H2nrw315
06.07.2007

# Energy Efficiency, No: It's Exergy Efficiency!

by
**Carl-Jochen Winter, Ueberlingen, Germany**[1]

***We are bad energy engineers, because we have too much energy.***
*Benjamin Franklin (paraphrased)*

Keywords: energy, exergy, anergy, exergo-thermodynamics, hydrogen energy, de-carbonization, hydrogenation, de-materialization

***Abstract:***
*Elevated energy efficiencies seem politically beyond dispute as measures against anthropogenic climate change. Energy efficiencies, however elevated they become, remain within the applied energy system, though. The paper draws attention to the exergo-thermodynamical system change of splitting up energy into exergy and anergy where exergy is the maximum of available technical work drawn from energy. Consequently, it is the elevated exergy efficiency, which deserves the attendance of energy engineers helping to reduce greenhouse gas emissions.*

The attentive political observer takes note that elevated efficiencies (and renewable energies) are politically beyond all dispute as measures against anthropogenic climate change. 4 x 20 reads the EU – Ministerial Council's formula of spring 2007: 20% less primary energies, a 20% share for renewable energies, and 20% less greenhouse gas (GHG) emissions, each by 2020. The G8 summit in Heiligendamm, Germany, even decided to halve GHG emissions by 2050, i.e., in the extremely short time of only 43 years from now! And Germany envisaged the ambitious goal of raising the national efficiency by 3% p.a..

[1] Professor Dr.-Ing. Carl-Jochen Winter, Vice President - The International Association for Hydrogen Energy (IAHE), c/o ENERGON Carl-Jochen Winter, O. St.- Leonhardstr. 9, D-88662 Ueberlingen, T/F +49 7551 944 5940/1, www.itsHYtime.de, cjwinter.ENERGON@t-online.de

Here, it is not the place to discuss whether those decisions are technologically and economically verifiable, whether it is reasonable to assume that they can be realized, and, the most important touchstone of all, whether these measures can sufficiently restrict the men-made GHG–effect in its consequences for humans, fauna and flora.

It is trivial to say that kilowatt-hours not required thanks to conservative and more effective energy usage and elevated energy efficiencies are environmentally and climatically irrelevant, and that operations using carbon-free renewable (and nuclear) energies do not contribute to the GHG–effect.

Not at all trivial, however, is – and that is the central point of this paper – which efficiency is meant, energy efficiency or exergy efficiency. Because exergo-thermodynamics tells that each energy conversion step along the complete energy conversion chain, link by link from production via storage, transport and dissemination, and finally to utilization of energy services, splits up energy into exergy and anergy: energy = exergy + anergy. Truly, obtaining more exergy from energy is the real goal of any energy conversion, because exergy means available technical work, this is the ultimate energy challenge. Exergy can be converted into each and every other form of energy, anergy cannot[2]. What exergy so urgently needs is farsightedness, not tackling day-to-day inconveniencies!

Let's make it plausible: After more than 200 years of national energy the energy efficiency of Germany is a little more than 30%, and that of the world not much more than 10%. Germany has to introduce three kilowatt-hours of primary energy raw materials into the country's energy system, in order to provide one kilowatt-hour of energy services after having completed the run through the national energy conversion chain, and, bitter to say, for the world the ratio is 10 : 1! The industrialized country's efficiency is not very impressive at all, but that of the world is devastating. - And further, that is only one side of the coin. The other side, and the much more important one, is that Germany's exergy efficiency is c. 15%, while that of the world amounts to only a few percent.

[2] Z. Rant, Thermodynamische Berechnung der Verluste bei technischen Energieumwandlungen, Brennstoff-Wärme-Kraft 16 (1964) Nr. 9, September; H.D.Baehr, Definition und Berechnung von Exergie und Anergie, Brennstoff-Wärme-Kraft 17 (1965) Nr. 1 Januar

What does that practically mean? The energy systems of the world, of course, including Germany's, produce much too much heat of the false temperature at the wrong location (= anergy): Thermal power stations, however admirable the envisaged modern hard coal stations' electrical efficiencies of a little less than 50% may be, still provide – predominantly because of the boiler's exergy destructions due to irreversible combustion and heat transfer – huge amounts of anergetic heat at locations where no user buys it. – The boiler in the central heating system of a residential or commercial building has a similar problem: it has a flame temperature of up to 1,000 °C, although the room radiators only require 70°C. – And there is a third, very similar, heat problem in the internal combustion automobile engine: only 20% (30% at the utmost) of the energy content of gasoline or diesel goes into traction (= exergy): the much bigger part is discharged into the environment via heat exchange in the cooler, or via tail pipe exhaust.

