Interdisciplinary Project
Waste Energy Utilization Strategies – a Contribution to Entropic Economics

Strategy of Waste Energy Usage and the Conception of Entropy Economics

Berlin-Brandenburg Academy of Sciences and Humanities
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Preface

With the present report the Berlin-Brandenburg Academy of Sciences and Humanities wants to draw attention to the results of one of its interdisciplinary projects, which are published elsewhere in more detail. [1]

The authors believe that their particular approach to the subject of "waste energy recovery", in combination with an interdisciplinary perspective, suggests a new way of discussing energy problems that has the potential to lead to qualified statements.

Starting point was the explicit incorporation of the statements of the second law of thermodynamics, which first of all enables a more precise comprehension of the term *waste energy. This term is not only linked to* waste heat, although this is quantitatively most important, but it also includes a part connected to material. This is due to the fact that the state of mass or material export is different from the state of the environment. The energy and mass transfer to the environment, with parameters different from those of the environment, cause via transfer processes external irreversibilities, which for the system itself constitute an entropy export. This finding suggests the importance of the realm of waste material economy in the analyses.

On the other hand, considering environment as a factor in the study of waste energy recovery could contribute to the discussions on the subject of sustainable development. This is underscored by the very fact that energy carriers represent the largest mass transfer between human society and its environment. If we describe such a view from a thermodynamic stand point as an entropy economy, we can then consider its goal as a positive contribution to sustainable development.

The possibilities to improve technological systems do not depend on energetic structures alone, but also and especially on basic conditions of society. This is well known from past experience, and we tried hard to estimate their influence on possible technical solutions.

The scientific and technical possibilities to positively organise an entropy economy are very manifold and can yield essential contributions to a sustainable development under different conditions. Societal basic conditions very often drastically restrict those possibilities. Thus some principles of sustainable development are violated. Therefore, heuristic knowledge is meant to give recommendations for development options worth striving for.

The summary of the essential results and recommended options of the interdisciplinary project *Waste Energy Utilization Strategies – a Contribution to Entropic Economics* aims to make a contribution to sustainable development. Further information can be obtained from the Berlin-Brandenburg Academy of Sciences and Humanities or can be found in the book publication [1] of the academy project.

Berlin, in September 2000
Wolfgang Fratzscher and Karl Stephan

Strategy of Waste Energy Usage and the Conception of Entropy Economics

1 Energy economy – Sustainable development and the principle of entropy

From all of the discussions concerning the possible future development of humanity, the term sustainable development has developed into a useful albeit somewhat inadequate term. A sensible approximation of this term can be accomplished using the following definition: a development that satisfies its contemporary requirements, without endangering the ability of *future generations* to fulfil their own requirements. The achieved state of development serves as an irreversible starting point and possibly permits statements about potential of future capacities. Obviously, this is only possible if the unpredictable and quantitatively new possibilities present themselves in regard to the currently known level. But this can surely be expected, because as the past has consistently proven, the future is "open". This fact is often overlooked in these discussions. The results are then extrapolations leading to Armageddon and other horror scenarios. In view of the growing number of mankind and the increasing complexity and interweaving of problems it seems nevertheless important not to make present decisions based on contemporary views alone, but in connection with the "lifetime" of the underlying facts, which, in large technological systems, reach far into the future and concern later generations. With that, one follows the guidelines of sustainable development.

The problems, which one has to keep in mind, regard primarily the interaction of mankind with the requirements on earth. This interaction is accomplished in a further sense through the technological systems themselves or generally speaking through the technology system. For the construction and usage of this technological system, mass and energy exchange with the state of environment is necessary. With that, this *mass and energy exchange represents the* material side of the interaction. The evaluation attempt is therefore a first approximation to the quantification of the term "sustainable development". Since there are principles for the conservation of energy as well as mass, the term "sustainable development" cannot be limited to the unchanged sustainability of the environment.

If the extraction of raw materials in the current technological systems are considered under this aspect with regard to the world economy, it has to be maintained that sources of energy such as coal, petroleum, natural gas and wood represent by far the largest quantity. In connection with these sources of energy there are first of all problems with the damage of the environment and the plundering of resources.

Since, on the other hand, in accordance of the principle of the conservation of matter, everything that is incorporated has to be emitted again, it logically follows that the enormous supply of matter within these sources of energy is also connected with the emission of matter in the technological systems, which, if they are not put into balance with the environment, can result in respective strains on the environment. An excellent example for this is the CO_2-problem.

If the facts concerning "sustainable development" were to be discussed, these connections would be primarily important for the Energy industry. These facts have been taken as a basis for this study. With this, a confinement of the general facts concerning "sustainable development" has, of course, been given. Problems that, for example, are connected with toxicity of materials, or those that can be traced to emotional or intellectual-cultural components, are therefore excluded. All these components, whose effects cannot be quantitatively researched with regards to the presented research, can be described as "Imponderable". It has to be underlined that statements should in no way be made concerning the importance of problems connected with that. For the debate over economical energy usage one obviously has to take the term "energy", from the side of natural sciences, as a basis. For energy as well as for mass exists the concept of conservation after which all of the static energy that is transferred into a certain system has to again be emitted. Because of this, the problems concerning the energy industry are often discussed in the same way as those of the process industry. But this is incomplete.

In the process industry, one is interested in a certain material as a product goal, whose characteristics should be utilised. The goal of the energy industry on the other hand, is the production and maintenance of a specific condition within a system in order to run processes in a certain direction. For that, however, it is not necessary to have a specific source of energy. The different sources of energy and their different types are substitutable. Following the laws of nature, this is not in the same way possible for mass. The uniqueness of energy means e.g. that for the solution of specific questions concerning the economy of energy, a large number of technological systems often come into question.

Regarding the debate on energy questions, it has to be considered yet another issue. Energy processes also follow, aside from the concept of the conservation of energy, the natural law of entropy or the 2nd law of thermodynamics, which makes statements about the direction in which processes in nature occur and therefore about the quality of states and forms of energy. For the problem at hand this means that the energy that is transferred, within a static system – which we want primarily to observe, since it is for practical cases the most important – has to again be emitted, since the entropy of the emission is higher than the transfer, because the entropy production results from natural processes and the quality of energy has been reduced. With energy emission, the same effect can never be reached with the energy transmission, in spite of the same amount.

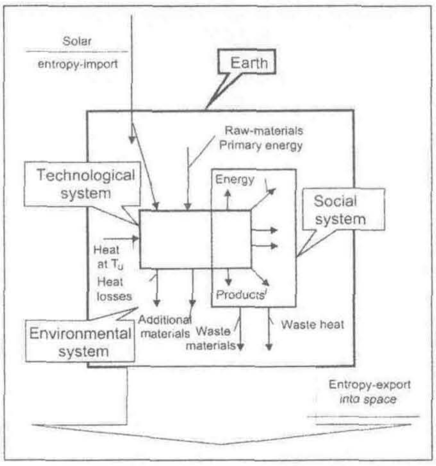
Furthermore, one has to bear in mind that the state of energy emission is dependent on the environmental conditions of the respective systems. In order to be able to realise energy emission using natural processes, there has to be a difference in potential between emission and surrounding conditions.

These connections necessitate that the given environmental conditions on earth for energy research as a heat reservoir are thereby based on a natural point of reference, whose interactions with technological systems have to be explicitly included in this observation. This shows in several respects a broadening of normal ways of observation that are generally satisfied with the surrounding of technological systems themselves. In this way the state of emitted energy is regarded more closely in our examination. It is determined on the one hand by irreversibilities in the technological system itself, and necessitates on the other hand further irreversibilities through the transition of energy and its sources. Losses are caused through this which are simply labelled as "waste energy". Their reduction finally leads to a corresponding reduction of the necessary energy input and represents a fundamental contribution to sustainable development.

