Decentralized Power and Heat Production
"The Chance to Achieve the Goals of Kyoto"

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Initial circumstances

The increase of CO_2 in the atmosphere in the last 200 years is considerable. For this reason, numerous research studies investigated the influence of CO_2 emissions caused by man (anthropogenic). Figure 1 shows the increase of CO_2 in the atmosphere since 1750; the measured value of atmospheric CO_2 is presently 365 ppm. Figure 2 indicates the breakdown of anthropogenic greenhouse gases: a magnitude of 50 % of the yearly greenhouse gas production stems directly from fossil sources; a further 15 % comes from the methane from agricultural sources.

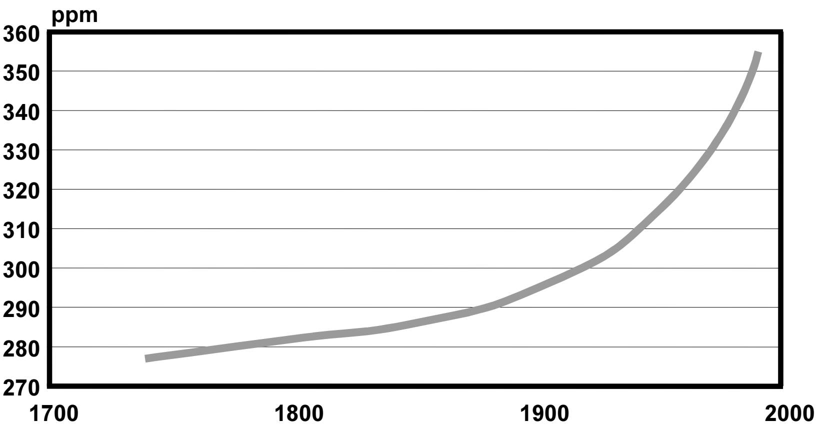


Figure 1: CO_2 increase in the atmosphere

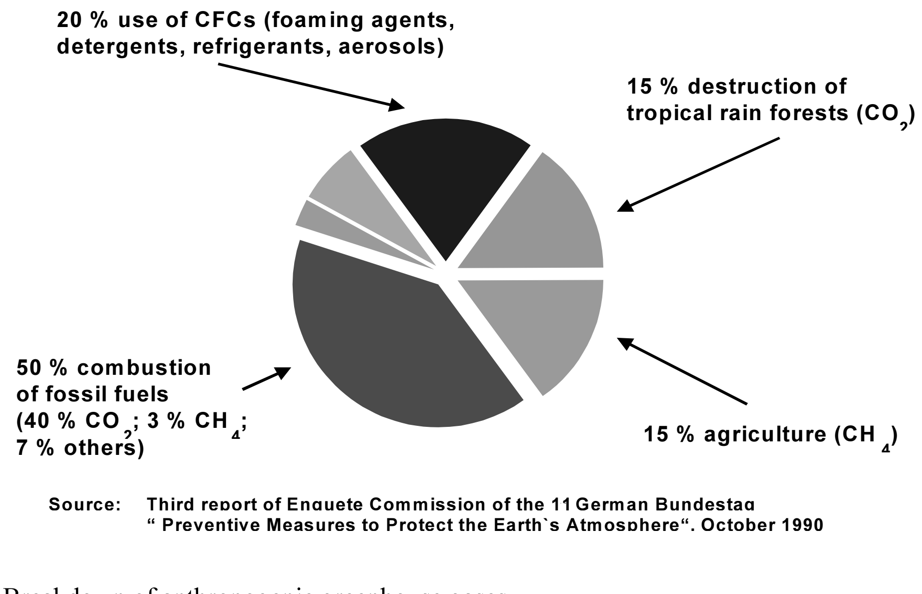
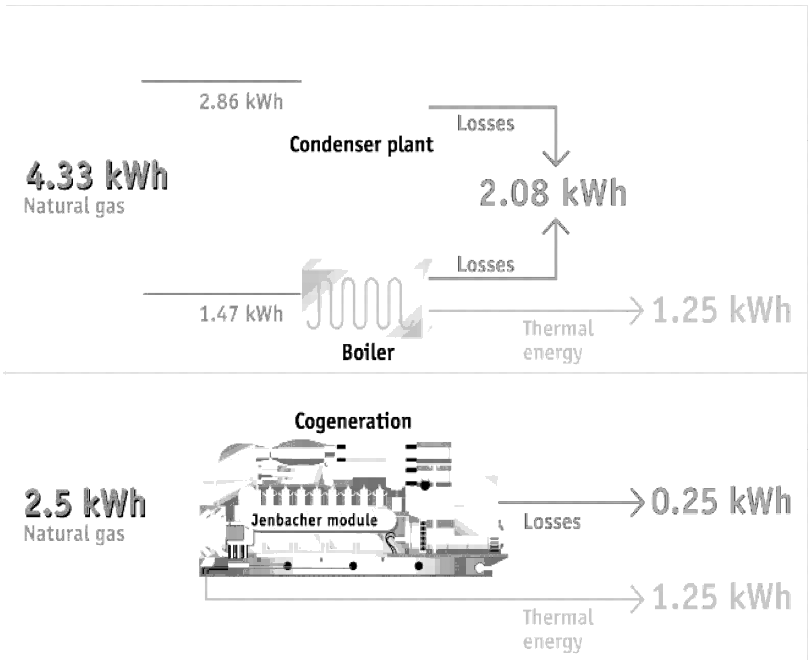


Figure 2: Breakdown of anthropogenic greenhouse gases

That is to say, 65% of the greenhouse gases can be influenced by process optimization and ingenious utilization of primary power and natural resources. The decentralized production of power in CHP plants can therefore be considered very important. The remaining 35 % cannot be influenced by measures such as power-saving, efficiency optimization, etc. Particular attention must be paid to methane emissions, since these have a greenhouse gas potential that is 22 times higher than CO_2.

Power and Heat Production – Comparison of technologies

As mentioned above, the employment of CHP technology can reduce greenhouse gas emissions sustainably. In this regard, Figure 3 shows the present situation of centralized power production and decentralized heat production in comparison to decentralized CHP technology. For the same output of 1 kWh_{el} or 1.25 kWh_{therm}, respectively, 4.33 kWh must be expended in centralized power production; in the case of decentralized and mutual production of power and heat, however, only 2.5 kWh. This results in a savings of the primary energy source – natural gas - of 42 %; and the same amount of greenhouse gas CO_2 is reduced as well. The savings potentials of greenhouse gases can be evaluated very differently from country to country. Furthermore, it is also important which political conditions had an effect in the past on the power and heat production of the individual countries.



$$\left(1 - \frac{2.50}{4.33}\right) \times 100 = 42\ \%\ \text{savings or primary energy with cogeneration}$$

Figure 3: Centralized power production vs. cogeneration of heat and power

Figure 4 shows the contrary conditions of power production in Austria and France. Disregarding the fact that power production in France is about nine times more than in Austria, the structure there is completely different from that in Austria. The base load in France stems mainly from nuclear power stations (about 56 %).The portion of caloric power production amounts to only 17.4 %; in comparison, Austria has no nuclear power plants at all. The greatest portion of power production in Austria is through hydro power. The portion of calorically produced power amounts to just about 30 %.

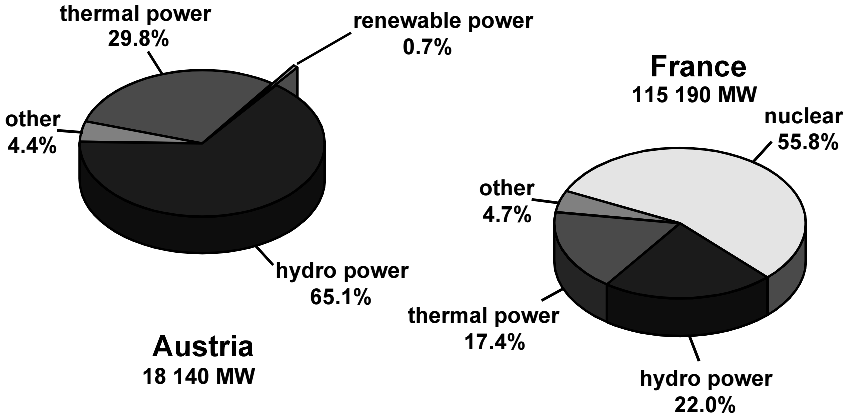


Figure 4: Power generation - Austria compared to France

The supply situation in Austria does not mean that there is no atomic power in the supply grids. Depending on the regional supplier, there are also varying quantities of nuclear power in the grid through the European network associations and through the exchange of power quotas. Figure 5 shows an analysis of Global 2000. Depending on one's approach, most of the Austrian suppliers have between 10 % and just above 20 % nuclear power. Only selected eco-energy suppliers are known not to purchase any nuclear power. However, the quantities of power presently sold can be considered small in comparison to the large suppliers.

