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# Improving energy flows in an industrial society by taxing exergy losses in material production

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## Abstract

In most of the Western hemisphere there is presently an intensive debate regarding the proper pricing of energy. Attempts to internalize the social and environmental costs related to energy consumption are confronted by the wish to maintain national industry in an increasingly free, global market. In this paper it is shown that the energy-consumption in the energy intensive industries can be split into two different categories; the energy which is physically required to make a product and the energy which is lost during the production. Without lowering the production, it is only the energy losses which the industry can reduce and which the society can exploit better. By focusing taxation on these losses, we can create a stronger economic incentive for energy efficient designs in industry. Implementation of such a two-price system is discussed, and it will be shown that this system can be introduced in both free and protected markets without altering the international competitiveness of their industries. On the contrary, in case of a later, global increase in energy prices, the plants and national economies which are already accustomed to a higher marginal energy price will get a competitive advantage.

## INTRODUCTION

As electric energy is gradually becoming a commodity in a free, global market, the separation between environmentally sound and bad electricity is loosing some of its former importance. In a free market with an increasing capacity among the consumers to switch to and from gas, oil and electricity based energy consumption, the energy market, at least in several regions, will develop towards a common market. Thus, as long as there are no inexpensive, unlimited, sustainable energy resources available, a wise energy tax system could put some taxes on energy consumption in general, and some more particular taxes on the environmentally or socially least acceptable production methods, through for instance a $CO_2, NO_X$ or $SO_2$ tax.

The environmental motivation for increased energy taxes is generally confronted, however, by the wish to maintain and develop national industry in an increasingly free, global market. Hence the energy intensive industries, which are often the main energy users in a country, are often exempted from energy taxes in order to protect their competitiveness. Being aware of this dilemma between global environmental interests and national economic interests, the World Energy Council and International Chamber of Commerce observe several difficulties in introducing general energy taxes (Kohn et al., 1996). The International Energy Agency accordingly recommends a change in the energy tax structure and an extension to private industry if energy related emmisions are to be reduced (NOU, 1996). The tax system proposed here is an attempt to find such a new tax structure - a system aimed specifically at the major energy users in (private) industry, a system which strongly increases their motivation for energy efficient design and operation, and a system which can leave their international competitiveness unharmed - or even improved.

An important point in this article is that energy is not equally consumed by all consumers. According to the 1st law of thermodynamics, energy is actually never consumed. It is preserved. On the other hand, the 2nd law of thermodynamics says that the energy always proceeds towards poorer quality, and it is when this quality is reduced, that we in everyday terms say that the energy is consumed. When electricity is used to heat a house, for instance, that energy will have lost all its "quality" within a few days; firstly, due to the transfer of electricity into heat, and secondly, due to the loss of heat through the walls and windows. Electricity (or any other energy source) used to produce a metal from minerals, on the other hand, will only have been partially lost. The energy preserved in the metal will still be there. Strictly speaking, that part has merely been transformed, and could even (in theory) be used to make electricity again at a later time. It is like loading and discharging a battery. Similar losses as in household heating are abundant, however, and major losses normally appear as heat losses through the pipe exhaust and as outlets of warm water. A comparison of the two situations is shown in figure 1.

In this paper the terms *exergy* and *anergy* are introduced from the discipline of thermodynamics in order to facilitate a singular, well-defined measure of the energy losses. These terms will be used in the more technical parts of the paper while the conventional term *energy* will be used otherwise. Other methodologies and terms for energy loss calculation exist, but they will generally be applicable only to a certain group of processes. *Exergy* derives from the greek word *ex* (out) and energy, and refers to the part of energy which it is possible to utilize, i.e. to take. out. Electricity for instance, is 100% exergy. Anergy, on the contrary, is the name for all other forms of energy - the "dead" forms. A typical industrial process transforms some of the exergy input from fuels and raw materials into the exergy content of the product, but at the same time looses some of the exergy due to a