2 Entropy economy

The interaction of technological systems, with the environment over waste energy, was the starting point for the present research *(Figure 1)*. In contrast to the usual observations, which are fundamentally related to the energy input, the present discussion starts from the state of the energy emission under the given conditions. A qualification of the interesting connections can be made with entropy and the corresponding thermodynamic functions of state. With that, it is also possible to make a generalisation and an exact definition of the term waste energy, which can lead to new insights for improvements in regard to thermodynamics. In order to widen the usual discussion, the observation and procedure are defined as Entropy economy. Obviously, the statements

Figure 1: Interdependences of technological systems



thereby achieved do not contradict the generally known aims, but supplement and define them in a way that allows concrete approaches and strategies to be derived for an increase in the levels of energy.

In order to give an illustration and quantification of the statements given in the 2nd law of thermodynamics, a term can be used for technical purposes that is known by the experts in that field as "Exergy". Under the term exergy, one understands the workable part of energy that means the amount that can be transformed under the given environmental conditions into mechanical work. This amount allows the statements relevant to exergy within the 2nd law of thermodynamics to register explicitly in the scale of energy. Accordingly, the 2nd law of thermodynamics reads: the exergy decreases in all natural processes in accordance to the measurement of irreversibilities. It possesses its natural reference point in the state of the environment, here it becomes Zero.

In this way, the actual energy losses are measured and these cause exergy losses through irreversibilities. Interior and exterior exergy losses have to be differentiated as well. While the inner irreversibilities are determined by the natural processes in the technological Systems, the exterior irreversibilities are determined by the differences between the emission conditions of mass and energy flow and the state of the environment, as stated above. Estimations show that in the end, exactly these losses necessitate the amount of the total expenditure.

The analysis of these relationships means that in order to evaluate energy problems, the research always has to be done up to the state of environment of the researched system. In this regard, the term waste energy also has to be extended to waste material and should not only be limited to heat loss. For this reason, the material and energy utilisation of wastes has also been included in the presented research.

Some recommendations for treatment are derived from such considerations in the planning and organisation of data and statistics regarding energy occurrences in society in order to expose the real sources of loss. For that, a standardised recording or description of the different types of waste energy, i.e. mass and energy flow, is necessary, which at this time are restricted by various institutions and responsible parties. As a starting point it has to be established, that in order to satisfy energy requirements, the actual commodity has to be exergy. Finally, the various forms and sources of energy are only the means of exergy transport.

3 Recommended Technical Actions

In this aspect the technical points of view concerning the structuring of an entropy-economy as a contribution to a sustainable development may be directly derived, since every decrease in irreversibilities can lead to an increase in energy efficiency. With regard to external irreversibilities, i.e. the waste energies, the goal has to involve the final discharge of all flows after processing into the environment, in a state, whenever possible, close to equilibrium with the environment. Therefore, energy cascades are to be striven for. These are supported in a closer sense, for example, by the use of industrial waste heat for domestic heating or by a wider use of co-generation for the simultaneous supply of heat and electric consumers. In addition to this, exist technically well developed proposals that could be realised on the basis of a network of integrated systems, especially from heat and district heating networks.

There are currently no limitations for these kinds of developments from a technical stand point, but from the realm of economic, institutional, and legal requirements. Inadequate information also continues to play a limiting role.

The appropriate developments in the regenerative use of heat, which have a significant importance in regards to quality, are being restricted in industry through the loss of useful temperature levels as a result of the focus placed on product oriented essential sectors. The dominance of chemical processing and production in the structuring of industrial processes suppresses the significance of structuring according to the principles of energy cascades and thereby, in principal, of rational energy use and of entropy-economy.

Certain exceptions are the fundamental processes of food industries, as well as specialised areas of chemical, energy, and waste disposal industries, examples are petroleum refineries and thermal process industries.

Of very high importance in such studies is the process of heat transfer, which, as it is well known, is responsible for the largest entropy production in economics and society. A possible solution to such a situation that causes difficulties in the construction of heat transmission cascades is offered by the integration of heat transformation processes of various kinds. Because of these, unoccupied or unavailable levels of energy use can be bridged through circuit processes, integrated into the process, placed before or after the process. The technical possibilities for these processes are well-known to exist in the entire capacity range, from a few kW to a few MW. Due to liberalisation of the energy market for electrical energy, which is available in a widely branched network, the option of implementing such processes appears to be gaining importance. With this, close link-ups of production processes and reciprocal dependencies, which require safety devices and corresponding reserve circuits, can be avoided.

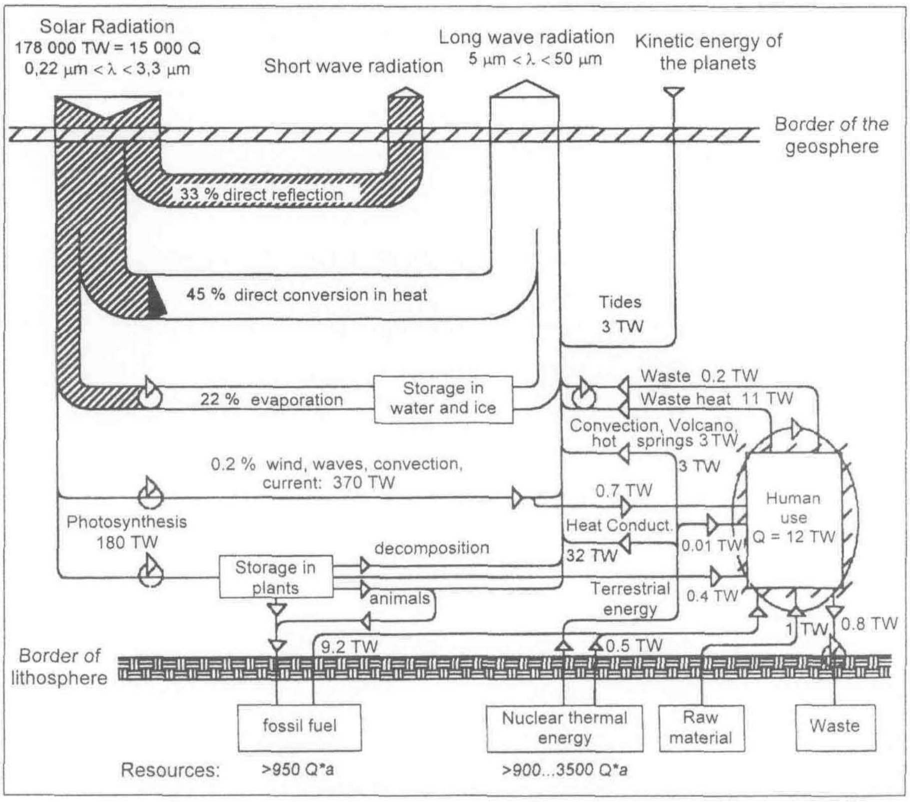
In conjunction with the evaluation of the possibilities in the gas industry it has to be mentioned that the combustion process, apart from heat transfer, is likewise through its irreversible direction one of the biggest sources of loss in the entire supply of energy. The present technology of gas usage means that combustion processes are further-on contemporary technologies, and because of this no new level of quality is being attained from a thermodynamic view in comparison with other sources of energy. This is only possible in conjunction with the use of fuel cells. In light of the strong impact of heat transfer and combustion processes, methods such as fuel cells and various forms of sorption and thermo-chemical cycles appear to be of special significance. A great deal of attention should therefore be devoted to these in research.

