the control over the whole cycle of the product. This is an important difference to the production of today, which gives the major attention to the production branch. So far, in particular the emissions during the production, operating and reduction phases are not considered correctly.

One important difference between technological and biological cycles is material specific. While carbon -based compounds are adapted to the oxygen atmosphere, partly or fully metallic structures suffer corrosion problems.

In the competition between biological and technical products the principle of entropy production introduces a new joint measure of "costs". So far, such a comparison has been impossible. If one uses this new valusystem, one simultaneously selects environmenally compatible structures, e.g. low emission and recyclable products and machines.

3.5 CELLULAR STRUCTURES

In the production and reduction branches almost always subunits (cells) are used. If one uses substructures of any kind one can replace a single cell and the lifetime of a building block does not detemine the lifetime of the complete unit anymore, just like the single ant does not detemine the existence of the anthill. The opposite effect, however, occurs if one uses many distinctly different building blocks.

Because of the replaceability of the subunits, cellular composed structures also have distinct security advantages ("Wound healing") over large monolithic structures, in particular regarding corrosion and natural catastrophies.

The build-up of exchangable units goes with the introduction of inner boundaries which separate the individual units from each other, but also have to connect those units: by definition interfaces often reduce secondary entropy, as they can prevent the mixing of elements if properly constructed, i.e. if they indeed block diffusion. Inner surfaces (membranes) are extensively used in biological systems. The individual surface is not very entropy-productive, granted that the surface layer is reducable, i.e. every concrete cellular structure should be also judged by the principle of minimal total entropy production. This is valid for the packaging of single units as well as for the build-up of large connected cellular units. Nature shows the way here, too : for example, destroyed parts of a honeycomb are completely recycled by the bee population (Fig. 19)

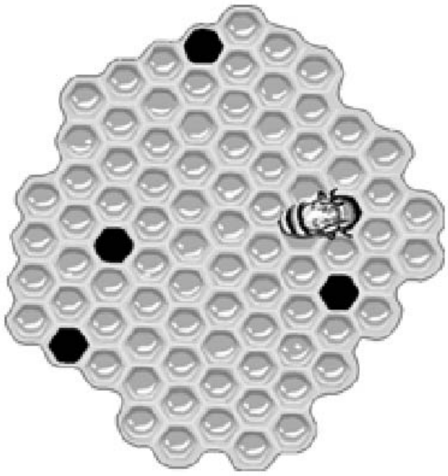


Fig. 19. The honeycomb is an example for a re-usable cellular structur

3.5.1 Digitalisation of the working sphere - Dimension of the subunits

In principle, subunits of every size are possible - but what is the correct size in a given case ? Every subunit defines itself by the existence of a limiting boundary surface area. If the entropy would be significantly enhanced through the introduction of many internal and external surfaces one would rather use larger homogeneous units (monolithic structures) and the use of smaller units (cells) would have to be ababdoned. As a potential entropy production is always proportional to the number N of objects to be disarranged, dS/dt is largest in the realm of molecules. So there would be a general increase of the entropy of cellular objects going down in size.

However, by evaluating the potential atomic disorder (7.5) it can be shown that the walls of cellular structures do not have potentially large entropies as compared to the enclosed volume down to the nm-region. In this respect, the introduction of internal surfaces is acceptable down to this size.

Are there additional criteria for the choice of the correct dimension ?

As a rule, if the dimension of the subunit decreases, the realisation of the substructure (miniaturisation) becomes more and more entropy intensive. The length scales directly usable by man is between 1m and 1mm; this is called the "central regime" (of the human species). As the unarmed man as a biological unit is entropy conserving, he can act entropy reducing inside of this dimensions. Outside of the central region man has to arm his senses and his coordination, using microscopes and micromanipulation for the smaller dimension, and telescopes and building machines for the larger ones (McLuhan). This technological extensions are however usually very entropy intensive and have to be used with caution. Therefore, the optimal cell dimension will be in the central i.e. manual region, unless there are secondary entropy arguments.

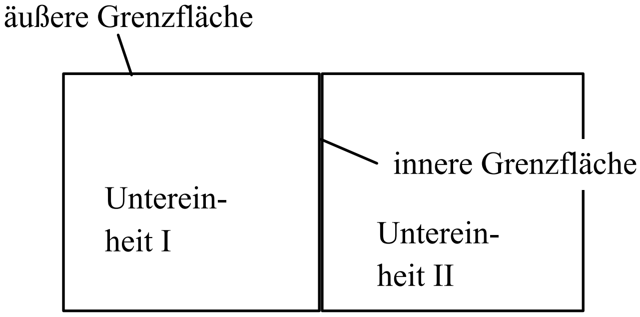


Fig. 20. Substructure by dividing into two sub-units

3.5.2 Microstructures and Macrostructures

Do we have a single optimal cell size for each artificial structure or exist always a larger number of characteristic dimensions ? As technical products do not yet run through a true cycle, today the answer remains somewhat speculative. However, we can be guided again by looking at the organisation elements of nature. Here, starting from a basic cell structure , we always find a whole hierarchy of characteristic dimensions, i.e. segments occur from almost all size regimes. A tree, for example has the subsegments: leave segment-leave-twig-branch-stem, and thus even has a fractal substructuring, i.e. each subsegment is always similar to the larger segment whose part it is. Relying on evolution, entropy increase cannot be very high with this (plant-) strategy and we are well advised to simulate it with engineering structures. The systematic use of fractalisation, i.s substructuring of every part, obviously would help also with reduction and repair, as the larger quantity of segments can always be reused. We remember, as long as such a substructuring can be done in the central size regime, entropy production will be small as man can do it. The use of microtechnology will enhance entropy production. Obviously, the two effects compete in the downsizing and this will result in an optimal basic size in every case. One may speculate that the optimal structures are above or close to light optical size enlargement factors, as smaller visual size enlargement systems - for example electronmicroscopy- are increasingly technology involved, requiring another step in (secondary) entropy production (optical window limits, installation costs). The tested biological cell size tells the same story. Obviously, biological data processing and immune system strategies are exceptions, as they go down to the molecular level., though probably for different reasons (information density / central size of the competing population).

Microstructures

Nature shows us that the basic cell structure is rather small and not very far away from molecular dimensions. Again, we are advised to use the fact that entropy production does not rise significantly as long as we substructure in a dimensional regime well above the molecular one.

This applies to the technical world as well : if for example we would put together a car from many reusable small pieces - as there is only one final arrangement - the entropy after construction would be small. Even disarranging the pieces would not be too entropy intensive, as long as these can be easily discriminated and separated.

Substructuring just above the molecular dimension is, however, not common with technical products - except for microchips which follow this tendency, however, without being reusable.

A car body part from iron, for example, has only two characteristic dimensions :

(1) as a part in the meter region

(2) as remeltable waste in the atomic dimension, 10^{-10}m

Indeed, with recycling one encounters the well-known difficulties:

(1) Problems with the separation of composite structures, usually resulting in water and air pollution

(2) problems with energy consumption-melting iron requires a large amount of primary energy

In both cases a large amount of entropy is produced. Clearly, "cold" and non-polluting reduction procedures are preferable. Cold processes could stem from biological processes (for example Fe-processing bacteria), or through the use of smaller elements (further substructuring). The latter would, however, require the capability to store, assemble and disassemble a large number of small parts, today this might be possible through automatisation.

Macrostructures

In the macrodomain, the cellular structure is necessarily given by the central, i.e. the direct human manipulation regime (1mm-10m). Civilisatory structures beyond the human size are always cellularly composed. If the production of the smaller cell units is reducable, the high scaling would be without problem. As long as this is not the case , megastructures produce a lot of waste, too. Moreover, in a megastructure the number of elements can get that high that it is comparable with the molecue number of the basic cell - in that limit additional entropy considerations appear. For an estimate of this limit we may take the central dimension (meter) down to the optical microstructure (10^{-6} m) and then extend beyond by the same amplification factor; this gives a limiting macrostructure size of 10^6m or 1000 km.

We do not have planar or spatial objects of this size yet, except maybe in one dimension (e.g. the railway and highway systems).

3.5.3 Composite materials

The recycling of composite materials may produce a large entropy. In order to give this statement a more concrete basis,we turn to the mixing entropy. First, the mixing entropy contribution will be as smaller, the fewer materials A,B,C ... we use. A reduction in the number of materials used is considered already today as a valid tool in the build-up of an environmentally sound production, however, so far a quantitative measure had been missing.

For a first example , let us connect two parts of a material A either with a screw of material A, or with a glue of material B. Obviously, the potential mixing entropy of an arrangement ABA is higher as that of AAA. This we will experience on recycling: assume that we have to melt both AAA and ABA along the reduction branch. In the first case we will have no element mixing, while in the second case A and B will mix and already a small fraction of B will create a large increase in entropy (see 7.4). Composite materials which cannot be mechanically separated thus will have a large entropy production at recycling, which we can reverse only by activating an external separation unit.

However, here on word of caution. For each product, one has to carefully calculate the total entropy production of the full cycle, and only then choose the optimal result: assume that the production of the connecting screw in AAA is very entropy intensive , while the glue in ABA is (water) soluble with the solute easily to be separated from the solvent. In that case, the assignments might be reversed.

General rules like minimal entropy production and total entropy balance should not be confused with particular product solutions, which might loose their ranking fast with experience increasing.

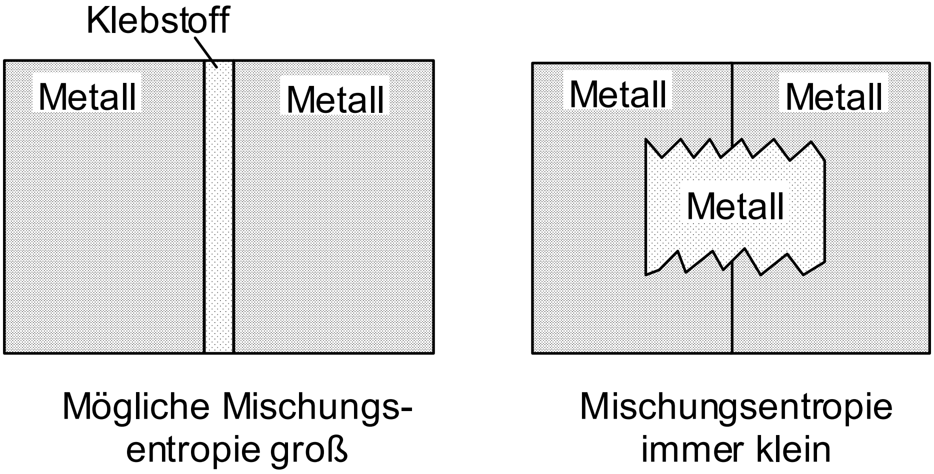


Fig 21. The best joining technology is the one with least entropy productio (including recycling)

3.5.4 Corrosion

Corrosion is considered a high economic cost factor even today. Corrosion increases the entropy by distributing (rust) particles, by oxidizing the starting material and by reducing the function of an appliance. In terms of entropy cost, corrosion might be even more cost efficient.

Corrosion follows from the fact, that man uses material flows which have nothing to do with his bological basis, the plant cover. In fact this mirrors again the controversy between technosphere and biosphere. The oxygen rich, wet atmosphere, optimized for the biomass, favors oxides and hydroxides, not the reduced metals. Thus, for metal parts, one is always forced to use oxydic or non-oxydizing protecting layers. This protection enhances the lifetime of a part and thus reduces entropy production. Often, however, the corrosion protection of the diverse parts of a unit is not total lifetime adapted: the surface coating of a certain functional element might be that good that this part has a longer lifetime as other parts and with it as the final product - for example, galvanized and laquered car body parts as compared to the exhaust pipe. Moreover, such very longlasting parts are often difficult to reduce. Indeed, corrosion delayed by surface protection produces a delayed materials mixing, whose (eventual toxic) effects are thus difficult to detect today.

With corrosion, at least one should strive for lifetime adaption. With non-toxic corrosion, sometimes it would even pay to let corrosion proceed, i.e. one would prefer an early replacement.

Another obvious approach would be the increased use of atmosphere adapted materials, i.e. mechanically stable ceramics and oxyde protective layers (Al_2O_3,SiO_2, etc.)

3.5.5. Multifunctional elements

Biological structures and biomaterials are often multifunctional, while technical structures and building units are generally unifunctional. Wood (lignin) for example is multifunctional in the living plant (protection, structural integrity, capillary channels) as well as in its use by men (burning material, building material, paper). Interestingly, wood stores a residual energy as evidenced by its use of fuel and degradation by microorganisms. Thus, it can be conserved only over a certain period of time; this in turn suggests to use lifetime adaption, here in particular with regenerative building materials : the projected time of use should be equal to the expected lifetime. Thus, in a given situation an early replacement could be better than a toxic waterproof, which would be hard to recycle at a later time.

Multifunctionality carries with it a saving of building units but often reduces the quality of the single function. However, with the majority of products never all functions and in particular not all specifications of the used raw materials are needed. In those cases multifunctional strategies could be found entropy reducing.

Even biological products are not always multifunctional (e.g. mussel shell, antlers, cornea). In contrast, brain and hand are almost synonymous for multifunctionality. On the other hand, we find multifunctionality with technical products as well, often achieved by a simple segmentation into building blocks:

A screw/plate combination can be used as screw,cover, sieve,ventilation grid or traffic sign, depending on if and where one turns in the screws (fig.22).

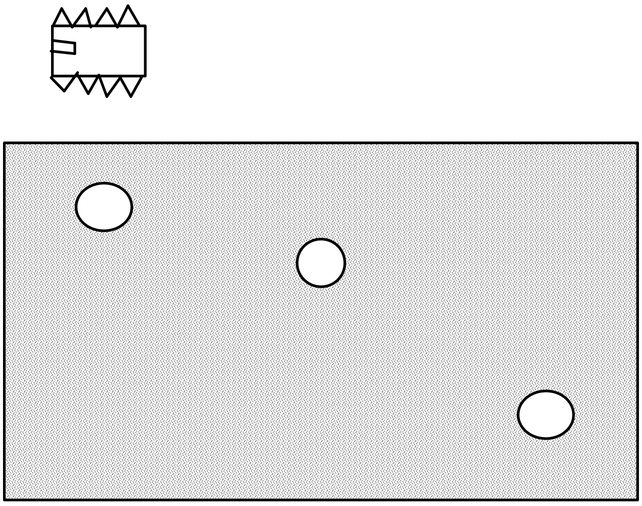


Fig. 22. Baukastenprinzip mit kleiner Anzahl verschiedener Bausteine zur Verwirklichung geschlossener Produktionszyklen.

3.5.6 Buildings

Buildings are also human products and such should be subjects of production-reduction cycles and its rules. Their long lifetime and thus also long cycle time at first sight result in an advantageous low entropy production. Buildings also help to avoid hazards (secondary entropy production) as they offer protection and resistance against the elements, in particular against heat, cold and storm. However, there are also disadvantages : (1) the time of usefulness of a building is often smaller than its lifetime (2) just because of this long lifetime , which might stretch over several generations, people do not connect buildings with their entropic responsibilty. (3) Waste from torn down buildings is the largest waste contribution in volume- fortunately toxic only in small parts (asbestos, lead pipes etc). Today buildings are used by many generations; on the other hand our quickly changing world, increasingly threatened by climatic changes, asks for building blocks of a lifetime close to a human lifespan, i.e. between 50 and 100 years - after that there should be some recycling. Quite different from these ideas is the tendency of men to use the long lifetime of buildings for a perpetuation of ideas or a grip on power in a dynasty; this usually is not in the interests of the generations to follow:

> *The memorial of king Mausolus was considered as one of the seven wonders of the ancient world. It was discovered only late, as the local people had used the cut marble stones for the construction of their own dwellings - though probably only after some earthquakes had occured . An early example for the recycling of cellular units within the building industry.*

The example also shows that one has to think about the optimal kind and size of building blocks if there will be a faster recycling of building in the future.

3.5.7 Investments into the future

The pollution of the atmosphere and the sea we have often compared with a mortgage, which we have taken up but which has to be paid by future generations. What investments into the future can we offer in return ? Traditionally, here one believes in the collection and ordering of knowledge, i.e. the development of science (1). Only recently, the regeneration of the earth has been advanced as a goal (2); in our language, the thermal cleaning of the earth and the assembling of artifical fuel depots, before the natural (fossile) fuel storages are exhausted. Asking for cleaning now considers the fact that with the help of fossile reserves, today one is in a position to separate and store rather diluted materials (e.g. noble metals, nuclear fuels)(3). This will be a difficult task in a stationary society with a large population to sustain with a limited amount of clean primary energy. Another possibility is the build up of cellular structures today, which might reach far into the stationary society because the subunits have to be remade only slowly due to their repeated use and their universal usefulness. In the current economy is seems senseless to divide a metal piece into parts, as the raw material is abundant and cutting only would increase costs. However, within a full production/reduction cycle, replacement and reduceability would be increased, allowing a better performing cycle. Thus, as an investment in the future it would make sense to produce these subunits and also install the production and reduction lines already today (4), i.e. far before reaching a stationary society .

4. Entropy Sources and Sinks

4.1 GLOBAL DISTRIBUTION OF THE ENTROPYPRODUCTION

We have pointed out in the earlier chapters that the quantity entropyreduction helps us to evaluate products and energy conversion units. In this chapter, we discuss the possible influence of this new thinking on the manmade global distribution of matrials and energy. In doing this, we want in particular develop rules for the conservation of the biosphere.

As a first guideline we assume that the early entropy flows and entropy potentials can serve as a precedent for the industrial product flows as well as human migration and settlement. Therefore we start with some fundamentals/ /.

For an ideally lightabsorbing earth the yearly entropy production through conversion of the sun's radiation is the lightenergy forshadowed by the earth, divided by its average temperature, i.e. $5x10^{15}$ (kWh/aK) (a = annum = 1 year)- see also the flow diagram in fig. 23. From now on, we abbriviate the unit of entropyproduction : 1 kWh/aK = 1 u . In the diagram, the entropy flows are per total earth surface A. i.e. counted per square meter, one has $\pm\frac{\Delta S}{A\Delta t}$ (entropy sources positive, entropy sinks negative). If one considers a part of the surface only, one has to consider the area ratio.

Our earth has a backreflection (albedo) of about 30%. Thus, 30% of the potential entropy, i.e. 1.5 105 u, will not be produced on earth . This large potential entropy flow can be considered a momentaneous entropy export (via reflection). As we consider an entropy export as a value, this ,inparticular tells us that small changes in the albedo can lead to large costs, e.g. additional surface entropy production. That in turn suggests that the higher atmospheric layers should be kept intact.

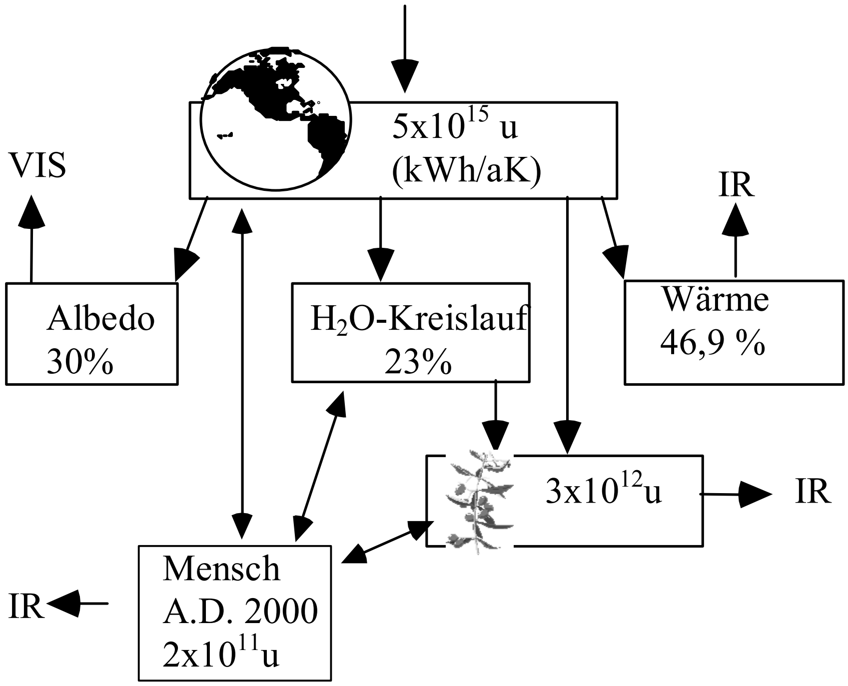


Fig 23. Gobal Entropy production and it's distribution in 2000. "IR" refers to Infrared off-radiation; "VIS" reflection of (visible" sun light, resp. The plant signifies earth's biomass, excluding men.

23% of the onfalling light is needed to maintain the atmospheric and oceanic flows. These flows guarantee the distribution of water and are therefore essential for our food production. The remaining 47% of the entropyproduction result from the direct conversion of sunlight into heat. Here lies a large potential in entropyreduction, in particular if one remembers that the plants reduce this entropy production only be several tenth's of a percent. i.e. -3 1012 u. On the other hand, from their strategy we can derive another rule : mankind also should disturb todays flow system as little as possible.

From the numbers shown in the flow diagram one could conclude that the comparatively small heat production of mankind, 2 . 1011 u, has no significant influence on the global accounting. However, the real problem are the material emissions caused by the human activities, which are not included. We have seen that emissions without recovery can cause very large secondary entropy productions, for example via the closing of the atmosphere to thermal entropy export (global warming).

We have also found that too fast a use of stored energy results in a strong entropyreduction which can endanger whole populations (see also appendix 7). Therfore we should know the entropy potential of both the short term energy storages - which are mainly connected with the oceans and the atmosphere - and the long term energy storages - which are mainly connected with the richer fossile and nuclear minerals in the earth's crust.

For estimating the potential entropy production we have also to know the natural and/or the planned storage time. The short term storage times lie between several days (atmosphere) and several years (oceans). For the long term storages usually the velocity of resource mining is determinative; this is in turn intimately connected with the population dynamics.

4.1.1 Short term energy storages

The short term energy storages can also be considered as entropy-export reserves. What is their further role within the global entropy balance? The oceans, for example, constitute big short term storages. This becomes apparent when we look at the melting of the polar ice caps, whereupon heat is consumed. Certainly this is equivalent to an entropy-export, as the same amount of heat could also have been offradiated. How long could one block the daily offradiation until this reserve was exhausted ? Would the polar ice caps melt in one year, one would have an entropy-export of -8 .1015 u; this is equivalent to about one yearly onradiation of sunlight, stored. Energy is also stored in the motions of the oceans and the atmosphere. The water cycle, in particular, conains convertible energy equivalent to approximately + 3.1015 u. Again, this would amount to about one solar year. Therefore, appliances which couple to these short term energy storages - like dams, windmills etc. - are to be classified int the same category like solar cells, which in the long run should balance the yearly cycle, like the plants. Today the feedback of these particular engeneering elements on the atmospheric and oceanic processes are still small.

None of the short term storage equivalents significantly exceeds the average yearly sun-onradiation (MJS). This makes the short term storages look like elements of the mean earth's tempeature (Te) regulation. Indeed, the polar ice caps grow in the winter releasing latent heat, which in turn is absorbed in the summer when melting sets in. The oceanic ans atmospheric flows, riven by temperature and pressure inequalities, very evidently tend to cancel the temperature gradients on earth. Even the plant cover takes part in this regulatory process. Because of the regulatory function of these natural flows (H20,CO2,O2,N2), manmade material flows can only be coupled to them in a limited amount. Reading from this, for manmade flows we rule :

> Civilisatory distribution structures and reservoirs should aim at the stabilisation and not the destabilisation of the biosphere.

4.1.2 Long term energy storages

Fossile energy

If we assume about 300 years for using up the fossil resources (gas,coal,mineral oil), we reach a primary entropy flow of 1.1012u. This value lies in the range of the yearly entropy reduction by the plant cover. The use of fossile fuels could be justified f the atmosphere were not loades with hothouse gases.

Prefossile energy

The consequences of the use of prefossile energy, mediated by fissionable or fusionable nucleids - which have been produced with the birth of the stars, i.e. long before the appearance of the biosphere - are vevewd quite controversly today.

The amount of minable, fission nucleids - mainly the isotopes of uran - in the upper earth's crust is limited. If one expects to use up the easily accessible resources also during the next 300 years, then the potential thermal entropy production is .5 .1012 u. This value is comparable with that relating to the fossile fuels. Here it is not the changes in the atmosphere which is alarming, but the direct impact upon the genetic material of humans, fauna and flora via the radioactive radiation which is released in the wake of extensive use of nuclear fuel. One cannot hope to avoid completely the mixing of radioactive material with non-radioactive material.

Fusion of light nucleids, primarily based on condensing the heavy isotopes of hydrogen to helium has been the great hope for an indefinite source of "clean" energy in the past. First, we can estimate the potential thermal energy production; taking a civilisation period of 60 000 years, i.e. about twice the historic time span, from the resources of heavy water one arrives at 4.1021 u. This value is indeed far beyond the huan entropyproduction of today, about 2.1011 u, and even higher as the total solar onradiation equivalent. It is hardly possible that such an increase of the entropyproduction could be operated in today's entropic structures. Thus, even if this energy source can be opened under justifyable efforts, one would have to limit it, even because of the thermal entropy production alone. Aside from that on would have to include all kinds of secondary entropy production, in particular the separation of radioactive and non-radioactive materials ("thermal cleaning").

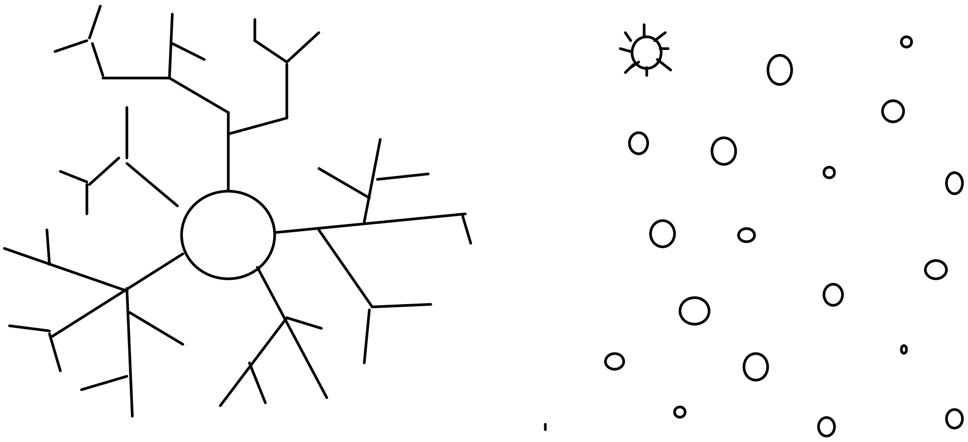
So far it has not been possible to use these long term energy reservoirs without creating large and threatening secondary entropy productions. In such a situation, at least the energy consumption should be delayed.

