Strategy of the Energy Supply in the Paper- and Cardboard-Industry

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This essay considers the macroeconomic context of the predominant supra-regional energy scenarios, the economical aspects and, derived from both, the technical concept of the combined heat and power station (cogeneration) technique for an industrial company with a three-shift operation in Germany.

Preface to the edition 2010
The elaboration prepared in 2007 is based on the scenarios recognizable at that time. These were reviewed in 2010 with the result that events of these scenarios have already arrived. The scenarios are still up to date.

1 Limits of Growth

Two ranges of topics have determined the entrepreneurial evaluation for an in-house energy supply of a company. These were, and still are electricity and primary energy. Added to this is the industrial influence on climate control loops, which are constantly accompanied us continuously for a decade now under the term climate change and CO_2 emissions. From the situation of today overseeable energy scenarios, the energy supply strategy of the privately-operated companies is derived from. Therefore, the most important scenarios will be analysed briefly and in summary.

1.1 Primary Energy

During 20 years, until 2004, the organisation of the Organisation of the Petroleum Exporting Countries OPEC kept the crude oil price at a level below 28 US$ per barrel. The former almost normal fluctuations in oil prices on the Rotterdam spot market were subject to the respective current status of the oil stocks and the resulting demand. With the emergence of economic powers in Asia the market behaviour has changed.
No longer the demand from the U.S. but from China and India affects the price of crude oil, which receives an additional uncertainty component due to speculation.
After the nationalisation of the production facilities in Venezuela, 80 % of crude oil production has fallen into government hands, which usually perform a conservative investment policy.
Thanks to the energy policy of the 1980, triggered by the OPEC oil price shock in 1974, the today crude oil prices above 70 US$ per barrel do not cause noticeable disturbance of the economy. At that time the concept of the German Government was: "Moving away from oil" as fuel for the electricity industry and expansion of nuclear energy. The exploitation of gas and oil deposits in the North Sea has also become lucrative at the time.
Germany actually reduced its primary energy growth. Since 1995, the increase is declining. The primary energy consumption decreased between 1995 and 2006 by 1.0 %, while the gross domestic product increased by approximately 24 % and the electricity consumption increased by approximately 12.5 %. Gross Domestic Product and Electricity Consumption are closely connected according to global statistics.

There is no shortage of natural gas in the foreseeable future. The price for natural gas supply from Norway and Russia, however, is still bound by contract for years with those countries to the oil price. The current price of crude oil, as the basis of calculating the price of natural gas, is considerably influenced by global crises. The increasing threat to the world community is difficult to assess. This price determination is expected to be broken through diversification of supply from additional supplier countries. New projects shall make sure this, such as the construction of the North Stream Baltic Sea pipeline and other projects, such as planning the Blue Stream and Nabucco pipeline from the Iranian and Kazakh area (Fig. 1). Natural gas continues to be the ideal fuel for industry. It burns to about 45 weight percent to water and to about 55 weight percent to CO_2; natural gas is an environmentally friendly fossil fuel.

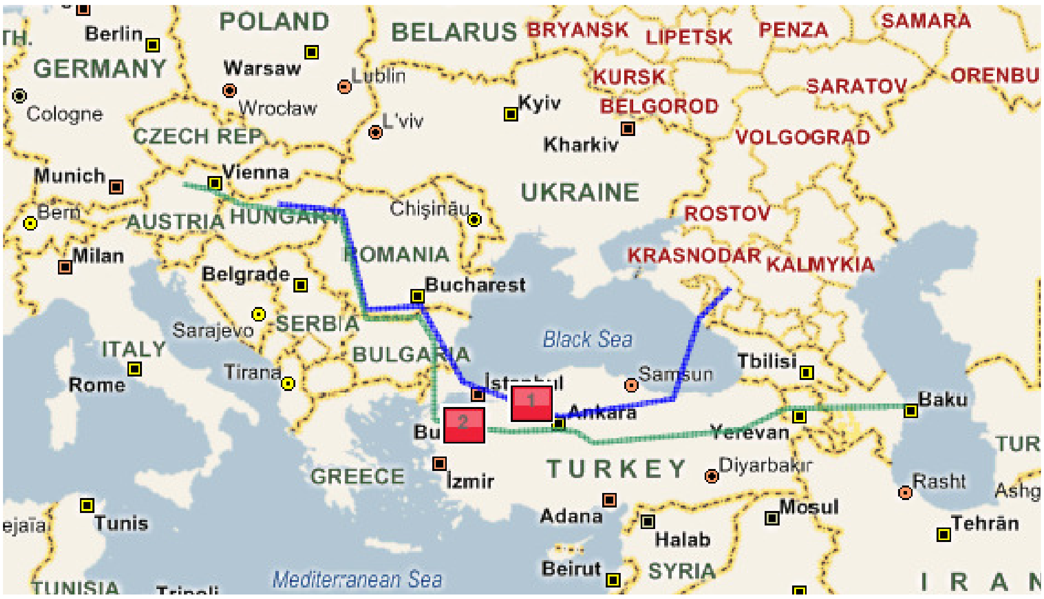

Figure 1 above: Newly constructed natural gas pipeline North Stream
Figure 1 below: Newly planned natural gas pipelines (1=Blue Stream; 2=Nabucco pipeline)

