EXPERIENCES AND DATA OF A GERMAN 7-MILLION LBS/HOUR 500 MW CO-GENERATION SYSTEM

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Combined heat and power generation in Germany can look back on a long tradition, particularly in industries having high heat requirements, such as the chemical, paper and sugar industries.

Industrial power generation, roughly one-half in the form of co-generation and one-half pure electrical generation, accounted up to 1962 for approximately 38% of all power generated. This percentage has steadily dropped since then to the current level of 18%.

The development is due to a variety of reasons.

1. Combined industrial heat and power generation in Germany represents an ideal complement to public electrical generation. The greatest electricity demand peaks occur in winter, that is to say, at times when the electricity generated through co-generation systems is at its maximum, due to the high heating energy demand. The public electricity suppliers were, therefore, prepared to provide the industrial power generators with additional power at lower prices to cover their demand in summer. However, this readiness decreased with the start-up of large-scale public power stations, because of high supplementary electrical requirements during annual maintenance shutdowns.

2. For a long time, the technical developments in co-generation ran parallel to the technology of public electricity generation, and were even able to provide valuable contributions to the latter, owing to the more favorable competitive conditions. The reasons here were the higher acceptable specific investment costs for industrial power generation as opposed to public power generation. This comes from the fact that no additional power transport costs occur in the case of co-generation and that the number of operating hours per year is normally much higher.

   However, at the start of the 1960's, the public power stations, unlike the industrial co-generating systems began to develop toward increasingly larger and more economical unit sizes (300/600/1,200 MW). Since the price of electricity dropped as each new large-scale power station was opened, the public power generating sector began to regard industrial power generation as a rival, and consequently made it more difficult for the companies to build new industrial power stations by introducing parallel-operation fees, high reserve capacity costs and special tariffs for additional power demands.

3. Hydroelectric power plays only an insignificant role in power generation in the Federal Republic of Germany. The prices for conventional fossil fuels are, therefore, of equal importance for both industry and the public utilities and - compared to the situation in the USA - prices are high. Fuel savings of up to 60% with co-generation as opposed to public power generation by the condensing method thus play a major role, particularly in the case of high numbers of operating hours, and even more so because fuel transport is cheaper than power transport.

   Not until nuclear energy arrived on the scene did public condenser-type power stations gain competitive advantages. Nuclear power stations may be built outside conurbation areas, but not in densely-populated industrial areas where the best conditions for combined heat and power generation exist.

4. The major fuel savings of co-generation, requiring approx. 40% of the heat needed for condenser-type power stations, reduces environmental pollution to the same extent. Correspondingly, lesser quantities of waste are produced, less flue gas and pollutants are emitted, and the effects of the waste heat on the environment are also reduced accordingly. These factors have become more important today.

5. Industrial self-generation increases the supply security of a plant considerably, and, in the event of faults in the utility grid, permits continued operation of important production facilities on an isolated supply basis, or at least the correct shut-down of such plants without danger to human life or to the environment. This type of plant security is also becoming increasingly important in Germany as a result of statutory regulations.

6. In many cases, an additional, small-scale condenser-type generating system will offer an economical capability for avoiding expensive power demand peaks. This applies particularly in instances where condenser-type generation is only required at times having a low heat demand, i.e. where no additional boiler or topping turbine capacities are necessary for this purpose. Since electricity charges generally include considerable capacity charges, the mere existence of an additional condensing turbine can already achieve major savings in power costs.

The above-named points resulted in the described developments in the past. In view of rising energy prices, difficulties in procuring new power station sites, and also in attempts to reduce its balance-of-payments difficulties, the Government is trying to achieve a broader application range for combined heat and power generation, particularly with a view to district-heating systems. Numerous measures have been implemented to this end:

1. In the face of slight pressure from the Government, the associations of industry and of the public utility companies have concluded an agreement which establishes the following points aimed at eliminating any discrimination against industrial power generation on the basis of combined heat and power generation:

   a. No fees may be levied for operation parallel to the utility grid system.

   b. Purchasers of supplementary power must not be put at a disadvantage over exclusive customers.

   c. The customer can himself establish the level of the required reserve capacity in advance from year to year, irrespective of the size of his power generating units.

   d. Superfluous electricity must be absorbed by the public utility at fixed minimum prices. These minimum prices are higher in the case of regenerative energies, such as hydro power or refuse, than for cases where oil or gas is used. In the case of guaranteed supplies, e.g. on a programmed basis, capacity costs must also be paid.

   e. The transmission of electricity via the utility grid system to a different plant belonging to the same industrial company must be permitted by paying an appropriate transmission fee.

   f. In return, the electricity companies demand that, during periods of lesser industrial activity, the self-generation of electricity should be reduced to the same extent as the purchase of electricity.

2. A similar agreement was reached with respect to the feeding of industrial waste heat into district-heating systems.

3. In accordance with Article 4a of the Investment Grants Act (investitionszulagegesetz), the State awards tax-free grants amounting to 7.5% of the investment cost for the construction of combined heat and power stations, refuse-fired heating stations, heat recovery plants and district heating networks.

4. A fund supported by fees levied on electrical consumers on the basis of the 3rd Electricity Supply Act (Verstromungsgesetz) is used to subsidize the construction of coal-fired power stations and the use of domestic coal. Combined heat and power stations can receive grants of up to DM 480.00 per KW toward the investment cost of installed electric power, provided that they agree to use at least a certain minimum amount of coal over a 10-year period.

