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Biomass Combustion and Cofiring

Joint workshop with Task 33
State-of-the-art technologies for small biomass co-generation

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Content:
Minutes of the workshop
State-of-the-art technologies for small biomass co-generation

7 October, 2010
Copenhagen, Denmark

IEA Bioenergy Task 32
Workshop Report
7 October, 2010, Copenhagen, Denmark

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Preface

As of yet, power generation from solid biomass is typically based on conventional steam turbine technologies, in combination with a combustion system. The lower capacity limit for steam turbine based power generation from biomass is related to economy of scale effects for steam turbines. Although steam turbine technology does still improve over time, biomass based power generation on a scale smaller than a few MW are therefore usually too expensive for financially competitive operation.

A large application for energy from solid biomass is the production of heat for district heating and industrial processes. This market typically serves heat demands up to a few MW_e. From a CO_2 mitigation perspective, it would be interesting to combine the production of heat with electricity production to obtain heat demand driven CHP operation. For CHP technologies to be applied in this market however, requested capacities would have to come down significantly from the capacity range currently served by steam turbines.

Recently, several newly emerging technologies have come to the market, which could make biomass based electricity generation on a smaller scale potentially attractive. These technologies are either based on combustion or gasification of solid biomass, and include ORC technology, Stirling engines, gas engines or other concepts for power generation. Some of these technologies are already offered commercially, others are still in the development stage.

Task 32 and Task 33 joined forces in the organization of this expert workshop, to present an update on the recent developments in relatively small scale (up to 10 MW_e) power plants based on either combustion or gasification of solid biomass fuels.

This report provides the contents of the presentations offered by individual speakers in the workshop, and does not necessarily reflect the opinion of Task 32 or Task 33 of the IEA Bioenergy Agreement. For a comprehensive description of the typical status of different biomass combustion based CHP technologies with key figures on costs and efficiency, the reader is referred to the following Task 32 publications:

- Handbook of Biomass Combustion and Cofiring (2nd edition), Van Loo & Koppejan (Eds), 2008, see here.
- Basic information regarding decentralised CHP plants based on biomass combustion in IEA partner countries. (Prof Dr. Ingwald Obernberger, Dipl-Ing Gerold Thek, March 2004), see here
- Techno-Economic evaluation of selected decentralised CHP plants based on biomass combustion in IEA partner countries. (Prof Dr. Ingwald Obernberger, Dipl-Ing Gerold Thek, March 2004), see here.

Programme

Thursday, 7 October 2010:
Joint workshop with Task 33
State-of-the-art technologies for small biomass co-generation

Venue: The Danish Society of Engineers, Copenhagen

From	Topic
09:00	Welcome and introduction: Why small scale CHP and where is the market? Jaap Koppejan, task manager, IEA Bioenergy Task 32, Netherlands
09:05	Next Generation of Pellet Combustion with Thermoelectric Power Generation Wilhelm Moser, Bioenergy 2020+, Austria
09:30	Gasfication in stirling engine applications Lars Jagd, Stirling.dk, Denmark
09:55	Staged gasification with gas engine, the Viking Gasifier Morten Grøn, Weiss A/S, Denmark
10:20	Coffee / tea break
10:35	Steam engines T. Augustin, Spilling Energie GmbH, Germany
11:00	State-of-the-art of ORC technology for biomass plants Roberto Bini, Turboden SRL, Italy
11:25	Downdraft gasification with gas engine Herbert Gemperle, Pyroforce, Switzerland
11:50	Lunch
12:50	Updraft gasification with gas engine Robert Heeb, Babcock & Wilcox Vølund A/S, Denmark
13:15	Indirect gasifier Reinhard Rauch, TU Vienna, Austria
13:40	Upscaling the LTCFB (Low Temperature Circulating Fluid Bed) gasifier Anders Boisen, DONG Energy, Denmark
14:05	The Skive plant (BFB gasification): status and perspectives Bettina Skjoldborg, Aaen consulting and Henrik Flyver Christiansen, Danish Energy Agency

14:30	Steam turbines: what is the lower limit for feasibility, recent developments to reduce costs and increase efficiency in small steam turbine systems Reiner Schenk, Siemens Frankenthal, Germany
14:55	Coffee / tea break
15:10	Summary of technology presentations: an attempt to present a comparable status of performance and economic data, application scale and technology readiness. Anders Evald, Force Technology, Denmark Perspectives to data collected through the Danish follow-up program for biomass CHP Henrik Flyver Christiansen, Danish Energy Agency, Denmark
16:10	Closing and transportation to Stirling.DK
16:30	Visit to Stirling.dk
18:15	End of site visit, bus transport back

Workshop report

Venue: The Danish Society of Engineers, Copenhagen

Welcome and introduction: Why small scale CHP and where is the market?
Jaap Koppejan, IEA Bioenergy Task 32

This workshop on recent developments in small scale power production from solid biomass was jointly organised by Task 32 and Task 33. Jaap Koppejan welcomed all participants to this workshop and gave an introduction to IEA Bioenergy and the market perspective for small scale biomass power production (see Annex 1).

While heat utilisation in large scale power plants is often difficult because of the large volumes of heat that need to be consumed, power production options are currently limited for smaller scale heat demands. Both effects limit the CO_2 impact of bioenergy technologies. There is therefore a need to develop CHP technologies for small scale applications. According to the Renewable Heating and Cooling Technology Platform, CHP technologies will become more common in the common decades, from household level and upwards, with about 100 GW_e of biomass based electricity.

This workshop will cover the development status of a wide variety of power technologies for solid biomass, based on both gasification and combustion. This should enable a good comparison of the efficiencies, reliability, operational experience and costs.

Next Generation of Pellet Combustion with Thermoelectric Power Generation
Wilhelm Moser, Bioenergy 2020+, Austria

Wilhelm Moser presented the current status of the Thermoelectric Power Generation (TEG) technology, see Annex 2. This solid state semiconductor technology generates a voltage over a semiconductor junction when a temperature difference is applied. Prototypes based on Bismuth Telluride have achieved electrical efficiencies of around 1-2 % at a temperature of approx 250 °C, which might go up to 7% in case of optimised application of another, new material that can withstand 400°C. If the technology is used in heat following mode however, such low efficiencies could still be justifiable. The main application foreseen is in automatic pellet furnaces to enable grid independent operation. The bottleneck for the further development is in the development of suitable materials, not the integration itself. If both the additional investment and fuel consumption are taken into account, the current electricity production costs of the tested prototypes are around 80 €ct/kWh. The aim is to reduce this by about 50%.

Gasfication in stirling engine applications
Lars Jagd, Stirling.dk, Denmark

Lars Jagd of Stirling.DK explained the current status of the Stirling engine technology (see Annex 3). This technology is based on a helium driven piston, where helium cycles between a high temperature of 700 °C on the hot side and a temperature of 60-80°C on the cold side.

Since the hot side of the stirling engine operates at around 700 °C, the remaining heat in the flue gases of the boiler is normally used to preheat combustion air up to around 400-500°C. As of yet, 5 combustion based Stirling engines have been installed, with a total operation time of 40,000 hours. The maximum operation time of a single engine has been around 5000 hours.

In order to prevent ash related heat transfer problems for the hot side, the foreseen application strategy is by exposing the heat exchanger to a relatively clean flue gas, generated by burning a clean fuel from e.g. a fixed bed gasifier or flash pyrolysis, instead of flue gases from a biomass combustion system. Standard gasification based plants for 1-4 engines of 35 kWe have been developed. Currently, 7 engines are operational based on gasification engines.

There are however still some important challenges to be resolved before the technology can be sold as commercially proven, e.g. related to metal fatigue of some of the internal moving parts.

About 35-40 persons are currently employed at Stirling DK. The aim is to commercialise the technology within 6-12 months as OEM through established biomass boiler manufacturers, such as Viessmann and Danstoker. The main market foreseen is small scale power production (30-500 kW_e). The technology is characterised by relatively high investment costs (about 10.000 Euro/kW_e) and low O&M costs. Efficiencies to be expected are around 18%.

Staged gasification with gas engine, the Viking Gasifier Morten Grøn, Weiss A/S, Denmark

Morten Grøn of Weiss A/S explained the technology of staged gasification for power production, such as first applied with the Viking gasifier (80 kWe). See Annex 4 for the presentation. The technology can be regarded as in the demonstration stage, with around 5000 operating hours of experience and a few examples operational now (Hadsund, 200 kW_e) or soon to be built (Hillerød, 500 kW_e).

The gasification process starts with a drier for the fresh wood chips. Here, superheated steam produced by the waste heat of the gas engine is used to produce the superheated steam required. The dried wood chips enter a screw pyrolysis reactor, which is indirectly heated by the hot gases from a fixed bed downdraught gasifier, where both the pyrolysis products (char and pyrolysis gas) are further gasified at high temperature to produce a relatively clean gas. The hot producer gas transfers heat to the pyrolyser and then preheats the gasification air. It is then further cooled down and cleaned, before entering the gas engine.

Anticipated electrical efficiencies are around 30%, for a typical system size of 0.2-1 MWe. Specific investment costs are in the order of 4-10 million Euro/MWe in the size of 0.2-1 MWe

Steam engines T. Augustin, Spilling Energie GmbH, Germany

Spilling Energie GmbH can be regarded as the key producer or steam piston engines. About 200-300 plants on biomass are currently in operation. The technology uses 6-60 Bar saturated steam (up to 40 tph) in 1-6 cylinders to produce 0.15-1,2 MW of electricity in load following mode at about 10-15% electrical efficiency.

Although this efficiency is relatively low in comparison to most of the other technologies available or under development, this technology has several advantages. It can be operated on saturated steam, has good part load behaviour (individual cylinders can be switched on or off), modest water requirements and that it can be maintained by local technical staff. It can therefore be regarded as a relatively robust technology, with application potential in remote locations with little attention.

State-of-the-art of ORC technology for biomass plants Roberto Bini, Turboden SRL, Italy

Dr. Bini, general manager of Turboden SRL presented the current status of the ORC technology (see Annex 6). Turboden started in 1987 with the development of biomass combustion based ORC technology, and can now be regarded as the key technology supplier for this application with 152 biomass fuelled plants in operation or under construction (mainly in Italy, Austria and Germany). The technology is supplied on (multiple) skids for standard sizes of 0,2-3 MWe, eventually custom sizes are available.

In contrast to a conventional steam based Carnot cycle, the ORC technology is based on an organic medium (usually toluene). The operation is much simpler than a steam based cycle, with simple start-stop cycles, good part load efficiencies, high availabilities and low O&M costs.

Normally heat is transferred to an ORC system from a biomass boiler using thermal oil at a temperature of around 300 °C. This implies that a hot flue gas temperature remains after the thermal oil circuit. A recent innovation by Turboden is to apply a ‘split system’ in which part of the heat is supplied to the ORC at a lower temperature level. This results in higher boiler efficiencies, and thereby higher electrical efficiencies. The electrical efficiency can be further improved by reducing the condensing temperature. Electrical efficiencies are in the range of 16-20% depending on heat utilization.

Downdraft gasification with gas engine Herbert Gemperle, Pyroforce, Switzerland

Pyroforce is a Swiss company, focussed for over 15 years on the development and commercialisation of a downdraught fixed bed gasification technology. A standard reactor has been developed that can feed a gas engine of 150-170 kW_e after the gas has been cooled and cleaned using a dosing unit for calcium carbonate, baghouse filter and wet scrubber. See Annex 7 for the presentation.

5 plants are now in operation with a total operating time of around 50,000 hours:
- Emmen 80 kW_e, 3,500 hrs.
- Spiez 130 kW_e, 17,000 hrs.
- Güssing 300 kW_e, 6,000 hrs.
- Stans I, 600 kW_e, 7,500 hrs.
- Stans II, 600 kW_e, 13,000 hrs

Investment costs are in the range of 3.5-4 million Euro/MW_e for installations of a typical size of around 1 MWe. Typical electrical efficiencies are around 25%.

Updraft gasification with gas engine
Robert Heeb, Babcock & Wilcox Vølund A/S, Denmark

Babcock & Wilcox Vølund A/S is a company with 350 employees and a turnover of approx. 100 million Euro/year, focussed on WtE systems, biomass combustion and gasification systems. The company has performed R&D on updraught gasification using steam/air since 1988 and has provided an application license to a Japanese company. The 1 MW_e/3.5 MW_{th} Harboøre plant, commissioned in 1996 is a well known example of the technology. 4 other installations are in operation in Denmark and Japan (8-12 MW_{th}), with a total of 120,000 operating hours for the gasifiers.

In the gasification concept (see Annex 8), tar is removed from the producer gas in a gas cooler/cleaner. From this process, tar is separated and used as a fuel. Washing water containing some organic components is thermally treated in a separate process step, named TARWATC. Clean producer gas is used in a gas engine.

While average annual efficiencies in 2006 experienced for the Harboøre plant were 23% electricity, 57% heat and 13% tar (total 93%), today's knowledge makes it possible to apply the technology to produce electricity at a net electrical efficiency of 28%. Eventually the tar can be burned to further heat up the gas engine flue gases before producing steam in a waste heat recovery boiler, to make extra electricity in a steam turbine (a combined cycle concept). Specific investments are in the range of 4-6 million Euro/MW_e for a 2 MW_e system.

Indirect gasifier
Reinhard Rauch, TU Vienna, Austria

Dr Rauch of TU Vienna is involved in the development of an innovative gasification technology based on a combination of a circulating fluid bed steam gasifier and a bubbling fluid bed combustion system, where bed material for the gasification zone is heated in the combustor. See Annex 9 for his presentation.

This gasification concept was first applied in practise in Güssing, Austria. This installation has an electrical efficiency of 25% (2 MW_e, based on 8 MW fuel input). Product gas is first cooled and then cleaned in a two stage gas cleaning system (pre-coated filter and RME scrubber) before it enters the gas engine. The resulting RME from the scrubber is burned in the combustion section. Slipstreams of the product gas are also used for various R&D projects on development on microgasturbines, fuel cells, methanisation, Fischer Tropsch synthesis, etc. Other work is done on optimisation of the electrical efficiency, e.g. by adding an ORC to the engine waste heat. This can result in an efficiency exceeding 30%.

The plant has been operational since 2002 and has operated for approx 7000 hours per year since 2005. It can therefore be regarded as highly successful. After Güssing, the plant in Oberwart was built in 2008, this plant is equipped with an ORC in addition to a gas engine and is now operational. In 2010 and 2011, four other plants of this concept are constructed in Germany and Austria and another 6 in the range of 2-5,3 MWe are in the planning phase. Investment costs for Güssing and Oberwart are around 5 million Euro per MW_e.

Upscaling the LTCFB gasifier
Anders Boisen, DONG Energy, Denmark

Anders Boisen of DONG Energy (a large electricity producer in Denmark) elaborated on the Low Temperature Circulating Fluid Bed (LTCFB) gasification technology. This process has been developed by Danish Technical University and will be put into practice through a 6 MW_{th} demonstration plant, to be built by Dong Energy at their coal fired power plant at Kalundborg, Sealand, Denmark.

Dry fuel is pyrolysed in a CFB reactor at 650 °C into a tar containing gas. Char residues and sand are separated from the gas in a cyclone, after which the char is burned in a separate reactor, thereby heating up the sand before it is returned to the pyrolysis CFB. The final gas is cleaned in a second cylone to remove the ash, before it can be used as a clean fuel for e.g. cofiring.

Since the produced gas is not directly burned in a gas engine, but burned to produce heat for a steam cycle, the process can be seen as a pretreatment step to reduce the logistical costs of biomass fuels while at the same time removing harmful alkaline fuel components before utilization in a conventional boiler. It is in this sense different from the other technologies presented in this workshop as it is not directly used for small scale power production.

The Skive plant (BFB gasification): status and perspectives
Bettina Skjoldborg, Aaen consulting and Henrik Flyver Christiansen, Danish Energy Agency

Bettina Skjoldborg presented the experience with the biomass gasification plant, which was installed and is now used at the district heating system of the Danish town Skive (see Annex 11). This district heating system delivers 120 GWh of heat to 8000-9000 households through a network of 67 km of transportation pipelines and 54 km distribution pipelines. With the increasing heat demand there was a need to expand the heat generation capacity. Since it was expected that biomass could provide the perspective of a more stable heat price on the long run than natural gas, it was decided to install a wood pellet gasification plant.

The fluid bed gasifier produces 20 MW of wood gas. Tars are reformed catalytically before the gas is cooled down, dedusted and washed to produce a clean gas that can be used to feed three gas engines with a total capacity of 6 MWe.

The building process started in 2005 and the plant was commissioned in 2008. There were several drawbacks in the project development and startup. The total project costs was about 50% higher than anticipated. The plant has resulted in 70% of the planned output, and 50% availability, while 100% output and 90% availability were expected. In addition to that the fuel cost has significantly risen. As a result of these factors, the total heat price now expected is at a level of 365 DKK/MWh, against a predicted value of only 278 DKK/MWh.

Steam turbines: what is the lower limit for feasibility, recent developments to reduce costs and increase efficiency in small steam turbine systems
Reiner Schenk, Siemens Frankenthal, Germany

Mr Reiner Schenk of Siemens Turbomachinery Equipment presented the current market market application status of steam turbines for small scale power production from biomass combustion applications, see Annex 12.

In 2006, Siemens acquired over 95% of the shares of the company KKK, which was specialised in the production of pre-designed small scale steam turbines (from 45 kWe up to approx 10 MW) which are of particularly interest in the market for many biomass combustion based CHP applications. Live steam pressures vary from 3-132 Bar, up to 530 °C.

Through the standard sizes and modular design, the specific costs can be kept at an acceptable level and different configurations can be made to tailor specific conditions. For example, different turbines can be arranged in twin order, as separate high pressure and low pressure turbines, or in tandem arrangement, where different turbines operating at the same inlet and outlet conditions drive the same generator through a mechanical gearbox. This has the advantage that individual turbines can be switched on or off to improve part load behaviour as compared to a single larger turbine. Isentropic efficiencies of these turbines are approx 72%, and specific investment costs approx 850 €/kWe for a 1 MWe system.

Summary of technology presentations: an attempt to present a comparable status of performance and economic data, application scale and technology readiness.
Anders Evald, Force Technology, Denmark

Based on the presentations given earlier on the day, Anders Evald presented a summary matrix of the various technologies presented, see **Fout! Verwijzingsbron niet gevonden.**. From all technologies, steam engines, steam turbines and ORC's are currently most commonly applied for small scale power generation from solid biomass, with each technology applied several hundreds of times. Other technologies that have been implemented in less projects but have recently become commercially available are gas engines with downdraught or downdraught gasification (Pyroforce and Vølund) and indirect gasification (as applied in Gussing).

Several other technologies are currently in the demonstration stage, e.g. Stirling engines, gas engines fuelled with gas from staged gasification (Weiss) or BFB gasification (as applied in Skive). Thermoelectric conversion is currently in the experimental stage, much work needs to be done and this technology is expected to have a limited market potential in pellet boilers.

Electrical efficiencies for small scale power production from solid biomass to be expected vary from approx 1-2% for thermoelectric generators to 10% for steam engines, 17-22% for ORC's, Stirling engines and steam turbines and 23-28% for gasification based power production. The low-temperature CFB based gasification process is attributed efficiencies over 40%, but that merely depends on the power plant where the produced gas is cofired.

Perspectives to data collected through the Danish follow-up program for biomass CHP
Henrik Flyver Christiansen, Danish Energy Agency, Denmark

Henrik Flyver Christiansen of the Danish Energy Agency presented the results of an assessment made in Denmark on the performance of biomass based CHP plants, see Annex 13. In the period 1993-2005, years, the energetic, environmental and financial performance of a large number of heat and CHP plants was monitored on a monthly basis. This yielded several interesting observations.

The average heat loss of the district heating network in the 189 district heating plants was 16%. Total operating hours per year varied from 4600-8700 hours, and efficiency from 68-95%. The evaluation illustrated that the project complexity and technology and project risks are often underestimated, resulting in underperformance and lower than expected efficiencies and plant availabilities. It is also seen that over time, technology has substantially improved in reliability, efficiency and costs. As an example, steam pressure for straw fired boilers applied in practice has increased from 65 to 310 Bar in the 20 years period 1981-2001, resulting in increased efficiencies.

Visit to Stirling.dk

A field trip was made to the demonstration site of Stirling DK in Copenhagen. Here, the producer gas from a 200 kW fixed bed updraught gasifier is burned in a separate combustion chamber to produce the required heat for a 35 kWe Stirling engine. This demonstration plant has an electrical efficiency of approx 17%. The heat is delivered to the neighbouring waste incinerator, which transfers it to the district heating network of Copenhagen.

Assessment of technology presentations

Introduction

Approach

An attempt has been made to summarize the information given by the presenters during the day in the below tables. This information was compiled as follows:

1. At the end of the day, the data overview was presented to the audience and general and specific comments were taken.
2. After the seminar, the data overview were distributed among the 11 presenters. This way the authors could verify that data were correct and commented properly, give supplementary data, or delete information when the context was relevant.
3. Following this verification, the authors were asked supplementary questions in order to complete the information matrix as far as possible.
4. Finally, the original very large table was divided into the following 6 summary tables, each presenting specific characteristics of the technologies.

The tables present an overview of the technologies presented during the workshop. Some technologies are not covered, either because they represent options, which are still very far from the market, or simply because we were restricted to a certain number of presentations during the day. Such "missing" technologies include fuel cell applications, indirectly fired gas turbines and others. Also please note, that the tables are a snapshot from the companies invited to the workshop - there are in most cases several other companies, who supply similar solutions.

Definition of figures

Though we have attempted to present comparable data for the individual technologies, this was not always possible due to different definitions used by the presenters and the context of the data. Background information is therefore provided with the data tables to understand the context of each figure given. As a consequence, the reader also has to be careful to directly compare technologies based on the data given in the tables.

For example, the steam turbine technology described can be regarded as a mature reference technology, offered by several suppliers, and running in hundreds of biomass power plants worldwide. But the data in the tables covers the steam turbine technology as such, not the complete biomass CHP plant.

Another example is the LT-CFB technology. First of all this technology is being developed for a much larger scale than the rest. Second, the application is for gas to be used in a thermal power plant boiler, so the technology is basically different from the others, that integrates the thermal process (boiler, gasifier etc.) and a prime mover (engine, turbine or similar).

Reliability of the data

Data in the summary tables are generally stated as given by the presenters. This way, the figures represents the knowledge and estimates from the invited companies. Other companies may offer similar technology with different characteristics, e.g. smaller or larger plants, cheaper or more expensive plants etc. With this approach, there is a risk that the summary contains data which cannot be generalized to other technology suppliers.

IEA Bioenergy Task 32 as co-organizers of the workshop wish to stress, that the information given is solely the responsibility of the authors. We are aware of information, that for some technologies show significantly poorer performance e.g. on operational reliability or electric efficiency than indicated.

Summary tables

Table 1 Technologies and presenters overview

Technology	Presented by	Presenter	Title
Thermoelectric conversion	Bioenergy 2020+	Wilhelm Moser	Next generation pellet combustion with thermoelectric power generation
Stirling engine w. gasifier	Stirling.dk	Lars Jagd	Gasfication in stirling engine applications
Gas engine w. staged gasifier	Weiss A/S	Bjarne Skyum	Staged gasification with gas engine, the Viking Gasifier
Steam engine w. steam boiler	Spilling	Till Augustin	Steam engines
ORC w. hot-oil boiler	Turboden	Roberto Bini	State-of-the-art of ORC technology for biomass plants
Gas engine w. downdraft gasifier	Pyroforce	Herbert Gemperle	Downdraft gasification with gas engine
Gas engine w. updraft gasifier	Vølund	Robert Heeb	Updraft gasification with gas engine
Gas engine w. indirect gasifier	TU-Wien	Reinhard Rauch	Indirect gasifier - biomass CHP in Güssing and follow-up plants
Steam syst. w. LT-CFB gasifier	DONG Energy	Anders Boisen	Upscaling the LT-CFB (Low Temperature Circulating Fluid Bed) gasifier
Gas engine w. BFB gasifier	Aaen Consulting	Bettina Skjoldborg	The Skive plant (BFB gasification): status and perspectives
Steam turbine w. steam boiler	Siemens	Reiner Schenk	Steam turbines: what is the lower limit for feasibility, recent developments to reduce costs and increase efficiency in small steam turbine systems

Technology status

Technology maturity is stated as experimental (lab. testing or pilot plant), demonstration or commercial. The distinction relies on the subjective evaluation of the authors.
Number of companies globally active in the development and marketing of the technology is stated.

Number of plants in operation globally is stated, either from the company of the invited speaker or including plants from other companies. In the comments, information on accumulated number of operational hours is given if available.

Table 2 Technologies and presenters overview

Technology / Presenter	Maturity	Commercial status		Comments from presenter
		# of companies	# of plants	
Thermoelectric conversion Bioenergy 2020+	Experimental	6	0	One producer of stoves, three of boilers, two developing companies (furnaces and thermoelectric generators)
Stirling engine w. gasifier Strling.dk	Commercial	1	10	Stirling.dk supplies and develops biomass fuelled CHP plants.
Gas engine w. staged gasifier Weiss A/S	Demonstration	1	2	Operational hours: Hadsund: 1000 h, DTU-plant: 4000 h
Steam engine w. steam boiler Spilling	Commercial	1	200-300	Fully commercial technology
ORC w. hot-oil boiler Turboden	Commercial	2	150	About 10 plants installed by other companies
Gas engine w. downdraft gasifier Pyroforce	Commercial	Several	5	5 Pyroforce plants between 3500 to 16000 engine hours each. Globally, hundreds of similar plants exist.
Gas engine w. updraft gasifier Vølund	Commercial	Several	5	First plant in Harboøre: 120000 op. hours, including more than 80000 hours of gas engine operation
Gas engine w. indirect gasifier TU-Wien	Commercial	2	2	Active companies: 1) Ortner Anlagenbau 2) Repotec. Another 4 plants in construction, engineering or commissioning.
Steam syst. w. LT-CFB gasifier DONG Energy	Demonstration	1	2	500 kW test plant total running hours approx. 500 hours, plus 6 MW demo plant (under construction)
Gas engine w. BFB gasifier Aaen Consulting	Demonstration	1	1	10730 engine hours in the Skive plant
Steam turbine w. steam boiler Siemens	Commercial	Several	100's	Fully commercial technology

Technology capacity range

Table 3 Technology Application Range

Technology / presented by	Application range MW(e)			Comments from presenter
	Lower MW(e)	Typical MW(e)	Higher MW(e)	
Thermoelectric conversion Bioenergy 2020+	0.0001	0.0002	0.005	For small scale wood fired heating appliances
Stirling engine w. gasifier Strling.dk	0.035	0.1	0.5	Modular units, each 35 kW(e)
Gas engine w. staged gasifier Weiss A/S	0.2	0.5	1	0.2, 0.5 and 1.0 MW(e) represents 3 standard plants
Steam engine w. steam boiler Spilling	0.15	0.4	1	Typical output range 0.1 to 1.0 MW(e)
ORC w. hot-oil boiler Turboden	0.2	1	3	Standard size. In customized product up to 10 MW(e)
Gas engine w. downdraft gasifier Pyroforce	0.15	0.6	1.2	Largest Pyroforce plant so far: 0.6 MW(e)
Gas engine w. updraft gasifier Vølund	1	2	5	Future plants with combined cycle anticipated at 4-5 MW(e)
Gas engine w. indirect gasifier TU-Wien	2	2.8	5.5	Scale-up based on dual gasifiers possible
Steam syst. w. LT-CFB gasifier DONG Energy	6	25	100	The LT-CFB is meant as an add-on to a large power plant boiler. Range figures refer to fuel feed (thermal capacity).
Gas engine w. BFB gasifier Aaen Consulting	-	6	-	Capacity figure refers to the derated power in the Skive plant. Larger plants expected in the future.
Steam turbine w. steam boiler Siemens	0.045	5	>500	Larger steam turbines possible in any size

Investment costs

A range is given for the specific investment costs. The figures are calculated as the actual investment in € divided by the installed electric capacity (in kW_e). The lower and higher end of the range are intended to illustrate the variation found for the technology. Variation could be caused by scale, local conditions etc. The lower figure reflects the lowest specific cost, which is often a larger plant due to economy of scale, while the higher figure represents highest specific costs, correspondingly this will often reflect a smaller plant.