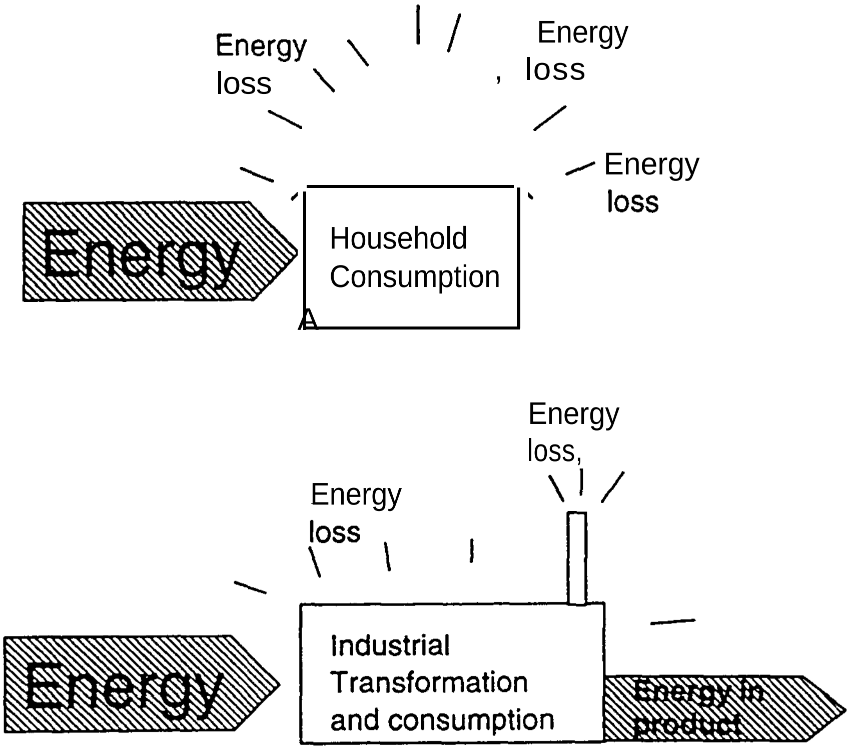

Figure 1: The energy required to keep a household (above) running is almost completely consumed and can generally not be regained or reused. In the energy intensive industrial processes the situation is normally differ&t. A substantial amount of energy often merely changes form, and the new product is both a product and an energy carrier. Due to inefficient operation or design, large amounts of energy are also lost in industry in the same way as in a household.

more or less inefficient process, see figure 1. The lost exergy becomes degraded to anergy. This degradation is also often described as ***entropy production,*** and it is to this part of the process that we want to allocate the major part of industrial energy taxes. Thus this paper can be said to follow up some of Nobel Prize winner Trygve Haavelmo's ideas about *"Entropy taxation"* (Kjelstrup Ratkje, 1985).

Some further description of exergy and anergy will be given in the first section before an overview of the potential energy flows in an industrial ecology is given. Examples of typical, industrial processes will be presented. We will then proceed to discuss different possibilities for taxing or pricing exergy losses higher than the mere exergy *transformations.* These possibilities will be shown to be compatible with both a free energy market and a protected or subsidized market. Most important, it will also be shown that such tax systems can be introduced without changing the competitive balance between those industries within the system and those outside. The last section summarizes the characteristica of the proposed tax system, and compares them with major policy recommendations by the World Energy

Council, the International Chamber of Commerce and the European Commision.

The determination of the appropriate level for a general energy taxation based on estimates of environmental and social costs is another topic, and has been dealt with extensively by others, see e.g. the European Commision (1994), Desvousges (1995) and Viscusi et al. (1994). It will thus not be discussed here.

# WHATISEXERGYANDANERGY ?

In order to make the reader more familiar with the concepts of this analysis, we will begin by a further explanation of the terms exergy and anergy. A heat source at 20 °C (60 °F) in surroundings with the same temperature has no exergy. That means that if you have a water basin at this temperature indoors (at the same temperature), it will be impossible to construct a machine which derives energy from the water in order to make for instance, electricity. For comparison, in a hot spring on Iceland with temperatures around 70 °C and with a surrounding temperature around the freezing point, 20 % of the heat is exergy. Hence, if this hot spring was used for electricity production, maximum 20 % of the heat could be converted into electricity.

The terms exergy and anergy have been increasingly used in the literature of physics, thermodynamics and engineering since the 50's, and can perhaps be best explained from Tolman and Fine's (1948) equation:

$$W = \Delta Ex - T_0 \Delta S^i \qquad (1)$$

which says that the maximum amount of work (W) whichcan be derived from a process is the change in the exergy content of the streams going into and out of the process, $\Delta Ex$. Work is here work in the physical sense, and could for instance be production of electricity, ferro alloys or aluminum. Any entropy production due to inefficient designs (As') however, will decrease the amount of work that can be extracted by the factor $T_o \Delta S^i$ where $T_0$ is the temperature of the surroundings. Thus exergy is sometimes also referred to as availability - the part of energy which is available for the performance of work (Gouy, 1889). The term $T_o \Delta S^i$ will in this paper mainly be referred to as the lost exergy in a process, and is thus also equal to the increase in anergy (dead energy):

$$\textit{Lost Exergy} = T_0 \Delta S^i = \textit{Increased Anergy} \qquad (2)$$

The methods for calculation of exergy losses are well defined in the engineering literature (see e.g. Szargut et al., 1988 or Morris et al., 1993), and there are even new methods under development that will ease the calculations further (Haug-Warberg, 1998). *Exergy analysis has the advantage of taking all energy forms into account* with respect to their ability to perform work in the physical sense. Thus a discussion of conversion factors between electricity, oil, heat, natural gas, coal and other energy forms is not needed. It is prescribed by the energy carrier's ability to perform work (like producing electricity) rather than by contemporary conversion efficiencies (see e.g. Howarth et al., 1993).

The exergy content of some energy sources relative to their heat content (with surroundings at $T$ = 25°C and a pressure of **1** atmosphere) is shown in table 1:

**Table 1: The exergy content of some conventional energy sources.**

| Energy Carrier | Electricity | Fossil Fuels | Heat (60 C) | Heat (800 C) | Heat (6000 C) |
|---|---|---|---|---|---|
| Exergy content | 100 % | 96-100 % | 11 % | **72 %** | **95 %** |

Many might perhaps be surprised to see that the exergy content of natural gas and oil is practically 100 % since it is well-known that only some 55 % of the energy in fossil fuels can be transformed into electricity in todays power plants. The reason for that, however, is that the fossil fuels in todays power plants are converted to heat first, which only afterwards is used to produce electricity. And heat, although at 800 $^{0}C$, is only 72 % exergy. This also shows why the fuel cells are so promising for electricity production. Since they convert natural gas into electricity directly without the intermediate heat production, their maximal exergy efficiencies are often around 80 %.