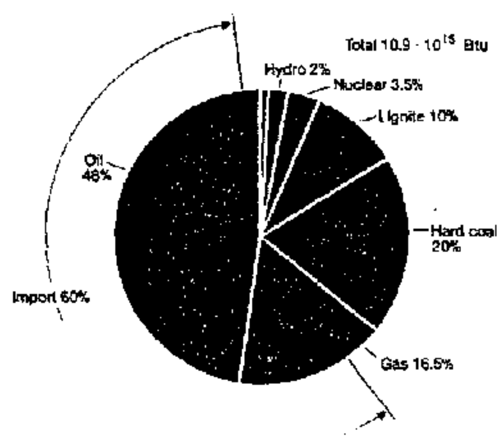
5. The State governments use tax funds to subsidize various regional programmes for accelerated construction of co-generation systems and district heating networks, - ~~particularly for the supply of public~~ heating, for saving light fuel oil and for reducing effects on the environment. An example of such a project is the district heating system in the Ruhr district.

These subsidies are still required, even at today's high energy costs, due to the considerable capital expenditure costs and the low annual utilization of the public district heating supply systems. Unfortunately, the poor general economic situation and the resultant poor state of the Treasury mean that the available funds have almost been exhausted. In my opinion, the development and expansion of district heating supply systems can be regarded as a structural measure, similar, for example, to the construction of roads and underground railways.

6. The Regulation on Large-Scale Firing Systems (Grossfeuerungsverordnung) currently in preparation, specifies merely the use of coal having a sulphur content of less than 1% and the verification of an SO_2 content of less than 2,500 mg/m^3 in the flue gas. This applies to firing systems under 19 MM scf flue gas or approximately 1.4 x 10^9 BTU/hr. In addition, combined heat and power stations may be credited for their SO_2 emissions that are avoided by replacing existing individual firing systems.

However, I do not wish to paint too rosy a picture of the energy situation in the Federal Republic of Germany by listing the above points. In fact, there is considerable resistance to the construction of new co-generation systems from environmentalists, and citizens' action groups. The energy supply situation in the Federal Republic of Germany at the moment can be described as follows. (Fig. 1)

Fig. 1

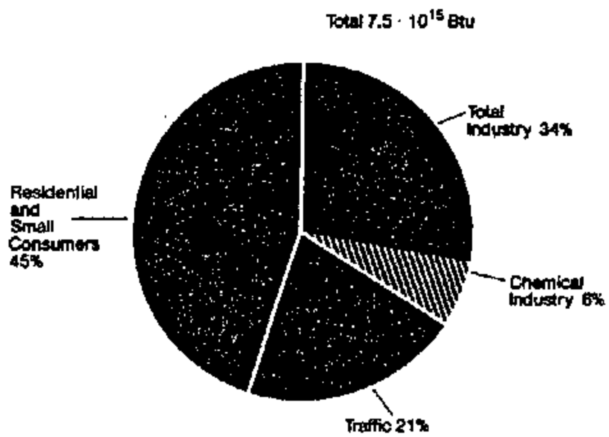


Bayer	Primary Energy Consumption 1980 FR Germany	IfEN 81-061

Two-thirds of the total primary energy demand is covered by oil and natural gas, some 90% of which has to be imported. Domestic hard coal is very expensive due to its deep geological location, and is subsidized by the Government. Consequently, oil can only be substituted by imported coal and by nuclear energy.

The final energy demand is divided among three consumer sectors: households, transportation, and industry. (Fig. 2)

Fig. 2

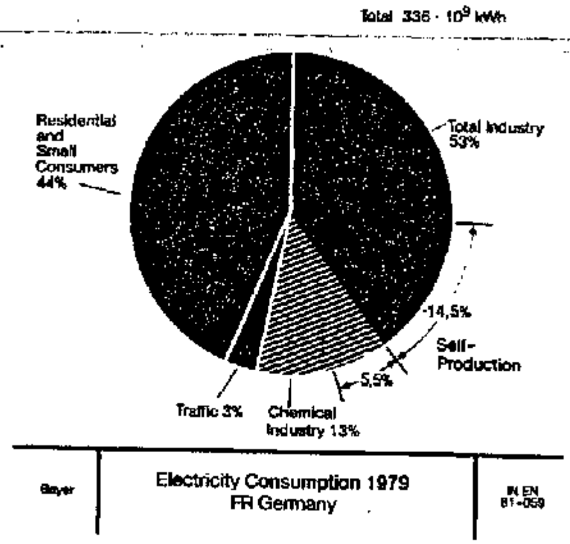


Bayer	Final Energy Consumption 1979 FR Germany	IN EN 81-060

In 1979, 34% of the total final energy demand in the Federal Republic of Germany was attributable to industry. The chemical industry required 6% of the total final energy demand (excluding raw materials). The chemical industry requires considerable quantities of energy vehicles such as naphtha, natural gas, etc. as chemical raw materials. The total including these raw materials then increases to 16%.

The pro rate power consumption of industry and of the chemical industry amounts to 53% and 13% respectively. (Fig. 3) Industry including the chemical industry generates - some 40% of its own power requirements. Backpressure generation accounts for some 84% of the power generated in the chemical industry, thus making the chemical industry the largest user of co-generation systems.