Notes explain the conditions for investment figures given. Please note the significant difference in the extent of supply (from turbine only to complete CHP plant) between technologies.

Table 4 Technology Investments

Technology / Presented by	**Specific costs**		**Comment**
	Lower	**Higher**	
	€/kWe	**€/kWe**	
Thermoelectric conversion Bioenergy 2020+	8,000	14,000	Estimate of present extra costs of thermoelectric conversion for end user compared to normal stove or boiler. Reductions expected through further R&D.
Stirling engine w. gasifier Strling.dk	3,000	6,000	Complete CHP plant
Gas engine w. staged gasifier Weiss A/S	4,000	6,200	Complete CHP plant. The lower figure represents a 1.0 MW(e) plant; the higher figure a 0.5 MW_e plant.
Steam engine w. steam boiler Spilling	500	1,000	Spilling engine alone; for complete CHP unit multiply by 3 to 3.5
ORC w. hot-oil boiler Turboden	800	2,000	ORC engine alone
Gas engine w. downdraft gasifier Pyroforce	3,500	4,000	Complete CHP plant
Gas engine w. updraft gasifier Vølund	4,000	6,000	6000 is for a 1 MW(e) turnkey plant, electromechanical scope
Gas engine w. indirect gasifier TU-Wien	5,700	6,500	Complete CHP plant
Steam syst. w. LT-CFB gasifier DONG Energy	500	1,700	As add-on gasification; excl. steam cycle; lower figure represents a large plant 100 MW thermal
Gas engine w. BFB gasifier Aaen Consulting	3,700	5,600	Investment figures refer to the derated power in the Skive plant. The lower figure refers to original budget; the higher to actual costs
Steam turbine w. steam boiler Siemens	350	850	Steam turbine unit alone. Lower figure is for approx 10 MW_e; higher for approx. 1 MW_e

Efficiency figures

Efficiency is given as electric and heat efficiencies, usually based on the lower heating value of the fuel input. Figures could be based on short term test, or annual averages.
Please note, that for two technologies, we are not able to give relevant efficiency figures. For the LTCFB, relevant efficiency figures cannot be stated as the gas is supplied into a power plant boiler, thus the efficiency is determined by the power plant as such, and not by the LT-CFB. And for Siemens steam turbine data, the complete CHP plant efficiency is not stated. Please refer to other sources for documented reference information on performance of steam turbine based small scale biomass CHP plants. One example of such references: Biomass CHP Best Practice Guide – Performance comparison and recommendations for future CHP systems utilizing biomass fuels, Anders Evald, FORCE Technology and Janet Witt, Institute for Energy and Environment, 2006.
A few technologies output other energy services than electricity and heat. This could be gases or a liquid oil product. Such details are given in the notes.

Table 5 System efficiencies

Technology / Presented by	**Efficiency, electric (e)**		**Efficiency, heat (h)**	
	%	**Comments from presenter**	**%**	**Comments from presenter**
Thermoelectric conversion Bioenergy 2020+	3%	2-4 % fuel to power. Potential is higher.	90%	Fuel to energy (ncv)
Stirling engine w. gasifier Strling.dk	18%	Fuel to power	70%	Fuel to heat
Gas engine w. staged gasifier Weiss A/S	30%	Measured in Hadsund; for next plant in Hillerød 33% is expected	-	No heat efficiency stated; expect a total of electricity and thermal around 85 %
Steam engine w. steam boiler Spilling	10%	Energy balance calculation, double stage engine	70%	Normally 60 % to 80 % heat utilization
ORC w. hot-oil boiler Turboden	17%	Fuel to power, gross, based on 88 % boiler efficiency.	70%	Fuel to heat
Gas engine w. downdraft gasifier Pyroforce	25%	Fuel to power. Experience from accumulated operational experience	50%	Fuel to heat
Gas engine w. updraft gasifier Vølund	23%	Fuel to power. Annual figure for year 2006 (up to 29.5% in short term measurements)	57%	Fuel to heat. Annual figure for year 2006. Liquid fuel production (approx. 13% of fuel input) on top of power and heat.
Gas engine w. indirect gasifier TU-Wien	25%	Fuel to power	55%	Fuel to heat
Steam syst. w. LT-CFB gasifier DONG Energy	-	Determined by efficiency of the thermal power plant where the gas is cofired	-	Determined by efficiency of the thermal power plant where the gas is cofired
Gas engine w. BFB gasifier Aaen Consulting	28%	Fuel to power	47%	Fuel to heat
Steam turbine w. steam boiler Siemens	-	See notes in main text	-	See notes in general text

Manpower requirements

Low operating costs and high reliability is essential for the economic performance of a small scale biomass CHP plant. Thus authors were asked to state to which extend a plant currently could run automatically, and estimate the extent of manning required during normal daily operation.

Table 6 Automation degree / manning requirements

Technology / Presented by	**Manning requirements and degree of automation**
Thermoelectric conversion Bioenergy 2020+	None additional compared to normal stoves or boilers
Stirling engine w. gasifier Strling.dk	Fully automated plant
Gas engine w. staged gasifier Weiss A/S	
Steam engine w. steam boiler Spilling	Maintenance by local staff possible
ORC w. hot-oil boiler Turboden	Fully automatic. Manning requirement: few hours/week
Gas engine w. downdraft gasifier Pyroforce	Fully automatic w. remote control. 1 operator for a 0.6 MW(e) plant.
Gas engine w. updraft gasifier Vølund	Fully automatic. Manning approx. 30-40 hours/week
Gas engine w. indirect gasifier TU-Wien	1 person/shift necessary
Steam syst. w. LT-CFB gasifier DONG Energy	
Gas engine w. BFB gasifier Aaen Consulting	Unmanned operation evenings and night time expected
Steam turbine w. steam boiler Siemens	

Fuel specification

In choosing the best technology for a given application, the fuel specification is very important. Some technologies are highly sensitive to e.g. alkali containing biomass fuels, others may not accept wood chips with the usual fraction of fine particles in the fuel. Therefore the authors were asked to supply a fuel specification for their technology, including type, form and moisture restrictions.

Table 7 Fuel specification

Technology / Presented by	**Fuel specification**
Thermoelectric conversion Bioenergy 2020+	Woodpellets (high quality)
Stirling engine w. gasifier Strling.dk	Moist wood chips; other biomass fuels on request
Gas engine w. staged gasifier Weiss A/S	Moist wood chips (35 % to 50 % moisture)
Steam engine w. steam boiler Spilling	Solid biomass, or any other steam boiler fuel
ORC w. hot-oil boiler Turboden	Any fuel, that can be burnt in a furnace
Gas engine w. downdraft gasifier Pyroforce	Dry wood chips (less than 15 % moisture)
Gas engine w. updraft gasifier Vølund	Moist wood chips (35% to 55% moisture) Demolition wood
Gas engine w. indirect gasifier TU-Wien	Wood chips G30 or G50 are preferred All fuels with ash melting above 1000°C possible
Steam syst. w. LT-CFB gasifier DONG Energy	Suitable for high alkali biomass (straw, food industry residues, manure fibres etc.)
Gas engine w. BFB gasifier Aaen Consulting	Wood pellets
Steam turbine w. steam boiler Siemens	Any fuel suitable for steam boiler, including wood fuels.

Market outlook

The authors give comments on the most obvious markets (in terms or region/country, and application) and information on the progress towards maturity of the technology, including anticipated development in improvement on efficiency and other performance parameters.

Table 8 Market outlook

	Market outlook
Thermoelectric conversion Presented by Bioenergy 2020+	EU (pellet markets), Eastern Europe, Northamerica
Stirling engine w. gasifier Presented by Strling.dk	European market estimated at 2-5 billion €/year
Gas engine w. staged gasifier Presented by Weiss A/S	EU
Steam engine w. steam boiler Presented by Spilling	Industrial applications with steam boilers and waste heat value
ORC w. hot-oil boiler Presented by Turboden	EU markets with high value of kWh's produced. New optimzed units eff. above 20%
Gas engine w. downdraft gasifier Presented by Pyroforce	EU (DE, IT and AT is first priority)
Gas engine w. updraft gasifier Presented by Vølund	Markets with kWh-support: Japan (DE, UK, IT) 37% electrical efficiency in combined cycle systems
Gas engine w. indirect gasifier Presented by TU-Wien	Combined with ORC, electric eff. can reach 31%
Steam syst. w. LT-CFB gasifier Presented by DONG Energy	Utilize cheap local waste fractions to replace expensive natural gas
Gas engine w. BFB gasifier Presented by Aaen Consulting	Operational stability must be acvieved
Steam turbine w. steam boiler Presented by Siemens	Co-generation, biomass, waste-to-energy. Most applications industrial

Conclusions

Selection criteria of technology

In a situation, where a small scale CHP plant based on solid biomass fuels is considered, the following questions and criteria can be a guideline for the selection of an appropriate technical solution:

- Is the aim of the project to realize a commercial plant based on proven technology with maximum reliability, a demonstration plant for a new technology, or a pilot plant for yet immature technology but with potential benefits, where R&D can be performed? In the latter case, one can expect to encounter operational problems; this is much less the case if a technology with proven track record is chosen.
- Demonstrated reliability - how many accumulated operational hours can the technology demonstrate?
- Automatic operation - especially for small scale plants, the costs for manpower can ruin project viability
- Fuel selection - does the fuel available match the requirements from the technology?
- Electric efficiency - does the plant supply enough kWh's as compared to the fuel input when considering the investment cost?

- Heat efficiency and heat utilization - does the plant supply a high recovery rate of heat, and is the heat available at conditions (temperature, steam pressure), where it can be utilized under local conditions?
- Does the technology supply other energy products such as combustible gases, charcoal or liquid fuels, and can these be utilized or sold with an economic benefit?

R&D needs

From the discussions in the audience by the end of the seminar, the following conclusions were drawn regarding R&D needs for biomass based power generation:

- Operational reliability needs **improvement** through automation and technology optimization
- For many technologies that are in the process of commercialization, we still need to **demonstrate** operational stability on several plants and in thousands of hours
- There is a strong requirement, especially for the smallest scale technologies, that **unmanned** operation is possible
- Electric efficiency is key to economic performance, and the efficiency still needs significant **improvement**, both as short term measured data, and on an annual basis
- Investments need to be **reduced**.

Annex 1. Welcome and introduction: Why small scale CHP and where is the market?

Jaap Koppejan, task manager, IEA Bioenergy Task 32, Netherlands

Expert workshop on
Small scale biomass co-generation Technology status and market opportunities

Jaap Koppejan

Biomass Combustion and Cofiring
IEA Bioenergy Task 32

Procede Biomass BV
PO Box 328, 7500 AH, Enschede
The Netherlands
www.procede.nl

International Energy Agency

- The IEA was founded under the OECD to implement an international energy programme in response to the oil shocks.
- Activities are directed towards collective energy policy objectives of energy security, economic and social development, and environmental protection.
- Activities are set up under Implementing Agreements. There are 40 active Implementing Agreements.

iea International Energy Agency

IEA Bioenergy Tasks

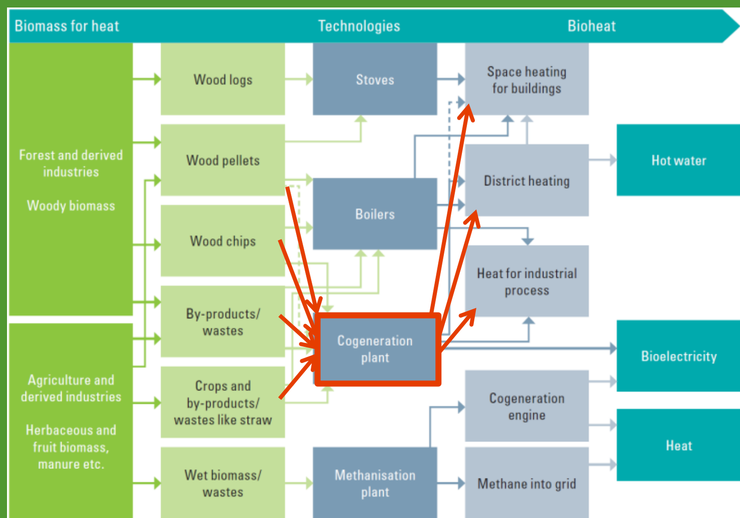
Task 29 : Socio-Economic Drivers
Task 32 : Combustion and Co-firing
Task 33 : Gasification
Task 34 : Pyrolysis
Task 36 : Energy from Solid Waste
Task 37 : Energy from Biogas
Task 38 : Greenhouse Gas Balances
Task 39 : Liquid Biofuels
Task 40 : Bioenergy Trade
Task 41 : Joint project with the Advanced Motor Fuels Implementing Agreement
Task 42 : Biorefineries
Task 43 : Biomass Feedstocks

IEA Bioenergy Task 32: Biomass Combustion and Co-firing

- **Experts from 13 countries:**
  Austria, Canada, Denmark, Finland , Germany, Ireland, Italy, Netherlands, Norway, Sweden, Switzerland, Turkey, United Kingdom
- **Working together in:**
  - Cooperative projects
  - Meetings, Workshops, Conferences, Excursions
  - Cooperation with other Networks
- **Reports etc. can be found on our website:**
  www.ieabioenergytask32.com

Biomass Combustion and Cofiring
IEA Bioenergy Task 32
Workshop on Small Scale Biomass CHP, 7 Oct 2010

Where is the market for biomass CHP?



Development of the heat market

2020:

- increased oil prices makes biomass heat much more popular for households
- Bioenergy = 60% of 2020 targets (EREC)

2030:

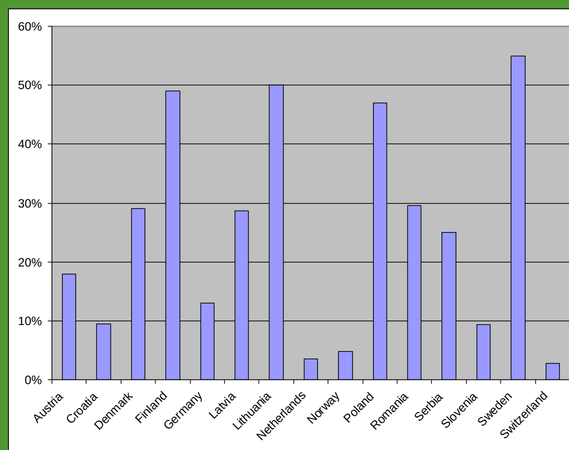
- pellets, chips and wood logs are important energy sources for individual heating
- CHP will be available from household level upwards
- DHC will be much more renewable

2050:

- Scarcity, policital tensions, make bioenergy even more popular
- No power without heat utilisation
- No heat without power production
- DHC even in rural areas

Source: Biomass For Heating & Cooling - Vision Document – Executive Summary, July 2010, ETP-RHC

Penetration of district heating in residential heating market



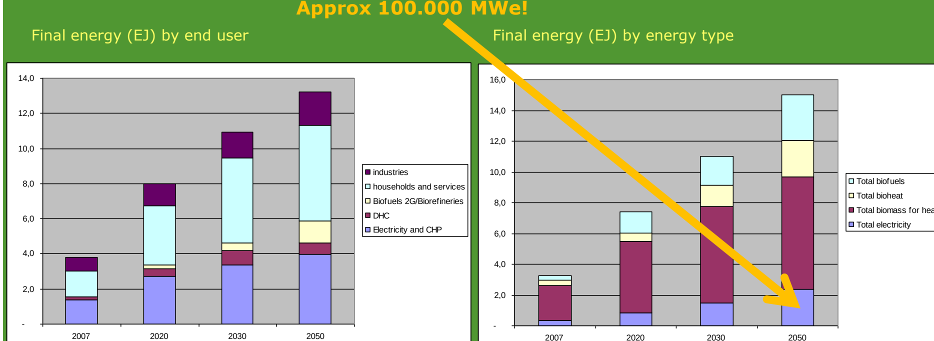
Source: Euroheat and Power – Country statistics on district heating, 2010

Why small scale CHP and where will the market be?

Approx 100.000 MWe!

Final energy (EJ) by end user

Final energy (EJ) by energy type



Source: All figures in EJ. Biomass For Heating & Cooling - Vision Document – Executive Summary, July 2010, ETP-RHC

Agenda for today

09:00	Welcome and introduction, Jaap Koppejan, IEA Bioenergy Task 32, Netherlands
09:05	Next Generation of Pellet Combustion with Thermoelectric Power Generation, Wilhelm Moser, Bioenergy 2020+, Austria
09:30	Gasfication in stirling engine applications, Lars Jagd, Stirling.dk, Denmark
09:55	Staged gasification with gas engine, the Viking Gasifier, Morten Grøn, Weiss A/S, Denmark
10:20	*Coffee / tea break*
10:35	Steam engines, T. Augustin, Spilling Energie GmbH, Germany
11:00	State-of-the-art of ORC technology for biomass plants, Roberto Bini, Turboden SRL, Italy
11:25	Downdraft gasification with gas engine, Herbert Gemperle, Pyroforce, Switzerland
11:50	*Lunch*
12:50	Updraft gasification with gas engine, Robert Heeb, Babcock & Wilcox Vølund A/S, Denmark
13:15	Indirect gasifier, Reinhard Rauch, task member IEA Bioenergy Task 33, Austria
13:40	Upscaling the LTCFB gasifier, Anders Boisen, DONG Energy, Denmark
14:05	The Skive plant (BFB gasification): status and perspectives Bettina Skjoldborg, Aaen consulting and Henrik Flyver Christiansen, Danish Energy Agency
14:30	Steam turbines, Reiner Schenk, Siemens Frankenthal, Germany
14:55	*Coffee / tea break*
15:10	Summary of technology presentations Anders Evald, Force Technology, Denmark
15:40	Panel discussion
16:10	*Closing and transportation to Stirling.DK*
16:30	Visit to Stirling.dk
18:15	*End of site visit, bus transport back*

Aspects to cover

- **Operating principle**
- **Operational experience**
  - Number of plants built
  - Number of operational hours
- **Efficiencies**
  - Electric
  - Thermal
- **Scale of application (MW_{th}, MW_e)**
- **Specific investment (Euro/kWe)**
- **Operational costs**
- **Fuel specifications and fuel flexibility**
- **Challenges for further deployment**

Biomass Combustion and Cofiring
IEA Bioenergy Task 32
Workshop on Small Scale Biomass CHP, 7 Oct 2010
PROCEDE Chemical Engineering Solutions

Statements for discussion

- **Gasification based CHP is more efficient but less mature/reliable than combustion based CHP.**

- **We should not give subsidy to development of all new CHP concepts, but support only a few selected concepts to commercial application**

- **All CHP plants should be used in heat following mode, and biomass should be sourced locally**

Annex 2. Next Generation of Pellet Combustion with Thermoelectric Power Generation

Wilhelm Moser, Bioenergy 2020+, Austria

bioenergy2020+

Next Generation Pellet Combustion with Thermoelectric Power Generation

Expert Workshop IEA Task 32 and Task 33:
Small scale biomass co-generation –
Technology status and market opportunities

Wilhelm Moser
wilhlem.moser@bioenergy2020.eu

Copenhagen, October 7th 2010

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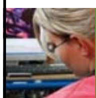

Content

- Operation Principle and Idea
- Efficiencies & Maturity Status of the Technology
- Experience with Biomass
- Application Market & Economics
- Future Outlook

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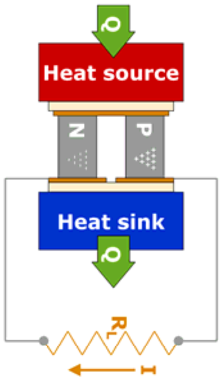
Operation Principle of Thermoelectric Power Generation



Principle of TE
Power Generation

- **Direct Energy Conversion**
- **No Moving Parts**
- **No Working Fluids**
- **Maintenance-free Durability**
- **Noiseless Operation**

Predestined for
Micro-Scale CHP
Based on Biomass

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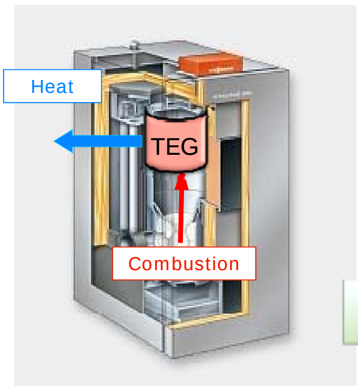
Idea – Integration of a Thermoelectric Generator (TEG) into a Biomass Furnace



Combustion Unit from Viessman

Hot combustion gases = Heat source for thermoelectric power generation

TEG Cooling Water or Air = Heat for domestic use

Micro Heating System → Micro CHP System

→ **Grid Independent Operation**

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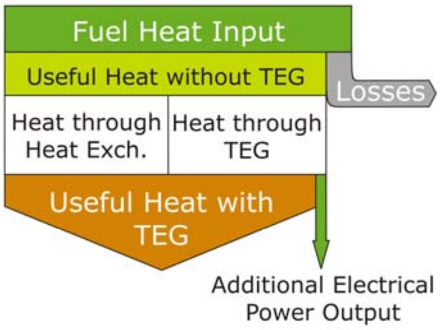
Thermal Efficiency of a micro-scale CHP with TEG



- Maximising Heat Flow through TEG
- High Temperatures on Small Surfaces
- Maximum Efficiency of the TEG

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Efficiency and Maturity Status of TE Power Generation

Industrial available TEGs from Cooling Technology:

- Bismuth Telluride with maximum Efficiency 5-6 %
- Allowed Temperatures up to 250 °C

(Still) Under Development – Materials and Technology for higher Temperatures:

- Our Aim: 10 % with Temperatures up to 400 °C
- Published 15-18 % with higher Temperatures

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First Prototype with TEG 250

Design

- Thermoelectric Material: Bismuth Telluride
- Hot-side Temperature: 250 ° C
- Cold-side Temperature: 60 ° C

Target Values

- Heat Input: 5 kW out of 10 kW
- Electrical Efficiency TEG: 4 %
- Nominal Electrical Power: 200 W
- Electrical Efficiency CHP: 2 %

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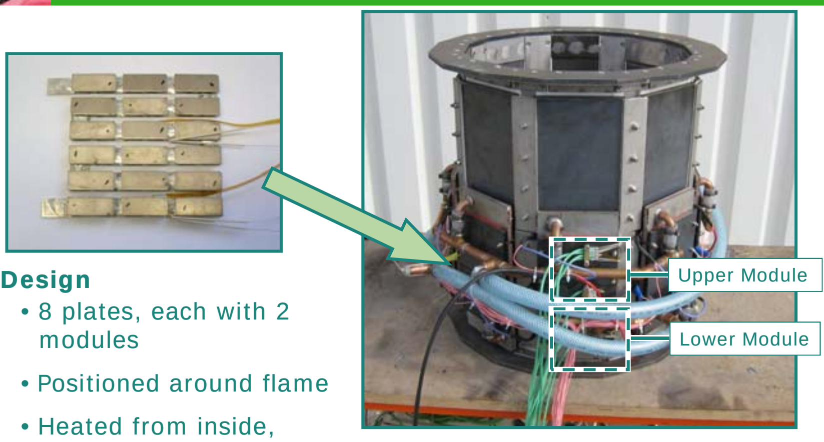
Prototype TEG 250



Generator and Modules developed in cooperation with TECCOM

Design

- 8 plates, each with 2 modules
- Positioned around flame
- Heated from inside, cooled from outside

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First Prototype with TEG 250

Boiler with TEG 250
10 kW_{th}, 200 W_{el}

Results	Target	Achieved
Useful Heat Extraction	50 %	> 50 %
Generator Efficiency	4%	3,5 %
Electrical Efficiency	2 %	1,7 %
Electric Power	200 W	170 W

→ Potential for grid independent operation confirmed

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Slide 9

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Prototypes planned for use of TEG 400 – Operation with "Thermal Models"

Stove with TEG 400
Max: 8 kW_{th}, 100 W_{el}

Boiler with TEG 400
Max: 12 kW_{th}, 300 W_{el}

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Slide 10

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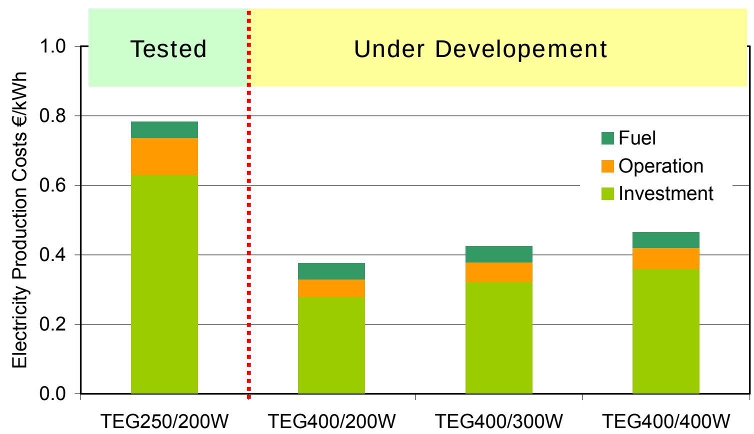
Application Market

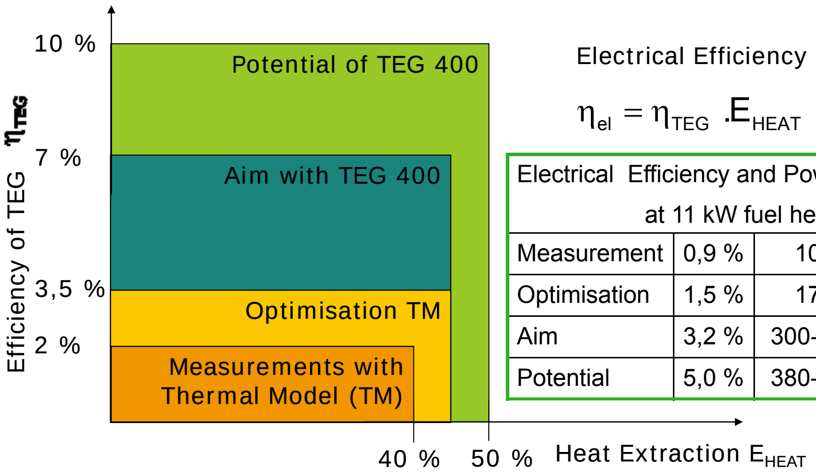
- Every established **Market for Automatic Pellet Furnaces**, especially Small Scale Combustion Units for End-Users
- Great Chance for **East of Europe and North-America** because of unreliable Electric Power Grids

Economics



Assumed 9 kW Heat Output for Calculation

Potential of Pellet Combustion with Thermoelectric Power Generation



Electrical Efficiency

$$\eta_{el} = \eta_{TEG} \cdot E_{HEAT}$$

Electrical Efficiency and Power at 11 kW fuel heat input		
Measurement	0,9 %	100 W
Optimisation	1,5 %	170 W
Aim	3,2 %	300-350 W
Potential	5,0 %	380-550 W

Areas correspond to total electrical efficiency

Vision – Grid Independent Operation and...