SHORT TERM STORAGE	Atmosphere + Oceans	$3*10^{15}$ u
	Polar caps	$-8*10^{15}$ u
	Biomass	$3*10^{14}$ u

LONG-TERM STORAGE	Fossil Energy	Coal, oil, gas	$1*10^{12}$ u
	Pre-fossil Energy	Nuclear Fission (Uran)	$0.5*10^{12}$ u
		Nuclear Fusion (Deuterium)	$4*10^{21}$ u

4.1.3 Man made entropy sources

Let us look a little closer at the entropy sources which appear because of the human activities. Such soureces are for example the conversion of electrical energy into heat - also often called energy consumption - or the burning of wood,oil,gas and coal, including the distribution of the raction products. The sources are mosty located at the outer brnches of a distribution network of a higher valued energy, but can also be the end of a pure materials distribution (fertilizers,pestizides, hothouse gases etc.). First we want to optimize the distribution of such entropy sources, for example by asking if a higher valued energy is better to be converted in central or decentralized appliances (fig.24).



zentral dezentral

Fig. 24. Centralized and Decentralized Entropy sources: Powerplant with electrical grid on the left; Creosote bushes in the desert on the right. (circles represent major entropy sources; lines are minor ones).

We first consider the fuels. If one burns a certain quantity of fuel it does not matter if one does it in a central power station or in a decentralized household : the heat and the reaction products will be homogeneously distributed into the atmosphere anyway. If one operates with unclean fuels, however, the filtering of secondary reaction products like sulfuric or nitric oxides - is done more efficient in a central station as compared to many small units, since a desulfurisation unit cannot be applied to every coal oven. Also, the fuel transport costs are smaller with a central unit. However, in order to reach the consumer a distribution network has to be installed, e.g. power lines or heat pipes. This can be very costly in its installation and is also very sensitive to external influences cusing failure. This in turn creates secondary entropy production connected with the fixing or renewal of the broken sections. As an example :

A distant settlement which is connected with only a power and a gas line is disconnected by say a natural catastrophy - for example by an earthquake break in both lines. Exlosions and the lack of electrical power lead to large devastations before help arrives. If energy producer and consumer were closer, help could get on the spot much faster.

In summary, both the pure central and the decentral scenarios have marked disadvantages. Thus we often find a mixed scenario, for example a power net combined with a local energy source, say n oil reservoir(fig.25). This combination we immediately recognize as a twin system which in fact contains a redundancy and thus increases the safety of our energy provisions. However, in our view these twin systems are wrongly connected today : if electrical power fails (house-) heating and cooling (refrigerator) stops and a reserve (diesel) generator, fueled by the oil reserve, is not installed. Mixed systems like in fig.25 are very seldom found in the civil sector today, inplicitely assuming that failures will happen but seldom. However, one has to reconsider this view, not only to increase safety, but also because of the increase of natural catastrophes which we can expect in the wake of global warming etc.

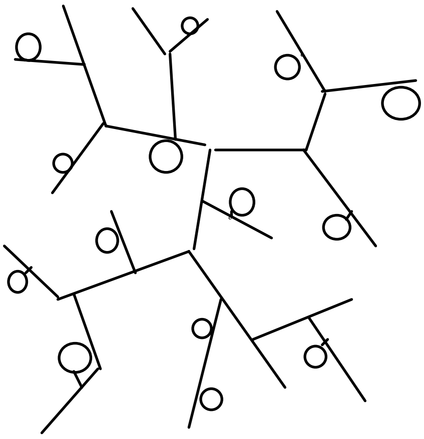


Fig. 25. Combined Centralized and Decentralized energy distribution – e.g. a network of households with their own storage and energy producing capabilities.

4.1.4 Human dwellings

Fig.25 is also similar to a road map. from this we conclude that a mixed form of distribution of resources is also optimal for the planning of human settlements. This in particular reaches into the neverending discussion whether central od decentralized living is preferable (big city versus country villages) and also touches on the optimal size of buildings (private homes versus high risers).

Cities are still important today because of short transportation routes, the concentration of information, people and goods. Representative (state) buildings, museums, sports arenas, mass transit and living space concentration, which are entropy reductive through multiple use, would not exist otherwise.

As trade and transfer crossing points the cities ate also important to uphold a (federative) infrastructure. However, there are also disturbing features. For example, the construction and maintainance of todays skyscrapers is only possible within an energyintensive civilisation. The concentration of people itself does not necessarily mean a large energy consumption, as suggested by the centers of the ancient high cultures. All that might have to do with the fact that man as a lifeform is energy conserving while its machines and buildings are not.

The crowded cities are also susceptible to even short interruptions of the energy flow, to (fast) expanding infections and density stress. Moreover, there is no fallback position in case of an environmental crisis, while villagers might still find alternatives.

Rural settlements use strategies similar to the plants. For each plant to grow one has to dedicate a certain area and therefore for fields , meadows and farms as well. This can be reduced to the low density solar energy in the majority of cases. Sometimes , however, mineral and water depletion take over the size requierements (deserts).

Empirically such distributed settlements are less sensitive to a crisis. However, today only about 10% of the people live in the country, as ever increasing areas per farm are needed for "economically" successful agriculture, i.e. low food costs. One basic reason for the low cost of food is of course the well functioning biological reduction chain.

However, if one would account for the emissions with occur with todays technologically oriented agriculture, the costs of agricultural products would go up and more people could live and make a living in the country, while a complete subdivision to make everyone a farmer would be impossible, at least in the densely populated areas of the world.

Solar strategies always mean low energy technologies and this always leads to a area contingency - that is what corn fields and solar roofs have in common. Since the electronic media today distribute information globally, the cities increasingly loose their information monopoles. This might lead to the dissolution of the megacenters in the future. i.e. a transition to distributed smaller settlements everywhere (new global village). For such a future scenario there exist already some speculative ideas, which we will lead up to by looking at nature's distribution strategies.

Nature features individual provisions as well as energy distribution through networks. Within an individual plant, for example, energy rich materials (sugar, starch) circulate. Warmblooded animals use a central energy source in connection with a distribution network: energy is burned locally (liver) but distributed over the blood circulation (network). High energy chemicals are also distributed first and then burned at various places (muscle action). In order to survive the winter, animals build up local food storages. The mixed distribution system is in particular used in the context of plant reproduction, as it also looks like a berry tree. In summary, nature seems to use all possible variants, depending on the situation. Looking in more detail, however, nature tends to use networks and local storages in a paricular hierarchy, i.e networks are imbedded in individuals, just opposite to civilisation, where individuals are the beneficiaries of a network. Eventually this mirror image is an indication of a new evolutionary thrust, that his the global community as a single mind individual. Some see the internet already as the nervous system of such an entity. In fact, one can identify fig.25 also a a schematic of an (internal) information distribution system. Similar to local settlement supplies breakdown,affecting but only lttle the rest of the country, dead servers or partial nets are circumvented to insure that the information flow in the still functioning regions is only insignificantly hampered.

Similarily in the view of networks being part of an individual, any electrical or materials distribution network can be looked upon as the circulation of a huge plant (global mistletoe) which serves and connects all subunits; for example a truly global power line system. However, today we are still far away from that scenario.

Nuclear power, solar collectors and fossile fuel power stations are currently only connected to national (or at least continental) electrical distribution networks. Local storages contain (heating) oil, coal and (liquified) gas.

What will be distributed on networks after the depleton of the fossile reserves? What will be the local energy reserves ? Or will that distinction be without meaning in the future ?

Thus, in the coming chapters we will in particular look at the potential reserve nuclear and solar energies and their eventual use within the distribution schemes discussed above; of course under advisement of the principle of entropy minimalisation.

4.2 A SECOND SUN ?

4.2.1 Nuclear fission

At a first glimpse nuclear energy has ecological advantages only: one has here a longlasting and very concentrated (high energy density) source of primary energy without hothouse gas emissions. If however, on the basis of that arguments one now goes ahead and builds nuclear reactors everywhere one will encounter a secondary entropy production of a special kind. Smaller and larger accidental emissions of radioactive gases and/or dust particles carrying radioactive elements into the atmosphere as well as unintentional infusions of radioactive solutions into the waters will create an unprecedented materials flow, at best comparable with the 14C flow within the CO2-cycle. The carbon 14 flow arises from extraterrestrial high energy radiation which penetrate the upper levels of the atmosphere and activate carbon 12. This materials flow is created mainly by the fusion reactor sun. Leaky reactors here on earth will create another but similar radioactive materials flow. Radioactivity is connected with particle energies far beyond the thermodynamic particle energies and thus are harmful for our genetic material and its repair mechanisms. In the course of evolution the genetic repair mechanisms have adapted somewhat to the small level of natural radioactivity (background radiation comes from minerals and atmospheric activation), they cannot cope, however, with larger doses of hard radiation. Thus, one understands that the population in particular living close to nuclear reactors, additionally sensitized by operation accidents, has a very dim view on such civilisatory radioactive materials distributions.

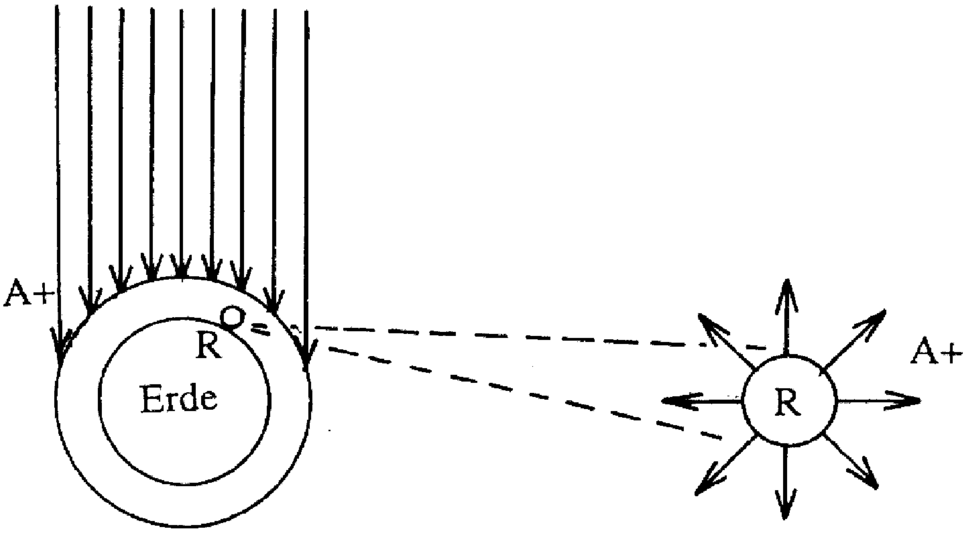


Fig. 26. External and internal activation of the biosphere.

We remember that one has to connect such an evaluation with an entropy reduction, i.e. a thermodynamic separator which collects the escaped radioactive material, concentrates it and puts it away in a safe deposit. This appliance might get very costly. First, because of the multitude of the radoactive decay channels, a multitude of (radioactive) chemical elements have to be collected (first cost factor). Second, because the material flows are dangerous they have to be collected even while they are small. The concentration of dilute elements of any kind is, however, expensive (Ch.7.4, second cost factor). Third, the control of such an unit would be hazardous because of the intended concentration of radioactive elements and special protective measures would have to be taken (third cost factor).

Let us just look closer at the dilution related cost factor. Assuming that the separator is directly solar energy driven, the cost for the concentration of *radioactive material would be proportional to the photon flow intensity Iph needed (primary energy) and inversely proportional to the material flow Ix of the selected radioactive species, as cleaning becomes more costly with dilution (see Ch. 7.8). Having energies of 2 elektronvolt (eV) per photon versus 200 MeV per radioactive particle if only one particle were emitted per cut fission particle, we would have a ratio* $I_{ph}/I_x = 10^8$*, which could be taken as a cost measure. If one compares that number with the cost per* CO_2 *recovery from the atmosphere (chemical energy of burning one C : about 2eV),* $I_{ph}/I(CO_2) = 1$*, i.e. the recovery of a particle of hothouse gas would be much cheaper. In an attempt to avoid such an exoensive cleaning up- and that would substantially reduce the primary energy gains - one tries to suppress the radioactive leak flow, at least to keep it below the background radiation Ir. However, with increasing use of nuclear fission radioactive radiation would ultimately escape its containment , pollute the atmosphere and the waters, and at some point of time exceed Ir, if measures are not taken beforehand.*

What measures other than a shutt-off of reactors could be taken ? The reduction of the radiation down to the background radiation asks for a leakage suppression (leakage factor) of $a = I_r/I_x \approx 1:10^9$ (Ch.7.3.4). That is possible, but only if there is absolutely no leakage during fission and transport of the nuclear material. Unfortunately there is not too much statistical material available on leakage accidents. That is why national and/or international committees come up with quite different security evaluations (weight factors gi) in this matter. There is, however, also a difference in principle between radiation hazards and thermodynamical ones : lifeforms could always adapt to harsh environmental conditions. In contrast, a survival of any species under the longlasting influence of hard radiation has not been shown as yet.

From the fact that radioactive particle currents will be higher in the vicinity of nuclear reactors, coupled with their high (negative) genetic efficiency, one can derive as a first rule:

> A sharper separation of the biosphere and the reactors as is used today should be attempted in the future.

Evolution has occured in an environment which was well protected from the hard radiation of the fusion reactor sun; (1) we have an astronomical distance between sun and biosphere; (2) we have a (earth's) magnetic field which deflects at least all charged high energy particles. All that is not the case if we install nuclear reactors in heavily populated areas and if we continue to transport radioactive material through such areas; transport usually means thinner walls of containment and with it a higher radioactive emission.

Further rules can be derived from the leakage problem in conjunction with the high energy density of the nuclear fuels. We remamber that a delayed burning of fuels generally reduces entropy. In this context this suggests not to burn uranium rich minerals now but to store them for use in cases of utmost necessity. Then we would have the following beneficial effects :

(1) Because of the use to be stretched in time, at least the average radiation flow can be kept below Ir.

(2) For an energy storage we should always select a material which combines a high energy density with a long storage time - that is true for uranium.

(3) If one starts a (emergency) use later one could better ensure that this is hamdled entropy efficient, i.e. production of primary energy, chemical recuparation of unused burning material as well as the collection and final storage could be done at one location using a combined installation (see Ch.3)

(4) a delayed use could also provide a base for an average lifetimeadjustment; i.e. the time of use can be set equal to the average radiation decay time , Tz = τ ; that would also help to avoid hot reactor ruins.

Of couse, only an efficient low entropy production society would have this option. A society dedicated nuclear from the beginning would not have such a fallback position.

4.2.2 Nuclear fusion

One of the big hopes for the future is the construction of fusion reactors here on earth , i.e. installations which mimick fusion processes in the sun on a smaller scale. Fuel (isotopes of hydrogen such as deuterium and tritium to be burned to helium 4He) is contained in the oceans for many thousands of years. As today we do not even have a prototype fusion reactor, it is impossible to estimate the primary energy gain and the sources of secondary entropy production, in particular the radioactive load which accompanies the operation and reduction of fusion reactors.

One can ,however, forward a few speculative arguments. Good news would be that the fusion reaction does not produce heavy instable isotopes and that the containement walls could be made from medium sized elements (Al,Cu,Fe), whose isotopes once activated would decay fast. A negative rating would have the penetrating electromagnetic radiation (y-rays) and impurities od heavy isotopes in the wall materials. Thus, the radiation load per gained Joule could well lie over that of conventional fission reactors.

However, we can estimate the thermal cleaning costs and the required wall tightness for fusion in the same rough way as for fission: take the 20MeV per reaction to be carried awy by one radioactive particle; assume further, that fusion technology will be used over the whole civilisation period of say 60 000 years. Then, Ix/Iph = 0.08. As the ratio of background and photon fluxes is Ir/Iph = 10 -18 we would then need a screening factor of a = Ir/Ix = 10 -17. Using the wall extinction formula (Ch 7.6), this would require about 20m thick concrete walls for containment without the smallest leak.

A surplus of primary energy created via fusion is thus improbable; nobody can guarantee such a non-leakage performance. Thus, even fusion seems to be of limited gain, for example it might replace fission once the resources of fissionable material run out.

If one goes, however, for a limited use, by setting the permissible radiation load equal to the background radiation as a condition, this would reduce the screening factot to a = 10^{-12}. Then fusion could provide a prmary energy flow equivalent to a (second) suns flow. There would be still a considerable accident risk as this second sun would be distributed over the earth. Interstingly though, using delayed fission one would have a (longlasting) secondary energy potential, which is not possible with nuclear fission. One estimates that fissionable materials run out in about 300 years.

As one usually design fusion reactors to be attached to electrical energy distribution, one would have to convert for reserve energy potentials (fuels) also.

In any case, even if one operates with two sun equivalents, a renewal of todays wasteful production is inescapable.

4.3 PIGGY BACK METHOD

As there are many primary energy alternatives, often a discussion arises in which sequence the different types are to be created and reduced. For example, does it make sense to use fossile fuels to build solar cells even before solar technology can support itsself if left alone ?

According to our concept the answer is yes, as we have here a typical case of a delayed entropy production : the fuel could have been just burned (heat and emissions), but now it is (in part) dedicated to a potential entropy reduction, carried out later by the solar cell in operation. The principle of minimalizing entropy production values every kind of entropy reduction positive. This does not exclude a future better reduction through improved regenerative processes. Evolutionary improvements are always welcome.

What would be, however, the correct sequence of the use of primary energies of today ? First, whatever the sequence is , a delayed burning of all the constituents will reduce entropy production. If we asumme specifically that it is always the secondary entropy production that is decisive, i.e. that the inversion of emssions is the most cost efficient item, then the primary energy which produces the largest non-thermal entropy has to be burned last. That evaluation should also include the species specific weight factors, i.e. the danger to life for a given emission.

Then overall, we arrive at the following sequence: (1) solar energy and its derivates (2) fossile fuels (3) nuclear fuels

4.4 REGENERATIVE TECHNOLOGIES

regenerative technologies use the same ligth- and material fluxes as the plants, i.e. they are not supposed to change the average yearly temperature Te anymore. That would indeed comply with our evolutionary set preconditions. However, today we run a technology which is very much dependent on the existence and the exploitation of fossile resources. all our technolgy products rely on the millons of tons of mineral oil which are pumped and burned every year. Within a strictly solar society it would be virtually impossible to use todays technologies. Thus one has to develop a new class of 'low energy" technologies and try to introduce it long before the turning point in the global energy economy. The saving of fuel and the supplement of todays economy via regenerative approaches will not suffice in the long run. The precondition for the introduction of new primary energies would be that the whole new energy producing system is sustainable itself, i.e. aside from serving the population there has to be enough surplus for the installation, the maintainance and the reduction of the new primary energy producing units.

4.4.1 Energy harvesting factors

At this point usually the question comes up how to define sustainability not only in general terms but quantitatively. For example, under which conditions will be more solar energy produced and converted as is necessary to build the converter (windmill, solar cell, etc.) > This is called the break even point; only the eventual surplus will go into human consumption. Usually the definition is based on energy harvesting factors, that is the ratio of "produced" and "consumed" energies. In the view of entropy production this is not sufficient. Obviously, the more general approach would be to introduce entropy reduction factors. Fundamental to this approach id Fig.4, where the total entropy reduction of a product is depicted. One can view an enegy converter as a product and calculate its total entropy production /reduction along the same lines. The total entropy produced within a cycle we can write as a mean entropy production. This already includes the entropy reduction which we gain in producing primary energy, for example a stored solar electrical power. Let the total entropy per cycle be DSz. Without the product being in use, we would still have an entropy produced, DSo, over the cycle time. That is a reminder of the fact that without the solar converter the sunlight would be directlt converted into heat. The entropic gain per cycle, Gs, shown as a (stored) primary energy, would then be the difference Gs = DSo-DSoz This gain definition includes all secondary costs and is therefore more close to reality as the energy harvesting factors. However, if we want a measure that is more close to energy harvesting, we can look at the ratio of the entropies described, i.e. F = DSo/DSz. If this factor is larger then 1, the gain is larger than zero . that means that with the use of the converter the total entropy produced per cycle is smaller as without it and we would have an overall entropy reduction. Only then the installation and operation of a converter is worthwhile. In contrast to energy harvesting F and Gs contain all contributions which relate to material emissions during the life cycle of the unit. i.e. all secondary entropy productions. It is clear that truly regenerative units , F > 1, are not easy to build.

The only sunlight operating system that can be considered really regenerative is that based on photosynthesis, i.e. the plants - and this took evolution a long time to develop. Artificial photosynthesis, i.e. the production of lifeform base molecules just from light, water, CO2 and minerals thus appears to b one of the primary challenges of the future.

even as the use of solar power stations , windmills and other sunlight based is acceptable today as some entropy reduction is achieved (see also "piggyback" method), we should not forget that these installations depend today on the availability of the fossile reserves. In the long run we will have to have a completely regenerative primary energy production. The susstainabilty of today solar collectors and windmills are by no means certain. For example, large amounts of raw materials and primary energy have to be dedicated just to the installation of the solar collector frames. This is related to the very low energy density of the sunlight as compared to oil and coal. Also, if we build central solar power stations, the storag, the transport and the distribution of electrical energy will invite additional costs. That again suggests :

Concepts which are successful for the distribution of concentrated energy carriers cannot be readily used with diluted energy sources.

Diluted energy sources tend to use large areas and thus have inherently a tendency for decentralisation. We also note that,

> The regenerative system of the plant cover is our only fall-back position if we are not able to create our own regenerative cycle.

Unfortunately the plant cover is increasingly reduced by the human population. In addition, its regulatory measures are increasingly set side through the burning of fossile fuels and the emissions of toxic waste. the plant cover, which has carried so many people in the past, eventually will be lost as a fallback position if a rethinking occurs only shortly before the last resources are used up.

4.4.2 Solar energy

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Par. 2- not yet translated

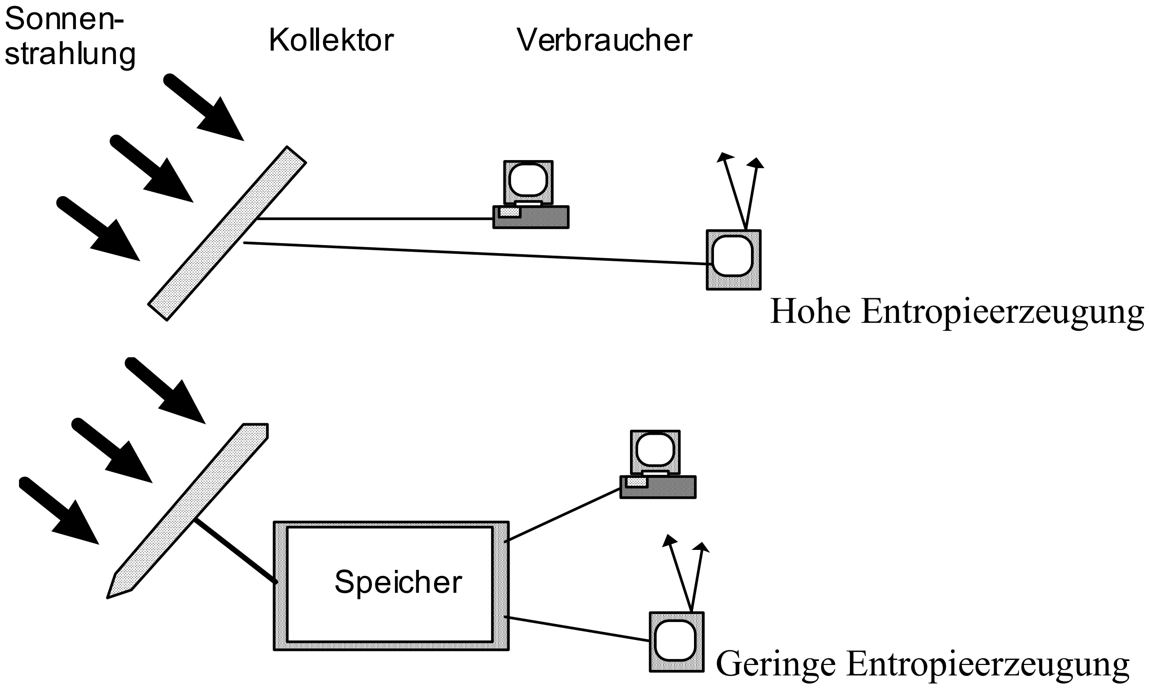

Fig. 27. Lowering of entropy production rate by storage of high-value (= low-entropic) energy.

Example – not yet translated

Par. 3 - not yet translated

Par. 4- not yet translated

Par. 5- not yet translated

4.4.3 Wind and water power

Par. 1- not yet translated

Fig. 28. Electricity from modern wind turbines.

Par. 2 - not yet translated

Par. 3 - not yet translated

Par. 4- not yet translated

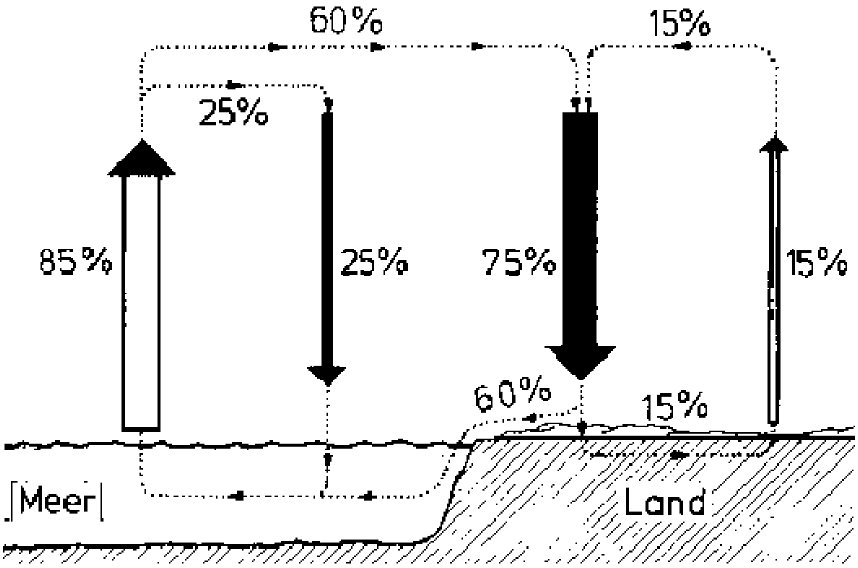

Fig. 29. Global water circulation scheme. De-saltration and long-term energy storage by evaporation from the oceans and condensation and rain on the continents.

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4.5 PLANETARY SOURCES

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4.6 COLLECTOR AND NETWORK DISTRIBUTION

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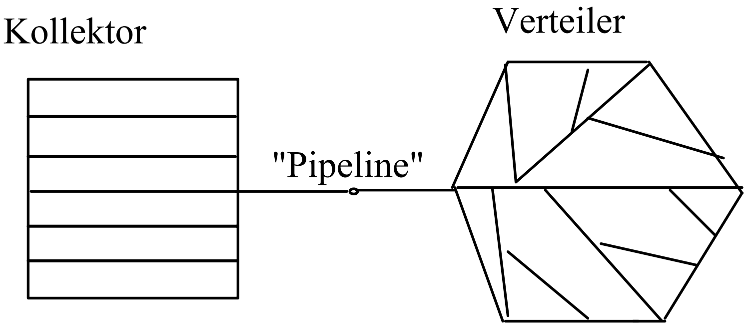

Fig. 30. Seperated entropy sources and sinks.

Par. 3- not yet translated

example – not yet translated.

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4.7 ARTIFICIAL PLANTS

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5. Entropic evaluation of social strategies

5.1 AN ENTROPIC VALUE SOCIETY - CHANCES FOR SUCCESS

Often ecology-oriented groups , and this applies also to a future ecologically oriented society, are set equal to a bunch of flower children which would have no chance in this "real" world, where only the most unscrupulous individuals or societies supposedly have a chance to survive. However, if one thinks back to the food intensive dinosaurs, for example, one finds that after a global catastrophy, they were replaced by more energy conserving species. From that we conclude that it is not the total amount of the converted energy which matters, but the incapability to vary it after a certain development is finalized. That inflexibility makes a seemingly optimal adapted species vulnerable and might even threaten its existence.