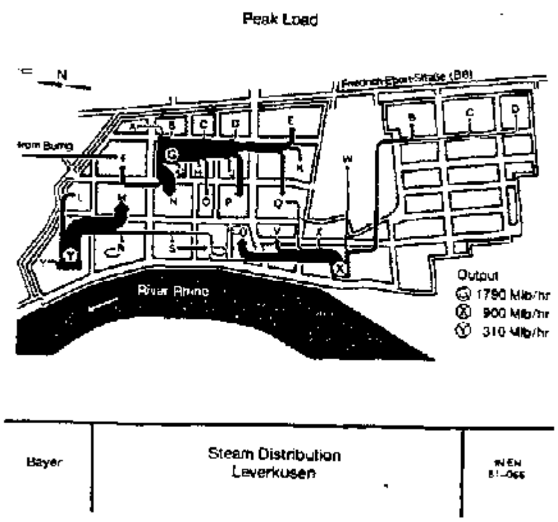
Fig. 3



The following is a description of experience obtained from the design and operation of combined heat and power generation systems, taking the Bayer AG company as an example.

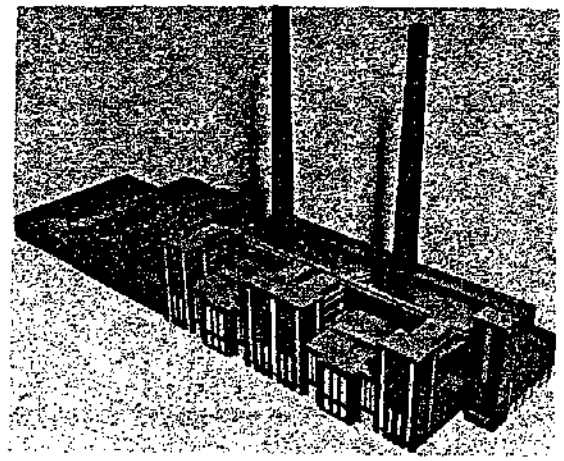
In its plants in the Federal Republic of Germany, Bayer operates a steam boiler capacity of 7.1 million lb/hr and an electricity or power generating capacity of approximately 600 MW, 95% of which is based on co-generation. Roughly half of these generating facilities are located in Leverkusen. Fig. 4 shows the plant location at the river Rhine and the steam flow during peak load. The plant covers 700 acres.

Fig. 4



Co-generation on a major scale started in our Leverkusen plant in 1925. Today, our Leverkusen plant is capable of generating approx. 3.4 million lb/hr useful steam with a combined back-pressure power output of approx. 230 MW electric and an additional 17 MW from full condensing turbines. The main power station (Fig. 5) consists of 4 coal fired and 4 oil/gas fired boilers, 12 electrical generators and includes also the central compressed air generation. The length of the block is 780 ft.

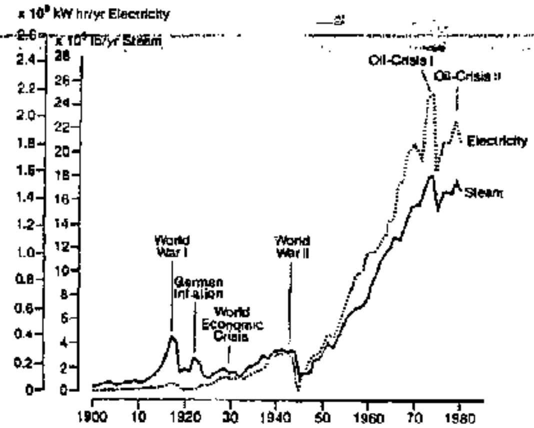
Fig. 5



Bayer	Main Power Station Leverkusen Steamcapacity 2.2 MMlb/hr	INEN 91-062

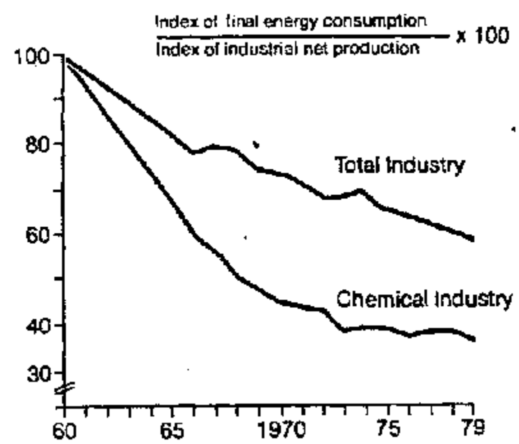
As mentioned, energy generation has increased considerably. Fig.6 should help to illustrate the development of the steam and electricity demand at Leverkusen, since 1900. Energy consumption increased significantly in the 50's and 60's. In spite of this increase major energy savings were achieved. Fig. 7 shows that the specific energy consumption level of the German chemical industry today is only about one-third of the value of 1960.

Fig. 6



Bayer	Energy Consumption Leverkusen	IN EN 81-045

Fig. 7



Bayer	Specific Final Energy Consumption FR Germany	IN EN 81-050

Not only steam, electricity and water are centrally generated and distributed at Bayer, but also compressed air, refrigeration and industrial gases. (Fig. 8) The useful steam is delivered to the production facilities at various header pressures. More than 60% of the steam consumed is supplied at pressures of 70 psi or less. There are major chemical companies in Germany which operate with steam distribution networks down to pressures as low as 40 psi. The higher investment cost for the additional steam pipelines is soon offset.