- Decentralized production for decentralized utilization
- Production of electricity during periods of high heat demand and low offer of other renewable electricity
- Mass production reduces production costs
- Integration into existing infrastructure
- Increase of efficiency of the energy system

bioenergy2020+

Thank you for your Attention!

Wilhelm Moser wilhelm.moser@bioenergy2020.eu

The presented projects are performed and funded in the frame of the **K***plus*- & COMET-programme of the Austrian Federal Government. The funding by the Austrian Research Promotion Agency and the Federal Governments of the Provinces Styria and Lower Austria shall be highly acknowledged.

TU VIENNA · BLT Wieselburg · RIKA · SHT · VIESSMANN · DLR · TEC COM · HET Energietechnik · KWB · SCHRÖDL

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Annex 3. Gasfication in stirling engine applications

Lars Jagd, Stirling.dk, Denmark

Gasification in Stirling Engine Applications

October 2010

STIRLING DK
Clean Power Production

Stirling DK's Value Proposition

Conversion of Low-value Biomass, Biofuel, and Gas Into High-value,Distributed (35-500 kWe) Clean Electricity and Heat

2

Stirling DK CHP Plant

Biomass

Biofuel

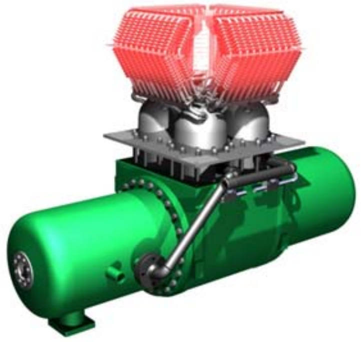
Direct Combustion or Gasification of Biomass

District Heating or Heating for Industrial Purposes

Electrical Power For Grid or Local Use

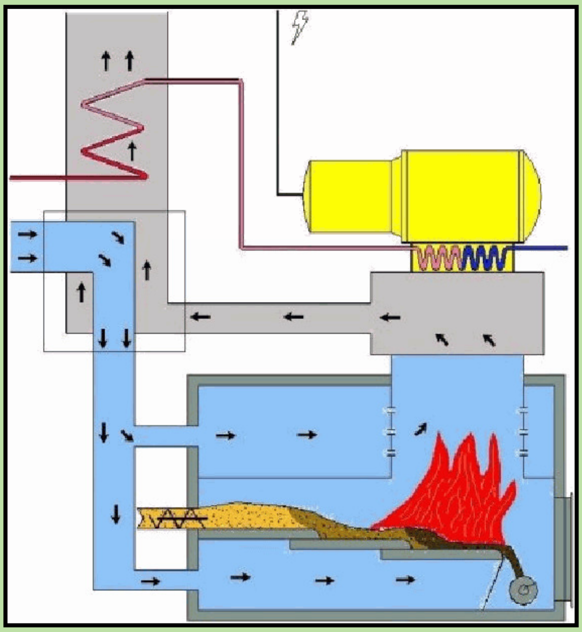
Stirling Engine Vs. Diesel Engine

Fuelled by External Heat Source

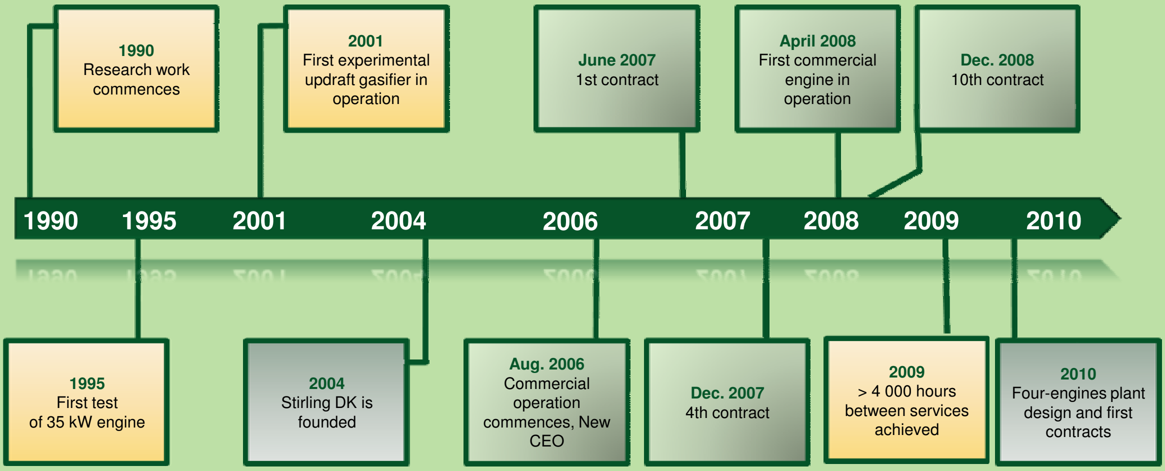


Stirling Engine Principle

Engine Driven by External Heat Source



Historic Development of Stirling DK



Company is Owned by German and Danish Investors, including RWE Innogy and the Growth Foundation, and the Founder Group

Technology Fills a Market Gap

Technology Unique for Distributed CHP Production

The market potential ín Europe is several billions of Eur per annum and a significant technology gap exists:

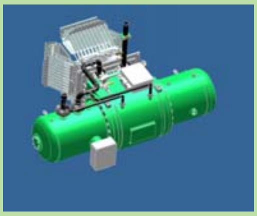
”***The market for sub 1 MW biomass CHP technology could be worth over half a billion pounds per annum from 2016 if technological and supply capacity contraints are overcome. Biomass CHP on this scale is not currently commercially mature, though pre-commercial trials are underway***”

ref. Report by the UK Renewables Advisory Board www.renewables-advisory-board.org.uk, 2009

Product Portfolio

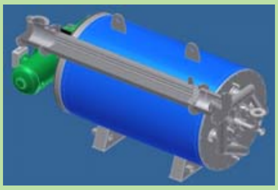
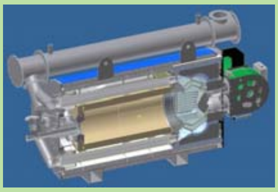
3 Product Configurations Serving Differentiated Market Needs

Stand-alone Engine
- Stirling Engine
- Interface
- Control system


OEM delivery to boiler manufacturers

Engine with CoC
- Stirling engine
- Combustion Chamber
- Burner System
- Control system

OEM delivery to producers of gasifiers, biogas, landfill gas systems, etc.

CHP Plant
- Engine with CoC
- Updraft Gasifier
- Plant Control system
- Interfaces to end user

OEM delivery to contractors

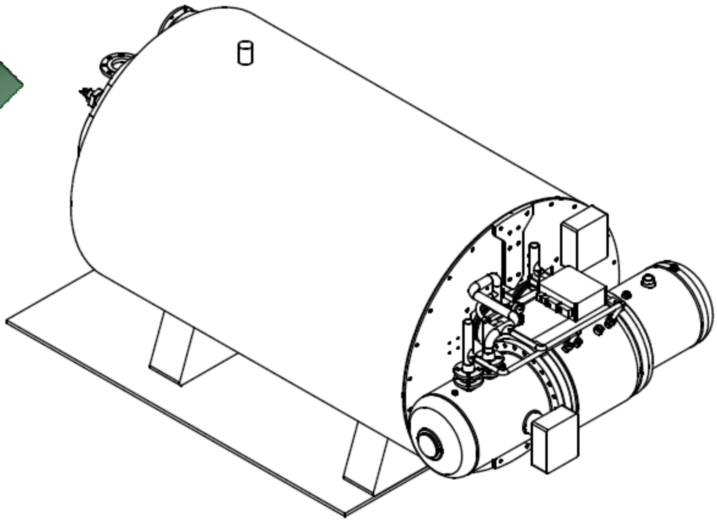
Stand-alone Engines

Solution for Direct Combustion

- 5 engines installed on Wood Chips Boilers
- Totally around 40,000 hours of operation clocked
- Engine availability above 95%

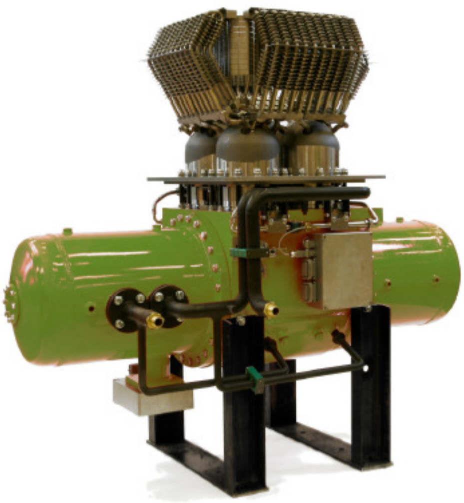
Engine with Combustion Chamber

E.g. Pyrolysis Oil,
By-products from biofuel production,
Low energy content gas



Gasification and Stirling Engine

Updraft Gasifier and Stirling Engine

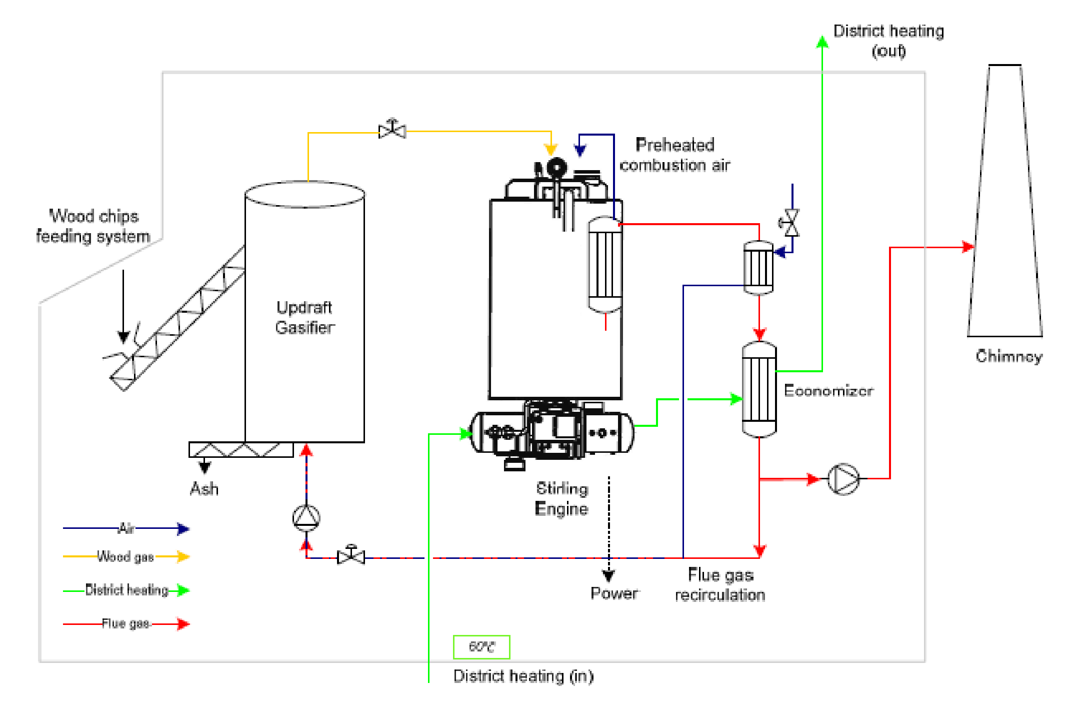


35 kWel Stirling engine

200 kW
updraft gasifier

Gasification and Stirling Engine

Process Diagram for 1-Engine Plant



Gasification and Stirling Engine

Gasification of Wood Chips

- Standard plants for 1-4 engines developed
- 4-engine plant has an output of 140 kWe / 600 kWth
- Low dust levels ~ low heater cleaning requirements
- Plant efficiency 88%, Electrical efficiency 17%
- 5 plants with a total of 7 engines installed
- 2 plants with a total of 8 engines under construction

Gasification and Stirling Engine

2-engine 70 kWe / 280 kWth Plant for Hospital in Hannover

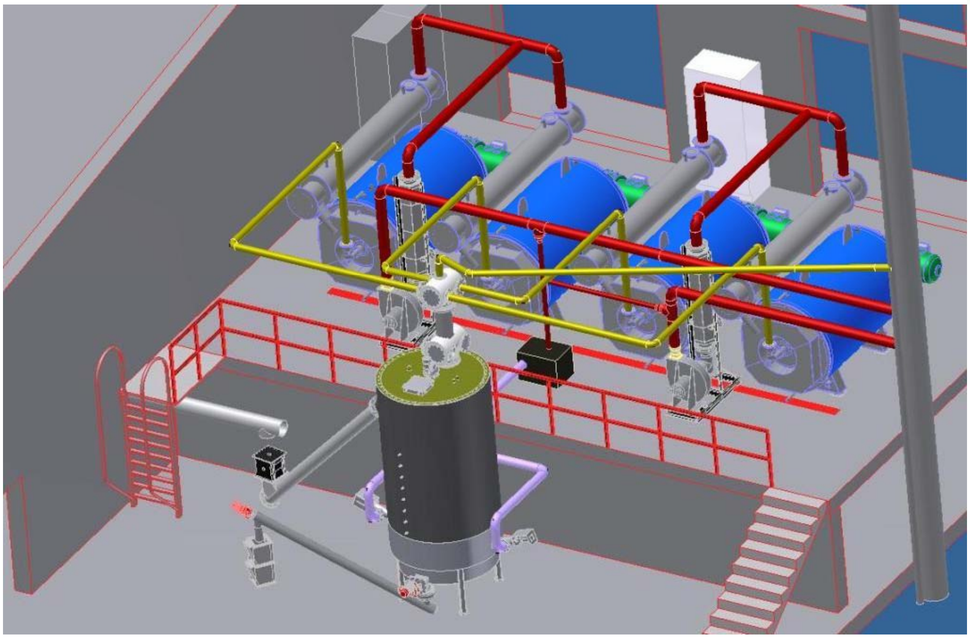
Gasification and Stirling Engine

Containerized One-engine Plant in Copenhagen

- Allows production under factory conditions and easy ”plug-and-play” installation
- Built into three (3) standard 20’ ship containers
- One additional fuel storage container

Gasification and Stirling Engine

Two Identical Four-engine Installations (140 kWe / 600 kWth)
Under Construction



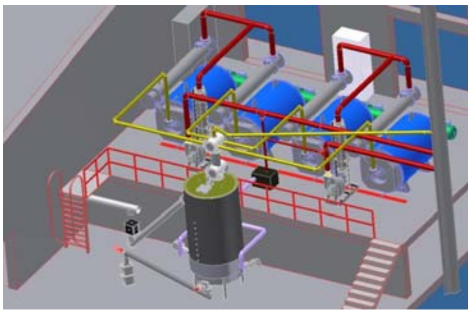
Gasification and Stirling Engine

Case Study: Four-engine Installation in Germany

Investment for End-customer

- Cost of plant equipment ~ 1,000,000 EUR (Stirling DK's delivery scope)
- Other project costs (including project management, civil works, erection, etc.) ~ 400,000 EUR
- Total project costs 1.4 million EUR

Plant Economy for Customer



- Fuel input: 800 kW
- Energy output: 140 kWe and 600 kWth
- Self-consumption: 10 kWe
- Annual operating hours: 7,000
- Yearly energy production: 910,000 kWhe and 4.2 GWhth
- Value of energy: 26,67 Cent/kWh power, 4 Cent/kWh heat
- Total yearly revenue: ~ 410,000 EUR
- Fuel cost: ~ 2.0 Cent/kWh
- Total fuel costs: 112,000 EUR/year
- Service and maintenance costs: ~ 2.5 Cent/kWh power plus 0.5 Cent kWh heat
- Total service, and maintenance costs: ~ 45,000 EUR
- Total contribution: 253,000 EUR/year ~ 5.5 years' payback time

Pyrolysator and Stirling Engine

Production of Clean Power, Heat, and Bio-Char

Contact Information:

CEO Dr. Lars Jagd

Tel +45 88 18 48 00
Fax +45 88 18 48 80
Cell +45 22 16 33 87
Mail lkj@stirling.dk
Web www.stirling.dk

STIRLING DK
Clean Power Production

Annex 4. Staged gasification with gas engine, the Viking Gasifier

Morten Grøn, Weiss A/S, Denmark

Annex 5. Steam engines

T. Augustin, Spilling Energie GmbH, Germany

IEA – Workshop Copenhagen

Small scale biomass co-generation

with modern steam engines

Dipl.-Ing. Till Augustin

October, 7th 2010

SPILLING Energie Systeme GmbH

Solid Biomass Cogeneration

with Spilling Steam Engines

Contents:

- Who is Spilling
- Heat and Power from Biomass Steam Power Plants
- The Spilling Steam Engine
- Examples

SPILLING Energie Systeme GmbH

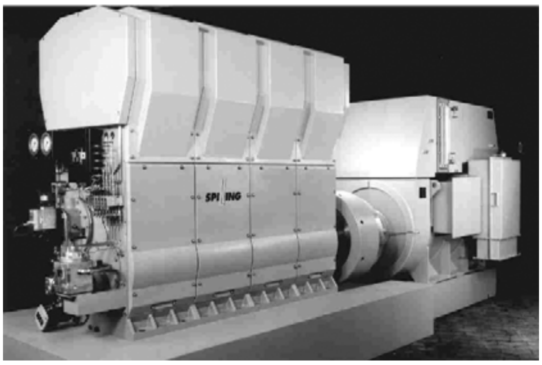
Spilling: Company Information

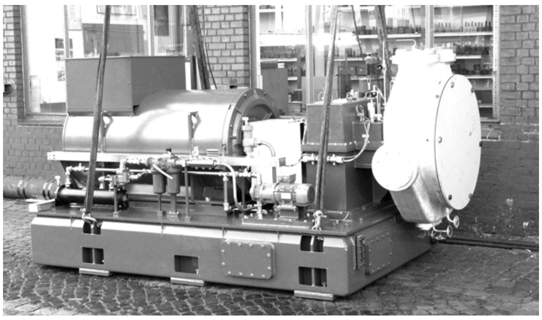
- Engine and Turbine Manufacturer
- Location: Hamburg
- Founded in 1889
- Product Lines: Steam Engines, Steam Turbines, Gas Expanders

SPILLING Energie Systeme GmbH

Spilling Steam Power: Engines and Turbines

Spilling‘s Program: Decentralized Co-Gen Equipment



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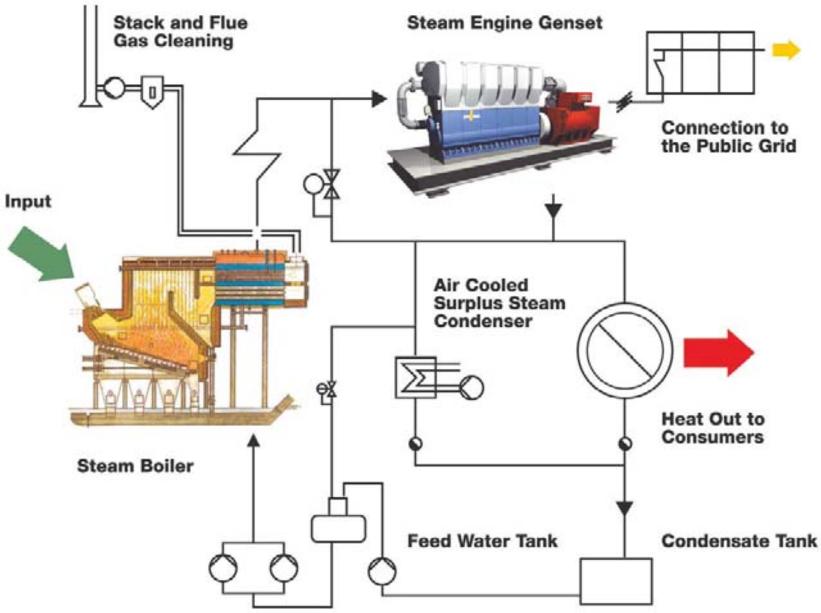
Biomass Steam Cogeneration



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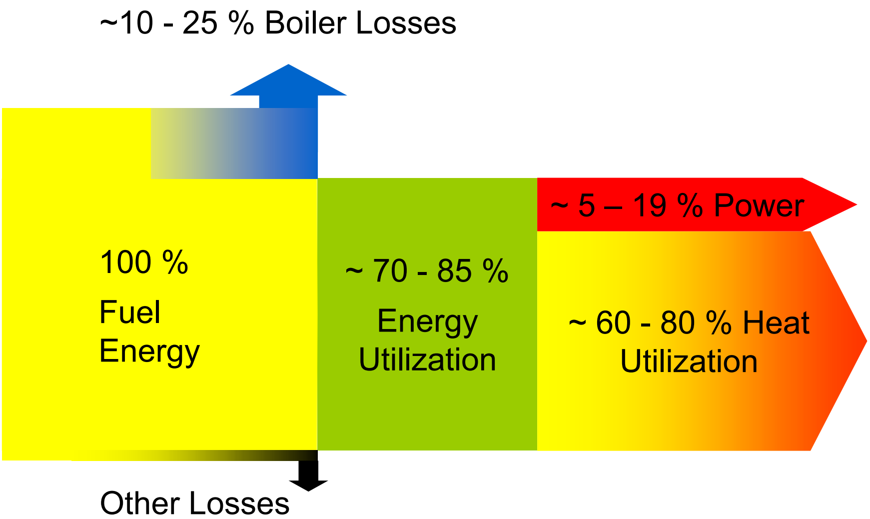
Optimal Use of Energy with CHP



Sankey Diagram of Biomass Steam CHP-Plant

SPILLING Energie Systeme GmbH

Optimal Use of Energy with CHP

Examples for Energy Balances: Biomass Steam Cogeneration Plants			Date / Name:	04.10.2010 / Au
Case		**1**	**2**	**3**
Primemover		**Turbine**	**Engine**	**Engine**
Design / Type		**Multi Stage**	**Single Stage**	**Double Stage**
Steam Pressure Boiler Outlet	[bar abs.]	42	62	26
Steam Temperature Boiler Outlet	[°C]	425	dry sat.	265
Fuel			Solid Biomass	
Steam Procution	**[t/h]**	**30,0**	**24,0**	**4,0**
Stecific Heat Demand for Steam Prorduction	[kWh/t]	782	649	685
Steam Heat Capacity Boiler	[kW]	23.460	15.576	2.740
Boiler Efficiency		0,88	0,88	0,84
Firing Capacity Boiler	**[kW]**	**26.659**	**17.700**	**3.262**
Inlet Engine / Turbine	[bar abs.]	40,0	60,0	25,0
Inlet Engine / Turbine	[°C]	420	dry sat.	260
Outlet Engine / Turbine	[bar abs.]	0,8	11,0	1,5
Output at Generator Terminals	**[kWel]**	**4.830**	**1.000**	**333**
Exhaust Steam Heat	**[kWth]**	**18.000**	**13.500**	**2.330**
El. Efficiency (gross) related to fuel input		**18,1%**	**5,6%**	**10,2%**
Exhaust Steam Temperature	[°C]	93	185	111
Exhaust Steam Utilization		District Heating	Process	Process and Heating

Electricity as valuable by-product

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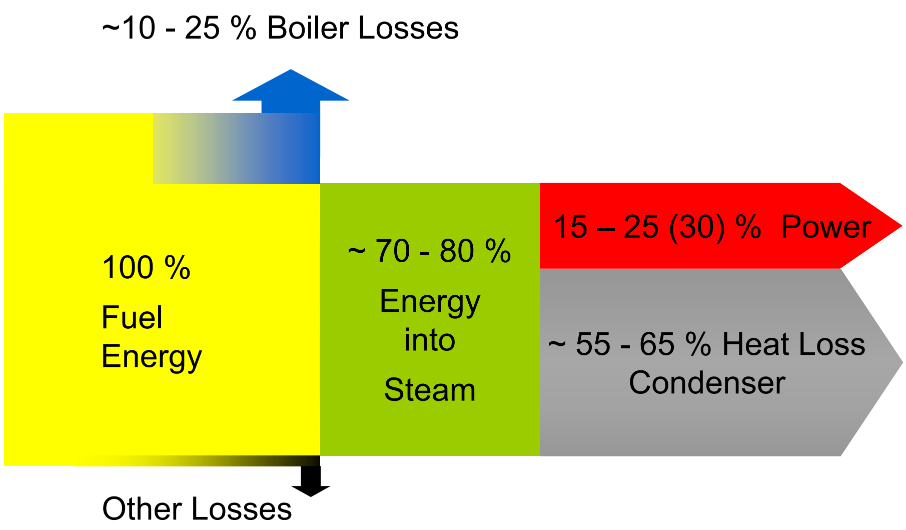
Pure Electricity Production



Sankey Diagram of Biomass Condensing Steam Power Plant

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Example for Vacuum Condensing Power Generation

Examples for Energy Balances: Biomass Steam Power Generation		
Case		**1**
Primemover		**Turbine**
Design / Type		**Multi Stage**
Steam Pressure Boiler Outlet	[bar abs.]	42
Steam Temperature Boiler Outlet	[°C]	425
Fuel		solid biomass
Steam Procution	**[t/h]**	**30,0**
Stecific Heat Demand for Steam Prorduction	[kWh/t]	782
Steam Heat Capacity Boiler	[kW]	23.460
Boiler Efficiency		0,88
Firing Capacity Boiler	**[kW]**	**26.659**
Inlet Engine / Turbine	[bar abs.]	40,0
Inlet Engine / Turbine	[°C]	420
Outlet Engine / Turbine	[bar abs.]	0,1
Output at Generator Terminals	**[kWel]**	**6.700**
El. Efficiency (gross) related to fuel input		**25,1%**
Exhaust Steam Temperature	[°C]	46
Exhaust Steam Utilization		none

