Biomass CHP best practice guide

Performance comparison and recommendations for future CHP systems utilising biomass fuels

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Photo: Torben Skøtt/BioPress

Preface

This *Best Practice Guide* presents the results from the activities in the Altener project "Bio-CHP - European Biomass CHP in practice", Altener contract no. 4.1030/Z/02-150/2002.

The report contains results and recommendations from analysis of monthly operational data from 63 biomass CHP plants during 24 months.

Information on individual plants cannot be recognized from data in this report. Due to the level of anonymity required from a number of plants participating in the project all plants are anonymous, even if many plants have accepted full publication of individual data. This is necessary to protect the required anonymity for those plants who cannot accept publication of plant specific data.

To enable clear reading of the included graphics, we recommend that prints made from the electronic version of the report should be made in colour.

For more information about the project please check web site at:

http://bio-chp.force.dk

- or contact the project co-ordinator:

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Anders Evald
March 2006

Disclaimer: A huge effort has been put into assuring high quality of data. This has been done through careful evaluation of primary data from the plants comparing them with data from earlier months, through formal quality control in other project partner offices and through identification of outliers in the total data system when files from all plants are compared and analyzed. However even after this effort we are not in a position where we can guarantee 100% correct data in this huge dataset covering more than 100 parameters for 63 plants in 24 months. Thus we cannot guarantee individual figures, and we cannot take responsibility for any actions taken on the basis of the information in this report.

Photo: Torben Skøtt/BioPress

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Introduction

The BIO-CHP project intends to contribute to an increased - and more efficient - use of biomass for combined heat and power (CHP) production in Europe.

From 2003 to 2006 the project collected and disseminated biomass CHP experience based on collected data from more than 60 existing CHP plants in Denmark, The Netherlands, Austria, Germany, Sweden and Finland.

BIO-CHP is partly funded by the European Commission Altener programme.

The Project aims are to:

- Promote biomass CHP in Europe by displaying experiences from solid biomass (including co-firing), Municipal Solid Waste (MSW), anaerobic digestion gas and landfill gas fuelled CHP plants and highlighting plants with the best operation
- Provide e.g. authorities and future plant owners with information about what performance to expect from biomass CHP plants and about best available technologies. This will help ensuring high quality of future plants
- Enable benchmarking and thus identify the improvement potential of the existing European CHP plants
- Replicate best practices on the operation of biomass CHP plants by extensive dissemination activities
- Create a network for exchange of good and not so good CHP experiences

Project partners

A total of 6 EU countries are partners in the project, each covering CHP plants in their home country, as well as other project activities.

Elvira Lutter, Östereichische Energie agentur - Austrian Energy Agency (AEA), Austria

Harrie Knoef, BTG Biomass Technology Group BV, The Netherlands

Kati Veijonen, VTT Processes, Finland

Johan Vinterbäck, Swedish Bioenergy Association Service AB, Sweden

Janet Witt, Institute for Energy and Environment, Germany

Anders Evald, FORCE Technology, Denmark

A few plants located in countries outside the partner countries were included in the study.

Method

A large number of combined heat and power plants located in the participating countries are invited to take part in the project as suppliers of key plant data and specific monthly operational figures and statistics. In return the plants receive access to a large data material covering similar installations in their home country and in other countries, which enables them to compare their own performance with others. This way changes can be made in operational patterns, in installations etc. to enable the plants to achieve an improved economic and environmental performance.

For each plant a series of key performance indicators were calculated. These parameters are the key to assessing operational performance from one month to the next, and in comparison with other plants.

The participating plants cover a wide range of technologies, which is classified into 7 categories:

- Biogas and landfill plants (from digestion of animal manure, agricultural residues and MSW)
- Gasification plants (using wood fuels)
- CFB (circulating fluidized bed) plants (using wood fuels, bark and peat)
- BFB (bubbling fluidized bed) plants (using wood fuels, bark and peat)
- Grate-fired steam boiler plants (using uncontaminated biomass such as wood chips, bark etc.)
- Grate-fired steam boiler plants (using MSW as a fuel)
- Dust-fired steam boiler plants (using a combination of coal and straw)

Information on key figures and monthly data were collected in the participating partner countries, validated and passed on to the central database system in FORCE Technology, Denmark.

The collection of monthly data covers a total of 24 month, starting September 2003 and ending August 2005.

Environmental performance data were collected. Due to incomparable data sets, the analyses of these data are limited to ash production and water consumption. A range of other emission parameters were collected.

A project website on the address bio-chp.force.dk has been established. The site covers all kinds of project related information, and includes an intermediate technical report, the e-mail newsletters, the best practice guide, details on the participating CHP plants etc.

E-mail newsletters are being distributed to a European target audience.

A project workshop presenting the results to a European audience was held in Vienna, Austria in March 2006.

Best practice conclusions and recommendations

This section contains conclusions and recommendations, which is general to biomass CHP. Please refer to the following chapters for more detailed conclusions regarding the individual CHP technologies.

Photo: Kokkola Power Plant, Finland

Big is beautiful

Biomass energy systems, being renewable energy systems, are in some contexts considered “green”, “alternative” technology, which should develop based on a local urge to do something about environmental problems. This “think globally, act locally” idea will often point towards small scale technical systems, that depend on fuel supply from within a short distance, and cover relatively small energy demands.

For biomass CHP systems, this idea is in contradiction to the findings from plants in operation. In general we observe higher efficiency, lower own consumption and better availability for the larger plants, which means that larger plants perform significantly better in fossil fuel substitution and in operational economic performance.

And even though our study does not cover investment cost for the CHP plants, it is evident from other studies and from general economic mechanisms, that larger systems show lower investment cost relative to the size of the plant. Thus the general perspective for development of biomass CHP systems is “bigger is better”, meaning that for the resources given (capital, biomass, manpower) the bigger the plant, the more renewable energy is produced.

Such a recommendation obviously has limitations. One is, that biomass CHP systems are limited by the size of the heat market, they can be connected to. Another is that the conclusion might be slightly different for biogas and landfill gas engine systems, where the size dependency is less significant than for other technologies. A third is that in a more mature market development, series production of energy systems might bring down capital costs for smaller units. A fourth limitation arises from biomass availability.

Capacity and utilisation

Looking across the different CHP technologies there seems to be a general tendency that the CHP plants are built with a too high capacity. This is evident from the relatively low utilisation factor shown for the majority of the plants included in the survey.

Selecting the right size for a CHP system connected to a heat system is by no means trivial. A large plant, covering close to or even more than the peak heat demand in winter will show a low utilisation of installed capacity the main part of the year, and it might even have to shut down during summer due to limitation in low load operation. On the other hand a relatively large plant can benefit from larger electricity sales, and when coupled to a heat accumulator it can benefit from changing electricity tariffs by producing the heat when the value of electricity is the highest.

Also many plant owners, who presently do not utilise the installed capacity (plants too big for the heat market) argue that the size of the plant does not necessarily match the present heat demand, but rather a future heat demand created by more heat consumers being connected to the district heating system.

A high utilisation of the installed capacity can be achieved if the plant is relatively small, covering only e.g. 40 % of the peak winter heat demand. This generally gives a better payback on the investment in the CHP system, but due to the need for a generally more expensive peak load supplementary heat production and due to a smaller impact from the CHP system on the total heat production costs in the heating system, a very small system is not optimal either.

The optimal CHP plant capacity in a given heat distribution system depends on fuel costs, investment cost, peak load heat production costs, electricity tariffs, expected development in heat demand and a number of other economic parameters. Optimal performance studies generally indicate that the economic optimal capacity is in the order of 50 to 70 % of winter peak heat load. Lower and higher end of this interval corresponds to 86 % to 98 % of annual heat demand covered by the CHP system and 74 % to 61 % utilisation factor (calculated figures, assuming Danish climatic conditions and full availability - in Southern Europe the different climate will lead to different optimal conditions).

The fuel and systems available to supply peak heat demand and demand when CHP is out of operation also influences optimal plant size and operational pattern. This is discussed in further detail in the section on BFB-boiler, but is relevant for other technologies as well.

CHP or not CHP

We have included some biogas and landfill gas plants in the study, which only to a very limited extent utilises the heat associated with the power production. One might argue that such plants are not truly combined heat and power plants; on the other hand as long as a small fraction of the heat is actually utilised, the plants are at least partially CHP.

The point is emphasized by the fact that in some countries biogas and landfill gas plants are subject to premium price schemes for renewable electricity no matter if the heat is utilised or not. In this way, support schemes for renewable electricity promotes development of renewable electricity, however not necessarily as electricity produced with high total efficiency in combined heat and power systems.

Also for a few other plants based on solid fuels the amount of heat connected to the plant is too small to match the potential heat production from the plant. This is true especially for a couple of large waste incineration plants, which is connected to relatively small process heat demands, most likely because these plants for localization reasons are placed far from domestic district heating systems.

Generally combined heat and power production is highly efficient. National support schemes for renewable electricity might support the development of biomass CHP systems, but if support is given for electricity-only as well as for combined production, there is no specific incentive to install CHP systems and locate the plants near a heat demand. Such a support scheme might initiate more renewable electricity, but not in the most efficient way as CHP.

Balancing heat and power

From a general energy efficiency point of view electricity is the more valued of the two energy products from a CHP system. This is in most cases also true when it comes to the sales value of the two products. However, for industrial plants, and for plants located where heat has a high value (e.g. in several Nordic countries, where taxes on fossil fuels makes heat a valuable energy service, comparable in price to electricity) the two products may be more balanced. Industrial facilities might operate the CHP plant primarily for the sake of its own steam consumption, and a Nordic CHP plant might create by far the largest income from sales of heat to a district heating system.

Choosing the right technology

The different CHP technologies are quite different when it comes to efficiency. While most perform well in heat utilisation (this is by far the easiest from a technical point of view), difference in electric efficiency might be very big. Additional income from high electricity sales must off course be balanced against any additional investment costs.

For all plant types that involve a steam cycle, the steam data are extremely important for efficiency. This is trivial for the energy engineer, but maybe not so much for the investor or plant management board. The higher pressure and the higher temperature in the steam cycle the better. Generally larger plants operate at higher steam data and modern plants are also better in this context than older plants. When decisions are to be made on investment in CHP systems, the efficiency gain must be weighed against the costs of boiler, turbine and other equipment and against risk of corrosion and other operational problems.

Retrofitting older equipment often pays back well. Increasing steam data or changing an old inefficient turbine to a newer model might add very significantly to the operational performance of the plant.

Industrial systems

CHP plants built to provide steam and other heat demand for an industrial facility seem to provide a less solid foundation for an efficient biomass CHP operation. One CHP plant is in danger of closure due to its main industrial steam user being closed down; another has skipped completely the heat sales part of what was from the outset a combined heat and power plant. Several CHP plants installed in industrial facilities have rather limited heat demand connected, and operate to a large extend after this heat/steam demand leading to low electric efficiency, extended periods of stand still and general poor utilisation of the plant. Electric efficiency in industrial power plants is often lower simply because their most important product is not electricity but steam (or heat). They use bled steam for industrial processes which naturally decreases the electricity production.

Reducing own consumption

The consumption of power for internal purposes within the CHP plant is significant and needs to be addressed already in the planning phase in order to keep it as low as possible.

The different CHP technologies show rather large difference in own consumption, meaning a sensible choice of technology is important.

Modern plants show lower own consumption than older ones; this indicates a potential to reduce the own consumption by retrofitting important auxiliary equipment in the plant.

Finally plants with a high electric efficiency presents a relatively low own consumption. If the choice falls on a low budget turbine plant with low steam data, be prepared for using a very large fraction of the produced electricity within the plant.

Operational problems

Co-firing common fossil fuels with solid biomass and recycled fuels poses new challenges for power plant operators. E.g. sintering of bed-particles has been observed in many biofuel-fired fluidized bed boilers, which can lead to shutdown of the boiler due to decreased fluidization. Deposits on heat transfer surfaces reduce the heat transfer, decrease the efficiency of the boiler and increase the risks for high temperature corrosion. Also the variations in the moisture content of biomass fuels set demands e.g. for combustion process and the auxiliary equipment (e.g. flue gas fans) of the boiler. Due to these operational problems boiler efficiency decreases and the operating and maintenance costs increase, significantly influencing the total economy of the plant.