Heating still is a major need in human society, but as can be seen from table 1, the exergy content of domestic heat needs is generally below 11%. Thus the use of electricity for household heating represents a poor usk of energy resources. As can be seen from table 1, the heat must have a temperature above 6000 $^{o}C$ before its exergy content resembles electricity. The use of electricity for household heating thus can be compared to the use of a heat source at more than 6000 $^{o}C$ for heating at 20 $^{o}C$. In everyday terms this could be compared to the use of mahogny in domestic fire places.

The exergy content of heat is always defined relative to the temperature of the environment, and can be calculated according to:

$$Exergy\ Content = 100(1-\frac{T_{env}}{T_H})\% \tag{3}$$

where $T_{env}$ is the temperature of the environment and $T_H$ is the temperature of the heat source or heat need.

# IRREVERSIBLE LOSSES IN MATERIAL CYCLES

Figure 2 illustrates some of the energy flows in an industrial economy with recycling of energy intensive materials. The exergy losses in such material cycles are generally released to the environment as heat, and the left side of the figure shows the potential use of this heat at different temperatures. As can be seen, the net flow of energy and materials goes from "Resource Extraction" in the upper, left corner to wasted energy and materials in the lower part of the figure. The rate of energy extraction in this system can be reduced by (1) enhanced production efficiencies, (2) increased degree and efficiency of recycling and (3) increased use of the heat released during the life cycle of the product.

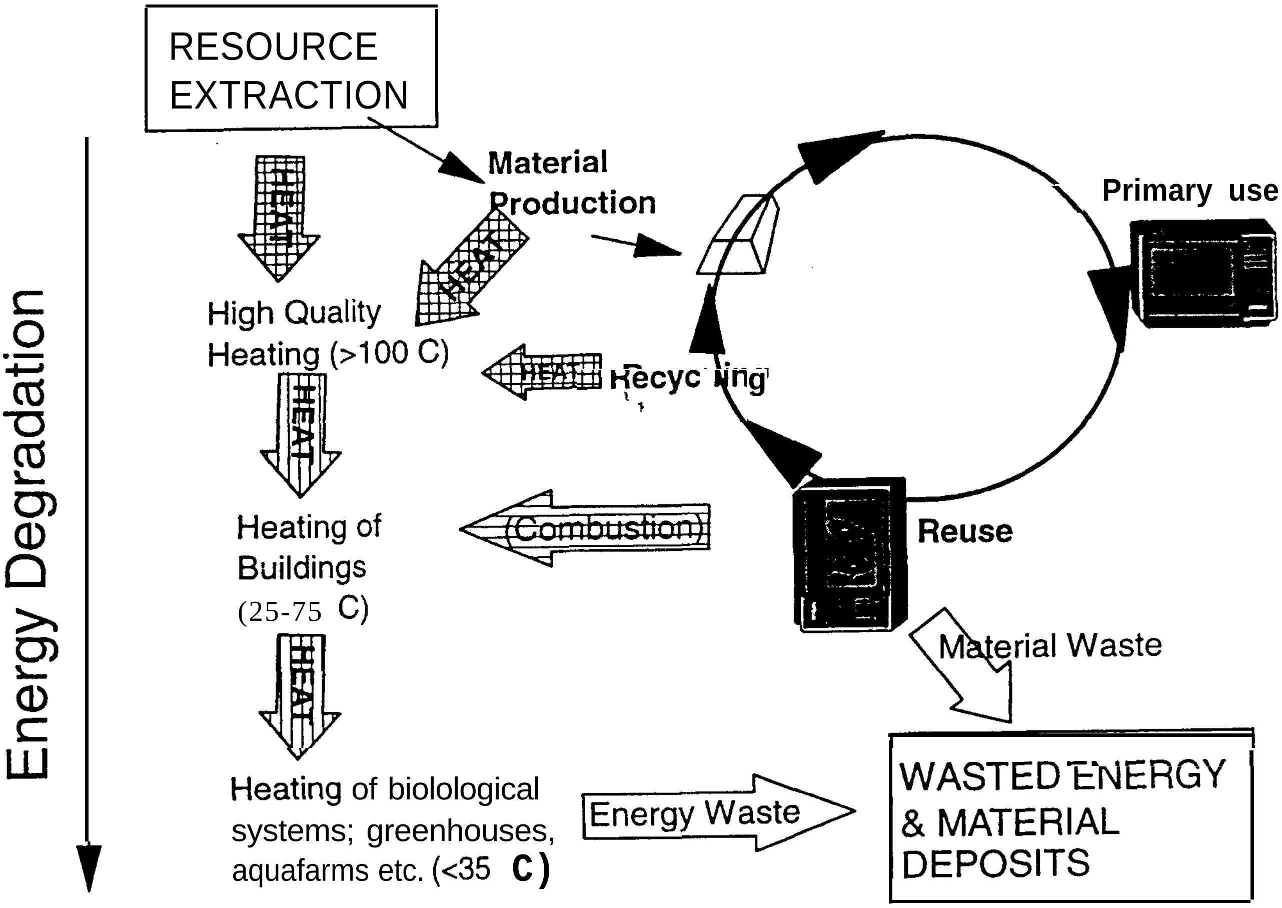

Figure 2: Energy flows in an industrial economy with recycling og energy intensive materials, and extensive use of the heat released during the material's life cycle.