New natural gas pipelines as well as additional liquefied natural gas deloading stations shall ensure the natural gas supply of Europe in the long term.

1.2 Electricity

Electricity supply is the fundamental basis for the production of the gross domestic product (GDP) and consequently prosperity of a country. Specifically, highly available, frequency-precise and low-cost electricity generation. In the sector of the electricity industry drastic changes have occurred in the past two legislative sessions, and shortly before. The liberalisation of the electricity market in 1998/99 in Germany initially led to a short-term price decline with starts of economic growth. The price drop of electricity caused a restructuring of the electricity market as well.

Today we are dealing with privately-owned large-scale corporations, whose pricing (including high government charges) are subject to supply and demand, which is from the market economy standpoint not objectionable. The constellation of public energy policy is unfortunately marked by controversy trends. Phase-out of the global economy stabilising nuclear energy and substitution of available energy resources (such as uranium) by energies, that are subject to a statistical random (such as wind), are just two of the economically incompatible scenarios.

A substitution of nuclear energy by wind turbines, as a political target for two legislative periods, has not been managed until today despite a huge installed capacity of wind turbines (27 gigawatts at the end of 2010). For wind turbines, installed in the main land, in annual mean only 10 to 20 % of the installed capacity of a wind generator can get used for the generation of electricity work due to statistical frequency of wind speed. For off-shore wind turbines, this proportion is about 40 – 50 %. For all wind turbines in Germany, this proportion is about 15 – 20 %. However, the electricity generated by wind energy has an advantage: the construction of wind turbines had so far prevented a shortage situation of the electricity generation, which would be caused by stagnation of public power plant construction. Even if we accept today the wind power because of the CO_2-reducing electricity supply, the wind power trigger technical supply disruptions from consisting in that the existing electrical grid structure can not follow the electrical power load requirements resulting from this technique. Storms are causing large-area protective shut-downs at wind turbines, which can technically still be absorbed by the rotating reserves of conventional peak-load power plants. But the transmission grids do not have the capacities to manage the step-changing electricity flow without disruptions. The shut-down of a transmission line on 4$^{th.}$ of November 2006 in conjunction with a boat transfer at the Ems River, nearly a year after the snow chaos in Münster, shows the vulnerability of the electricity distribution system whose impact was felt as far as Spain.

Further installations in wind power technology require, because of their weather-dependent random electricity generation availability, additionally electricity generating capacity on the basis of a secure primary energy availability for reserve management and an electric grid expansion, which can compensate the suddenly occurring asymmetries of electricity flow. These loads would have to bear the wind energy sector by economic theory, what it does not, however. For urgently needed investment in electrical grids, high-voltage power lines and coupling points with neighbouring countries, planning security and energy policy framework is missing.

We see electrical grid investments as well as performance improvement investments of conventional power plants with priority. England and France have become known to an expansion of power plant capacity. Eon and RWE do invest several billion Euros in Great Britain in new power plants. The flow of capital for new power plant constructions goes to Scandinavia and possibly to Russia as well. While some coal power plants (Grevenbroich, Hamm and others) are under construction also in Germany, mainly as a replacement for existing power plants, there is no sustainable solution for their climate impact, let alone an accepted state of the art.

1.3 Climate Control Loops

Since 2004, European countries are, triggered by the Kyoto Protocol, subject to an emission limit for CO_2-emitting products and plants that alone does not necessarily mean a loss of prosperity. It is an undisputed objective that the earth must be relieved from of trace gases and from the amount of CO_2-emissions that can not be regulated in the earth atmosphere anymore and that cause a greenhouse effect. We will not be able to avoid mitigating global warming worldwide.