In the following sections on technologies, more details on operational problems are listed for BFB and CFB. This might indicate that other technologies are problem free, however operational problems exist for all biomass CHP technologies; only more details were available from the BFB and CFB plants.

Definitions

Utilisation factor

The extent, to which installed capacity is utilised, is studied using a performance indicator called the *utilisation factor.* It is calculated from monthly produced power in MWh divided by the plant capacity in MWh assuming the plant runs continuously at full load the whole month. The utilisation period expresses the extent to which the plant capacity is utilised: a low figure means low capacity utilisation caused by stand still or part load operation, a high figure means constant full load operation.

The utilisation factor will generally be higher for industrial CHP systems, where process related heat or steam demand fluctuate less than outside temperature dependent heat load in district heating plants.

Availability

The performance indicator *availability* describes the extent to which the plant is ready for operation (not necessarily in operation). It is calculated as 100% minus (weighted hours of out of operation due to damage + hours out of operation due to of revision) divided by hours in a month.

Energy production

The energy production is the total production of heat and electricity for the plant in the period.

Electric efficiency

Average efficiency (monthly or annual) measured as net power produced divided by fuel consumption in the plant measured in energy units using lower heating value.

Total efficiency

Average efficiency (monthly or annual) measured as net power produced and net heat produced divided by fuel consumption in the plant measured in energy units using lower heating value.

Operational efficiency

This is the actual electricity and heat efficiency observed in the plants monthly operational data. Nominal efficiency This is the efficiency, as anticipated by designers and plant owners as the expected nominal performance of the plant.

Own consumption

Internal consumption of electricity at the plant.

It should be noted, that while we have attempted to include only internal electricity consumption at the plant, we cannot rule out that a few plants might give data that includes other electricity consumption as well.

Specific own power consumption

Internal consumption of electricity at the plant as a ratio to the gross power production.

Photo: Torben Skøtt/BioPress

Photo: Torben Skøtt/BioPress

Photo: Courtesy Rural Generation, Northern Ireland

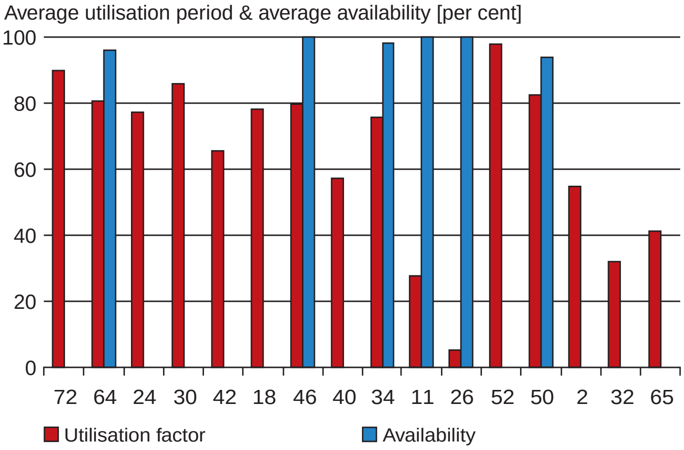
Biogas and landfill gas plants

This technology classification covers 19 gas based CHP systems (gas engines) based on biogas from dedicated biogas plants or landfill gas. For plant no 26 only the first 11 months data are included.

The analyses focus on the performance of the gas engine systems as such, because of the diversity of the biogas raw materials used and the immeasurable nature of the landfill gas biomass consumption.

Some of the plants present virtually no heat production, either because there is no heat production, or because the heat used locally is not measured. Please refer to the general conclusions section for a detailed discussion of the implications of this.

Utilisation and availability



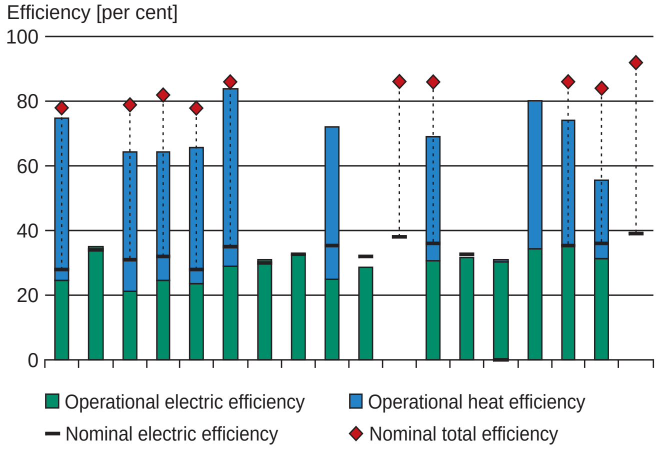
Utilisation factor and availability for 16 biogas and landfill CHP plants. Figures are shown as average values for 24 months, September 2003 to August 2005.

Several plants uses the installed capacity only about 25%. This is a severe loss on invested capital. At least for some of the plants, it is caused by to large installed engine capacity as compared to the biogas production potential.

There seems to be a tendency that the larger plants has a lower utilisation of installed capacity (not shown in graphics).

The majority of plants have a very high availability. When compared to the other types of CHP plants, the gas engine themselves are not very technically complicated which gives shorter period of non-availability.

Efficiency



Nominal and operational efficiencies for 18 biogas and landfill CHP systems. Operational figures are average values for 24 months, September 2003 to August 2005.

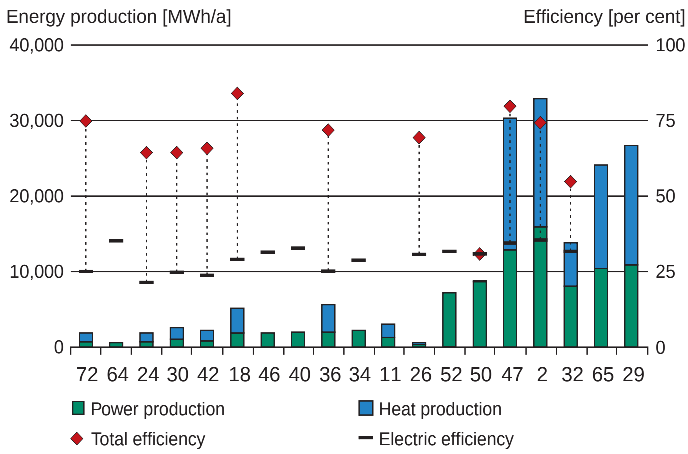
Except for two plants, the practical total efficiency is significantly lower than the nominal. For all plants, where data validation allows this comparison, the electric efficiency is significantly lower than the nominal.

As income from sales of electricity is the main sales value for most plants (heat is less significant from an economic point of view) this has a great negative impact on the economic performance of the plants.

Several plants have not been able to supply reliable data on heat production. These are typically biogas plants in Germany with the highest income from electricity sales, connected to a very small local heat demand, which is often not even measured.

For plant no. 32 the anticipated connection to a heat demand in reality was much smaller, hence the low operational heat efficiency.

Efficiency and annual energy production

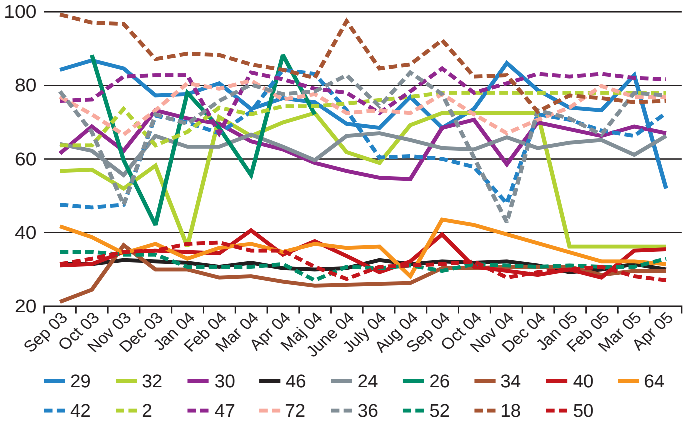


Operational efficiencies for 19 biogas and landfill gas CHP systems compared to the size of the plant shown as the annual production of electricity and heat. Operational figures are average values for 24 months, September 2003 to August 2005.

There is no clear indication that operational performance for larger plants are more efficient than smaller plants. This is clearly different from the other CHP technologies, where larger plants generally present higher (electric) efficiency.

The size range between smallest and largest plant is very wide, illustrated by the difference in annual heat and power production.

Efficiency over time

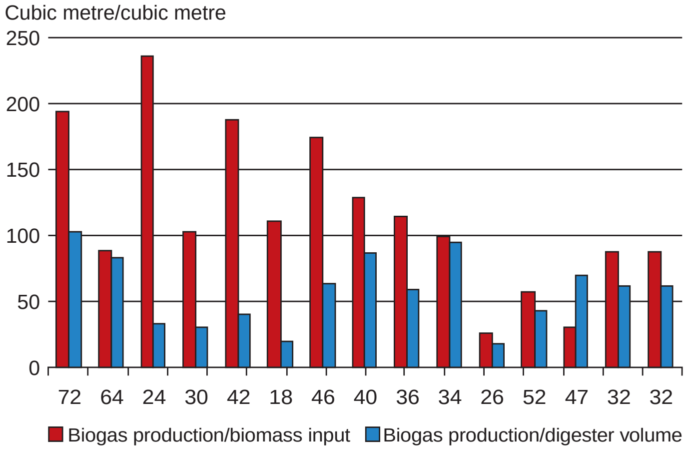


Total of heat and electric efficiencies for 19 biogas and landfill gas CHP systems. Operational figures are monthly data shown for 24 months, September 2003 to August 2005.

Variation in efficiency from month to month is very high. This implies improvement options for the individual plant by carefully following these data and copying operational patterns from the best months (choice of biomass raw material, operational pattern, load condition etc.).

Some plants shown do not have valid figures for heat production - these are the group of six plants showing data in the 20 to 40 % range, which must be then read as electric efficiency and not directly comparable to the other plants. Plant 42 had no heat sales in the first months, and also other plants have irregular periods with very low heat production.

Biogas production



Biogas production relative to the volume of biomass input and to the digester capacity for 15 biogas CHP systems (landfill gas systems not shown here). Operational figures are monthly data shown for 24 months, September 2003 to August 2005.

The plants show huge variation in the efficiency of producing gas the biomass raw material - from 25 to more than 200. This is probably caused by different raw materials used.

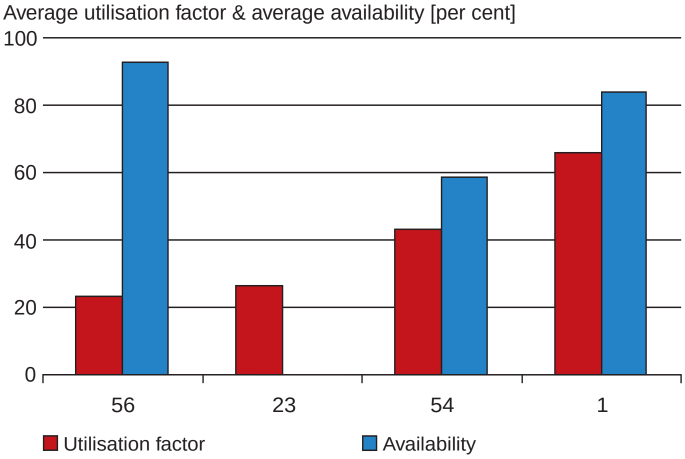
There is also an extreme variation in the gas production based on digester volume. From 17 to 102 m^3/m^3.

Smallest plants are shown to the left, largest to the right. There is no indication that plant size has any influence on these important performance parameters.

Gasification plants

This technology class consists of 4 plants, of highly variable size. For plant no 54 only the first 12 month data are included.