Especially close connections exist between energy and chemical industries in the reprocessing and use of waste and also in the supply and use of bio-masses. It has been well established that chemical energy from waste, using current methods, can be converted up to 80% into thermal energy. If only substances are recycled the chemical energy is preserved, the process requires, however, the use of energy. These interrelations as an alternative to purely energetic methods, i.e. in connection to complete chemical recycling, have to be taken into consideration. The use of bio-mass as a source of energy can be, for example in rural regions, an interesting solution for all sorts of reasons and of course not only for those concerning energy. It is interesting that the material structure of biomasses as energy sources, in comparison with fossil fuels from an entropic point of view have some characteristics, such as high humidity, high oxygen content and thus a high entropy of reaction, that should be determinedly used in gasification reactions in connection with a heat-input from the environment. Otherwise, the implementation of these sources of energy are primarily associated with logistic problems.

Summarised, it has to be maintained that from a technical point of view a variety and number of possibilites are known useful for a reduction and utilisation of waste energy. They contribute to a reduction of energy usage and are, due to the quantitative importance of the energy industry, a fundamental contribution to a sustainable development. However, their usage is being limited if not all together obstructed by a wide range of social conditions. In order to follow these connections it is necessary to start on the one hand from general considerations of the concrete requirements of usage. By doing that one should avoid drawing one-dimensional and therefore only partially valid conclusions from general statements, for it is well-known that these often lead to unproductive discussions. Furthermore, one should try to demonstrate the important range of social conditions and to evaluate the extent of possible variations. Additionally, aside from general considerations, one has to keep in mind concrete situations.

In order to put these considerations into the proper perspective one has to begin with the earth's balance of energy. The starting point is the current human energy requirement of 12TW. This amount is to be seen as a type of reference point in the evaluation of sustainable development. It is practical to distinguish between the capacity of energy and the income of energy. The income of energy as a matter of performance should be directly compared with this amount. There is an infinitely large time frame in which this energy is available to humans. Aside from this absolute amount, power densities and time structures have to be considered for a technical use, which of course requires technical- and monetary-intensive solutions. The capacity of energy is best measured in a time frame which is scaled according to the current usage of energy. The numbers shown in *Figure 2* represent years that are covered by the energy capacity of 12TW. In all discussion involving these numbers it is necessary to maintain that this amount is comparable to the time period of the known history of humanity. With that, these estimations refer more to the conservative amounts and include into this consideration only the use of

Figure 2: Energy flow of the Earth



nuclear power produced by thermal reactors. From these numbers one can derive the importance of the usage of nuclear energy that finally has to be the deciding factor for its implementation.

At this stage it is to be pointed out that the attempt of resource evaluation can also be undertaken with the suggested concept of entropy-economy, which can lead to interesting insights, especially for sources of energy production also known in contemporary usage as "renewable energy sources".

This analysis has not been carried out in our presentation but has been ascertained through proven examples given in the assessments of bio-masses.

In the evaluation of global dimension it now has to be maintained that subsequently all of the transferred energy result in external irreversibilities in technological systems, which for these systems is seen as entropy-export. Since these external irreversibilities can be regarded in a wider sense as waste energy, the important analysis of possibilities for their avoidance and usage has been chosen as a starting point for the present paper.

In order to estimate the repercussions of such possible effects, the global level cannot not be used, since it can lead to one-sided and unreal statements. Therefore, considerations have been based on specific regional objects. As such, two conurbations and two rural areas have been studied. The industrial metropolis of Duisburg and the municipality of Düsseldorf have been looked at as conurbations. Their energy structures differ significantly from each other. Accordingly, one also has to analyse the significance of various technical solutions in the improvement of energy efficiency. The other two regional objects characterise a typical rural area, the rural district of Spree-Neiße, and the administrative district of Wesel as an example for a rural district with local conurbations. The energy figures show that household energy use is of the same magnitude in both areas but obviously energy usage from commercial and industrial conditions differ from one another on a large scale, causing different technical solutions to appear practical. The qualifications of these regional objects make clear the magnitude of work necessary to create these types of insights.

Concrete research has been done in order to find examples derived from these technical possibilities. These are, on the whole, applications for heat transformation processes, bio-mass usage, structural suggestions for energy supply systems, as well as the incorporation of waste utilisation. In each case certain considerable thermodynamic improvements up to, for example, 50% could be proven. In so doing, the proposals for solutions have only employed known and usable technology, such as the cross-linking via heat-networks and the use of co-generators for conurbations, for industrial consumers, and for individual consumers in rural areas. All examples clearly demonstrate the importance of the planning and design stage. During this stage the greatest number of degrees of freedom exist, and it seems advisable to demand on this occasion for alternative concepts of waste disposal, as already regulated by law, for example in Switzerland.

The type of research, which is presented here, requires the incorporation of the procedures within the waste disposal industry. In this evaluation, it has to be taken into consideration that waste disposal without prior treatment will be permitted in Germany only in exceptional cases up to the year 2005 at the latest. Mechanical and bio-mechanical methods of treatment, waste incineration, as well as alternative thermal methods are available as possible methods of processing. Only in the case of an avoidance and usage quota of over 60% and an additional 40% of mass reduction can the creation of new treatment facilities be given up.

The first criteria in the choice of procedure for new facilities today are primarily safety criteria. This has been preferentially employed up to now due to multiple, macroscale technical experiences with waste incineration facilities. Their efficiency in transforming chemical energy stored in waste into electricity or steam is, however, two times as inefficient as today's steam power stations. This is based on the parameters of combustion and steam production, which result from the low heat of combustion of waste and the avoidance of the creation of new dioxins and furans as well as the aggressiveness of fumes. Higher efficiencies can be reached with these alternative thermal processes. This is true, however, only under the condition that produced process gases are not burned but used as raw gas i.e. in chemical facilities.

Bio-mechanical methods of treatment procedures are inferior from the aspect of entropy-economy, since a large part of the energy stored in waste is lost to the environment. Advantages of these procedures lie at best in a flexible quantitative reduction of wastes, which can be used to optimal capacity in connection with the operation of incineration facilities.

4 Consequences from the social realm of requirements

From the perspective of entropy economy, waste energy usage means first of all the analysis of the external irreversibilities, the external losses of exergy. Thermodynamics proposes a number of different solutions for the improvement of the current situation, leading to the approximation of reversibility. Their technical realisation seems much more possible today than it seemed in the past, because of the possibilities in modern production technology and especially in automation technology. Their technical and practical implementation depends closely on the social realm of requirements. The effect of this realm of requirements limits e.g. the technical possibilities in such a way as to even force an increase in the irreversibilities, and thereby goes against sustainable development demanded in entropy economy.

First of all, the economical aspects seem to be of high importance.

Economical Aspects

From the analysis of the given economical realm of requirements and their correlation with energy-technological, judicial and social requirements, the following conclusions and treatment recommendations for the use and further improvement of economical assessments are derived formulated hypothesises:

- An economic assessment of strategies concerning waste energy use is indispensable. It allows a comparison between expenditure and usage for various technical/technological options in terms of equivalent cost and monetary worth respectively. Further observation, as for example social demands and consequences, cannot replace this. For future reference one should take note that, especially in fixed cost and international comparison, cost reductions seem to be possible around 25%.

- Present conflicts in the aim between ecology and economy, between short and long-term oriented interests as well as between narrow managerial and complex general economical interests demand the integration of external costs and usage components in the economic evaluation. There exists for example a conflict of interest between the industrial companies as a heat provider on the one hand who aim at short- or mid-term (obligatory) contracts at best, and the heat users as well as the power stations on the other hand, aiming at long-term provision. Furthermore we want to point out that the respective time frames of the heat provider and the heat user are clearly different, which could require additional technical investments. Examples such as negligence and damage costs as well as codetermined ecological advantages (reduced environmental stress) come into question as external expenditure and usage components.

Particularly, in view of the liberalisation of the power and gas market, initiating the stronger reduction in price of the contemporary sources of energy, it is important to resist the opinion that the use of heat loss and bio-mass is uneconomical and unworthy of notice. A considerable contribution would be the inclusion of costs for the emissions of harmful substances (from CO_2, CH_4 etc) as well as the limitation of fossil energies into the economical comparisons. But an economical evaluation is not enough. The comparison of the competing energy systems demands an extended and complex assessment.