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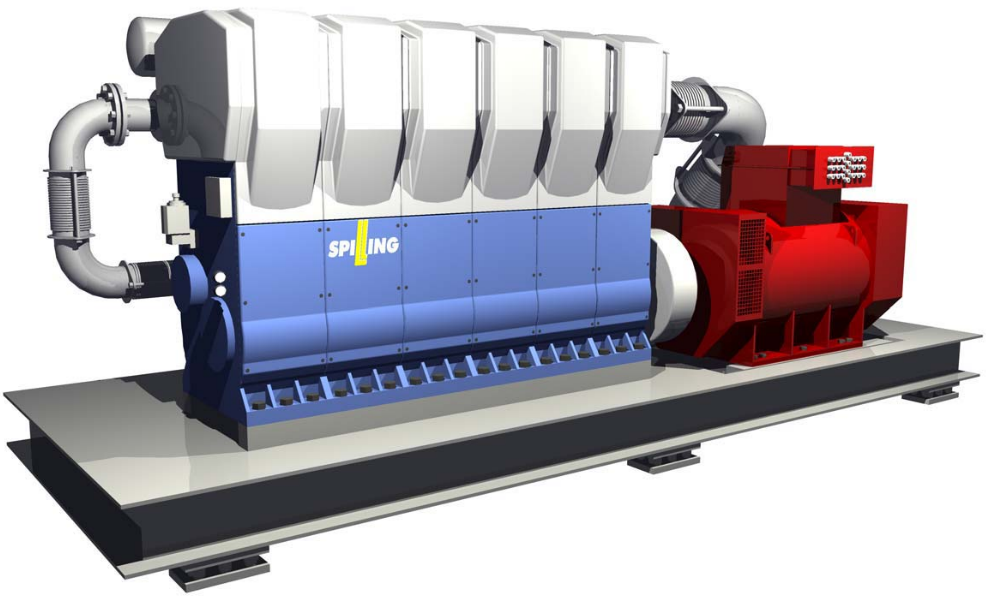
Spilling Steam Power: Engines and Turbines

The Spilling Steam Engine: Modular Design



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The Spilling Steam Engine

Design Features:

- modular design

  (from 1 to 6 cylinders; 15 different piston diameters)
- volumetric flow control: filling regulation
- oil free steam
- skid mounted engine set for flexible installation

SPILLING Energie Systeme GmbH

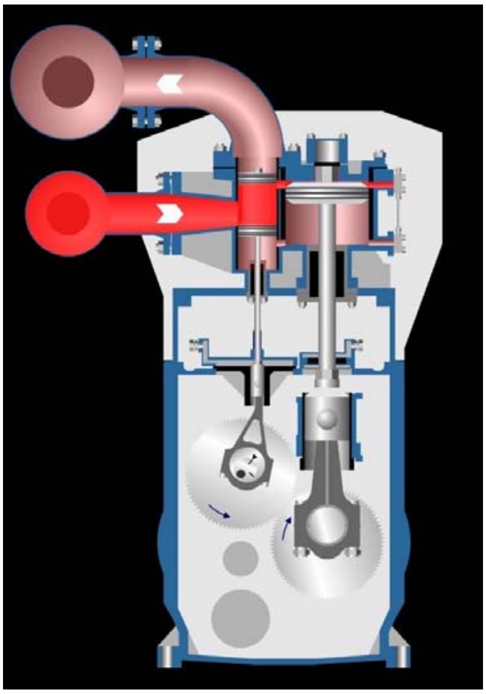
The Spilling Steam Engine

Key Figures and Facts

Power Output	up to ~ 1.200 kW
Steam Flow Rates	up to ~ 40 t/h
Live Steam Pressures	~ 6 to 60 bar
Back Pressures	up to ~ 15 bar

SPILLING Energie Systeme GmbH

Spilling Steam Engine

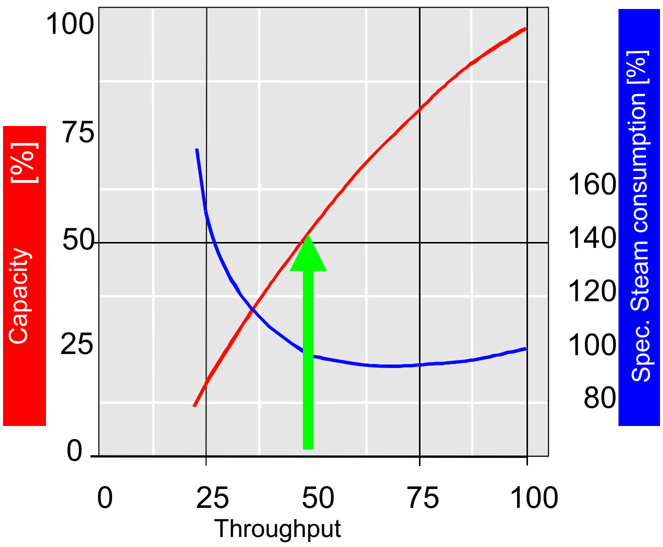


Animation Steam Engine

Spilling Energie Systeme GmbH

Spilling Steam Power: Engines and Turbines

Spilling Steam Engines: High Part Load Performance

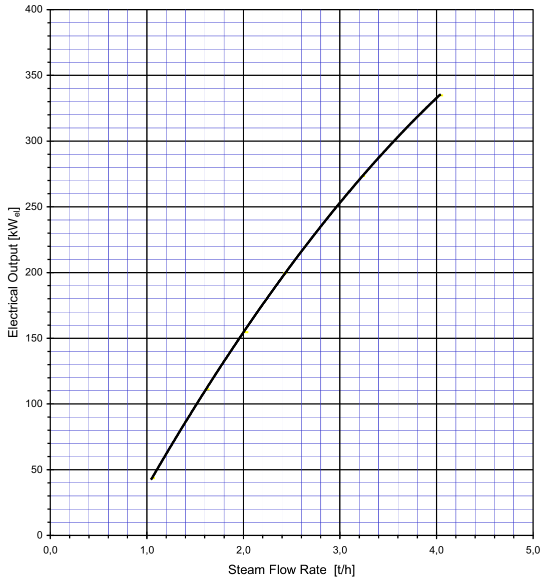


Spilling Energie Systeme GmbH

Spilling Steam Engines:

Example 4 t/h

Engine Type:		1/ 1-H12 TS
Number of Expansion Stages:		2
Number of Cylinders:		2
Speed:	[rpm]	1000
Generator Rating:	[kVA]	420
Voltage:	[V]	400
Frequency:	[Hz]	50
Boiler (Exit):	[barg] / [°C]	25,0/ 265
Inlet - Engine:	[barg] / [°C]	24,0/ 260
Outlet - Engine:	[barg]	0,5



Project: Example IEA - Workshop
Steam Engine Set

Chart: DA 14056
Name: Au
Date: 4.10.10

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Spilling Engine: Characteristics / Advantages:

- wide operation range
- high (partload) efficiencies
- good regulation behaviour at fluctuating live steam cond.
- good capability for saturated steam
- moderate requirements for boiler feed water treatment
- maintenance by local staff / technicians possible

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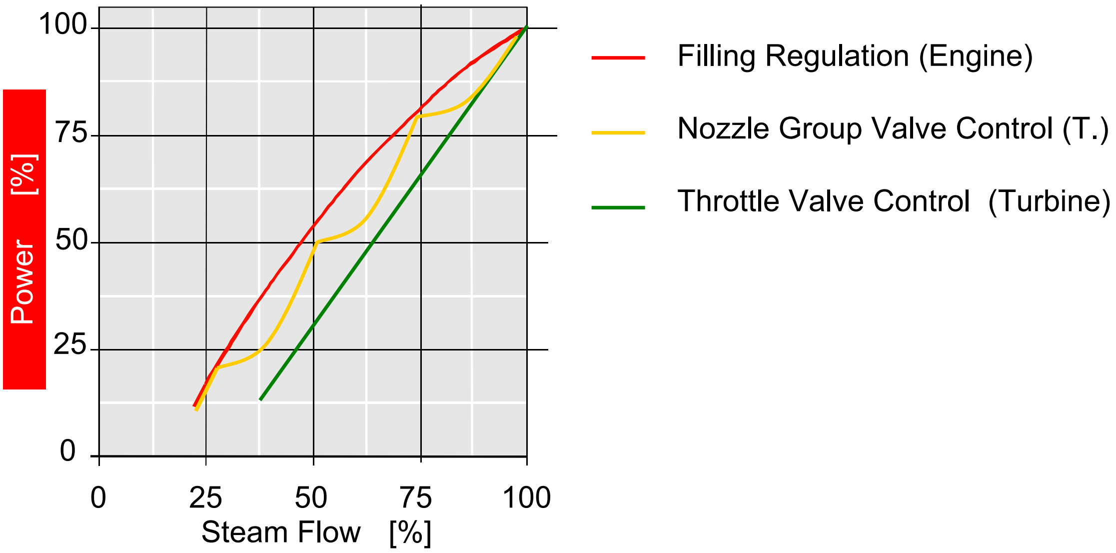
Comparision of Output Regulation Principles



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Example 1

Bio Sludge Incineration Plant (Netherlands)

Exhaust Steam Utilization for Boiler Feed Water Preheating and Space Heating

El. Output:	**514 kWel**
Live Steam Data:	**11 t/h / 8 bar / Saturated**
Steam Outlet Pressure:	**0,5 barg**

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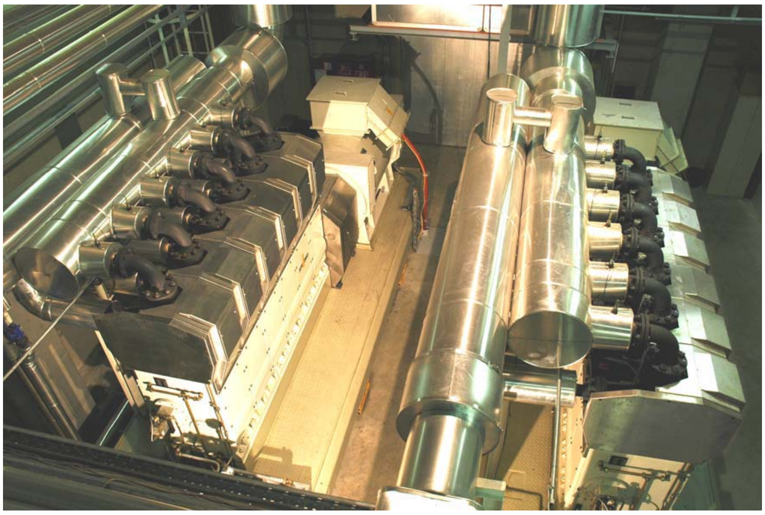
Example 2



**Wood Industry
Wood Residues Fired
Boiler Plant
(Austria)**

**Exhaust Steam
Utilization for Process
and Drying Kilns**

El. Output:	**2 x 1.000 kWel**
Live Steam Data:	**2 x 24 t/h / 60 bar / Saturated**
Steam Outlet Pressure:	**11 barg**

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Example 3

**Remote Power
Generation for
Saw Mill
(Congo)**

**with Wood fired
Steam Boiler**

El. Output:	**700 kWel**
Live Steam Data:	**9 t/h / 25 bar / 250 °C**
Steam Outlet Pressure:	**0,5 barg**

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Example 4

Power Generation in a Saw Mill (Australia)

with Wood Fired Steam Boiler

El. Output:	**425 kWel**
Live Steam Data:	**5,5 t/h / 34 bar / dry sat.**
Steam Outlet Pressure:	**1,0 barg**

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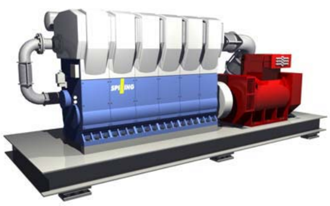
Spilling Steam Engines suit perfect in small scale co-generation applications with ...

- typical output range from 100 to 1.000 kWel
- fluctuating live steam conditions
- variable steam flow rates
- moderate live steam parameters



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Energie Systeme GmbH

Annex 6. State-of-the-art of ORC technology for biomass plants

Roberto Bini, Turboden SRL, Italy

Cod.10A08190

Expert workshop

Small scale biomass co-generation
Technology status and market opportunities

STATE OF THE ART OF ORC TECHNOLOGY FOR BIOMASS PLANTS

Roberto Bini – General Manager - Technical Area –Turboden srl - I

Copenhagen, October 7th 2010

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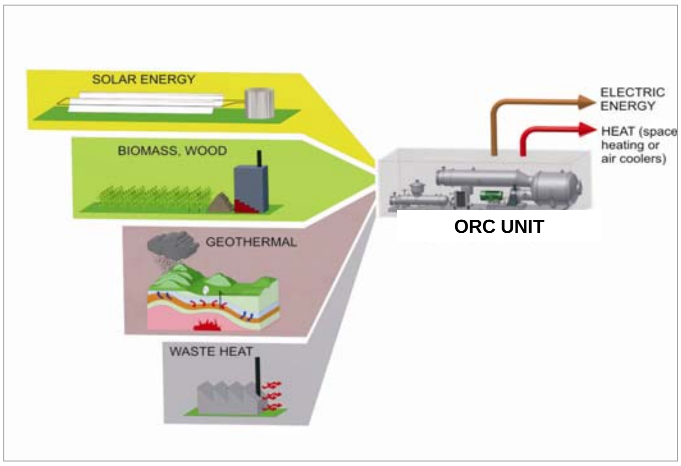
1. **Introduction & technology diffusion**
2. Biomass cogeneration and the Split System
3. Biomass fuels & applications
4. High electrical efficiency units and new developments

ORC application



- **standard size Turbogenerators: from 200 kW to 3 MW**
- **customized products: up to 10 MW**

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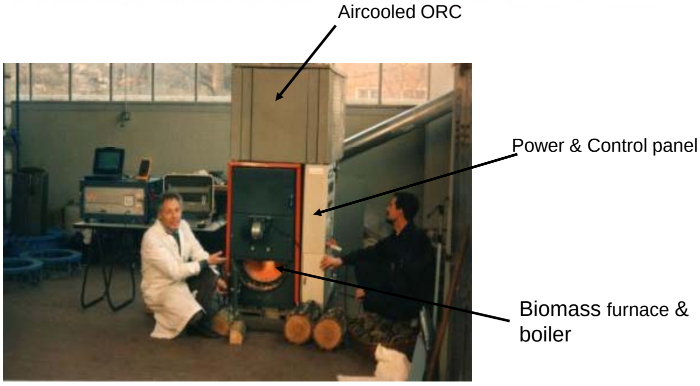
First ORC unit for biomass application. Turboden -1987



1987: A 3 kW_{el} CHP biomass ORC turbogenerator prototype in Milan

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Single skid ORC Turbogenerators

Typical single skid ORC unit for biomass cogeneration (~ 700 kWel)

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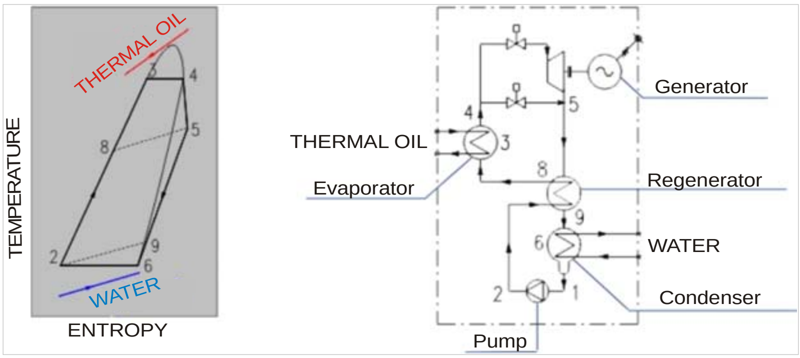
The Thermodynamic Principle: The ORC Cycle



The turbogenerator uses the hot temperature thermal oil to pre-heat and vaporize a suitable organic working fluid in the evaporator (8 3 4). The organic fluid vapor powers the turbine (4 5), which is directly coupled to the electric generator through an elastic coupling. The exhaust vapor flows through the regenerator (5 9) where it heats the organic liquid (2 8). The vapor is then condensed in the condenser (cooled by the water flow) (9 6 1). The organic fluid liquid is finally pumped (1 2) to the regenerator and then to the evaporator, thus completing the sequence of operations in the closed-loop circuit.

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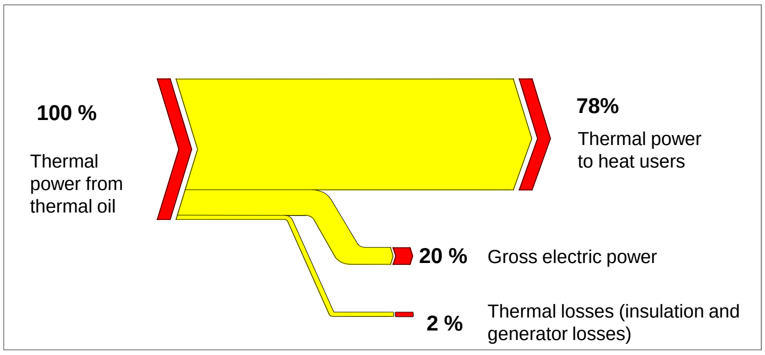
ORC Plants – Perfomances



➢Gross electric efficiency: nearly 20%, Overall energy efficiency: 98%

Starting from biomass and considering boiler efficiency, the overall electric efficiency becomes about 16%

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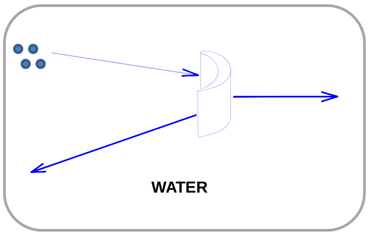
Why High Molecular Mass Working Fluid Instead of Water?

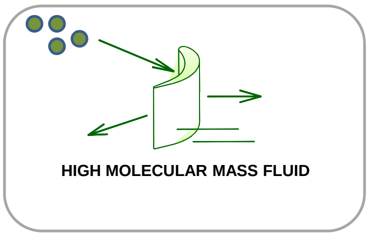
Water

- **Small, fast moving molecules**
- **Metal parts and blade erosion**
- **Multistage turbine and high mechanical stress**

Organic Fluid

- **Very large flow rate**
- **Larger diameter turbine**
- **No wear of blades and metal parts**





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Advantages of ORC Turbogenerators

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Technical advantages

- High cycle efficiency
- Very high turbine efficiency (up to 90%)
- Low mechanical stress of the turbine due to the low peripheral speed
- Low RPM of the turbine allowing the direct drive of the electric generator without reduction gear
- No erosion of blades, thanks to the absence of moisture in the vapor nozzles

Operational advantages / results

- Simple start-stop procedures
- Automatic and continuous operation
- No operator attendance needed
- Quiet operation
- High Availability (Admont – over 50,000 hours of operation, availability > 98%)
- Partial load operation down to 10% of nominal power
- High efficiency even at partial load
- Low O&M requirements: about 3-5 hours / week
- Long life

Layout – Some Examples

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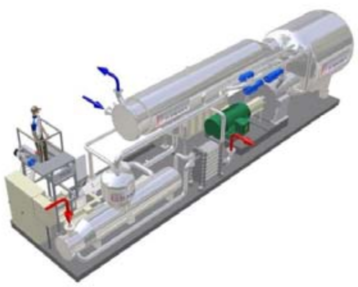
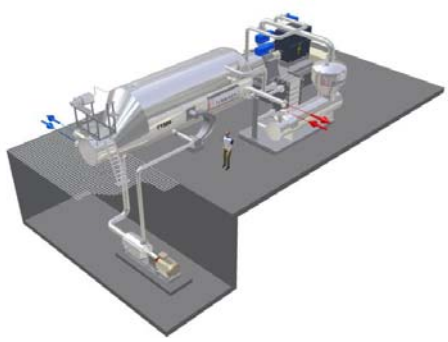
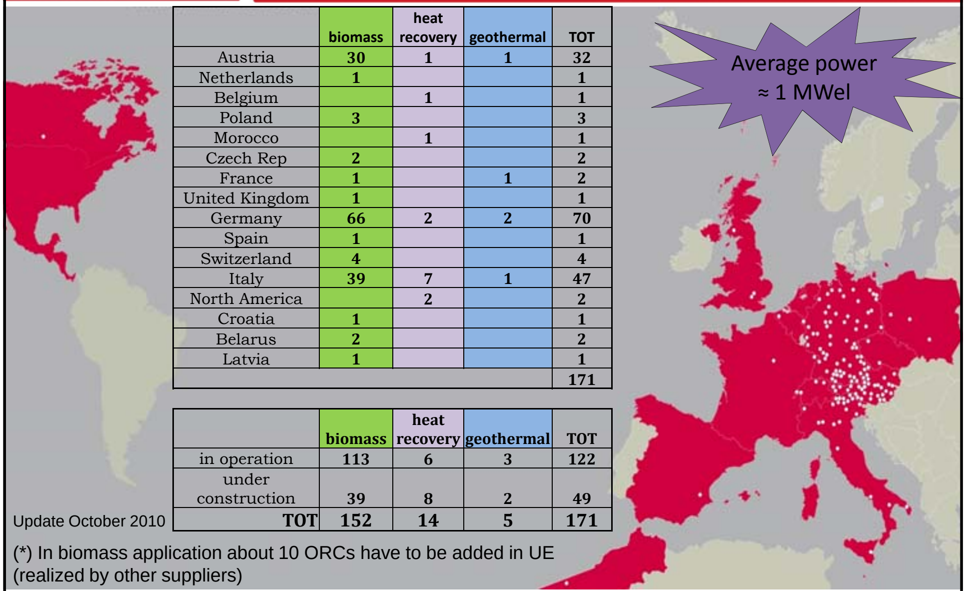


Single skid layout (< 700kWel)



Multiple skid layout (> 700kWel)

Map of ORCs installed by Turboden (*)

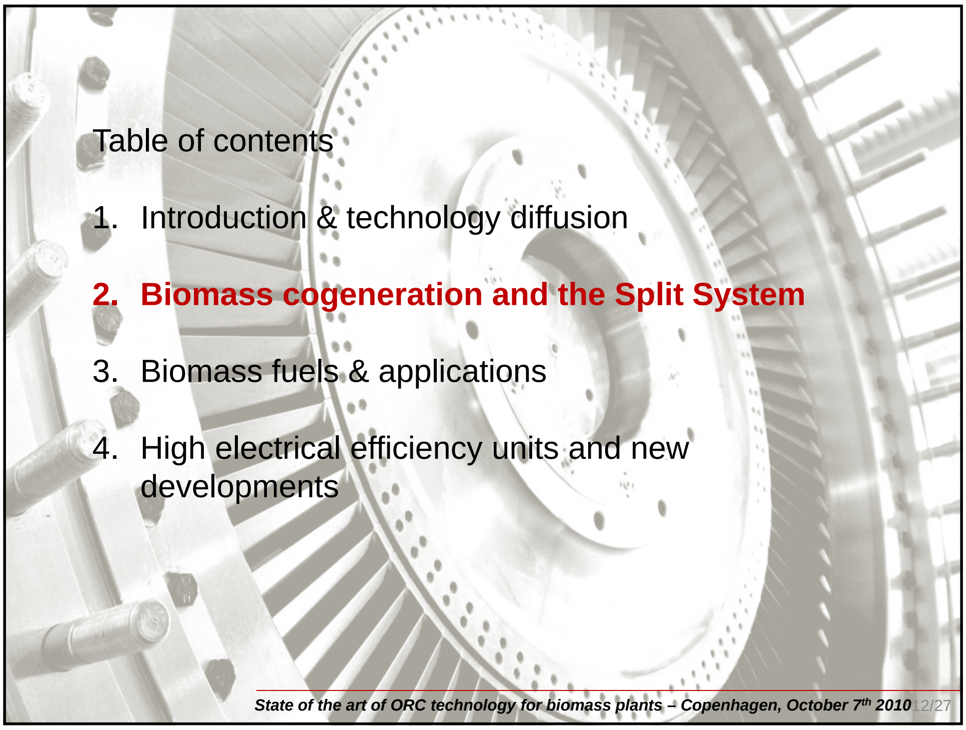


	biomass	heat recovery	geothermal	TOT
Austria	30	1	1	32
Netherlands	1			1
Belgium		1		1
Poland	3			3
Morocco		1		1
Czech Rep	2			2
France	1		1	2
United Kingdom	1			1
Germany	66	2	2	70
Spain	1			1
Switzerland	4			4
Italy	39	7	1	47
North America		2		2
Croatia	1			1
Belarus	2			2
Latvia	1			1
				171

	biomass	heat recovery	geothermal	TOT
in operation	113	6	3	122
under construction	39	8	2	49
TOT	152	14	5	171

Update October 2010

(*) In biomass application about 10 ORCs have to be added in UE (realized by other suppliers)



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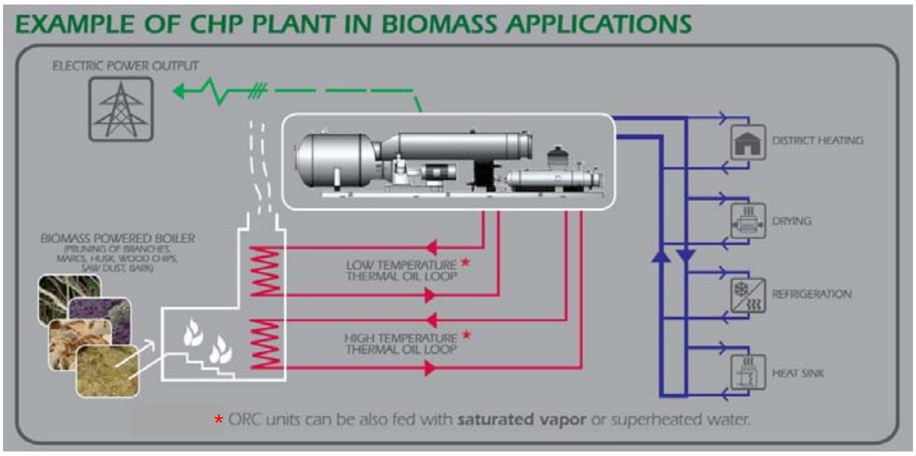
ORC Plant in a Process of Cogeneration from Biomass



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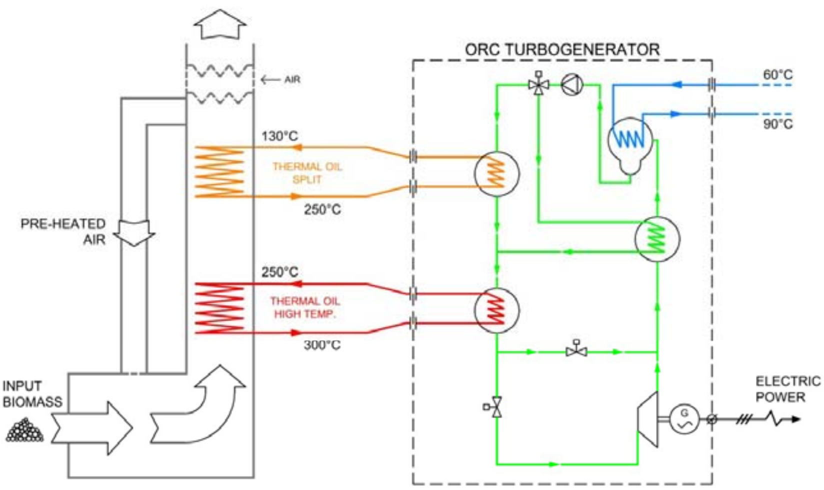
The Split System