Utilisation and availability



Utilisation factor and availability for 4 gasification biomass CHP plants. Figures are shown as average values for 24 months, September 2003 to August 2005.

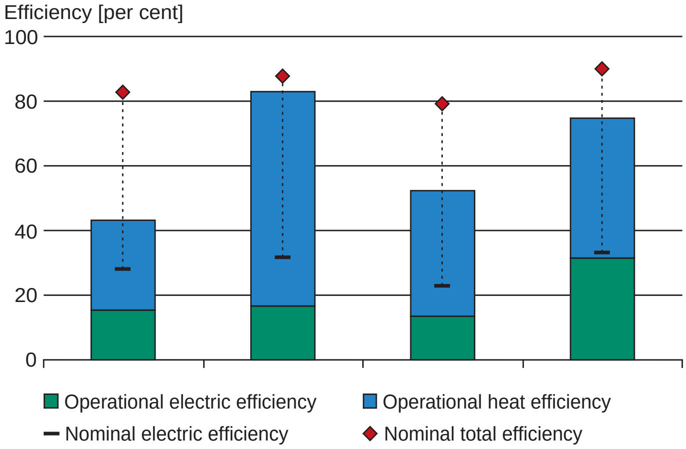
All gasification plants show low utilisation factor - two of four plants utilise the installed capacity less than 30 %. This is a loss on invested capital.

Plant no. 56 is out of operation for prolonged periods during the project period. This is caused by damage to vital engine parts occurring three times in 24 months as well as intentional non-operational periods and periods with too low heat demand. For plant no. 23 the low utilisation is caused by a too large installed engine capacity. Total capacity is 1.4 MW (electric power), while the gasifier gas production capacity only corresponds to about 0.8 MW (electric power).

Availability is low: the plants are not ready for operation more than 10% of the time; one plant even 41% of the time. However the dataset is too limited to draw a general conclusion from this.

Availability and utilisation are shown for the power producing part of the plant (engine or turbine). When looking at the gasifier alone, the situation might be somewhat different.

Efficiency



Nominal and operational efficiencies for 4 biomass gasification CHP systems. Operational figures are average values for 24 months, September 2003 to August 2005.

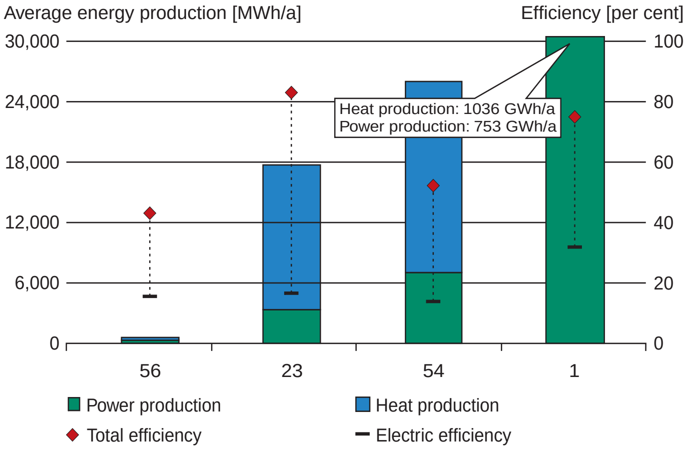
The operational total efficiency is significantly lower than the nominal. Further, the electric efficiency is significantly lower than the nominal.

As income from sales of electricity is the main sales value for most plants (heat is less significant from an economic point of view) this has a great negative impact on the economic performance of the plants.

Further the heat efficiency for two of the four plants is low. This is linked to limitations in the heat market as well as to technical constraints at the plants.

The plant to the right in the graphics consists of a combination of a biomass gasifier and a coal fired boiler, which share one steam turbine. For this plant, the efficiency description covers the combined system.

Efficiency and annual energy production

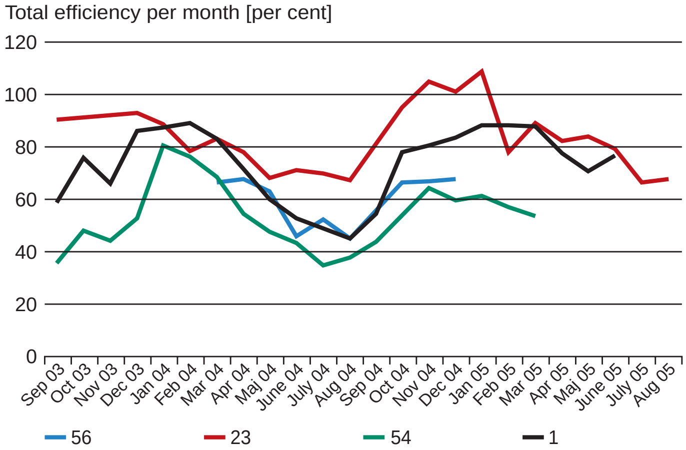


Operational efficiencies for 4 biomass gasifier CHP systems compared to the size of the plant shown as the annual production of electricity and heat. Operational figures are average values for 24 months, September 2003 to August 2005.

Compared with the very large plant (no. 1), the three smaller plants show significantly lower electric efficiency, between 14 and 17 % based on operational data from 24 months.

Plant no. 1 is special as mentioned above.

Efficiency over time



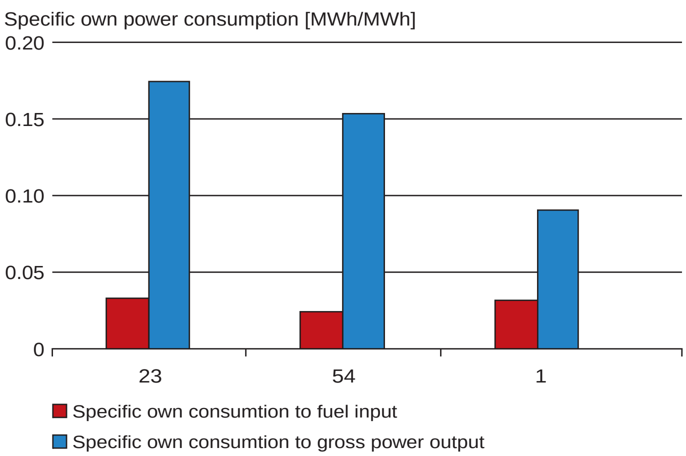
Total of heat and electric efficiencies for 4 biomass gasifier CHP systems. Operational figures are monthly data shown for 24 months, September 2003 to August 2005.

Seasonal variation in efficiency is very high. This implies improvement options for the individual plant by carefully following these data and copying operational patterns from the best months (choice of biomass raw material, operational pattern, load condition etc.).

Further there seems to be a seasonal variation, showing lower efficiency during the summer. This is most likely caused by part load operation during the summer, where heat demand is low or by reduced heat sales during summer, where some plants (e.g. plant no. 1) cool of excess heat. Condensing power operation or cooling off excess heat places a question mark to the classification as a CHP plant. It does however makes sense when the plant can have a a high income from the electricity sales, or avoid buying electricity (industrial applications).

Plant no. 56 is completely out of operation for extended periods (explained above).

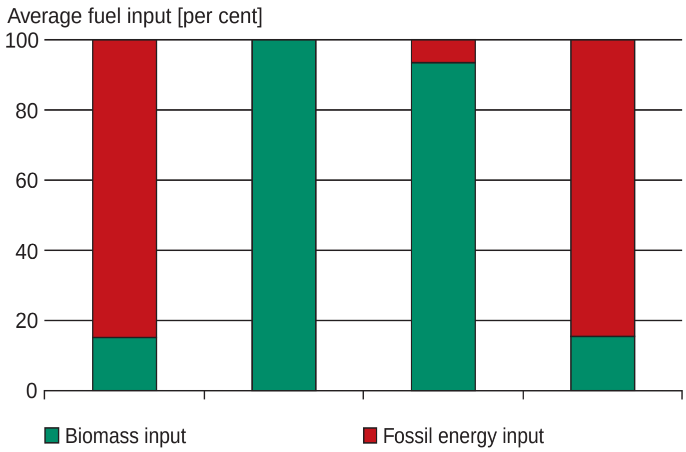
Own power consumption



Own power consumption for 3 biomass gasification CHP plants. Data are shown as averages for the 24 month period September 2003 to August 2005.

For the 3 plants where valid data are available, the internal power consumption are 9 to 17 % of the power produced. The two higher values raise concern about the economic performance of the plants as a significant fraction of the electricity produced is used internally.

Fuels used



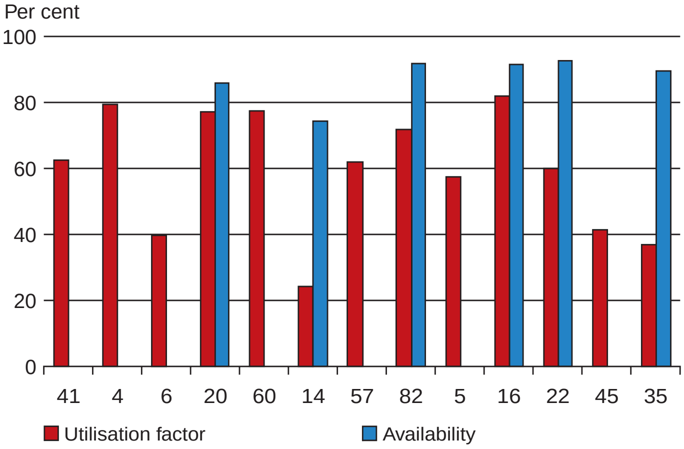
Division between biomass fuels and fossil fuels used in 4 biomass gasification CHP plants. Average figures for 24 months, September 2003 to August 2005.

The figures illustrate the very large difference in the type of the plants. Plant no. 1 is a dedicated combined fuels plant, where biomass fuels is only a minor fraction. In plant no. 56 the engine operates on as well gasification gas as diesel oil. When the owners need the power production, but does not operate the gasifier, diesel substitutes biomass.

Grate fired boilers

A total of 14 plants are included in the survey categorized as grate fired boilers. The majority of the plants are wood fired steam boilers with one or more steam turbines. For plants no 4 and 6 only the first 12 months of data are included.

Utilisation and availability



Utilisation factor and availability for 13 grate fired biomass CHP plants. Figures are shown as average values for 24 months, September 2003 to August 2005.

Some plants utilise installed capacity very badly, less than 50 %, and one is even below 25 %. General reasons for this is explained in the initial conclusive chapter.

Plant no. 14 shows very low utilisation due to extensive and repeated periods out of operation. 4 out 24 month was stand still caused by a damaged superheater, and 2.5 additional months was spend on planned revision work.

Another reason for the utilisation to be low is that the nominal installed capacity is never achieved during operation - the plant was simply sold as bigger than it is in reality.

Finally the utilisation is low for some plants due to extended periods out of operation due to damage to critical parts in the plant such as superheater, turbine etc.

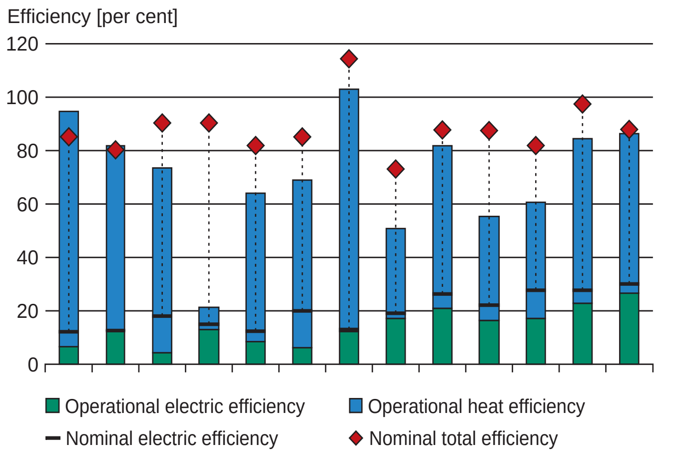
Availability for most plants is acceptable. When compared to other CHP technologies, grate fired systems perform relatively well.