Typically, the exergy efficiency of a primary material production process ranges from 25 to 60 % while the exergy efficiency of a recycling process often is around 90-95 %. (This does not include transport requirements.) The taxation of exergy losses in materials production presented in the next section aims mainly at improving the production and recycling efficiencies. In practice the tax means that the industry must pay for producing and letting out warm water and hot exhaust gas. The total effect of the tax could be increased further, however if the industry was given tax deductions for heat distributed to the other heating needs in society. Then also the energy flow in the left section of figure 2 would be improved.

Process heat is generally released at the operating temperatures of the plants (50-1000 °C). Various heat recovery systems inside the plant then uses this heat where they need it or for internal electricity generation. When the hot streamshave reached temperatures around 100 °C, the exergy content is so low that it is rarely profitable to make electricity from the streams. For general heating purposes, however, the heat is still highly valuable because the major heating needs in society are at temperatures around 20 °C. A process stream (often water) at 100°C can release heat at all temperatures below 100 °C (in practice 90 °C due to heat exchanger losses). Using this heat directly for heating of buildings at 20 °C is often the most economic alternative, but the optimal use of exergy would be obtained by first giving away heat at 80 °C to a laundry, then distributing heat to households or commercial buildings before finally letting the water out at 25 °C to a marine farm or to snow melting of streets and pavements. In that way the society would use the “heat fall” in a manner similar to the use of waterfalls, where the most energy is produced when the maximum metric fall is exploited.

In Norway most domestic heating is made by electricity although much poorer energy qualities can be used. That means, however, that warm streams at low temperatures with 10 % exergy content can replace the use of electricity (or fossil fuels) which represent 100 % exergy. That is a lucrative, thermodynamic business.

# EXERGY LOSSES IN INDUSTRIAL PROCESSES

## Two typical industrial processes

The exergy flows in a typical industrial process plant using electricity or fossil fuels in order to produce product A is shown in figure 3. As in all physical processes, the exergy flows out of the process in figure 3 are smaller than the exergy input flows. Thus a certain loss has occured. In this case 20 % has been lost as heat leaks and 30 % has been lost together with the hot flue gas. Some of the exergy (50 %) is still preserved, however, in the product. In theory, and often in practise, this exergy can later be released to perform new work like electricity production, manufacturing or heating. Combustion or recycling of plastic, metal and paper are good examples.

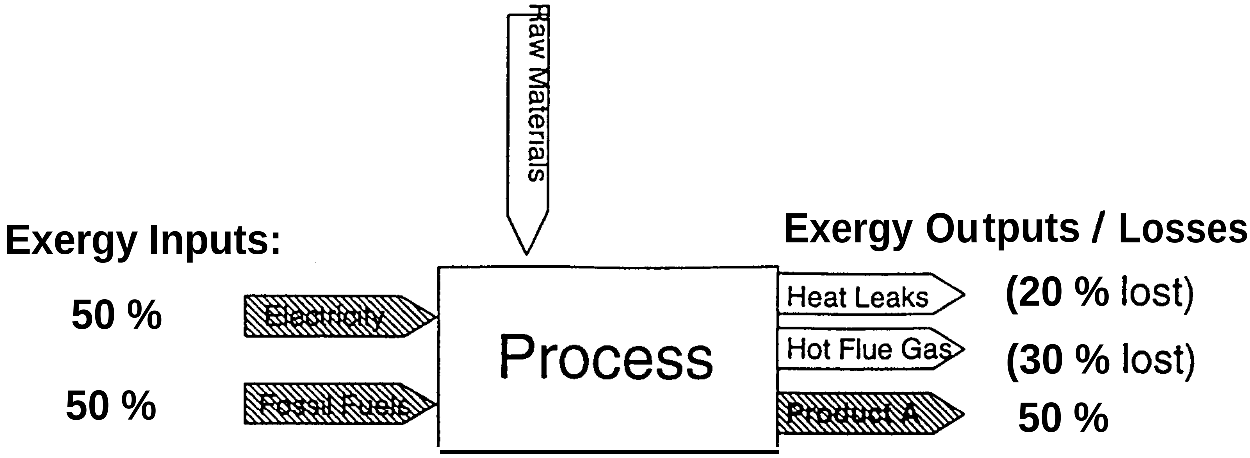

Figure 3: Example of an industrial process. Energy and Raw Materials are used to produce Product A, a product which physically contains 50 % of the exergy input to the process. 20 % of the exergy input is lost as heat leaks. 30 % is lost together with the hot flue gas.

