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Opportunities for Engine-Driven Cogeneration and its Benefits

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Abstract

The increase in electricity use in Hungary in connection with the predicted rise in wealth level has to be met with a maximum utilisation of the national and imported fuel resources. Both the environment and the economy will benefit from a high fuel efficiency. Modern cogeneration installations fuelled by natural gas can play an important role in this. Reciprocating-engine-driven generators offer a high energy conversion efficiency and a maximum flexibility in capacity build up. Moreover, their emission level is so low that no burden for the Hungarian environment will occur. Hungary has a much lower population density and energy use density than most countries in Western Europe and therefore it is not sensible for the economy to simply copy stringent emission regulations of other countries. Distributed electricity generation with cogeneration installations will further improve the reliability of the electricity supply system at minimum costs.

1. Introduction

Hungary can be seen as a country with many opportunities for expanding the energy supply system in such a way that it stimulates the economy while the environment will not be negatively affected. The expected growth of the economy in Hungary will certainly cause an increase in energy consumption per capita in the near future. Especially the demand for electricity will rise, since electricity can be seen as the motor of innovation. However, with a clever approach, the energy intensity of the economy, that is the amount of energy per unit of Gross Domestic Product (GPD), can be brought down considerably. Since emissions are directly connected with energy use, optimum utilisation of fuel will generally result in lower emissions. Another aspect is the use of clean modern processes for converting fuel into useable energy. Cogeneration of electricity and heat can certainly be seen as an effective method to improve fuel utilisation and to reduce emissions.

Cogeneration of heat and electricity implies that electricity is generated at sites where the heat released can be used. Process industries with a substantial, fairly constant, heat demand are ideal locations for cogeneration because of the nearly permanent use of the capital investment. Other important applications are district heating, hospitals and greenhouses. In countries in Central Europe, winters are generally cold and dark so that the demand for building heating and for electricity for lighting largely coincide. Installing cogeneration sets close to heat users automatically results in a distributed way of generating electricity. Distributed generation means that generally the electricity is also produced close to the users, in contrast with central generation. As a result, a smaller transport and distribution system for electricity is required and that saves investments and distribution losses. Hungary has already a tradition of district heating and there is much experience with relative smaller size power stations which will facilitate a further implementation of cogeneration.

Modern gas-fuelled reciprocating engines are ideal prime movers to drive generators in cogeneration installations. Such engines have high shaft efficiencies allowing electricity production with an efficiency ranging between 38% and 45%. The total efficiency including heat usage can exceed 85%. The high combined fuel utilisation efficiency and the use of gas as a fuel result in very low specific CO_2 emissions. Also the emissions of species connected with acid rain and air quality are very low. The benefits for fuel savings and for the environment are therefore obvious. At the same time, engine-driven cogeneration plants allow for a high flexibility in power capacity build-up because of short lead times and easy transportability. This paper will further discuss the advantages of cogeneration for Hungary.

2. Energy use and emissions in Hungary

The energy use per person per year in Hungary is about 2.5 ton oil equivalent (toe) or 105 GJ at the moment. That equals a constant energy supply flow of 3.3 kW per person. Globally seen, there is a direct relationship between energy use and wealth level. Naturally, there is also a link between energy use and the local climate. The wealth level of a country is generally expressed in the GDP per person with a correction for the so-called Purchase Power Parity (PPP). This PPP intends to express the difference in buying power of a Euro or a US$ depending upon the price level in a country. If salary levels are low and if many natural resources are within easy reach, the PPP per money unit will be higher. As an example, the fertile soil in Hungary and the still relative low costs of its agricultural sector make that food is inexpensive in comparison with Western Europe. Consequently, more food can be bought per Euro. The energy intensity of the economy in Hungary is currently about 15.5 MJ/US$ (PPP) [1]. This is higher than the roughly 10 MJ/US$ (PPP) in Western Europe. Hungary has already made improvements, since before 1980 the energy intensity was roughly 19 MJ/US$. The US$ value used here is based on the year 1990. The relatively high energy intensity of the Hungarian economy reflects some inefficiency in energy use. If the PPP is not taken into consideration, the energy intensity in Hungary is even a factor 4 higher than in e.g. Germany. A better energy utilisation is therefore of utmost importance for Hungary, especially since much fuel has to be imported.

The annual electricity consumption per capita in Hungary was close to 3.5 MWh in the year 2000. This is about the same as in Poland. In Germany, The Netherlands and Denmark the yearly electricity use is about 6.4 MWh/capita. Consequently, a substantial increase in electricity use can be expected in connection with a growing economy. The averaged efficiency of the power plants in Hungary approaches 35%, which means that improvements are possible. Currently, of all 49 power plants above 3 MW, only 6 have a capacity exceeding 100 MW. The bigger power plants are nuclear installations with a good reputation. They produce about 37% of the total electricity demand. Power stations fuelled by indigenous lignite produce 24% of the electricity while oil and gas fired stations generate 28% (source MVM). Slightly less than 2% comes from autoproducers and hydropower. At least in theory, much space would exist for gas-fired cogeneration. An optimum use of gas is extra recommendable since about 75% of it has to be imported, primarily from Russia.