Due to the external effects and the failure in the market in competition with the already established energy systems, government support, financial aid and other interventions are justified and necessary for waste energy usage. Market conforming policies like proposed, long-term developments of energy prices and taxes on energy or ecology should have preference over individual subventions as well as tax reductions. In a concrete implementation the practical experiences of Switzerland, with calculable additional fees on energy prices, could be analysed.

A state (pre-) financing of networks for heat transport and distribution in the course of infrastructure investment seems to be justified under certain market conditions, not least in regard to the provision of other infrastructural facilities (such as water- and drainage facilities, public streets etc.). These market conditions are characterised by the present findings as follows:

- Either there is a great potential of existing, not yet used heat loss (from industry and from co-generation of heat and power processes) or one can count on a great demand for district heating (thanks to customers in industry, trade, and households willing to be connected). In both cases, investment-intensive Heat supply network can become a deterrent.
- After the establishment of the network (Heat supply network) its general, indiscriminate usage, i.e. the factual right of transfer for all providers and users will be guaranteed.
- For the usage of the Heat supply networks (being the property of the state to begin with) transfer fees and thereby customary rules of competition are used in analogy to electric and gas transfer.

Since, in practical applications, economical compromises can only be made via politics, special rules have to be taken into consideration. At least two demands should be placed from the beginning on the selective subventions and financial aids in question: On the one hand they should be temporary and digressively scaled in order to permanently and increasingly push for cost reduction, rationalisation, and improvement of competition. On the other hand one should only support such cases that do have a real economical chance for success in usage according to experts, i. e. if the additional expenses of waste energy usage, as opposed to the competing energy, does not overstep certain determined critical values.

For an entropy oriented strategy of waste energy usage it seems helpful if state interventions in market mechanisms favour those energy processes which go along with comparably few irreversibilities and thereby small entropy increase. These could particularly be processes with material recycling and high waste energy usage. The latter can be characterised more specifically through a high degree of usage in the employed primary energy and through a small emission density. Typical examples for this are co-generators and bio-mass usage. If one concentrates on both of the named indicators, it is to be expected that the optimisation of development strategies based on the criteria "high economic efficiency/ low total costs" (under integration of emissions) correlates to a great extent with the criteria "limited entropy increase/exergy loss".

Finally we believe it is necessary to continue economically analysing and researching new trends in development. Primarily, there are three questions. How will the reciprocal price effects on the liberalisation of the energy and gas markets have an influence on heat costs, and could this influence make it possible that the tendency of decreasing prices can be extended to the cost of heat? How strongly is the development of regenerative energies (including heat loss and bio-mass) being enforced and supported in the European Union as a contribution to sustainable development? Will taxes on energy and ecology and other regulations be in harmony to a great extent?

Optimal design for norms of legal control mechanisms

If something can be reached by market-conforming means, the solution should already be shown as politically correct, even if legally correct means are allowed. Close market control aims at an understanding of self-responsibility of design in human behaviour in the realm of recognised options and factual parameters. This can be achieved by governmental guidance on all levels, central, regional or communal, as for example through the task of developing concepts of heat loss usage as suggested in some cases, as long as it is legal. With that, legal sanctions, obligations, and rates can raise costs; privileges like tax-reduction or subventions can reduce costs. In the selection of control mechanisms, the cost-use-ratio for possible observation and management has to be compared with tax receipts, tax reductions, subventions and similar means.

In influencing the realm of requirements as well as the selection of admissible and optimal instructions of control for the areas of environmental preservation and rational energy production and usage, it has to be observed which norms already exist, and whether or not these existing norms are functional, and which legal norms should be enacted in the future in order to guarantee the functionality of the individual norms as well as the norms of entire legal areas. Aside from the question of legal dogma in regard to the constitutionality of norms, there is also the legal-political aspect "de lege ferenda", which concerns itself with how norms have to be within the constitutional boundaries in order to optimally achieve legal objectives. Finally, it is also advantageous to fall back upon the comparisons of experiences within other legal systems.

The necessity to interfere with legal means that guide in economic actions – and in this case, truly in the production and usage of energy – results, on the one hand, from the required approach of individual and public interests, and on the other hand, from the compensation of "market imperfections". At the same time, the law can bring about, i.e. through debit rate or relief, an increase or decrease in the costs of raw energy material and energy production procedures. Hereby, a truly rational and cost oriented way of production can be assured that preserves the environment and reduces dependencies on raw energy material-exporting countries, which could potentially cause political conflicts.

At this point it should be stated that, from a thermodynamic point of view, it is possible to find a generally valid framework for such a concept, using the fundamentals of the law of entropy, since it is better, for a number of reasons, to prescribe basic methods instead of giving instructions in the form of charts and limiting values.

Moreover, classic, legal instrumentation is available. In addition to this there are prohibitions and orders that can be connected with the planning procedures, the permission, and directions.

Finally, a large framework has to be assured for the instrumentation of direct support of activities and rational energy usage or usage of renewable energy. These are redistribution measures which have to be justified through public interests, since those means of support have to first be acquired by the state through taxes.

In selecting control mechanisms, implementation costs as well as factual and personal expenditure of administration procedures have to be paid attention to. The experience of previous years has shown that such costs, particularly in environmental laws, can be high enough to bring about a deficit. Furthermore, supervision through scientific relationships can be limited or impossible.

Immaterial costs as well as permissible limitations on freedom, which require justification and touch on the aspect of political acceptance, are regularly seen as burdens by citizens. The discussion over the competitiveness of German businesses that are influenced by environmental protection measures shows, on the other hand, under which difficult situations these political decisions have to be made.

Possible instruments not only have to be successful, but also have to be designed in such a way as to ensure their public acceptance, which then decreases their personal and financial expenditures.

On the one hand, the question of legally and politically adequate control instruments demands a rational identification of desired or even – as in the case of environmental aspects – existentially necessary aims and aim-driven treatment alternatives. The choice between these alternatives is then generally fact-oriented as far as it is bound by constitutional rights. But problems of political acceptance arise within this framework. The self-liability of private producers[1], especially favoured by German lawmakers, who sometimes argue over savings on implementation costs, can limit[2] legal possibilities of action within the federal states, and therefore has to be seen cautiously.

The named, legal control mechanisms for resource preservation and for environmental protection also work from the perspective of an improved entropy economy, but are only valid for individual sources of energy and energy technologies and have an isolated effect within the entire system of control mechanisms, as for example the implemented ecological taxation within the general laws of taxation. The imperfection in these kinds of suggestions could be overcome through an attempt at placing more focus on energetic considerations, substitution possibilities for sources of energy, and energy transformation technologies, since the existing laws often lead to preferences and discriminations that are not scientifically or technically realisable.

A possible approach for a comprehensive view could lie in the fact that it is not primarily human labour but energy consumption, in the form of irreversible entropy production, that is based on the tax load, and therefore induces energetically wanted and politically rational behaviours. This – permissible – political approach does not mean that entropy is solely used in the formulation of laws, but that instructions have to be formulated for temperature differences, recommended speeds, losses of pressure, etc., as for example in the "law of heat usage", where entropy ratios have been prejudged over the overall heat transfer coefficient. A debate over these kinds of considerations would be true basic research from a legal point of view.

Increase of social acceptance and its realisation in political action

Social components are playing an ever increasing role in society apart from the economic and legal realm of requirements. Although a principal hostility towards technology cannot be proven, the public has shown a much more critical opinion towards technical and especially energy-technical developments than a hundred years ago.