Figure 4 shows another process example. Again the exergy stream going into the process is larger than the exergy streams going out, and the total exergy loss is estimated to constitute 60 % of the exergy input. The most visible difference from the process in figure 3 is that this plant produces electricity as a side product. Thus it might initially seem environmentally and socially better than the previous example. Such an evaluation though, is merely due to the fact that it is easy to forget that all the process streams of raw materials and products are also energy streams. In a process where hydrogen and nitrogen

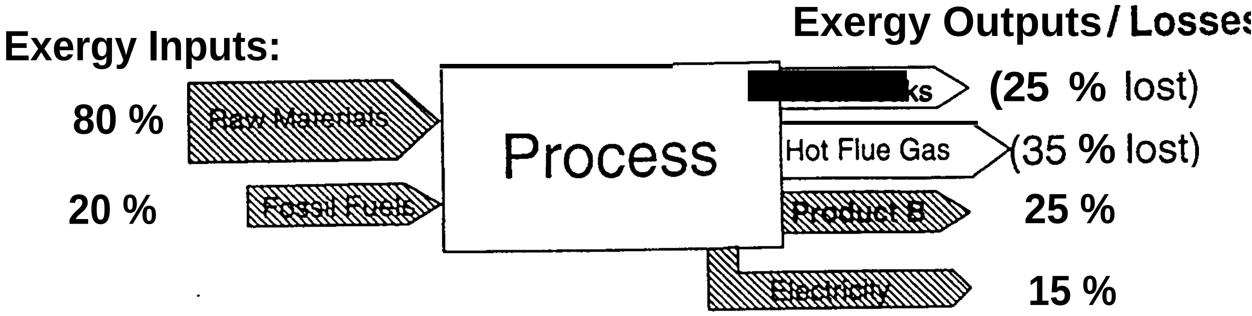

Figure 4: Example of an industrial process. Energy intensive raw materials and some fossil fuel are used to produce Product B with electricity as a side product, a product which physically contains 25 % of the exergy input to the process. In addition, 15 % of the exergy input is recovered as exergy, while 25 % of the exergy is lost as heat leaks, and 35 % is lost together with the hot flue gas.

is changed into ammonia with electricity as a side product for instance, the electricity production is physically equivalent to burning a conventional fuel and making electricity out of it.

## Taxing the energy losses

The central idea in this paper is to tax (or price) the exergy losses higher than the exergy which goes into the product. Thus the total energy costs of the process industries can remain unaltered while the marginal energy costs (per product unit) can increase significantly. This is somewhat similar to the increased marginal tax for high personal incomes in some countries (e.g. Norway and Sweden) or the increased marginal tax on company surplus in others (e.g. USA). In this case, however, the aim is not primarily one of social redistribution, but rather to increase the motivation for energy efficiency in the industry while maintaining international competitiveness.

If, for instance 1000 kWh are normally used today to make a product, the first 700 kWh (per product unit) could be available with a low or no tax. Any exceeding energy consumption, however, could be subject to a substantial tax [1]. And since this energy loss *tax* applies only to a fraction of the energy required to make the product, it can be much higher than an alternative, equal tax on all energy consumption [2].

An advantage with such a tax allocation is that only the energy *which the industry can eliminate becomes more expensive.* In other words, the energy price is increased only in a market segment with price elasticity. Since the price after tax in this segment can be increased substantially within the proposed system, the economic incentive for energy optimization is increased several times more than if the same environmental or social tax was distributed evenly to all energy consumption.

In regulated or protected energy markets where the energy intensive industries have access to energy at a lower price than other customers, *the same effect can be achieved by providing the industries with two energy prices.* The energy which goes directly into the product could be available at the lower price while the energy which becomes lost in the industry must be bought at a higher price.

In general, increased marginal energy prices will make other process designs favourable and more optimization profitable. Thus a larger part of the energy conservation supply curves (see e.g. Stoft, 1995) will become profitable. In many chemical processes for instance,

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[1] In subsidized or protected markets the same effect can be achieved by letting the last fraction of the energy be bought at a higher price or at the open market.

[2] The total tax burden may of course still remain unchanged, increased or reduced according to political decisions.

there is always a trade-off between investment costs and energy costs (see e.g. Linnhoff et al., 1983, or Sauar et al., 1996). An increased marginal energy price will thus create a shift in these trade-offs such that more energy efficient equipment are favoured over the more inexpensive, less efficient alternatives. One of the classical trade-offs between energy costs and investment costs (for system size) is shown in figure 5.