The nowadays manifested climate protection targets - 40% reduction of CO_2-emissions by 2020 - are definitely manageable. However, it requires a conversion from conventional, in the past economically justified cost-effective techniques to best available techniques. The increase in electrical efficiency for pure electricity generation, which is on national average at about 41%, is now under the term "efficiency improvement" a recognized target.
Combined heat and power (CHP), also known as Cogeneration, has in the last two decades contributed to keeping the primary energy consumption in Germany constant with increasing electricity generation. The use of cogeneration technology for nationwide electricity supply is also limited. CHP can only exploit the potential of the existing heat demand. Since the electricity consumption in Germany is many times, about a factor of 2,5 - 3 higher than the exploitable cogeneration potential of the industry and district heating sector, always condensing power plants (for example coal-fired power plants), next to systems of renewable electricity generation will be required for the main supply of an industrial state in the best available techniques.

1.4 Résumé of the Energy Scenarios

As a summary, the following trends can be forecasted from today's perspective:

- The public electricity supply in Germany is heading to a electricity supply shortage, particularly in South-Germany, with market conditions based (supply and demand) rising electricity prices, and
- to a decreasing availability of the electrical grids.
- Depending on the speed and the extent of the development of alternative electricity generation technologies in comparison with the development of the electrical grids, there will be times when not all of the electricity produced in the north of Germany can be transmitted to the south of Germany, without using the foreign electrical grids.
- Increasing capacity of the primary energy supply by natural gas with a reserve range of several decades has to be seen as positive.

2 Strategy

Factors such as liquidity, availability, energy cost sensitivity are among other things of importance to the business decision for or against an own electricity generation. A key indicator that describes the price constellation is the ratio of electricity price to fuel price (based on the lower heating value). This indicator for the fuel natural gas has decreased since 1990 from the number 4, with variations of course, to the number of about 2.6. Today's price index is dominated by the escalation of crude oil prices on the international markets shortly before the start of the Iraq war.

The paper- and cardboard manufacturing industry which, like the chemical industry and mining sector, is extremely electricity-oriented, the question arises concerning an energy concept, which is insensitive against future price fluctuations.

2.1 Best Possible Techniques (Best Available Techniques)

Under the pressure of future expected restricted electricity supply, it is important, that CHP potential, that lies mainly in the private sector, shall be used even more. Each unnecessarily primary energy wasting plant or waiving of cogeneration with best possible techniques is national-economically a disadvantage, which ultimately negatively affects in addition the economic growth in Germany. The mechanisms of the free market will affect as ordering factors again in the future under the pressure of price escalation in electricity generation.

For further understanding, the concept of the electricity-to-heat ratio will be briefly explained. The ratio of electrical power generation to useful heat power supply we call the plant electricity-to-heat ratio, it is dimensionless. One ton per hour of process steam is converted into heating power with the heat-equivalent 650 kWh/t (applies to saturated steam or slightly superheated steam with 2.5 to 5 bar).

Under fuel utilisation factor, we mean the ratio of the sum of the useful energy produced and delivered (in this case electricity and process steam) and the energy input into the plant (firing rate).

In this context, we understand the best possible techniques for cogeneration plants not only for those plants with the highest possible time reliability and other required characteristics, but especially plants, that achieve highest primary energy savings compared to similar plants with the same useful energy generation, and which air pollutant emissions are minimised by primary measures with emission related best possible techniques.

For turbine-based cogeneration plants, best possible techniques are high-grade combined heat and power stations with highest possible fuel utilisation factor and elevated electricity-to-heat ratio, as offered by plants with a combined gas turbine and steam turbine process (combined cycle CHP stations) with radiation-type steam generator and low emission steam generator firing.

The ordering forces of a market concern especially less efficient CHP plants, whose fuel efficiency is often in the range of 75%. These plants had a growth in times with cheaper natural gas prices. That growth collapsed in the moment when the price ratio electricity to natural gas fell below the value of 3,6. At today's energy prices, simple generation plants do not achieve a sufficient investment pay back anymore. Through conversion, for example from gas turbines with low-pressure heat recovery steam generators to combined gas turbine and steam turbine CHP stations with radiation-type steam generators and additional steam turbines, older gas turbine cogeneration CHP stations can save up to 20% of its current consumption of primary energy, provided that either by using the same gas turbine, the amount of useful heat demand makes even with the use of a radiation-type steam generator steam condensation unnecessary or the gas turbine is reduced in size.

A comparison of the cost of electricity self-generation of an industrial company with the use of various cogeneration technologies (*Figure 2*) shows, that plants with steam generation in radiation-type steam generator technology - which are steam turbine CHP stations and CHP stations with a combined gas turbine and steam turbine process (combined cycle CHP) with radiation-type steam generators - have an economic superiority. It must however be added, that steam turbine cogeneration plants with pure back-pressure steam turbines for industrial use achieve only electricity-to-heat ratios of about 0.2, lack of electricity has to be bought then in addition. In a mixed calculation thus, higher energy costs are resulted, as *Figure 2* conveys. For the paper and cardboard industry, which requires electricity-to-heat ratios between 0.3 to 0.65 (without pulp), CHP stations with a combined gas turbine and steam turbine process with radiation-type steam generators low emission steam generator firing such as for example the SYSTEM HUTTER are the better choice.