Certainly, it is easy for the reviewer to lament the miserable exergetical condition of his country and the world without trying to look for ways out of the dilemma: First of all, it is astounding how little the laws of exergo-thermodynamics, known since the 1960s (see Z. Rant and H.D. Baehr), have so far entered the legislative processes. The laws of parliaments and the laws of nature increasingly diverge, and it is not to be expected that the laws of nature will yield! Efficiency increase, that is, more energy services from less primary energy, remains part of a system which came down to us over hundreds of years of energy handling, which, though, fails to recognize that exergy efficiency increases have a huge, dormant virtual potential, which, however, requires a system change! "Virtual" means that the potentials are real, though hidden, and remained untapped – so far.

Let us try to make this clear using the already mentioned three examples (there are many more examples in all energy sectors - industry, transport, buildings, trade … ). The first example: We spoke about the impressive, though asymptotical (from a materials technology point of view, more and more difficult to obtain) ever higher temperatures which are demanded for elevated electrical efficiencies of coal fired power stations; these are efficiency increases within the applied system; but still approximately half of the energy content of the coal is not converted into technical work (= exergy). – A system change towards much higher exergies, such as the combined production of hydrogen and electricity via air separation, coal gasification, $CO_2$ sequestration, hydrogen production, and combined cycle power generation – all more or less marketed technologies – delivers, with $CO_2$ capture of some 90%, 58% of the coal's energy content as hydrogen and 4% as electricity, together 62%[3]. Even if we reserve 10% for $CO_2$ capture, liquefaction and final storage we end up with 52%. All this is not a matter of technology, we said it: it is a matter of economic viability, of societal acceptance, and political will. (For comparison: electricity generation even in a modern coal plant with an electrical efficiency of , say, 46% and energy required for capture, liquefaction, and storage of co-produced $CO_2$ of 10% sums up to 36%).

The second example: The already mentioned boiler of the central heating system of a building is energetically excellent, almost 100% of the energy content of natural gas or light oil is converted to heat, although of a temperature for which no user exists. Exergetically, however, the boiler is miserable, because it is exergo-thermodynamically simply absurd to generate flame temperatures of up to 1,000°C with the objective of supplying room radiator temperatures of some 60 to 70°C. If a hydrogen fuelled (pure hydrogen or natural gas-reformate) low temperature (<100°C) or middle temperature (≤200°C) fuel cell is installed in the boiler's stead, it firsthand generates electricity (= pure exergy) from 35-40% of the fuel's energy, with the remaining heat sufficing to warm the building over most of the year. A thought experiment: If the present 15 million boilers in Germany alone were replaced by fuel cells of, say, 5 kWe each, an IT-controlled "distributed power station" of 75,000 MWe would develop which comes near the present centrally structured installations of some 100,000 MWe: an exergetization par excellence of the country's central heating system! (Thought experiments seldom become real, but often a true kernel is in them! Here, a distributed competitor of boasting significantly higher exergy efficiency will have emerged to challenge the electricity utility system in place!) – All this is not inevitable, but it indicates what we ought to be heading towards: We certainly ought to, but – so far – we don't!

Gelöscht:

And finally the third example: the prime mover in automobiles. Here, it is not to be denied that there are exergo-thermodynamic potentials within the developed system which are being stepwise activated. The Otto and Diesel engines, as inventions of the later 19$^{th}$ century both more than one hundred years old, are still not yet fully developed: there is still potential, particularly when the entire auto system is taken into account. – However, what interests here is the system change towards exergetization: renewable hydrogen or hydrogen from $CO_2$ sequestered fossil fuels, from nuclear electricity or – better – nuclear heat is supplied to a hydrogen optimised internal combustion engine (ICE) or a low temperature fuel cell. Both are environmentally clean, and, without $CO_2$ emissions along the complete life cycle (well-to-wheel), both do not contribute