There are no indications that larger plants are better than smaller plants.

Efficiency

While the total of heat and electricity show acceptable values in the order of 80% for most plants, the electric efficiency found from operational data are by no means impressive. 10 to 15% electric efficiency seems to the norm for this technology.

The practical total efficiency is significantly lower than the nominal. More important however is that the electric efficiency is many cases much lower than nominal, under practical condition less than 10 %!



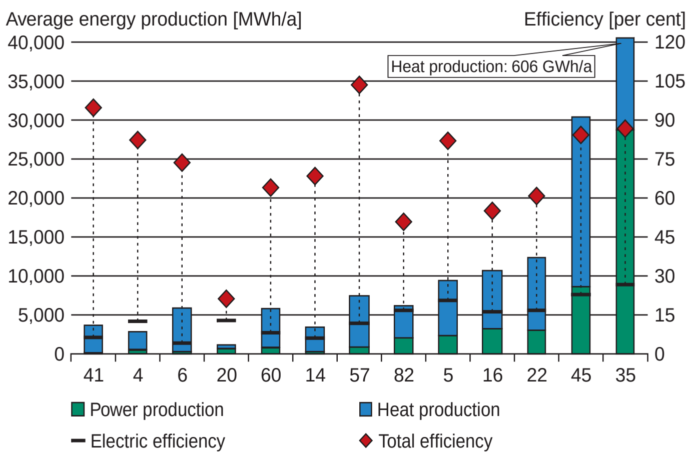
Nominal and operational efficiencies for 13 grate fired biomass CHP systems. Operational figures are average values for 24 months, September 2003 to August 2005.

There are a long range of explanations for the electric efficiency to be lower than the nominal value. Part load operation is one; turbines generally perform best at 100 % load. Some plants operates in on/off mode, taking advantages of the highest tariff for electricity during peak hours, operating at high efficiency (full load) and storing heat in a heat accumulator for continuous heat supply. Such plants however have reduced average efficiency due to losses during start-up and shutdown procedures, even though such procedures can be relatively short (50 to 120 minutes) for modern plants.

As income from sales of electricity is the main sales value for most plant (heat is less significant from an economic point of view) this has a great negative impact on the economic performance of the plants.

Some plants show efficiencies above 100% - these are equipped with flue gas condensing systems.

Efficiency and annual energy production



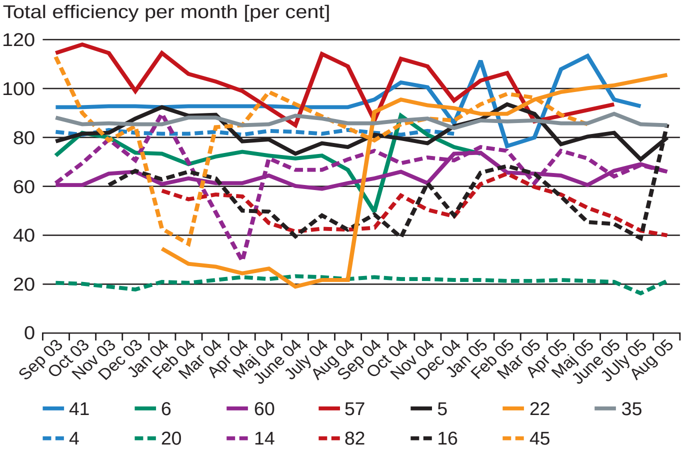
Operational efficiencies for 13 grate fired biomass CHP systems compared to the size of the plant shown as the annual production of electricity and heat. Operational figures are average values for 24 months, September 2003 to August 2005.

While the total efficiency (heat plus electricity) is in the same order of magnitude for most plants it is evident, that the larger plants show significantly better electric efficiency (approximately twice) than the smaller ones. This confirms the general conclusion that larger plants generally perform better.

Electric efficiency for steam cycle plants is largely determined by the basic steam data (pressure and temperature) from the boiler. Generally larger plants will operate in higher steam data, and also technology development in steam boiler steel quality etc. enables higher steam data and consequently higher efficiency in newer plants as compared to older plants.

Some plants show efficiencies near or above 100% – these are equipped with flue gas condensing systems.

Efficiency over time



Total of heat and electric efficiencies for 13 grate fired biomass CHP systems. Operational figures are monthly data shown for 24 months, September 2003 to August 2005

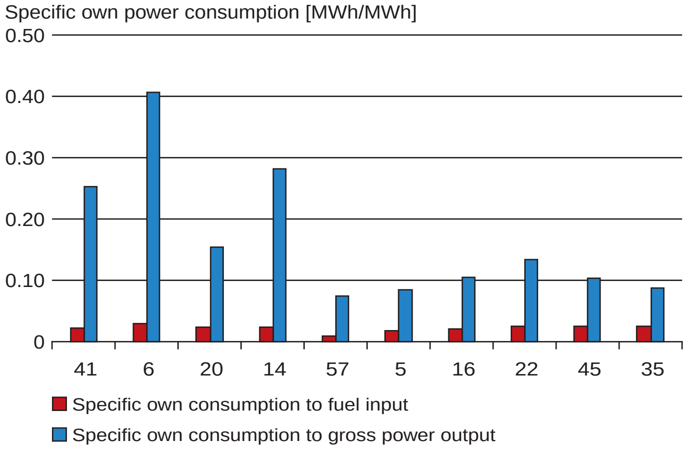
This class of CHP plants shows more stable efficiency during the year than the other classes.

A few plants show efficiencies above 100 % in some months. These plants are equipped with flue gas condensing systems, which gives a higher heat production, but does not influence electric efficiency. It should be noted, that the high heat efficiency means that in a given heat market (district heating system) less electricity production is possible.

Some plants exhibit months with much lower than usual efficiency. This should be investigated by the plant owners.

Plant no. 20 presents very low total efficiency. This is an industrial facility, where heat demand is limited to drying and local space heating, without connection to a district heating network. Surplus heat is cooled off in a cooling tower. As steam demand is limited, so is the heat efficiency; one might argue that the plant is not truly a CHP system. Similarly plant no. 22 has no heat demand for the first 8 months shown as the heat demand was not connected initially.

Own power consumption



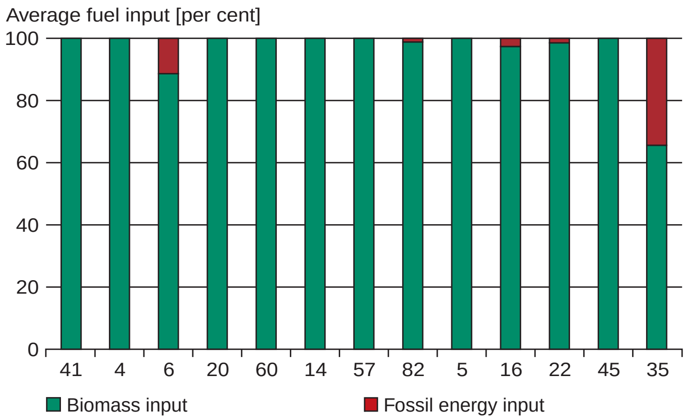
Own power consumption for 10 grate fired biomass CHP plants. Data are shown as averages for the 24 month period September 2003 to August 2005.

8 to 15% own consumption seems to be the rule for this type of CHP plant. This is less than the CFB and BFB plants, but still a significant and a high figure.

The highest specific own consumption is found in the smallest plants, because these have the lowest electric efficiency. There would also be a tendency, that older plants show higher specific own consumption.

Some plants show extremely high own consumption. For plant 6 and 14 this is probably caused by industrial power consumption being included, while plant 41 suffers from a very low electric efficiency, which results in a high relative figure for own consumption.

Fuels used



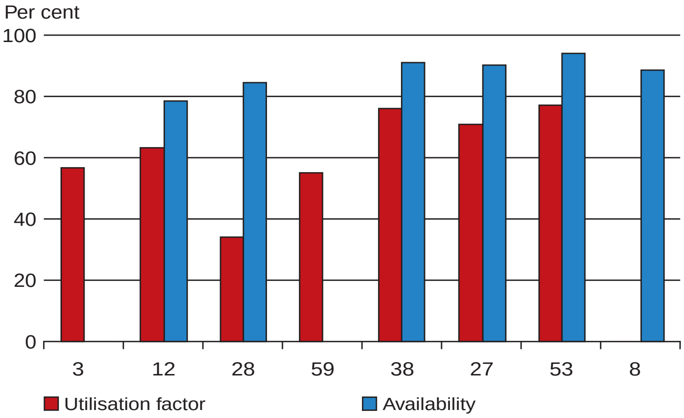
Division between biomass fuels and fossil fuels used in 13 grate fired biomass CHP plants. Average figures for 24 months, September 2003 to August 2005.

Generally gratefired systems are independent of fossils fuels, however two plants (6 and 35) are specifically designed for co-firing fossil fuels with wood. Plant no. 35 is a dedicated co-firing unit combining wood chips and natural gas. This plant also shows the highest electric efficiency in the group.

MSW grate fired boiler plants

A total of 8 CHP plants based on combustion of municipal solid waste (MSW) are included in the study. Although of a different size the plants are built on more or less the same technology: combustion on a grate and steam cycle for power production. Thus this technology class is more homogeneous than the others.

Utilisation and availability



Utilisation factor and availability for 8 MSW grate fired biomass CHP plants. Figures are shown as average values for 24 months, September 2003 to August 2005.

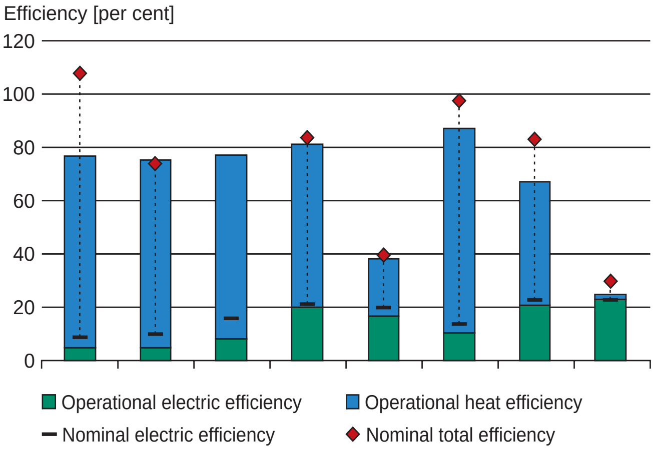
Availability is rather low, but more even between the plants. A low figure here must be attributed to the use of MSW, which causes regular maintenance work on the boiler.

Utilisation is better than other technologies. The main purpose of the plant operation is to handle waste, which creates additional income as compared to other CHP technologies, where fuel is a cost.

There is no tendency that larger plants perform better than smaller ones.

The lowest utilisation factor of 34% is certainly low for a technology with such high investment costs; for this particular plant it is caused by less incentive for operation as compared to other plants due to a low value of electricity (no special feed-in tariff valid for this plant).

Efficiency



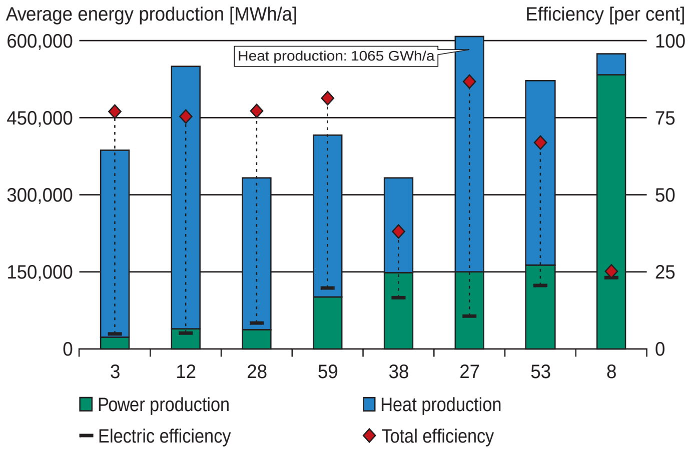
Nominal and operational efficiencies for 8 MSW grate fired biomass CHP systems. Operational figures are average values for 24 months, September 2003 to August 2005.