Defining absolute limits for anthropogenic emissions is complicated. Worldwide, emission limits tend to be expressed in gram/m^3 or ppm in the exhaust gas, or in gram/GJ related to the fuel energy input. Such emission limits are often called specific emission limits. That does not take into account the total mass emitted per km^2 or the concentration level ('immission level') in the environmental air. If the population density in a country is very low and if the energy use per person is low, the allowed specific emissions can be higher without any harm for the environment. The author highly recommends that such national or regional circumstances are taken into account for national emission regulations. Table 1 compares typical environmental load factors of Hungary, Germany and The Netherlands without directly using actual emission data. It is very clear that even without actual emission data, the allowed emission per unit of fuel energy can be much higher in Hungary than in a densely populated country such as The Netherlands. Having specific emissions limits in Hungary equal to those in The Netherlands or Germany would put an unnecessary burden on the Hungarian economy.

Table 1: Typical environmental load factors for Hungary, Germany and The Netherlands (2000).

Country	population density	economic density	energy density
	people/km^2	MUS$ (PPP)/km^2	kToe/ km^2
Hungary	107	0.73	0.27
Germany	229	4.03	0.97
Netherlands	462	8.70	2.20

In Hungary, the use of lignite with a high concentration of sulphur makes that SOx is the major contributor to the total emission of acidifying components. The specific SOx emission averaged over all energy use is 530 g/GJ (data year 1999). The total SOx emission in tons per year has already roughly been halved compared with the year 1980. Since lignite accounts for about 17 % of the Total Primary Energy Supply for Hungary, the specific SOx emission for lignite use is close to 3 kg/GJ. Lignite has a calorific value ranging between 6 and 10 MJ/kg. It should not be recommended that Hungary stops using lignite because it is an important national fuel resource with many jobs involved. It is however necessary to clean the flue gases effectively, which can be best carried out in larger power stations. The UN ECE Gothenburg protocol for transboundary emissions mentions for Hungary a maximum emission of SOx of 550 kton/year for the year 2010 compared with 1010 kton/year in 1990. The Netherlands are only allowed to emit 50 kton of SOx in 2010.

The specific NOx emission over all energy use in Hungary is roughly 200 g/GJ (1999). This is slightly higher than in The Netherlands (180 g/GJ). The major cause of NOx is automotive traffic. The introduction of catalyst for road vehicles will lower the NOx output. The same applies for CO, which is now about 690 g/GJ in Hungary. The specific emission of the total of non-methane volatile organic components (NMVOC) amounts to about 135 g/GJ. Cleaner combustion processes and oxidation catalysts can help to decrease CO and NMVOC. However, CO is about a factor 150 less toxic than NO_2 so that CO is not really a problem, except perhaps in more densely populated areas in inner cities. With a gradual renovation of combustion processes, NOx, CO and VOC can probably be kept at acceptable levels in Hungary, even with a doubling of the energy use per capita.

3. Energy efficiency of reciprocating-engine-driven cogeneration

As mentioned earlier, cogeneration installations driven by reciprocating engines can have electric efficiencies up to 45% and a total fuel utilisation efficiency over 85% [2]. In addition, less transmission losses will occur with cogeneration since the locally produced electricity will generally also be consumed locally. Transmission losses account on the average for 5 to 8% of the generated electricity. Additionally, also combined cycle power stations for electricity generation will have to adapt to the instantaneous demand. That means that they have to run at loads lower than the rated load with resulting lower efficiencies. Consequently, electricity from a modern combined-cycle plant will probably have an ultimate net efficiency of about 50%. Figure 2 illustrates the mechanism of fuel savings with cogeneration driven by modern gas engines.