[3] P. Chiesa et al., Co-production of hydrogen, electricity and $CO_2$ with commercially ready technology, Part A: Performance and emissions, Part B: Economic analysis; Int'l J Hydrogen Energy 30 (2005) 747-767, 769-784

to the GHG–effect, they are climatically clean, too. For the engineer the development “race” between the two is highly exciting, but it is not decided yet: to make a long story short, despite all the development aims of the past for Stirlings, gas turbines, Wankels, … aboard automobiles, the fuel cell is the first real alternative in the history of technology to truly be taken seriously As a non–Carnotian energy converter, it is an exergetically highly efficient, clean, quiet, compact and non-vibrating prime mover competitor. However, the ICE doesn’t sit there, waiting for the stroke which will finish it off. It is more than one hundred years old, we said that, and according to the extremely strict codes of legislatures it is environmentally clean, and, its potential of reducing $CO_2$ is not yet zero, and, perhaps the most convincing argument vis-à-vis the fuel cell, it is marketed for a few 10 EURO/kW! From this figure the fuel cell is miles away – so far; it tries hard to catch up!

**To sum up:**
Higher efficiencies within the operational system in place are highly appreciated. The real breakthrough, however, to environmental and climatic responsibility asks for higher exergy efficiencies and, thus, a system change which seems expressly suitable for an energy poor, though technology rich industrialized country: Germany’s almost inexhaustible “energy” potential is the knowledge of its scientists and the skill of its engineers and craftsmen. Wise energy policy prior to operationally active technology politics provides an entry into the hydrogen energy economy, the necessary change to the non–Carnotian, small to medium size energy converters (watt to a few megawatts), to the according move to the centre-of-gravity of importance within the national energy chain towards its end into the secondary energy realm, i.e., secondary energies become more important than primary energies. Thinking and acting in primary energy raw materials was 19$^{th}$ and 20$^{th}$ century, thinking and acting in exergy efficient energy conversion technologies is 21$^{st}$ century.

The dispassionate energy economist may now object that such a system change needs decades, if not half centuries to centuries, and trillions worth the investments. Certainly, it is impossible in the twinkling of an eye to turn the energy system in place into systematically something else and pay for it out of petty cash. In addition, the longevity of just installed (and still to be installed in coming years) investments worth billions (power stations, refineries, pipeline grids and the like) are also many decades, up to half centuries. – But, climate change doesn’t care about any of this. The expectation may be deceptive: to reduce the anthropogenic GHG–effect to a level tolerable for humans, fauna and flora, simply through further, perhaps a little accelerated, development of today's energy system. The 2 degrees-plus figure of policy makers as the anthropogenic atmospheric temperature increase considered allowable is fictitious; its realization is not yet at hand, by far. At the latest after future gigantic hurricanes and floods à la New Orleans, at the latest after the melting of land-based ice of Greenland and Antarctica and the following rise in ocean level and flooding of the earth's marsh-lands where at least one billion people live, or at the latest after arable land which used to feed entire populations has turned into dried-out deserts, all this followed by streams of millions of climate refugees washed ashore where the wealthy highlanders live – then at the latest the call for a system change starts. To be exergo-thermodynamically well-equipped, not more, not less, is the objective of this paper.

Human imagination is rather finite, its temporal intrusion into the future is only a few years, if that. Regularly, foresights are brought to an end by unforeseen surprises, because they are simply extensions of the present[4]. Examples for such surprises are wars, tanker shipwrecks, the intended disposal of an oil platform in the North Sea, diplomatically irritating playing with the throughput throttle of an international natural gas grid, nuclear reactor accidents, or simply presidential remarks from a major oil exporting country: the almost immediate consequences are jumps in the price of oil, then of other fuels in the global energy trade system, price jumps which hit the nearly unprotected energy buying countries with their extremely high import quota and rather small exergy efficiencies (energy-short Germany's national import quota is 75%, its exergy efficiency ≈ 15%).

An effective surprise barrier is a system change to the exergy efficient hydrogen energy supported energy system; for it, prospective imagination is not necessary: whatever will come, exergy is the non-surmountable maximum of technical work which can be made available from energy! This limit is set by thermodynamics. So far, no country of the world has ever touched this limit. The goal is within reach, but it's a long way to Tipperary. Anthropogenic climate change calls for taking this way and seeing it through! Hydrogen energy helps, it crosses the border, disclosing the system change. Hydrogen energy exergizes the system.

…and be advised: itsHYtime.de

[4] similar thoughts in D.S.Scott, Smelling Land, The Hydrogen Defense against Climate Catastrophe, 2007 www.h2.com