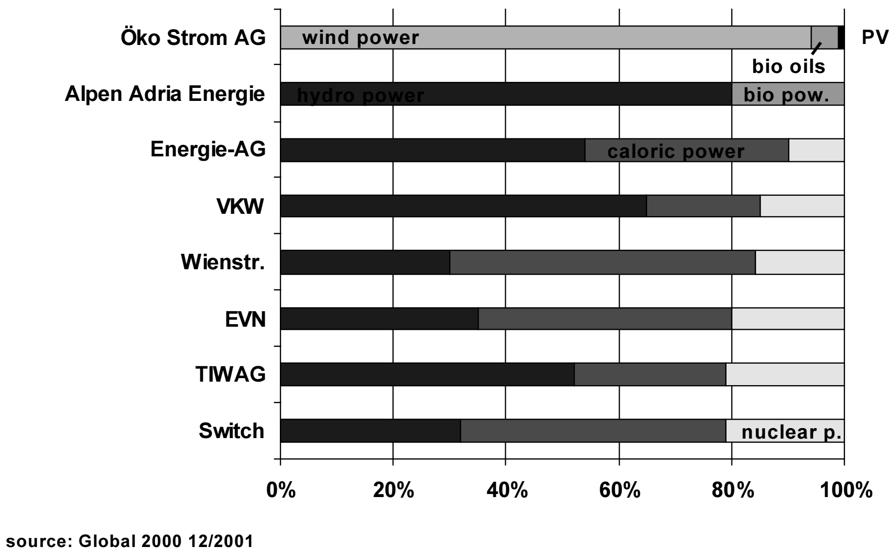


Figure 5: Power sources of power suppliers in Austria

For the utilization of CHP technology and the potentials the European market must be analyzed in terms of "electrical power trading". Figure 6 shows the situation in the year 2000. Export country No. 1 (especially with nuclear power for the base load) is France; the greatest import country is Italy. Depending on the future policy regarding realization of the Kyoto objectives and the attitude of the various governments to nuclear power stations, there can be very great potentials for CHP technology or also a "distortion" of the relationships in conformity with the attainable market prices. In the case of a "soft" move away from nuclear power station technology (as in Germany), CHP technology has great chances that can also be utilized especially for reduction of greenhouse gases. Numerous studies show the potentials and postulate that the Kyoto objectives can be achieved only by using CHP technology. An additional potential results through the utilization of renewable energy sources.

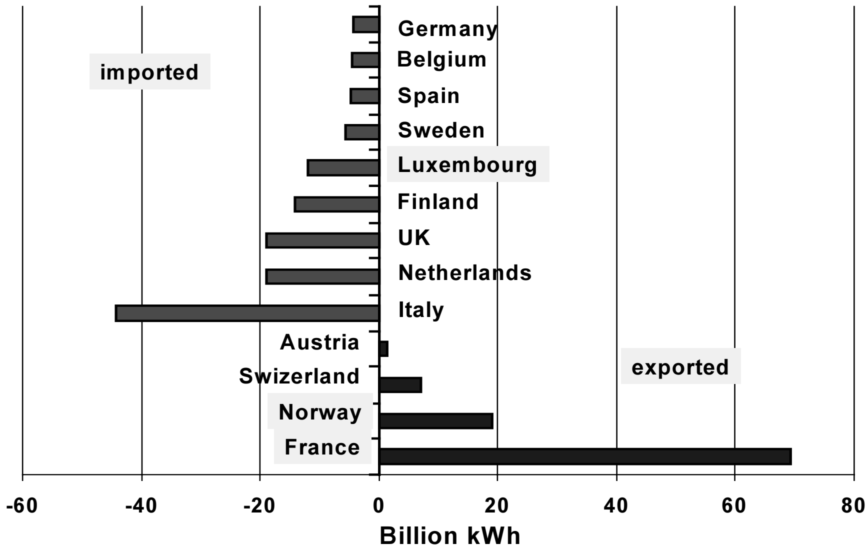


Figure 6: Export / import countries in Europe

Further potentials for reduction of CO_2 emissions are possible through modernization of existing power stations. Figure 7 shows the potentials in this regard: one can expect a 20% reduction of CO_2 through modernization measures. In comparison to coal-fired power stations (lignite, bit coal), the CO_2 emissions of the decentralized CHP plants amount to about one half. Only large power stations having the combination of a gas and steam power station (GUD) have a better specific CO_2 emission in the case of condensation operation. Condensation operation, however, means that almost 40 % of the primarily used energy source is lost compared with CHP technology; with a view to achieving the Kyoto goals this path should therefore not be taken.

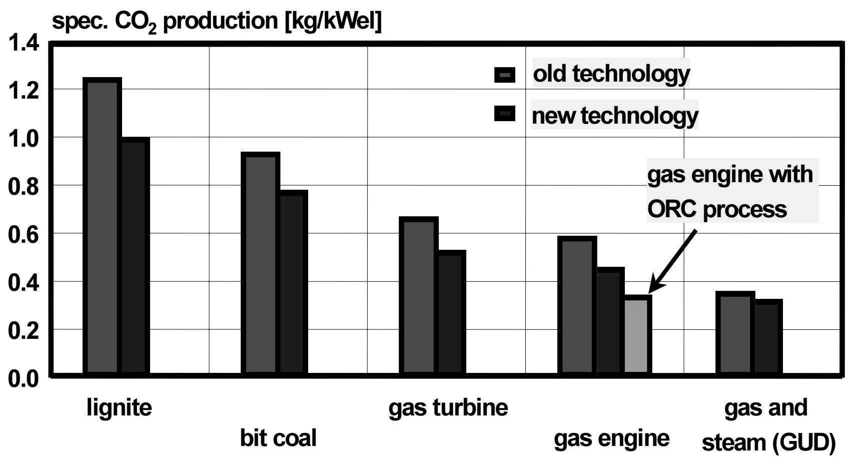


Figure 7: CO_2 emissions of different technologies

The basis of Figure 7 is the amount of C in the primary energy source used. Figure 8 shows the specific CO_2 emissions of the various fuels with complete combustion in kg CO_2/kWh energy content.

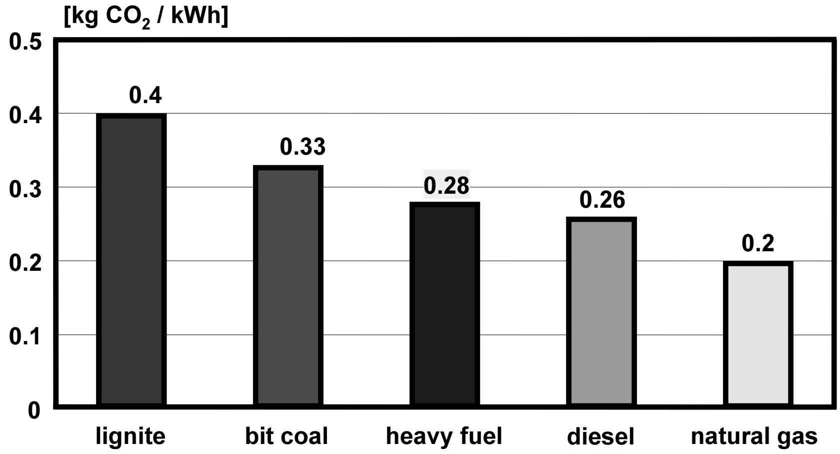


Figure 8: Spec. CO_2 production of different fuels

A further aspect speaking in favor of decentralized power and heat production is the transmission losses in the grids. According to the statistics of the Austrian federal load distributor the transmission losses presently amount to about 6 %; an essential reduction is not possible due to distributor structures (high voltage, medium voltage and low voltage)(Figure 9). Figure 10 shows the detailed situation of the losses of different voltage levels in the grids. To transmit, e.g. 400 MW on a voltage level of 110 kV (dual cable), losses of about 80 MW (20%) result on a line distance of 100 km. Since the transmission of large power outputs are sensible only at high voltage levels, the overhead transmission lines are therefore enlarged to permit a suitable voltage level (220 and 380 kV).

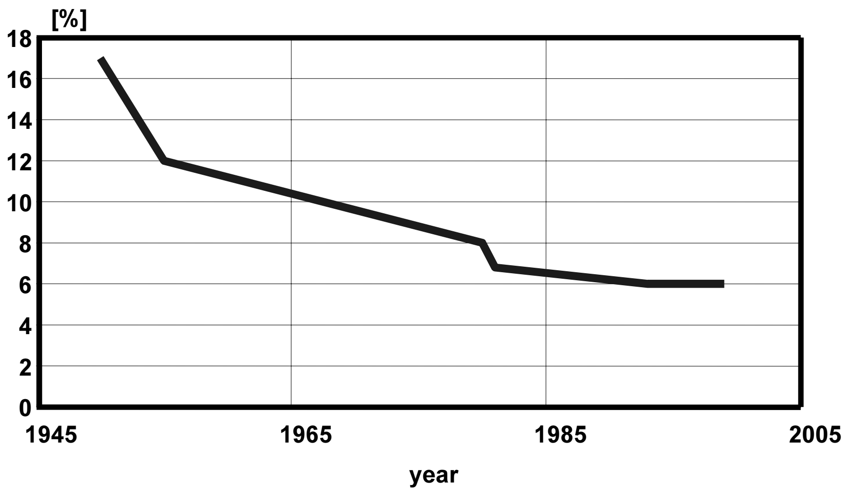


Figure 9: Transmission losses in the Austrian grid

In comparison to the line losses of the power grids, according to data provided by the gas suppliers the losses of the natural gas pipelines are considerably smaller.

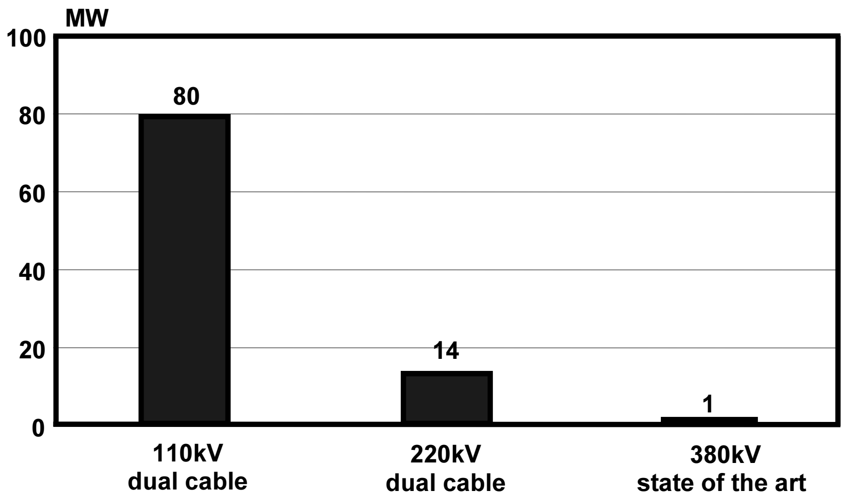


Figure 10: Dependence of the losses on the voltage level

Figure 11 shows data provided by three supply companies. Depending on the viewpoint, the specific losses in the gas pipes amount to only about 1/10 of those of the power grids. This approach speaks clearly in favor of a decentralized CHP technology by distributing the primary energy within a natural gas network.