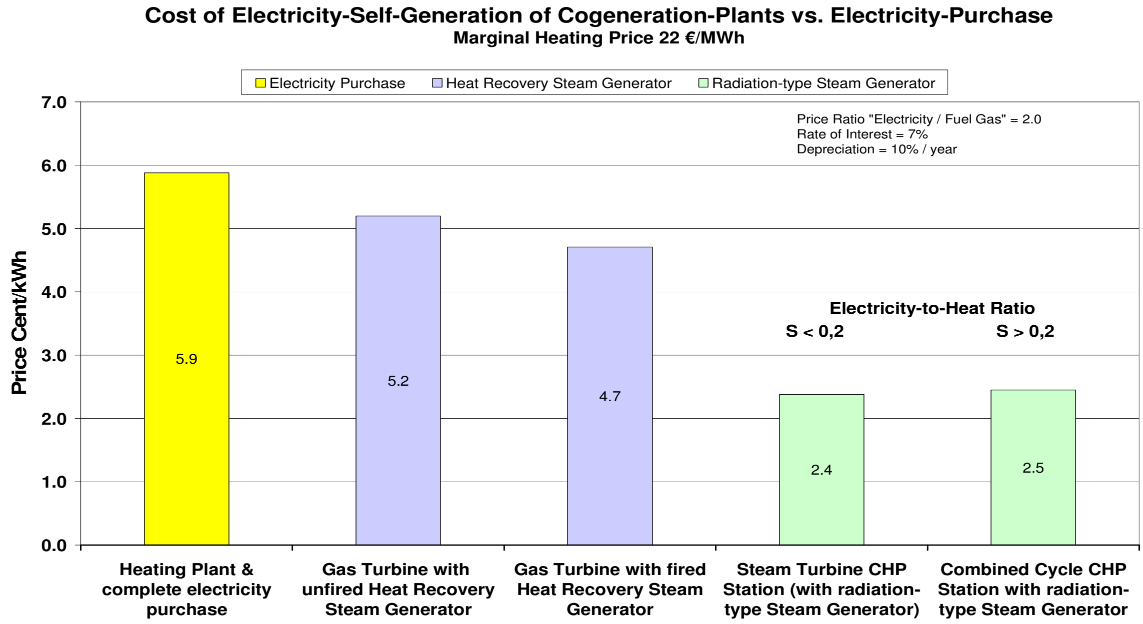

Figure 2: Steam turbine CHP stations as well as CHP stations with combined gas turbine and steam turbine process (Combined Cycle CHP stations) with radiation-type steam generators do have the lowest cost of electricity self-generation

2.2 Economic Requirements

The achievable fuel utilisation factor of industrial turbine-based CHP stations is subject to physical limits; namely in dependence on the chosen electrical power output per ton per hour steam. The limit of the efficiency at turbine-based CHP stations depends on the one hand on the amount of the exhaust gas mass flow and on the other hand on a “temperature bottleneck” within a steam generator, which is called pinch point. Pinch point is the smallest temperature difference between the exhaust gas medium and the water-steam medium in the steam generator. The place of occurrence of the pinch point in the steam generator and its value significantly determine the minimum achievable flue gas temperature before the chimney. In gas turbine with heat recovery steam generator plants, the pinch point is located at the evaporator and thus the minimum achievable flue gas temperatures before chimney are limited with small and medium supplementary firing rates in the steam generator limited at higher temperature values. In gas turbine with radiation-type steam generator plants, the pinch point is located at the end of the steam generator, so that the flue gas temperature before chimney is determined only by the entering feedwater temperature in the boiler and by the terminal temperature difference of the last steam generator heat exchanger and thus may achieve low values.

In combined cycle CHP stations and Gas Turbine CHP stations, the rule for plant electricity-to-heat ratios above approx. 0,4 is, the higher the electricity generation of a CHP plant per tonne per hour of process steam supply, the lower the best possible realisable fuel efficiency becomes. *Figure 3* shows the dependence of the fuel utilisation factor of the selected electricity-to-heat ratio for a CHP station with a combined gas turbine and steam turbine process with pure back-pressure steam turbine for a constant nominal process steam supply of 100 tons per hour.