In order to find more specific guidelines to avoid this trap, we now discuss some of the more common survival strategies of modern societies in the light of a varying entropy balance.

5.1.1 Back to Nature ?

According to the entropy balancing concept, a high "energy consumption" can be tolerated - provided that the produced entropy in the end can be exported into space. That also means that this concept can be applied practically independent of the consumption level of a given population. It is this point which makes the concept developed here markedly different from the usual "back-to-nature" strategies, where a high consumption is rejected - we all go back to be farmers. "Back-to-nature" strategies will not work with the large population density which has already developed today. On the other hand, entropy balance at a high level should not be misunderstood as a license for unlimited growth. Indeed, the balance is easier to perform, the lower the positive and negative totals, i.e. the production and reduction of entropy, are.

5.1.2 Collective intelligence

Evolution has gone a new way with the creation of the human species. Humans have not developed wings or fins but a larger brain instead. The hitherto successful method to bodily adapt to specific environments was abandoned in favor of a more abstract but also more general adaptibility, i.e. the intellectual capacity. That creates artificial wings and fins and allows survival in otherwise extremely life-threatening and therefore hitherto unconquered regions - like antarctica or space. If this course will be successful in the end in terms of the expansion of life cannot be stated with finality today. There is also a negative side to this evolutionary step: the high intellect of the individual is propped on an animal instinct which ensures survival and reproduction, and thus the intellect is cast in the role of guide and planner of survival, but does not act as a primary motivator . That is why any new organisation principle in the end can only be explained and promoted as a survival strategy, not as a religious or scientific rule.

If a new principle, here the balancing of the entropy, is integrated and successfully applied, concerns us all. One of the obstacles with this and all other abstract concepts evidently is the selfinterest - it is always easier to let the neighbour clean up the mess. This is often categorized as the cerebellum/cerebrum conflict or more simple, the conflict between instinctive and controlled intelligent action. Culture pessimists always looked upon that as a barrier for a moral evolution of mankind and thus also for its final success as a species. Some even go so far as to claim that the self interest of the individual blocks any intelligent action of humans as a group and that is why humanity, in the evaluation of a species, may be less successful in the end as a "so-called" non-intelligent but still cooperating species. For example a symbiosis of plants/animals or a collaboration of insects (anthill). Those cases indeed constitute forms of proven collective intelligence.

Others, however, see in the agressive individuality an evolutionary advan-tage : even in a society which has no external enemies or challenges, an "evolutionary pressure" is upheld.

5.2 THE ENEMY PORTRAIT

The internal conflict of our species always creates absurdities not only in a moral sense but also in the light of logic. Of those, probably the oldest one is the "enemy portrait". As "external" enemy one considers a member of a competing group of individuals B, on which the social rules for the members of the group A are not applied. In order to show consistency, members of the group B and in particular their representatives are usually quickly clothed with monstrous properties, although in fact the members of group B are vitually the same as group A members. Here we have an "ethical" dilemma and the principle of entropy minimalisation cannot help - indeed individuals of the same entropy production can be exchanged under that principle. Moreover, it happens that the entropic view can be used to create new "enemy portraits": so it has been reported that citizens which did not conform to the (bio/techno-) waste separation were mobbed ("internal enemies"). Globally, this is a new means to scare up conflicts between groups : if one national state contributes overwhelmingly to the pollution of the common goods atmosphere and oceans, military force may be used by the others to stop that excessive pollution. The resources needed to be stored for such an action (and warfare in general), i.e. storages of fuel and munitions, is viewed positive by the minimalisation principle, as storage (of chemical and /or nuclear energy) is equivalent to an entropy reduction. The (quick) use-up of these storages during combat, however, is extremely entropy and secondary entropy intensive - in extreme cases it can be destructive for the whole population (A and/or B) - a view of war that is quite generally accepted today.

Export of waste from rich to poor countries produces similar problems : if an emitting production is transfered from a country with a high environmental standard to a low emission standard country, the overall effect is an increase of the pollution worldwide.

Another kind of pollution export is to locate emitting productions close to a border or the disregard of international emission agreements. This way new enemy portraits can appear.

In peaceful times the regenerative work which would be done by an entropy abiding society would have to be valued higher anyway. However, populations with a better environmental adaption will be successful in an evolutionary sense only if they are able to safeguard their structures through equally advanced defense strategies. That rule also applies to a future entropy balanced society, which eventually would have to compete, at least for a transitional period, with more wasteful but agressive groups. Success in a conflict, however, would be rather probable, as the new society can be based only on a high degree of organisation and storage of resources - both are consistent with the entropy production minimalisation.

5.3 BIOTECHNOLOGY

Different venues into a stationary society can be envisioned, the most prominent discussed today are (1) expanding technology but adapting it to biological strategies and cyclic processes, or (2) using biological - eventually genetically modified - structures directly, while scaling back 19th century technology. The answer to what is right cannot be given by the principle as it is supposed to apply to both cases and any mixture of them. The return to classical biosystems ("return to nature") alone would certainly not suffice to feed todays or future populations. Genetic manipulation, earlier done only longterm by nature, will certainly be accelerated by mankind, including all its risks.

Worrysome in particular would be changes in the bio-reduction chain : what would happen if tomatoes would not decompose anymore or could not be reduced by the bacteria of the human digestive system? Can it be ensured that a genetically modified tomatoe only holds off decomposition to live longer - which would be positive in the sense of storage and entropy reduction, or are positive and negative effects intertwined? Today we have but little knowledge about possible secondary effects which go along with genetic modifications. One dangerous possibility would be a concurrent weakness against a specific yet to be discovered parasite which could eliminate the whole modified tomatoe population. That clearly would have to be valued negative. The example shows the adverse effect of a reduction of the genetic diversity: in the example, the elimination of all other kinds of tomatoes which might be stable against this parasite, but are outgrown by the new species.

One more specific proposal which reoccurs from time to time is a purely plant based food supply (vegetarian). What position takes the minimalsation principle here ? If one really could produce the same combination of substances (sugar, proteins, minerals, vitamins etc.) purely plant based, including comparable storage densities and storage times, then the direct approach, i.e. a vegetarian food basis would be preferable.

If one uses animals as intermediaries, one also relies on plants, but the life functions of the animals produce entropy which is not useful for us. However, before we can think about a complete conversion, one really has to meet many conditions : the animal related materials conversion (grass-milk etc.) must be replaced, but with less entropic cost. If this is not met, the result will only be that the better scheme is lost. Todays technological and biotechnical means are not developed far enough to allow a complete replacement: in particular, one must keep in mind the investment and maintainance entropic costs of the technical appliances, which probably compare unfavorable with existing biological species. Thus, animal based products will be with us for some more time, which at least ensures the protection of some brother species.

Aside from the food production, the use of biotechnics for medical research and treatment often takes center stage. Again, not all the steps which could be taken will be useful in terms of an overall entropy reduction. Cloning , for example, would not be beneficial, as a clone is defined by having exactly the same genetic information as the original and thus would not contribute to the genetic diversity. This judgement is also reached by the entropy minimalisation principle: let the structural negentropy of an individual of a certain species be $-\Delta S$; then, the information of N individuals of this species would roughly be $-N\Delta S$ (genetic pool). In contrast, N clones would have only $-N\Delta S/N = -\Delta S$ structural entropy; that is equivalent to only one individual and thus is a much smaller entropy reduction.

The principle of entropy minimalisation thus prefers N individualists to N clones, assuming the same lifetime T_L for both :

$$(dS/dt)_{min} = -N\Delta S/T_L$$

is certainly the smaller value. In this context one could argue that the above estimate for the structural entropy of N individuals is much too optimistic, as similar individuals of the same species have many partial features in common. The structural entropy of an individual, however, consists rather of combinations of features as of a sum of separate features. The number of combinations changes strongly even if only some of the elements are exchanged. That is very similar to the strong increase of the mixing entropy when adding only a few inpurities to a pure matrix. This is shown by a simple example:

The arrangement of 9 = 3x3 white balls in a square is supposed to be equivalent to one clone. 9 such clones would still be equivalent to this one unique arrangement. Now we replace one of the white balls by a black one and again form squares using all 9 balls. Positioning the black ball differently one now obtains 9 certainly different arrangements (indivi-duals). These 9 individuals indeed contain the ninefold information. Evolution cannot anticipate which of those individuals has to be selected for the best adaption at a later time, so it prepares for all eventualities.

Thus, while a twin or an identical back-up system can still be considered to be useful as a ways of reducing the demolition risk to 1/2 or, alternatively, of doubling the security of a certain information, an N-fold multiplication has already to be considered redundant. The same argument applies for monocultures like the one genetically modified globally distributed tomato.

We have now seen that evolutionary arguments and the use of the minimum principle give the same result : a larger gene-pool allows better and faster adaption to changing environmental conditions. Exact copies, in contrast, lead to a decrease of the adaptibility. Such a population would in particular be overly sensitive to a specific infection, just as a monoculture is helpless against an adapted parasite.

5.4 ROBOTS AND ARTIFICIAL INTELLIGENCE

Humans have always tried to stabilize their dominance by domesticating useful lifeforms. Aside from the breeding of certain animals and plants, the construction of machines and other equipment, which in the end will be given mobility and artificial intelligence, is a never ending effort. Robots are in particular useful as agents of man in not so easily accessible regions (microcosmos, macrocosmos) and hostile environments (oceans, space). If one looks more closely, they can be identified as extensions of human senses and organs (McLuhan). This development has been successful so far and is envisioned to be helpful also for the complex production-reduction cycles of the future. These fast developing intelligent machines are being build today, however, without consideration of the entropy production minimalisation principle - see for example the increasing amount of antiquated computer and computer extensions waste. Computers should be constructed in such a way that they themselves are easy to reduce. For future design one should in particular look at the biocycle: intelligent subunits should be developed which take the role of the multifunctional parts of the biological production-reduction chain.

Artificial intelligence can be useful locally and globally. Locally it can help with an eventual future substructuring of parts or as a never sleeping security system. Globally it can connect distant individuals (internet etc.) . This way one can hope to construct a global information feedback loop - a precondition of true global regulating devices. Unfortunately, global artificial intelligence can have the same fate as global natural intelligence. The latter was so far transported by the spoken and written word but slowly; it was, however, always rather canceled out because of different interests and value systems. The introduction of the technical part of a global network in itself is no guarantee for the development of a global intelligence; a minimal condition for that would be a basic reform and unification of the human action evaluation criteria.

5.5 THE MONSTERS WE RAISE

In this chapter we try to look into the future, i.e. we would like to see the end of the road on which we are going. For that we assume the position of an alien observer, who is placed to evaluate the human activities. If he would have to describe our strategy, he would probably come to the following conclusions: Mankind alters the environment which he has evolved from; the changes go in a direction which is rather unfavorable for the species as a whole (pollution). That sets the stage for the evolution of another species, one which is almost created by the environmental changes caused by man and as such can survive that new environment longer. If one has to profile this new species, it would look as follows: an extreme pollution and radiation resistive species, one which has extremely developed decontamination organs and a low energy and oxygen consumption. That can be done best by simple species: single cell lifeforms or at best decendents of the insects (cockroaches etc.). All "culture followers" , i.e. for us useful plants and animals and even rats would be gone together with todays leading species.

In summary, life itself will probably persist on the planet but eventually without us. For evolution we are only one attempt, not necessarily a final solution. If from the surviving species in the end another intelligent species will evolve, will be determined by chance. In that context, the often discussed scenario, where a small group of humans comes back to earth in a space ship exactly at the moment where the environmental situation on earth has improved following a bigger catastrophy, is just improbable. More likely is the scenario in which there will be no second chance if the human species stages its own destruction. A short term displacement of a group of humans (on mars etc.) could only help if intelligent life had stabilized on earth, but was the victim of a chance hit by an asteroid. So far, we do not know how a long term stable, mobile and intelligent earth population looks like. We only know our growth society and the now endangered long term stable plant life.

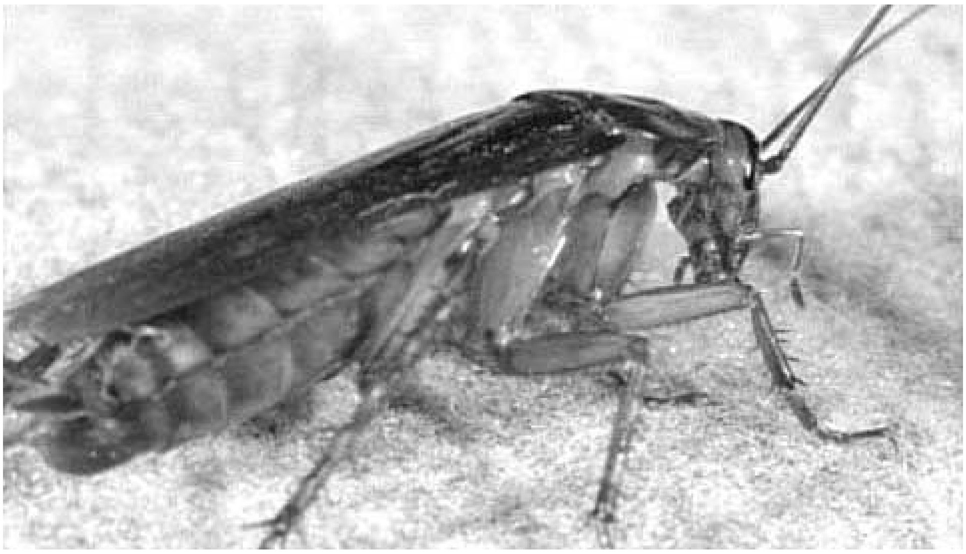

Fig. 31. Our successor?

5.6 ENTROPY PRODUCTION AND END TIME SHOCK

Is it possible to determine the fate of a given population by considering its population dynamics and the associated entropy production ? One hint is the fact that high cultures tend to occur only periodically: they are usually disrupted by periods of lower cultural and living standards. We also note that high cultures are usually connected with a high entropy production, more agriculturally based cultures have a lower entropy production. Is that again a call for "going back to nature" ? No, the important aspect is the entropy balance, not its absolute magnitude.

An example would be a high culture whose food production drops suddenly. Distribution conflicts will precede its final falldown. There might

be an agrarian base left upon which the next high culture could develop, presumably at another location. For a global civilisation such a change of location is impossible. For that global scenario we will now discuss the population dynamics.

Population and Regulation

One hears that every day one of the many species disappears from the surface of the earth, usually through the destruction of its environment. More specifically, it is the too fast change of the conditions, say deforestation or pollution, which inflicts this population catastrophy. If the given species would have more time, it would probably adapt and thus survive. Do we have to use a specific approach in each case or is it possible to develop a general scheme ? If yes, what general answers can be given in respect of a particular species, including the homo sapiens?

External influences on the growth and decay of plant or animal populations can be described formally using a feedback loop. The degree of complexity of the function in question or a possible intertwining of different feedback loops changes the general picture only marginally: a regulated, i.e. to be held constant quantity is for example the inner body temperature (T_{IB}=37.5°C), which is almost independent of the (maximal) number of individuals on a given territory N . For both properties feedback loops are needed and they are in a way related, for example via the food production; however, they can be discussed independently.

In a given feedback loop the information about the to be regulated quantity, T_{IB} or N, is transported around a loop. This not only leads to a difference between the momentary value of the quantity in question Q_m and its target value Q_t, but also to a temporal shift between the deviation (Q_m - Q_t) and the reaction to it. Thisleads to a damped oscillatory behaviour - also called loop oscillations - which in the optimal case degenerate to an asymptotic or fastest approach behaviour.

One well-known example is the so-called pig cycle:

(1) there is not enough pig meat on the market

(2) → the price per pound increases

(3) → more pig breeders decide to produce more pig meat

(4) → next year (delayed reaction !) too much pig meat is on the market

(5) → the price per pound goes down

(6) → the pig breeders get disappointed and turn to other activities

(7,1) → in the following year we have again a shortage of pig meat

(1) through (7) describes the period of a functioning feedback loop if the meat production is not too far from the actual demand. Apparently, a permanent oscillatory behaviour is possible - in which case the momentary value oscillates around the target value. In a precivilisation ecosystem such an oscillation would for example describe a prey-predator relation.

The feedback loop also knows a catastrophic case. That occurs if a functional error occurs in the loop, or if an external disturbance occurs which is too strong and too abrupt to be balanced out.

One example for a functional error is a flawed comparison between momentary and target value. A too strong external disturbance would be a larger manmade or natural catastrophy. In both cases we might find catastrophic oscillations. An example : the fast overgrazing, often observed with insects or bacteria, is based on a deficit of regulatory mechanism in conjunction with a population explosion. A population which approaches the limit of its growth too fast, faces extinction with the first oscillatory downturn even without natural catastrophies: all resources disappear simultaneously and the population reaches a critical value (end time shock, figure 32). Among the external influences which might lead to a catastrophic oscillation, in particular longlasting disturbances are detrimental if they influence the birth rate directly. Candidates for that are stellar or nuclear catastrophies since they are accompanied by longlasting dustclouds or radiation, while the hot-house effect has to work on us indirectly, i.e. over a longlasting reduction of the food basis (floods, desert expansion etc.).

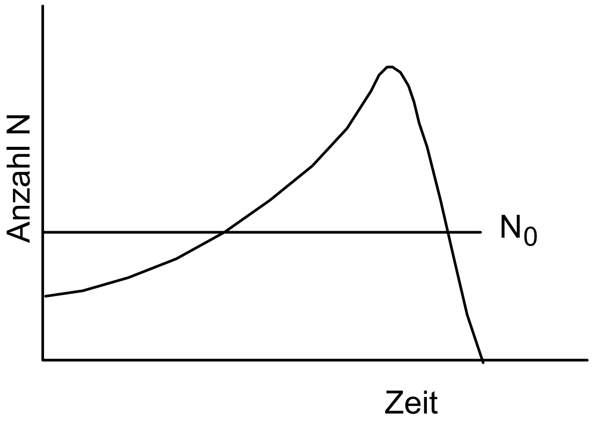

Fig. 32. Catastrophic oscillation of a malfunctioning or overstreched feedback loop. It describes the disappearance of species even if the species developed quite normally earlier (for more details see appendix)..

At first sight, one would not expect a deficit of regulatory mechanisms or malfunctions of those with the highly developed human species. However, mankind was originally dependent on the regulatory means of the plants and historically does not care too much about the development of own regulatory measures. Also, man has no natural enemies anymore which would provide a regulation of his population. On the other hand, today the plant cycles are increasingly destroyed. Thus, mankind might well get extinct on the finite surface of the earth, equivalent to bacteria in a Petri dish unless he invents and observes effective rules globally.

In this context the argument is made, that even if a catastrophic oscillation occurs after the limits of growth are reached, one can hope for a recovery from scratch. However, in the end that would only lead to a damped oscillatory population density, as each new high culture development would start with less resources (see figure 33). Thus , while at times one would be in a high culture state, this road also leads into extinction. It therefore has to be our aim to hold up an existing population at its high level as long as it is possible, while at all times inviting evolutionary changes to the better. How long can such a civilisation exist ? As we look for a general answer, i.e. one which avoids singular events like meteor hits, we turn again to the concept of entropy balance.

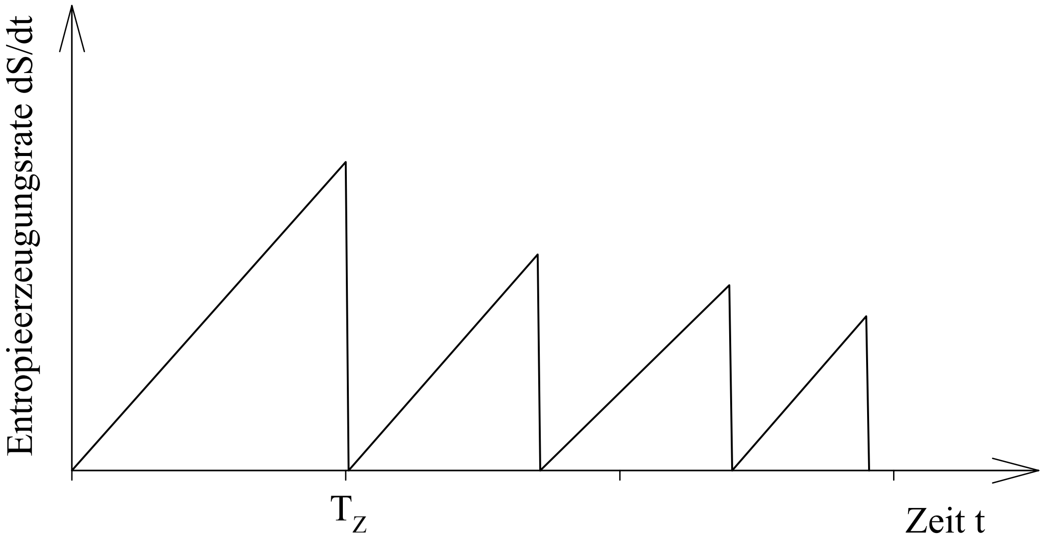

Fig. 33 After the first civilisation catastrophy, a new civilisatory effort begins, however, with far less resources.

Let us assume that a civilisation ends when we exceed a certain (high) value of entropy ΔS_{crit}. One possibility would be the total mixing of the atmosphere with CO_2 (catastrophy k). The critical pollution would in general come from many individual sources (i) , each of which only partially contributes to the CO_2-

problem, i.e. we will have to give a damage factor g_{ik} to each individual direct or indirect source. The entropy production which potentially ends the high culture would then be given by the sum of weighted individual contributions $g_{ik}(dSi/dt)$ over time; as long as the integrated value stays below the critical entropy $\Delta S^k{}_{crit}$, the civilisation would still exist. Therefore, the obvious conclusion would be to hold the sum close to zero over time by using entropy reducing measures after each entropy production. That in turn leads back to an ocillatory entropy production (fig.34). This, however, is the earmark of an intermittend stationary state where entropy production and entropy export balance over the cycle time. The lifetime T_Z of such a civilisation would go to infinity while the measures to balance the entropy can be environmental conservation but also the increase of the entropy export.

Because of the summation over time, most dangerous are large entropy productions which cannot be reduced or can be reduced only slowly - like ozone depletion or hothouse gases.

Another possible catastrophy k would be the destruction of the high culture due to a large drop in the food production - food can be considered storable converted solar energy and as such it indeed reduces the total entropy production. The species specific weight factor g_{ik} is then related to the usability of a given food plant. Cactus, for example, converts solar energy to chemical energy in a comparable amount as grain, but its weight factor is practically zero, as cacti cannot be eaten. On the other hand, a too fast depletion of the grain storages leads to a fast increasing entropy production (see fig.33). That was for the old high cultures as dangerous as the too fast use-up of the fossile resources are today.

There are quite different prognosis as to actual duration of our civilisation. Assuming that the passge into a stationary society is rejected, pessimists see the end directly after the fossile fuels are used up, i.e. about 300 years. Others see the melting of the polar caps as final catastrophy. For a time limit in that case one obtains almost the same result: the estimated increase of temperature caused by the hothouse gas emissions was 2°C in 100 years (see Appendix); if the polar caps indeed melt at 6°C temperature increase, one obtains again a 300 years period of grace. That would only be 10 generations left to live in a growth society. A completely different result is obtained if the society makes it into a stationary state, i.e. observes entropy balancing.

The lifetime of a stationary society can be infinite if there is no stellar catastropy that finishes the entropic cycle.

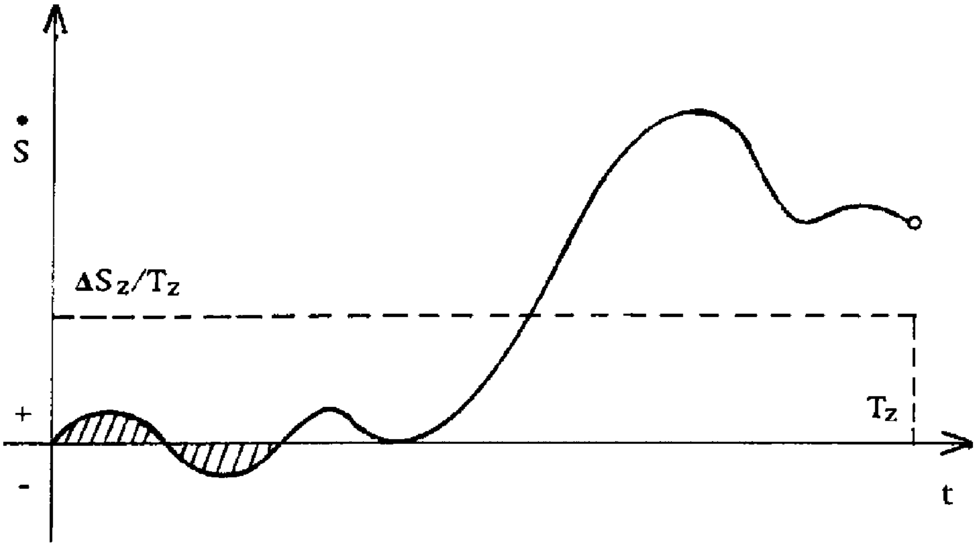

Fig. 34. Lifetime of a civilisation can be infinite if entropy production and reduction average out to zero with time. On the other hand, if a certain entropy exceeds a critical limit, a population catastrophe will occur.

5.7 OTHER PLANETS

The situation at the turning point into a stationary society can be compared with the landing of a larger group of humans on an unknown planet with no fossile resources which could be used up. There is, however, a certain biofriendly environment on the planet, i.e. atmosphere, water and selfgrowing, eatable plants. In order to survive, the group would have to adopt a sustainable technology. The only resources brought along by the space travellers consists of a large data storage which practically contains the up to date knowledge and experience of mankind. We know, that the planet earth and its lifeforms are unique and that a similar object probably does not exists inside a cube of basis length 100 Parsec. If humanity does not survive longtime under the earth's favorable conditions, it will not survive at lesser locations: thermodynamic selfcleaning and artificial cleaning is the more difficult, the less primary energy, wind and water are available. That we know from our own desert areas; they are much more susceptible as wheather-active regions. A civilisation on a bioadverse planet, say mars, would have to be much more environmentally sensitive as one here on earth. Thus, an outpost on Mars would make sense only as an insurance against an interstellar catastrophy here on earth. Space travel and planet colonization need much better techniques as we have in our arsenal today. However, these new techniques would have to be developed here on earth during the growth period and their number one target would have to be the conservation of the earth itself.