Fig. 8

Steam	70 psi 210 psi 435 psi 1560 psi
Electricity	500/660 V 5/6/10 kV 25/30 kV 110 kV
Water	Potable Water Plant Water Cooling Water Soft Water Demineralized Water
Compressed Air	43 psi 85 psi 175 psi Instrument Air
Refrigeration	Block Ice Brine Ammonia
Natural Gas	1 psi 100 psi
Technical Gases Heavy Fuel Oil	

Bayer | Types of Centrally-distributed Energy | IN EN 81-047

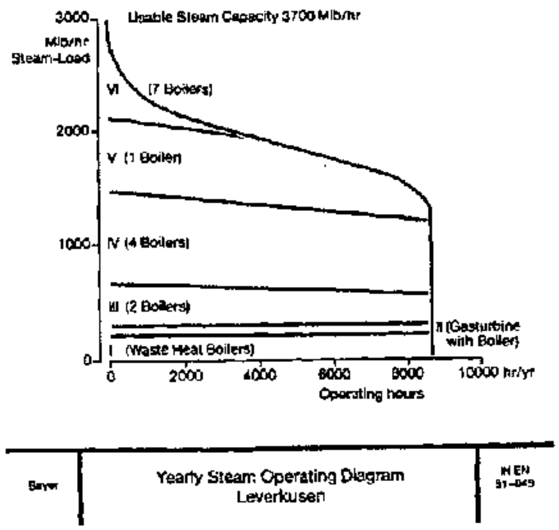
For the operation of a combined heat and power station, it is extremely important to have steam price differentiation, so as to stimulate the use of steam at lower pressures. It is for this reason that, at steam pressures exceeding 70 psi, the extra costs for the additional electrical power required from external sources are included in the price of the steam.

In order to charge out the production costs for steam and electricity as fairly as possible with respect to the real cost of these supplies, the fixed costs (e.g. depreciation, wages, repairs) are charged out in accordance with the maximum acceptance capacities of the consumer, and the variable costs (e.g. fuels) in accordance with the amounts of energy consumed.

Compressed air - and refrigeration - are supplied at various pressures and temperatures for reasons of energy economy and charged with accordingly different prices.

An ordered annual frequency diagram of the steam demand of our Leverkusen plant shows in simplified form the application ranges of the individual co-generating systems and steam boilers. (Fig. 9)

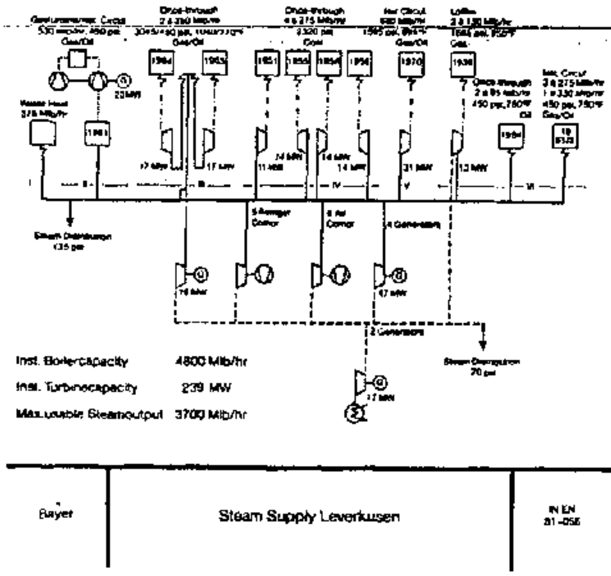
Fig. 9



In the bottom range, Range I, a large number of waste-heat boilers generate a steam output of approximately 220 thousand lb/hr more or less uniformly throughout the entire year. The steam is generated at the highest possible header pressure, so as to have the minimum effect on backpressure power generation.

The next range up, Range II, includes the plant with the most intensive electrical yield, a gas turbine rated at 23 MW of electrical power, which feeds 120 thousand lb/hr of steam into the 435 psi header via a waste-heat boiler. An additional firing of natural gas makes it possible to increase the steam output of this waste-heat boiler to up to 530 thousand lb/hr in a very short space of time. This means that this boiler together with other steam boilers assumes the responsibility for safeguarding steam supplies in the event of unexpected outages. (Fig. 10)

Fig. 10



The next-highest ranges, Ranges III - V, include further co-generation systems with intensive electrical yield, these being ordered on the basis of decreasing power yield or increasing fuel prices.

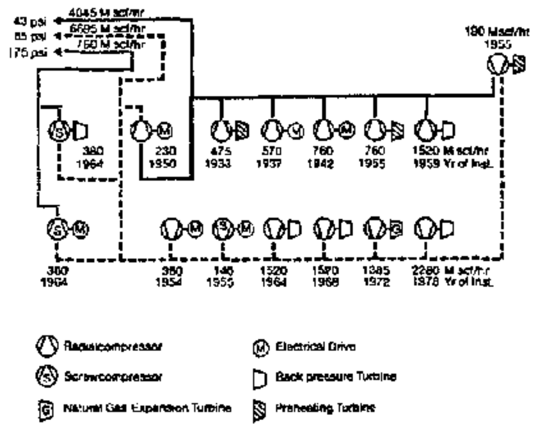
The medium load, up to roughly 4,000 hours of full-load operation, Range VI, is covered by steam boilers of lower electrical yield but with good efficiencies (90 - 92%). Finally, peak demands are covered by rapid-start steam boilers with lower efficiencies which are also used in the event of breakdowns.

All high-pressure boilers and the associated topping turbines are connected as units and operate on two 435 psi main steam headers. Approximately 30% of this steam passes into the factory headers. The rest of the steam is expanded down to 70 psi in low-pressure turbines which drive electrical generators, water pumps, compressed-air and refrigeration compressors. Further preheating turbines expand the steam below 70 psi, and drive feed water pumps, forced-air fans or air compressors. This steam is used for heating feed-water and combustion air.