Like other CHP plants no one is over performing, all plants are to a larger or smaller extent performing poorer than anticipated in the nominal data. For 3 plants the average electric efficiency is less than half of what is stated as the nominal efficiency of the plant. It seems that 20 % electric efficiency, or just above this figure, is what can be expected as an annual average for this technology.

The plant to the right in the graphics has only a very small heat demand connected, which causes very low heat efficiency.

The plant to the left in the graphics has flue gas condensing system, this causing efficiencies above 100%.

Efficiency and annual energy production



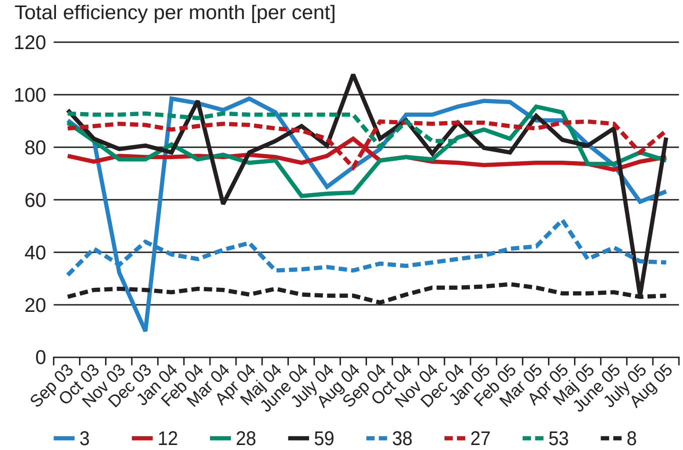
Operational efficiencies for 8 grate fired biomass CHP systems compared to the size of the plant shown as the annual production of electricity and heat. Operational figures are average values for 24 months, September 2003 to August 2005.

There is a clear tendency that the bigger plants perform significantly better than the smaller ones in electric efficiency. Looking at the total of heat and electric efficiency this tendency does not exist - the smaller plants gain from higher heat utilisation, and the larger ones might even be limited on the possibility to connect sufficient heat demand.

Plant no. 8 show very low heat utilisation - the potential for additional income is significant if a large district heating network could be connected, making the plant truly a combined heat and power plant. Also plant no. 38 present low heat utilisation caused by limitations in the connected process heat demand.

Some plants (e.g. no. 3, 12 and 28) clearly have more focus on heat production and waste incineration than optimizing electricity production. Low steam data (35 to 40 bar and temperature below 400 degrees is part of the technical cause for low electric efficiency in these plants.

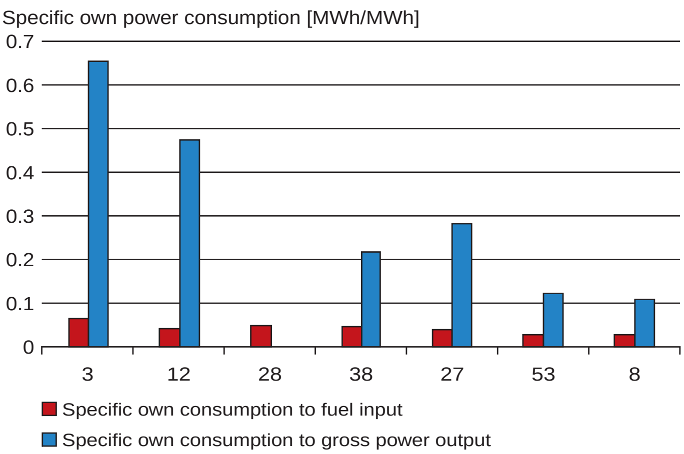
Efficiency over time



Total of heat and electric efficiencies for 8 MSW grate fired biomass CHP systems. Operational figures are monthly data shown for 24 months, September 2003 to August 2005.

Most plants show stable operating performance. Seasonal variations are observed; less heat sales during summer. Operational problems can be observed in some months (plant no. 3 and no. 59).

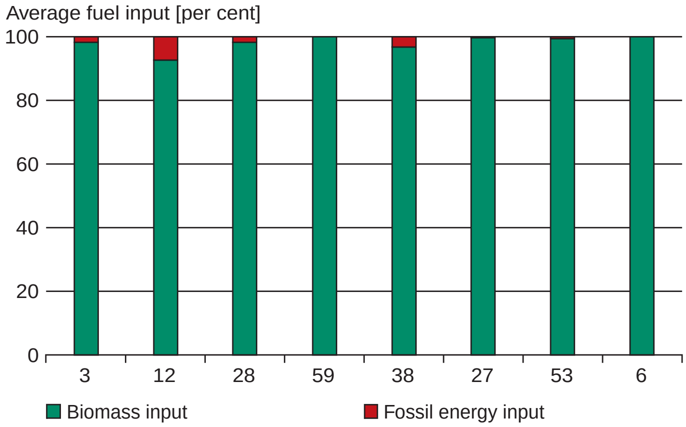
Own power consumption



Own power consumption for 7 MSW grate fired biomass CHP plants. Data are shown as averages for the 24 month period September 2003 to August 2005.

Two plants seem to operate fine with low internal power consumption, two plants are intermediate, and two plants, no. 3 and 12, show extremely high own consumption of electricity. This is caused to some extend by external electricity consumption being included (district heating pumps etc.), and it is also one of several reasons for the same plants showing very low net electric efficiency.

Fuels used



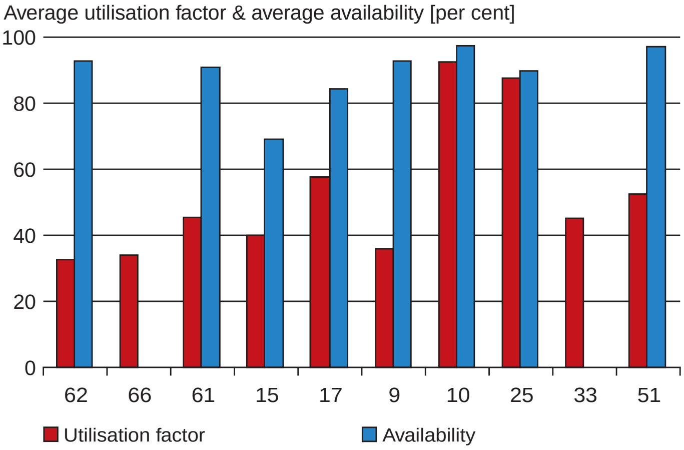
Division between biomass fuels and fossil fuels used in 8 MSW grate fired biomass CHP plants. Average figures for 24 months, September 2003 to August 2005.

Small fractions of fossil fuel are used in the MSW boilers for start-up and support fuel. In a few plants natural gas is used also for flue gas cleaning processes.

CFB plants

This technology classification includes 10 circulating fluid bed boiler plants with steam boiler and steam turbine. Most of the plants are relatively big, 8 out 10 is above 7 MW (electric capacity).

Utilisation and availability



Utilisation factor and availability for 10 CFB biomass CHP plants. Figures are shown as average values for 24 months, September 2003 to August 2005.

Several plants utilise installed capacity very badly. A utilisation factor in the range 30 to 60 % for 7 of the 10 plants indicates that these might be rather large in installed capacity for the heat market connected or out of operation for extended periods.

One example of the operational logic behind a relatively low utilisation factor would be CHP systems shut down completely during the summer period. In Nordic climate there is a large difference between load in summer and winter - the maximum load in winter might be 10 times higher than in the summer. Even if the plant is designed at a sensible size, covering in the order of 40 to 80 percent of winter peak heat demand, the summer conditions would require plants to operate at less than 30 percent load, which is from a technically point not possible. Such a plant will shut down during summer, unless the heat can be cooled of, but then it no longer a 100 percent combined heat and power. Several Swedish systems follow this operational pattern, and still perform well economically due to the fact, that old biomass heat-only boilers, and not oil, cover the summer heat demand. A similar operational pattern might be chosen for summer operation due to low market value for electricity produced during the summertime.

Other examples are plant no. 62 and 66, both are stopped during weekends as the plant is installed in an industrial facility and dependent on the energy demand and working hours in the industry.

The very high utilisation and availability seen for plant no. 10 is caused partially by this plant being virtually independent of the limitations of a heat market (no heat production). One has to stretch the definition to call this plant a CHP-system; however the plant was originally built as a CHP plant, and we have kept it in the study to illustrate e.g. the influence on utilisation.

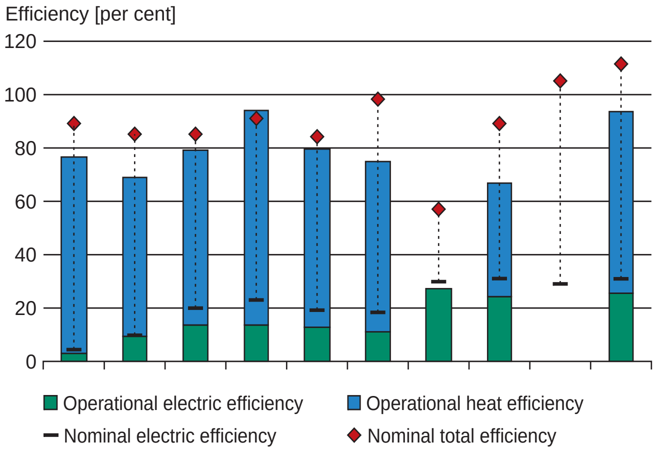
Availability for most plants are acceptable, however a few plants is only 70 % to 85 % or lower, thus these plants are not ready for operation 15-30 % of the time.

There are no indications that larger plants are better than smaller plants.

The participating CFB plants present also an insight to the operational problems that are often seen in biomass-fired CFB boiler. In general problems are observed in combustion and fuel feeding because of bad fuel quality. Sintering of the bed is a problem, likewise blocked superheaters and excessive deposit formation. Sometimes high moisture content in the biofuel limits plant total capacity because flue gas blowers are running at their upper limits (moisture in flue gas ad to the flue gas volume).

Further plant operators report occasional problems with fuel feeding equipments, steam leaks, malfunction in district heating pump operation, turbine shut-downs, electrical failures, and in periods of low heat demand, part load operation can cause operational problems.

Efficiency



Nominal and operational efficiencies for 10 CFB biomass CHP systems. Operational figures are average values for 24 months, September 2003 to August 2005.

The electric efficiency achieved is not impressive, less than 30% in all cases, and in most cases in the order of 10 % to 15 %.

The practical total efficiency is also for CFB-plants significantly lower than the nominal. Further and more important from an economic point of view, the electric efficiency is significantly lower than the nominal.

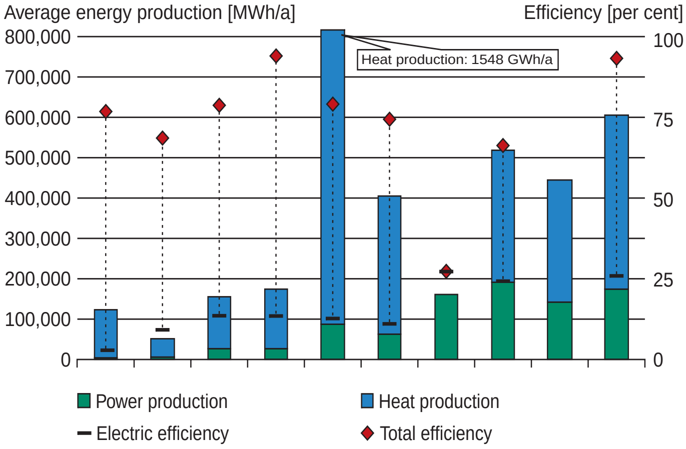
As income from sales of electricity is the main sales value for most plants (heat is less significant from an economic point of view) this has a great negative impact on the economic performance of the plants.

Four of the plants showing electric efficiency around or below 10 % are installed in wood manufacturing industry. Focus might be more on getting rid of wood waste and producing steam rather than operation of an efficient energy plant. Low feed-in tariff for electricity for such plants add to this picture.