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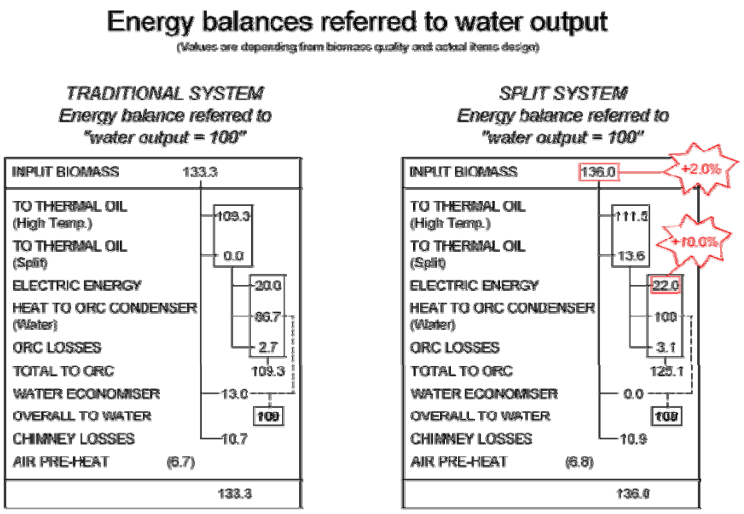
The Split System introduced in year 2000



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Biomass fuels & applications

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Fuels

- **Wood biomass: sawdust, woodchips, bark, treated wood**
- **Other biomass: dried sewage sludge, straw, green cuttings, rice husk, etc.**
- **Waste material**

Heat Consumers

- **Timber drying in sawmills**
- **Saw dust drying in wood pellet factories**
- **Air pre-heating in MDF industry**
- **District Heating networks**
- **Refrigeration**
- **Greenhouses**

ORC Application in Sawmills

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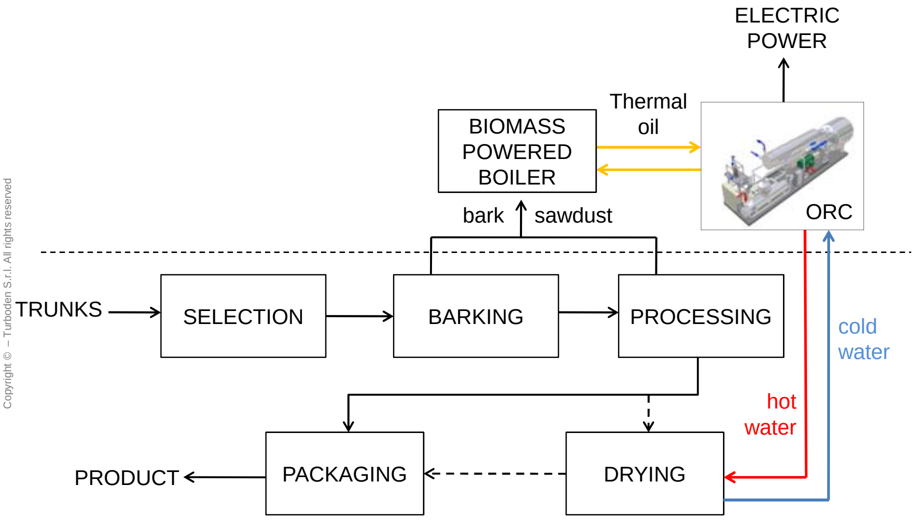
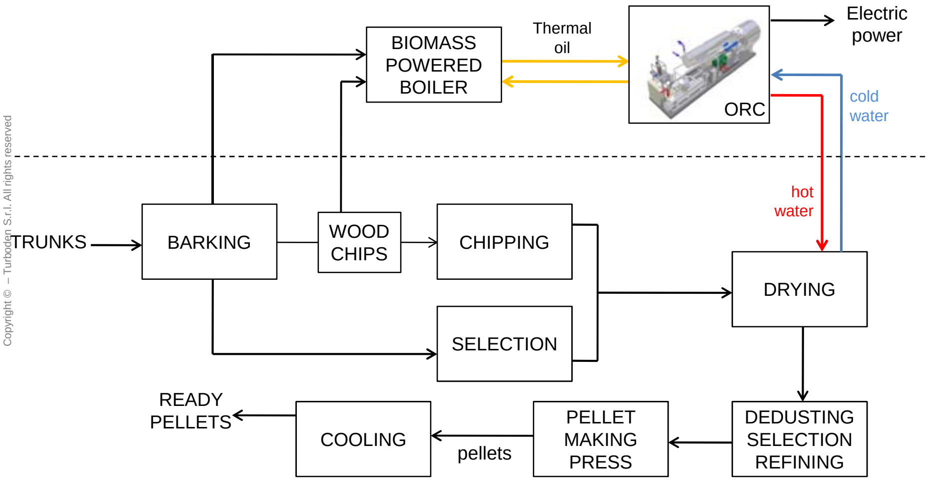


CHP Applications: Wood Pellet Production with ORC



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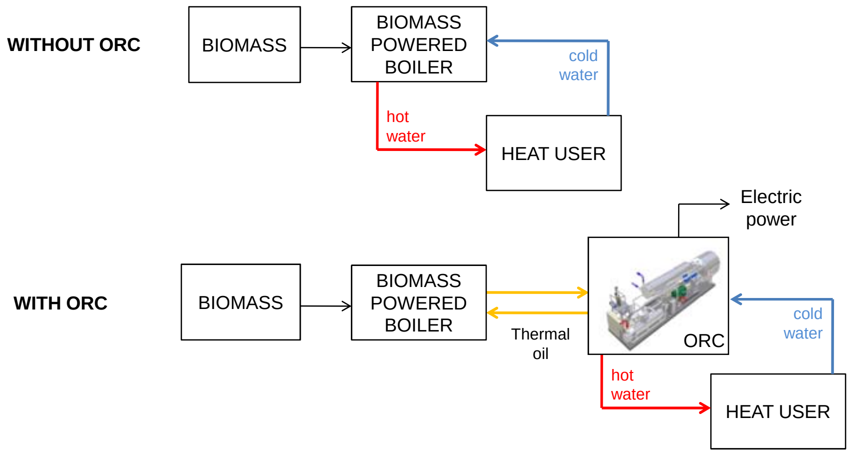
CHP – District Heating Networks



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1. Introduction & technology diffusion
2. Biomass cogeneration and the Split System
3. Biomass fuels & applications
4. **High electrical efficiency units and new developments**

High electrical efficiency ORC units

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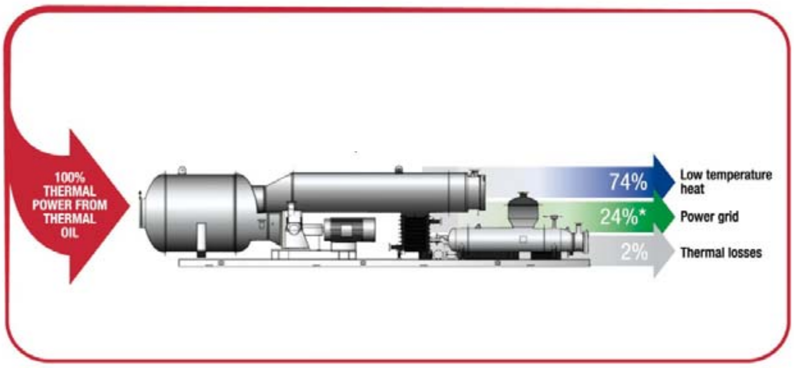
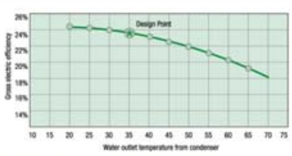
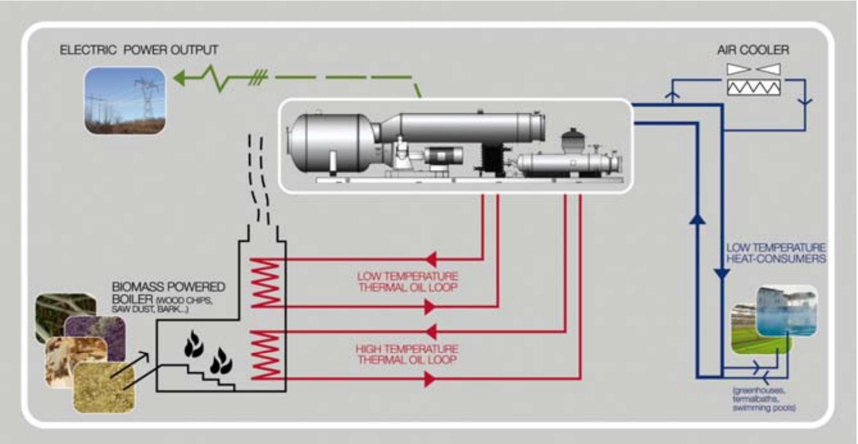




Gross performance of the Turboden HRS modules at various condensation water temperatures

High electrical efficiency ORC units



AVAILABLE SIZES: 1.2, 2.4 MWel

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High electrical efficiency ORC units

HRS for biomass application - Standard Sizes and typical performances

		TURBODEN 12 HRS		TURBODEN 24 HRS	
		Pel=1156 kW with Split* standard conditions	Pel=1188 kW without Split standard conditions	Pel=2269 kW with Split* standard conditions	Pel=2342 kW without Split standard conditions
INPUT - Thermal oil					
Nominal temperature "HT" loop (in/out)	°C	305/210	305/206	300/214	300/211
Thermal power input "HT" loop	kW	4425	4817	8850	9634
Nominal temperature "LT" loop (in/out)	°C	210/130	-	214/130	-
Thermal power input "LT" loop	kW	392	-	784	-
Overall thermal power input	kW	4817	4817	9634	9634
OUTPUT - Cooling water					
Cooling water temperature (in/out)	°C	25/35	25/35	24/37	24/37
Thermal power to the cooling water	kW	3586	3556	7212	7143
PERFORMANCES					
Gross electric power	kW	1156	1188	2269	2342
Gross electric efficiency		24,0%	24,7%	23,6%	24,3%
Captive power consumption	kW	46	49	89	94
Net active electric power output	kW	1110	1139	2180	2248
Net electric efficiency		23,0%	23,6%	22,6%	23,3%
Electrical generator		asynchronous triphase, L.V.	asynchronous triphase, L.V.	asynchronous triphase, M.V.	asynchronous triphase, M.V.
Plant size		multiple skid	multiple skid	multiple skid	multiple skid
Biomass consumption**	kg/h	2105	2316	4211	4632

(*) The Turboden split system allows maximizing power production for a given biomass consumption.
(**) Assuming a low heat value of biomass = 2,6 kWh/kg and boiler efficiency = 0,88 in case of ORC with split , = 0,80 in case of ORC without split. The thermal oil boiler is not included in the Turboden scope of supply.

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New developments of high efficiency ORC units

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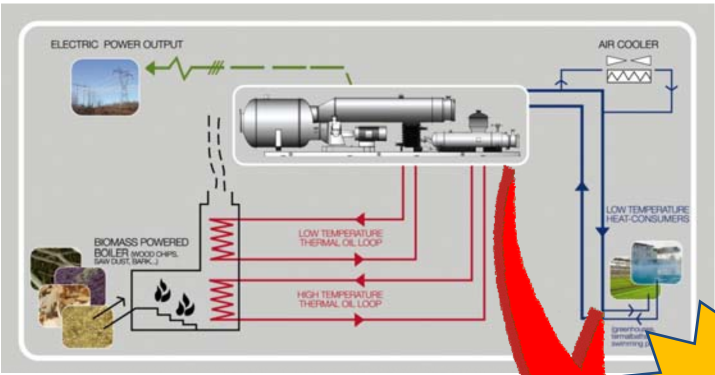

Plus possibility of 60 - 80°C water cogeneration fraction!

Biomass

New developments of high efficiency ORC units

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With new ORC units today it is possible to produce:

1000 kWel

	Electricity Net efficiency	plus	Cogenerative fraction water (60-80°C)	plus	Waste heat (or low temp. utilization) water (25-35°C)	Operation
CHP unit	16.5%		70%		/	Fully cogenerative
HRS unit operated at different conditions	20.4%		0%		66%	Power only
HRS unit operated at different conditions	19%		9%		58.5%	Partially cogenerative
HRS unit operated at different conditions	16.2%		20%		50.3%	Partially cogenerative

Efficiencies are referred to biomass input = 100% with a boiler efficiency of 88% (with split system) and include air coolers consumption (water pumps and fans) if present


Thank you for your attention!
Roberto Bini – General Manager -Technical Area –Turboden srl - I

Annex 7. Downdraft gasification with gas engine

Herbert Gemperle, Pyroforce, Switzerland

SWISS ENERGY TECHNOLOGY

www.PYROFORCE®.ch

– WE ARE ENERGY!

Herbert Gemperle
Geschäftsleiter / Managing Director

PYROFORCE®-Technology

PYROFORCE Energietechnologie AG
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CH – 6020 Emmenbrücke
www.pyroforce.ch

GemperlePartners AG
Engineering & Consulting
Reusseggstrasse 17
CH – 6020 Emmenbrücke
www.gemperlepartners.ch

Gliederung

- Hintergrund
- Verfahrensbeschreibung – Grundlagen
- Erfahrungen und technische Umsetzung
- Entwicklung
- Anlagenbeispiele
- Fazit

Die PYCON – erfolgreiche Zusammenarbeit

PYROFORCE Energietechnologie AG

- entwickelte einen teerarmen Festbett-Gleichstrom Reaktor für Wald-, Rest- und Abfallholz in der Leistungsgrösse 150 kW_{el} bis 170 kW_{el}

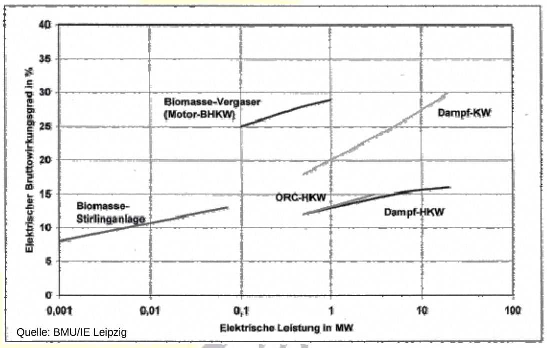
CTU – Conzepte Technik Umwelt AG

- entwickelte das zugehörige Trocken-Synthesegasreinigungssystem um die Emissionsstandards für Wald-, Rest- und Abfallholz einzuhalten und den Gasmotor (BHKW) im Holzgasbetrieb vor Beschädigungen zu schützen.

Nach mehrjähriger gemeinsamer Entwicklungsarbeit, gründeten die beiden Technologieunternehmen im Jahre 2006 eine gemeinsame Vertriebsgesellschaft. Die PYCON Pyroforce Conzepte AG hat zum Ziel und Zweck, die Unternehmenssynergien auszubauen, den gemeinsamen internationalen Vertrieb aufzubauen, und gegenüber dem Kunden als alleiniger Ansprechpartner aufzutreten.

Warum thermochemische Vergasung?

- Produktion von CO_2 neutraler und nachhaltiger Energie
- Holz ist ein idealer Energieträger, mit regionaler Verfügbarkeit, aus dem sich mittels Vergasungs-technologie ein hochwertiges Gas gewinnen lässt.
- Klassische Biomasseverstromung ist erst ab ca. 5 MW_{el} wirtschaftlich interessant (Dampfprozesse).



Quelle: BMU/IE Leipzig

→ Holzvergasung eignet sich für kleinere dezentrale Energieversorgung
→ eine besondere Vorteilhaftigkeit ergibt sich für den Einsatz von Altholz
→ Kommunen, Gewerbe- und Industriebetriebe können Ihre eigen CO2 - neutrale Energieversorgung sicherstellen
→ Nachhaltige Einflussfaktoren für die regionale Wirtschaft

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Hintergrund

5

Definition

VERGASUNG:

THERMOCHEMISCHER PROZESS ZUR UMWANDLUNG BIOGENER FESTBRENNSTOFFE (KOHLENSTOFFHALTIGER VERBINDUNGEN) IN EINEN GASFÖRMIGEN ENERGIETRÄGER.

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Verfahrensbeschreibung - Grundlagen

6

Fakten und Zahlen 1 / Facts and Figures 1

- 15 Jahre Forschung & Entwicklung
- Gleichstrom Festbett Vergaser 150 kWel, Holzverbrauch ca. 135 kg/h (atro 15%), ca. 1-2 % Asche
- Trockene Gasreinigung, Adsorbensverbrauch ca. 0.5 kg/h/Reaktor und ca. 0.5l/h/Reaktor RME
- 5 Anlagen erstellt:
- - Emmen 80 kWel, 3‘500 Std.
- - Spiez 130 kWel, 17‘000 Std.
- - Güssing 300 kWel, 6‘000 Std.
- - Stans I 600 kWel, 7‘500 Std.
- - Stans II 600 kWel, 13‘000 Std.

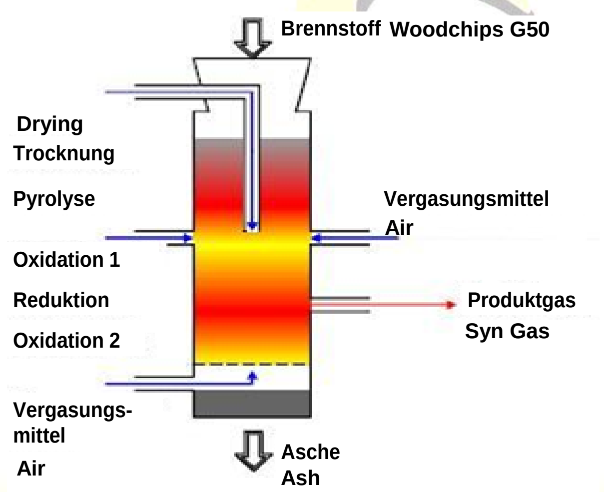
- 15 Years reserch & development
- Fixedbed cocurrent flow gasifire, wood cons. Ca. 135 kg/h (drysubstance), ca. 1-2% ash
- Dry gascleaning, calcium carbonate ca. 0.5 kg/h/reactor, and RME 0.5 l/h/r
- 5 plants well-built:
- - Emmen 80 kWel, 3‘500 hrs.
- - Spiez 130 kWel, 17‘000 hrs.
- - Güssing 300 kWel, 6‘000 hrs.
- - Stans I, 600 kWel, 7‘500 hrs.
- - Stans II, 600 kWel, 13‘000 hrs.

Fakten und Zahlen 2 / Facts and Figures 2

- Erwartung > 7‘500 Std./a, Stans II mit neuer Automation Juni-Sept. 2‘700 Std. (97%)
- 100% Automatikbetrieb mit Fernwartung
- 1 Arbeitskraft / 600 kWel
- Wartung und Unterhalt zu 90% keine Abschalten der Anlage

- Forecast > 7‘500 hrs/y, Stans II since new automation june-sept. 2‘700 hrs. (97%)
- 100% automatic operating with remote maintenace
- 1 operator / 600 kWel
- Servicing and maintenance 90% without shutdown of the plant

Gasreaktor / gasifire



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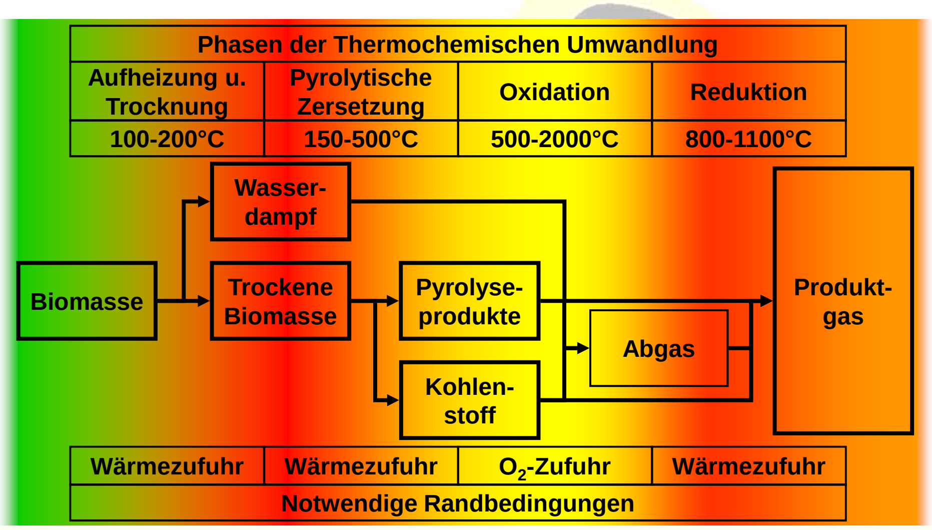
Teilprozesse der Vergasung



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Verfahrensbeschreibung - Grundlagen

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Trocknung bei unter 200°C

Erwärmung des zu vergasenden Rohstoffs

↓

Trocknung

↓

Wasserdampf entsteht

↓ In der nachfolgenden Zone in der Wassergasreaktion umgewandelt

↓ Verlässt den Reaktor als gasförmige Komponente

Keine chemische Veränderung des Rohstoffs!
Struktur wird lediglich durch makro- und mikroskopische Risse verändert

Pyrolyse bei 200 bis 500°C

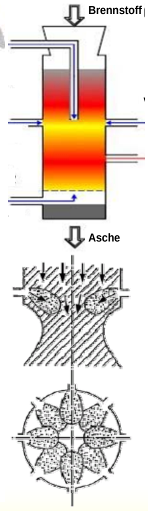
- Makromolekulare Bestandteile werden thermisch und unter Luftabschluß zerlegt
- **Entstehung von:**
  - Kohlenwasserstoffverbindungen
  - Pyrolyse-Öle
  - Pyrolysekoks
- **Ablauf hängt ab von:**
  - Temperatur
  - Anheizgeschwindigkeit
  - Größe der Brennstoffpartikel
- Teerkonzentration in dieser Zone sehr hoch

Oxidation bei 500 bis 2000°C

- Gasförmige, flüssige und feste Produkte der Pyrolyse reagieren mit Sauerstoff
- Koks und Teil der höheren Kohlenwasserstoffverbindungen werden in kleinere gasförmige Moleküle gespalten
- Partielle Verbrennung von Kohlenstoff
- Wichtigste, in dieser Zone ablaufende Reaktionen:

$CO + \frac{1}{2} O_2 \leftrightarrow CO_2$ $\Delta H = -283{,}0$ kJ/mol

$H_2 + \frac{1}{2} O_2 \leftrightarrow H_2O$ $\Delta H = -285{,}9$ kJ/mol



Reduktion bei 800 bis 1100°C

Boudouard-Reaktion:

$C + CO_2 \leftrightarrow 2CO$ $\Delta H = 159{,}9$ kJ/mol

Heterogene Wassergas-Reaktion:

$C + H_2O \leftrightarrow CO + H_2$ $\Delta H = 118{,}5$ kJ/mol

Homogene Wassergas-Reaktion:

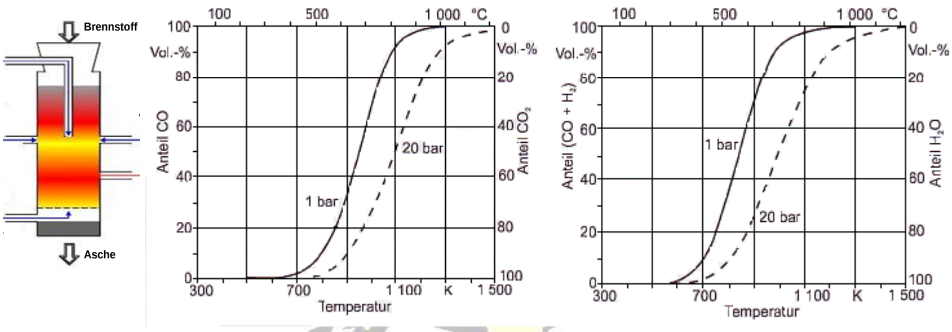
$CO + H_2O \leftrightarrow CO_2 + H_2$ $\Delta H = -40{,}9$ kJ/mol

Methan-Reaktion:

$C + 2H_2 \leftrightarrow CH_4$ $\Delta H = -87{,}5$ kJ/mol

Gleichgewichtskurve bei Boudouard- und heterogener Wassergas Reaktion

PYROFORCE



Quelle: M. Kaltschmitt, Energie aus Biomasse

Links: CO/CO_2-Gleichgewicht (Boudouard-Reaktion)

Rechts: $H_2O/CO/H_2$-Gleichgewicht (heterogene Wassergas-Reaktion)

Verfahrensbeschreibung - Grundlagen

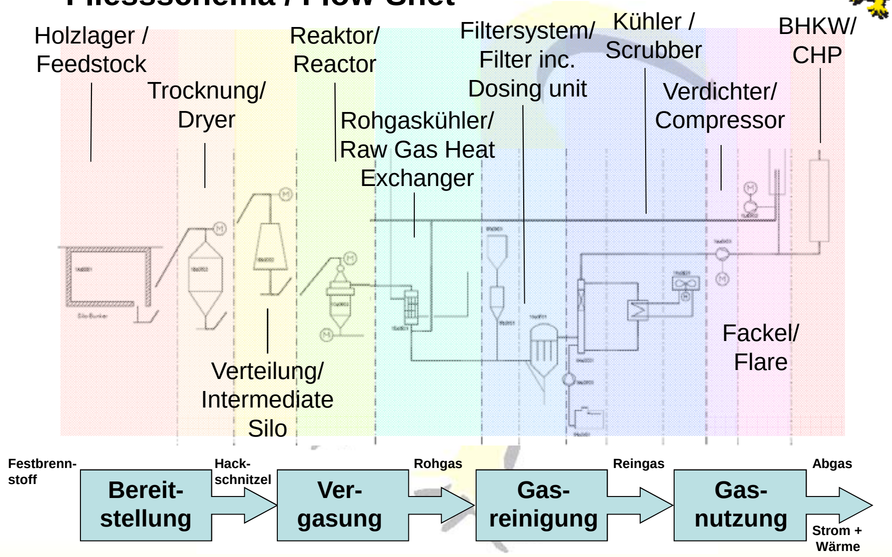
Produktgases / Syngas

PYROFORCE

Gaskomponente [Vol-%]	Vergasungsmittel		
	Luft	Luft/O_2 (80 %)	Wasserdampf
CO	10–20	40–50	25–47
H_2	9–20	9–17	35–50
CH_4	1–8	< 1	14–25
CO_2	10–20	19–25	9–15
N_2	40–55	15–30	2–3
Heizwert [MJ/m^3_N]$_{tr}$	4–6,5	7–9	12–17

Quelle: FNR, Schriftenreihe „Nachwachsende Rohstoffe“ Band 29

Fliessschema / Flow-Shet



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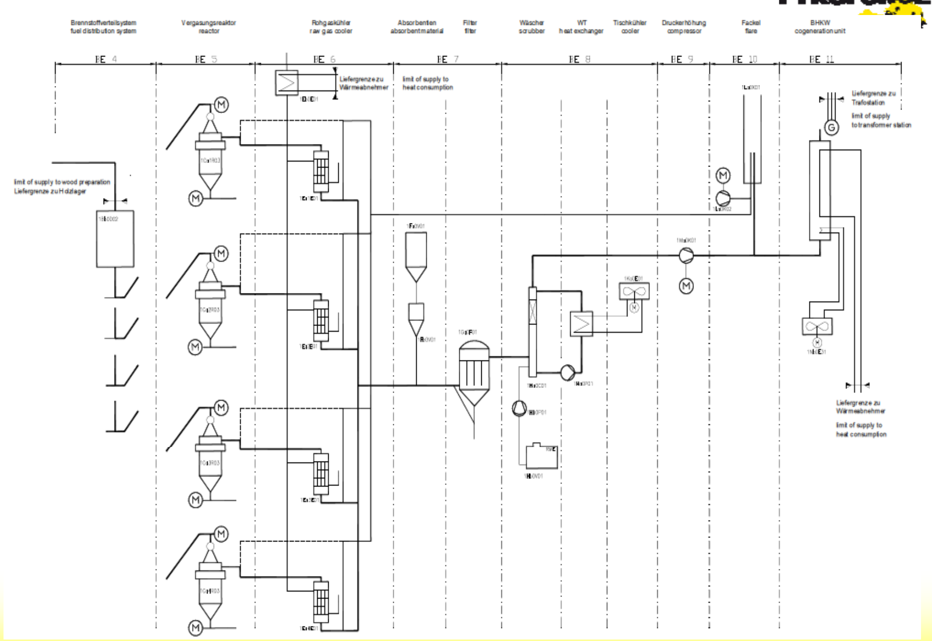