Thus, if at all possible, the available mechanical energy is used for direct and reliable driving of large machines, in order to avoid the double conversion losses in generator and motor. Further, energy savings can be achieved by means of speed control on centrifugal pumps or compressors, particularly for partial-load operation. In many cases, this even permits savings in capital expenditure, for instance by eliminating gearbox units.

The compressed-air supply at our Leverkusen plant (Fig. 11) is provided by compressors, six of which are driven by low-pressure turbines and three by preheating turbines. This arrangement results in almost no failures in the supply of instrument air.

Fig. 11



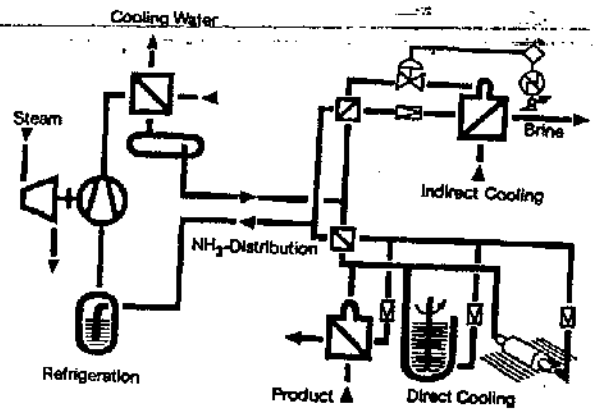
Bayer | Scheme of the Compressed-Air Supply Leverkusen | IN EN 81-046

Nevertheless, we are of the opinion that every plant must be designed in such a way that, should the central energy supply system fail, be it steam, electricity or air, no danger can arise to either persons or the environment.

Our central refrigeration supply is also equipped with several steam drives. The production facilities are centrally supplied with refrigeration at temperatures of +23°F and -5°F. If lower temperatures are required a localized booster is switched into the gaseous NH_3-line and the gas is compressed to a temperature of -5°F.

The extensive lines for liquid and gaseous ammonia on the pipe bridges are not insulated, since a liquid-vapor heat exchanger is always used to heat the cold gas to approximately ambient temperature by means of the warm liquid. Conversely the cold gas also cools the liquid considerably, so that refrigeration power is recovered. (Fig. 12)

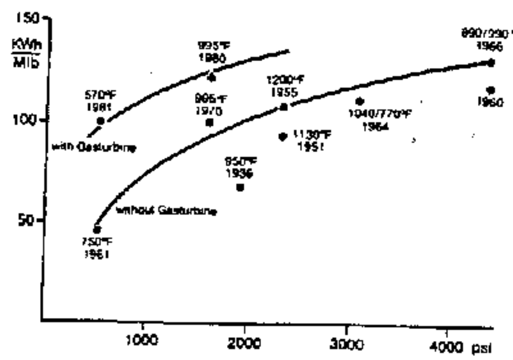
Fig. 12



Bayer | Refrigeration Scheme

Fig. 13 shows some data of our co-generation systems. The design of our high-yield co-generation systems permits conclusions with respect to the fuel, electricity and system prices at various times in the past. For a long time, the trend was toward ever-increasing power yields. The only fuel available was lignite or hard coal. We implemented two different developments: high-temperature technology and the very-high-pressure technique in once-through boilers with a useful steam capacity between 200 and 330 Mlb/hr.

Fig. 13

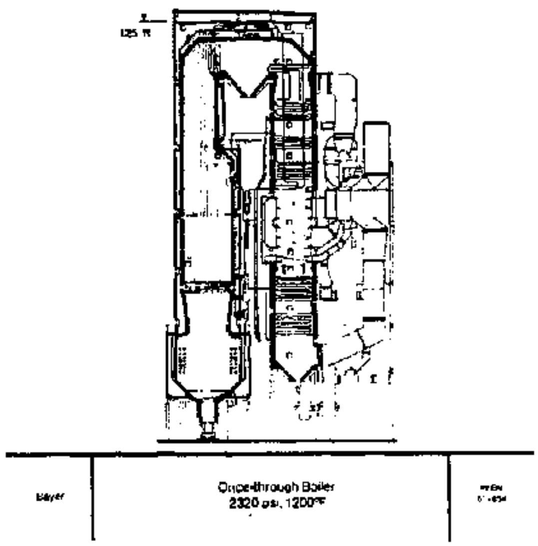


Bayer | Electricity/Steam Ratio of some Cogeneration Plants

In the 1950's, Bayer constructed six units with steam temperatures of 1,200 °F and a steam pressure of 2,300 psi, the power yield being 110 KWH per 1,000 lb useful steam at 70 psi.

Fig. 14 shows a section through a hard coal fired steam boiler with liquid slag removal. The coal dust comes from the corners. The superheater built with austenitic steel is located in the second draft.

Fig. 14



In Fig. 15 a lignite fired steam boiler with dry ash removal is shown. The austenitic superheater is partly located in the upper walls of the first draft.