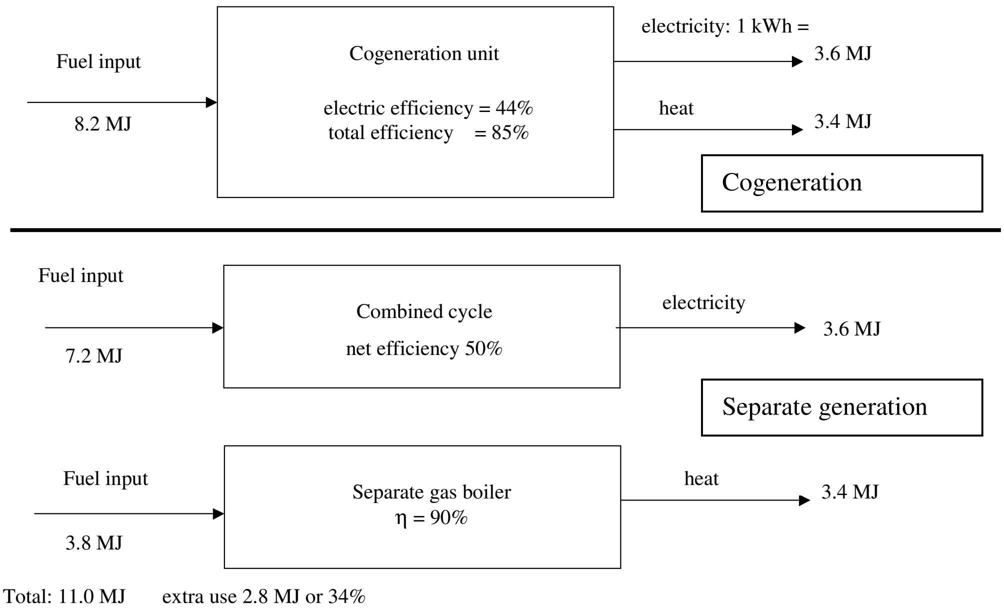

Figure 1: The extra fuel use of separate generation compared with cogeneration.

The efficiency of reciprocating-engine-driven generators depends on the engine type and on the engine load. Engines with a larger cylinder bore and a leaner mixture more closely approach an adiabatic process. That means that relatively less heat will escape towards the cylinder wall so that a higher conversion efficiency results. Also, a higher specific load of the engine (bmep or kJ/m^3 work per cycle and unit of swept volume) improves the efficiency [2]. Figure 2 gives the net electric efficiency of the range of Wärtsilä gas engines. The annotation SG means spark ignited while DF indicates that a small diesel pilot is used to ignite the mixture of fuel gas and air. For each engine type, the efficiency is given in the load range between 50% and 100%. Clearly can be seen that such highly turbocharged engines show only a minor decrease in efficiency in the load range between 80% and 100%. This implies that some load variation is possible without severe negative effects on the efficiency. For larger total load changes, single engines from a cluster of units in parallel can easily be switched off [2]. Such an approach also lowers the maintenance and operation costs per kWh.

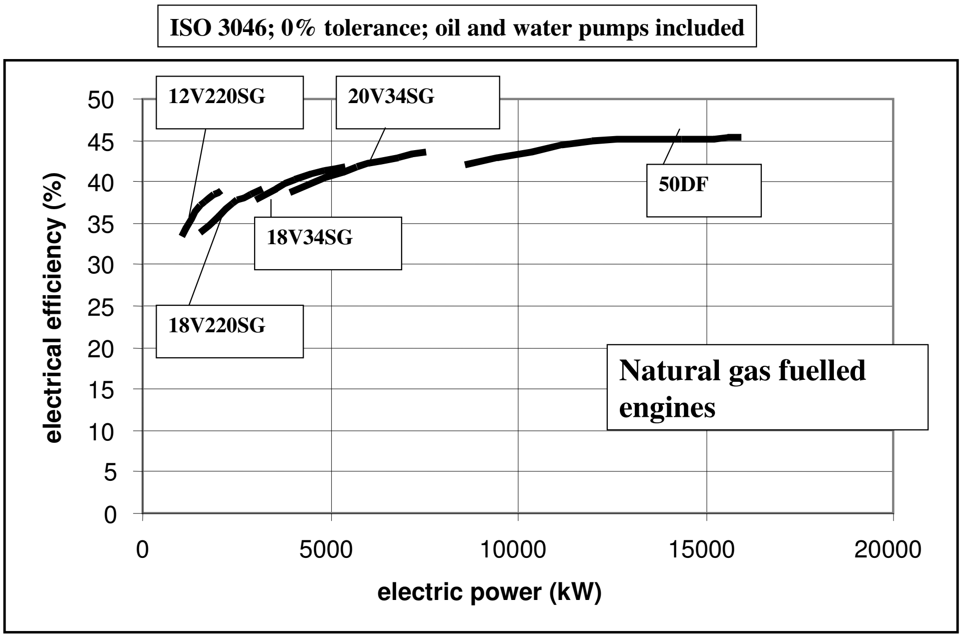

Figure 2: The net generating efficiency of some reciprocating-engine-driven generators.