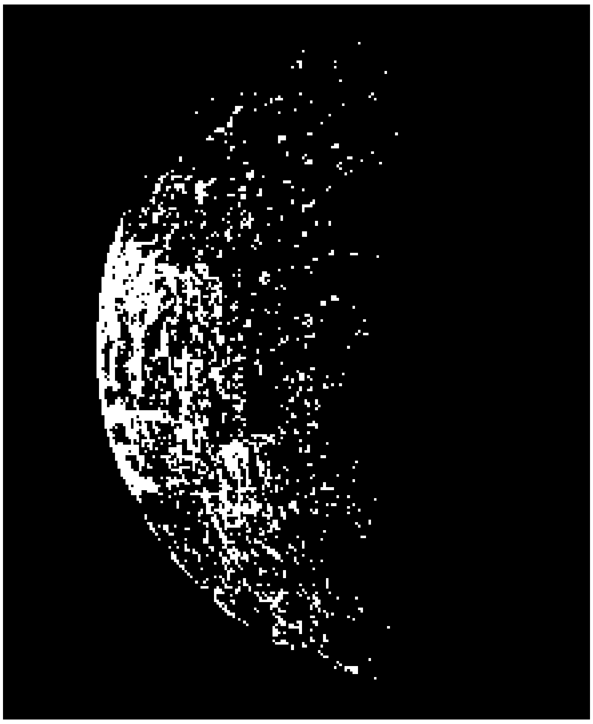

Fig 34. Before one can think about space travel and colonization of other planets, we have to solve the much easier task to stabilize our life support system here on earth.

6. Epilogue

The plants live successfully on this planet and, in the course of time, have changed the earth's surface and its atmosphere to their advantage.

They regulate the composition of the atmosphere via photosynthesis, i.e. in particulat the relative amounts of oxygen O_2 and carbondioxide CO_2. The plants also influence the on-and offradiation of light energy and thus contribute to insure the constancy of the average earth's temperature. They use the strategies of entropy reduction: at night they off-radiate heat , i.e. they export thermal entropy above average. The non-exportable mixing entropy is reduced in a cycle, at least in the case of the life supporting materials CO_2, H_2O, O_2, N_2, etc., i.e. at emission these entropies are produced and with collection they are reduced in the same amount. We find the root and leave systems to be effective chemical separators. The plant photosynthesis delays a potential entropy production, i.e. the direct conversion of sunlight into heat. The highly mobile higher lifeforms, i.e. humans and animals, so far did not constructively participate in the regulatory measures installed by the plants. From the viewpoint of the successful regenerative plant population these higher lifeforms are parasitic; at best they have symbiotic functions, for example their contribution to the distribution of the lesser mobile plants. In contrast, the micro-organism are important for the reduction branch of the plant cycle.

If we reduce or completely replace the plants, we have to substitute all of the plants regulatory measures and their entropy reduction - a gigantic task.

On the other hand, for us the way back to nature is blocked, i.e. we cannot hope to live like the indigenous people since we have developed away from that condition both in terms of population dynamics as well as in genetic development.

Today every individual depends very much on our selfmade industrial development, which in turn garantuees our dominance as a species. However, the everincreasing destruction of our life sphere forces us to rethink technology use. This contribution tries to promote a synthesis of biology and technology by looking for a common principle which allows to take the successful strategies of the plants to another, more abstract level. This way our technical extensions might be conserved without destroying the natural environment, whose part we are, too. In our view, leading the way is the balance of entropy production and reduction, under the rule of species specific weight factors. This approach allows for an environ-mentally sound comparison of biological and technical products and processes and furthermore, we can derive a value scale for our actions globally and locally.

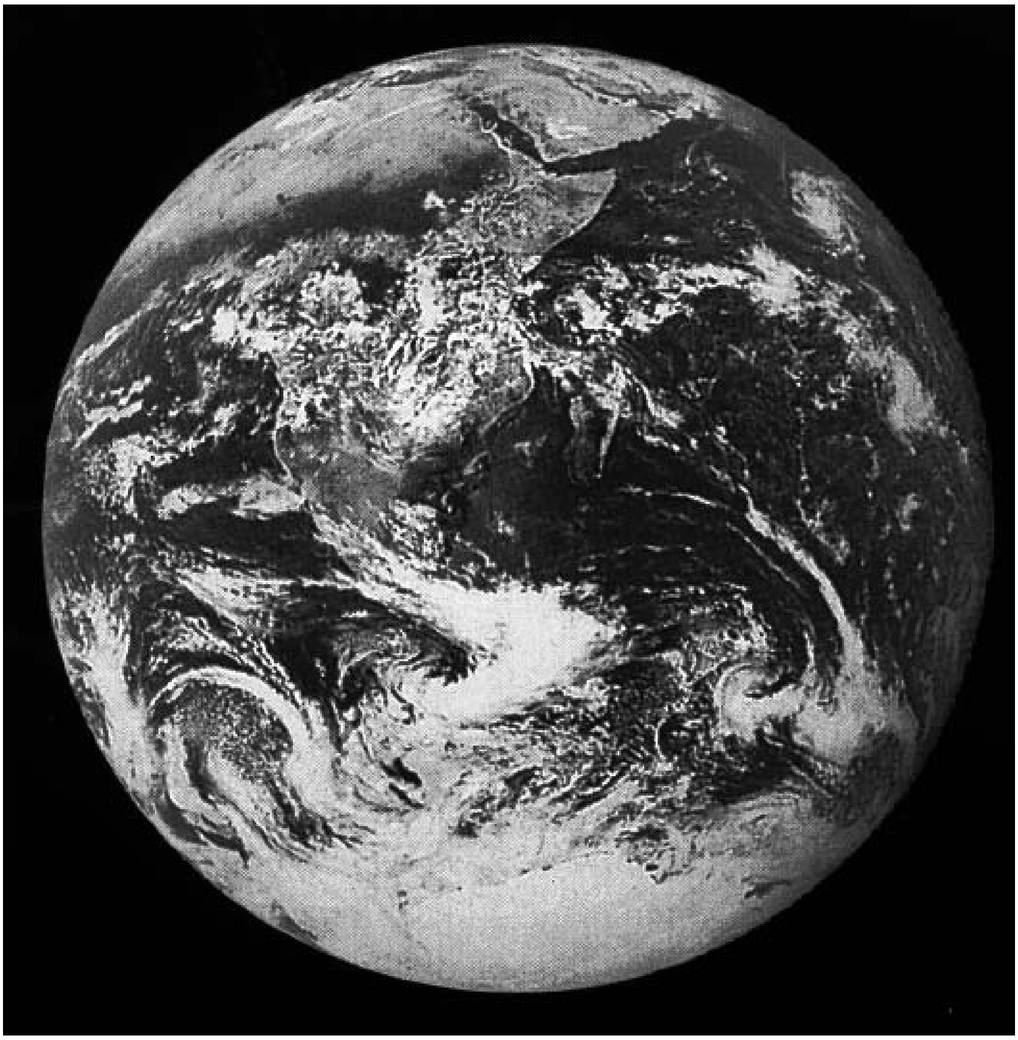

Fig. 36 Can we conserve the biosphere of the spaceship earth in such a way that it offers a permanent existential basis for mankind ?

7. Appendix

7.1 MECHANISTIC DEMONSTRATION OF THE ENTROPY

The thermal entropy of a gas can be related to the disorder of motion of the gas molecules. For that, figure A1 shows the trajectory of a single particle, taken out from an ensemble of N such molecules.

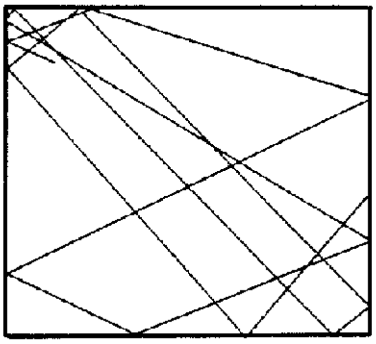

Fig. A1. Trajectory of a single gas particle in a closed box.

One observes, that over a longer time interval and repeated reflections on the walls, the motion of a particular molecule adopts all directions. This is also true for a snapshot of the whole ensemble; the N molecules adopt all kinds of trajectories at that moment in time. In contrast to that, the trajectories under the same energy of motion (kinetic energy) per particle could be ordered, like depicted in figA2.

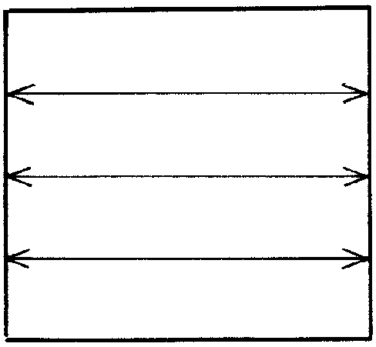

Fig. A2. Hypothetical trajectoies of three molecules in a box with exactly parallel and perfectly smooth walls.

Here in particular are shown the trajectories of 3 particles, which continuously repeat their (oscillatory) motion like balls on a perfect pool billiard table. Like with gas molecules in a real container, the walls of any real billiard table, however, always have a certain roughness and therefore these trajectories cannot be upheld, i.e. in the end they will be transformed into trajectories which cover the whole table area (ergodic behaviour- see fig. A1). If one starts from the three parallel trajectories one would decribe this change in motion as an increase of the disorder with time, i.e. an entropy production dS/dt. Thermodynamics tells us that in a large enough ensemble of N molecules, such a distribution of the trajectories will always happen, either through collisions between the molecules or through collisions of the molecules with the (rough) wall. This phenomenon gives time a direction, a property which it does not have in the Newtonian mechanics where the fundamental equations are invariant against time reversal.

The principle of equal distribution of motion onto all three linear independent directions in space tells us, that in the course of time not only all possible trajectories are attained, but that all particles will also obtain the same average energy of motion, which in turn defines the temperature of the gas via $(1/2)mv_{th}^2 = (3/2)kT$ (v_{th}: thermal velocity, T: absolute temperature , k : Boltzmann's constant).The exact details of the conversion of deterministic particle trajectories into a statistical (random) behaviour were unclear for a long time. Recently, nonlinear physics has made some progress in this direction (see bifurcation and strange attractors).

The equipartition principle which was just discussed is based on the assumption that nature will always provide mechanisms which distribute a given concentration of energy. This is also the reason why energy storage. i.e. generally speaking N_1 high energy level particles inside of $N >> N_1$ low energy level particles, is usually difficult to perform. A thermal energy storage, for example, will be emptied relatively fast by the elementary process of heat conduction (diffusion of the thermal energy) .

Thermal entropy can be demonstrated also in solids and liquids. With solids, the fundamental motion of an individual atom or molecule is a harmonic oscillation, as each molecule is bound elastically to its neighbours. However, the axes of oscillation can be different (high entropy) or equal (low entropy) for each atom, even at the same average energy of oscillation per atom (fig.A3). Fig. A4 shows that the ordered oscillation of the same number of molecules, can be considered a section out of a sound wave.

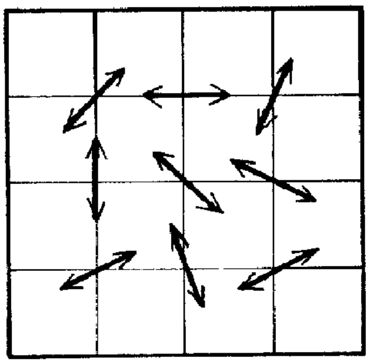

Fig A3. Thermal oscillations of the atoms in a solid cube.

7.2 MIXING ENTROPY

If two pure substances A and B are mixed, obviously one has to consider two kinds of particles A and B with total numbers $N_A+N_B = N$. Again we can have an ordered or a disordered state. The difference is shown in figures A5 and A6. In fig. A5 we find 8 white (A) and 8 dashed (B) fields, but well ordered. That is representative of a segregated, i.e. non-mixed state of A on top of B. Obviously, only one state of this kind exists, if one does not count extra the states which are obtained by rotating the frame.

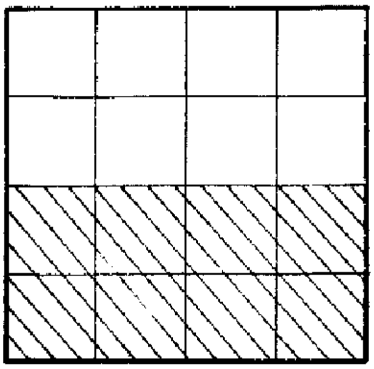

Fig A5. Ordered stated (Separation).

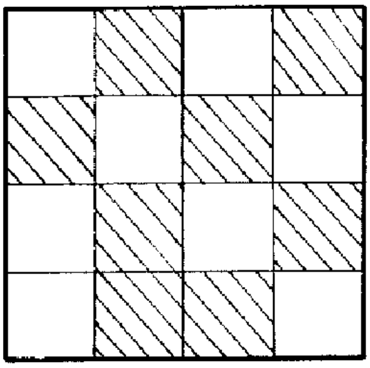

Fig. A6. Disordered state (mixing).

If, however, one is allowed to mix the A and B molecules (or atoms), we will find a much higher number (w) of configurations - one of them is shown in fig. A6. Increasing N, the configurations of this kind grow like a geometrical sum. That is why one uses a logarithmic measure for this kind of disorder. Again following Boltzmann, the mixing entropy is expressed as:

$$\text{a1.}\quad S_{mix} = k\ln w$$

We still can have an average binding energy per atom to give a condensed (liquid or solid) state at low temperatures. However, strong specific bonds, say A-B, at low temperatures would yield a new compound AB. In that case, in the solid AB the white and dashed fields would be crosswise ordered like a chessboard (see upper part of the A6 configuration). We would then obtain a new low entropy, i.e. ordered state - it would represent, say, the lattice of a new "pure" material AB (NaCl etc.). Here we see already that the formation of chemical compounds is well suited to reduce the entropy increase with time and that chemical compounds are useful "energy" storages. The entropy is always higher in the random, i.e. disordered state as compared to the ordered one and the former is usually installed at higher temperatures. But exactly that has to be avoided for biological and technical products as long as possible, if one wants to observe $dS/dt = Min$.

7.2.1 Distribution of foreign substances in an uniform matrix

Gases in the atmosphere

Specific gases like CH_4 and CO_2, initially foreign to the atmosphere - which basically consists of a mixture of oxygen O_2 and nitrogen N_2 - are being distributed in it independent of their origin. This type of pollution has been disregarded for a long time because the plants supplied the entropy reduction measures, but today it has added up to deliver global warming. The principle of entropy production minimalisation considers the infusion of foreign gases as a cost factor right from the start as a mixing entropy is involved. If one allows a certain number n_i of foreign molecules to expand into a larger volume of a pure component, the mixing entropy increases. If this is seen positive or negative in a given situation is in the discretion of society (weight factors). A limited increase of the oxygen content or CO_2-content would eventually be seen positive as it supports plant life, while a strong enhancement of the CO_2-content would not. Certainly, an enhancement of the concentration of the toxic gas carbonmonoxide (CO) would be valued negative.

In what follows we propose a simple way to calculate the unweighted entropy increase which is connected with gas emissions into the atmosphere, independent of the nature of the gas. For that we take the gas mixture of the normal atmosphere as a pure matrix, i.e. we basically replace the N_2 and O_2 molecules by average $(O_2/N_2)/2$ molecules of number N. As we have seen earlier, the mixing entropy is proportional to the natural logarithm of the possible stable configurations w of a system of N atoms of the elements A and B. Now B is the average air molecule and A is the foreign molecule. When we look at the increase of the mixing entropy after a certain time t_1 has passed, i.e. when we start with an initially polluted volume V_1, the number of foreign molecules n_i is supposed to be already small as compared to the number N_1 of air molecules; however, that is long before the final distribution of A in the atmosphere (B) is completed. Because of $n_i < N_1 < N$ for all times $t > t_1$, the concentration $c(t) = n_i/N$ is always small and gets even smaller with increasing expansion of the polluted volume, i.e. under these conditions the mixing entropy always increases. If, however, the concentrations are small from the start, one can approximate the expression for the mixing entropy from :

$$S = -Nk_B \left[c \ln c + (1-c) \ln(1-c) \right]$$

to:

$$S = n_i k_B \ln\left(\frac{1}{c} \right).$$

The number of injected foreign molecules n_i is constant, but the number of "air molecules" in which they are distributed increases with incresing dilution. Thus, 1/c and with it S increases ! If one is interested in the entropy production of this process in a more quantitative way, one can now take the time derivative of S (quasistatic approach):

$$\frac{dS}{dt} = -\frac{n_i k_B}{c} \frac{dc}{dt}$$

That equation represents a conservative estimate - the real entropy production would always be higher. In order to go further one has to know the polluted volume V(t) at the time t.

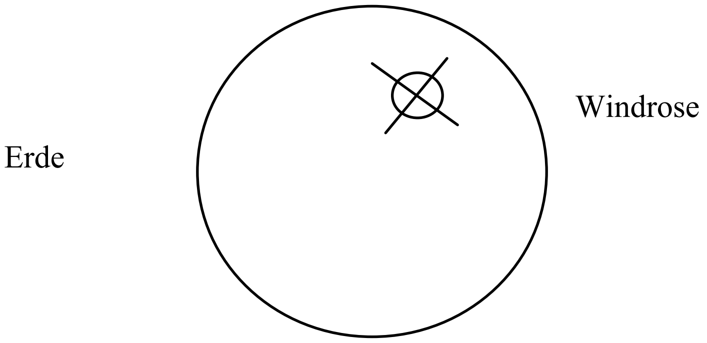

Fig A7.

For that we use a rough distribution model (fig. A7): the volume V(t) = Ah is supposed to have a base area A = $(vt)^2$, the radius of which is given by the average wind velocity $v_x = v_y = v$ (isotropic velocity distribution) and the time t which has elapsed. The cylinder height h= $|(D_i t)$ is assumed to be determined by an upward diffusion (D_i effective diffusion constant, includes weak upwinds and turbulences). The real conditions might be more complex, however , the processes convection, turbulence and diffusion will always be involved.

Since the particle number is proportional to the volume: V= N v_o (v_o average volume per molecule), we have

$$\frac{1}{c} = \frac{1}{n_i} N(t) = \frac{1}{V_1} V(t) = \frac{v^2 t^2}{V_1} \sqrt{D_i t}$$

and thus :

$$\frac{dS}{dt} = \frac{5}{2} \frac{n_i k_B}{t}$$

In the time interval $t_1 < t < t_2$; here, t_2 is the time when the distribution of A into the troposphere is completed. We assume that at the same time the vertical distribution is completed and thus : $4\pi R^2 H = v^2 t_2^2 H$, if R is the earth radius and H the height of the troposphere (figA8).

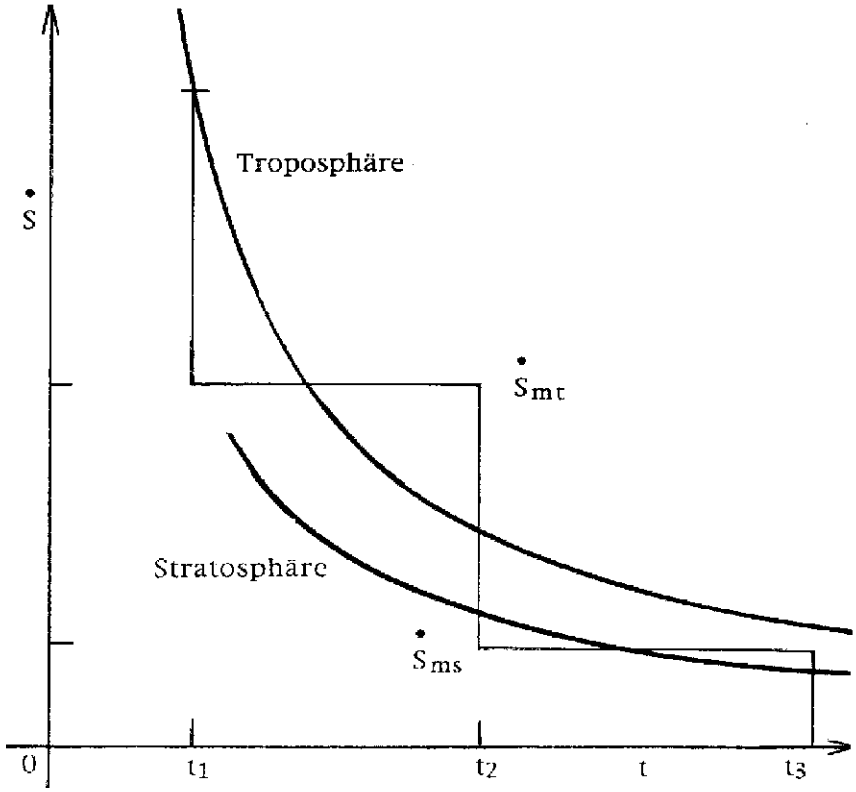

Fig A8. Time dependence of entropy production for mixing of gases in the atmosphere..

Similarly, the initial volume can be connected with the time t_1 : $V_1 = v^2 t_1^2 |D_i t_1$. Then, the average entropy production, i.e. the average $(dS/dt)_m$ over the whole process is :

$$\left(\frac{dS}{dt}\right)_m = \frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} \frac{dS}{dt} = \frac{5 n_i k}{2(t_2 - t_1)} \ln\left(\frac{t_2}{t_1}\right).$$

If, as assumed initially $t_1 << t_2$, because of 1 ♠ $\ln(t_2/t_1) << t_2 - t_1$, the shortened version of the last equation reads :

$$\left(\frac{dS}{dt}\right)_m \approx \frac{5}{2} \frac{k_B v n_i}{R\sqrt{4\pi}}$$

As expected, the average entropy production is proportional to the total amount of foreign material n_i and also to the average wind velocity v. Often, the distribution of foreign gases into the troposphere is followed by a diffusive distribution of the same material into the stratosphere. However, while we still have selfcleaning mechanisms in the troposphere (acid rain etc.), usually selfcleaning is absent in the stratosphere. Material, once injected there, will persist for a long time and with it eventual negative effects which are based on them (ozone-hole etc.).

We can write down the entropy production for injection into the strato-sphere in a similar fashion. Diffusion in three dimensions will give :

$$\frac{1}{c} = \frac{V(t)}{V_1} = \frac{[D_i t]^{3/2}}{V_1}$$

and thus :

$$\frac{dS}{dt} = \frac{3}{2} \frac{n_i k_B}{t}$$

The average entropy production now results from the integration between the times t_1' and t_2'. Because of the relatively fast distribution of material inside the troposphere we can set $t_1' = t_2$, i.e. the distribution of material into the stratosphere follows that into the troposphere. Then, $t_2' = t_3 >> t_2$ is the end of the diffusive distribution. The time t_3 we obtain as before from the vertical dimension of the stratosphere H_S using $4\pi R^2 H_S = (D_i t_3)^{3/2}$. Then:

$$\frac{dS}{dt} = \frac{3}{2} \frac{n_i k_B D_i}{\left[4\pi R^2 H_S\right]^{2/3}}$$

The distribution of foreign material into the stratosphere takes longer, but the material also stays longer, and thus might have an even stronger influence on the human population, in particular if the diffusion constants are small ; usually they are small with high molecular weight materials: FCKW's etc.) Fig A8 shows the development of dS/dt for both processes. If one is interested in the total entropy in a shorter time interval , one may intrgrate eq.'s a5,9 over that interval.

Distribution of foreign material into the seas

If we assume the oceans to be segregated into a layer structure, too, we have lateral surface currents and the silent deep sea Then we can estimate the pollution of the seas in a similar fashion: we again have to assume convection, turbulence and diffusion, but now in the waters. Vertical currents are supposed to be small again and the average wind velocity is replaced by the average water current velocity. As water is a solvent, the foreign substances are predominantly of another character, namely the ions of various salts. For the average entropy production in the surface waters we obtain:

$$\left(\frac{dS}{dt}\right)_m \approx \frac{5}{2}\frac{n_{ik}k_B v}{R\sqrt{4\pi}}$$

while for the deposition of chemical (and/or radioactive) waste in the deep seas we have :

$$\frac{dS}{dt} = \frac{3}{2}\frac{n_i k_B D_i}{\left[4\pi R^2 H_T\right]^{2/3}}$$

Similar to the atmospheric layering, H_T is the vertical dimension of the deep sea (Fig.A9). Reasoning as before tells us that waste deposited into the deep sea remains as a mortgage for future generations.

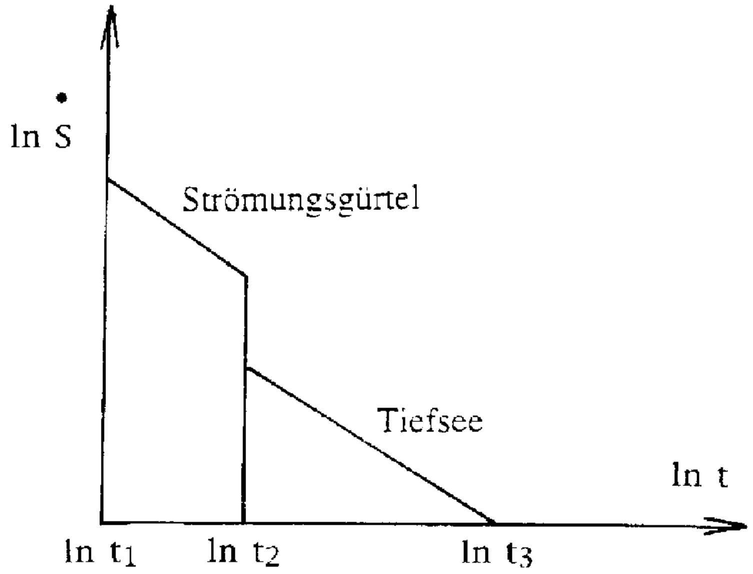

Fig A9. Time dependence of entropy production after dumpig a foreign substance at t1..

Asymptotic approach to absolute purity

If one envisions a completely pure material (B) to exist, i.e. an ideally segregated situation with $n_i = 0$, the concentration of a foreign material A in the matrix B is exactly zero, $c = n_i/N = 0$. Then both the mixing entropy S_m and its time derivative $\Delta S_m/\Delta t$ are zero, too, taking for granted that there was no interdiffusion during Δt.

If, alternatively, one approaches the ideally segregated case from a dilute mixture, one has as before:

$$dS_m/dt = (-n_i/c)(dc/dt)$$

As concentrated material will always diffuse away to some extent, the concentration change dc/dt will always be finite. Then we have dS/dt to go to infinity for c--> 0. Two different results for the entropy production in the segregated state are physically impossible. Diffusion will stop only at zero absolute temperature, however, that temperature can only be approached asymptotically - that is the third law of thermodynamics. Thus, diffusion can vanish only asymptotically, too. Obviously, the same is true for absolute purity; it also can be approached only asymptotically. That means, that the second choice , dS/dt--> ∞, is the correct one. If one again views dS/dt as a cost factor, that would mean that absolute purity cannot be paid and that the costs increase by a factor of ten with every added order of magnitude : using a percentage notation for c like 99.999% purity, with every added 9, the entropic cost increases tenfold.

By the same argument one cannot hope to avoid poisoning of a lifeform with time, as its life support and cleaning structures will get affected simultaneously.

Also, because of the relation of negative entropy and information, one can only asymptotically approach the mathematical identity of two objects.

Pollution by radioactive isotopes

In order to protect the biosphere from the hard radiation which is produced while burning nuclear fuel, we have to find efficient shielding techniques. Indeed, an increasingly thick reactor- or transporter wall weakens even hard radiation exponentially and thus a reduction of the radiation by up to 9 orders of magnitude is possible. Assume a wall extinction coefficient of $2m^{-1}$ (that would apply to 10 MeV γ-rays going through a water wall) and a reactor core of 2m in diameter, we would need a wall thickness w of about 10m. However, a leak of only 1 steradiant space angle would immediately increase the outside radiation by a factor of 10^4. Thus, when we use radioactive material, the leak probability is the determining risk factor and because of that we historically have a whealth of competing while statistically unproven scenarios by different analysts.