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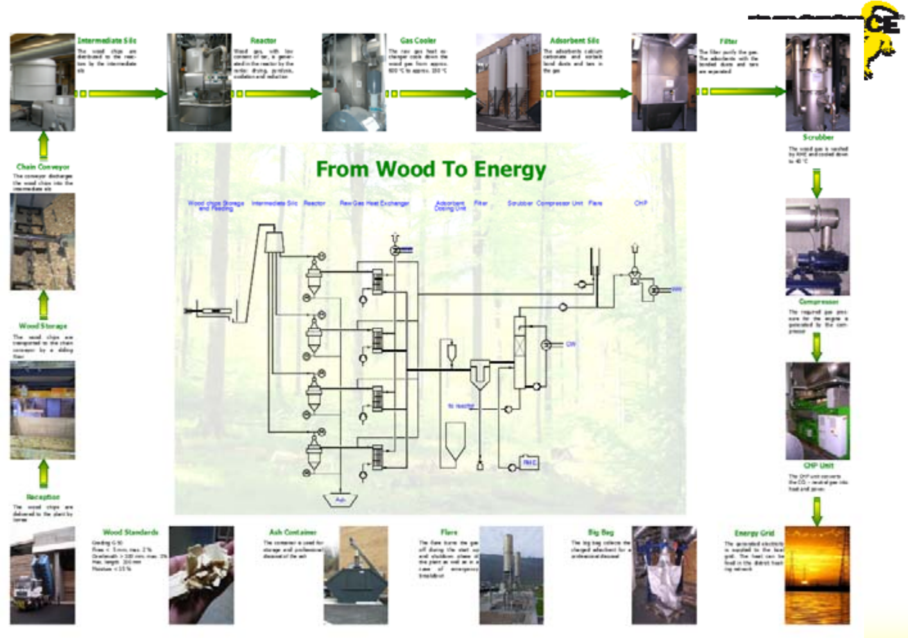

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Brennstofflogistik / Feedstock logistic

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Holzqualität entscheidet / Woodquality is relevant

Stückigkeit					
	Hauptanteil: min. 80%	Feinanteil: max. 2%	Überlängen: max. 1%	Maximale Länge	Maximale Diagonale im Querschnitt
G 63	8 mm bis 63mm	Kleiner 5 mm	Grösser 100 mm	200 mm	30 mm

Und wenn die nicht stimmt / If it's not correct

Brennstofflagerung / Wood chips Storage

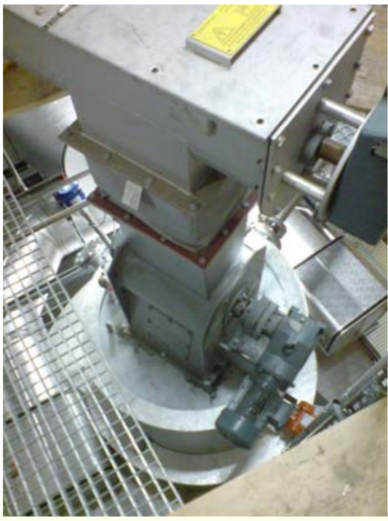



Brennstoffförderung /

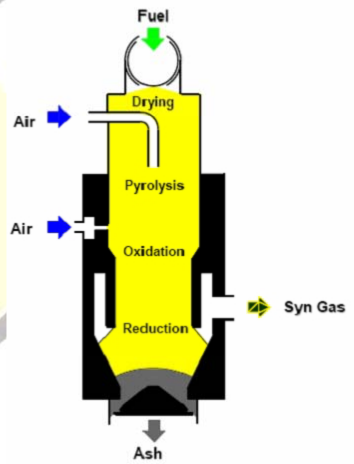



Brennstoffverteilung / Intermediate Silo

Brennstoffeinschleusung / Lock



Reaktor / Reactor



Ascheaustrag / Ash

+

=

+

Rohgaskühlung / Raw Gas Heat Exchanger



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Rohgaskühlung / Raw Gas Heat Exchanger




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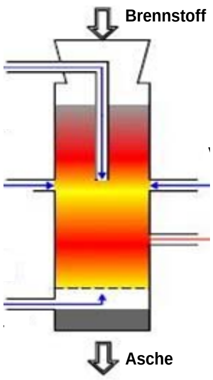
Kalkdosierung / Calcium Carbonat dosing unit

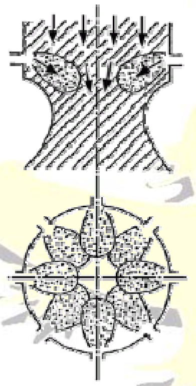
Gewebefilter / Baghouse Filter

PYROFORCE

Wäscherkühlung / Scrubber



REAKTOR

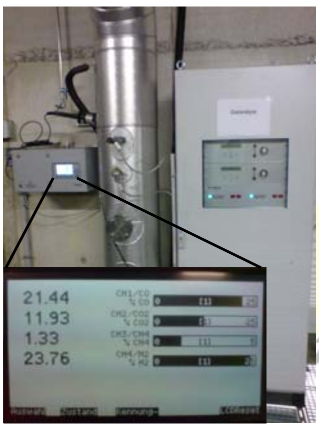


OXIDATIONSZONE

WÄSCHERKÜHLER

PYROFORCE

Gasanalyse, Druckerhöhung / Gasanalysis, Compr.

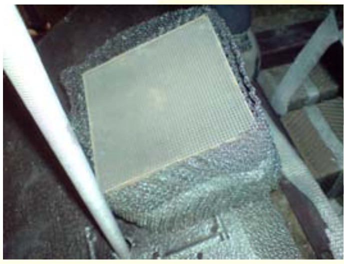


Gasdruckregelstrecke

Verfahren – techn. Umsetzung

BHKW / CHP

Abgasbehandlung / Exhaust Gas cleaning



Fackel / Flare

Druckluft- und Stickstofferzeugung

Spitzenlastabdeckung

Fernwärme / District heating

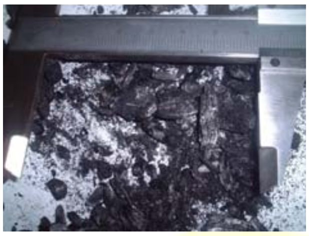
Die Ziele

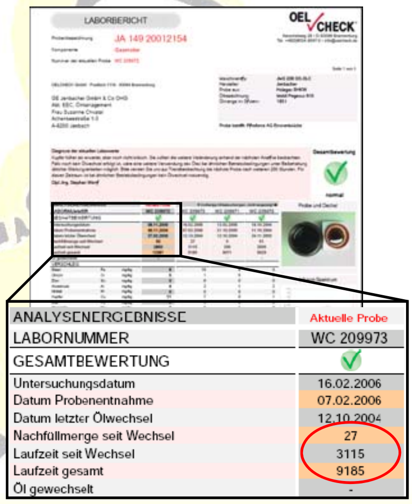
Die Entwicklung des PYROFORCE® - Verfahrens hat auf der Pilot- und Demonstrationsanlage in CH – Spiez stattgefunden

Unsere Zielsetzungen:

- Betriebssicherheit für Mensch, Umwelt und Anlage
- Einhaltung der gesetzlich vorgeschriebenen Emissionsgrenzwerte
- Reduktion der Abfall- und Reststoffe
- Vergasung diverser Holzarten- und Fraktionen
- Optimaler Betriebsmittelverbrauch
- Hohe Verfügbarkeit und Reduktion der Wartungsintervalle
- Erprobung von langzeittauglichem Equipment und Materialien
- Leistungssteigerung und Wirtschaftlichkeit
- Markttauglichkeit

Die Herausforderungen





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Entwicklung

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Der Weg

- Optimierung der Reaktorbauart
- Weitere Teerreduktion
- Verzicht auf Zyklon
- Modulare Bauweise
- Kompakte Anlagenmasse
- Reduktion der Reststoffe
- Hohe Energieeffizienz
- Wartungsarmer Betrieb
- Geringe Störanfälligkeit
- Einfachste Bedienung
- Weinig Personalaufwand
- Hohe Rentabilität

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Entwicklung

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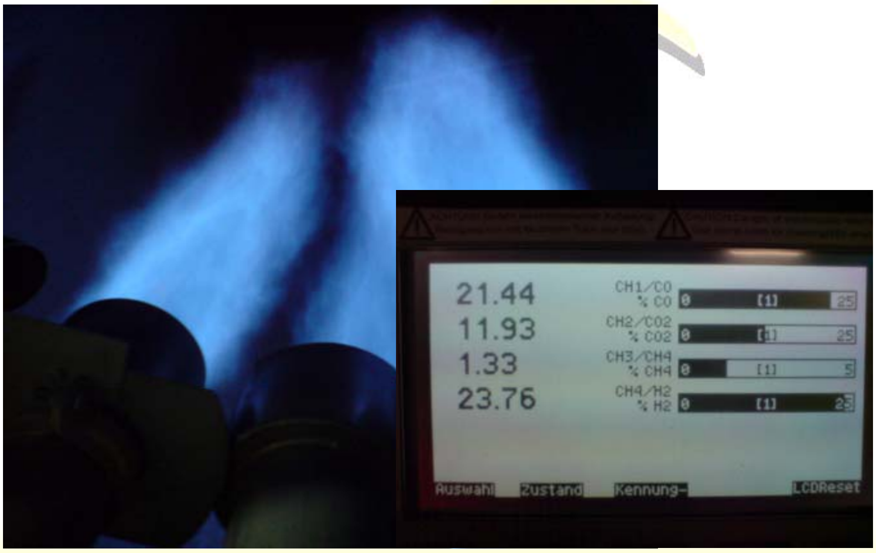
Der Erfolg mit Gas …



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… und Strom

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Die Zeugnisse

Anlagenmerkmale Spiez

Bauherrschaft	**Bundesamt für Verteidigung, Bevölkerungsschutz und Sport (VBS)**
Einbindung	100 % KWK Nutzung
Leistung elektrisch	130 kW, Abnehmer EW
Leistung thermisch (1) 70°C/90°C	175 kW, Abnehmer Bauherr, WW + HZ
Leistung thermisch (2) 145°C	80 kW, Abnehmer Anlage, Holztrocknung
Holzart-/qualität	Sägereirestholz und Waldhackgut G50
Holzverbrauch	0,8 kg/kWel @ atro 15
Adsorbensverbrauch	ca. 5 kg/h
Waschmedium / Verbrauch	Wasser / ca. 4 lit./h
Reststoff Rostasche	0,5 Gew%
Reststoff Zyklonasche	2,0 Gew%
Reststoff Filterasche	ca. 5 kg/h
Reststoff Kondensat	ca. 2 kg/h
Personalaufwand	0,3 MP / 1 Shift / d
Betrieb ohne Betreuung	Max. 3 d
BHKW Betriebsstunden	17´000 h
Wartungsintervalle	ca. 3´000 h

Anlage Spiez (CH) / Spiez plant (CH)

Anlagenmerkmale Güssing (A)

Bauherrschaft	Pyrotherm Kraftwerk Güssing GmbH
Einbindung	100 % KWK Nutzung
Leistung elektrisch	350 kW, Abnehmer EW
Leistung thermisch (1) 70°C/90°C	437 kW, Abnehmer Bauherr, FWHZ
Leistung thermisch (2) 115°C	140 kW, Abnehmer Bauherr, FWHZ
Holzart-/qualität	Restholz aus Parkettindustrie geschreddert
Holzverbrauch	0,9 kg/kWel @ < 11% atro
Adsorbensverbrauch	ca. 3,5 kg/h
Waschmedium / Verbrauch	RME / ca. 5 lit./h
Reststoff Rostasche	ca. 0,05 kg/h
Reststoff Zyklonasche	0,0 kg/h
Reststoff Kondensat	0,0 kg/h
Personalaufwand	1 MP / 1 Shift / d

Güssing (A)

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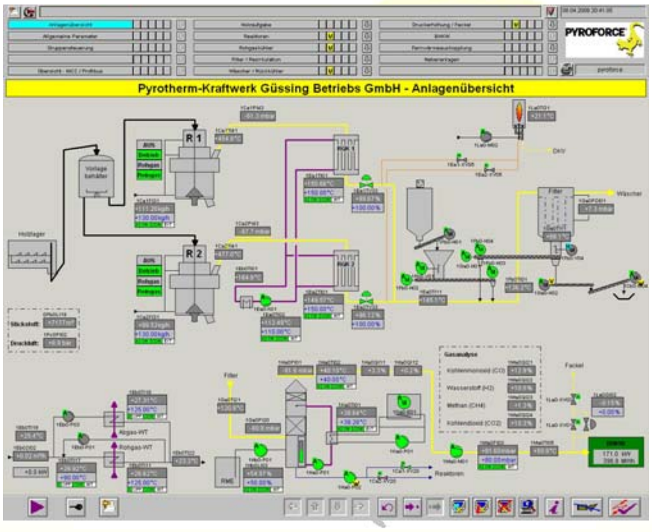
Güssing (A)



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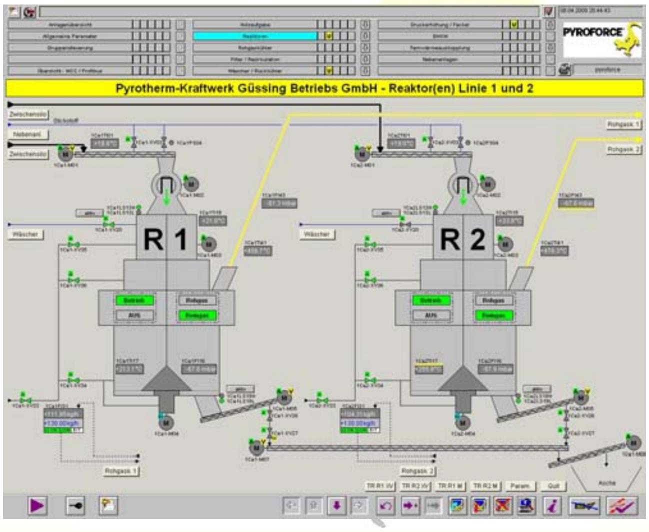
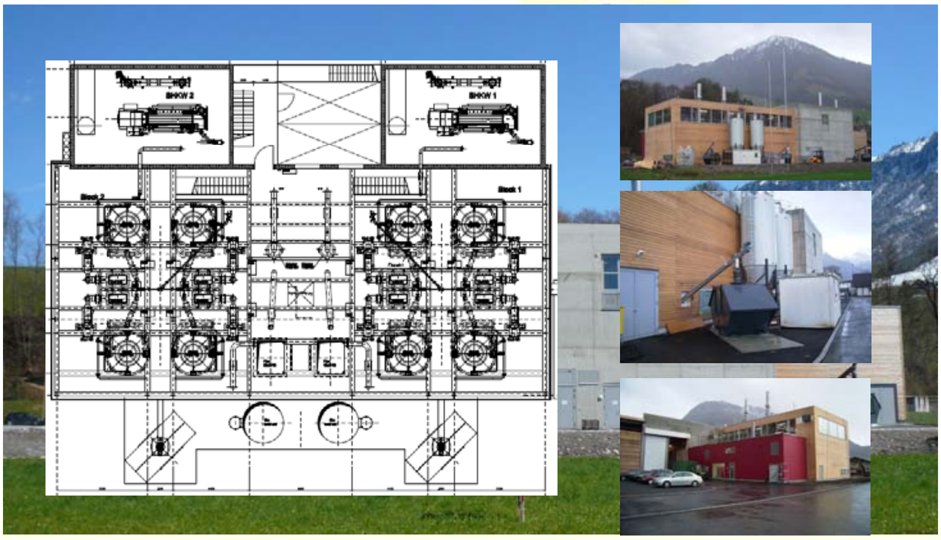
Reaktoren Güssing (A)



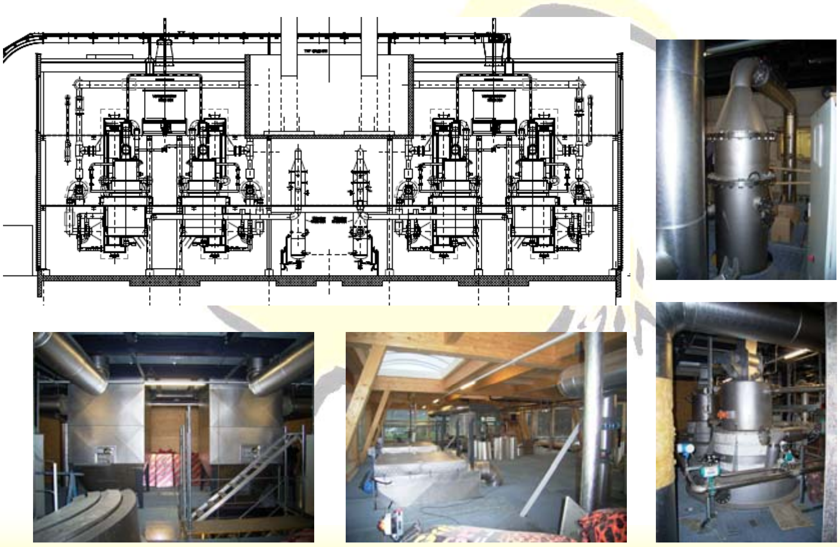
Anlagenmerkmale Nidwalden

Bauherrschaft	Genossenkorporation Stans
Einbindung	100 % KWK Nutzung
Leistung elektrisch	2 x 650 kW, Abnehmer EW
Leistung thermisch (1) 70°C/90°C	2 x 850 kW, Abnehmer Bauherr, FWHZ
Leistung thermisch (2) 70°C/90°C	2 x 280 kW, Abnehmer Bauherr, FWHZ
Holzart-/qualität	Altholz geschreddert
Holzverbrauch	0,9 kg/kWel @ < 11% atro
Adsorbensverbrauch	ca. 2 x 7 kg/h
Waschmedium / Verbrauch	Block 1: RME / ca. 7 lit./h
	Block 2: Wasser / ca. 7 lit./h
Reststoff Rostasche	Aktuell keine Angaben
Reststoff Zyklonasche	0,0 kg/h
Reststoff Kondensat	0,0 kg/h
Personalaufwand	2 MP / 1 Shift / d

Stans I + II (CH)



Stans I + II (CH)



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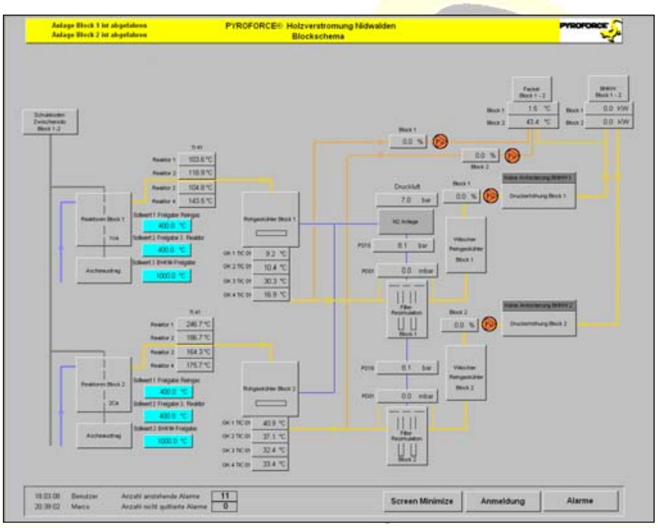
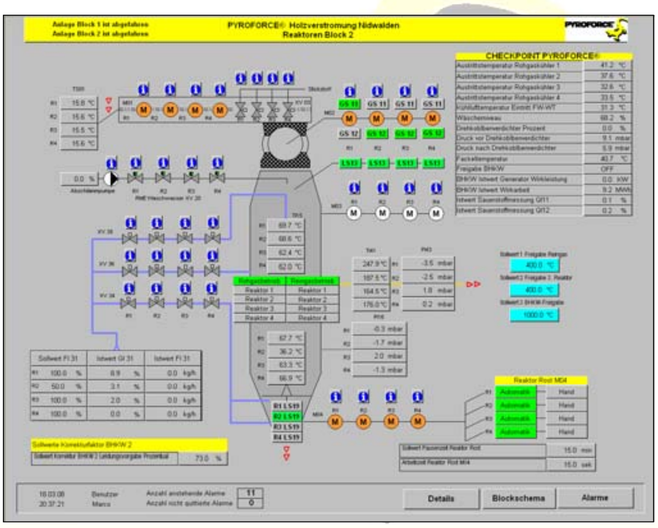


14. Dezember 2010

Anlagenbeispiele

57

Reaktorhauptseite



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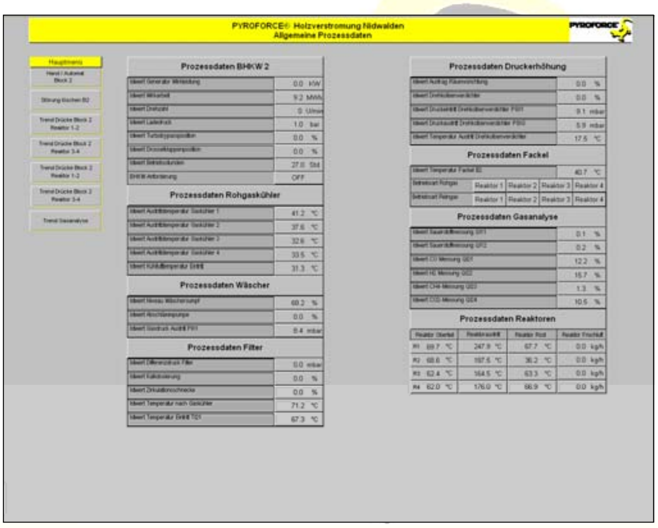
Anlagenbeispiele

58

Prozessdaten auf 2. Bildschirm



Fazit / Conclusion

Die PYROFORCE® Technologie ist wirtschaftlich umsetzbar
cost effectiv

Die PYROFORCE® Technologie gewährt Zusicherungen
allowd representations

- Stromleistung / El. power
- Wärmeleistung / Heat
- Wirkungsgrad / Efficiency
- Betriebsmittelverbrauch / Consumption
- Verfügbarkeit / operational availability

Selbstverständlich werden die Zusicherung nur bei Einhaltung der Technischen Anweisungen und der Unterhalt- und Wartungsvorschriften gewährt

Der Ausblick

Die Entwicklung des PYROFORCE® - Verfahrens ist nach erreichen der Marktreife natürlich nicht beendet. Unsere Forschung verfolgt aktuell folgende Ziele:

- Steigerung des Energiegehaltes im Reingas
- Kostenreduktion im Anlagenbau
- Entwicklung einer 1,4 MW Anlage ohne redundante BHKW
- Vergasung mit stickstoffarmer, vorgewärmter Luft
- uvm.

Gerne führen wir für Sie Machbarkeitsstudien und allfälliges Basic-Engineering aus.