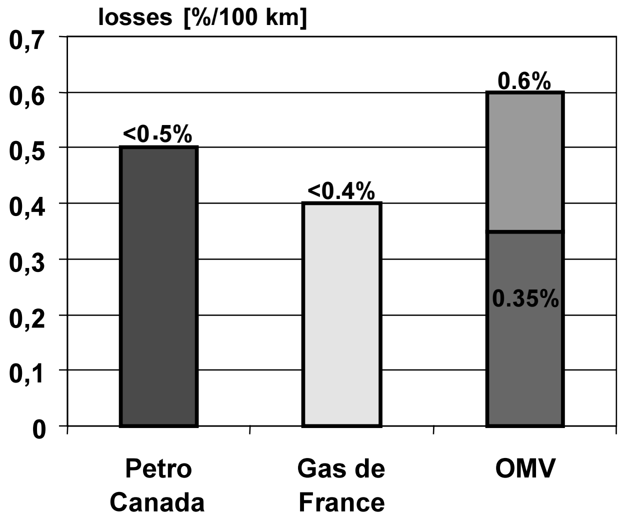


Figure 11: Transmission losses in gas pipes

Technology solutions for CHP

Several technology solutions are possible to construct a CHP plant. Figure 12 shows a comparison of various technologies regarding efficiency and electrical power output. In small plants (exceptions up to max. 800 kW) the use of engines with stoichiometric combustion is known, however the lean-burn engines were able to find greater acceptance because of the clearly better degrees of efficiency. The gas turbines have low electrical efficiency especially in the lower power range and presently have a chance only in the higher output range on the part of economic efficiency. Highly developed gas engines attain efficiencies equal to those of diesel engines. Only large diesel engines in the power output range above 5 MW are presently better in terms of specific fuel consumption. Combined power stations are able to achieve efficiencies of about 55 % (condensation operation) already with sizes around 30 MW.

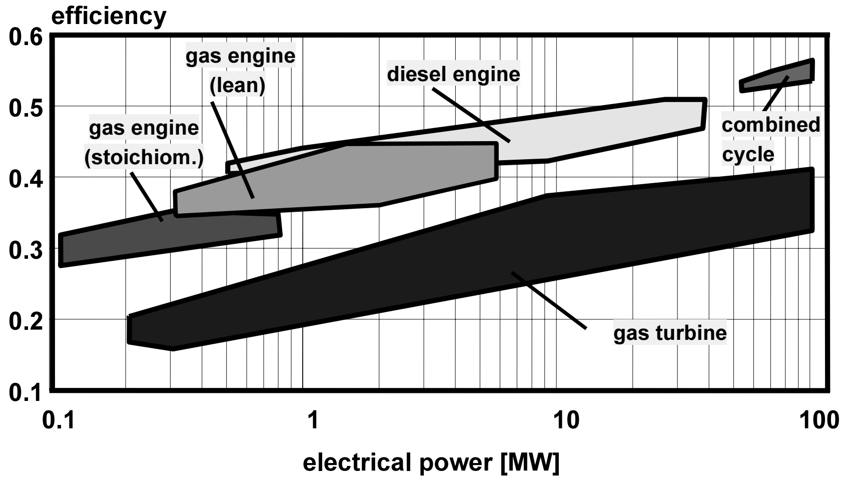


Figure 12. Efficiencies of different internal combustion engines

The equality of the efficiencies of the gas engines to the diesel engines (output range up to just about 2 MW) is shown in Figure 13. The latest development of Jenbacher (J 420 HEC) is well able to hold its own in this output range with the efficiencies of morn diesel engines. To be able to carry out a comparison of actual values, the specific consumption values of the gas- and diesel engines were given in MJ/kWh.

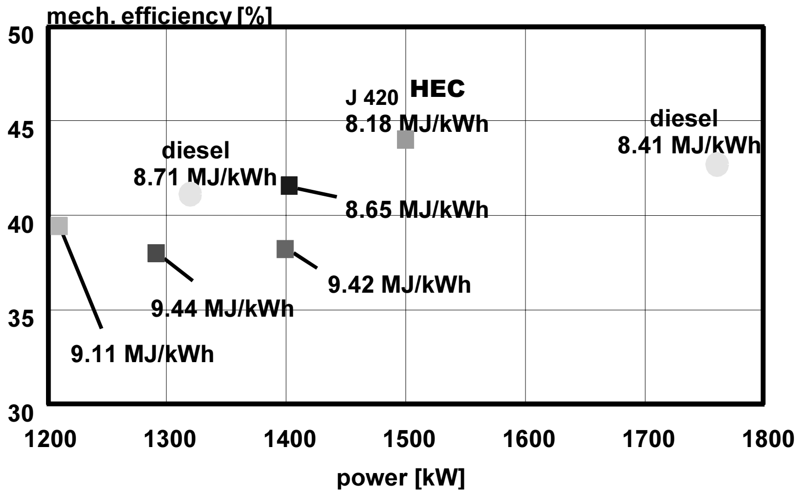


Figure 13: Comparison of efficiency - Jenbacher HEC concept vs diesel engines

The same situation results in the higher output range up to 6 MW, with the gas engine of type J 620 from Jenbacher taking a top position. Furthermore, regarding emissions an essential disadvantage is inherent in the diesel engines. The situation of exhaust emissions of diesel engines (TA-Luft) in comparison to gas engines is shown in Figure 14. The diesel engines have NO_X emissions that are 5 to 10 times higher than the gas engines and additionally have a soot (particle) emission due to the combustion concept. If a diesel engine is utilized in a CHP plant, it is necessary to use secondary exhaust gas treatment (SCR-catalytic converter incl. a soot filter). The costs and the technological requirements including the running costs for these solutions are considerable.

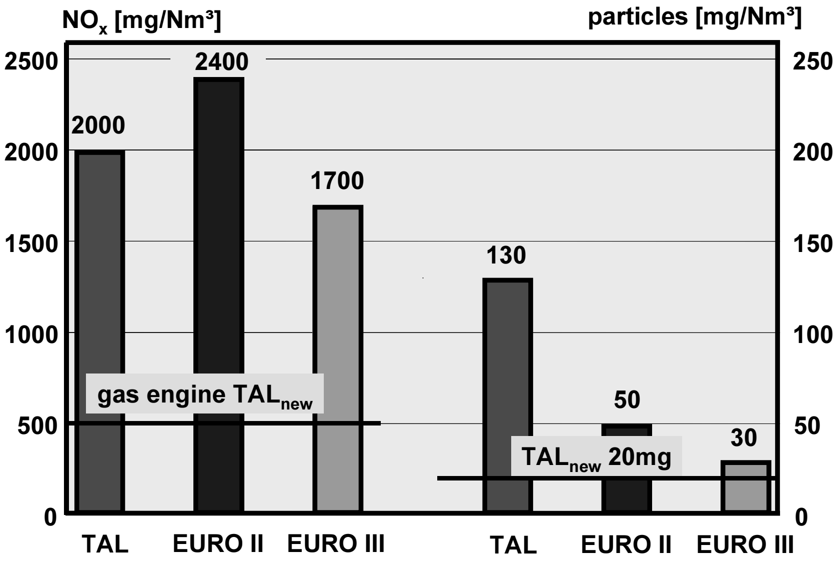


Figure 14: Comparison of NOx emissions - Gas- vs. diesel engine

The philosophy of Jenbacher aims at securing not only the highest possible efficiencies, but also low secondary costs for the building housing the engine (no extra foundation) and packaging. Manufacturers of CHP systems over 3 MWel very often present the argumentation of so-called "medium-speed" engines offering the better efficiency of this type of engine. In this regard, Figure 15 shows the actual situation of different manufacturers on the market (speeds 750, 1000 and 1500 min^{-1}).

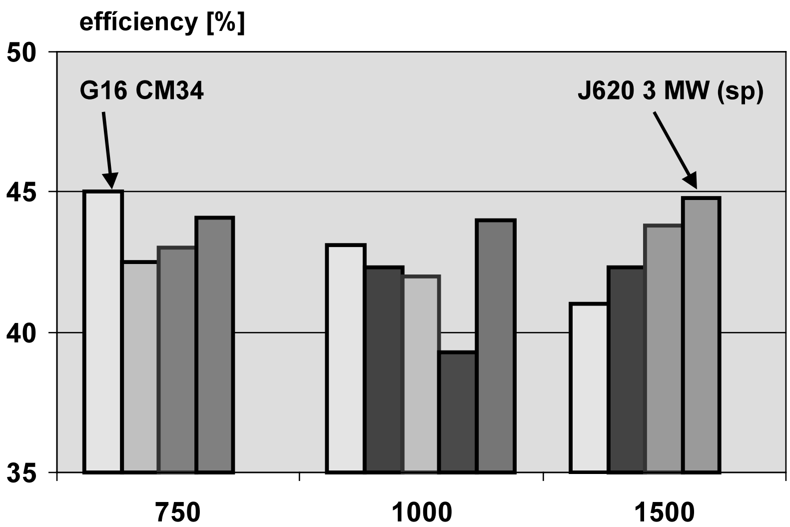


Figure 15: 1500/1000/750 engine speed, efficiencies in the market today

The most efficient engine, with 750 min^{-1} (output just over 6 MW) according to the specification sheets, has actually only a marginal advantage compared with the 3 MW Series 6 engines operating at a speed of 1500 min^{-1} (J 620 - efficiency optimized). That is to say, the speed must not necessarily be a criterion for a better degree of efficiency. The decisive aspect is the available know-how and the realization of potentials of thermodynamics and the development of mechanical components. Figure 16 indicates the weight of a gen-set with a nominal speed of 1500 min^{-1} compared with competitors with a speed of 1000 min^{-1} (output range 3 MW). The engine with the nominal speed of 1500 min^{-1} has a weight advantage of about 50 % compared with the closest competitor; specifically, the Jenbacher engine requires no separate foundation, but can be set up relatively simply utilizing of decoupling with rubber elements.