Fig. 15

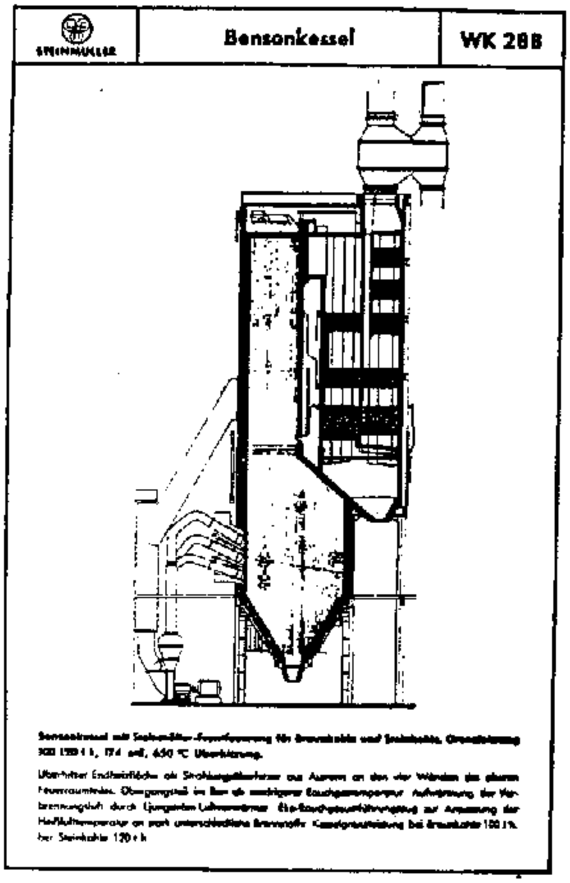
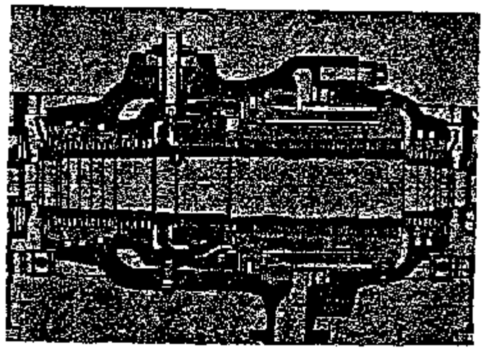


Fig. 16 shows a section through an associated high temperature turbine with a vessel case. Only the dark colored parts at the steam inlet are made of austenitic steel. The electrical capacity of the turbine is 13 MW.

Fig. 16

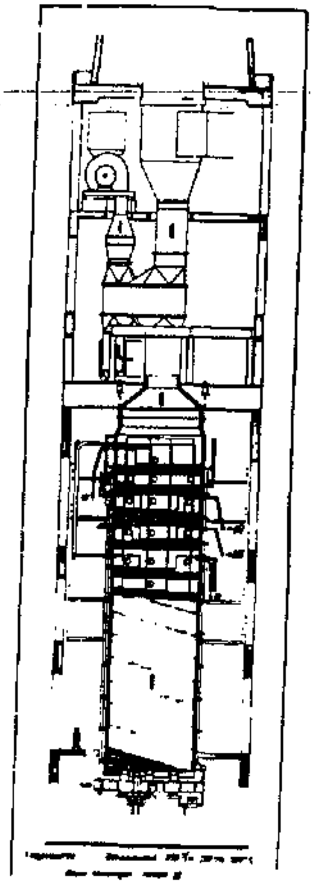


Bayer	HP-Turbine, 1200°F	NEN 81-051

Parallel to these, Bayer also built three units with a steam pressure of 4,340 psi and a steam temperature of 995 °F with reheating to 955 °F at 1,600 psi. In these units, no austenitic steel was used. The power yield of these boilers is 140 KWH per 1,000 lb useful steam.

Fig. 17 shows the section through an oil fired boiler with bottom burners. It is situated in the shaft of a 590 ft high stack and has a capacity of 330 Mlb/hr useful steam.

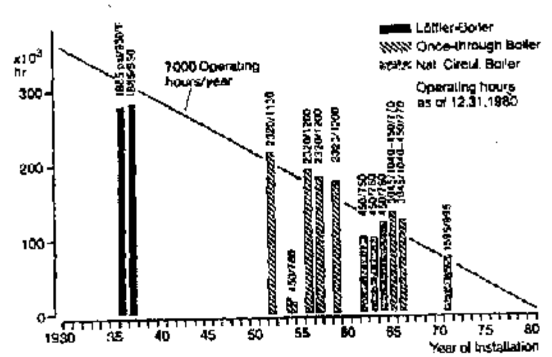
Fig. 17



The availability of the above-named systems is good. Although the system elements were originally designed for a service life of 100,000 hours, no unacceptable creeping or materials damage has yet been determined after roughly 200,000 hours.

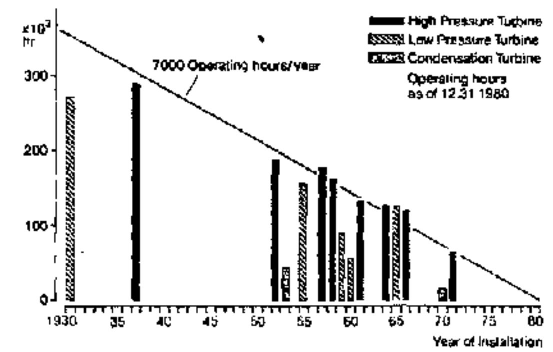
Fig. 18 and Fig. 19 show the operating hours of the steam boilers respectively of the associated steam turbine in Leverkusen. The annual operating hours of the base-load units are higher than 7000 hours per annum.