Swiss Energy Technology

PYROFORCE®

Erfolgreich im Einsatz
Successful in operation

Annex 8. Updraft gasification with gas engine
Robert Heeb, Babcock & Wilcox Vølund A/S, Denmark

B&W vølund

Up-date on the Gasification Technology
October 2010
IEA Bioenergy

Robert Heeb

babcock & wilcox vølund

Facts at a glance

- ***Main office in Denmark***
- ***Founded in 1898***
- ***100% owned by The Babcock & Wilcox Power Generation Group Ltd., USA since 2000***
- ***350 employees***
- ***Turnover 100 million EUR***

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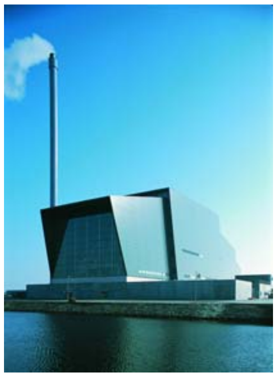
Main Business Areas

- Waste to energy systems
- Biomass energy systems
- Gasification

- After sales service
  - Refurbishment/rebuilding
  - Components/parts
  - Inspection/analysis



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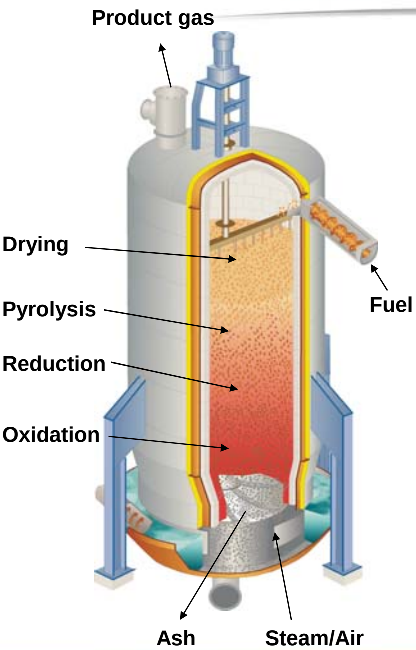

Up-draft gasification

Up-draft technology originally acquired from Dr. Gatzke

- A B&W Vølund research area since 1988

- Licensed to:
  - JFE Engineering Corp. - Japan

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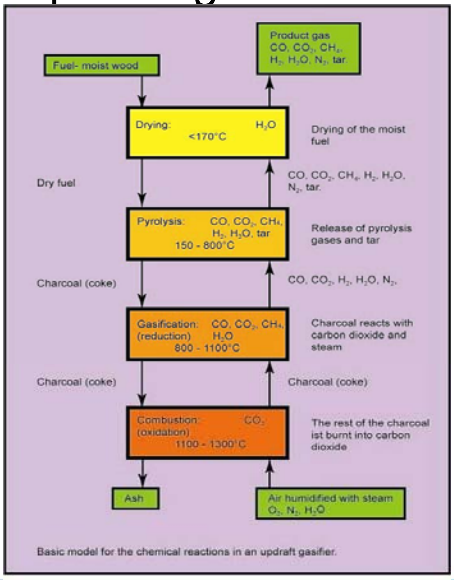
Up-draft gasification



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The Harboøre CHP plant

- First of a kind – focus on having the overall concept working – not optimization of the performance
- Fuel: Woodchips. Moisture content: 35-55 %
- 3.5 MW_{th} / 1 MW_e
- Commissioned in 1996
- CHP capability added in 2000
- Originally designed for district heating

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Experiences with up-draft gasifiers

- ***First pilot plant (1 MW) set up in 1989 at the Kyndby CHP.*** Dismantled.
- ***Mid 1990's: experiments on a 500 kW unit at Kommune Kemi – a Hazardous Waste facility.*** Dismantled.
- ***1993-96: Erection of the Harboøre plant.*** In operation.
- ***2006: Ansager plant - a 200 kW unit with a stirling engine.*** In operation.
- ***2007: Yamagata (8 MW_{fuel}/2 MW_{power}) plant in Japan by JFE.*** In operation.
- ***2008: Ishikawa (2,5MW_{power}) plant in Japan by JFE. In operation***
- ***2008 Daio paper 12MWth plant in Japan by JFE. In operation.***

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Operational status

- ***Gasifier operated for more than 120 000 hours***
- ***Gas engines operated more than 80 000 hours***
- ***More than 36 000 MWh supplied to the power grid***
- ***Present power production: more than 500 MWh per month***

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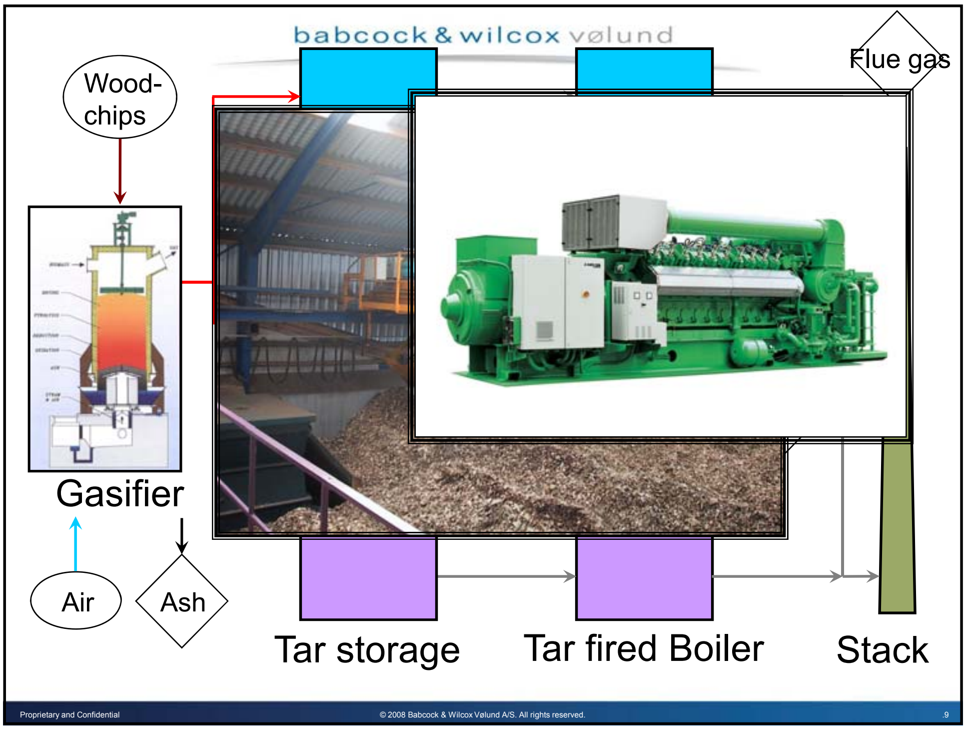

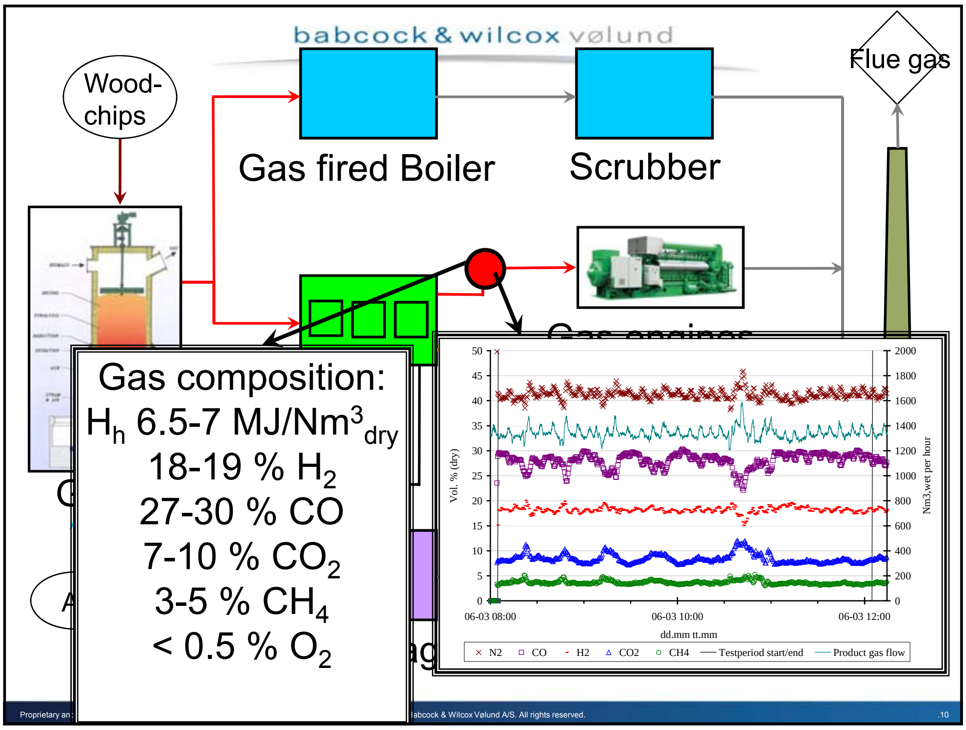

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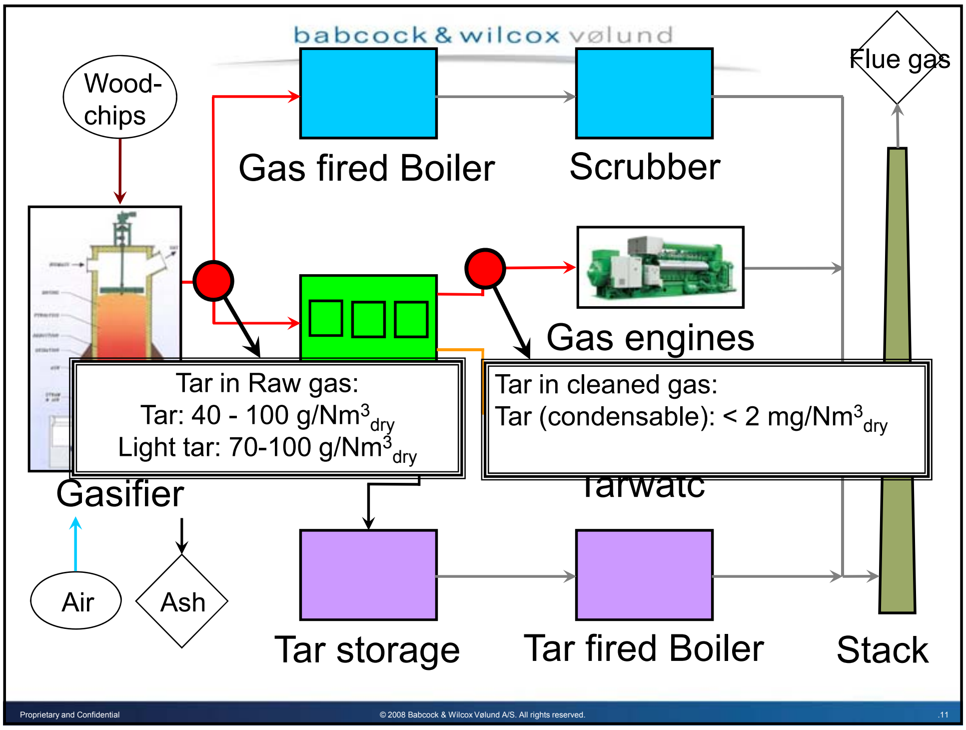

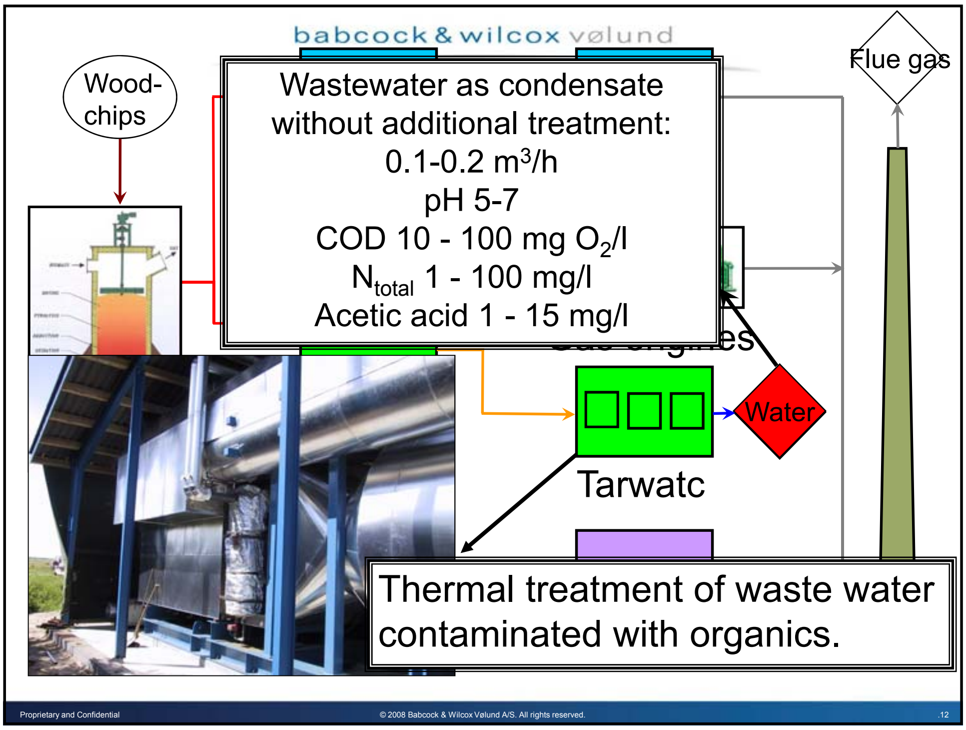

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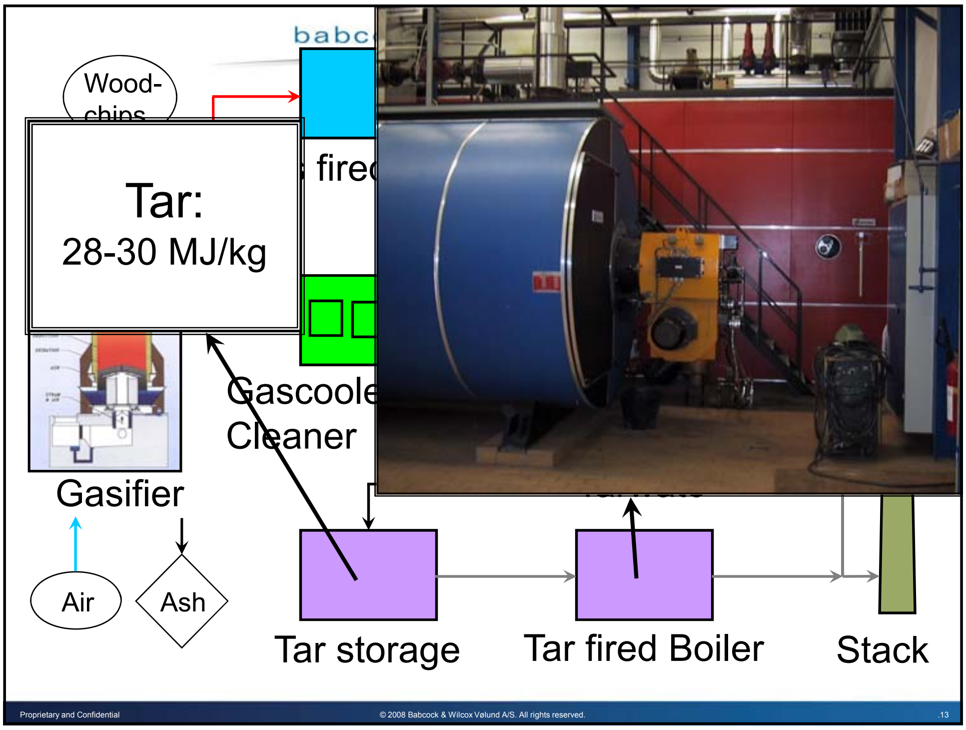

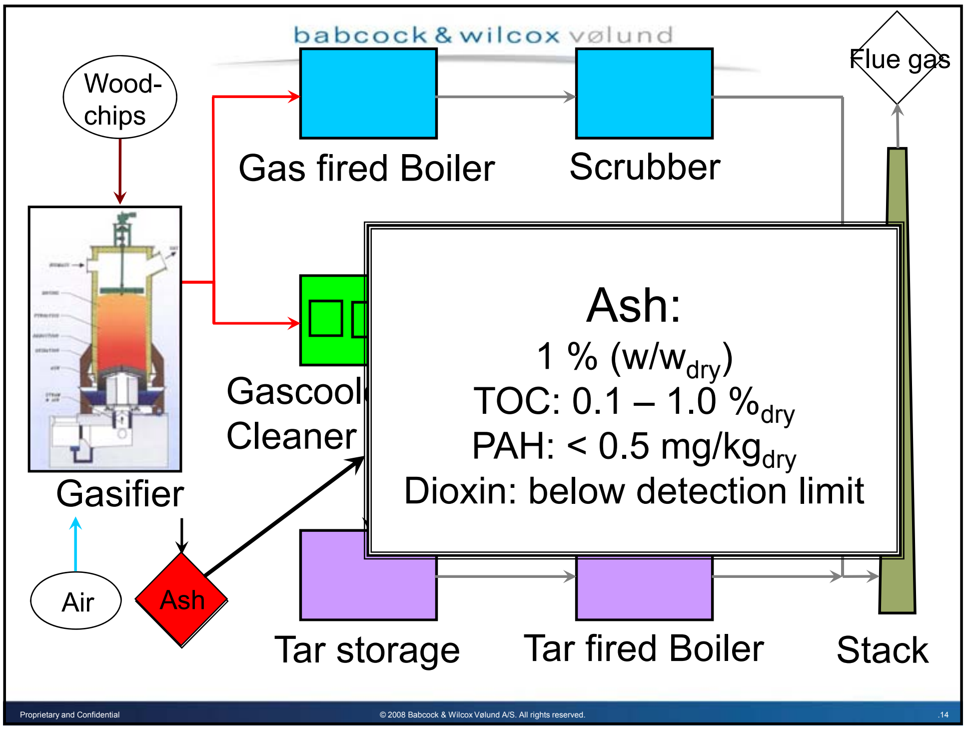

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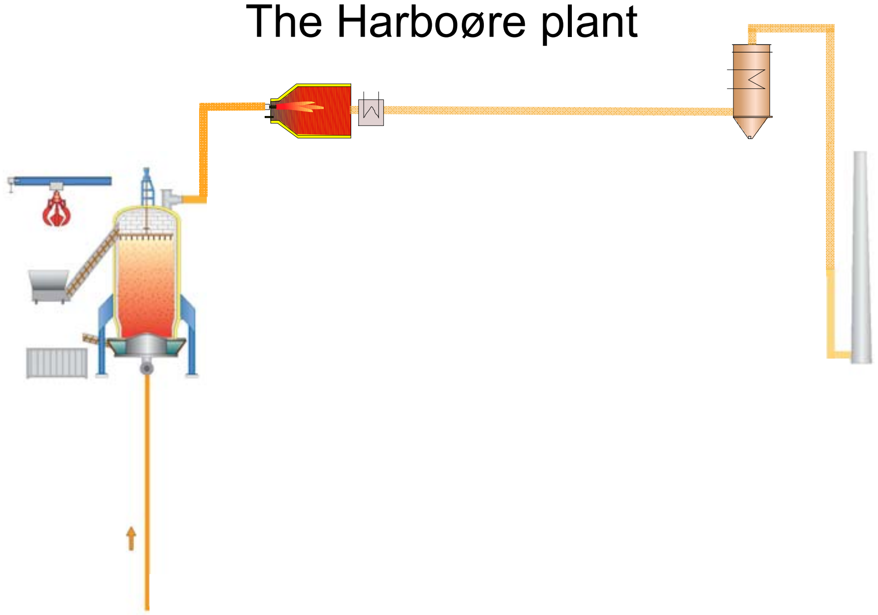
The Harboøre plant



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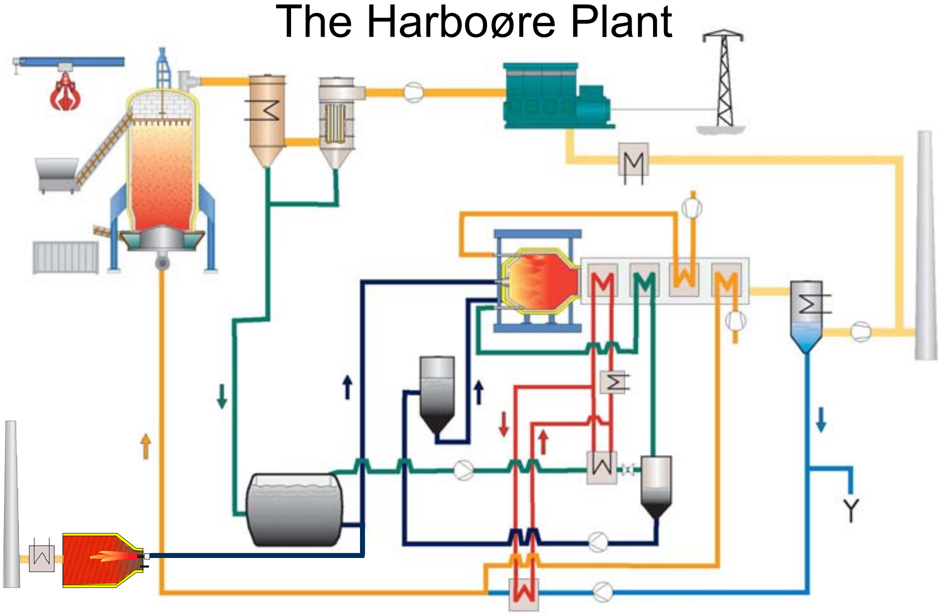
The Harboøre Plant



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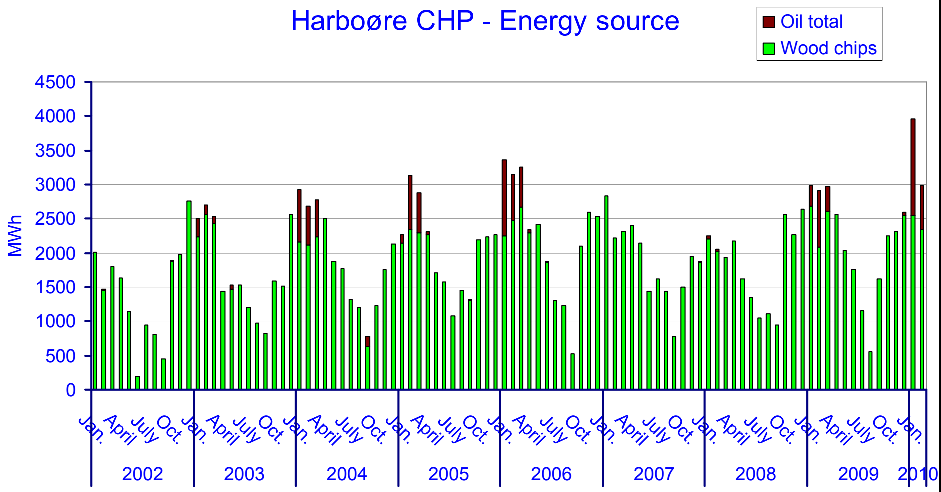
Harboøre CHP – Fuel consumption



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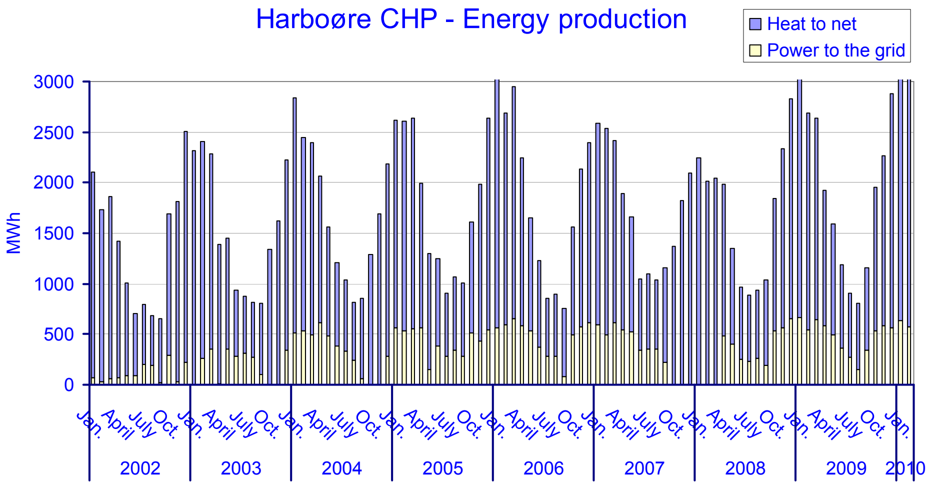
Harboøre CHP – Energy production



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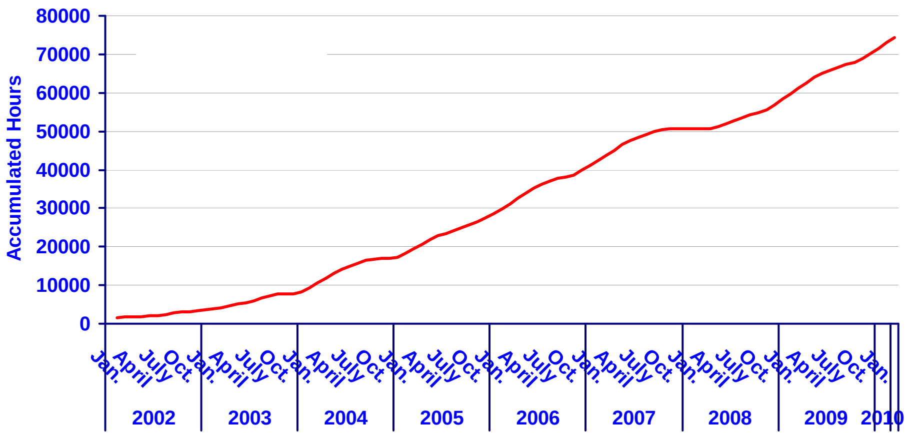
Harboøre CHP – Gasengine operation



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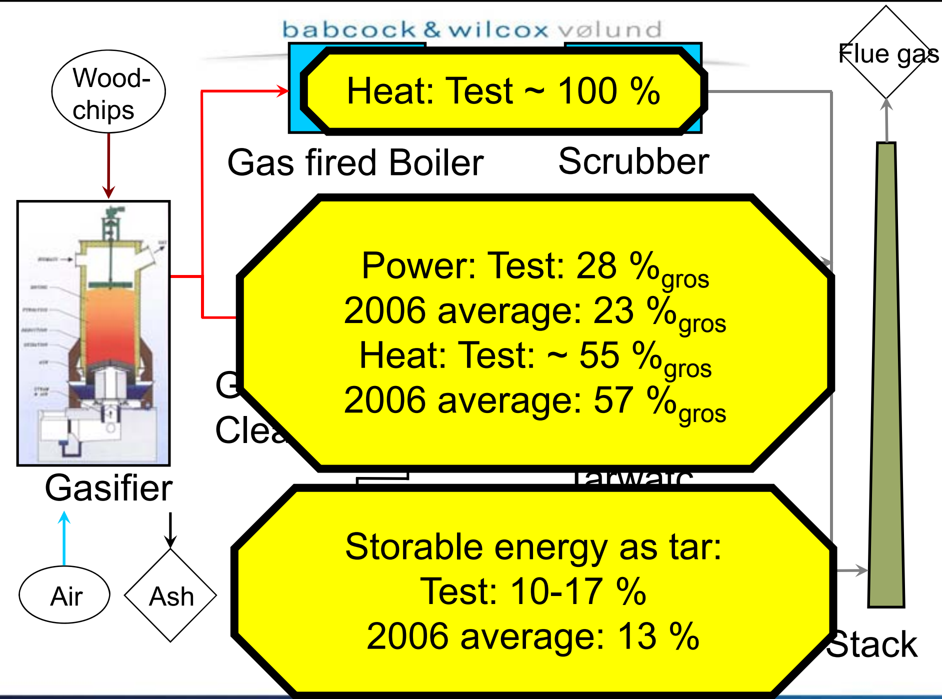

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Advantages

- ✓ High efficiency
- ✓ High potential for further developments
- ✓ Flexibility
- ✓ Turn-down ratio
- ✓ Fast ramping

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B&W Vølund gasification

Licensee JFE – Japan:

- ➢ Yamagata plant in operation (8 MWth)
- ➢ Ishigawa plant in operation (9 MWth)
- ➢ Daio plant in operation (12 MWth)

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Yamagata – a 2 MWe plant

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Autumn 2007 at Yamagata (2 MWe)

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Spring 2009 at Ishigawa

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Spring 2009 – Fuel for Daio plant

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Commercialising the technology: Concepts

- Combined heat and power stations
- Burnable gas generator
- Wasteboost – external superheater for Waste fired power plants
- Combined cycle gasifier based power station

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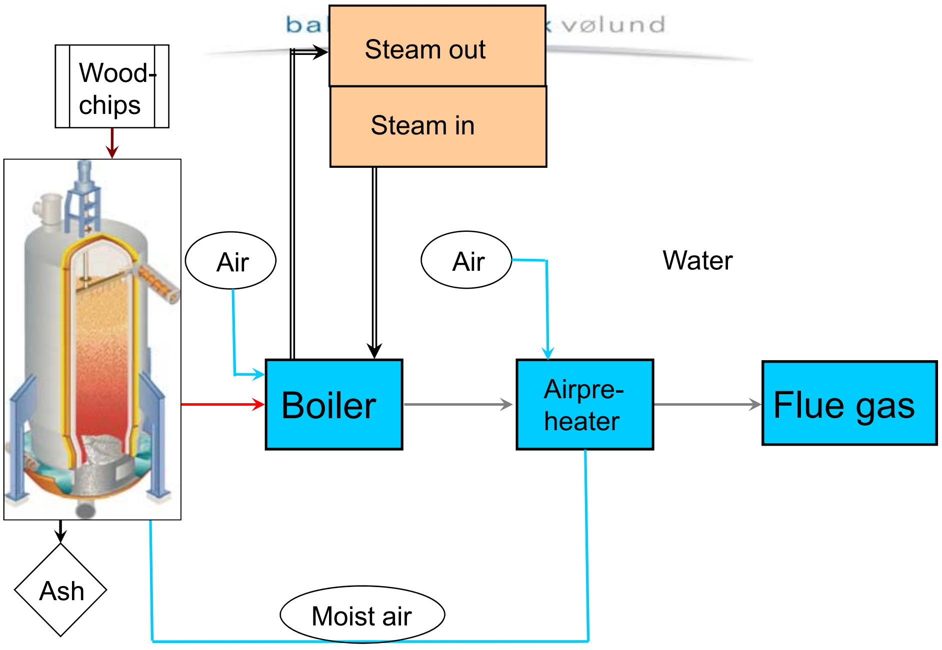

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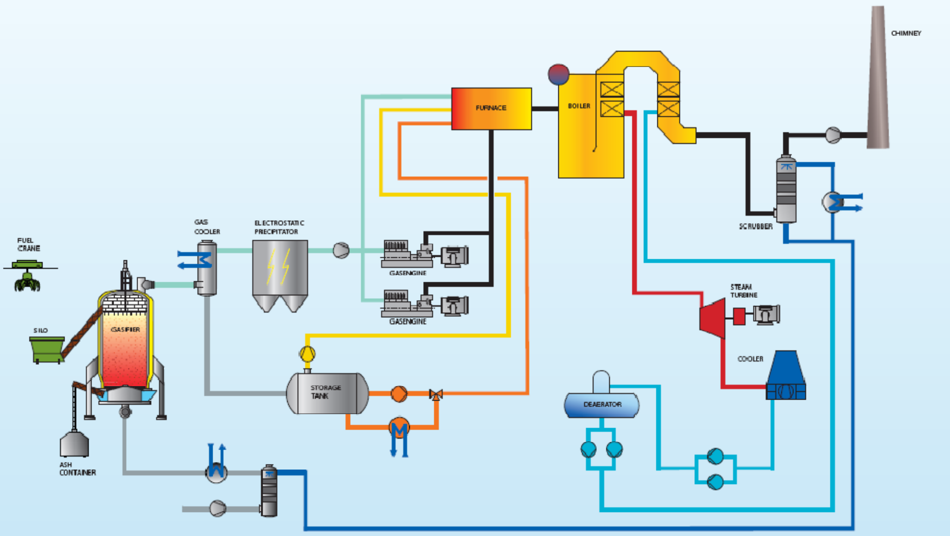
Combined Cycle Gasifier - Process



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Financial and technical figures 2MWe

4-6 MEUR/MWe installed

η_e = 28% CHP

η_{th} = 55% CHP

Bio oil = 13%

1 week per year for maintenance

O&M excluding manpower but including wearparts, consumable, service, office cost, insurance

225.000 EUR per year

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Financial and technical figures 5MWe

4-5 MEUR/MWe installed

η_e = 38% CCGP

1 week per year for maintenance

O&M excluding manpower but including wearparts, consumable, service, office cost, insurance

375.000 EUR per year

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General for Fuel

Wood chips, rounded and homogenous and with a good 'sliding effect':

Ash content, approx.	%	0 – 2
Ash softening temperature	°C	>1000
Apparent density	kg/m3	200-300
Moisture content	%	35 – 55
Heat value, lower	MJ/kg	8.4 – 11.6

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Grain size distribution for wood chips

	Riddle tray	
Small	< 4%	≤ 3.15 mm
Fine	< 8%	3.15 ≤ x ≤ 8 mm
Medium	< 25%	8 ≤ x ≤ 16 mm
Large*		16 ≤ x ≤ 45 mm
Extra large*	< 60%	45 ≤ x ≤ 63 mm
Excess size*		> 63 mm
Excess length 10	< 6%	100 – 200 mm long
Excess length 20	< 1.5	> 200 mm

* These 3 groups must add up to at least 60%.