In order to record connected facts the term "estimation of technological consequences" has been introduced and coined. Individual methods have been developed in order to achieve qualitative observations, and surveys that cover a representative cross-section of society and work with methods *of hierarchical evaluations* have proven to be suitable. The introduction of suggestions concerning waste energy evaluation has led to the following results: The fact of rationally dealing with energy alone was able to increase the attraction of the "resource preservation" scenario. The evaluation of the new scenario "New Life style" has almost stayed the same in contrast to the original life style. From these results the conclusion can be drawn that energy politics concerned with the usage of waste energy would not be rejected because of its social acceptance.
If one took the relevance and evaluation of

the participants from a cross-section of the relevant social groups, then all suggested measures for waste energy usage would be able to be used creatively. Most of these variants for usage have better results in the environmental criteria than only supply-oriented energy systems, and they also seem to keep pace in regards to user friendliness with those systems used until recently. According to the participants involved, the problem of higher costs appears to be less pronounced as it might otherwise seem.

A definite preference for solutions of a small scope lies in the choice between high versus low networked systems, whereas central solutions are still regarded as fundamentally more positive than supply oriented energy scenarios. This is valid for both research groups; the engineer as well as the church representative.

Even though positively accepted by these two groups, the chances of realisation are still regarded as rather minimal. Neither the realm of requirement nor the institutional prerequisites are said to be given in order to find new ways in energy politics concerning waste energy usage. Therefore, it seems to be necessary to identify the required instruments and measures that can bring about a compatibility with the preferences of the involved groups and of energy politics. However, it will not be enough to count only on politics or on economy. A combination of navigational instruments has to be put together that helps to achieve the desired aim effectively and efficiently.

Belonging to these are:

In politics:

- Improvement in the realm of requirements for businesses in order for them to attain a solid foundation in the heat industry.
- Support of research and development in the creation of innovative technical solutions.

In the Economy:

- Co-operation or Subsidising of necessary achievements in infrastructure, in the economy: co-operative forms in planning and reconciliation between energy suppliers and users.
- Joint ventures between waste energy suppliers and potential users.
- Joint ventures between private investors and public funds (especially for the realisation of heat supply networks).

In the sciences:

- Development of concrete concepts for various areas of supply.
- Development of integrated technical concepts for rational energy usage
- Accompaniment of prototypical implementations in chosen fields.
- Evaluation of trial programs.

In the social system:

- Support of intentions through community leaders of socially relevant groups.
- Information of and communication with effected citizens through science, politics and associations.
- Development of solutions that meet the concerns of the citizens, regarding dependencies and losses in sovereignty.
- Medial support of suggestions in print and electric media.

Only in the combined effect of all these measures lies at last the key for a successful implementation of technical suggestions. On the basis of the presented research, a positive image for the realisation of such an undertaking is shown. However, the economical and organising effects have to be more carefully tested before these suggestions can be implemented. With all those positive evaluations it still must not be forgotten that the estimations presented here have been done on the basis of larger insecurities and on a very low representation of the involved judges. It would therefore be sensible to initiate discursive processes in evaluation in those regions where their implementation is necessary.

Co-ordination of activities for change

Finally, the historical development of respective fields of study and their technical realisation also belong to the social realm of requirements. Present treatment recommendations can also be derived from this perspective. The transition to an entropy economy means a transition to another technological system. With the concept of "big technological systems" the historical sciences offer a defining template that can also be applied to the presented research. "Big technological systems" are not only the result of a successful implementation of technological processes and of technical and scientific accuracy, as earlier findings suggest, but also, if not even more so, a result of multiple consensus-forming activities of the involved groups. Especially effective institutions and convincing arguments are required for that. Successful system founders distinguish themselves through the ability to develop relationships and congruities in spite of diversity, unity, in spite pluralism and centralisation and in spite of chaos.

This also means having the ability to constantly react to the challenges and to integrate those external factors that can be threatening to the continued existence of the system.

How can the history of waste energy usage be evaluated in this regard? In regard to technical and scientific accuracy, or termed differently, the achievement of consensus within those relevant disciplines, the theory of waste energy usage still shows shortcomings. Terms and theories have still not been unitarily formulated and are still widely controversial. Until now many formulations of this strongly persuasive core argument have failed in this respect. In the 1920's the imprecise term "heat economy" could not prevail in usage against the appeal of the term "rationalisation". The current terms "waste energy usage" and "rational energy usage" probably sound too academic and complex to prevail in published opinions in contrast to the dominating terms "globalisation" or "sustainable development". In what way the term entropy will succeed should be considered. Prevailing institutions existed only temporarily in the 1920's, later the organisations acted seldomly and less successfully. From this perspective, the displayed initiative "industries helping industries" by the VIK[3] has to be seen positively. If it were possible to more strongly co-ordinate research and activities in order to build an effective knowledge-management, this would be a step in the direction of centralisation in spite of pluralism.

The shown developments in the 1990's, the increasing acceptance of equality in various sources of energy, and energy technologies, and the breaking with attempts at having a dominating source of energy, have to be positively evaluated from the perspective of creating a unity in spite of diversity. With the paradigm "entropy economy" it could be possible to bring the various and partially contrary interests of society, economy, and ecology to a general consensus and to create relationships in spite of all differences and "chaos". Largely superfluous would be the highly debated assessment of environmental strain, the main hindrance in the implementation of environmentally compatible technology in general and especially in the development of an environmentally friendly energy supply; different interests would be quantified by a universal scale. So far it seems as if waste energy usage and rational energy usage have been integrated into the existing system more than they have posed a fundamental threat to the status quo or than having initiated a change towards a new energy system.

1 E. g. § 4 a of the "Stromeinspeisungsgesetzes" (Law regarding delivery of electricity into a network) or also as an alternative to a normative order in the case of § 5 Abs. 1 Nr. 4 "Bundesimmissionsschutzgesetz" (Federal law regarding imissions) provided the "Wärmenutzungsverordnung" (Order of heat usage).
2 Compare decision of the "Bundesverfassungsgerichts" (similar to Supreme Court) to the "Verpackungsabgabe" (Tax for left-over packages), published in Neue Juristische Wochenschrift 1998, 2341.
3 "Verband industrieller Kraftwerksbetreiber" (Union of the industrial users of power stations).

5 Practical Treatment Recommendations as Heuristic Rules

From the viewpoint of entropy economy, waste energy usage means first of all the study of external irreversibilities, the losses of external exergy. The most essential natural scientific criteria is the approach towards reversibility. Technology is able to show the expenditure connected with the necessary apparatuses in plants, different raw materials for safety, and the protection of the environment.

Whether or not the so defined technological systems become social reality depends on the given realms of requirements. Economical and legal aspects of these realms of requirements as well as their social acceptance in regard to historic development are mentioned above. Summarising, one can conclude that the aspects taken into consideration for the selection, design, and usage of technological systems are not singularly effective. Even though this could not be expected, considering the different structural conditions, it should be noted that they primarily show tendencies that fundamentally restrain entropy economy. But if sustainable development on Earth is considered correct and necessary, then this aim can only be achieved through a long-term strategy focused on the reduction of irreversibilities for which waste energy usage plays a central role.

Under these conditions, guidelines for treatment recommendations can be given only on the basis of experience -empiricism- in the form of heuristic Rules. This is not any different today than it was a hundred years ago, when Wilhelm Ostwald, who founded energetics as a naturalistic and social model, formulated the energetic imperative: "Don't waste energy – use it". It must be strongly emphasised that this general rule meets the aims of entropy economy. The same also goes for the slogan "Fight the irreversibilities" developed by Bošnjaković; in the 1930's, which was derived from experiences made in developments during the 1920's.

From the point of view of sustainable development, heuristic Rules were also suggested which aim correspondingly at resource management. The suggestion pictured in *Figure 3* has been derived from multiple discussions. For further reading on this, refer to the literature sited in the appendix [2 to 5]. At this point the reader's attention should be brought to some relevant view points on waste energy usage.