Fig. 18



Bayer	Cumulative Operating Hours of the Steamboilers at Leverkusen	H EN 81-043

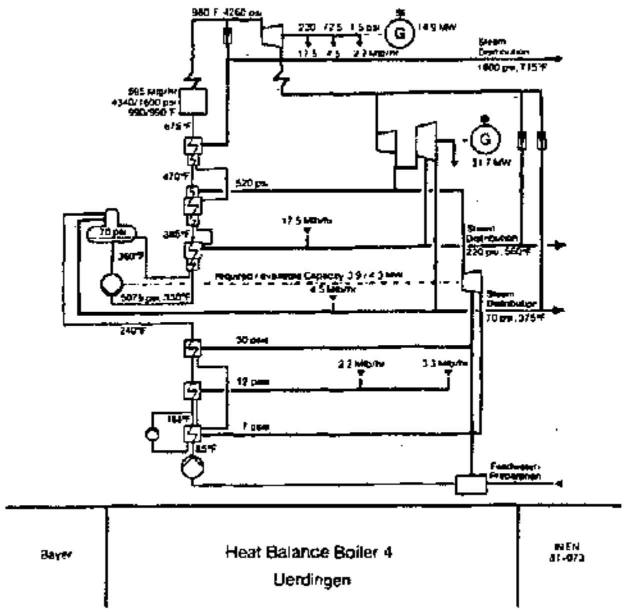
Fig. 19



Bayer	Cumulative Operating Hours of the Electricity Generators at Leverkusen	H EN 81-044

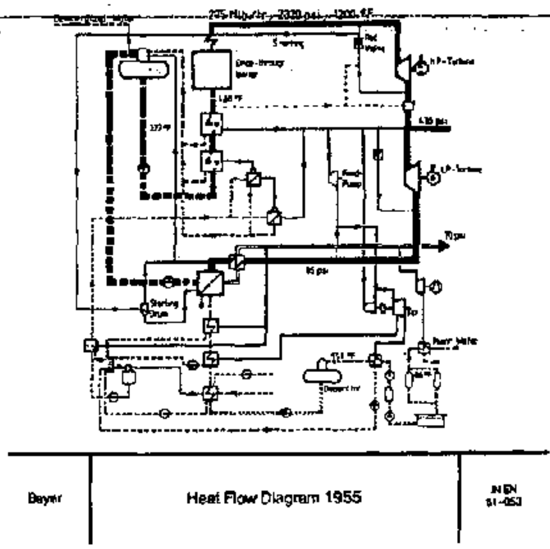
Great attention is paid to feed-water and combustion-air heating, in order to achieve greater power yields. Feed water heating by steam is used for temperatures up to 575 °F with the 4,350 psi boilers. (Fig. 20) The combustion air of oil-fired boilers is heated, in some cases, up to 390 °F by steam.

Fig. 20



Special care is taken to ensure good graduation of the preheater steam pressures and good utilization of the available superheating temperatures and, above all, of the condensate heat. As far as the heat balances permit, feed pumps and boiler fans are driven by preheating turbines which expand the steam required for preheating to the pressure necessary in each case. An old heat flow diagram for a high temperature boiler is shown in Fig. 21.

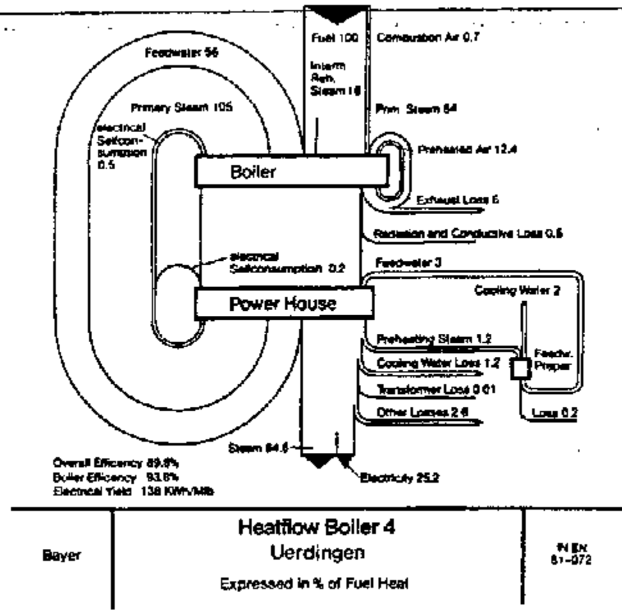
Fig. 21



Since these drive turbines are unable, in view of their partial-load characteristics, to expand all of the steam required for full-load operation, additional preheating turbines are used to drive air compressors, (lower right corner of Fig. 21). These units generate volumes of compressed air corresponding to the available drive power.

Depending on the fuel type used, the efficiency of the base-load and medium-load steam boilers lies between 90 and 92%. In the case of oil-fired steam boilers, the temperature of the exhaust gases is in the region of 340 °F, their excess oxygen content being approx. 1.5%. Fig. 22 shows the heat flow of the mentioned high pressure boiler.

Fig. 22



The efficiency of the overall system lies between 85 and 88%. The generator losses are frequently recuperated by incorporating the generator air cooler into the feed water heating system.

The heat requirement for 1 KWH of electric power produced in a co-generation system is, therefore, approximately 4,000 BTU. In order to achieve good operating efficiency and a good power yield, it is important that all of the high electrical yield boilers operate at constant full load. If possible only one boiler should operate at partial load. The boiler operating at partial load generally has a constant pressure of 435 psi. One electrical low-pressure turbine controls the 70 psi steam pressure, while all remaining electrical low-pressure turbines should preferably operate at full load. The low-pressure turbines which drive air or refrigeration compressors also operate at full load, apart from one turbine each, these being responsible for maintaining the compressed-air pressure and ammonia intake pressure at a constant level. Care must be taken to use as few low-pressure turbines as possible, i.e. to ensure that the largest turbines available are in operation.