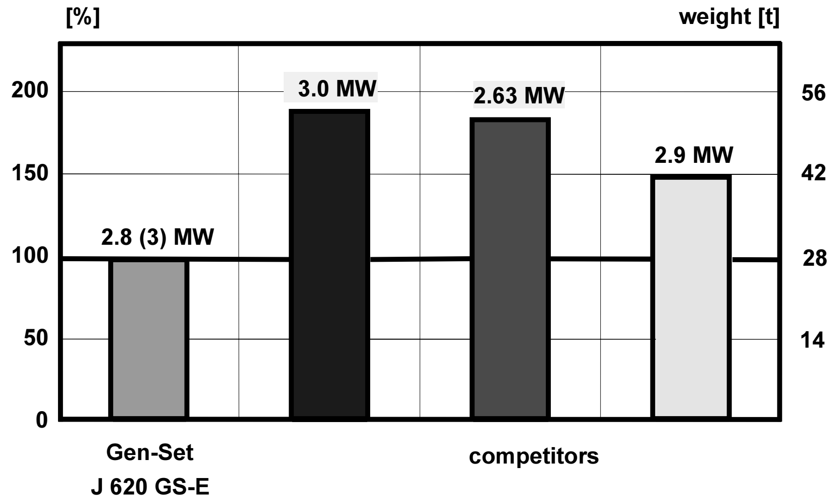


Figure 16: Weight comparison

Figure 17 shows the specific investment costs of different technologies. It is very interesting that that decentralized power and heat production is not necessarily more expensive than a conventional power plant. In comparison to wind driven power stations the specific investment costs amount to about 1/6.

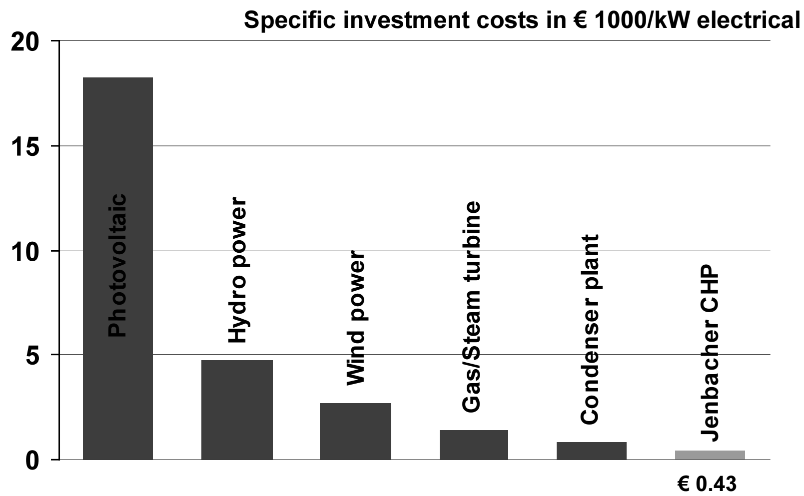


Figure 17: Specific costs of various technologies

Types of CHP plants

Decentralized CHP units can be operated in various modes. Figure 18 shows the daily consumption of power and heat of a brewery. The basic difference for operation is given through the "heat or power orientation" of the CHP plant. In the case of the brewery here, heat supply alone_through the engine is not sensible, since the heat requirement is subjected to great fluctuations from hour to hour. Operation on the basis of the power required, however, could be sensible depending on the structuring of the power tariffs. Extreme examples of power-oriented plants are known as peak load shaving (the purchased power peak is cut off) or as peak load sharing (the user leaves the grid for a specific time). To be able to plan a CHP plant properly, a yearly profile (e.g. heat requirement) is drawn up and then analyzed to determine whether the supply is practical with one or more modules. In any case, the combination of coverage of the peak heat requirement by means of a boiler proves to be sensible (Figure 19).

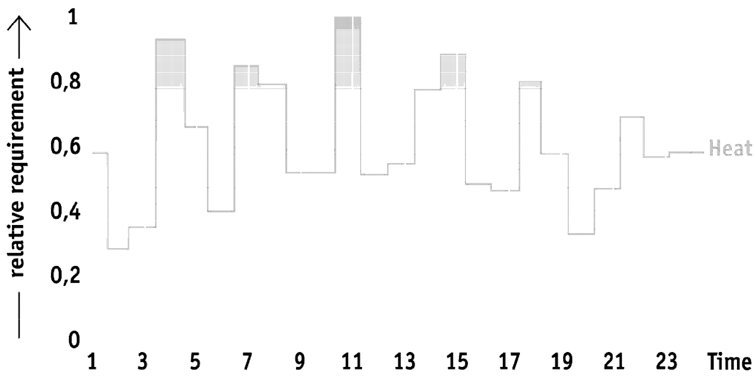


Figure 18: Heat/power-oriented CHP plant

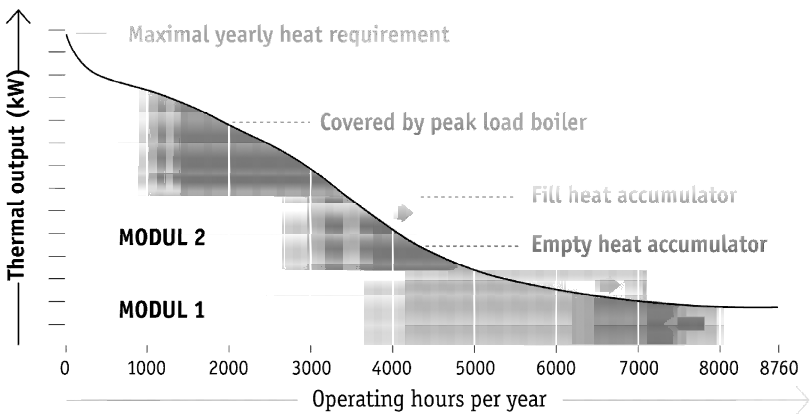


Figure 19: Splitting the yearly heat requirement into parts of the CHP plant and peak load boiler

There can be great differences between winter and summer operation especially with regard to the heat requirement. The example in Figure 20 shows the heat requirement for space heating or water heating, respectively.

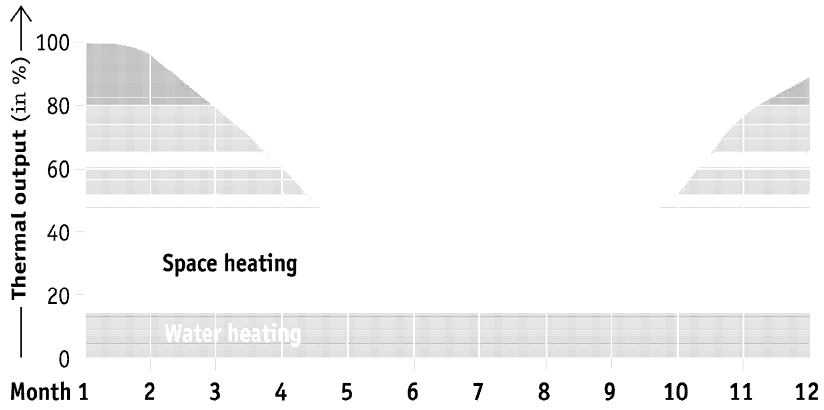


Figure 20: Yearly heat requirement of a building

Future potentials of the ICE

The development of gas engines is carried out very intensively at Jenbacher. As an example, Figure 21 shows the situation during further development regarding the power output of the Series 6 engine (presented as BMEP). In 1994 the BMEP of the engines was 1.2 MPa. In the 2002 product program all engines of Series 6 have a BMEP of 1.8 MPa, consequently 50% higher than in 1994. Figure 21 also shows the BMEPs as the engines were run on the test benches of the Development Department. With increased engine loading it is also necessary to adapt the mechanical components of the engine. In comparison to high-performance diesel engines, practically the same loads occur. Mastery of the combustion process is in any case the basis of success.

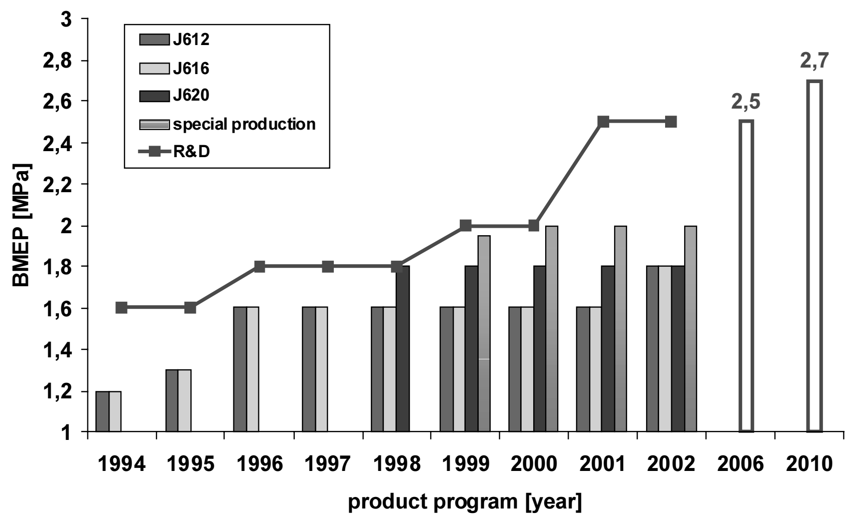


Figure 21: Example of the BMEP development of Series 6

The measurement of the fuel consumption of gas engines is laid down in ISO 3046/1. By definition, a deviation of consumption of +/- 5% is permitted. This helps primarily to allow for the influences of increased friction coefficients during the running-in period of the engine. To be able to provide an overview of the effect of this 5 % tolerance, Figure 22 shows a comparison of the utilization of different tolerance ranges (3 % and 5 %) in relation to the values guaranteed by Jenbacher. For its 2002 product program Jenbacher guarantees a 42.6 % efficiency of Series 6. In the case of a "more liberal" fuel consumption rating on the specification sheet, one could list 43.9 % for the utilization of a 3% value and 44.8 % for 5 %. In the case of a special type for a customer even 45.7 % would be possible in conformance with ISO directives. In the area of development work is already be carried out on the next generation, where degrees of efficiency up to 44.5 % are measured without tolerances.