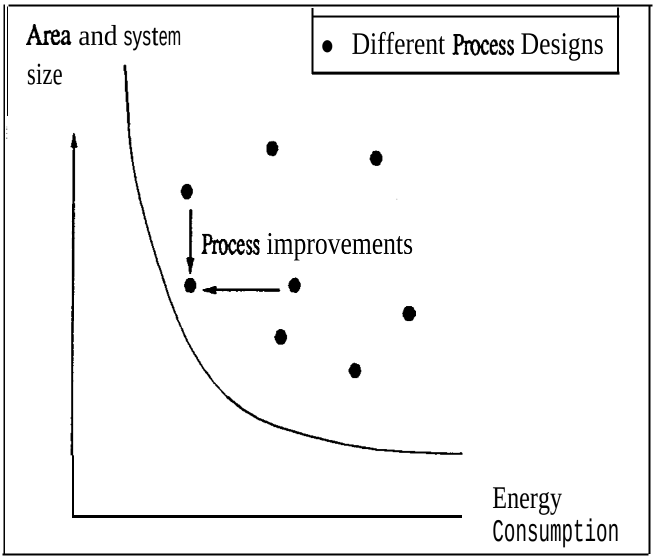

**Figure 5:** In process industry there is a well known trade-off between energy consumption and system size.

As the reader might have already seen, there are several measures to be decided upon and negotiated over in the proposed model. Before we proceed into discussing a framework for such negotiations, however, I would like to make one more point about the two examples presented in figure 3 and 4. *If* these processes were producing the same product, the proposed tax would imply higher energy taxes for the latter alternative than for the first since the latter process loses more energy and is less efficient. Merely taxing electricity consumption and fossil fuels, however, would mean that the first process gets the highest energy taxes although it is clearly the most efficient one.

# IMPLEMENTATION IN FREE OR SUBSIDIZED MARKETS

Figure 6 (a) shows an example of a traditional energy tax. All energy required to produce a product is equally taxed with for instance **0.2** US cents per kWh electricity and a similar rate for fossil fuels. Figure 6 (b) then shows a system where only the energy losses are subject to taxation. For aluminum production for instance (see table 1), this implies that approximately half of the energy presently required to make the product becomes tax free while the other half gets an increased tax - 0.4 US cents per kWh. Thus the marginal tax on energy consumption has been doubled without any increase in the total tax burden. For most industrial processes, however, the exergy efficiency is below 60%. Often it is even below 40 %. Thus if all the lost exergy should be taxed as in alternative 5 (b), the tax would still need to be fairly low if the average energy price is to remain unaltered. Both from an engineering and economic point of view, such an equal tax on all the energy losses would not be an optimal solution since processes with no losses would require infinite plant sizes and would hence not even be an aim for society at large.

Thus rather than taxing all energy losses equally, one might suggest a further concentration of the taxes to those losses which can possibly be reduced. The parts of the energy losses which in this way become exempted from taxation can be viewed as a kind of minimum exergy loss or minimum entropy production. The resulting mix of energy prices would then become as shown in figure 6 (c).

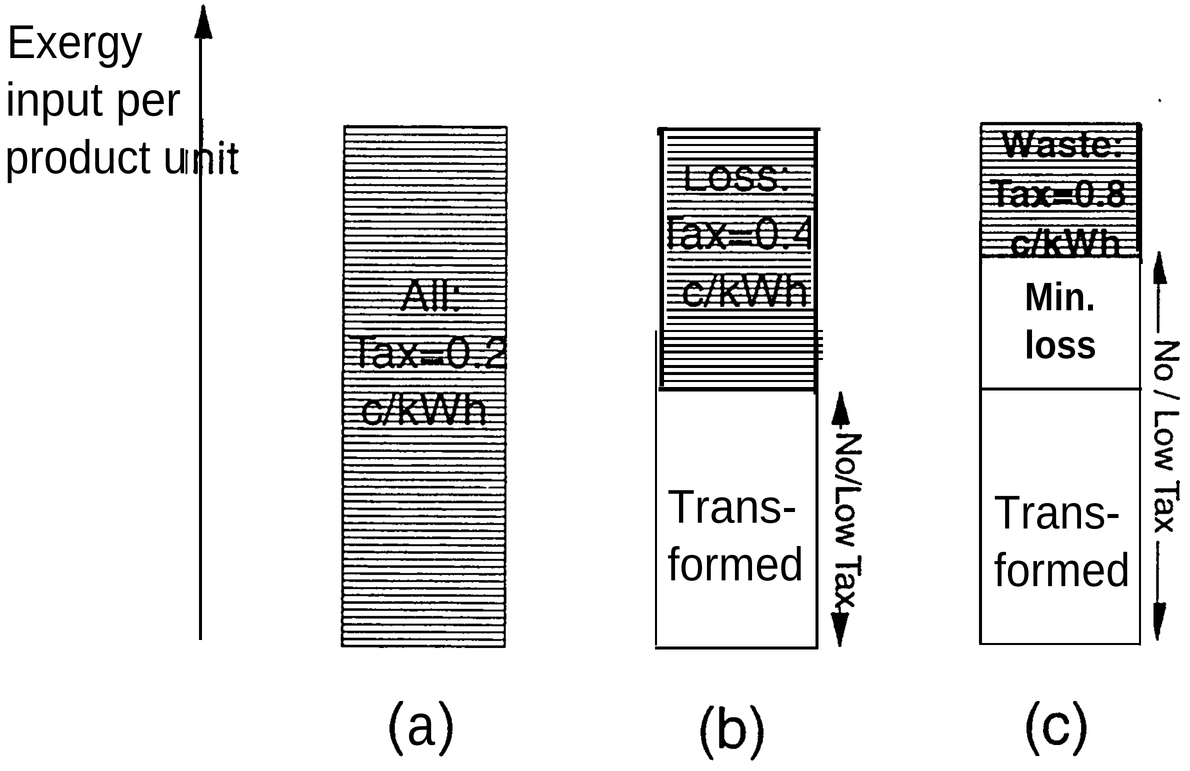

**Figure** 6: Three alternatives for energy taxation of an energy intensive process. All have the same total tax. Figure (a) shows the conventional energy tax which is applied equally to all energy input, figure (b) shows a tax allocated only to the lost energy, and figure (c) shows an even higher tax located only to the last 25 % of the energy demand per product unit. These last 25 % may represent the energy which it is assumed to be technically possible to save, and the remaining 75 % is thus called the “target”. Only the shaded areas are taxed.