Added to results seen in other technology classes it seems that industrial CHP plants, while operating at an acceptable total efficiency are less focussed on high electric efficiency and long operation periods, and more focussed on the production demands in the industry, such as working hours, steam demand or getting rid of waste products.

Some plants show efficiencies near or above 100% - these are equipped with flue gas condensing systems.

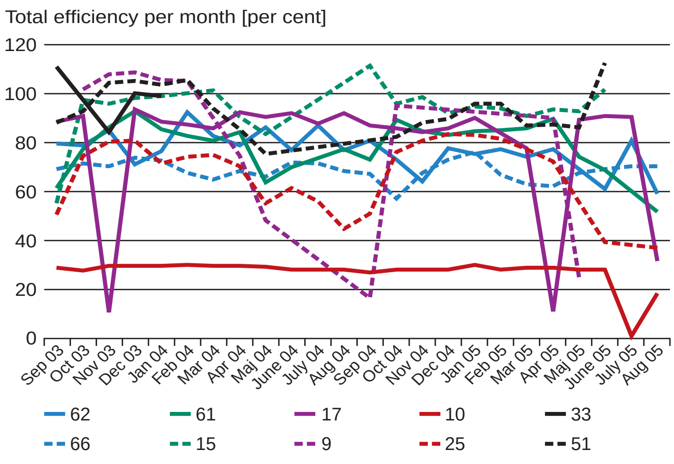
Efficiency and annual energy production



Operational efficiencies for 10 CFB biomass CHP systems compared to the size of the plant shown as the annual production of electricity and heat. Operational figures are average values for 24 months, September 2003 to August 2005.

It is significant, that the electric efficiency is far better for the larger plants. Total efficiency is not dependent on size, showing that smaller plants compensate for lower electric efficiency by higher heat utilisation.

Efficiency over time



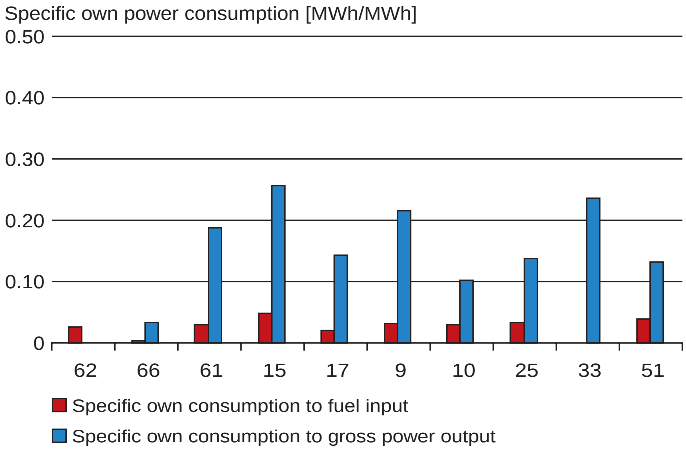
Total of heat and electric efficiencies for 10 CFB biomass CHP systems. Operational figures are monthly data shown for 24 months, September 2003 to August 2005

Variation in efficiency from month to month for this technology is smaller than other CHP technologies. This indicates less influence from part load operation, and generally stable operating conditions. However, when the number of operational hours in a certain month is very low due to annual revision, this may affect strongly the efficiency of that month as start-up and shut-down are reasonably exceptional moments in power plant operation.

Plant no. 10 is operating at exceptionally stable conditions. The plant runs continuous full load and it is not yet dependent on heat demand. Other plants present a few months with exceptionally poor results. These are in most cases caused by revision or operational problems at the plant.

Plant 25 presents much lower total efficiency in the summer months. Due to low heat summer demand the plants operates partially condensing power in the summer, thus reducing heat efficiency these months.

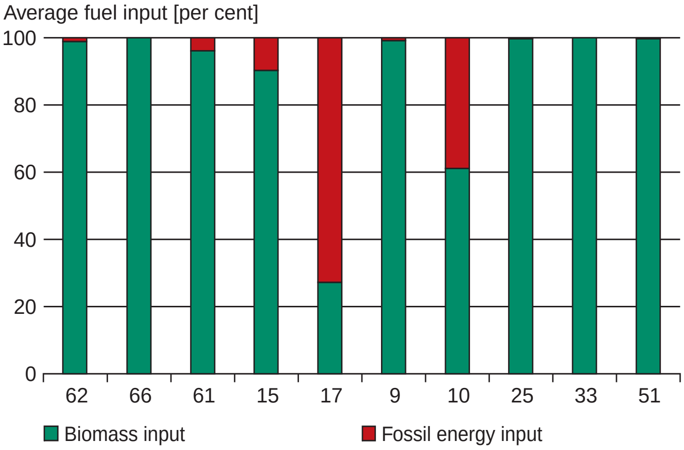
Own power consumption



Own power consumption for 10 CFB biomass CHP plants. Data are shown as averages for the 24 month period September 2003 to August 2005.

10 to 20 % or even 25 % own consumption seems to be the rule for this type of CHP plant. This is significant and a high figure.

Fuels used



Division between biomass fuels and fossil fuels used in 8 CFB biomass CHP plants. Average figures for 24 months, September 2003 to August 2005.

Virtually all CFB units use fossil fuels to some extent, showing that these are certainly versatile boilers. Fossil fuels are generally used for start-up and process stabilisation (e.g. some sulphur is required when burning wood to neutralize the alkali compounds in wood ash).

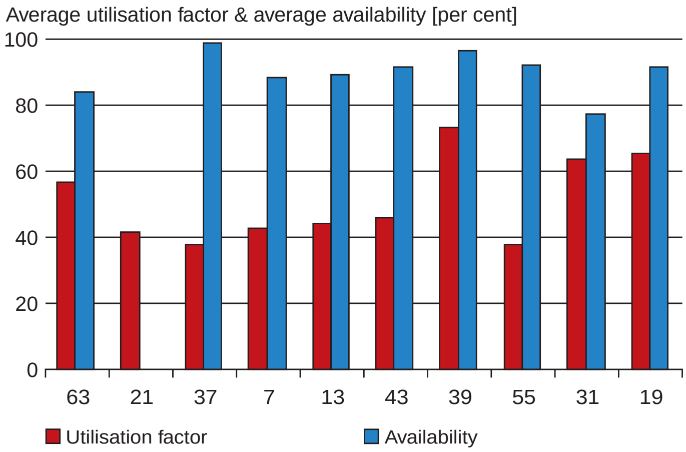
Peat fuel is here shown as biomass fuel using the Finnish definition of peat being a slowly renewable biomass based fuel (please note that under emission trading schemes peat is treated as fossil fuel).

Plant 17 is designed and operated as a co-firing plant with an intentional large fraction of fossil fuels; this does not however make this plant perform better or worse in any other key performance indicator.

BFB plants

This CHP technology classification includes 11 plants in this study. All of these are located in Finland or Sweden. For plant no 43 only the first 10 month data are included.

Utilisation and availability



Utilisation factor and availability for 10 BFB biomass CHP plants. Figures are shown as average values for 24 months, September 2003 to August 2005.

Several plants utilise installed capacity very badly, less than 50% is common. Some explanations for this are identical to those given for CFB plants. Several of the BFB plants are relatively new, which means that the connected heat demand has not yet developed to the anticipated figures, leading to a low utilisation of installed capacity in the first years of the plant life.

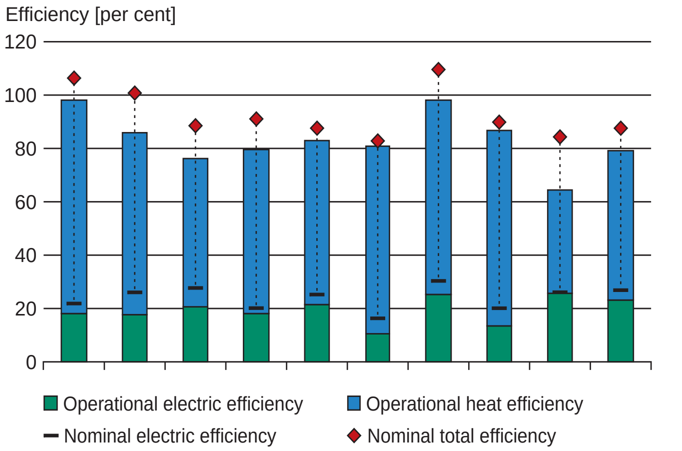
Revision period of typically one month also has severe influence on as well availability as utilisation factor.

Availability for some plants is only 75 % to 85 %, this should give cause for action by these plants. There are no indications that larger plants are better than smaller plants.

Operational problems reported by BFB operator mostly involve problems related to fuel quality. Poor fuel quality have caused problems such as bed de-fluidization, excessive slagging and fouling, superheater blocking, unplanned plant shut-downs, additional costs due to thorough boiler cleaning, limited power output, and bad fuel quality have also speeded up bed material replacement frequency etc. Further the plants list problems in bed material removal system, grate blockages due to stones in fuel, problems in fuel silos and fuel silo unloading screws, fuel conveyors, etc., most of these problems are also related to the fuel quality issue.

The plant operators also report occasional problems related to e.g. misuse failures specially at start-up, electrical fault related to the external grid, generator and turbine faults, turbine automation failures, electric precipitator blockage, additional turbine revisions, steam leak in boiler, DH-exchanger leak, HP water pre-heater leak, automation system problems, fire in ash silo, high silicate level in superheated steam, problems with flue gas blowers, turbine automation, ash dampening equipment and feed water pumps.

Efficiency



Nominal and operational efficiencies for 10 BFB biomass CHP systems. Operational figures are average values for 24 months, September 2003 to August 2005.

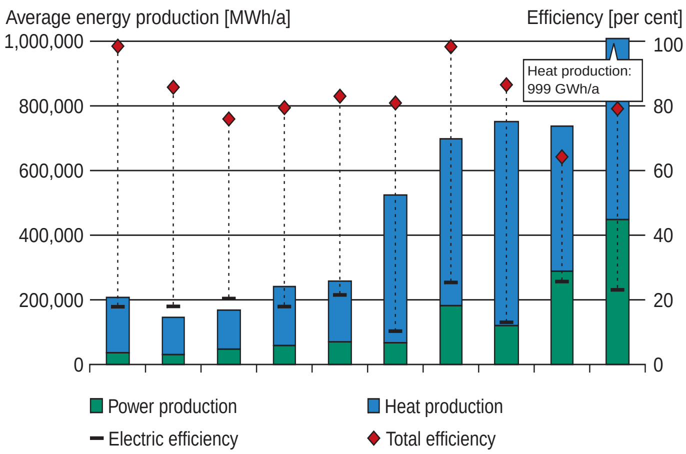
The practical total efficiency is significantly lower than the nominal. Further and more important from an economic point of view, the electric efficiency is significantly lower than the nominal for 10 plants out of 11.

Operational electric efficiency is about 20 % for most plants; the best plants present an average electric efficiency from 24 month of operation of 26 %.

As income from sales of electricity is the main sales value for most plant (heat is less significant from an economic point of view) this has a great negative impact on the economic performance of the plants.

Some plants show efficiencies above 100% - these are equipped with flue gas condensing systems. Flue gas condensing systems tends to be the standard in locations where the value of heat is high and the value of electricity low. And in locations with a relatively high electricity price and a lower heat price, the loss of electricity production from the increased heat efficiency does not justify installation of a flue gas condenser.