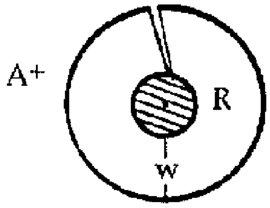

Fig A10. Radioactive Material in a protection container with crack.

While the probability of these scenarios would go to the weight (factor) of this kind of pollution, for a given leak one can calculate the entropy production : for that let us consider a simple but slow decay (decay time τ_1, activity A_1) of n_o nuclei which emit hard γ-radiation once they transform. Assuming a conversion factor of unity, we would then have a number n_1 of (other) activated atoms at the outer perimeter of the reactor wall. The decay time of this secondary decay (activated atoms) is τ_2 .Then,

$$n_1 = A_1\tau_2\exp(-\mu W) = a\,(\tau_2/\tau_1)n_o\exp(-t/\tau_1)$$

$$A_1 = (n_o/\tau_1)\exp(-t/\tau_1)\ \ ;\ \ a = \exp(-\mu W)$$

We assume further that the outside radioactivity is connected with the atmosphere because we have the isotopes as a gas (like radon) or because the isotopes use solid or liquid particles as a means of transportation. Then we would obtain as before :

$$S = n_1 k\ln(1/c)\quad \text{mit}\quad 1/c = N(t)/n_1$$

In this particular case the starting volume is equal to the reactor volume, but one cannot use $N/n_1 = V/V_1$ as before, as the number of activated atoms is now reduced exponentially with the time constant τ_2. If the original radioactive source is longlasting as compared to the outside activation, i.e. $\tau_2 \ll \tau_1$, the number of radioactive atoms which distribute in the (atmospheric) time interval $t_2 - t_1 \ll \tau_2$ is approximately $n_1 = a\tau_2 A_1 \exp(-t/\tau_2)$.

Here we have assumed in addition that the activation is even longer lasting as the atmospheric distribution (see for example Plutonium). Around $t - t_1 = 0$, however, one can use $N/V = n_1(0)/V1 = a\tau_2 A_1/V_1$, and then we find :

$$S = a\tau_2 A_1\exp(-t/\tau_2)\ln(1/c)\qquad 1/c = \exp(t/\tau_2)v^2t^2\sqrt{D}t/V_1$$

Eq. a17 shows that an additional dilution is obtained because of the decay of the activated atoms. As A_1 is practically constant during dilution, one obtains specifically :

$$dS/dt = a\tau_2 A_1 k(5/2t + 1/\tau_2) - (\ln(1/c) \exp(-t/\tau_2)/\tau_2)$$

Because of t2 > t2-t1 and because of the τ2 exponential decay, the second term is small and can be neglected. We find that compared to chemical pollution we have only a constant additional term to consider and that this term indeed accounts for the decay of the radioactivity while the distribution of the foreign atoms is going on :

$$dS/dt \approx a(\tau_2/\tau_1)n_o k \exp(-t/\tau_1) (5/2t + 1/\tau_2) ,$$

After the distribution is completed over the atmosphere, we can again write down the average entropy production :

$$(dS/dt)_m \approx a(\tau_2/\tau_1)n_o k \exp(-t/\tau_1) (5v/2R\sqrt{4\pi} + 1/\tau_2)$$

As we expect, this genetically destructive and thus dangerous entropy production is the higher, the more radioactive material we had to start with (n_1) and gets smaller if the screening (a) is improved. However, it is also smaller if the original nuclear material cools off faster and if the secondary, i.e. outside activation drops fast - i.e. one has to avoid isotopes with long decay times. Interestingly, according to eq. a20 the additional entropy production term is independent of the outside activation time constant, τ_2. This, however, is not fundamental but due to our approximations, whereby evidently the effects of a reduced activation and a consequently increased dilution cancel out.

In summary, one should avoid secondary activation as much as possible; in particular, the emission of radioactive material with long decay times has to be avoided. Eq. a 20 repeats also that dS/dt increases dramatically when a leak opens: n_1 jumps up and also $\tau_2 \dashrightarrow \tau_1$ in that case. If such radioactive species have escaped, one can only hope that the biological relevant particle currents stay below the danger values , i.e. about the size of the background radiation current of about $1/cm^2s$). Personal shielding and/or evacuation helps for a limited time period only.

Atmospheric pollution by stellar particles

A well-known example for a secondary activation which has always infiltrated the biosphere is the activation of ^{14}C in the outer atmosphere, better known for its use in the fossile age determination (radiocarbon method). Here, the activating radiation comes from outer space, so that the geometry is inverted as compared to the internal activation by reactor sites which were supposed to be evenly distributed on the earth's surface. However , the resulting entropy production has the same structure (eq.XXX). Here A_H is the total activity and the stratosphere is considered to be the screening wall.

$$^{14}(dS/dt)_m \approx a\, \tau_{14} A_H\, k\, (5v/2R\sqrt{4\pi} + 1/\tau_{14})$$

Here, A_H is the total secondary activity and the stratosphere is considered to be the screening wall.

The Meander Effect

Mineralized water (drinking water) flows into the sea and transforms to salt water as part of the water cycle.. After the rain, the salt content is practically zero but approaches the saturation concentration c_S close to the mouth of the river. For a given molar volume $V_S = n_S/c_S$ (n_S: mole fraction) the corresponding increase of the mixing entropy is :

$$-\Delta S = 0 - \left(-Nk_B c_S \ln c_S\right)$$

The specified volume appears at the shore after the time L/v_f has elapsed, with v_f the average river flow velocity and L the length of the river. The entropy production per molar volume then becomes :

$$\frac{\Delta S}{\Delta t} = n_S k_B \ln\left(\frac{1}{c_S}\right)\frac{v_F}{L}$$

Thus, in order to minimize the entropy production, the flow velocity has to be kept small and the river should be as long as possible - just like the river Meander. Straightening the river is only acceptable if reservoirs are introduced at the same time. When these reservoirs exist, the society values the corresponding entropy reduction positive, as a reservoir is also a storage of drinking water.

We are reminded that here we use a natural thermodynamic separator : the atmospheric processes, driven by the sun's radiation, provide a self cleaning mechanism for the salt water.

Entropy production-reduction caused by burning

If one burns one mole of methane CH_4 to give water (H_2O,liquid) and CO_2 (gas) and collects the reaction products in closed containers , in terms of entropy production one would only deal with the heat of reaction ΔQ_V, i.e. the entropy production would then be exclusively thermal: $dS/dt = \Delta Q_V/T_e\Delta t$ (Δt burning time), which then would be directly or indirectly (via a heat storage) exported into space. If one, however, lets the gaseous CO_2 escape into the atmosphere, not only one has to add the mixing entropy, but also a secondary entropy production, i.e. the reduction of the IR-emittivity of the earth. A reduced export, -(-dS/dt), is equivalent to an entropy production and as such constitutes an entropic "cost". In summary we have :

$$\frac{\Delta S}{\Delta t} = \frac{1}{\Delta t}\left(\frac{\Delta Q_V}{T_e} + \Delta S_m + \frac{dS_T}{dt}\Delta t_2\right)$$

where Δt_2 is the time interval during which the produced CO_2 stays in the atmosphere. Even if only that one mole stays in the atmosphere forever, Δt_2--> □, the total entropy production and with it the entropic cost would go to infinity. Therefore it is in the sense of entropy production minimalisation to better not to produce CO_2 at all, to bind CO_2 chemically (carbonates), or to avoid its escape by using containers. If none of these measures are taken, one has to build a thermodynamic separator which collects the CO_2 later. Of course, we would very much like to not bother with an additional technical separator, whose thermal entropy equivalent would be probably far above of the equivalents of the natural separators, mineralisation and tree planting.

Indeed, originally the reduction of CO_2 was done by the plants who were for a long time also mainly creating it, but within a regulatory cycle. However, this natural cycle is by far overstretched in capacity already today.

7.2.2 Mischungsentropie bei der Einführung von Grenzflächen

not yet translated

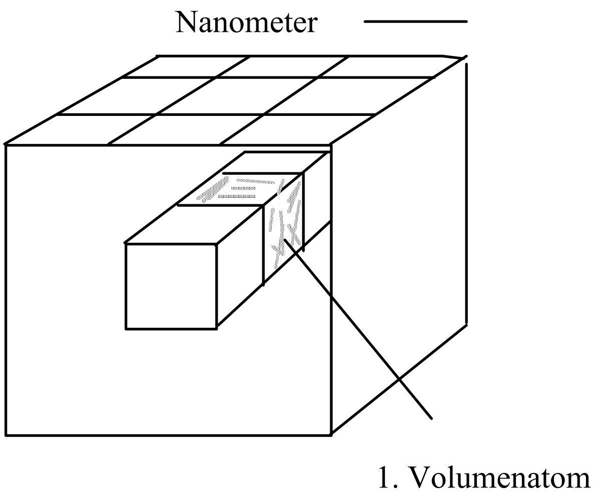

Fig. A11. A cube formed by 27 atoms contains only one volume atom.

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7.2.3 Thermodynamic separation- a thought experiment

Can we estimate the entropic cost for entropy reduction in general or do we have to treat every case differently ? In particular, we now try to find a base model for the mixing entropy production/reduction - like the Carnot cycle depicts one for the thermal entropy production/reduction. For that we construct a rather basic thermodynamic separator, consisting of a membrane , a solvent and a solute. For example, in a given volume $V= H_o^3$ of water, sugar and lipid molecules are initially distributed at random, i.e. we start with a high mixing entropy which we subsequently want to reduce. The lipid molecules are the ones who should eventually form a membrane, whereupon the volume is split in half, $V = 2V_1$. In a second step, we want to concentrate the sugar molecules in one of the halfs. Looking at the van't Hoff law, $pV = n_sRT$, (p: osmotic pressure, n_s molar fraction of the solute, R Gas constant), whose derivation is actually based on the concept of mixing entropy, we find that we need to do a mechanical work ΔpV_1 to concentrate, i.e. the volume V_1 is, for example, supposed to be pushed through the (as yet to be constructed) membrane, which in turn is supposed to let pass only the solvent (water) molecules. In the end, we would have achieved to concentrate the sugar solution. The volume V_1 can be set equal to the column of liquid which is lifted by half its height, H/2, in the inverse process, i.e. when we construct an osmotic cell. Such a cell may consist of a two curved communicating tubes separated by a semipermeable membrane (fig. A12).

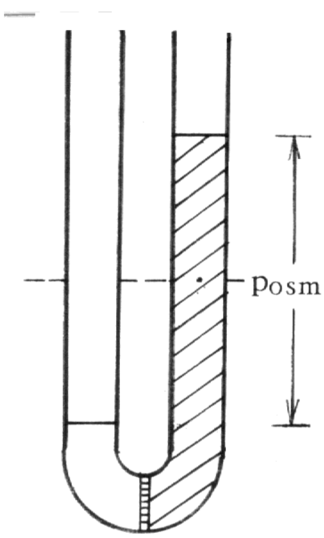

Fig A12. Osmotic pressure

In the beginning the tubes contain equal parts $V_O/2$ of liquid, one side containing the pure solvent and the other the sugar solution. Then, the solution wants to dilute itself further and thus the sovent (water) is pushed up on the solution side. The work then done is $mgH/2 = pV_O/2$ ($p = \rho gH$ is the hydrostatic pressure over the excess column). This neglects the fluid at the curved bottom. Setting the energy needed to push through a volume $V_O/2$ by applying a pressure difference Δp equal to p, we have an expression for the energy we need to concentrate the sugar. Moreover, from the distributed lipid molecules we have to construct the membrane. Since we want to use a flow of visible light from the sun with our (regenerative) separator, we could assume a light induced structural reconfiguration of the lipid molecule. For example, one that bends a former straight molecule in such a way that the bent molecules now tend to stack themselves to form a plane consisting of alternating up and downward pointed columns at certain nucleation sites (fig. A13).

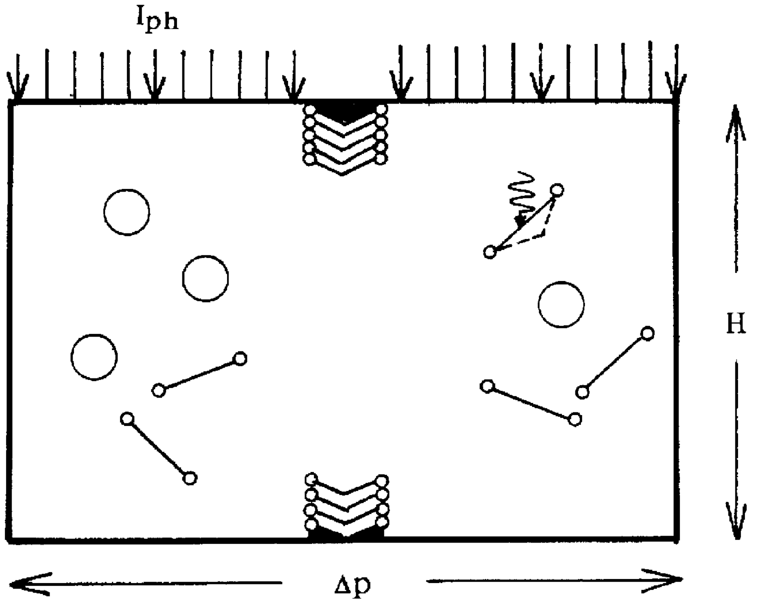

Fig A13. Formation of a membrane from lipid molecules.

If we have N_m lipid molecules in the total volume and if we let the light pass through the volume homogeneously, even with selective absorbtion we need a minimum of N_m light quanta (of energy $N_m hf$, h: Planck's constant, f: light frequency) to initialize the membrane construction. Then, equating the sum of the energies with the entropy term TΔS - entropy can only be reduced using an energy flow - we have :

$$T\Delta S = -pV/2 - N_m hf$$

As in a regenerative scenario the light comes from the sun of temperature T_S, as quantum energy one should use the radiation at the maximum intensity, $hf = 5kT_S$. Replacing the volume work pV/2 by $n_S RT$ and working the separator at the average earth's temperature $T = T_e$, we will have as (minimal) thermal entropy equivalent :

$$\Delta S = -n_S R/2 - 5 n_m R T_S/T_e$$

with n_S, n_m the molar fractions. In order to obtain an entropy production from that expression, we have to estimate the time needed for building up the membrane, Δt, and the time to build up the sugar concentration, Δt'. Both events rely on diffusion processes, but the enrichment of sugar can only happen after the membrane build-up. If we assume best conditions, i.e. selective nucleation of the membrane at preformed sites and that natural membrane structural defects constitute its semipermeability, at least the reconstructed lipid molecules would have to diffuse to the nucleation site. The corresponding time interval would be Δt

= H^2/D_m (D_m : diffusion constant of the modified lipid molecules), while the sugar molecules only have to diffuse through the finished membrane in the interval $\Delta t' = d^2/D$ (d: membrane thickness, D diffusion constant of water through the membrane). That would take less time, and thus $\Delta t' << \Delta t$., whereupon the longer time interval Δt practically determines both processes and we have :

$$- \Delta S/\Delta t = (RD_m n_s/H^2)(0.5 + (n_m/n_s)(5T_s/T_e))$$

The first term relates to the concentration of sugar, the second to the construction of the membrane. Which one is larger ? A first interesting result is obtained if one looks at the maximal possible suger concentration (saturation): let a solid sugar sphere be covered by a lipid membrane("bag of sugar"); then, from comparing the volumes, $n_m/n_s = 3d/r$, and one obtains for that particular (limiting) case :

$$-dS/dt = \text{const}\,(1 + (30d/r)(T_s/T_e))$$

Taking r as a biological cell radius and d as the membrane thickness, then ,as the membrane is part of the cell, at least d/r = 0.1, and the second term will be 60. That is large against the first term, 1. If the sugar gets diluted, the ratio n_m/n_s gets larger and the second term in the bracket increases further. The ratio increases as n_m can be considered a constant - one has to build only the one membrane - while n_s decreases with further dilution. Thus, the second term dominates more and more with increasing dilution. Since all life processes occur in watery solutions divided by membranes, this result is probably more general as suggested by our specific assumptions. Consequently, if one views the first term as representative for the metabolism and the second term for the selforganisation, we find that the organisation of lifeforms is more costly as their basic energy conversion (basic metabolic rate). The same result is obtained for technical structures : the entropic production costs of an appliance (per day) exceed by far its maintainance costs. Remembering the lifetime adaption rule, the ratio of the two terms would have to be close to the lifetime of the appliance in units of the production time interval. For human babys we have a factor of 50, dividing the carriage time by the average life expectancy. This factor usually increases with less complicated lifeforms and simple technology products.

7.2.4 Volume subdivision

Our thought experiment was designed in such a way that the magnitude of the initially used volume is arbitrary, i.e. the area of the membrane is supposed to be as large as designed and it is supposed to hold any concentration gradient. If, however, the useful membrane area is limited ($\approx L_{max}^2$) one would also have a maximum allowed volume $V = L_{max}^3$. Then, larger volumes would have to be divided into smaller volumes, say $V = mV_o$, and thus the whole process would have to be repeated m-fold. In the end , this yields a volume dependence for the entropy reduction, since :

a29. $$-dS/dt = -(V/V_o)(dS_o/dt)_o = m\,(dS_o/dt)_o$$

Here $(dS_o/dt)_o$ is the entropy production of the single unit. A similar result we obtain if there is a limiting workable concentration gradient, i.e. if $c_2 - c_1 = \Delta c =$ const. Here we would have to build a chain of concentration cells, whose single components would have to pump up the concentration to the saturation concentration using $m = (c_s - c_o)/\Delta c$ units, and then :

a30. $$-dS/dt = -\,(2V/V_o - 1)(dS_o/dt)_o = -\,(2m-1)(dS_o/dt)_o$$

Only because one has to deal with real membranes one obtains an explicit volume dependence for the reduction of the mixing entropy and that in turn delivers the important result that with increasing dilution of a substance its recovery gets increasingly costly. Restrictions of this kind are empirically well-known and statistically secured. The weaving defect probability increases with the total area of a rug; the same is true for solar collectors, electronic chips or telescope mirrors.

7.2.4 The limits of subdivision

We have seen that the separation usually involves volume separation via membranes, just as is found in biological structures. What, however, are the limits of volume separation ?

If we have a number w of stable configurations of an ensemble of say N objects, $S = k \ln w$ is the configurational entropy. In order to estimate the entropic costs connected with introducing internal an/or external surfaces, let us look at a simple cube made up of little cubes, each representing the space taken up by one ensemble member, say an atom. If there are N_e atoms on the cube edge, the number of configurations on the cube side is proportional to N_e^2, while the number of configurations within the whole cube is proportional to N_e^3. Thus, if the cube is large, $N_e >> 1$, the space related configurations are always more numerous as the planar configurations and thus the introduction of (internal) surfaces is rather harmless. If, however, the cube or particle becomes too small, the number of surface atoms can exceed the number of volume atoms. Actually, the first true volume atom appears if the edge holds 3 atoms (or molecules). In that case we have 27 atoms and 26 of them are surface atoms (fig. A12). With $N_e = 2$ we have only surface atoms left. As the dimension of the cube with $N_e = 3$ is about three times that of the individual element, for such a particle the critical dimension reaches into the nanometer range (10^{-9}m). Up to this critical dimension, say $d_c >$ 1nm, internal or external surfaces appear to be acceptable (see also nanotechnology). Biological cells and even cell kernels are indeed somewhat larger, about 10^{-6}m or 1micron. Interestingly, this value lies in the vicinity of the light optical resolution and obviously represents a more empirical critical dimension. Internal or external surfaces often hinder molecular interdiffusion and thus delay the production of secondary mixing entropies. On the other hand, a larger surface is more susceptible to chemical attack, i.e. corrosion. This practically gives a condition for nanotechnology : non-corrosive, i.e. biosphere compatible materials have to be used.

7.3 GLOBAL RADIATION EQUILIBRIUM

The global energy flow equilibrium is not concerned with inner frames. It considers only the final frame : the (prefossile) earth rotates and the on-radiated light energy (solar constant : 0.13 $Js^{-1}cm^{-2}$) is distributed more or less evenly onto the earth's surface (radiation heating). Because of the rotation of the earth we also have a periodical cooling off at night via infrared off-radiation (space cooling). On the average we obtain a surface temperature of about 15°C or 287 K. If the earth wouldn't rotate, life would probably be limited to the shadow border, as the illuminated areas would get too hot (desert belt) and the dark areas too cold (arctic region). Thus, only for a period of time longer than the day and night period one can talk about a radiation equilibrium. That is a stationary state which is not only in a minimum of entropy production, but the total entropy production also vanishes ($dS_T/dt = 0$): during the day the entropy is increased (radiation heating), and during the night (and day) the same amount of entropy is exported again (IR-cooling). Otherwise the average surface temperature would increase. Quantitatively, we have for the imported and exported entropy production :

$$\frac{\Delta S_d}{d} = \frac{S_0 \pi R_E^2}{2 T_0} = \frac{2\Delta Q}{T_{0d}} = \frac{2\Delta Q'}{T_{0d}} = S_{ir} 4\pi \frac{R_E^2}{T_0} = -\frac{\Delta S_n}{d} \quad ; To= Te \qquad (1G)$$

If one takes both the sun and the earth as blackbody radiators (Planck), the total emitted radiation energy per second and square centimeter J is given by the Boltzmann law : $J = \sigma T^4$.

This way, the surface temperature is related to the radiation of both bodies, but the space angle under which solar energy is taken up by the earth is only small : The earth as viewed from the sun. This angle is only a fraction of the full space angle 4π which can be utilized for the infrared emission from the earth. As the earth's average surface temperature T_e is a constant, the imported and exported energies ΔQ and ΔQ' have to be equal, too. Accordingly we have :

$$4\pi R_S^2 \frac{\Delta\Omega}{4\pi} \sigma T_S^4 = 4\pi R_E^2 \sigma T_E^4 \qquad (2G)$$

Thus, from astronomical data alone one can estimate the surface temperature of the (prefossile) earth using the geometrical relation :

$$\Delta\Omega/4\pi = \pi R_e^2/4\pi R_{se}^2$$

and then it follows:

$$T_e = \frac{T_S}{\sqrt{R_S / 2R_{SE}}} = 276K \qquad (3G)$$

$R_S = 0.7\ 10^6$ km: sun's radius, $R_{se} = 150\ 10^6$ km: (average) distance sun-earth, $T_S = 5714$ K : sun's surface temperature.

Using this relation between T_e and T_S, one obtains 276 K instead of 287 K. The difference has to do with the particulars of the off-and on-radiated surfaces and the earth's atmosphere (albedo, hothouse gases etc). However, using the same formula, one can also calculate the surface temperature of our neighbour planets*. Venus comes out to be too hot, $T_V = 370$K or +50°C, and Mars is too cold , $T_M = -54$°C. However, these two planets limit what is known as the stellar biosphere, i.e. the region of planet trajectories of potentially life bearing planets. Indeed, simple lifeforms exist on earth in up to 90°C hot wells*. On Mars on the other hand, CO_2 already freezes out (-79°C) close to the polar caps - thus forbidding a global CO_2-cycle, which is a basis of organic life all over our planet.

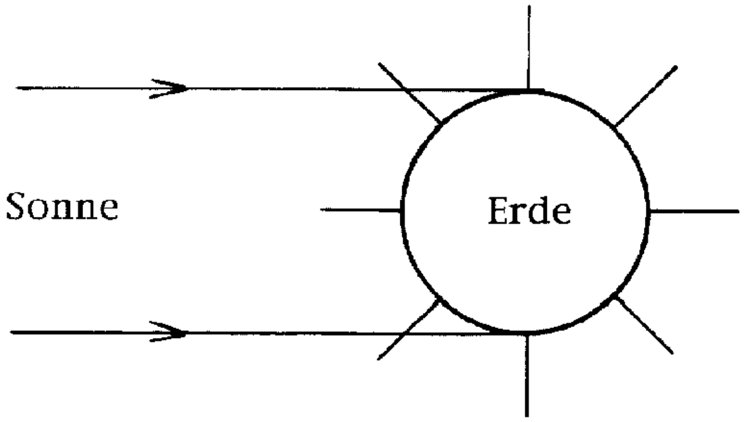

Fig. A15. Radiation equilibrium earth - sun

7.4 LOCAL HEAT STORAGE - LIGHT COLLECTOR

We have seen that the radiation equilibrium heats the earth up to an average temperature T_e. If we would shut off the solar radiation, the temperature would go down to absolute zero (0^oK), the temperature of stellar space. Thus , we can consider the earth a global heat storage at temperature $T_e > 0$. However, locally we can go above this temperature, by changing the absorption/emission properties of a local panel ("solar collector") , which is usually connected with a heat storage. Solar collectors should optimally convert sunlight into heat at high temperatures and this determines the design of the light collecting or off-radiating surface. When one constructs a solar collector one can first make use of the fact that the oncoming light is directed and in the visible spectral range, while constructing a radiator one has to keep in mind that the escaping light lies in the longer wavelength infrared region and off-radiates in all directions ("diffuse" radiation).

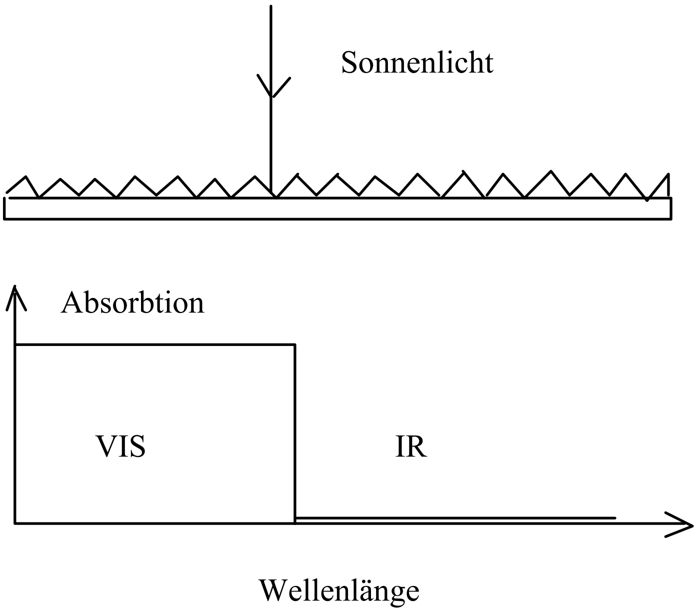

Fig. A15a. For optimized collector design, a surface with high absorption in the visible and low absorption in the infrared light spectrum is desireable.

In order to catch most of the visible light we should thus first construct a geometrical light trap, i.e. we implement a directed surface structure with a roughness larger than the visible light's wavelength and direct it towards the sun (fig.A17). When light quanta are reflected on a face of this structure, they have a good chance to fall on another face before they are reflected away and thus the chances that the light will get absorbed will increase.

If the light energy is converted almost in full to heat, no light comes back and the area appers dark even if the material used for the trap is not black at all. In order to further increase the conversion efficiency, in a second step we use a material with a high absorbtion in the visible and this way we come even more close to the optimum or "black" absorbtion. After all these measures are taken, the (entrance) valve for the impacting sunlight is now fully open. In contrast, as the visible light trap structure appears to be smooth for the higher wavelength off-radiated IR-light and as this emission is diffuse, we cannot geometrically trap the infrared light. The amount of diffuse off-radiation depends only on the IR-emissivity of the surface material. If, however, we would have a large specific absorbtion of the collector material also for IR-light, according to Kirchhoff's laws we would also have a large IR off-radiation and much of the collected heat would be lost again. In fact, the IR-valve, which should be closed in order to achieve a high collector temperature, would be open. The trick is now to choose a surface material which has a large specific absorbtion in the visible but a very small one in the IR -region. Then, the surface is practically "black" in the visible and "white" in the IR. Now we would have the input energy flow valve practically open, while the exit valve is practically closed, yielding a maximal collector temperature for further use. If our aim, however, would be to cool the local (or earth's) surface, we would have to use inverse property materials.