Rule 1 states, for example, that the technical solutions, which have to be realised, have to be characterised by a balance of the cost of waste energy usage and the connected "shadow prices". Although rule 2 is formulated in regards to matter it can easily be applied to sources of energy. Waste energy usage has always been connected to the reduction of primary input of energies and in that way contributes to the preservation of supplies in the same way as it does to the

Figure 3: Five Rules for resource management (from [4])

Topic 1: Substitution of natural and artificial capital[1]

1. Each use of natural capital must be balanced through a corresponding increase in artificial capital so that the quality of life for future generations (considering the importance of raising the quality of life of the current undeveloped countries) remains at least the same.

Topic 2: Management of non-renewable raw-materials: maintenance of functions of usage

2. Non-renewable natural resources have to be preserved to such an extent that their usage potential will also be available to future generations.
   2a. Non-renewable sources of energy can continue to be used as long as one of the following three questions can be answered affirmatively:
   Does the sum of the exploited raw-materials equal the sum of the additionally developed reserves at this point in time or the additional resources that are economically attainable through foreseeable improvements in know-how?
   Does the sum of the exploited raw-materials equal the substitution potential through renewable (first priority) or non-renewable (second priority) raw-material-energies under the requirement that the respective given service potential (heat, comfort, mobility and power) remains the same?[2]
   Does the sum of the exploited raw-materials equal the profit of usage through increase of efficiency in transformation?
   2b. Non-renewable raw-materials that are not implemented in the conversion of energy can be used as long as they are able to be reused with acceptable economical expenditure. This means, to what extent it is possible to transfer raw-materials into a circulation of usage that is at least partially closed. (Closure of circulation of matter)

Topic 3: Management of renewable raw-materials: provision of regeneration ability

3. When dealing with renewable resources as a source of raw material, it is true that utilisation and regeneration have to remain in balance with each other.
   3a. Renewable raw materials and the mediums that they require for their growth (like earth and water) should only be used to such an extent as to insure that a long-lasting balance occurs between usage and regeneration through intended interventions in the corresponding ecosystem (in replenishable resources) or through energy supply.
   3b. In all necessary environmental interventions steps must be taken to insure that the functionality of earth, water, and biotope remain the same so that a long-term harvest can be achieved even under poor conditions.

Topic 4: Use of the environment as a disposal area: do not exceed assimilation ability

4. For nature as a disposal area, it is true that the self-purification of resources should not be exceeded.
   4a. Environmental strains have to be categorically avoided where they either definitely damage human health or endanger the sustainability of natural systems of regulation (continuity of life-preserving cycles such as water, coal, nitrogen, etc.).
   4b. The following scale of priorities should be followed when encountering environmental strain caused by anthropogenic pollutants:
   - 1st priority: Avoidance of substances toxic to humans.
   - 2nd priority: Avoidance of materials that have a significant influence on the global climate as well as on global mass flows.
   - 3rd priority: Avoidance of substances that cause Eco-toxic effects in calculable areas.
   - 4th priority: Reduction of materials that cannot be biologically decomposed.
   - 5th priority: Reduction of all remaining anthropogenically originated mass flows.

Topic 5: Dealing with nature: Appreciation of worth even beyond economic availability

5. Every society (or union of states) should have the possibility, through consensus of the involved parties, to attribute inherent worth to natural objects.

1 With other words: substitution of artefacts for natural sources in order to reduce the need for them

2 It is also true in this case that the ability of renewable resources to regenerate themselves and the receptiveness of the ecosystems are not allowed to be questioned.

discovery of new supplies. Rule 3 poses possible consequences for problems in regard to energy supply and is therefore connected to certain consumer hierarchies. In regard to energy, rule 4 has to be supplemented with characterisation of the environment, as a heat reservoir, as a natural point of reference, and as a ground zero of exergy. From this perspective it can be assumed that the changes in intensive and molar states in the environment should be small in contrast to the changes in the sizes of technological systems.

Table 1: Criteria for the evaluation of waste energy systems

1	Technical functioning
2	Business management profitability
3	National economic efficiency
4	Careful exploitation of resources
5	Relief of the environment as sink
6	Surface consumption
7	Political and economic possibilities of realization
8	Social acceptance

From these rules, criteria can be derived that should, for example, be applied for the evaluation of energy systems. They are shown in *Table 1*. It can be deducted to which amount estimations can be made, in general and in specific cases, from the summaries given above.

Further emphasis of these rules can be made on the basis of many second-law-analyses that are derived from experiences stated in literature, which allow a focused design as well as an evaluation of the operation of technological systems. These rules not only include the explicit results of the 2nd law of thermodynamics, but also the experiences from the implicitly entailed statements from other dimensions of evaluation. When taking the entropy balance into consideration, such a heuristic catalogue of Rules can be systematically formulated. The approach towards reversibility, the reduction of irreversibilities, is the main principle. With that, the level of entropy balance for the maintenance of the state of order in a technological system is kept as low as possible.

Structure of entropy balance within technological systems

If one observes the appropriate image of energy flow, (not pictured here) as a stationary system, then it can be stated that the division of all flows is interesting but that the total balance is only trivial. Earth receives as much energy from the sun as it emits back. The equality of energy reception and emission is also true for systems like "technological systems" and "social systems". The difference between entropy-import from the sun at 5000K and the entropy export through the emission into space at 300K delivers the essential driving force for all processes on earth. This technological system also needs an entropy export in order to present the required goods and services, which are drawn from the difference between the low entropical input, the primary energies, and the raw-materials as well as the higher entropy in heat loss and non-used by products.
The entropy balance for the "technological System" reads as follows:

$$\dot{S}^{Export} = \dot{S}_{Product} + \dot{S}_{By-products} + \frac{\dot{Q}}{T}_{Waste\ heat} = \dot{S}^{Import} + \Delta\dot{S}_{Internal}$$

In the entropy export of materials and heat into the surroundings, which is not in equilibrium with the environment, there are dissipitation processes that lead to an external production of entropy. Internal and external entropy production are interconnected. That means, the effective usage of driving forces within "Technological Systems" leads to a decrease in depletion of resources as well as in their emission into the environment.

Conclusions can be drawn from the qualities of balance which can be manifested in the following heuristic Rules:

1. The artificial states of order that have to be provided require a higher entropy export than import via material and heat exchange. That means, waste energy is unavoidable but influenceable in quantity and quality.
2. The main part of entropy export is given through the emission of material and heat within the natural surrounding parameters.
3. The entropy export through heat or material, with parameters deviating from the surrounding, causes an external entropy production.
4. The main problem that needs to be solved results from required machines, apparatuses, plants (internal entropy production) designed for the provision of driving force, because they result in an additional entropy export.
5. The external irreversibilities can be reduced through integration and combination with further processes.
6. In certain marginal coupling-conditions, internal and external irreversibilities are only interchanged. But it is still possible that optimal problems can occur through different economical evaluations of flows and equipment.
7. The necessary entropy export is considerably influenced by the entropy import. The entropy level of raw materials and sources of energy must therefore be adapted to a usable level.

From these conclusions, the following six groups of heuristic Rules can be developed.

1. Rules in order to decrease reversible expenditure through reduction in demand on product specification and choice of suitable resources. (demand reduction).
2. Rules for the *use of structural effects* in decreasing technologically entailed irreversibilities through a selection of procedures with irreversibilities that tend to be low, and that are arranged in such an order as to make the constant reduction of driving forces possible. (Realisation of energy and mass change-cascades with processes that tend to be efficient; optimisation of structure).
3. Rules for the reduction of external irreversibilities through the optimisation of waste energy usage in return form or in additional processes. (waste energy usage).
4. Rules for the reduction of irreversibilities in processes through selection of apparatuses that provide highly specific transfer surfaces, and through design and site optimisation with the aim of achieving a *minimum budget for the flow of energy* and mass (apparatus and construction and plant design, design optimisation).
5. Rules for the coupling of processes in the mass and energy industry in apparatus,

plant technology, or in organising units for the reduction of transport, storage, and additional transfer-losses, which occur in coupling. (Apparatus and plant technology combination and integration).