By maintaining the same average energy tax in alternative (b) and (c) as in (a) we ensure that there is no impact on overall competitiveness. Thus it should be possible to implement the energy loss taxation by individual countries within all the present free trade and customs agreements. Actually, even a slight increase in average energy taxes may be added since the industries relatively soon will be able to reduce their energy consumption per product unit, thereby saving taxes for several years ahead.

A practical implementation of case (c) in figure 6 can be achieved for instance by negotiations and decisions within the following framework:

- Specify a certain target energy consumption per product unit in the energy intensive industries. This should be lower (better) than the present “Best Available Technology” can perform.
- Let this target amount be bought/sold with low or no taxes (or with a lower price in a regulated market).
- Assign relatively high taxes to all excess energy consumption. In energy economies which are not based on a totally free market, this point could read “let all excess energy consumption be bought at a higher price (for instance on an adjacent free market)”
- Allow for retargeting (point 1) after a reasonable time compared to both technology development and the time required for return on industrial investments, for instance every 15 or 20 years.

In table 2 energy data from a few energy intensive processes have been gathered and a possible target suggested. The numbers have been taken from Grjotheim and Kvande (1993), Kolbeinsen (1995), Valjord (1997) and Dybkjær (1995), and the energy amounts have been calculated as exergy.

As can be seen, the exergy efficiency of the processes vary from 21 % for glass to 66 % for ammonia. The low exergy efficiency for glass production is probably related to the relatively low energy consumption required. Thus the economic incentive for energy efficiency is lower in glass production than in for instance aluminum production, where energy costs are of primary importance.

Table 2: Present energy consumption, energy losses and possible target for the production of aluminimum [3], ferro silicons [4] , glass and ammonium. All forms of energy consumption are included and have been calculated as exergy [5].

| Product | Aluminum | Ferro Silicon | Glass | Ammonia |
|---|---|---|---|---|
| Reference | Grjotheim and Kvande | Kolbeinsen | Valjord | Dybkjær |
| Unit amount | 1 kg | 1 kg | 1 kg | 1 kg |
| Example of Present exergy consumption | 17 kWh | 15 -18kWh | 3.9 kWh | 7.3 kWh |
| Theoretical minimum | 8.5 kWh | 7.5-9 | 0.8 kWh | 4.8 kWh |
| Exergy Efficiency | 50 % | 50 % | 21 % | 66 % |
| Possible target | 13 kWh | 12-14 | 2.5 kWh | 6.2 kWh |
| Amount to be taxed | 4 kWh | 3-4 kWh | 1.4 kWh | 1.1 kWh |

The targets given in the table are merely the author's suggestions, and do not represent a scientific quantity as such. A rule-of-thumb in parts of the energy intensive process industries, however, is that the energy consumption per product unit is going down by approximately 1 % per year. Thus if a 20 year perspective is chosen, and the aim of the tax is to enhance the energy efficiency compared to status quo, the target should be at least 20 % lower than the present energy consumption. On the other side, the 1% improvement per year will become impossible to sustain as the energy consumption moves closer to the theoretical minimum. The production of ammonia for instance is already quite energy efficient, and it will probably become difficult to cut the energy consumption per kg by as much as 20 % more. Thus the estimated target for the ammonia production is only 15 % lower than the present energy consumption while the targets for aluminum and glass are 23 and 35 % lower.

### Time scale and tax level

Investments in energy efficient process designs require some kind of certainty that the profits will last for a given amount of time. Thus, the energy conservation effect from this kind of energy taxation is strongly dependent upon a guarantee that the system will not be changed outside certain boundary conditions. (For instance, any change within the first 15 years must be approved by both the industrial customers and the state.)

The determination of the appropriate tax level and targets for such a system will clearly be the result of political and industrial negotiations, and is not a topic here. An argument can be made, however, for setting the marginal taxes in figure 6 (c) somewhat higher so that the total tax revenue initially exceeds the total tax revenue in alternative 6 (a). The reason for this is that the industries already within the first 5 years probably will make significant improvements, and thereby reduce their taxes accordingly for the major part

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[3] The numbers are for the production of aluminum from alumina.

[4] There are several ferro silicons and other ferro alloys produced with significantly different energy consumption. The exergy efficiency for most of them is around 50 % (Kolbeinsen, 1995).

[5] The numbers are from different studies, but should still be comparable.

of the tax period. The tax burden and investment demands in the early phase of such a system may become quite substantial however, and the expected net present value of the increased taxes might be given to the industries initially provided they use them for energy conservation measures. A somewhat simpler, practical solution might be to implement the new taxes one or two years after they are decided upon so that the industries get some initial time to adapt to the new tax regime.