Efficiency and annual energy production



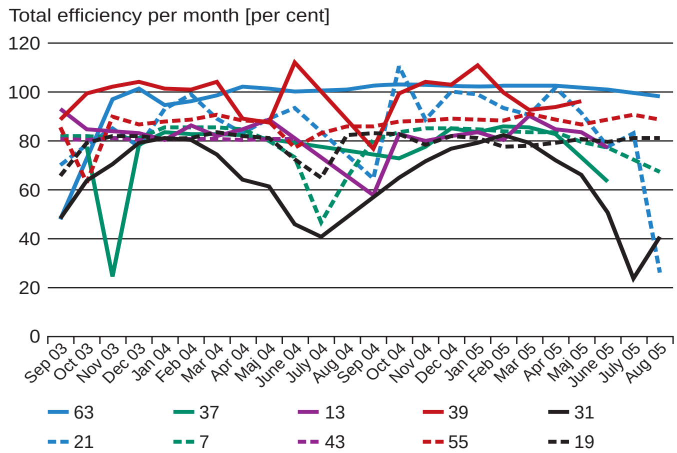
Operational efficiencies for 10 BFB biomass CHP systems compared to the size of the plant shown as the annual production of electricity and heat. Operational figures are average values for 24 months, September 2003 to August 2005.

The electric efficiency is not impressive, less than 30% in most cases.

Even though the plants are quite different in size, less size dependency for electric efficiency is observed as compared to other biomass CHP technologies.

Some plants operate wholly or partly as condensing power. This reduces heat production as well as the heat part of total efficiency.

Efficiency over time

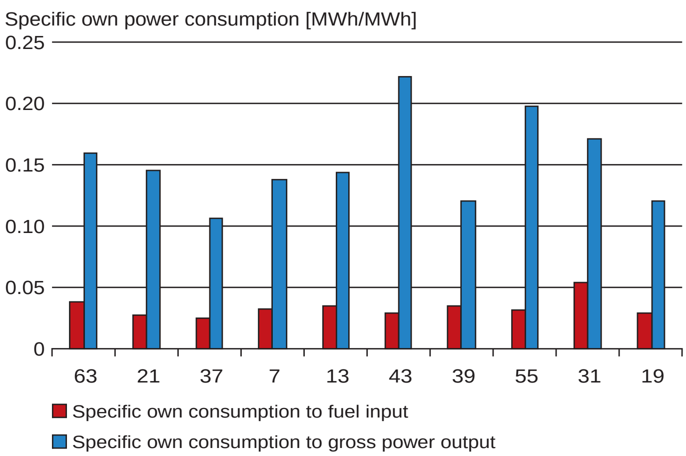


Total of heat and electric efficiencies for 10 BFB biomass CHP system. Operational figures are monthly data shown for 24 months, September 2003 to August 2005.

Several plants show lower efficiency during the summer months, caused by the plants operating part load, and for some plant because the plant is operating as condensing power (no or low utilised heat production) during the warm months (e.g. plant no. 31).

Some plants exhibit large variations in efficiency month by month, while other, like the older plant no. 19 are very stable.

Own power consumption



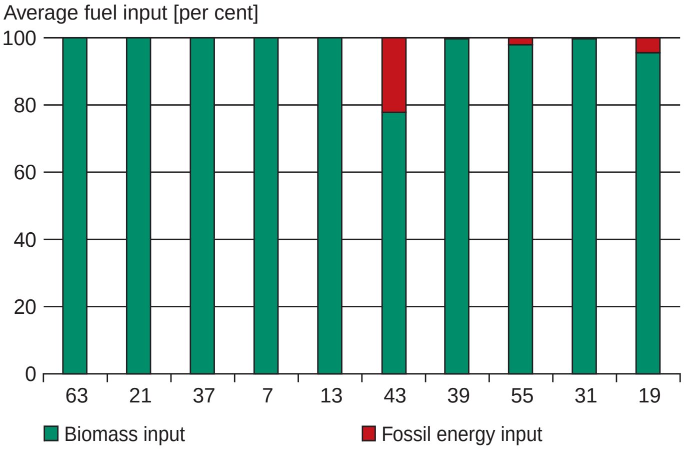
Own power consumption for 10 BFB biomass CHP plants. Data are shown as averages for the 24 month period September 2003 to August 2005.

10 to 20% own consumption seems to be the rule also for this type of CHP plant. This is significant and a high figure, and higher than other biomass CHP technologies.

Plant no. 43 and 55 are industrial installations. Internal power consumption other than the in the CHP plant itself might explain the high own consumption here.

Plant no. 37 is a new installation, where more efficient technology has reduced own consumption of electricity significantly.

Fuels used



Division between biomass fuels and fossil fuels used in 10 BFB biomass CHP plants. Average figures for 24 months, September 2003 to August 2005.

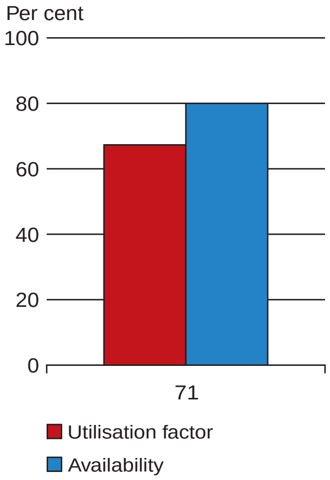
Virtually all BFB units use fossil fuels to a small extent, showing that these are certainly versatile boilers. Fossil fuels as well as peat are generally used for start-up and process stabilisation.

Peat fuel is here included in biomass fuel.

Dust-fired steam boiler plant

This technology class contains only dataset from one plant. The general anonymity methodology cannot be applied here, however, plant in question, Studstrupvaerket in Denmark, has no objection to any publication of data.

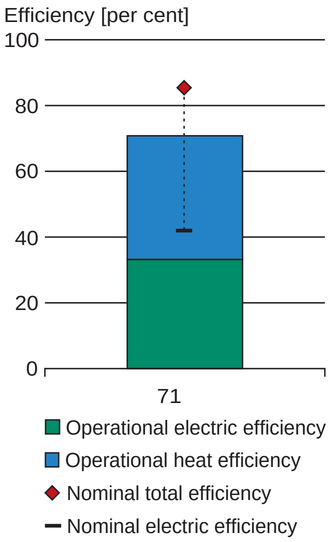
Utilisation and availability



Utilisation factor and availability for the dust-fired co-firing CHP plant. Average figures for 24 months, September 2003 to August 2005.

Utilisation and availability are comparable to what is achieved for other technologies, however 80 % availability is not impressive. By far the majority of unavailable hours are caused by one major revision of the plant.

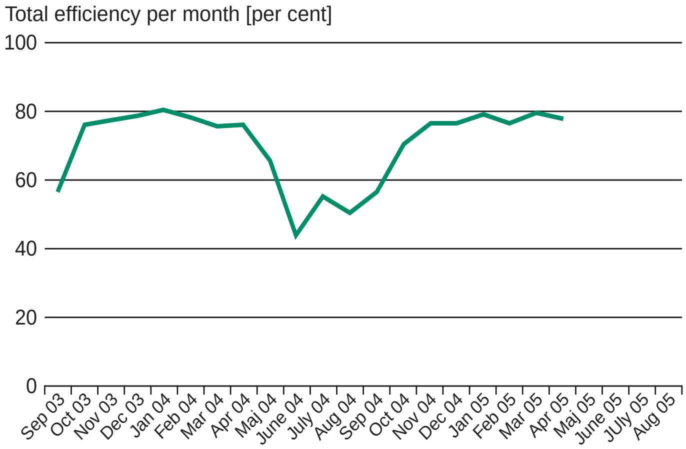
Efficiency



Nominal and operational efficiencies for the dust-fired CHP plant. Operational figures are average values for 24 months, September 2003 to August 2005.

Both electric and heat efficiencies are significantly lower in actual operational data compared to the plant nominal data.

Efficiency over time



Total of heat and electric efficiencies for the dust-fired CHP plant. Figures are monthly data shown for 24 months, September 2003 to August 2005.

Total efficiency drops significantly in summer months, where heat demand falls below the plant production capacity. From May 2005 the plant is out of operation for major revision works.

Own power consumption

The average own power consumption for this plant is calculated to 0.09 MWh pr. MWh gross electric production, and to 0.03 MWh pr. MWh fuel consumption.

As the own consumption is calculated for the plant inclusive 90 % coal consumption it does not however illustrate with accuracy of the performance of the biomass fraction of the CHP plant.

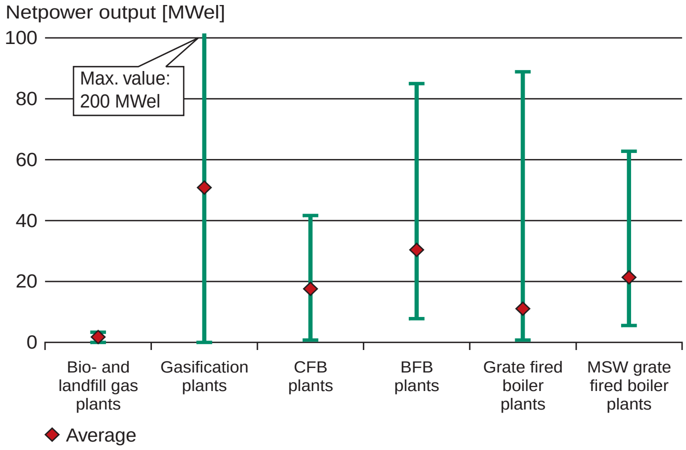
Fuels used

The average monthly biomass fuel input is 35511 MWh along with 351800 MWh fossil fuels. A 10 % biomass fraction (in this case straw) is normal for CHP plants co-firing biomass and coal in a dust-fired boiler.

Cross technology comparison

Key operational data for the technology classifications has been put together to enable a direct comparison between different technologies. The single dust-fired plant is not included in the graphics as it does not consist of a group of plants like the other technologies, thus average and min and max values are not defined.

Plant size

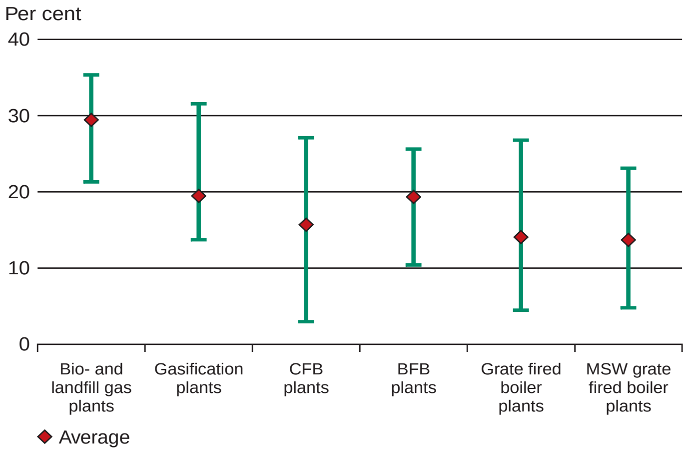


Comparison of the size, shown as min, max and average net electric capacity, for the different technologies.

Biogas and landfill gas plants are much smaller than the others. Gasification plants would generally be smaller than shown here because one very large plant is included among 4 units.

The dust-fired plant (not shown) is 260 MW net electric capacity. Representing ordinary coal power plant technology this type of plant would generally be this big; thus for a CHP plant this is only an option when connected to very large district heating systems.

Electric efficiency

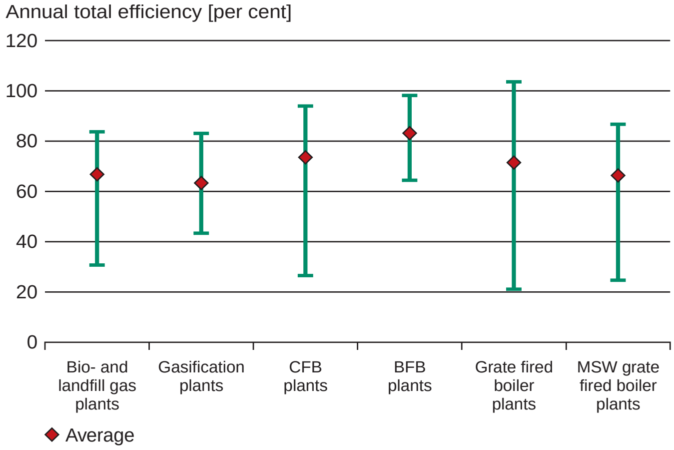


Comparison of min, max and average electric efficiency for the different technologies based on operational performance data for 24 months.