6. Rules for the reduction of industrial irreversibilities through optimised manufacturing procedures, dependent on raw-materials, energy, and production situation, and through management-measures that reduce storage and transport losses. (process, product controlling).

In the following, special rules that have already been partially stated in other publications are applied into this system as an illustration.

The structure of an heuristic catalogue of rules

From the thermodynamic analysis, mentioned above, follows the degree of efficiency *(direction of effects)* within the heuristic rules for the creation and usage of mass and energy transforming systems. They refer to the reversible operation of processes and to minimal need through reduction of internal and external losses. At the same time, qualitative differences in various materials, energies and losses can only be made visible under explicit consideration of the 2nd law of thermodynamics. Additionally, other quantities can be used aside from entropy or exergy, as the design process with t,Q-diagrams illustrates. The basic rules, from a thermodynamic point of view, that simultaneously provoke active measures from the perspective of a management system, are shown in *Figure 4*.

Figure 4: Basic heuristic rules from a thermodynamic perspective

1. Determine user requirements *(reversible demand).*
2. Design the structure (influence the *internal irreversibilities*).
3. Implement waste energy usage (decrease the *external irreversibilities*).
4. Combine material and energy economy (decrease the *external irreversibilities* not necessary for the production of desired states of order).
5. Optimise Machines, apparatuses and plants(optimise the *proportion between single and running entropy export* and thereby minimise the total entropy export).
6. Organise the management- and process-guidance-system (decrease the *regular internal and external losses*).

The combination of these rules with the process-engineering considerations, mentioned above, leads to a classification and model concept as illustrated in *Figure 5.* The sequence and labelling of these rules are strongly based on manufacturing technology process engineering assignments, but the procedure is stepwise.

This step by step way of thinking makes general iterations necessary. This especially concerns the combination of various systems and the usage of regeneration and feedback into preceding parts of the system. This catalogue of rules is expandable and changeable, as is typical of all heuristic rules. The actual aim of this description is to stimulate systematic arrangements of

Figure 5: Classes of heuristic rules in accordance with their usage in process engineering

1. *Demand Reduction:* Decrease of demands on product specification and choice of suitable resources.
2. *Optimisation of structure:* Decrease of technologically entailed irreversibilities through a selection of processing steps consisting of irreversibilities that tend to be low and that are arranged in such an order as to make a constant reduction of driving forces possible. (cascades with processes of change).
3. *Design Optimisation:* Reduction of irreversibilities in processes through selection of apparatuses that provide highly specific transfer surfaces. Design and site optimisation with the aim of achieving a minimum budget for the flow of energy and mass.
4. *Coupling of processes in mass and energy industry:* Adaptation of coupling parameters in order to reduce the losses that occur during coupling. Reduction of transport, storage, and additional transformation losses in apparatus, in plant technology, or in organising units that occur during coupling.
5. *Waste energy usage:* Reduction of external irreversibilities through utilisation of waste energy in the form of additional and return-processes.
6. *Process, product controlling:* reduction of industrial irreversibilities through optimised manufacturing procedures, dependent on raw-materials, energy, and production situation, and through management-measures that reduce storage and transport losses.

Figure 6: Heuristic rules for minimising demands, i.e. the reduction of reversible demands

1. *Reduce the quality requirements* from the desired level (with reserves for the succeeding processes or for the usage) to the absolutely necessary level (Attainment of the goal of usage possibly through additional control and management measures).
2. *Transfer the quality requirements to a form* that is technically fast and exactly measurable for controlling and management measures.
3. *Adjust production and usage* in such a manner that the requirements of successive processes regarding reversible expenditure and implementation of driving force become constant and define the quality parameters accordingly.
4. *Select raw materials and sources of energy* in such a way that they approach the product requirements.
5. *Realise coupling processes* if it is then possible to better adjust raw-materials and implementation of energy sources with multiple, simultaneously produced products.
6. *Choose selective transfer processes* in order to eliminate cleaning processes for used matter or the products.

Figure 7: Basic heuristic rules and steps of processing in structural arrangement and reduction of internal losses [7]

<table>
<tr><td colspan="2">1. Design the total structure as a combination of effective sub-systems (decomposition).
■ Subdivide the production task into sub tasks and select processes known to be effective.
■ Use specific heuristic rules for those subtasks if it is known for example
  ■ which differences there are between avoidable and unavoidable losses.
  ■ Avoid great driving forces (e.g. usage of countercurrent)
  ■ Split big mass flows and couple them singularly.
■ Look for better chains of transformation with different subtasks or different processes.
■ Connect processes for total structure and adjust current parameters on interfaces. Iterate if necessary.</td></tr>
<tr><td>Substance transformation path</td><td>Energy transformation path</td></tr>
<tr><td>2. Design the reaction-system.
■ Select the type of reaction in regard to reaction kinetics!
■ Evaluate and determine reaction parameters in regard to:
  ■ Reaction kinetics
  ■ Sources of energy
  ■ Substance separation system
■ Select and use catalysts in order to improve reaction kinetics and reaction parameters.
■ Use possibilities for matter recycling or additional transformation steps for non used by-products</td><td>2. Design the heat-provision system.
■ Select the type of energy transformation (e.g. open or closed system)
■ Select the type of combustion process
■ Determine the type of combustion process.
■ Use possibilities for pre-heating of fuels</td></tr>
<tr><td>3. Design the substance separation system.</td><td>3. Design the energy transformation system (Including turbines, pumps, compressors etc.).</td></tr>
<tr><td colspan="2">4. Design the heat transfer system.
■ Use flows with $T \neq T_0$ for internal (regenerative) heat transfer
■ Minimise differences in temperature for processes working close to or under the environmental temperature.
■ Avoid passing the environmental temperature within a heat exchanger
■ Use the t,Q-diagram of all sources and sinks of heat in order to evaluate non-avoidable losses and shortages.
■ Solve coupling tasks first at the pinch, couple sources and sinks principally according to their position within the t,Q-diagram.
■ Couple sources and sinks in the order of temperature (countercurrent principle).
■ Split big currents if there are great differences in the heat capacities of coupled currents.</td></tr>
<tr><td>5. Design the energy provision system and the corresponding supply system together with the machine system (turbines and compressors).</td><td>5. Design the waste product system and the separation system for the protection of the environment.</td></tr>
</table>

catalogues of rules for the various fields in process engineering.

The rules presented collectively in *Figure 6* have, from the perspective of entropy balance, the following background that is drawn from the circumstances in coupling of partial systems in the "technological systems" and in the "social systems":

1. Differentiate and evaluate demands and wishes.
2. Assess the important quality of main- and by-products.
3. Choose raw materials and sources of energy whose entropy level lies close to the process requirements.
4. Adapt usage and production quantitatively, qualitatively, timely and locally.

The rules for optimising structure are especially diverse but partially contradict each other when used for complex systems, and can be further subdivided in accordance with the points of view mentioned above. The summary in *Figure 7* can therefore only be seen as a selection.

The aim of these rules lies in the development of structural effects and the reduction of coupling losses. In the design of energy expenditure systems and material expenditure systems one considers different processes as main processes and other processes as aid or as side-processes, which makes their coupling more difficult in the step-by-step design.

The possibilities in combining energy and mass transformation processes indicate a comparison of both design phases in *Figure 7*. Considerations can also be expanded to levels of possible networking in mass- and energy industry in one location. From a thermodynamic point of view arises the principle of basic heuristic rules for this assignment, as shown in *Figure 8*.