The peak steam demand in winter had never been covered by a safe-guarded supply, so certain production facilities had to be cut back in the event of failures of the major steam generator. Special shut-down plans existed to cope with this eventuality.

The energy-saving measures taken have by now led to a situation where even the winter peaks are covered by safe supplies. However, new co-generation systems still need to be built, to replace 45-year old plants, on the one hand, and, above all, to permit once more the increased use of today's most economical fuel, coal.

In the past, Bayer was able to keep its energy cost increases below the average level by rapidly changing over to the most economical fuel available at various times. All available fuel types are used in our co-generation systems. Today we are burning 10% lignite, 25% hard coal, 0% heavy fuel oil, 60% natural gas and 5% refuse.

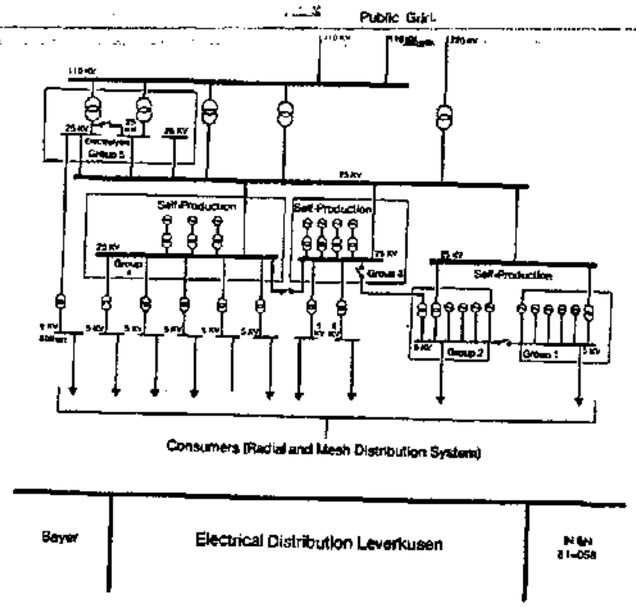
The refuse - provided that it complies with certain criteria with respect to its properties and pollutant content - is used in solid form mixed with coal, or also in liquid and gaseous form. Similar criteria are applied for the combustion of exhaust air or waste gas in the boilers. This is performed in two different ways: either with natural gas, enriched to well beyond the upper explosion limit to form a fuel, or with air, thinned to at least 50% below the lower explosion limit, for use as combustion air. Heating in the boiler furnace to over 2,700 °F and the long dwelling time of 3 to 5 seconds achieve efficient, energy-saving elimination of all pollutants in the exhaust air. The maintenance of the safety margins from the upper and lower explosion limits is monitored constantly. In the event of danger, quick shut-down and temporary blow-out at above roof level are accomplished.

In this context, it is of interest to note that all of our hard-coal-fired steam boilers operate with liquid slag removal. This molten granulate has the important advantage in our densely populated region that it can be dumped without difficulty - it does not generate dust and it is practically insoluble in water.

The chimney heights of our co-generation systems range between 400 ft (1925) and 660 ft (1964).

Back-pressure electrical generation is supplemented by a small amount of electrical generation from condensing turbines. The latter has the function of avoiding expensive peak purchases from external suppliers and of providing an additional supply safeguard, e.g. in the event of repair work on the transfer transformers of the public utility grid systems. In the past, even the public utility has used this generating capacity, since we are then in a position to reduce considerably our purchase of electricity.

Fig. 23



The internally generated electricity is integrated into our plant electrical distribution system. The overall plant is electrically sub-divided into five groups (Fig. 23), so that no electrical fault can ever affect the entire plant. Each group has a double or triple bus-bar system. The internal supply is connected to one bus-bar, the external supply to the other. Both bus-bars are connected via a loose coupling. Normally, approx. 2 MW flow from the internal bus via this coupling to the external supply bus. In the event of faults in the utility grid system, this coupling is disconnected very rapidly, so that the Bayer bus can continue to operate in isolated fashion. This means that only those consumers connected to the external supply bus will then suffer the power failure.

Conversely, the link is maintained in the event of a fault in the internal bus system, and the power consumers on the internal bus system continues to receive electricity. Thus, the consumers on the internal bus system are better safeguarded.

If the coupling switch is disconnected, the electricity generators concerned are switched over from steam-pressure to frequency control. Steam-pressure control is then accomplished by reducing stations.

Thus, combined generation of heat and power achieves, both in the ~~electricity supply sector and also in the compressed-air and~~ refrigeration power supply sector, not only considerable energy and, therefore, cost savings, but also important and inexpensive supply safeguards. In addition, the emission of pollutants and waste heat is considerably lower than is the case with separate generation of electricity by means of condensing turbines alone.

These facts are to be rated very highly in view of our increasing awareness of threats to the environment, and they should result in greater utilization of co-generation systems both for industry and utility grid systems. Both the legislative and the executive branches of government should try to clear the way for such developments by avoiding excessively stringent environmental and pollution regulations which make small-scale plants in particular far more economic than would otherwise be the case.

The best way to use coal with high efficiency is still the direct burning in co-generation plants. It should be used at every place, where a high heat demand allows economic plant sizes. In little units the first step may be not the generation of electricity but the use of mechanical power.