The price of electricity to the private households may be a good reference for the price (incl. tax) of lost energy to the process industry. This use is physically equal since the energy becomes equally consumed or lost, and such pricing will thus ensure a comparable marginal energy price in the two markets.

**Fiscal Considerations**
A major aim of the proposed tax system is enhanced energy efficiency in the process industries. Such enhancements will reduce the energy losses in the plants and thereby reduce their energy taxes. Thus after ten years one might perhaps see some industries pay virtually no energy tax compared to what they initially paid, and this situation may last until the “tax period” is over, and a new target can be made. Both from fiscal and commercial considerations such variations in the taxes may be unwanted. A possible solution to this problem may be the introduction of a staircase target - a target which is decreasing every 3 years for instance, according to a more or less fixed schedule.

## CHARACTERIZATION AND DISCUSSION OF MARGINAL ENERGY TAXATION

It has been shown that the proposed marginal energy taxation (or pricing) is feasible in *both free energy markets and the subsidized or protected markets.* Most importantly, it can also be *adopted by single countries or any part of a larger energy market* without altering the overall competitiveness balance within the greater market. In case of a later increase in the global or regional energy prices, those industrial plants (and national economies) that are already accustomed to high marginal energy prices will *benefit* from their more energy efficient plants. If, on the contrary, a new unlimited, non-hazardous source of energy were to be found, the taxes might simply be dropped, and the main cost would be a somewhat reduced profitability of former investments. Considering this possibility to be quite unlikely within the next 20 years, the proposed system has mainly a *potential economic benefit* both for the national energy intensive industries and the national economy as compared to status quo.

Thus the US or a group of countries like the European Union, or even a single country can introduce the proposed tax system alone without loosing the attraction of industrial investments. Especially if the reality of a global climate change continues to become more threatening while the “burden distribution problem” hinders satisfactory global agreements, energy loss taxation becomes attractive because (1) it stimulates national energy conservation, thereby reducing emmisions of $CO_2$ and (2) it prepares the national energy intensive industries to a higher energy price without reducing their present competitiveness. In case of a later global or regional increase in the energy prices, the national industries can cash in the profits from already enhanced energy efficiencies as compared to their competitors.

The economic incentives for energy efficient industrial processes will be enhanced by the proposed measures whether the products are recycled or not. However, the main environmental justification for selling parts of the energy to industry at a lower price is that some of the energy is not consumed, but merely transformed into another (thermodynamically equivalent) form. If the product is not recycled, but merely disposed as litter, that argument is no longer valid. Ideally, one may then argue that all energy sold to the energy intensive industries should have the full price or full tax. Such a measure carried out by a single country, however, would ruin the competitiveness of their national energy intensive industries. The proposed tax measures may thus be the best available measures even when full or partial recycling of products is not feasible.

The marginal energy tax is also an economic incentive for energy efficiency improvements in industry which are presently profitable for the national economy while of little interest to private commerce. One weakness of the proposed measures with respect to the overall energy conservation in society, however, is that they will not increase the incentives of customers to buy less energy intensive products since the average energy price remains unaltered. There is, however, no problem to combine the increased marginal energy taxation proposed here with a flat energy tax or generally increased energy prices.

## Comparison with major policy recommendations

A working Group established by the World Energy Concil and International Chamber of Commerce recently published a report (Kohn et al., 1996) on the role and effectiveness of economic instruments in the field of energy and environment. Regarding environmental taxes as an instrument to abate climate change, they concluded that (1) conventional ecotaxes were limited to cases where there is price elasticity in energy demand. Also, they found that (2) energy and carbon taxes are ineffective at reducing carbon dioxide emmissions unless set at unrealistically high rates, (3) that tax measures can detrimentally remove capital for environmental investments from industry and commerce, and (4) that ecotaxes need to be coordinated internationally to avoid distortions on export competitiveness.

As has been shown previously, the proposed energy loss taxation resolves these four problems. The tax can be set at “unrealistically high rates” (2) since it applies only to a fraction of the energy input to industry. It is introduced in a market segment with true “price elasticity”( 1) over time since all the taxed energy losses in principle can be removed. Solutions have also been suggested to facilitate capital for investments (3), and a high level of international co-ordination (4) is no longer required because a region or a state can introduce energy loss taxation without harming their own export industries.

In the European Union's White Paper and Green Paper, market integration, internalisation of costs (particularily with respect to competitiveness and environmental protection) and security of supply have been pointed out as three equally important principles of its energy policy. Yet, till now, the progress seems to have been made mostly along the free market axis (Klom, 1996). The tax system proposed here may contribute to alter this situation since internalisation of some of the environmental costs can be achieved without necessarily affecting the industrial competitiveness.

# CONCLUSIONS

A new energy tax system for the energy intensive industries has been proposed. The new tax is allocated to the energy losses in the factories, and gives the industry an enhanced economic motivation for reducing their energy losses. In this way the major drawbacks of conventional energy taxes are circumvented. Because the proposed tax applies only to a fraction of the energy input to the plants, it can be set at a much higher rate than other energy taxes, and it can also be introduced by single actors on the global market without harming their national industries. Most importantly, the tax avoids punishing industry for simply transforming energy from one form to another at the same time as it creates a major pressure on improvements where they can actually be made.

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