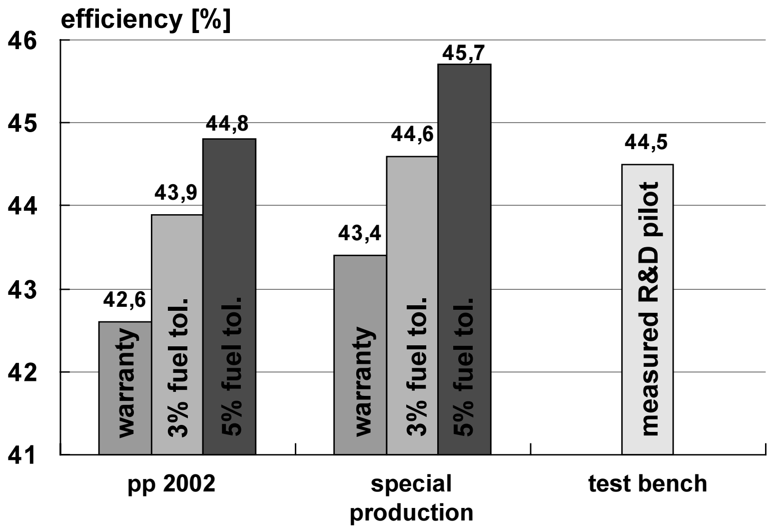


Figure 22: Efficiency from the viewpoint of ISO 3046/1 tolerances

To develop further potentials, intensive work is being carried out on combustion control. Figure 23 shows the influences of the compression ratio and combustion control on efficiency. From a thermodynamic standpoint no difference is made between a gasoline and a diesel engine process. The sole decisive factor is the build-up of pressure in the combustion chamber dependent on the compression ratio. The greatest potential in this regard is offered by the so-called constant volume cycle (combustion as quickly as possible).

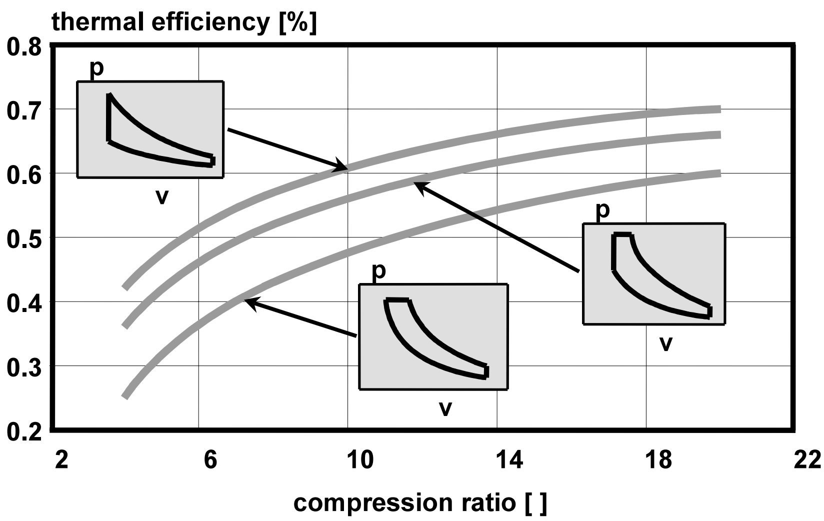


Figure 23: Influence of the compression ratio and the design of the combustion process

In the area of diesel engine combustion intensive work is being devoted to combustion that is as fast as possible. This combustion concept is designated as HCCI (homogeneous charge compression ignition). In principle, it is a combination of the gasoline and diesel engine. In this case, a homogeneous fuel/air mixture is compressed and then either self- or externally ignited close to TDC. Figure 24 shows the pressure increase in the combustion chamber with a fast burning of the fuel within 5° crank angle. The effects on the degree of efficiency dependent on the compression ratio and the combustion duration are shown in Figure 25. As can be seen from the pressure increase, the strains on the engine parts are considerable and it will take some time to make these concepts marketable.

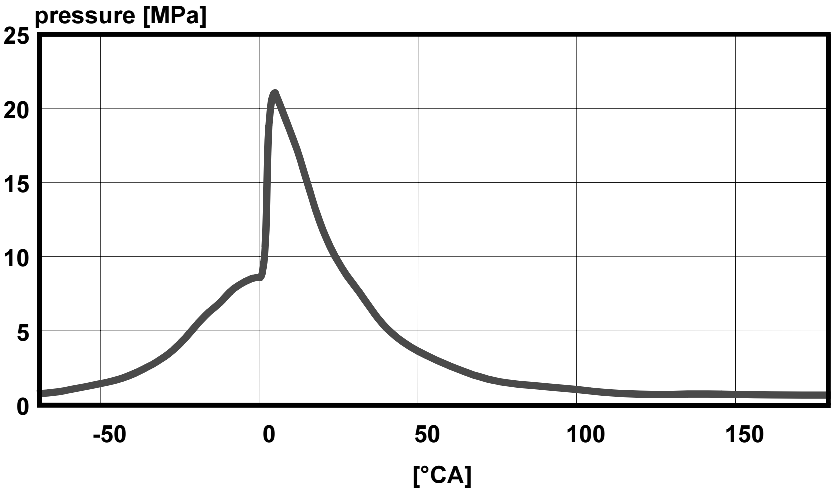


Figure 24: HCCI combustion concept

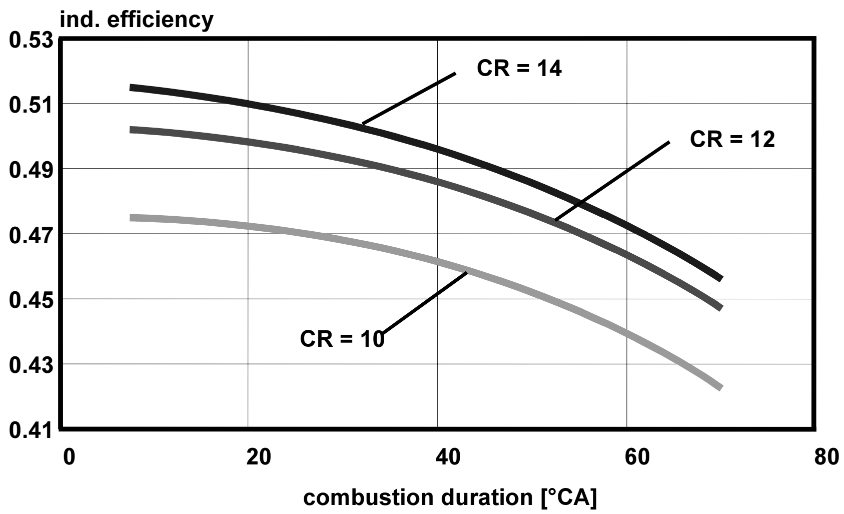


Figure 25: Combustion duration vs efficiency

Alternative (bio)fuels

The utilization of regenerative energy sources also represents a considerable potential to achieve the objectives of Kyoto. Figure 26 indicates the potentials in Austria regarding the use of agricultural liquid manure including biogenic wastes through cofermentation. According to a study published in 1998, the installed power output from this source in Austria amounts to 350 MW. By means of skillful management the power and heat production can be held constant in a yearly average, so that a total of 3000 GWh electrical power and additionally 3950 GWh heat could be produced yearly. The potentials in Germany are about ten times greater.

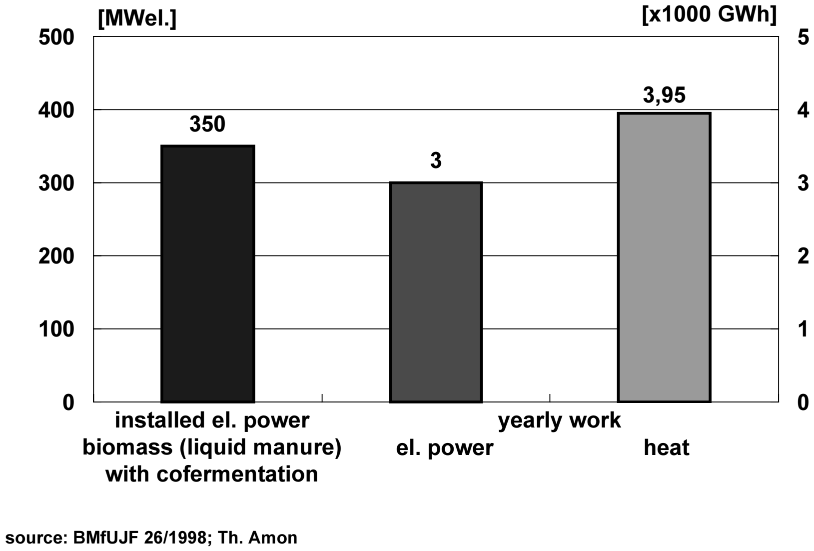


Figure 26 Potentials of biowaste with cofermentation (Austria)

A cost/benefit analysis of the biogas plants results in a minimum size of about 300 kW_{el}. With this size it is practical to offer suitably perfected engines. Jenbacher AG has suitably developed its smallest engine (J 208) for this purpose and can already offer efficiencies up to 40 % for biogas operation. Figure 27 shows the development of the efficiency of this engine over a period of time. Since 1994 it has been possible to improve its efficiency by somewhat more than 6 %. For the operation of biogas plants the exploitation of this potential is of decisive economic importance.