Before we connect the (up to 600°C) hot solar panel to a heat reservoir, we look at the properties of such reservoirs in more general terms.

As energy is conserved, the storage of heat can only mean that heat energy at higher temperature - which is higher valued entropically - is readily available in time and magnitude and after its use is turned into heat at a lower temperature which is valued less entropically.

In the language of entropy production energy storage and easy access means that a former entropy reduction is now - at use - turned into an entropy production. If, for example, light energy had been converted into chemical energy (fuel) at a time t_1, at that point in time the immediate conversion of light into (low temperature) heat had been avoided and that is equivalent to an entropy reduction or entropic gain.

Likewise the storage of heat at a higher temperature as T_e is an entropic gain. If, in particular, the conversion of high temperature into low temperature heat occurs at t_2 the "gain" received at t_1 is spent at time t_2. If one repeats this procedure, $t_2-t_1 = T_Z$ will be a cycle time between storage and use. Inside of this time interval the entropy is reduced as compared to an immediate conversion into heat at T_e.

7.5 NATURAL HEAT STORAGE

A "natural" heat storage shows no technical advances for light collection and thermal insulation and thus lacks efficiency. However, it already shows all the pertinent properties of a heat storage.

If a rock is heated by ΔQ by sunlight during the day, and then at night the heat ΔQ is released again, on the day and night average, the rock always has a higher temperature T_1 as the environment and thus acts as a natural heat storage with $T_1 > T_e$. At the same time the daily entropy production at this place has become smaller as $\Delta Q/T_1 d < \Delta Q/T_e d$. Again, energy storage and entropy reduction are related.

Storage of heat at a higher temperature in a volume V_1 can also be used to keep the temperature in another volume V_2 constant over the day and night cycle ("heat exchange"). Excavating the rock, defines the two volumina (cavity and solid rock shell). At daytime the cavity is cooler as the rock which has to heat up first. At night the temperature of the cavity is higher as the environmental temperature: while the rock releases heat in all directions, the outside air space is larger as that of the cavity and therefore stays at a lesser temperature. In both cases - rock with and without cavity- the entropy production/reduction is balanced over the full period $T_Z = d$ (see fig.A16).

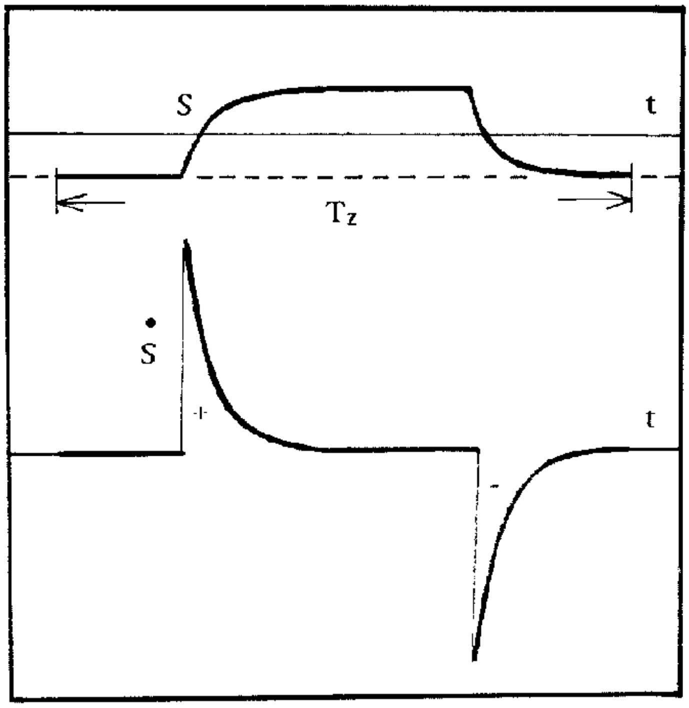

Fig A16. Charge and discharge of the heat storage

The entropy production itself can be written as:

$$\Delta S = \Delta Q/T_E dt = (mCp\ \Delta T)/(T_E \Delta t) = mCp\ (T-T_E)/(T_E \Delta t)$$

(c_p, m : specific heat capacity, mass of the material). Here we made use of the fact that for small temperature intervals $\Delta T << T_e$ the thermal entropy is proportional to the temperature. Expanding these considerations globally shows that an entropy balance is possible at average temperatures higher or lower than T_e (ice or desert ages) and that the called for constancy of T_e =300K is only a specific boundary condition for the human species as it has developed under just these conditions.

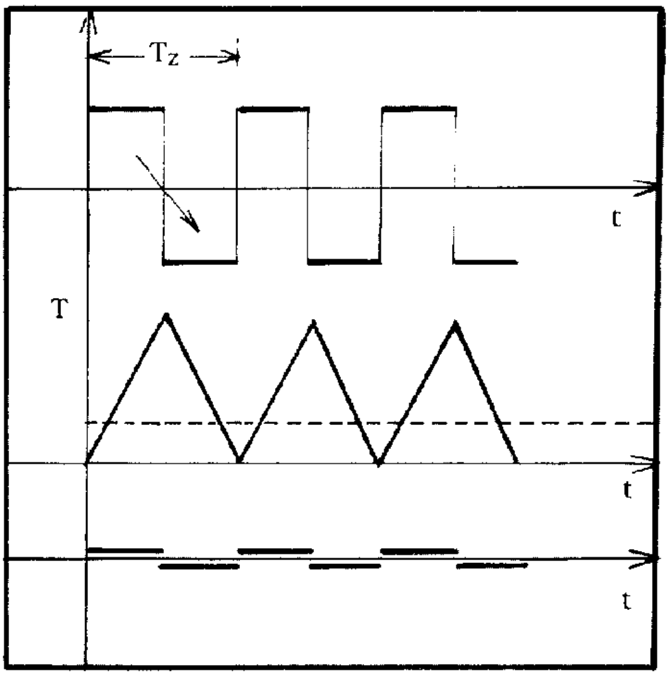

Fig. A17. Temperature of the environment, the heat storage, and the heat user in day&night cycle.

Constant temperatures in protected spaces in particular aids to uphold our life functions. The exchange of heat in the presence of a cavity is shown in fig. in an idealized way, i.e. without heat losses of the storage and without fig. A19 in an idealized way, i.e. without heat losses of the storage and without any delays in the heat exchange. As one can see just by taking the time derivative of the temperature, dT/dt - which is proportional to dS/dt, the entropy production is balanced not only in total in this case but also separately, i.e. for the user of the storage and the environment individually. All elements of the set-up thus appear to be in a stationary state over the cycle time T_Z. As with the harvest cycle, the consumption of stored energy is equally important as its storage. Moreover, one finds that intrusions into nature can be held harmless, but of course only over the full cycle time T_Z.

Immediate exchange of heat between two volumina as depicted in fig.A19 can be fulfilled only approximately because of the finite conduction of heat in all materials. How does the heat conduction modify the storage of heat problem ? As heat conduction itself is an irreversible process, it is connected with an entropy production of its own. Then, considering it together with the entropy change in the volume, for the first time we have to discuss two interrelated entropy sources .

Internal source heating

A first example of a lossy heat reservoir which considers two sources of entropy while being kept at a constant internal temperature T_S is the resistive (Joule) heating. In the (heat) flow equilibrium, the internal entropy production dS_i/dt is to be equal to the entropy export dS_e/dt, if there is to be a stationary state. We now consider in particular a current I_O through an electrical resistor R in a larger and only partially heat insulating box (fig.A18).

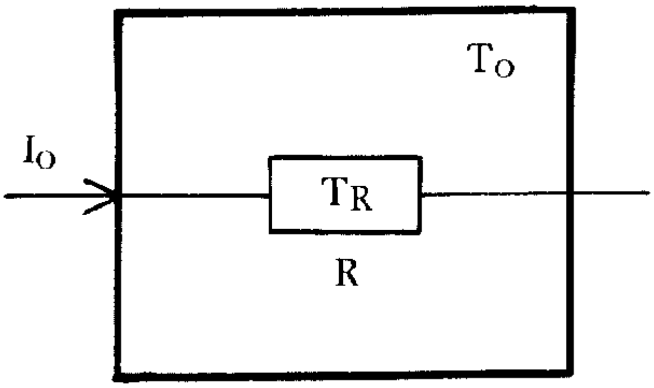

Fig. A18. Internal resistance heater

After a certain time a stationary state between the production of Joule heat P_O within the resistor, $dQ/dt = I_O^2R = P_O$ and the Newtonian cooling, $-dQ/dt = -a(T_S-T_O)$, of the resistor by the surrounding air in the box is installed (a: heat transfer number, T_S: resistor tempe-rature, T_O: air temperature in the box). Then, T_S is given by equating the heat currents dQ/dt or, alternatively, the entropy flows dS/dt. Taking the latter approach, we have to equate the internal entropy production of the resistor, $P_O/T_S = dS^i{}_1/dt$, and the entropy export, $dS_e/dt = a(T_S-T_O)/Ts$, and this yields :

$$P_O/T_S = a\ (T_S-T_O)/T_S = aX_S$$

If one now views the resistor plus box as the inner part of a stationary state (2), the entropy production in the box is the sum of the entropy production in the resistor volume, which drops with increasing resistor temperature, and the entropy production which is connected with the heat flow into the box, which increases with the resistor temperature. As the minimum principle should hold anyway, $d(dS^i{}_2/dt)/dX = 0$, now all parameters are fixed , and :

$$\Delta S_{2i}/\Delta t = P_O/T + a(T-T_O)/T = P_O(1-X)/T_O + aX \quad ; X = (T-T_O)/T$$

with $X = (T-T_o)/T$ the thermodynamic force. The partial differential being set zero now yields $(dS/dt)_{min} = P_o/T_o = a$ for all X. However, the stationary state force X_s was already given above: $X_s = P_o/aT_s$. Combining both results, we obtain $X_s = aT_o/aT_s = 1/2$ and thus, $T_s = 2T_o$, while $(dS^i{}_2/dt)_{min} = 2P_o/T_s$.

A balanced entropy export, i.e. a constant entropy and temperature inside the resistor, means for the larger system a minimum of the entropy production of double the entropy export out of the resistor. If the box were completely heat insulating, this entropy export would only be possible as long as $T_s > T_o$. If the export out of the larger frame is blocked, the temperature in the larger system increases and one would loose the flow equilibrium. $(dS^i{}_2/dt)_{min} = 2P_o/T_s$ now tells us in particular: the larger system (2) can be at constant internal entropy production > 0 and fixed temperatures only if there is another entropy export, but now through the outer wall. Using the same heat transfer number a : $dS^e{}_2/dt = 2dS^e{}_1/dt = 2a$, i.e. the temperature outside the outer wall has to be zero, so that the temperature cascade from resistor to the outside is : $2T_o$-T_o-0. A sequence of boundaries as assumed here is found elsewhere, too: one example : reactor cooling tower-atmosphere-space.

The energy flow has to be the same at all boundaries and equal to the innermost flow P_o; the larger entropy export out of system 2 is connected with the lowering of the temperature from T_s to T_o. This nesting of system spheres can be generalized and can also be applied to the mixing entropy.

Metabolism of warmblooded animals

Another application of these considerations is the prediction of the dependence of the basic metabolism of different mammals on their mass m or body volume V. $T_s = T_k = 37.5^oC$ is now their identical body internal temperature, $P_o \sim V$ now results from the conversion of chemicals (burning of food). The heat loss and with it the heat transfer number is proportional to the skin (fur) area A. Assuming further the same body density $\rho = m/V$, from $P_o = a(T_k-T_e) \sim A \sim V^{2/3}$, it follows that for mammals the basis metabolism is $P_o \sim m^{2/3}$. Large animals tend to deviate, which indicates that other entropy export means such as heat off-radiation become increasingly important (elephant ears etc.).

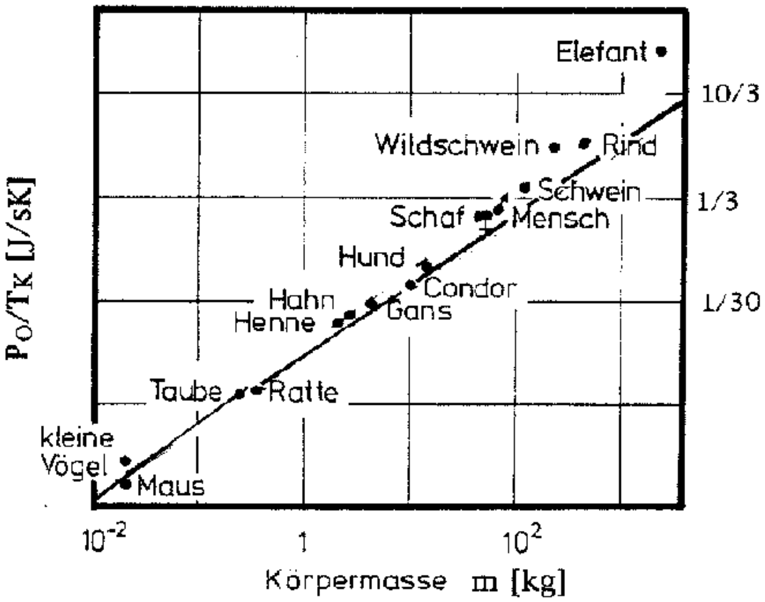

Fig. A19. "Idle" entropy production of different warm-blooded animals.

As in our calculation $(dS/dt)_{min}$ is constant for all X, probably in reality we have a very flat minimum (fig.A22) which is not revealed because we have considered Newtonian cooling alone. This indicates again that a second entropy flow has to be included, very likely the above mentioned heat off-radiation. Indeed, the resistor being at a higher temperature as its environment, it radiates off more IR- light quanta as it takes up from the environment. We can easily include this contribution, assuming a blackbody radiation. The light quanta current density in a given direction is $J = \sigma T^4$. As we consider small temperature differences only, we can use the differential $dJ = 4\sigma T^3 dT$. Interpreting this differential to be proportional to the actual current difference at a given surface A, the additional entropy reduction would be :

$$A dJ/T = 4\sigma A T^3 dT/T = ßX/(1-X)^3$$

Then, for the inner entropy production we obtain:

$$dS_{2i}/dt = Po(1-X)/To + aX + ßX/(1-X)^3$$

This dependence indeed yields a true minimum of dS/dt against the thermodynamic force X (fig. A22). From the non-symmetry of this minimum we also conclude that the parabolic representation of the minimum is a local approximation close to it (dashed line in fig.A20).

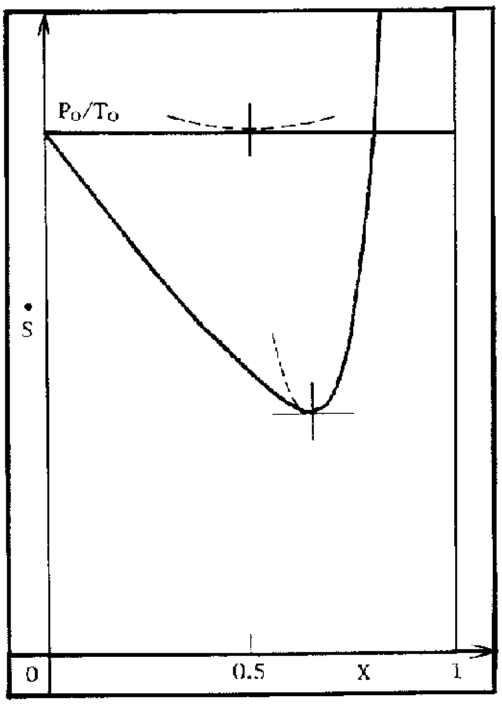

Fig A20. minimum of entropy production of a Joule-type resistor in a box with heat conduction and with resp. without (upper picture) off-radiation.

Bolometer

The Progogine theorem, in more general terms, reads $d(dS^i/dt)/dX = 0$, with X^i the various thermodynamic forces which can act on a system. In this context we cite a third example, the bolometer, usually applied to measure a light intensity. Here the production of heat in a resistor occurs by the on radiation of light. That changes the value of the resistance R somewhat. That change in resistance is now measured by applying an electrical voltage U to the resistor. The current I through the resistor, $I = U/R$, now produces a second (Joule) heat source, $P = I^2/R$. This heat should of course be kept low not to obscure the light intensity measurement. However, it adds to the entropy production and the first term of eq.a43 now reads :

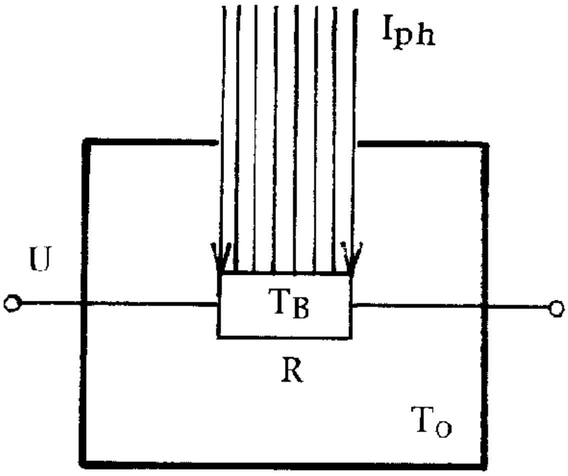

Fig A21. Bolometer.

$$P_o(1-X)/T_o = (AI_{ph} + U^2/R)(1-X)/T_o$$

The total entropy production now has its minimum at $U_s = 0 = X_s$ and depends on two thermodynamic forces U, X.

Thermal entropy - Interval method

Entropy balancing in a flow equilibrium is equivalent to the entropy minimalisation principle. Which concept to apply depends on the observation frame. That can be demonstrated through the introduction of inner boundaries at which the entropy is balanced individually.

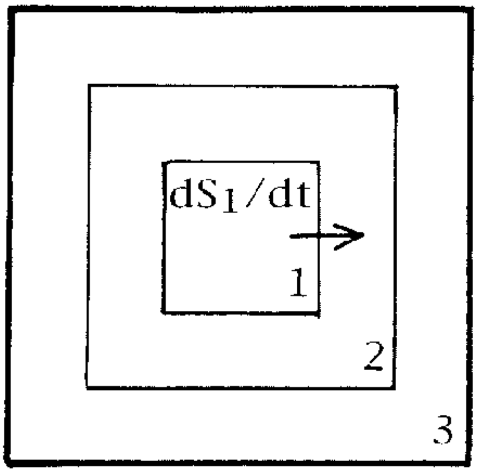

Bild A22. Einführung innerer Grenzflächen zur Entropiebilanzierung.

Formally, one can always approximate a minimum - here one of entropy production dS/dt versus an external thermodynamic force X -as a parabola. Using the shorter symbol y = dS/dt, we would have for the entropy production in a frame 1:

$$dS_1/dt = y - y_s = \gamma(X - X_s)^2 = \gamma(X^2+X_s^2) - 2\gamma XX_s = dS_{1i}/dt - dS_{1e}/dt$$

The entropy increase in frame 1 disappears at the minimum or flow equilibrium, i.e. at the thermodynamic force $X = X_s$. The two terms at the end of eq. a31 - the entropy production inside of frame 1 and the entropy export through the frame 1 boundary - balance; obviously they always represent two opposing effects, one which increases with X while the other decreases with X. If one now looks at an expanded frame 2 (fig.A24,A25), because of the inner entropy production now contains the entropy export of frame 1, one now has :

$$dS_{2i}/dt \geq dS_{1i}/dt + dS_{1e}/dt$$

Then, the entropy export out of frame 2 (at X=Xs) has to be at least double the entropy export out of frame 1:

$$(dS_{2e}/dt)_s \geq 4\gamma X_s^2 = 2(dS_{1e}/dt)_s$$

This is surprising, but only at first sight: in a flow equilibrium the energy flow $\Delta Q/\Delta t$ has to be constant, not the entropy flow. On the contrary, as the entropy export requires the same energy to be transported per time interval, but to a lower temperature site $T_2 < T_1$, $\Delta S = \Delta Q/T\Delta t$ has to increase. This is indeed shown in the heat storage examples below. The concept, however, is also applicable to the mixing entropy: just as the temperature is lowered in a cascade, so would be the concentration of a foreign substance, see for example the pollution frames troposphere/ stratosphere. In contrast to the IR-off radiation into space, however, here we have no final sink for the impurities. This calls for the use of thermodynamic separators. If we run them we can be sure that the heat equivalents also increase with increasing frames, i.e. towards the outer intervals.

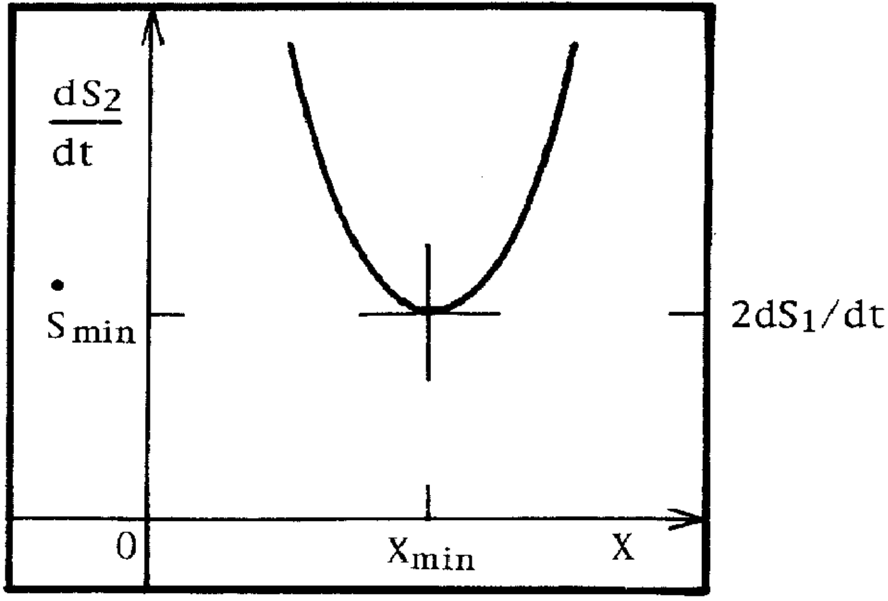

Fig A23. Standard parabel.

The nesting of intervals also allows for the inclusion of secondary entropy productions. For example, we can expect that always reaction chains exist - one example is the CO_2-problem in the troposphere - that reduces the heat transport out of the inner interval ocean, whereby the temperature of the inner frame must increase .

The strong stepping up of the entropy export while enlarging the volume of the frame is only acceptable if at the end it is possible to export into a volume that need not be viewed as an inner interval, i.e. space.

Lossy solar heat reservoir

What happens to the heat storage if we allow for a finite leak via heat conduction? For that, first we define the heat reservoir as a quadratic volume V_o = Ah, with one front (A_1) being an ideal absorber (ideal solar collector) and the backside being the only heat outflow (fig. A24). In particular, at A_1 not only we have a perfect conversion of the light energy into heat, but an immediate distribution of this heat into the volume V_o is also assumed (perfect heat pipe). The back plane being the only one to allow for an outflow of heat means that the other 4 sides are assumed to be completely heat insulating. That is why a wall thickness l_o is considered only at the back side. Because of the expected temperature differences, one of the thermodynamic forces is the relative temperature gradient X = dT/T with a corresponding flow. The heat current density is J_W = dQ/Adt (A : side area).

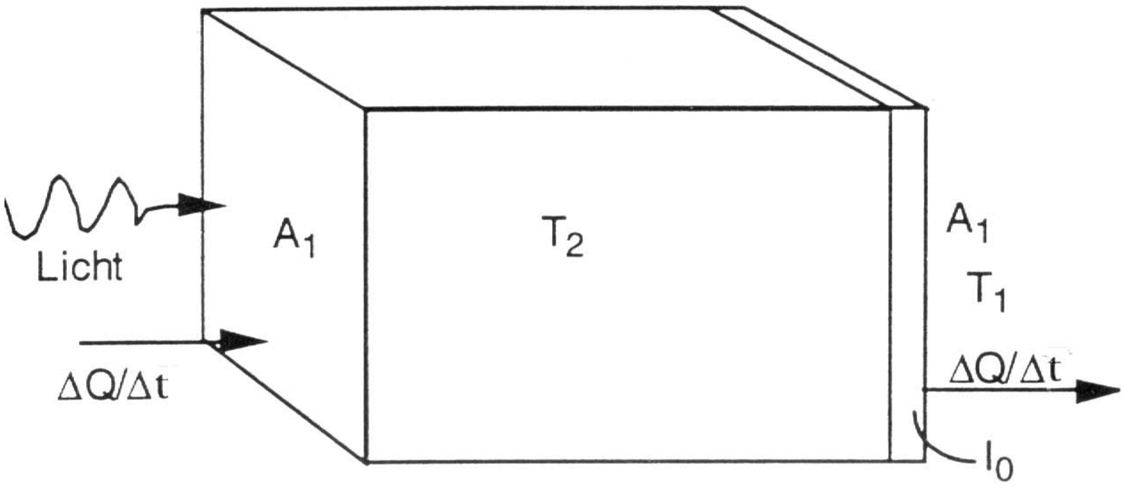

Bild A24. Heat reservoir

Because of the reservoir property, the heat flux dQ/dt through this structure id delayed in time. The heat conduction equation, now involves the particulars :

$$-\frac{\lambda}{l_0}(T_2 - T_1) = J_W = A\frac{dQ}{dt}$$

withT_2,T_1 the inner and the outer temperature. The entropy export comes put as:

$$a = \lambda \frac{A}{l_0} \qquad (4)$$

$$\Delta S\lambda/\Delta t = a \cdot \Delta T/T^* \text{ with } a = \lambda A/l_0$$

where $T^* = (T_1+T_2)/2$ is the average temperature and $\Delta T = T_2 - T_1$ the temperature difference. The combination of constants $a = \lambda A/l_0$ is a heat transfer number. It can be called also an exit valve setting parameter: a large (small) value of a means an open(closed) valve. Basically, if through heat loss, an amount -dQ of heat is extracted from the volume V_0 it has to be supplemented by the same amount +dQ through the front plane A_1, but at T_2. Heat transfer through A_1 in Δt, however, means an entropy flow dQ/T_2dt. Because of $T_2 = T_1 + \Delta T$, this contribution can be rewritten as :

$$dQ/T_2dt = (dQ/dtT^*)/(dT+T)/T^*).$$

If one now views T_1 as a (constant) environmental temperature and applies the minimum principle to this intermittend stationary state, one finds:

$$0 = \partial S^i/\partial X = \partial/\partial X\,[(\Delta Q/T^*\Delta t)/(\Delta T + T_1)/T^* + a\Delta T/T^*] \;\; ; X = \Delta T/T$$

Setting $T^* \approx$ constant - this selects low temperature heat reservoirs- we obtain as optimal storage temperature (T_{20}) and corresponding minimal entropy production:

$$T_{20} = [(\Delta Q/\Delta t)(T^*/a)]^{1/2}$$

$$(dS/dt)\text{min} = \Delta Q/(\Delta t T_{20}) + a(T_{20} - T_1)/T^* = 2[(\Delta Q/\Delta t)(a/T^*)]^{1/2}$$

$$aT_1/T^* > 0$$

As $T_{20} > T_1$, the minimal entropy production is always greater than zero. It exists, because two entropy productions compete: on the one hand the entropy production in the volume is reduced if ΔQ is added at a higher temperature T_2, on the other hand, the heat loss, i.e. the transformation to low temperature heat is increased when T_2 increases, which means that the diffusive entropy production is increased, too.