4. Emissions of gas-fuelled reciprocating engines in cogeneration applications

The specific CO_2 emission of gas-fuelled reciprocating-engine-driven cogeneration plants is very low. Via combustion, natural gas releases CO_2 at a level of about 56 g/MJ where lignite produces close to 109 g/MJ. A central power plant fuelled by lignite has a specific CO_2 emission of about 1300 g/kWh of electricity while a natural-gas-fuelled cogeneration plant emits the very low level of close to 250 g/kWh. In the latter case the benefit from the heat usage of cogeneration has been taken into account. In Hungary, the CO_2 emissions per capita are relatively low at the current level of energy use. Low CO_2 emissions leave more space for future increases in energy use and it gives opportunities for CO_2 trading. It is therefore important to keep the specific CO_2 emissions as low as possible.

The NOx emission of gas engines depends primarily on the setting of the air-to-fuel ratio. For the efficiency curves given in figure 2, the NOx emission at full load equals the TA-Luft value of 500 mg/m^3 at 5% O_2 in dried exhaust gas, which equals 160 g/GJ based on fuel energy input. For a shaft efficiency of 44%, this equals 655 mg/kWh without taking into account the benefit of the heat usage. The 160 g/GJ is already lower than the general NOx emission level of 200 g/GJ in Hungary as mentioned earlier. With some additional air, the specific NOx emission of many gas engine types can be decreased down to 80 g/GJ (half TA-Luft). A negative consequence is that the shaft efficiency decreases by 1.5 % point; this means that more fuel is required per kWh of electricity. Technically, the NOx emissions can be further reduced by about 90% by using Selective Catalytic Reduction based on a reaction of injected ammonia or urea with

NOx over a titanium/vanadium catalyst. The costs of such SCR systems depend on the size of the unit and on the reduction level required. They can vary between Euro 3000 and Euro 9000 per ton of NOx removed. Currently, there is no real need in Hungary to decrease the NOx emission of gas engines below the TA-Luft level. That would only increase the costs of energy without a clear environmental benefit.

Hydrocarbon emissions in the untreated exhaust gas of reciprocating engines can never be fully avoided if the fuel consists of hydrocarbons, since there is always some incomplete combustion. Natural gas however contains in general less than 5 % in volume (or about 10% by mass) of hydrocarbons higher than the non-reactive methane (CH_4). The composition of the unburned hydrocarbons in the exhaust gas roughly reflects the composition of the fuel gas. As a consequence, the specific emission of reactive hydrocarbons affecting air quality is relatively low. In urban areas with a high pollution level, any additional emissions might be unwelcome. In such situations, an inexpensive oxidation catalyst (investment about 20 Euro/kW) in the engine exhaust will help to decrease both the non-methane hydrocarbons and CO. Removal of over 90% of higher hydrocarbons and CO is no problem. Compared to automotive sources, gas-fired cogeneration plants hardly add to the local reactive hydrocarbon pollution. Unnecessary installing of oxidation catalysts on gas engines should not be promoted since that is an additional burden on the economy. Species such as CO are only toxic over a certain concentration in the air. The long-term exposure limit for human beings to CO is 50 ppm in the air, which is roughly a factor 200 higher than that for NO_2. The concentration of CO in the exhaust of lean-burn engines varies between 100 and 600 ppm depending on the engine type. Consequently, only little dilution is required to bring that down to an acceptable level.

5. Further benefits of distributed electricity generation

The local character of cogeneration of electricity and heat means that the installation is generally connected to the local electricity distribution grid. Engine-driven generators over a certain power capacity have been equipped with proper control systems so that the installations can contribute to the stabilisation of the voltage and frequency of the grid. Such units can also participate in carrying part of the reactive load of the grid. It can be proven statistically that a cluster of smaller well-controlled generators has a higher stability than just a few central power plants. Further, the transmission and distribution losses of electricity can be drastically reduced. Also, less capital has to be invested in the electricity transmission system.

Another benefit of multiple smaller electricity production sets is the increased reliability of the total electricity supply system. The probability that a high number of cogeneration sets fail at the same moment is very small while the impact of each of these generators on the total production capacity is limited. If one large central power plant fails, the relative loss in production capacity is much higher. Moreover, the maintenance of engine-driven generators can be carried out by local mechanics with some extra training. In contrast, the maintenance of the turbines in large combined cycle plants has to be carried out in special locations with, often foreign, specialist engineers.

6 In conclusion

1. In Hungary, the expected growth in wealth level in the near future is such that a substantial increase in electricity consumption can be expected. Next to central power stations fuelled by lignite and nuclear power stations, natural-gas-fuelled cogeneration installations can play an important role in this. Modern cogeneration installations guarantee a maximum utilisation of the fuel gas.
2. Cogeneration sets based on reciprocating engines have a high efficiency of converting fuel energy into electricity and they offer a maximum flexibility in power capacity build up. Next to that, the connected distributed way of generating adds to the flexibility, reliability and stability of the electricity system.
3. The emissions of modern reciprocating gas engines are low enough without additional treatment of the exhaust gases. In the Hungarian situation, it is not logical to use the stringent emission regulations existing in countries with a much higher population density.

References

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