It is now a question of evaluating the investment in the self-electricity generation portion of a cogeneration plant and of the desire of independence of public electrical grids, which total efficiency drop one would allow. The economic optimum may differ in fact from the technical optimum and is not necessarily the same as this. (For the district heating business with hot or warm water as useful heat, there are of course other contexts!)

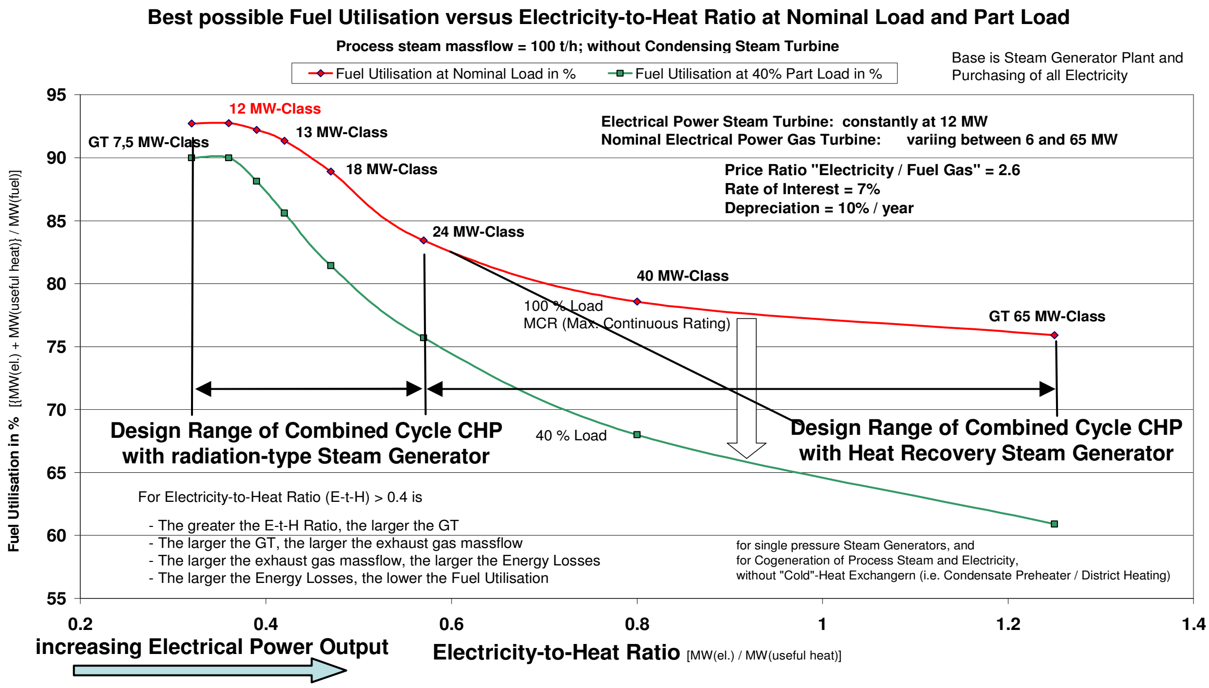

Figure 3: At plant electricity-to-heat ratios above approx. 0,4, the best possible fuel utilisation factor (total efficiency) and the part load capability of combined cycle CHP stations and Gas Turbine CHP stations become smaller

The manufacture of paper and cardboard needs electricity and useful heat in form of low pressure steam. The ratio of electricity and useful heat depends on the grammage and the drying process of the paper- or cardboard machine. The required electricity-to-heat ratio of a mill is in paper- and cardboard production in the range from 0,3 to 0,65. Pulp needs even higher operational electricity-to-heat ratios.

With respect to the energy supply, the profitability of a residue waste-to-energy plant, which generates live steam, shall be investigated in the event, that there are sufficient and adequate residues from paper- or cardboard manufacture. The residue waste-to-energy plant is to optimally design along with the CHP plant. The use of a residue waste-to-energy plant leads to a situation, that the CHP plant must have a higher plant electricity-to-heat ratio, as the steam supply from the CHP plant is reduced according to the residue waste-to-energy plant.

In the following it is assumed that no residue waste-to-energy plant is installed. Thus, the design of the CHP plant must be based on the demand of the paper or cardboard manufacture. *Figure 4* shows the IRR (Internal Rate of Return) -- calculated with a dynamic capital value method [4] -- depending on the electricity-to-heat ratio. The underlying calculations are based on a CHP plant with 100 tons per hour nominal process steam supply and a 12 MW back-pressure steam turbine without condensation process. The data points on the curve now represent different gas turbine models with an electrical capacity of between 6 and 60 MW. Each data point corresponds therefore to another CHP plant with different gas turbine nominal power, but all with the best possible fuel efficiency as shown in *Figure 3*.