Because of the day and night temperature cycle, however, the heat transfer into and out of the storage is shifted in time. Thus, in order to go further one has to define a storage timed τ . If one introduces the ratio of heating period (sunshine time t_S) and storage time, $ß = t_S/\tau$, ß would be close to 1/2 over the full cycle for a sunny day. Then, the heat production is $dQ = S_oAt_S$ (S_o solar constant: $0.13 W/cm^2$) and the mean heat flow would be dQ/τ . If one equates that with the quasi-stationary heat flow dQ/dt as defined above, one finds :

$$\Delta Q/\Delta t = S_0 A t_S/\tau = S_0 A ß$$

In that scenario the optimal storage temperature comes out as :

$$T_{20} = (S_o l_o ß T_1/l)^{1/2}$$

and the entropy production minimum will be $(dS/dt)_{min} = 2A$ at $X_{min} = T_{20}- T_1/T^*$. As with a solar heat storage the solar constant S_o, the average environmental temperature $T_1 = 300K$ and ß are practically constant, in order to achieve a lowest minimum for a given area A, the value λ/l_o has to be minimized, i.e. the heat conductivity of the back panel should be small and the wall should be thick. These are indeed the usual heat confinement strategies.

This suggests that the minimalisation principle holds for intermittend stationary states and slow oscillatory processes, too. Moreover, this type of calculation sets the stage for a discussionof the heat exchange between two heat reservoirs. For that, fig.A27 shows the dS/dt-minima for different values of the parameter $ß\lambda/l_o$. While a good heat confinement increases the storage temperature, it simultaneously increases the (minimal) entropy production. A short heating time ß << 1/2, on the other hand, reduces both quantities (low temperature storage). If, however, one has to satisfy a certain heat energy consumption in that case, one has to open the exit valve and then the entropy production increases again. Fig.A27 and the equations a51 and a52 also suggest that there is also a relation between the minimum $(dS/dt)_{min}$ and the storage temprature or X_{min}, called "leading trajectory" in this context.

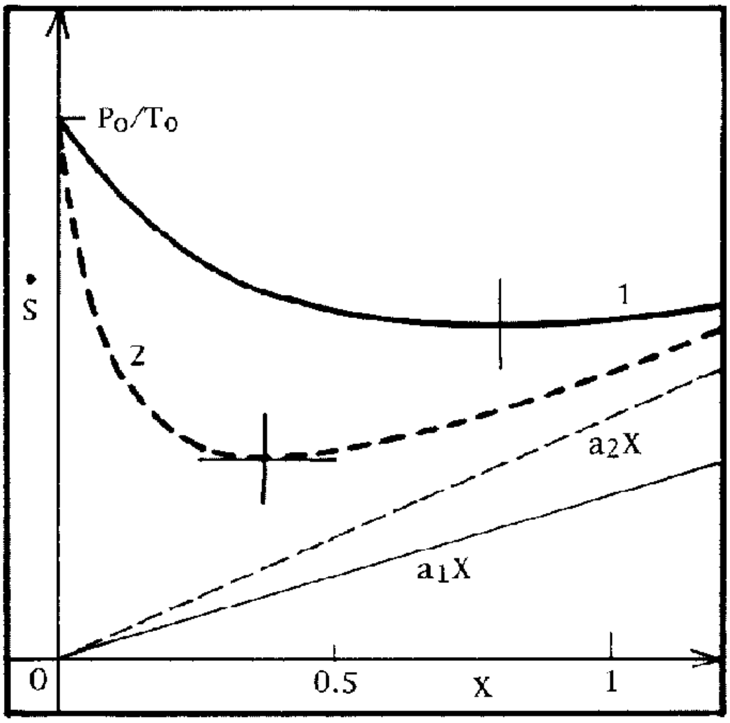

Fig A25. Minima of entropy production of two different heat reservoirs; $X = (T_2 - T_1)/T^*$ *thermodynamic force.*

Coupling of heat storage and user

The addition of a user to the storage can be treated as a partition of the stored heat onto two volumina, which are connected. in other words, we have two heat reservoirs at different temperatures which are coupled by a heat exchanger. In the end this analysis will lead to rules for the coupling of two local minima of the entropy production in general. In order to optimize the specific set-up we first try to determine the path of the minimum $(dS/dt)_{min}$ with X_{min}. For that we use eq. as derived above while allowing for a slowly varying energy loss Q'= dQ/dt. Indeed, because of the coupling element (heat exchanger) we can manipulate the heat flow out of the storage. Now the heat loss of the storage is intentionally variable because the heat exchanger can have a variable pumping rate. That also can be considered a thermodynamic force, but now acting between the two formerly independent reservoirs, i.e. X_{ij}. The former constant valve factor a = $A\lambda/l_o$ now represent the valve (and/or pump) settings. The heat loss of the storage then increases with a, to first order proportional Q' $\sim$ a , while the storage temperature would drop and thus be inversely proportional to a and therefore :

$$Q'/Q'_o = T_o/T_{sp} = a/a_o$$

Here T_o, Q_o' are the temperature and the heat loss of the closed high temperature storage and T_{sp}, Q' the corresponding values of the target storage (user). For X = 0, i.e. $T_{sp} = T_e$ in particular, only the first term of the equation remains, i.e. the entropy production is then $Q'a/a_oTe$ which is a constant in respect to the thermodynamic force X, but depends on the heat loss. Eq. can now be generalized to yield a "leading trajectory (LT)" : $(dS/dt)_{min}$ as function of X_{min} :

$$(dS/dt)_{min} \approx (Qo'a)/(a_oT_e) + aX_{min}$$

We have seen that the first term is the entropy production at X = O (user temperature) while the second term represents the heat flow out of the HT- storage. Now, the task is to operate the valves (and/or pump) so that user plus storage together have the lowest entropy production . For that, we propose the following construction Fig. A26 :

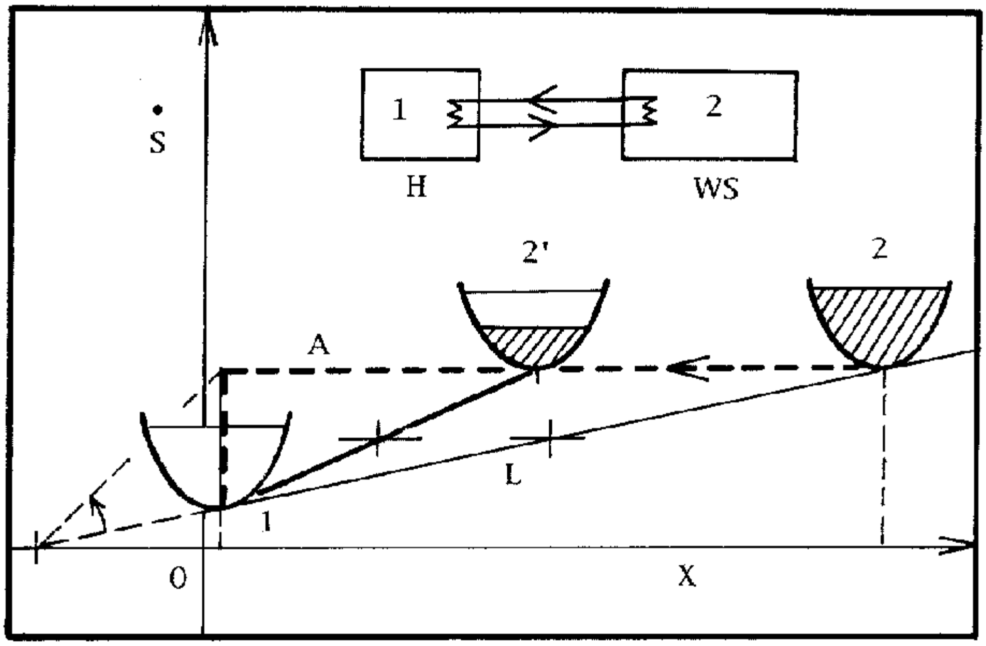

Fig. A26. Coupled system consisting of storage and user.

Storage 1 (user) should be insulating in the same quality as the source heat reservoir (storage 2); its minimum lies close to T_e , as it should average out fluctuations of the mean environmental temperature, i.e. it is also close to X = 0. As the insulation is the same, both minima are situated on the same leading trajectory. If one now wants to take heat out of the source reservoir, its exchange valve has to be opened. Then the valve factor a increases and with it the slope of the LT (see eq.). On the other hand we want the total (dS/dt)min as low as possible, i.e. we want to reduce it or at least to keep it constant. This limits the working range to the area between the dashed horizontal line and the original leading trajectory (LT). The displacement of the the storage 2 minimum(2->2') due to the heat loss also means a reduction of the average temperature of that storage. If one takes out hot fluid via the heat exchanger but wants to conserve the total particle number in the storage, a reduced temperature would mean that one has to replace the hot liquid volume by an equal amount of cold (T_e) liquid volume from storage 1, just as the word "heat exchanger" suggests. One property of this construction - the dS/dt-minimum staying constant- is that the average of the two S-minima of storage 1 and 2 always stays at the same level (crosses in the figure). At constant storage volume, the level stays at the center of the connecting LT; this is a kind of lever rule, which should also work with unequal volumina as long as the minima can be approximated by parabolae. Only when the heat transfer between storages 1 and 2 is finished, both storages collapse into the lower S-minimum because at this moment they are identical.

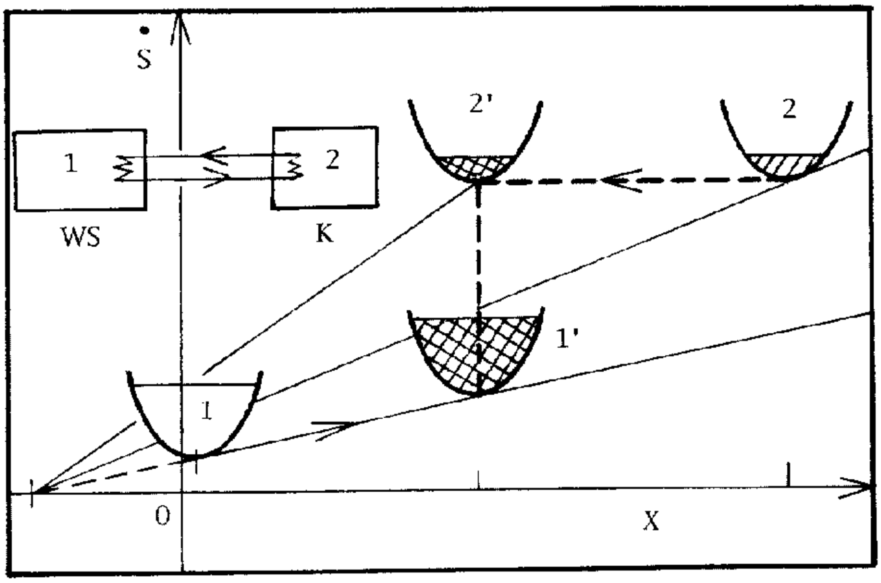

Fig. A27 Heating of the reservoir

If one wants to refill the source storage (now (1) in Fig XX) by, say a solar collector (2), which has a higher temperature but a lower working volume of liquid -it cannot be insulated as well as the target storage (now2)- one can design a similar construction. Heat is now taken from the collector (1-1') while the target storage slowly heats up (2-->2'), The target storage now moves up the leading trajectory while the collector follows the horizontal, as with the HT- storage discussed before. Heat transfer needs a tempe-rature gradient and thus will be impossible as soon as both storages reach the same temperature. As the solar collector has the lesser insulation, at this stage it should be disconnected (vertical dashed line). Now we have shown by example that the minimalisation principle can serve as a con-struction guide, but also a generalization suggests itself : a strong coupling of two formerly independent systems leads into a new joint mode of operation ("symbiotic mode"). Before the coupling, both storages were set to obtain the highest possible temperature and the best insulation, while now the entropic losses of the combined system during the heat exchange have to be kept as small as possible.

Changing the volume to surface ratio

We have seen that with lossy reservoirs the entropy production is proportional to the valve factor $a = A\lambda/l_0$. If we now consider heat storages which are heated by internal sources, such as the metabolism of warm-blooded animals, we can set the heat production proportional to their volume - large animals need proportionally more food- but their heat losses are proportional to their surface area. Then, simplified, we have the same heat production per unit (molecule) , $(dS/dt)_N$, for all such animals. If one now considers two differently large animals of the same kind, for example mother and child, they can reduce their joint heat loss (entropy production) by combining their surfaces (embracing). This strategy is often used in cold environmental conditions: an example involving a larger number of individuals is the beehive in winter: in the cold, first the bees choose a spherical form which has the smallest surface with a given volume. Second, the collective avoids a freezing off of the outer bees through a permanent exchange of bees from the inside to the outside. For an unequal pair this synentropic behaviour is shown in diagram A28.

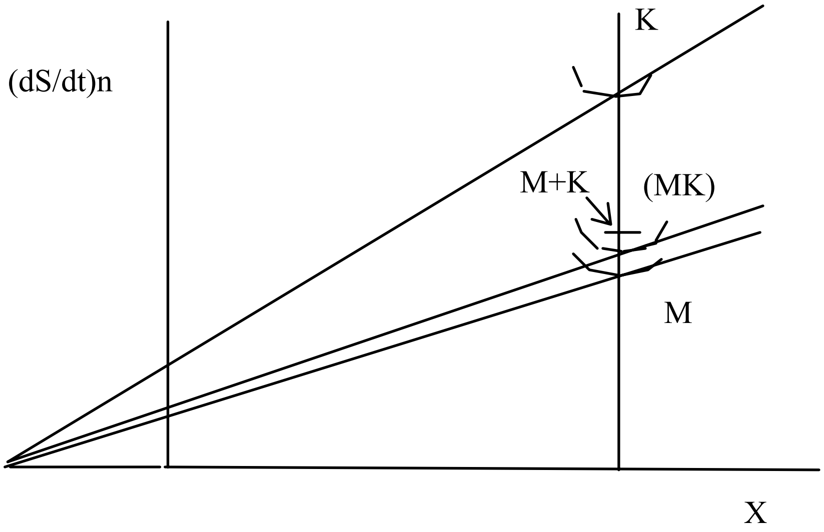

Fig. A28. Illustration of synentropic behaviour of mother and child.

The inner body temperature (T_{IB}=37,5^{o}C) is equal in all cases, i.e. at a given lower environmental temperature Te, all individual minima are at the same thermodynamic force X= (T_{IB}-T_e)/T_e. As argued above, the normalized entropy production $(dS/dt)_N$ is proportional to the ratio of area to volume, if heat conduction and insulation (clothing or fur) can be assumed to be equal. Then, through a reduction of the total surface at fixed total volume the total heat leak rate is reduced and with it the slope of the leading trajectory (LT). That is why the joint (synentropic) minimum MK falls below the average of the individual minima , M+K.

7.6 THE CARNOT CYCLE

The Carnot cycle consists of 4 steps. Two of those are taken while heat reservoirs T_1(hot) , T_3 (cold)are attached, while the other two take place whith no heat exchange allowed. The latter are thus steps under constant entropy or "adiabatic", while the former are under constant temperature or "isothermal'.The working medium is an ideal gas. Fig. a shows the cycle in a pressure-Volume (pV-) diagram, while Fig b shows the same cycle in an entropy-temperature (ST-) diagram.

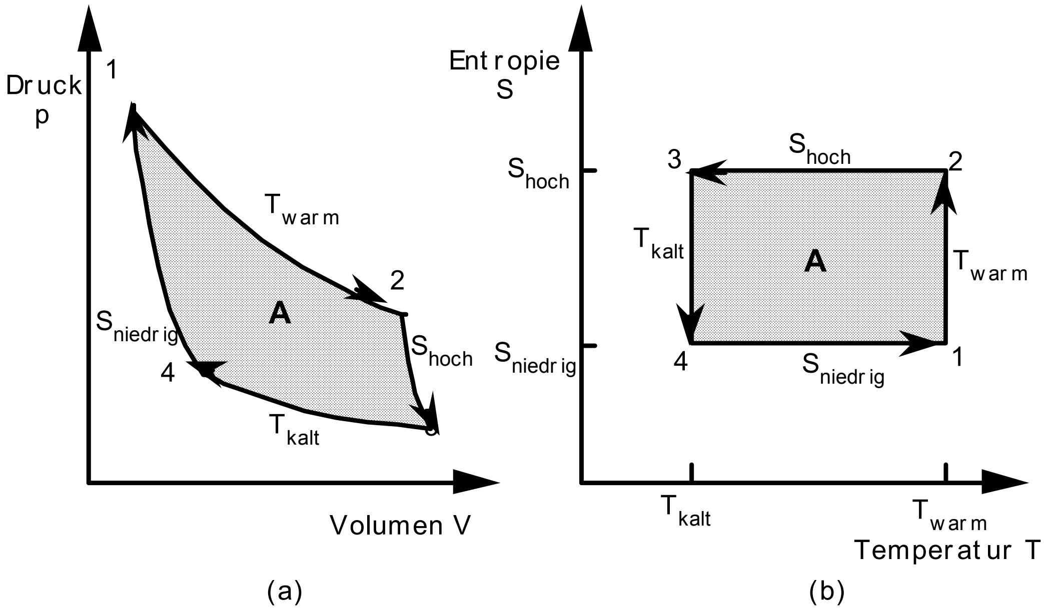

Fig. A29 Carnot Cycle.

Looking at the pV-diagram, one can envision a heat engine which uses a real gas as working medium. We start at point 1, at high pressure and temperature. The gas expands to a lower pressure and a larger volume up to point 2 while delivering mechanical work. Without a supply of (heat) energy the gas would cool off doing this. The energy (ΔQ_1)and with it the constant temperature during the expansion comes from the upper temperature reservoir. With the heat transfer, however, also the entropy rises - see cycle b. From point 2 on, the expansion continues but under constant entropy. i.e. without heat exchange with the outside. Thus, before one reaches point 3 the pressure is reduced further (and the volume is increased), while the temperature is now indeed reduced. As soon as the chosen lower temperature T_3 is reached, the gas is compressed again. For that, mechanical energy is needed and the gas would heat up unless a lower temperature reservoir takes up that extra heat (ΔQ_3), thus keeping the temperature constant. That means that heat is taken out of the cycle or in other words that entropy is exported to the cooling reservoir. During the last step 4-->1 the gas is compressed further but without heat exchange, i.e. at another constant entropy value. Accordingly, the gas heats up until we meet point 1. The mechanical work which comes out of the cycle during the adiabatic expansion is exact equal to that used for the adiabatic compression, as the internal energy of an ideal gas is constant on the same isotherm. Also, during path 1->2 exactly the same entropy is produced as it is exported along the path 3->4. Therefore the internal entropy is not increased over the full cycle, while the difference in heat energy $\Delta Q_1 - \Delta Q_3$ is converted into mechanical work A. The area which is enclosed by the cycle as sketched in Fig.s a,b is a measure of the mechanical work A gained during a period. This transformation of heat into mechanical work can be shown to be optimal, i.e. no engine can be constructed which transforms heat energy to 100% into mechanical energy. The optimal efficiency η depends on the temperature of the reservoirs, $\eta = 1-T_3/T_1$. The inverse process is easily done up to 100%, for example by using friction. The combustion engine process, on which our transportation depends upon to a large extent, can be depicted in similar diagrams. However, this process does not continually use the same working volume, but exchanges it with every cycle, while the upper heat reservoir is replaced by the chemical energy of the liquid fuel, while the lower heat reservoir is the environment. Thus, while the emitted heat finally gets exported into space, the chemical emissions (mostly CO_2) help to create a more serious problem (global warming).

7.7 IDEAL SOLAR CELL AS THERMODYNAMIC ENGINE

The characteristic of a photocell, i.e. the relation between source current and applied voltage can be written as

$$I = I_o(\exp(eU/kT_e)-1) - I_{ph}$$

U is the potential difference across the cell, I_o the sum of thermal generation currents of electrons and holes per cm^2 of the internal barrier layer, I_{ph} the photocurrent, directed in parallel with the barrier current I_o. The open circuit voltage U_l follows from that equation by setting $I = 0$, i.e.

$$U_L = (kT_e/e)\ln(I_{ph}/Io +1)$$

Let n_{ph} be the number of photons arriving per sec and cm^2; then, assuming a full quantum yield, i.e. the total conversion into electron-hole pairs, the short circuit current I_k (at $U = 0$) cannot exceed $I_{ph} = 2en_{ph} \geq I_k$.

Next, we consider a monochromatic beam of quantum energy hf which is supposed to be equal to the energy gap E_g of the cell material : E_g =hf. Then, for the efficiency of the solarcell, defined as the ratio of energies contained in the arriving photons and the supplied electrical energy, we find :

$$\eta < (U_L I_K/2)/n_{ph}hf = (kT_e/hf)\ln(I_{ph}/I_o + 1) ;$$

With symmetrical doping and equal (+-) carrier flows, i.e. the mobilities of electrons and holes are set equal $\mu_n = \mu_p$, and applying the mass action law : $np_n = n_i^2 = pn_p$ - the parameters with indices are the minority carrier concentrations , n_i the intrinsic carrier concentration - one finds :

$$I_o = e(n_p + p_n)v_D = 2en_i^2/n\ v_D = (2ev_D/n)n_o^2\exp(-E_g/kT_e) .$$

nV_D, n_pV_D etc. are the majority and minority carrier flows, e the elemen-tary charge and n_oV_D the intrinsic carrier flow for the case that the thermal energy were about equal to the gap value, $E_g \approx kT_e$. As the gap is usually much larger as the thermal energies, the concentration n_o is necessarily larger than the doping concentration n. The photon current can also be factorized: for higher quantum energies the black body frequency distribution can be reduced to an exponential (fig.). This gives :

$$I_{ph} = 2ean_{op}\exp(-hf/kT)$$

for the right hand side; here n_{op} is the photon flux close to the maximum of the solar radiation $hf_{max} = 5kT_S$. The loss factor a is conveniently set to unity, that means an optimal absorbtion and no recombination losses. As $I_{ph} >> I_o$, the unity term can be neglected. Then, observing E_g = hf, the efficiency is :

$$\eta < T_e(1/T_e - 1/T_S) + (kT_e/E_g)\ln(n\cdot n_{op}/v_D n_o^2)$$

The calculation is valid only as long as the space charge barrier is not flooded by the photogenerated carriers, that is at $n_{op} \approx nV_D$. However, as

$n \le n_i(T_e)$, the second term then automatically goes to -1 and with it the efficiency vanishes $\eta \rightarrow 0$.

Otherwise, the ratio under the logarithm is always < 1. However, it is possible to keep this term small and negative; for that a high doping n=p and a high photon flux are necessary. In fact, only close to the maximum of the spectral distribution (i.e. green) the optimal conditions can be met, although we already have an energy density increase by c/V_D: photons arrive at light velocity while electrons(holes) flow off with the drift velocity V_D, the reaction hf--> e+h itself being fast. Overall, the highest possible efficiency is :

$$\eta < 1 - T_e / T_S < 1$$

i.e. even with the best possible conditions the right hand side of this inequality never exceeds the thermodynamic optimum (Carnot cycle). The calculation also shows, that by using the solar energy one runs a thermodynamic cycle, where the cold reservoir is the earth (T_e) and the hot reservoir is the sun(T_S).

For the other regions of the solar spectrum the conversion is less advan-tageous, as one works outside the optimum.

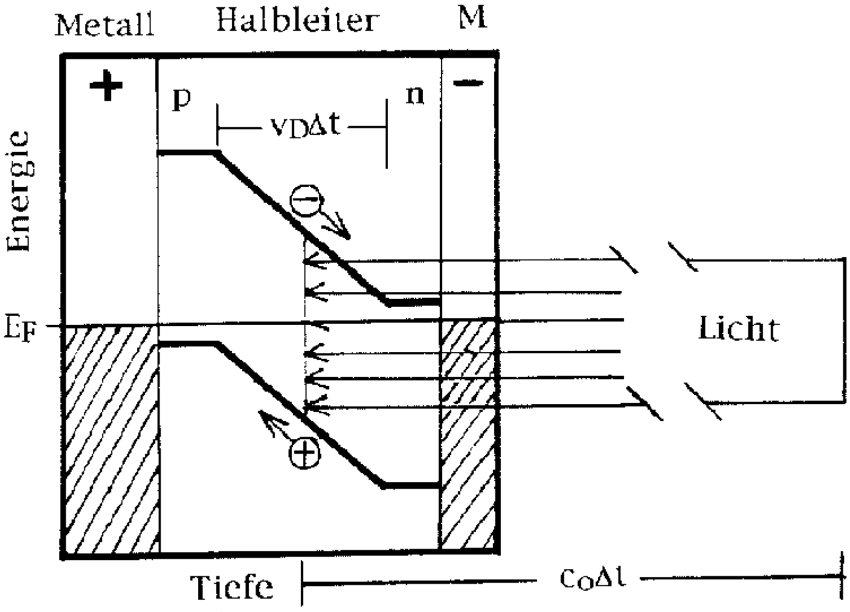

Fig A28. Energy distribution in the solar cell.

For the electronic optimization alone one would need a spectrum of energy gaps matching the solar spectral distribution plus a space charge barrier for each interval. If we use a single gap solar cell instead, one can expect an efficiency reduction . First, we replace the solar radiation by a spectrally homogeneous source of width f_1-f_2, with the frquencies set to match the atmospheric spectral window. That reduces the radiation density by about 1/2. Even for a polychromic array this would already reduce the efficiency from 95% ($T_S = 5800^oK$, $T_e = 300K$) to 95/2= 48%. Second, one may view the single gap cell as a highpass converter, as quantum energies higher than the gap value can yield an e-h pair, while lower values do not. This reduces the efficiency by another factor of 1/2, i.e. 24%.

Because of conversion and recombination losses even that value cannot be reached. The highest efficiencies reported go up to 20%.

Todays solar cells are designed for electrical energy production and distribution. However, uses similar to photosynthesis, in particular of carbohydrates production might be even more promising.