Figure 8: Heuristic rules for combination of material and energy economy

1. Study the possibilities for the mutual usage of raw materials and primary energy and the improve the combination of them.
2. Evaluate traits of energy transformation processes and usage of provided sources of energy for the design of a total system.
3. Analyse the usage of waste products in energy and material transformation plants.
4. Use heat emission from chemical reaction processes as an energy provision process with the goal of "energy-autarkical plants".
5. Link material transformation plants and energy transformation plants (Combination).
6. Use parts of material transformation plants together with energy transformation plants (e.g. chemical reactors as *evaporators*) (Integration).

The *Figures 9 to 10* should clarify other possibilities of influence according to positions 3, 5, 6 in *Figure 8*, i.e. the internal and external losses and the relationship between singular and continuing expenditures. Waste energy usage starts as End-of-Pipe-technology there, where the other measures in

Figure 9: Basic heuristic rules for the usage of waste energy and for the reduction of external irreversibilities

1. Use waste heat from currents with temperatures deviating from the environment.
   - *When determining the level of usage temperature, use the "hot" (with coldness "cold") side of the heat exchanger.*
   - *Use the heat of fluids through indirect heat transfer.*
   - *Use the heat of solid matter through direct heat transfer.*
   - *Use high-temperature heat in power processes if there are no high-temperature users.*
   - *Use lower-temperature heat through heat transformation processes if there are no low-temperature users.*
2. Use "pressure energy" of fluxes.
3. Use given chemical energy recycling of substances, as raw material or as fuel for other processes, in accordance with the environment
4. Use given concentration energy for recycling of substances or as a driving force in heat transformation processes.

system design have failed. As a rule, continuing expenditures are compensated by singular expenditures in design optimisation. The afore mentioned management intervention concerning the absorption of resources is often not adequately taken into consideration.

Summarised, it can be stated that the 2nd law of thermodynamics serves as a general instrument for evaluation and as a catalogue of rules, on how an environmentally correct technological development should be run, and also on how lasting social and economical development can be made possible. For

Figure 10: Basic heuristic rules for design optimisation

1. Provide preferably highly specific transfer surfaces for a reduction of irreversibilities through design of the apparatuses.
2. Realise a flow path within apparatuses that lead to an intensification of transformation processes.
3. Increase transfer surfaces until the higher costs, necessary for its implementation, exceed the savings in irreversibilities.
4. Operate under preferably high temperature (and pressure) conditions in work processes. Select working substances that, under the same pressure, result in higher temperatures. Provide the appropriate materials.
5. Reduce irreversibilities and losses of friction the more the lower the temperatures.
6. Arrange apparatuses in such a way that transport losses become minimal.

Figure 11: Basic heuristic rules for management, and for reduction of continuing inner and exterior losses.

1. Install energy-, matter-, quality, efficiency, and emission management as well as controlling-system.
2. Guarantee the implementation of the point of optimal operation for the corresponding raw material and energy supply as well as product situation through Process-Controlling.
3. Use Process-Controlling in combination with methods of diagnosis in order to ascertain accretion, corrosion, and catalyst activity not only for plant safety, but also for the supervision of available transfer surfaces. Make arrangements for maintenance or retrofitting.
4. Make arrangements for management measures in order to minimise storage and transport, especially in cases of varying processes.

design and evaluation assignments, conclusions suitable for formulating heuristic rules can be drawn, from general relationships between internal and external losses and from qualities in the sources of energy and raw materials. In connection with previous experience, design methods, and pre-established rules, these conclusions are also suited for arranging catalogues of rules and for assigning certain directions of operation. The second law of thermodynamics doesn't have to be explicitly mentioned in these rules, an implicit consideration focusing on marginal conditions is adequate for its validity. With that, these heuristic rules can be used as a tool for complex decision making, delivering at least a relatively fast classification of the problem at hand and a first estimated evaluation.

6 Research and development – Approaches and recommendations

In the sections 1–5 a variety of approaches have been shown for various disciplines and social areas, whose consistent pursuit can lead to positive contributions from the perspective of entropy economy. It has been shown, that much is known and that much has been brought about through corresponding research and development work in the past. Social practise shows that the achieved results are often considerable. From the perspective of entropy economy, it seems that previous developments and approaches are too closely oriented and uncomplimentary to each other. A strategic orientation, with a scale of value for the possible width of technical reality and goals, is missing. This is not only shown in the fact that, in spite of all success, external irreversibilities of actualised solutions increase, which leads to an enlargement of the waste energy production and thereby also leads to a damaging of the principles of sustainable development.

The concept of entropy economy can offer criteria here for the order and strategies of decisions, if it is based on corresponding analyses and assessments. The proceeding has to be given preference over instruction and labelling of concrete technical developments, in spite of how necessary such instructions may seem in detail for managerial as well as for national economic balances and prognoses. Such special technical developments are never general, i.e. they are not in all regions and branches and are also not always correct. New kinds of processes, new kinds of construction materials, the constant and quickly growing possibilities of information and automated technology, and the changes in the social realm of requirements always lead to shifts in emphasis in such developments. From the perspective of entropy economy and under the currently given conditions, these kinds of global developments have been indicated in section 3.

But the submission of sufficient work materials for analyses and assessments under explicit consideration of statements in the second law of thermodynamics has yet to be given. For that, data of material properties and instructions in handbooks and reference books and a corresponding catalogue of rules for the design and production of technological systems, not only energy systems, have to be made available. At the same time, there is perhaps no basic research, but a lot of applied research and development work to be done. The main goal should be to convert the generally known methods into practical usable working materials. Switzerland has already shown considerable results in this approach.

The energy level of a society is especially determined not only by scientific and technical possibilities but also through the conditions of economy, judicial and social structure. With that, these areas also carry responsibility for the usage of energy and for sustainable development of the entirety of the technological systems. In order to make statements about the interaction based here, analyses and general research have to be carried out, obviously not only generally but also specifically, as it was shown illustratively for the model-object area design optimisation in the presented project. In connection with this, social and especially economical and judicial agreements can be pursued and quantified in their effect on technical developments, e.g. through their influence on entropic behaviour in technological systems. In a different research, the term "estimated judicial consequences" has been used for these kinds of analyses in analogy of, and in contrast to the term "estimated technological consequences". As has also been shown in this research, the "estimated technological consequences"-complex has acquired an autonomous instrumentality of methods that can be employed for the quantification of social consequences and technical developments. This methodical task still has to be carried out for analyses of "estimated judicial consequences". Under the leadership of jurists, true basic research should be carried out.

The historical classification of the heat industry and thereby also the problems of waste energy usage and entropy economy has shown, that a long-term effective, independent importance could not be reached, especially because the experts in the field were not able to develop a generally applicable, accepted and valid terminology. Methods and labelling were often linked to certain technologies and a certain technical level. It can be expected that the concept of entropy economy gives approaches to overcome this problem. More research has to be done in the corresponding basic analysis.

Similarly, concepts for taxation and other rates can also be developed in accordance to the contribution of technologies in external entropy production and thereby, subsequently, toward energy usage. They would have the advantage, over previous suggestions, of being derived from a general comparable basis, as it has already been shown in section 4. In preparation of these concepts, basic research has to be done from a legal point of view.

Summarising, it should again be pointed out that a further improvement in dealing with energy through society, which seems to be suggestible in regard to sustainable development, can only be reached in the long term, if a wide range of research and development work is carried out in the different fields. First of all, one has to primarily label the scientific and technical problems and tasks that are addressed in section 3. Studies in the fields of economy and law have to be carried out, which can be derived from social and historical research and analyses. This should be done parallel with corresponding interactions to the above mentioned work. The social importance of energy problems requires the expansion of research and development work in these areas. The concept of entropy economy makes it possible to give derivations for all kinds of analyses as well as finding approaches for autonomous further developments in the respective fields. On this basis, dialectic interactions between natural and technical sciences, on the one hand, and liberal arts, on the other, would have to be defined in order to facilitate the transcendence of both cultural barriers, as they were at one time introduced by Snow.

Appendix

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