Biogas and landfill gas plants show significantly higher efficiency than other technologies. However these are not exactly comparable as the gas-based systems usually includes just a gas engine while the other technologies involves more complicated equipment to convert energy from solid biomass into electricity.

The dust-fired system (not shown) performs best of all: 33 %.

Total efficiency

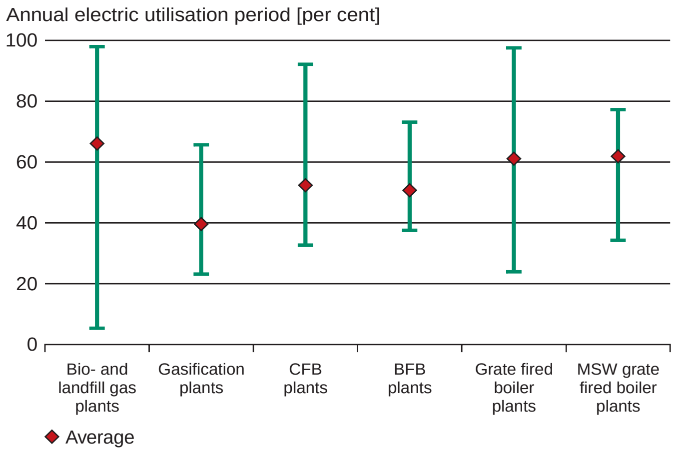


Comparison of the total of electric and heat efficiencies for the different technologies based on operational data for 24 months.

When adding heat and power, the different technologies are much more even. This is caused by the general thermodynamics in the plant: whatever energy input (fuel) not turned into electricity will convert into heat in one way or other.

The BFB plants generally perform best, also better than the dust-fired plant (not shown) at 71%.

Utilisation factor



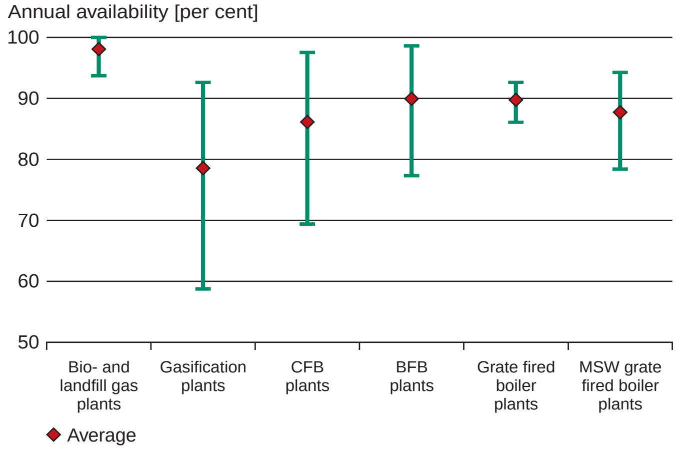
Comparison of the utilisation factor for the different technologies, based on operational data for 24 months

Gasification plants perform significantly poorer than the other technologies; do keep in mind however that this group includes only four plants. Again the biogas and landfill gas plants are the best for the same reason as described above.

The dust-fired plant (not shown) is 68 %, better than any average for the other technologies.

From a general economic performance perspective, and looking at the achieved averages across technologies, the utilisation is generally not impressive. The utilisation could be seen as the use of invested capital, and the general low figures show that many CHP systems either operate part load much of the time or is out of operation for longer periods.

Availability



Comparison of the availability for the different technologies, based on operational data for 24 months

Gas engine systems are very reliable compared to the other technologies, while gasification plants are unavailable for operation more than 20% of the year (note: average for only 4 plants).

The dust-fired plant is available 80% of the time in the 24 months.

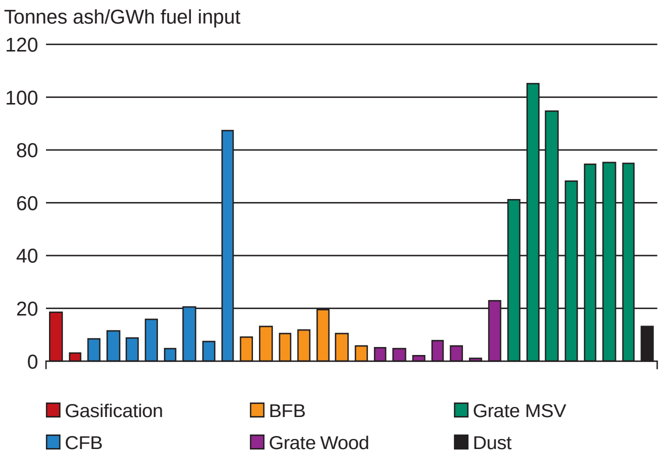
Environmental performance

A range of environmental performance indicators has been collected in order to present a “normal” range, and to present variation between individual plants and between technologies.

Most parameters however were given in incomparable units and based on incomparable measurement methods, leaving only the following few parameters for comparison.

Ash production

The amount of ash produced from the plant depend to a large extent of the fuel used, but also on the technology, including it’s capability to sustain complete burn-out of the organic matter in the fuel.



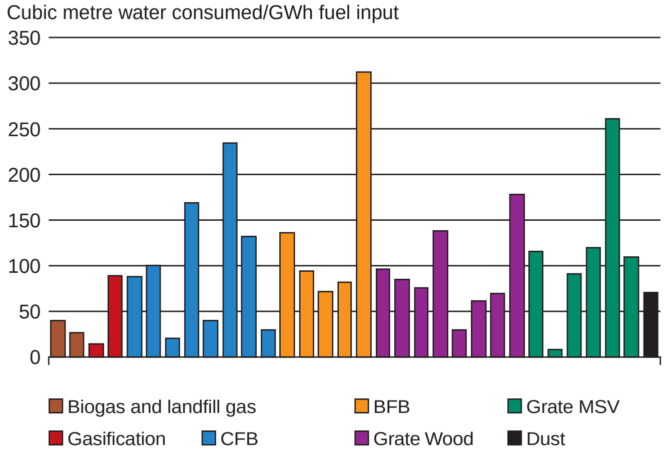
Amount of ash produced in the plants shown in metric tonnes pr. GWh fuel input. Ash weight includes any water mixed into the ashes.

BFB and CFB plant produce significantly more ash than gratefired plants; these figures may include some sand (bed material), however most of the CFB and BFB plants use a large share of peat with an ash content about 5 %, while 1 - 1.5 % is normal for wood fuels. The extremely high CFB plant in the graphics uses waste paper and bark, both with high mineral content as a fuel.

The MSW plants show much higher ash production figures than other plants. This is due to the nature of the waste, consisting of as well combustible organic and inorganic compounds as large fractions of metals and other incombustible materials.

Water consumption

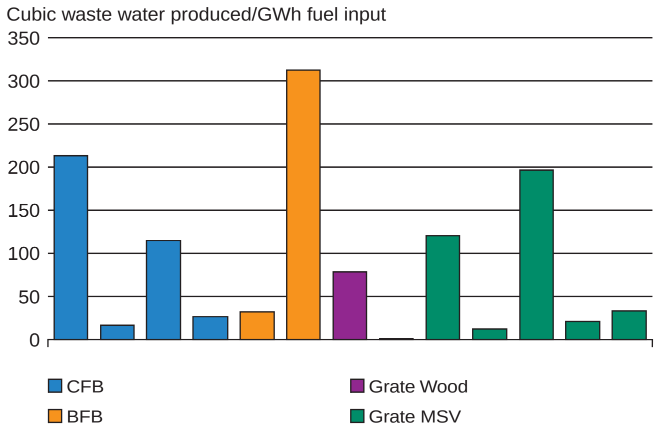
Water is consumed internally in the plants in large amounts, some for process purposes, some for steam production and some for other purposes.



Consumption of water in the plants shown in m³ pr. GWh fuel input.

Some plants shopwing higher figures than average produce process steam, and thus consume more water, while at the same time not generating waste water.

Waste water generation



Waste water generation from the plants shown in m3 pr. GWh fuel input

The variation between plants is higher than other performance parameters.

Bed material

For CFB plants the consumption of bed materials is significant, and counts in this technology performance both as an economic operational cost and as an environmental cost.

Participating CHP-plants

Anaerobic Digestion
Nahvärme Antiesenhofen (A)
Nahvärme Atzbach (A)
NEGH Bio-Strom (A)
De Scharlebelt (NL)
Ecopark De Wierde (NL)
Biogasanlage Preut (DE)
Graspower (A)
Biogasanlage Klaus Uidl (A)
GF-Bio-Energie Hasetal GmbH (DE)
Hashoej Power and Heat Supply (DK)
Kirchhorster Biogas GbR (DE)
ENR GmbH - LOICK Bioenergie (DE)
Linko Gas A.m.b.a (DK)
Projekt Neustrom (A)
Gedea-Novatech Biogasanlagen GmbH & Co. KG (DE)

Landfill gas plants
ARN Beuningen (NL)
Afvalverwerkingsinrichting de Meersteeg (NL)
Ecopark De Wierde (NL)
Glatved Landfill Gas Plant (DK)
Stige Oe Landfill Gas Plant (DK)

Gasification plants
Rural Generation (UK)
Biomassekraftwerk Güssing (A)
Harbooere District Heating Plant (DK)
Lahti Energia Oy, Kymijärvi Power Plant (FIN)

CFB plants
Biomasse-KWK-Anlage Wiesner Hager (A)
Etelä-Savon Energia Oy, Pursiala Power Plant (FIN)
Grenaa CHP plant (DK)
Jämtkraft AB, Lugnvik (SE)
Karlstad Energi AB, Heden (SE)
Nässjö Affärsverk AB (SE)
Perlen Papier AG (CH)
PROKON Nord Biomasseheizkraftwerk Papenburg GmbH & Co. KG (DE)
Vapo Oy, Lieksa power plant (FIN)
Växjö Energi AB, Sandvik 2 (SE)

BFB plants
E.ON Finland, Joensuu Power Plant (FIN)
Eskilstuna Energi & Miljö AB (SE)
Falu energi AB, Västermalmsverket (SE)
Forssan Energia Oy (FIN)
Jyväskylän Energiantuotanto Oy, Rauhalahti Power Plant (FIN)
Kokkolan Voima Oy, Kokkola power plant (FIN)
M-Real Oyj, Simpeleen kartonkitehdas (FIN)
Sala-Heby Energi AB, Silververket (SE)
Savon Voima Lämpö Oy, Iisalmi power plant (FIN)
UPM-Kymmene, Jämsänkoski power plant (FIN)
UPM-Kymmene, Kaukas (FIN)

Grate fired boiler plants
Assens District Heating (DK)
Bio Energiecentrale Schijndel VOF (NL)
Biomassa-centrale Lelystad (NL)
Biomasse-KWK-Anlage Lienz (A)
Biomasse-Heizkraftwerk Dresden-Niedersedlitz (DE)
Biomasse-Heizkraftwerk Mann Naturenergie GmbH & Co. KG (DE)
Biomasse-Heizkraftwerk Pfaffenhofen (DE)
Elsam A/S Herningvaerket (DK)
Enköpings Värmeverk AB (SE)
Hjordkaer District Heating Plant (DK)
SFW Biomasse-Heizkraftwerk Neufahrn (DE)
STIA-ORC-Admont (A)
Trans Energi AB, Södra Vakten (SE)
VKW Kaufmann (A)

MSW grate fired boiler plants
Afval Energie Bedrijf Gemeente Amsterdam (NL)
ARN Nijmegen (NL)
Odense CHP Plant (DK)
Renova AB, Sävenäs (SE)
Roskilde Incineration Plant, Line 5 (DK)
Thermische Abfallbehandlungsanlage Spittelau (A)
Umeå Energi AB, Dåva (SE)
Zweckverband Restmüllheizkraftwerk Böblingen (DE)

Dust fired steam boiler plants
Elsam A/S Studstrupvaerket, unit 4 (DK)

Altener contract no. 4.1030/Z/02-150/2002