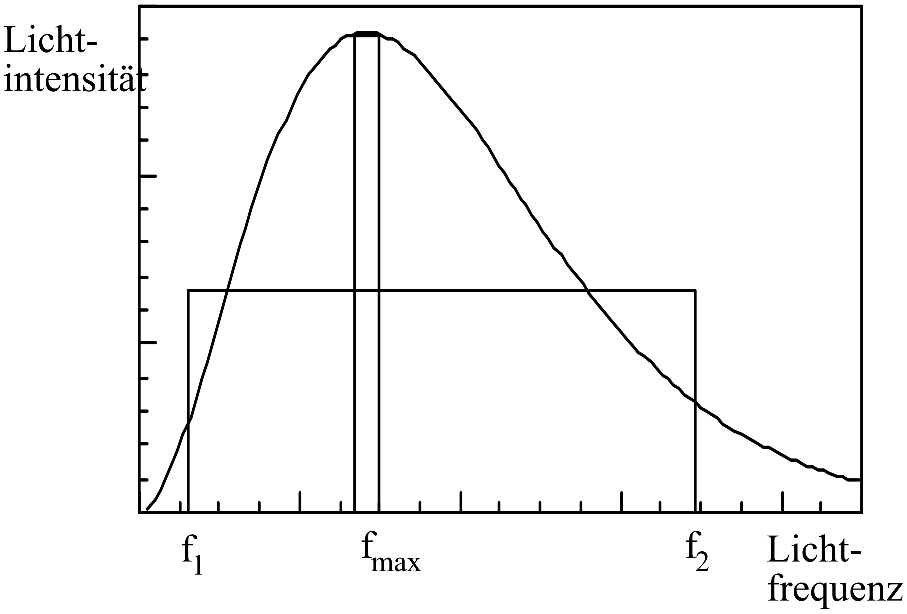

Fig A29. Reduction of the solar spectrum.

7.8 DARKENING OF THE IR-OFFRADIATION

Hothouse gases increasingly convert the earth into a global heat reservoir as they block the IR-offradiation, in other words the entropy export. We can estimate the total temperature increase based on the using up of the fossile resources. For that, first we estimate the yearly reduction of the entropy export caused by 1 l of CO_2 ($\approx 10^{-21}$% of the atmospheric volume). For simplicity we assume an IR-transparency factor of zero for CO_2, i.e. total blocking. Then we have $dS/dt = 10^{-22} \cdot 5 \cdot 10^{15}$ kWh/aK $= 5 \cdot 10^{-7}$ u, using todays yearly entropy export. If the worlds population $= 6 \cdot 10^9$ people produce 10 l CO_2 daily, we arrive at $2 \cdot 10^{16}$ l CO_2 per year, which yields 10^{10} u, i.e. a reduction of $\Delta S/S = 10^{-5}$. The entropy export, however, can be increased again by increasing the (average) earth's surface temperature by ΔT_e. The yearly ("per annum" a = 1 year) entropy export $\sigma T^4/aT$ of a black body radiator changes by $3\Delta T/T$. Setting this equal to 10^{-5}, at $T_e = 300K$ the yearly increase of T_e is 10^{-3}K. Now we assume that it takes 100 years to eliminate the extra CO_2 from the atmosphere due to chemical processes (mineralisation etc). Then, the temperature rises by 10^{-1} K per year. Doubling the population in 30 years, the temperature increase will be 1^oC by the year 2100. According to analyst it takes about an added 6^oC to melt the polar caps and in its wake flooding, atmospheric turbulence, but also dry periods and deforestation would occur.

The main point in the estimate was the almost permanent stay of CO_2 in the atmosphere. If one would have efficient CO_2 -reductors, that hothouse gas would not incresingly block the entropy export and an entropy balance could be reached. That's a general rule ; every kind of pollution which is not reduced, develops large problems over the time factor. Thus, even if one rearranges the estimates to a more optimistic outlook, in the end a change of thinking towards pollution is required.

7.9 POPULATION GROWTH AND FEEDBACK LOOPS

During long and quiet times the population growth follows a geometrical series, but will always be accompanied by regulatory mechanisms, which determine the number of individuals in shorter periods of time based on specific temporal and local external circumstances. These regulatory mechanism or feedback loops are for example visible through prey-predator oscillations.

As the name suggests, in a feedback - loop a quantity Q which is supposed to be held constant follows a circle. The property Q can be quite different, for example the body temperature, the muscle tension or the number of individuals in a restricted territory. In the schematic which shows that loop (fig. A30), we also find an external variable which influences the loop, the socalled "target" value. With the body temperature regulation this target value 37.5 ^oC, rests in the genetic code. The target value can also be slowly shifting - slow in comparison with the cycle time of the information flow.

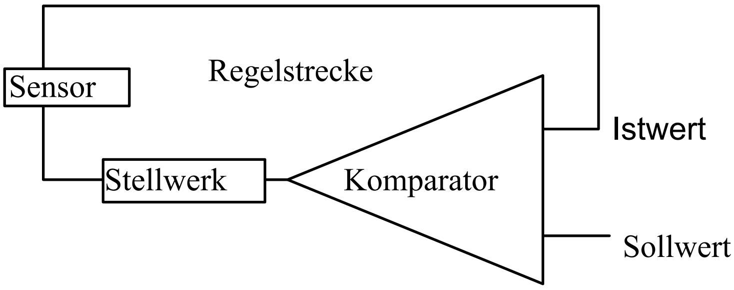

Fig A30. A simple Feedback-Loop.

Aside from these target values, the loop contains activators (steering appliances or organs) which can step up or down the to be regulated quantity Q and others, which measure Q (sensors). If one considers not an individual, but a group, these activators are certain group specific institutions.

After each cycle Q is measured and compared with the target value . While with an individual the target value is in general genetically fixed, with a population external conditions like the food supply is often the target value; that can shift with new methods or territories. However, under a feedback loop the target value can be approached only asymptotically or in a damped oscillatory fashion because of the lag between steering and measuring. A damped oscillatory approach which is close to the ideal (asymptotic) limit is shown in fig. A31.

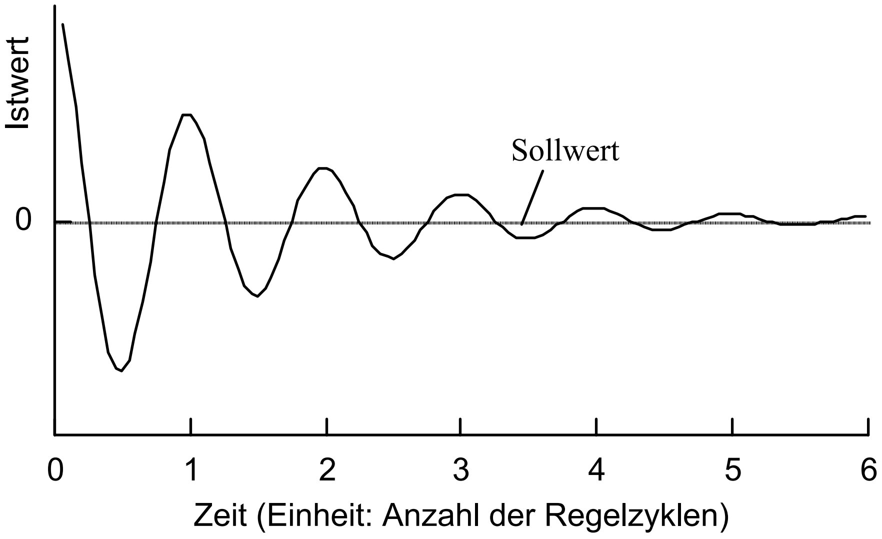

Fig. A31. Decreasing Oscillation; this could represent the sustainable stabilisation of the population.

This oscillation also shows that the loop is active and that the momentary value can approach the target value in a so called initial oscillatory move. This initial oscillation reveals the two important parameters of the loop, (1) the period $T = 2\pi/\omega$ (ω : loop characteristic frequency) and the decay time τ of the exponential envelope of the decreasing oscillation maximal amplitude. The period T is practically the time needed for an information to go around the loop, while the decay time is a measure of the reaction time of the steering unit. One might argue that for the best function these two times should be equal. That is correct but for a factor: the condition for the aperiodical limit (best case) is $\omega\tau = 1$. If the reaction is passed quickly enough but with a wrong sign, a reaction occurs to a false statement, the momentary" value oscillates between the physical limits of the steering unit with the period T- that is equivalent to a phase shift of 180° for a simple oscillation feedback-loop , this is also called "positive" feedback.

One that basis we now investigate a simple population dynamics. Slow growth (+) and decay(-) of a population follows an exponential, at least at the larger numbers which concern us here :

$$\text{(w1)} \qquad N = N_o \exp \pm|g|t$$

the parameter g_o is here the growth (+) or decay(-) rate, respectively. The initial value has to be between 2 and 14 individuals, according to estimates for a minimal stable start population **. A maximal population N_{max} is assumed to be given by the resource density of a certain territory. Assume that N_{max} is reached after a time t_o (end of the growth period . In order to keep the population stable at N_{max} for larger times $t > t_o$ one would have to formally set the generation rate to zero ($g=0$). That would be a mathematical and certainly a non-biological step, as it does not account for the finite lifetime of the individuals. A given population would react far more complex: not only to the birth&death cycle but also to internal group structures with their sensoric and dynamic characteristics. Thus, it is better to assume the generation rate itself to be a (damped oscillatory) function; that would be equivalent to assume a feedback-loop for the genberation rate g itself:

$$g = g_o + g_o' \exp(-t'/\tau) \cos(\omega t')$$

Here, $t'=0$ is the beginning of the steady state era and g_o' an initial response amplitude, ω the internal frequency of this feedback system and τ its damping constant . In the regime of growth, when a disturbance (natural catastrophy , war etc.) occurs one should also use g instead of g_o.

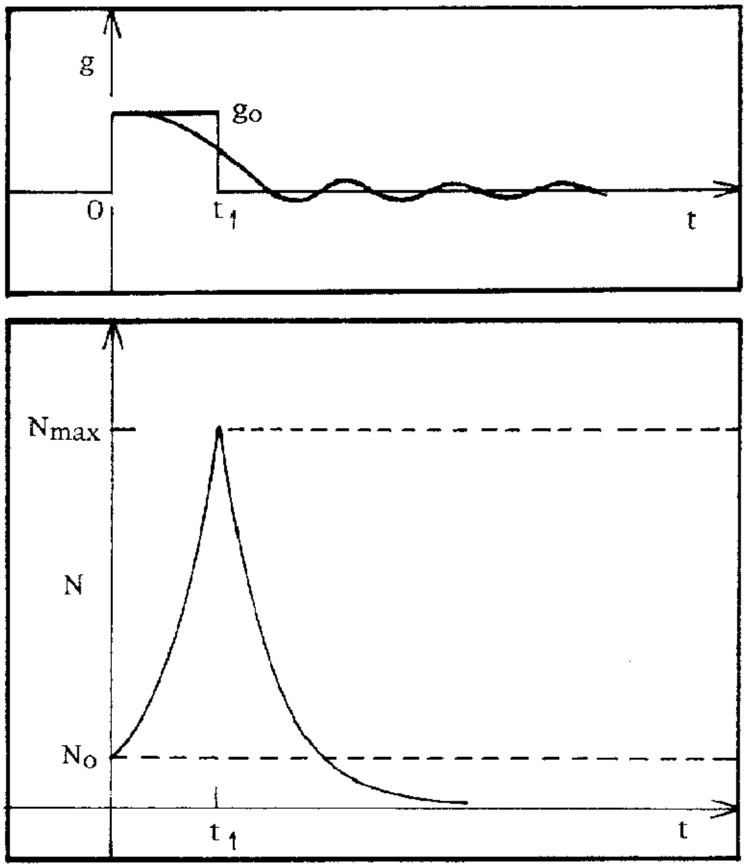

Fig. A32. above: Continous and disrupted generation rate. Below: Catastrophic behaviour of population after uncontrolled growth beyond the limit.

If one discusses an indisturbed growth , $g = g_o$, the end of the growth phase in itself is a disturbance (end time shock) and without the inner feedback-loop g would drop to zero in a short time, just as at the beginning of the growth g went from zero to g_o. As the sign of the slope is different to first order we can assume the same solution (exponential) but with a sign change in the exponent (decay function):

$$N = N_{max} \exp -g_o t'$$

The disturbance at the end of the growth period is by definition of long duration and will be answered by a decay function. Even if we have an oscillatory generation rate N(t) can falls below the starting number No and a population catastrophy can occur, i.e. the species would become extinct. Indeed, if one numerically sets the initial value of the cosine 1 and the damping small, the largest negative value of the g-oscillation occurs at $t_1' = T/2$; at that time $\cos\omega t1' = -1$. If at that time the critical population N_o is reached we have as "apocalyse" condition :

$$T/2 = t_1'(N_o) \leq t_o$$

Using $g_o = g_o'$, we can transform that into :

$$G_0 t_0 = \ln(N_{max}/N_0) \geq g_0'(T/2) \quad \text{or} \quad 2f \, . \, t_0 \geq 1$$

If we originally had a feedback-loop designed to even out short term population distrubances under $\tau = 1/2\pi f$, then this loop is necessarily fast against the total growth period : $\tau << t_o$, and then the apocalyse condition is almost naturally fulfilled. That means that the regulatory means in growth regimes are designed too fast to be suited for a growth society to transform into a stationary society. Obviously, for this we have to invent a new feedback-loop with a period close to the growth period, i.e. $2\pi\tau_s = t_1$, just as drawn in the figure A . That in turn means the installation of longterm intelligent behaviour and social structures which reach far beyond a single generation. Such institutions we do not have today; however, they will eventually be installed together with globalisation in the future.

For the stationary regime we now find another solution :

$$N = N_{max} \exp \{g_o' \exp(-t'/\tau_s) \cos(\omega t')\} \; t' \approx \; N_{max} \exp (ß\cos\omega t')$$

This approximation (fig.xx) holds in the regime $0 < t' < 2\tau s$ as $\tau' \exp(-t/\tau s)$ runs over a maximum at t_s. Interestingly, for large times this solution would go over to a constant population value N = const., which would again be non-biological. Even a so-called stationary population obviously has to undergo real or fictuous disruptions, i.e. pioneer or doomsday moods, in order to remain stable. These disruptions can and should, however, remain moderate, i.e. they need not explode into an apocalyptic or "lemming" jump. Condition w4 tells us also that in order to avoid population catastrophies, the reduction of the reproduction rate must be comparable with the groth period t_o, i.e. the time which under normal conditions is needed to reach the maximum population. A global regulatory mechanism, created artificially or evolutionary could always be tuned accordingly.

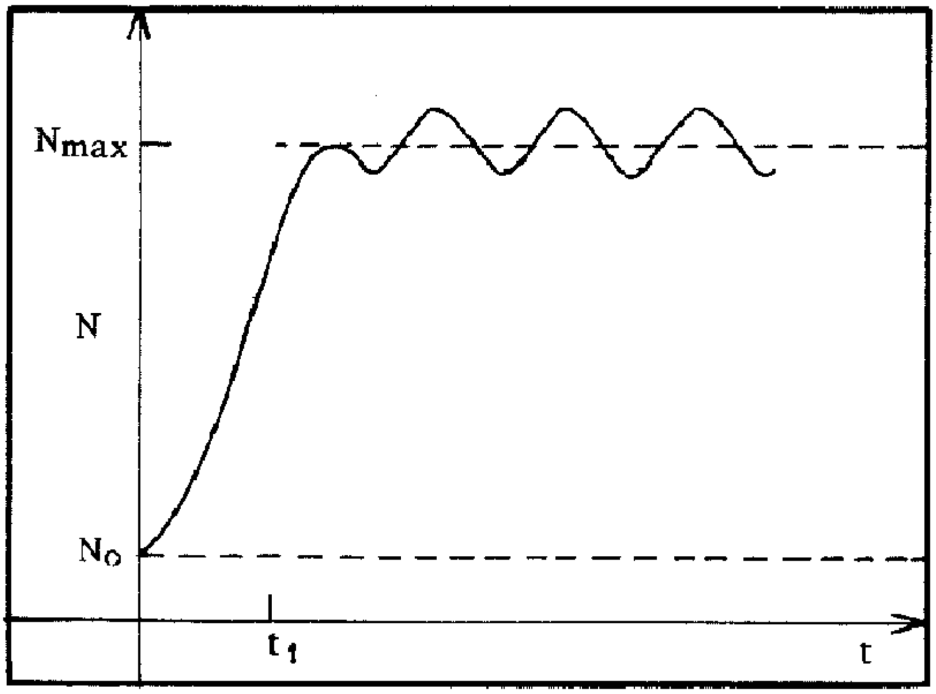

Fig. A33. Growth with controlled approach to the stable society

The validity of the apocalyse condition is not necessarily restricted to the drop-off in the growth rate. If there is no feedback-loop , i.e. if it is too slow or damaged, the damped oscillation of g can be viewed as an externally induced fluctuiation of g. Then τ is the decay time of this disturbance and ω and g_0' are the frequency and amplitude of its strongest (Fourier-) component.

Examples for that are the global nuclear holocaust or a cosmic collision. Clearly in those cases eq.w4 will be fulfilled: in the first case a longlasting fallout goes together with a steep drop in the reproduction rate, directly through the damage of the genetic material and indirectly through the reduction of the food basis. In the second case a longlasting dust cloud would damage the food basis and the environmental conditions quickly and lasting. Recently, global warming has been discussed along these lines. Longlasting climatic turbulences are thought to result in storms and flooding on the one hand and increasing of the desert areas on the other. Again the food basis gets hurt. Other kinds of longlasting pollution of the atmosphere and the waters, which are also connected with the population increase, would reduce the reproduction rate. However, selfpoisoning of a species is hardly seen in nature, species competition poisoning yes: snake and herbal poisons, insecticides etc. The mutation rate is generally too small to help adapt to the fast environmental changes which are seen today. Also , the mutation rate becomes pointless as soon as the population gets too small. Cloning or genetic manipulation would also not help with these kind of problems as nature does not care which species survives to crowd the earth..

7.10 ENTROPY AND INFORMATION

If one takes two different elements, say the binary number basis 0,1 , white and black balls or even more abstract pairs like yin and yen, one can construct an exponentially growing sequence of combinations (fig.A34). Each column is created through a decision for the one or other element, but under conservation of the prior decisions that were undertaken on this particular path. If one knows all decisions which have led to a particular combination, one has the "full information". The combinations missing in fig A34 are obtained if one starts with the black ball. If one thinks in terms of yin and yen, i.e. if one decides for good or bad, in each column the lowest combination shown describes the relapsed evil-doer, while the uppermost combination describes the always upright citizen - an information a detective would like to have.

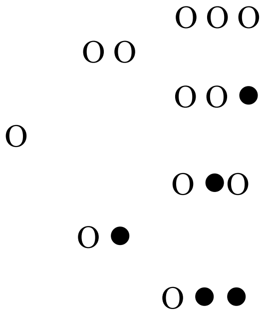

Fig. 34. Decision tree for binary systems; e.g. black and white balls.

The number of combinations after n columns n is $w = 2^n$. The first decision is the unit of information , $\log 2^1 = 1$bit. Consequently any larger information is , $\log 2^n = n$ bit = I , i.e. the information I can be numerically taken as $I = 2\log w$, similar to $S = -k\ln w$. As logarithm of different base can be converted into each other, entropy reduction $-dS/dt$ and information flow dI/dt (channel- or Baudrate) are proportional. A weighted entropy reduction, however, corresponds to the weighing of an information (survival or pleasure related, see Ch.III).

7.11 DISTRIBUTION OF THE ENTROPY PRODUCTION WITH COUPLED CYCLES

If we write down a weighted sum of individual entropy productions $dS/dt = \Sigma g_i dS_i/dt$ we have in mind a comprehensive evaluation of a number of independent activities. That is a rather rare case, as most human actions are interrelated. This raises the question of how to proceed if we have interdependent activities. If, for example, a technical product consists of different parts, who is responsible for the different entropy productions connected with the build-up of the product, the consumer, the producer of the final product or the producer(s) of the parts?

A similar question can be asked if we add a new individual to a group of species: who is accountable for the entropy production which is connected with the new individual, say a young frog. Himself,his parents or the stork, whose prey he eventually will be ? If one holds everybody in the chain totally accountable, dS/dt is counted too often.

Apparently one deals here with a matrix $g_{ik}dS_i/dt$, whose diagonal elements $g_{ii}dS_i/dt$ represent the selfcosts and whose non-diagonal elements represent the to be shared costs.

In order to look into the case more closer, we write down the simplest possible (two column-) matrix and try to match it to a pair of interrelated activities, for example a (single) part producer and an assembling-only endproducer, i.e. a brick and wall situation.

We desribe the individual entropy sources as a vector (a_1, a_2) with $a_1 = dS_1/dt$ the entropy production during the assembly and a_2 = dS2/dt the entropy production while making the part. Additional costs come from the transport and the raw materials, i.e. the final entropic costs, derscribed by the vector (b_1,b_2) are higher; the individual assignments are :

$$b_1 = g_{11}dS_1/dt + g_{12}\, dS_2/dt \quad \text{, the end producer}$$

$$b_2 = g_{21}dS_1/dt + g_{22}\, dS_2/dt \quad \text{, the part supplier}$$

Immediately one recognizes $g_{11}dS_1/dt$ as the running costs of the end producer and $g_{12}dS_2/dt$ as half of the transport (and material) costs, as only the running costs should be assigned directly to each partner. The other half of the transport costs should be assigned to the part producer, while the making of the part are his running costs. Who is responsible for the material ? In the existent economy it is the supplier, but in our scheme the responsibility for the material might as well be shared between the two.The relation of this matrix to the conventional accounting is also interesting. Today it is possible to order a service to cover the transport (and material) costs, instead to "do it yourself". On the other hand, each company can set up its own accounting, which virtually assumes an independence. That apparent conflict is resolved by a currency existing. In our construction this would be pictured as follows: If the non-diagonal elements of the matrix are equal, the matrix is called symmetric $g_{ik} = g_{ki}$. In that case one can transform a given matrix into another one with only the diagonal occupied with non-zero elements("trace").

Then we see only "internal" costs and an accounting can be made. Obviously it is the invention of money which makes that transformation possible in real life.

Usually there is a long chain of interdependent part producers (or lifeforms), consistent with the (closed) production-reduction scheme

raw material → production → lifetime → reduction → redistribution →

In such a chain, if we share both the transport and material costs, they would reduce to 1/n per partner, so that in the view of each individual company they get less and less important. If, however, the above cycle is broken, the reduction costs, for example remain with the last member, which is usually the consumer. Sometimes the disposal costs are too high, for example when we have a poisonous product. Then we find "midnight waste disposal". Here, the final responsibility for the reduction is delegated to a "spurious" company where one or more individuals simply commit a "criminal" act. In order to avoid midnight waste disposal, two steps have to be taken (1) the material reduction costs should be shared and not travel with the product, (2) the reduction chain should be completed so that the product cycle can finally be closed.

8. References

1 „Introduction to Thermodynamics of Irreversible Processes“. I. Prigogine, Interscience Publishers, New York, Third Edition (-> S=Min)

2 „The medium is the massage“ Marshall McLuhan, Q. Fiore 1984 (→ arms)

3 „The global village“ Marshall McLuhan, B.R. Powers 1995 (→ cities/villages)

4 „The Limits to Growth“ (Club of Rome), Dennis L. Meadows, Universe Books, New York 1972 (→ Population growth)

5 „Faktor 4 „ Ulrich v. Weiszäcker (in german; → change of production)

6 „Die Tücken der Technik - wenn Fortschritt sich rächt“ Eduard Tenner, S. Fischer Verlag 19.. Originaltitel (?) „Nature strikes back“ (-> Sekundärentropieproduktion)

7 „Design for Destiny“ (Global Thinking) Ervin Laszlo, Harper&Row, New York 1988 (-> S=Min, Energiewende)

8“The Law and the Profits“ C. Northcote Parkinson 1960, Penguin Books Ltd.Harmondsworth (→ criticizes law of economy)

9 „Energieversorgung“. Grathwohl. Walter de Gruyter, Berlin, N.Y. 1978 (german; → Distribution of entropy sources)

10 „Applied Solar Energy“. Meinel, M.P. Meinel Addison/Wesley, London 1979 (→ artificial photosynthesis)

11 „Synergetics“. Haken H., Teubner, Stuttgart 1973

11* „Thermal Physics“. Ch. Kittel J. Wiley 1969 (→ e.g. carnot cycle)

12 „Hydrogen in Metals I,II“ Topics in Applied Physics 29, G. Alefeld, J.Völkl, Ed.´s Springer Berlin , N.Y. 1978 (→ artificial photosynthesis)

13 „Wasserstoff als Energieträger“, C.J. Winter, J.Nitsch , Ed.´s Springer, Berlin N.Y. 1989 (German; → artificial photosynthesis)

14 „Kontrollierte Kernfusion“. J. Reader , Teubner Studienbücher 1981 (→ another sun?)

15 „Solar Energy Conversion“. Ed. B.O. Seraphin, Topics in Applied Physics 31, Springer , Berlin , N.Y. 1979, (→ artificial photosynthesis)

16 „Solarzellen“. Juster. Taylor&Francis 1981, (german; → artificial photosynthesis)

17 „Energie“. Fricke, W.L.Borst, R. Oldenbourg, München/Wien 1989 (german; distribution of entropy sources)

18 Informationswerk Sonnenenergie I-III Udo Pfriemer Verlag 1976,1977 (→ artificial photosynthesis)

19 „Wunschenergie Sonne“. Stoy. Energie-Verlag 1978 (→ artificial photosynthesis)

20 „Heizen mit Umgebungsenergie“. Paulisch&Reichel , Deutscher Consulting Verlag 1980 (german; → regenerative technology)

21 „Grundlagen der Thermodynamik Irreversibler Prozesse, de Groot“. P. Mazur , Teubner- Taschenbücher, (german; → S= Min)

22 „Heterojunctions and Metal-Semiconductor Junctions“ .Milnes, D.L. Feucht .. (→ artificial photosynthesis)

23 „Fuel Cells“ J.H. Hirschenhofer, D.B. Stauffer, R.R. Engleman Gilbert/Commonwealth Inc. Reading, PA 1994 (→ artificial photosynthesis)

24 „Grundlagen der Regelungstechnik“ G. Schmidt, Springer, Berlin, N.Y. 1984 (→ feedback loops)

25 „Fordern statt Verwöhnen“. Cube, D. Alshent. Serie Piper 949 (german; economy critics)

26 „Ökologie“. Hermann Remmert. Springer, Heidelberg 1978. (german; growth and economy critics)

27 „Grundlagen der allgemeinen Ökologie“. Bogdan Stugren Gustav Fischer, Jena, 1974 (german; → feedback loops; economy critics)

28 „Ökologie“. Hartmut Bick. Gustav Fischer Verlag, Stuttgart 1989 (→ growth, economy critics)

29 „Biologie der Populationen“. MacArthur,Cornell , BVL-Verlag München (→ growth)

30 „Ökologie der Tiere, Demökologie“. Fritz Schwerdtfeger, Verlag Paul Parey, Hamburg 1968 (→ growth; economy citics)

31 „Die Globalisierungsfalle“. H.P. Martin, H. Schumann. Rowohlt Hamburg. ISBN 3498043811 (→ economy critics)

32 „Parkinson‘s Law“ C. Northcote Parkinson, Penguin Books (→ economy critics)

33 „Und es ward Licht“ Rudolf Thiel, Rowohlt Verlag, Hamburg1956 (astronomic data)

34 „Die Ordnung des Lebendigen „ Rupert Riedl , Serie Piper, München 1990 ISNB 3-492-11018-5

35 „Bumblebee economics“ .....(→ new economic model)

36 „Biographie“ Henry Ford (-> fit of life cycle)

37 „Bionik - von der Natur lernen“ Hans Marguerre. Siemens AG, München 1991 (→ bionic; solving technical problems by analysing nature)

38 „Metabolism in hyperthermophilic microorganisms“. Antonie van Leeuvenhoek 66 (1994) 247. Kluwer Academic Publishers. (→ micro-organisms in hot spas)

39 Science, Bd. 280, p.2095 (→ mirco-organisms in the antarctic)