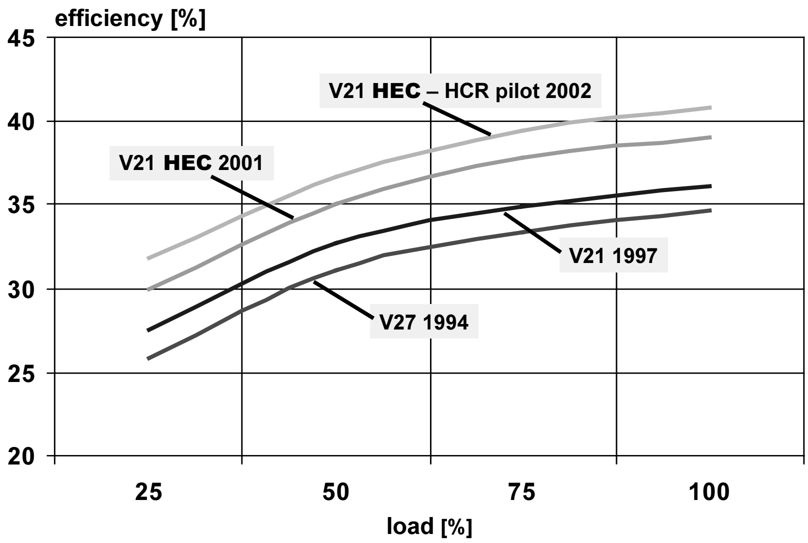


Figure 27: Engine optimization for biogas

A further potential regarding the renewable energy sources is the gasification of solid biomass. Figure 28 shows the potential in Austria. Since these plants have a high accumulation of thermal energy, operation is practical only during the cold part of the year. According to the analyzed study the installed output amounts to 410 MW (operation only 5000 h/a.). Therefore a total of 1700 GWh of electrical power and additionally 4400 GWh of heat can be produced decentrally during the winter season.

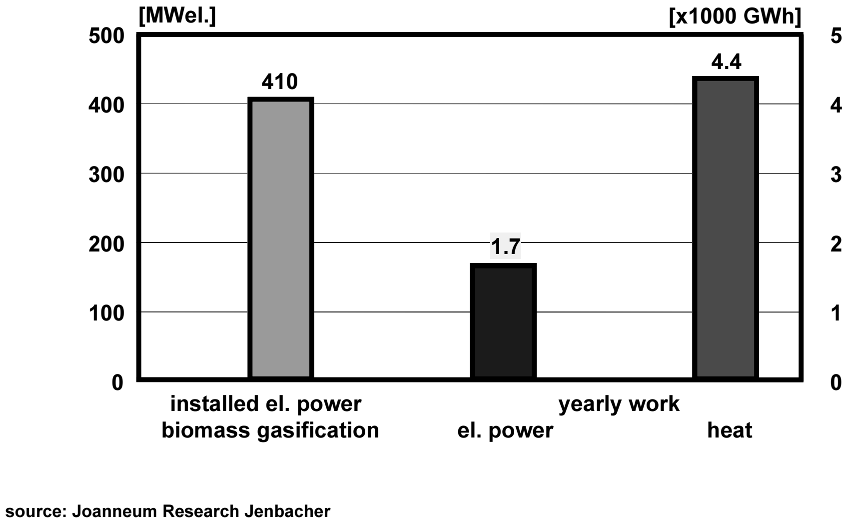


Figure 28: Potentials of wood (biomass) gasification in Austria

Comparative studies treating the conversion of the solid biomass of an ORC (organic rankine cycle) process, a steam process or the combination of a biomass gasifier with a gas engine show clear advantages in favor of the gas engine. Depending upon the gasification concept, electrical efficiencies up to 30 % can be achieved with total efficiencies (thermally + electrically) of 63 %. All the values given in Figure 29 are measured values and clearly illustrate the potential of biomass and the utilization of gasification of wood gas in a gas engine.

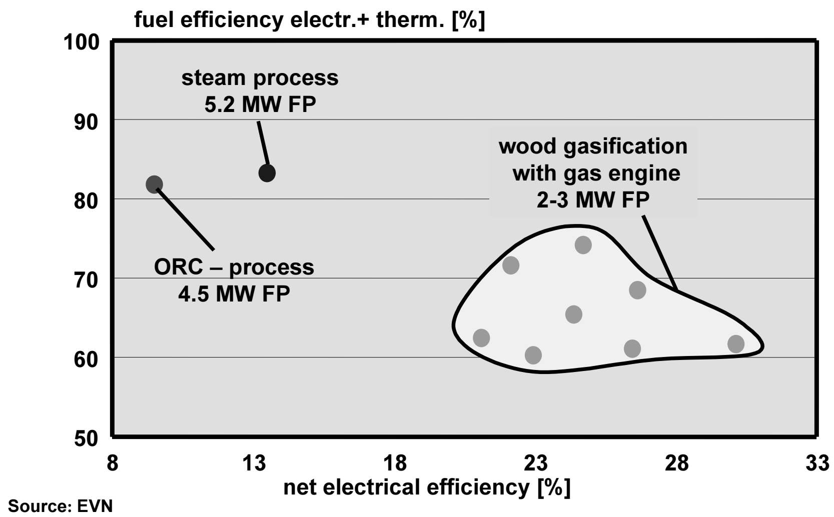


Figure 29: Fuel efficiency of different conversion concepts

Additional potentials to cut down on CO_2 result through pyrolysis (and gasification) of high-energy waste components such as plastic and paper. A great part of these fractions presently ends up on landfills without being used energetically. Various suppliers have recognized the possibilities and already offer processes that permit suitable waste components to be gasified and then utilized in a gas engine. The first supplier of this technology was the company Thermoselect, and the first plant gaining positive experience is in Japan (Chiba Seiyaku). Further plants with similar technologies are planned in Japan and Europe. An overview of the gas analyses of the produced gases is shown in Figure 30. An extreme case of utilization of the waste gas of a chemical process (production of formaldehyde from methanol) of the company Dynea Austria (formerly Krems Chemie) is also indicated.

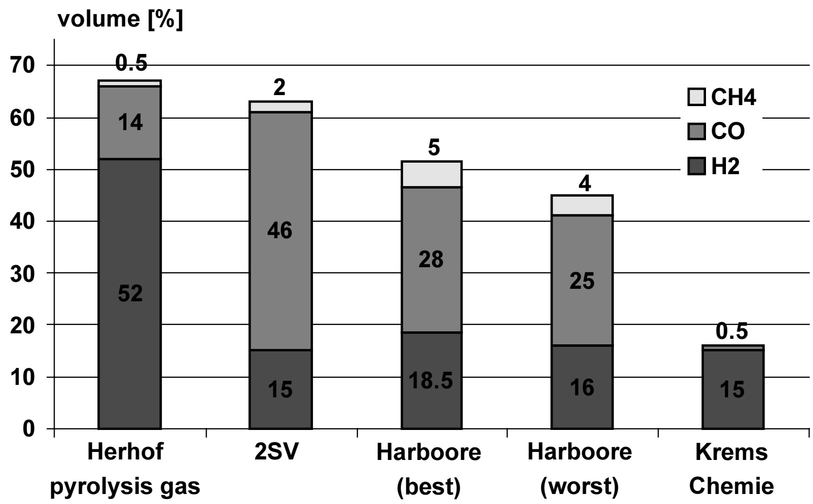


Figure 30: Possible fuels for optimized gas engines

The spectrum of gas compositions usable in a gas engine is very large. The decisive factor in any case is the know-how to be able to utilize these gases with the highest possible efficiency. Besides parameters such as calorific value, methane number, Wobbe index, etc., the mixture ratios of the individual components are also important. To provide an overview of the minimum calorific values of gas mixtures, several relations are shown in Figure 31.

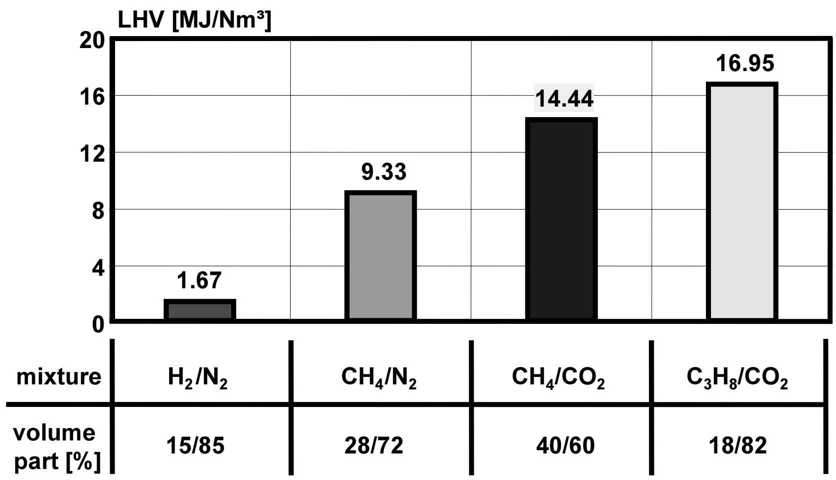


Figure 31: Possible low heat values (LHV)

An example of an extreme case of utilization of a gas mixture (15 % H2 and 85 % N2) in an engine is Dynea Austria. There the calorific value was only 1.67 MJ/Nm^3 = 1/20 of the calorific value of natural gas. Different calorific value limits therefore result depending on the mixture ratio of combustible to inert components. In comparison to gasoline/diesel engines driven with liquid fuels, where the calorific values indicate only minor differences, gas engines show differences as much as 60 times higher than the lowest usable LHV. The carburetion units must then meet corresponding requirements.