The chosen example with a heat output of 100 t/h nominal process steam supply can for other process steam supply ratings be estimated proportionally. The selected field parameter for the price ratio electricity to natural gas is 2.6. For each individual mill, an own assessment must be performed of course.

The diagram in *Figure 4* shows that the economic optimum of a CHP plant with combined gas turbine and steam turbine process is in the area of plant electricity-to-heat ratios between 0,3 and 0,45. The internal rate of return reacts extremely sensitive to the plant electricity-to-heat ratio and according to the context in *Figure 3* as well to the fuel utilisation factor. A difference in total efficiency of less than 15 percentage points in absolute terms determines, whether a CHP plant is profitable or not. Subsidies and KWK-support (Cogen support) according to Cogen laws are not considered in the calculations, they are not necessary above a certain plant size for the economic use of a good CHP technique.

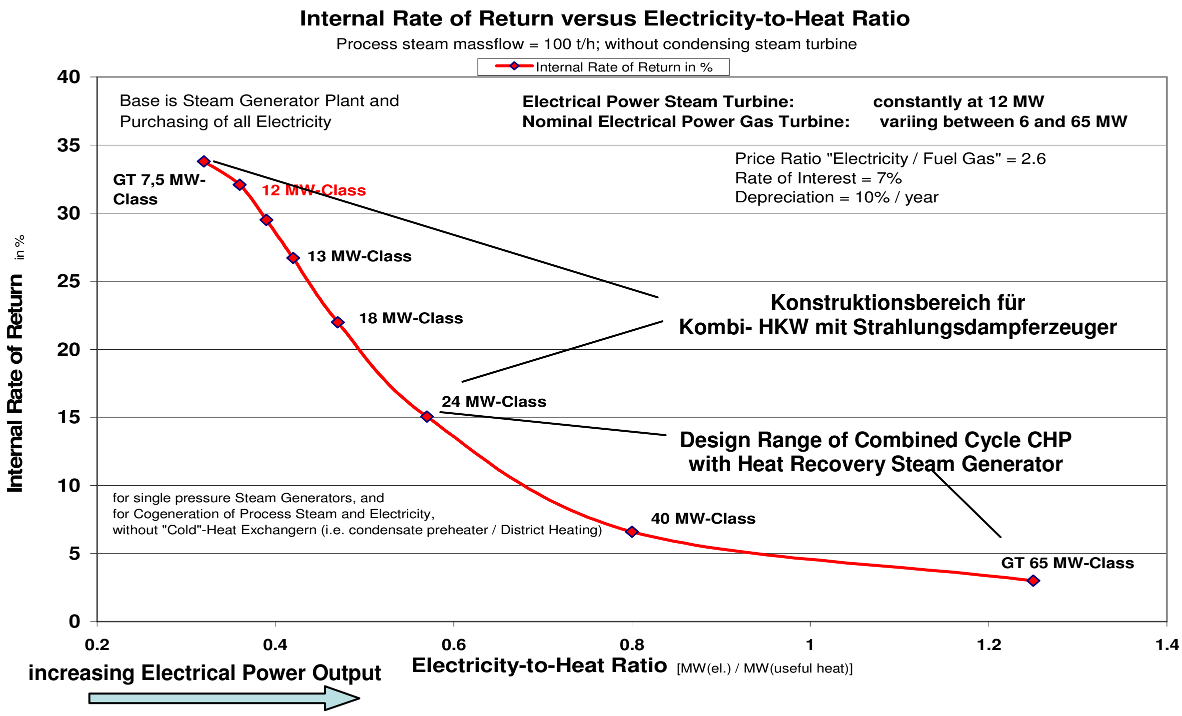

Figure 4: High-grade CHP-plants with high fuel utilisation (Combined Cycle CHP with radiation-type steam generator) achieve a high rate of return.

2.3 Technical Requirement

The special task in paper and cardboard manufacture requires a wide range of part load of the steam generator, in which the high-pressure steam conditions can be kept over the possible load range of the boiler with regard to steam temperature and -pressure. Gas turbine CHP plants with heat recovery steam generators have a limited part-load capability with regard to the min. steam generation. For applications with steam as useful energy (e.g. process steam), CHP plants with high fuel utilisation can only be realised with radiation-type steam generators. Conventional radiation-type steam generators in combined cycle CHP plants cover in relation to the steam production only a load range between approx. 60 to 100 %. Below an approx. 50% - steam generation load, the steam turbine are known to go into protective shut-down, if no special measures such as energy-wasting steam blow-off or steam condensation are taken. For reasons of energy-savings, new requirements on the part load behaviour of a plant are demanded.

Figure 5 shows the trend of the steam temperature after final superheater in a modern, newly developed radiation-type SYSTEM HUTTER steam generator with live steam conditions at 90 bar and 470 °C. While in conventional steam generators in combined gas- and steam turbine CHP stations at part load, the steam turbine will go in protective shut-down below a HP steam temperature of an approximately 410 °C limit, the modern plant can hold the nominal live steam temperature almost even when the steam generator firing is switched-off and the steam turbine remains in operation. The result is an extended controllable part load range up to about 20 – 25 % of the rated live steam generation.

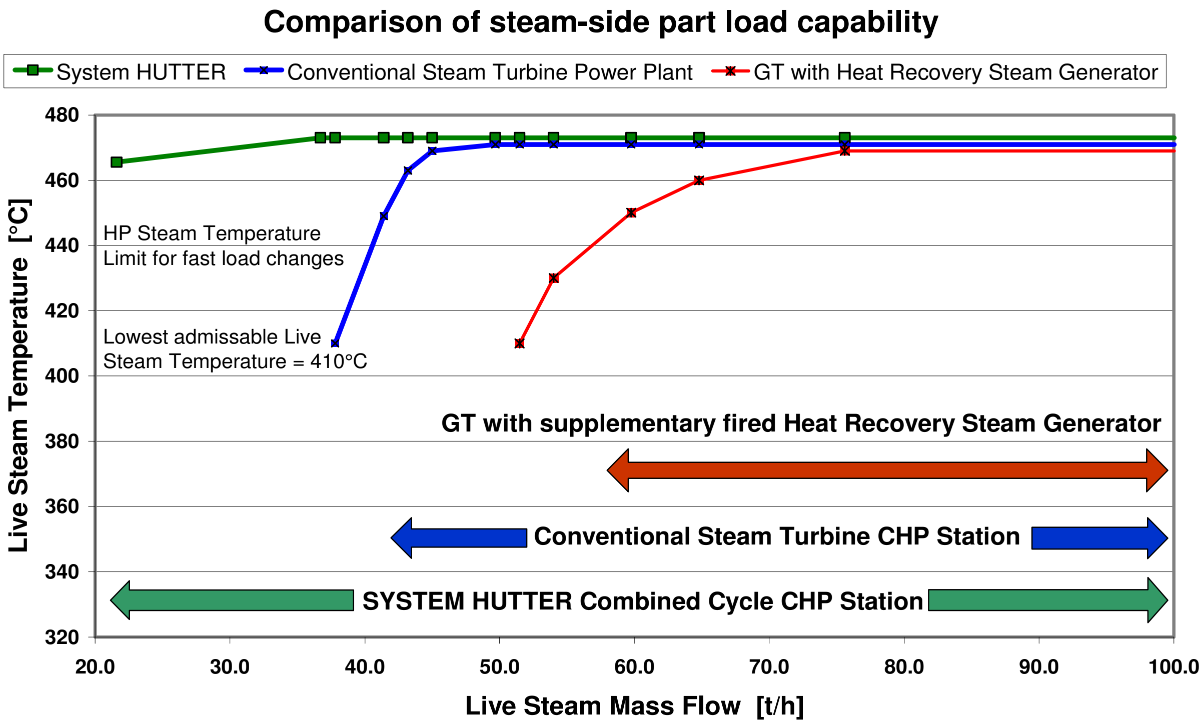

Figure 5: Steam-side part load capability and live steam temperature curve in a modern combined cycle CHP station with radiation-type SYSTEM HUTTER steam generator compared with a steam turbine CHP station with conventional radiation-type steam generator and with a gas turbine CHP station with fired heat recovery steam generator and steam turbine

2.4 Résumé of the Supply Strategy

From the above explanations, the following energy supply strategy arises to our knowledge for the paper- and cardboard manufacture, which is:

- as far as possible self-sufficient supply with electricity and heat with sufficient reserve.
- Investment in self-supply combined heat and power (CHP) plants with best possible fuel utilisation factor.
- Investigation of a residue waste-to-energy plant with optimal integration in the CHP station, where the supply during the planned standstills of the residue waste-to-energy plant is to be considered as well.

For an investment decision, a high profitability is a crucial prerequisite for the use of a CHP technology in the paper- and cardboard industry. In addition, technical capabilities of a CHP plant and the chosen CHP technology play an equally important role for the company decision.