Special applications with gas engines

While the gas engines up to the beginning of the 90's were acknowledged as only stationary engines that were to be run with a constant load, the requirements today are considerably greater. To some extent, gas engines must also take over the functions of stand-by diesel engines; as a result of developmental achievements and the employment of state-of-the-art control systems, these requirements can also be fulfilled by gas engines. Figure 32 shows in this regard the situation of a plant (the engine is pre-heated) that has to take over the electrical load of an industrial plant in a very short space of time. The process from start-up until the beginning of load connection takes 15 seconds; in a further 15 seconds already 50 % of the nominal load has been reached. Depending on requirements set on the quality of the grid frequency, it is also possible to take over higher loads in pure island operation.

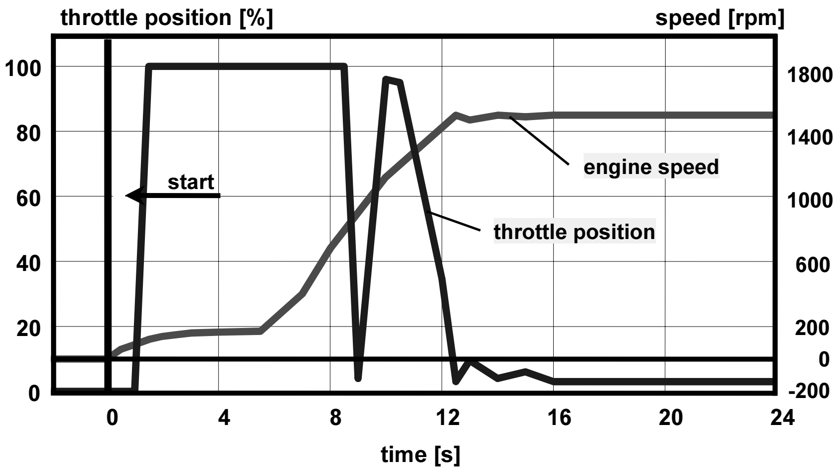


Figure 32: Fast start applications

The application mentioned above is possible by means of a Jenbacher development of a turbocharger bypass (JES Boost Control System). Here the speed of the wheel is maintained as high as possible and the control reserve is brought about by a mass flow flowing back to the intake side of the compressor. The Jenbacher Boost Control concept is presented in Figure 33.

A further innovative application of gas engine technology is shown in Figure 34. In this case the consumption advantages of a gas engine plant for production of power and steam are compared with a gas turbine plant. In both cases a co-firing system is connected downstream from a combustion engine (gas engine/gas turbine) for production of amount of steam varying over a period of time. If the concepts are looked at more exactly, with the same electrical output of 3.38 MW and 5.13 MW steam the gas engine plant requires 11 % less primary energy, i.e. the CO_2 emissions are also reduced by 11 %.

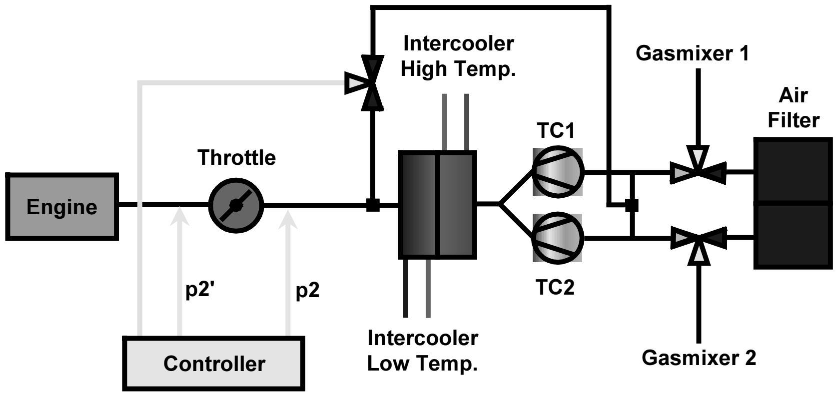


Figure 33: Jenbacher "Boost Control System"

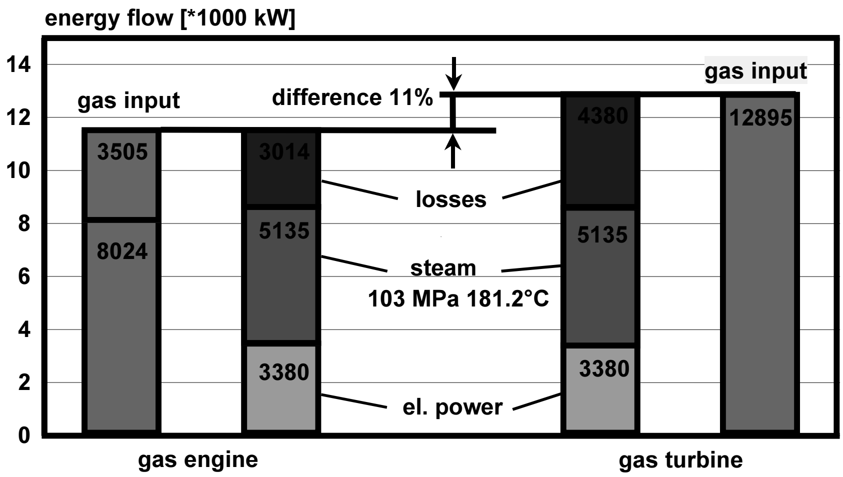


Figure 34: Steam production with gas engines

Other fuel conversion possibilities in the case of biogas

Especially in the utilization of biogenic energy sources the conversion efficiencies are of great importance for economic efficiency. In this context, Figure 35 shows a comparison based on the state of the art of a "low-tech gas engine" to the technology offered by Jenbacher and to a landfill gas electricity generation plant with the help of a Rolls Royce KB-7 turbine. Figure 35 also shows the situation of a micro turbine (Capstone) with increased efficiency. Especially when looking at the high-tech gas engines compared with the gas turbine, the differences are enormous and amount to about 40 % more electrical output in favor of the gas engine. A big "loss factor" in the case of the gas turbine is the prior compression of the landfill gas to 1.93 MPa, which necessitates 20 % of the net produced power. In the case of the use of micro turbines the amount of electricity produced is cut nearly in half.

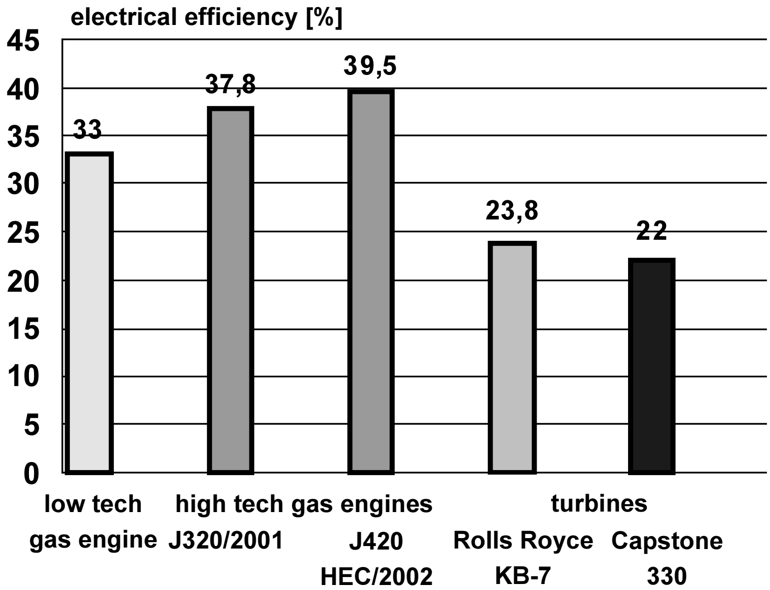


Figure 35: Comparison of efficiency - gas engine technology vs gas turbines

Also regarding specific investment costs the gas turbines are clearly inferior to gas engines. Figure 36 shows a comparison of the individual output classes. The micro turbines presently have clear advantages, especially in terms of emissions: Figure 37 provides a comparison.

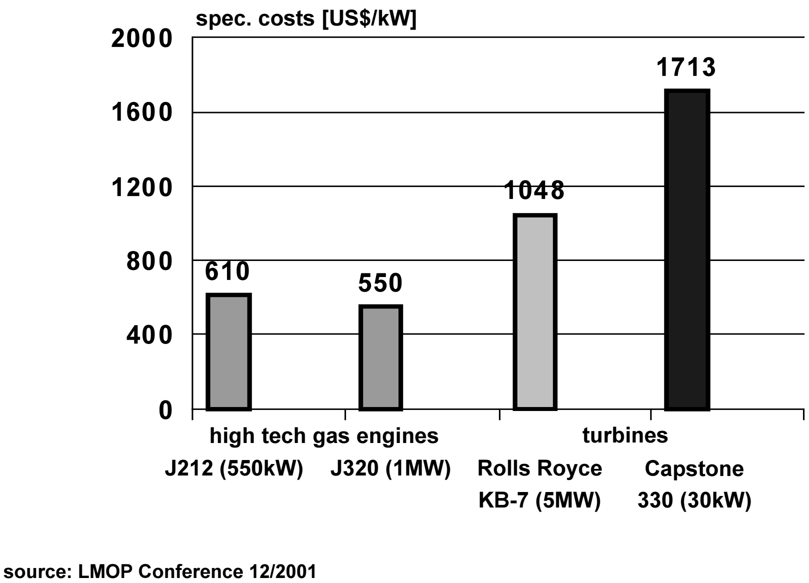


Figure 36: Specific system costs – engines vs turbines

The different influence of ambient conditions between gas turbines and gas engines should not remain unmentioned. The influence of temperature is shown in Figure 38. The rated output and the efficiencies of gas turbines are defined at 15° C in conformance with ISO requirements. With an increasing ambient temperature the derating amounts to 0.9 %/°C for the output. In comparison, the nominal output point of gas engines is fixed at 25° C; the output derating amounts to only 0.5 %/°C.

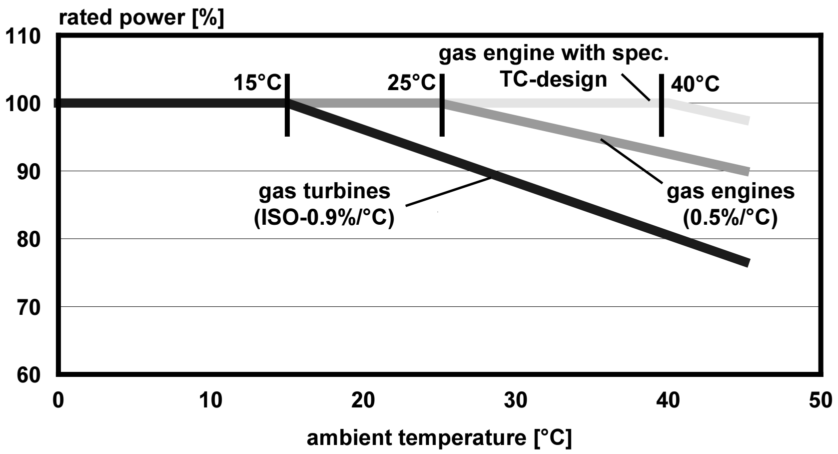


Figure 37: Emission features of micro turbines

For special applications it is possible to dimension the turbocharging system of the gas engines (special Jenbacher feature) for ambient conditions up to max. 40° C (rated output). Specifically, this characteristic means that with an ambient temperature of 40° C the gas turbine has to be dimensioned for an output that is about 20 % higher. This then means additional costs for gas turbine technology. The special adaptation of the turbocharging system also creates additional potentials regarding so-called high-altitude applications of gas engines. As an example, the CHP plant in the winter sports area of Sestriere at 2050 m can be mentioned, where it was possible to have the same power output as at sea level by means of adaptation of the turbocharging system.

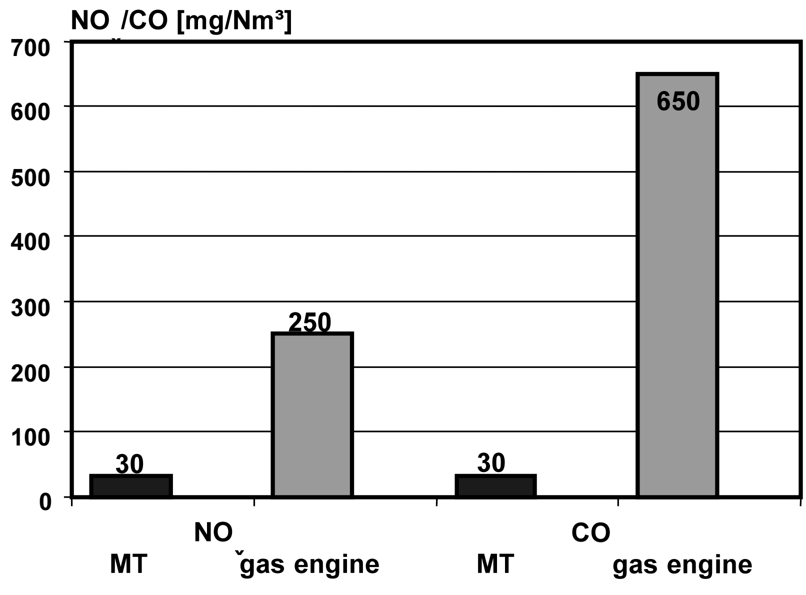


Figure 38: Comparison of the influence of ambient conditions on turbines and engines - ISO

When looked at more exactly, the total efficiencies of the recently strongly promoted micro turbine technology shows a not so insignificant weakness. In this regard, Figure 39 shows a comparison of the micro turbine from Capstone with gas engines over the load. Besides the modest electrical efficiency of the small turbine, the thermal output is also considerably smaller than that of gas engines. At full load there is a difference of about 15 % lower "fuel efficiency".

At smaller loads, e.g. 25 %, the thermal output of the turbine sinks dramatically and differences of up to 40 % are the case. That is to say, turbine technology is usable only for specific CHP applications, such as greenhouses in combination with fertilizers with CO_2 from the exhaust or very large plants (higher than 20 MW).

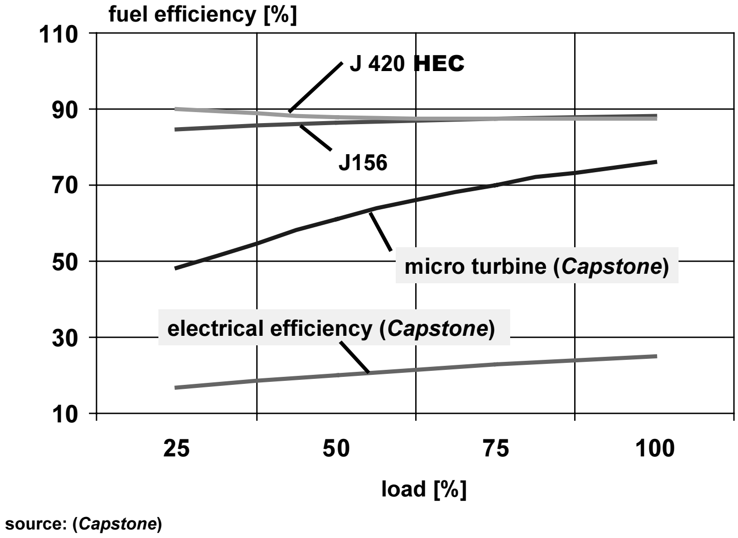


Figure 39: Fuel efficiency of micro turbines in a CHP plant

Fuel Cell Technology

The fuel cell is presently viewed as a further future technology. The PAFC (low-temperature fuel cell) made by the Onsi Company has been available for about 10 years and there are several publications about the state of this technology. Without mentioning details, it can be said that this technology is also inferior to gas engines regarding CHP applications. A comparison of "fuel efficiency" is presented in Figure 40. Similar to the micro gas turbines, the thermal output sinks dramatically in the lower load range and is thus also inferior to gas engines.

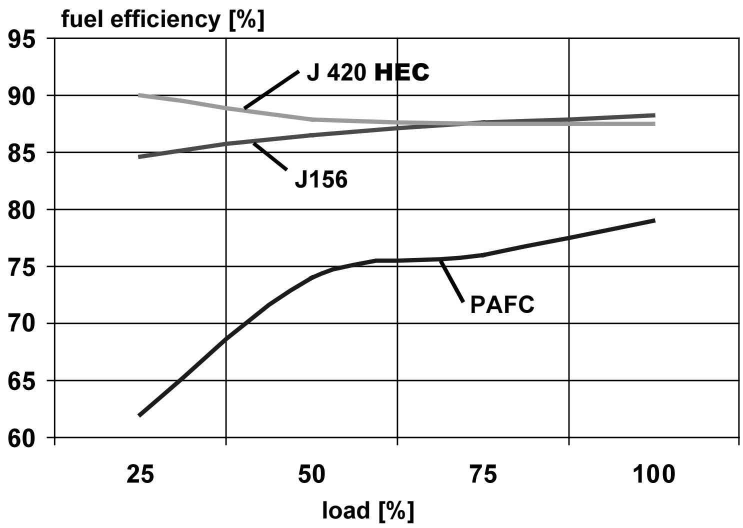


Figure 40: Fuel efficiency of a low temperature fuel cell in a CHP plant

Summary

From a holistic viewpoint, the gas engine represents a highly perfected technology for CHP applications that can also be utilized effectively to reduce greenhouse gases. A reorganization of the energy supply structures to the increased utilization of natural gas, regenerative energy sources and combustible process gases creates the potentials to also be able to fulfill the stipulations of Kyoto. Also the so-called future technologies, such as the fuel cell and the micro turbine, will remain restricted to individual market niches, because they are inferior to the gas engine especially for the cogeneration of heat and power. The situation of "fuel efficiency" is presented in Figure 41. Both types of fuel cells, low- and high-temperature, have only limited potential to attain the efficiency of the gas engine.

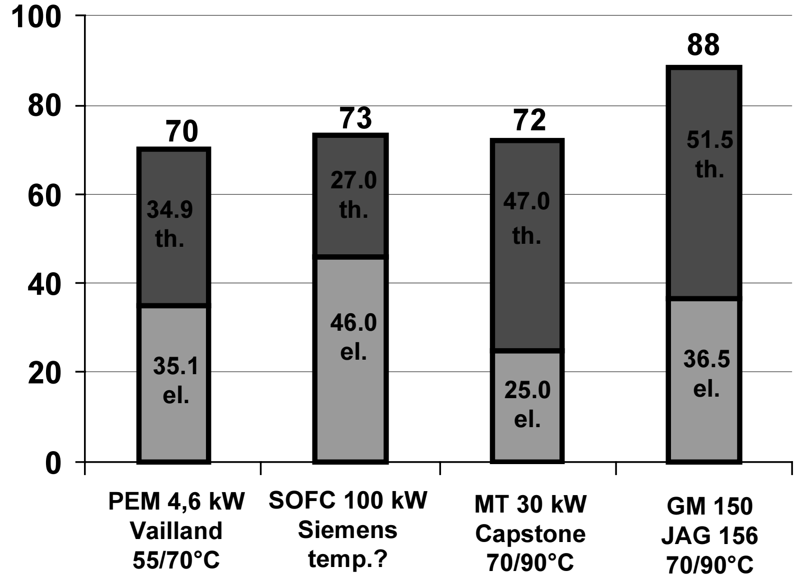


Figure 41: Comparison of different technologies for CHP plants

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