A high fuel utilisation factor, as derived above, is a basic requirement for today's combined heat and power stations. To be able to orient themselves in the variety of turbine-based CHP technologies, that are offered in the market today, the chart in Figure 6 may be a help. In *Figure 6*, fields as simplified representation are shown over the plant electricity-to-heat ratio, which present the design limit of various turbine-based cogeneration technologies. The fuel utilisation factor is shown on the ordinate axis.

CHP plants with radiation-type steam generators, both pure steam turbine CHP stations as well as CHP stations with a combined gas turbine and steam turbine process (Combined Cycle CHP stations) with radiation-type steam generators such as the SYSTEM HUTTER, which achieve a fuel utilisation factor of 88 – 93 %, thereby represent the superior technology.

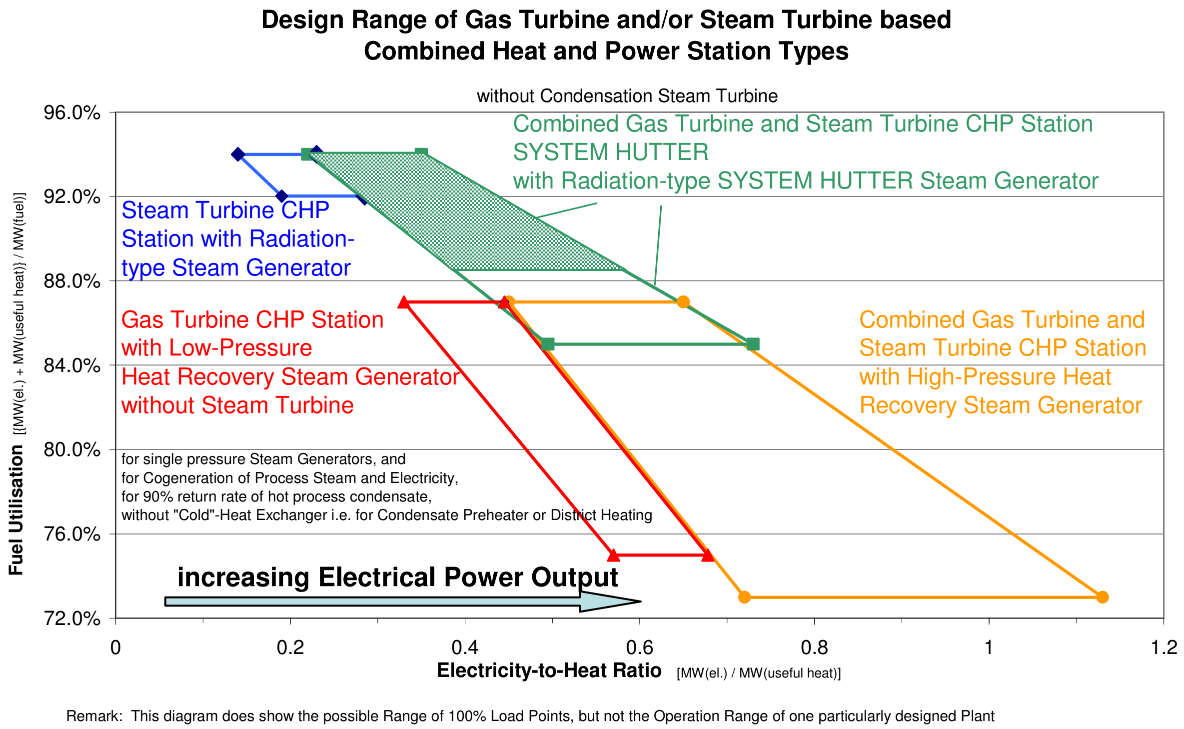

Figure 6: Design range of turbine-based CHP stations

3 Summary

Private sector companies do have about 80 % of the cogeneration potential in Germany [1]. For the further realisation of this potential, technically high-grade combined heat and power stations with combined gas turbine and steam turbine process (combined cycle CHP stations) are available, which achieve highest fuel utilisation factors of up to 93 %. Properly designed cogeneration plants are a capital investment with a return (internal rate of return) of over 25 to 30 %. They not only contribute to save the country's CO_2-emissions, but also create an independence of the public electricity supply, whose time availability will be difficult to ensure under the prevailing supply scenarios.

Apart from energy savings, high-grade natural gas-fired CHP stations with high fuel utilisation factors for industrial applications, residue waste-to-energy plants, waste incineration plants as well as a large-area electricity supply on the basis of hydropower, hydrogen technology and to a certain extent of the wind energy and domestic biomass, are those approaches to a solution, that will allow us over generations to obtain the vital CO_2-balance and to sustain prosperity.

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