Fuels such as forestry brash that contains stones and earth are not suitable.

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Challenges

- Location with subsidies on the feed in tariff
- Location with heat or steam demand
- All the crock around the world gives a bad rumor

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Annex 9. Indirect gasifier

Reinhard Rauch, TU Vienna, Austria

TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

Indirect gasification

Workshop at IEA Bioenergy Task32 and Task33 Meeting, October 2010

Dr. Reinhard Rauch

Institute of Chemical Engineering
Working Group Future Energy Technology

Content

- Technology
- Operational status
- Efficiencies
- Investment costs
- Fuels and specifications

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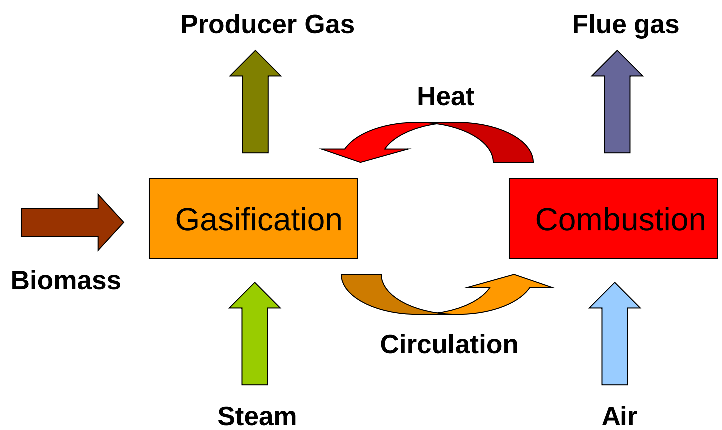
Gasification Concept



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Data CHP Güssing

Start of construction		September 2000	
Start up		January 2002	
Fuel	~2,2	to/h	(Wood chips)
Water content	15	%	(35 %)
Fuel power	8	MW	
Electrical power	2	MW	
Thermal power	4,5	MW	
Electrical efficiency	25	%	(20%)
Total efficiency	80	%	

Owner and operator Güssing Biomass Power Station Association

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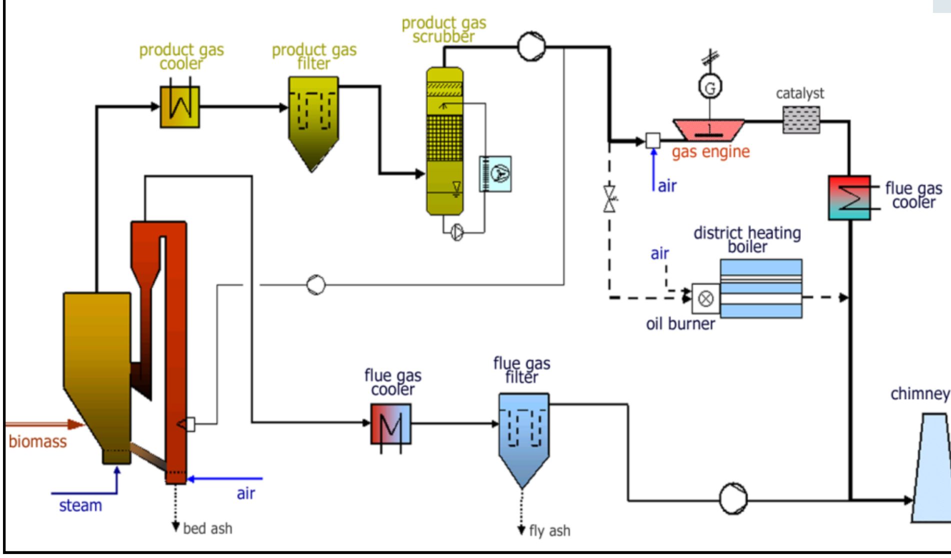
Working Group Future Energy Technology

CHP-Plant Güssing



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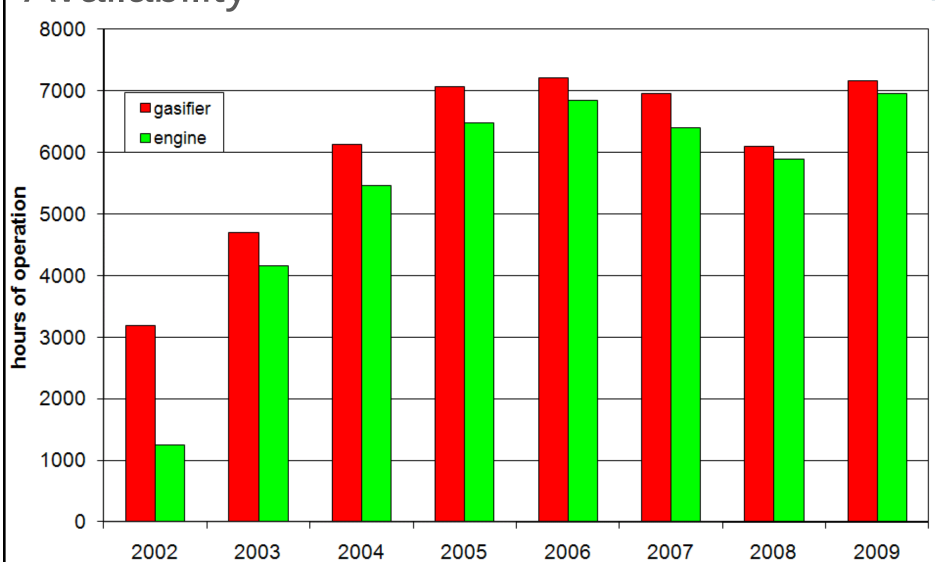
Availability



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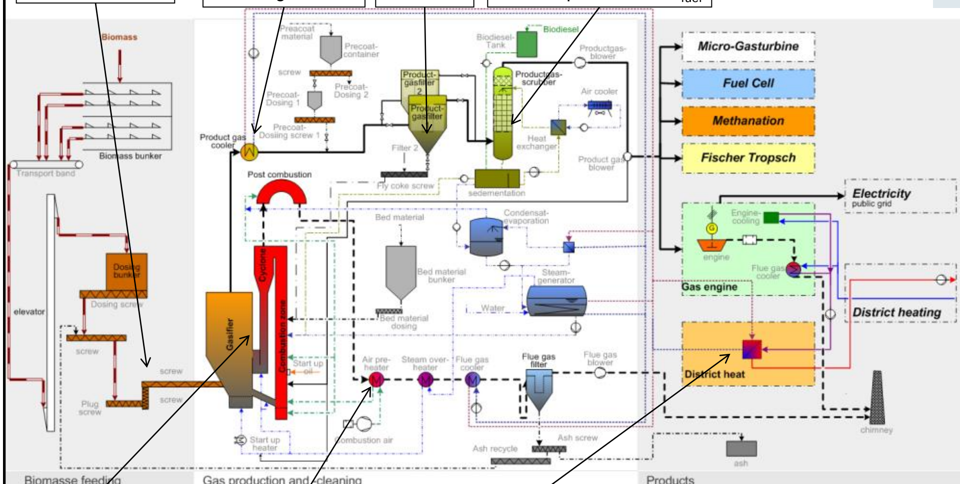
Optimisation of Availability

Biomass feeding

PG cooler
Cleaning >4000h

PG filter
>20 000h

PG scrubber
Consumption: ~1l/MW_{fuel}



Refractory gasifier
repaired 2-3 years

Air preheater
Cleaning: 500-1000 h

Control of district heat

7

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Economic frame conditions

- Biomass costs: 1.8-1.9 c€/kWh (80-90 €/t_{dry})
- Feed in rate for electricity: 16 c€/kWh
  for electricity from forest wood chips, <2MW_{el},
  independent on technology
- Price of heat: 2.5-3.0 c€/kWh, depends on average biomass price and light heating oil price
- Funding of investment costs, due to demonstration plant

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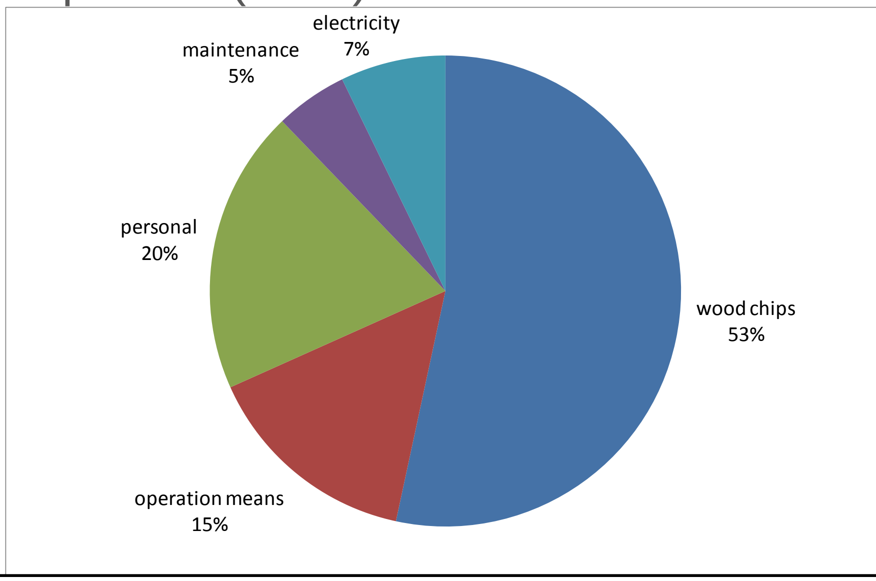
Expenses (2009)



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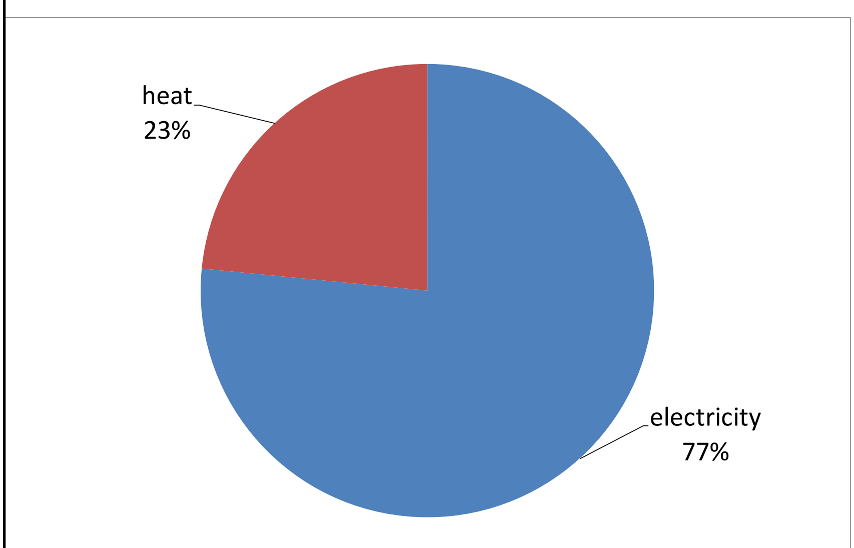
Income (2009)



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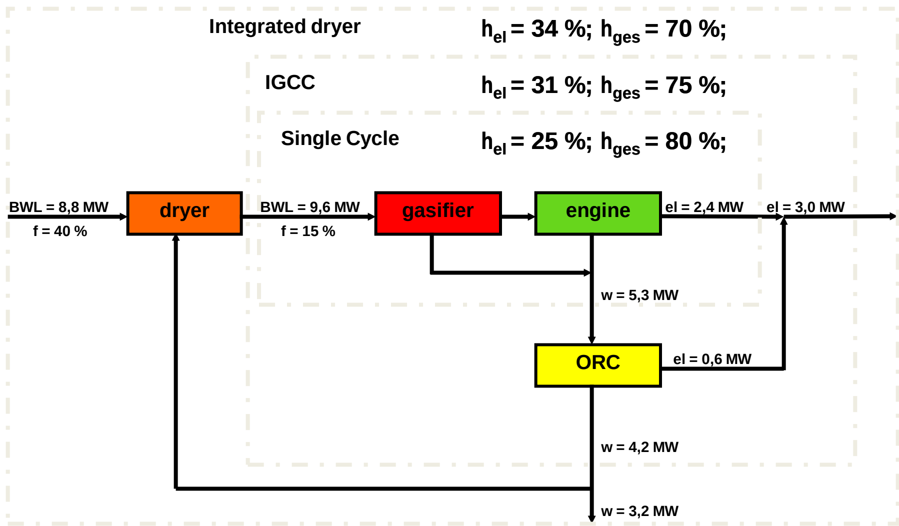
Optimisation of Efficiency



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Commercial FICFB gasifiers

Location	Electricity production	Fuel / electr. MW, MWel	Start up	Status
Güssing, AT	Gas engine	8.0 / 2.0	2002	Operational
Oberwart, AT	Gas engine / ORC	8.5 / 2.8	2008	Operational
Villach, AT	Gas engine	15 / 3.7	2010	In commissioning
Klagenfurt, AT	Gas engine	25 / 5.5	2011	Detailed engineering
Ulm, DE	Gas engine / ORC	15 / 5.3	2010	Under construction
Geislingen, DE	AER-process / Gas engine / ORC	10 / 3.3	2010	Detailed engineering

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Commercial FICFB gasifiers

Location	Electricity production	Fuel / electr. MW, MWel	Supplier	Investment costs (M€)
Güssing, AT	Gas engine	8.0 / 2.0	Austrian Energy / Repotec	10.7
Oberwart, AT	Gas engine / ORC	8.5 / 2.8	Ortner Anlagenbau	16
Villach, AT	Gas engine	15 / 3.7	Ortner Anlagenbau	?
Klagenfurt, AT	Gas engine	25 / 5.5	Ortner Anlagenbau	?
Ulm, DE	Gas engine / ORC	15 / 5.3	Repotec	?
Geislingen, DE	AER-process / Gas engine / ORC	10 / 3.3	Repotec	?

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FICFB Ulm, Germany

http://www.swu.de/index.php?eID=z7_swuwebcam_popup

Biomasses tested in the 100kW pilot scale FICFB gasifier

- Wood pellets
- Water content (Wood chips)
- Particle size (Saw dust)
- Fixed carbon (Coal)
- Waste wood
- Ash content (Sewage sludge pellets)
- Impurities (Animal residue)
- Ash melting (Straw)
- SRC (Willow)
- Waste

All fuels can be used, if the ash melting point is above 1000°C as pure fuel.
Fuels with lower ash melting point have to be used as mixture (e.g. 15% straw works well)

Current Status and Outlook

Successful scale up of a dual fluidized bed steam gasification system from laboratory to industrial scale **(within 10 years)**

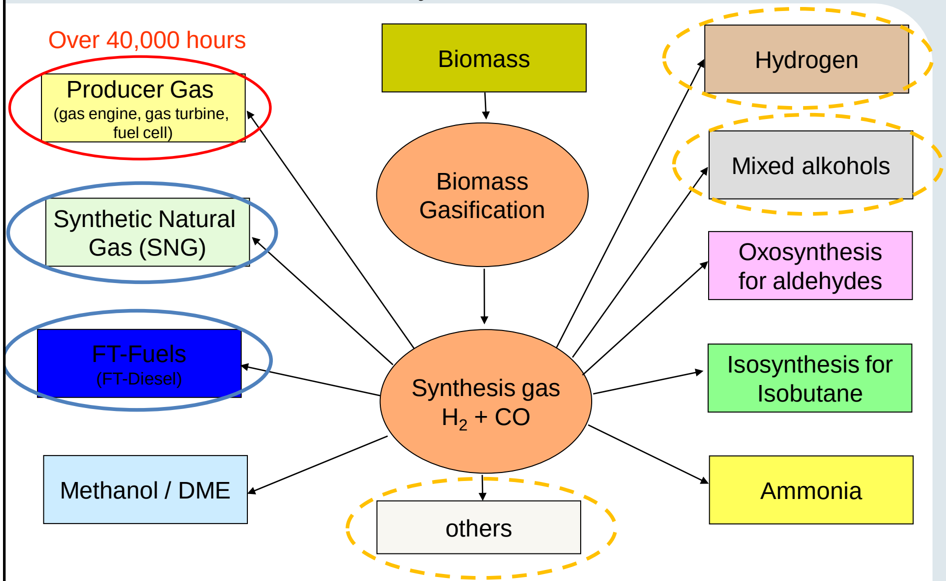
Industrial plant available with

- High electrical efficiency (> 30 % with combined gas engine and ORC-process)
- No solid residues (without ash, carbon content <0,5 %)
- No liquid condensates
- European emission requirements are met
- High availabilities (>90 %)
- Second plant is already in operation (~10 MW_{fuel})

High potential for biofuels (BioSNG, BioFiT)

- BioSNG, most suitable, 1 MW (100 m^3/h BioSNG) was demonstrated from wood chips, till using the BioSNG in cars
- Fischer Tropsch, research ongoing, scale up to 1 bpd is ongoing

The basic concept – "Green Chemistry"



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Outlook: usage as synthesis gas

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Vienna University of Technology

Thank you for your attention

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Dr. Reinhard Rauch
E-Mail: reinhard.rauch@tuwien.ac.at
Tel.: +43 1 588 01 – 15954

Annex 10. Upscaling the LTCFB (Low Temperature Circulating Fluid Bed) gasifier

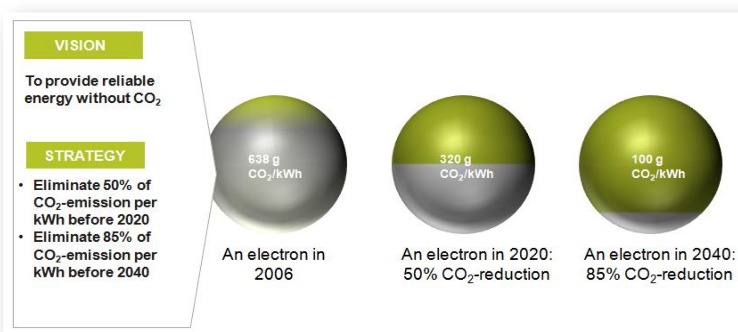
Anders Boisen, DONG Energy, Denmark

Low Temperature Gasification

7th October 2010
Anders Boisen

DONG energy

DONG Energy Power in transition 85/15



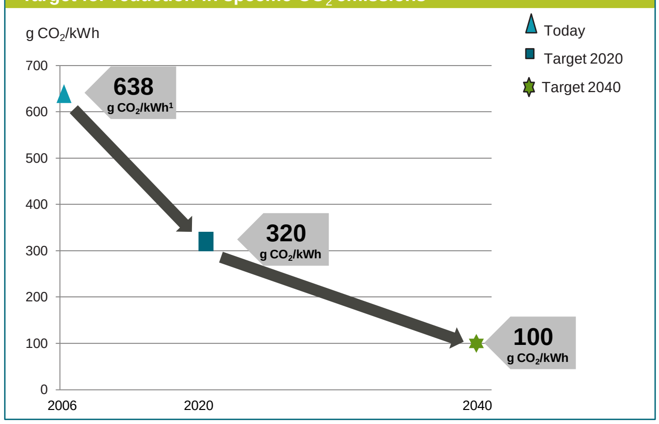
- DONG Energy has decided to transform into a CO_2 neutral future
- Investments in thermal energy are moved from coal to biomass and natural gas

DONG energy

The 85/15 is frontloaded - with ambitious targets for 2020 and 2040

VISION	STRATEGY
To provide reliable energy without CO_2	Eliminate 50% of CO_2 emission per kWh before 2020 Eliminate 85% of CO_2 emission per kWh before 2040

Target for reduction in specific CO_2 emissions

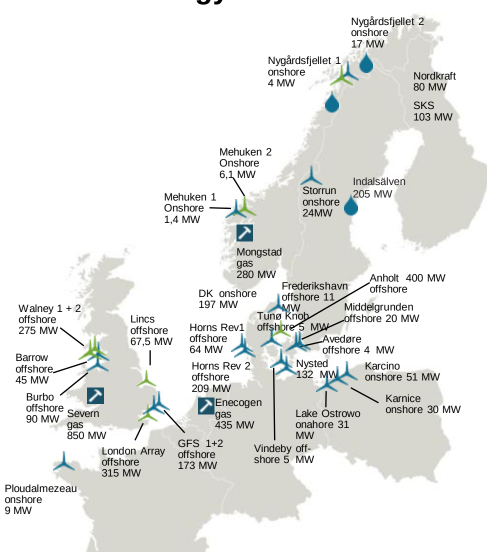


1) 2006 total heat and power production 28,5 TWh eleq/ CO_2 emissions 18,2 mt = 638 g CO_2/kWh

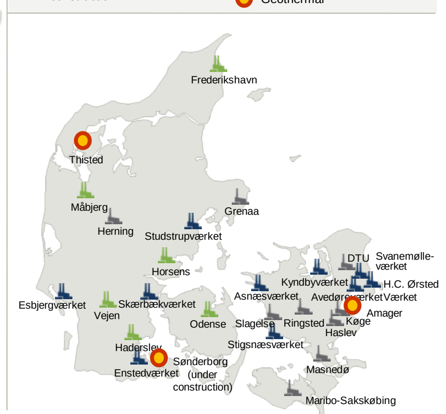
DONG energy

3

DONG Energy Power: Activities and development plan



THERMAL CAPACITY		RENEWABLES CAPACITY	
Central	5,350 MW	Hydropower	388 MW**
Decentral	216 MW	Wind in operation	1,098 MW***
Waste	96 MW	Wind under construction	1074 MW****
Thermal – under construction*	1,565 MW	Geothermal	

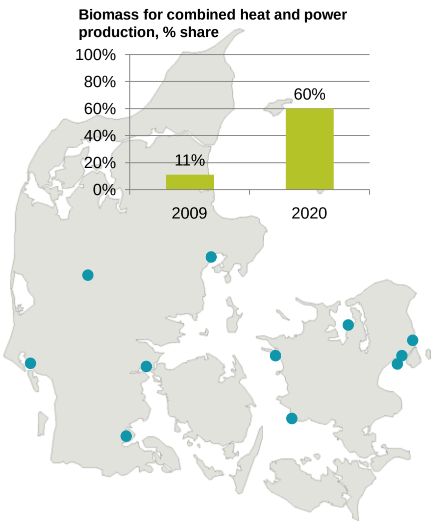


* DONG Energy's share of ownership
** DONG Energy's share of ownership incl. associated companies and indirect ownership.
*** DONG Energy's share of MW in operation (Annual report 2009) excl. minorities' ownership of Storrun (6 MW)
**** DONG Energy's share of MW under construction incl. Anholt

DONG energy

4

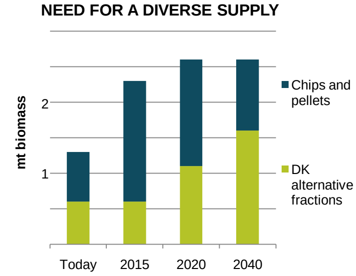
A large-scale green conversion of DONG Energy's CHP production in Denmark



BUILDING ON EXISTING COMPETENCIES IN BIOMASS

HUGE POTENTIAL
Today less than 0.5% of annual wood harvest residues are converted to wood pellets. Global demand expected to grow steeply

NEED FOR A DIVERSE SUPPLY



DONG energy

5

LT-CFB – the simple process

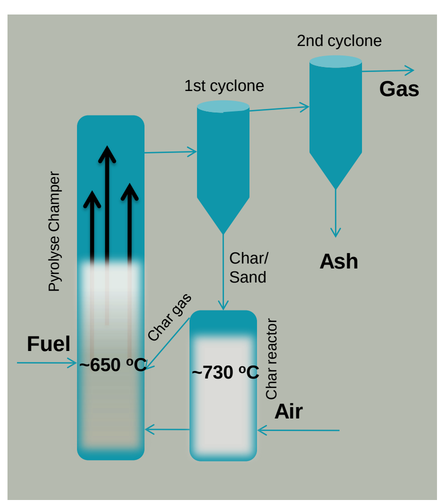
Dry fuel is pyrolysed into a tar containing gas

Char residues and sand is separated in the 1st cyclone

Char is oxidised with air in the char reactor, heating the sand

Sand is transported to the Pyrolysis CFB, and pyrolysis the fuel

The final char gas is cleaned in the 2nd cylone



DONG energy

LT-CFB Landmarks I

- 1999 - 50 kW DTU
- 2003 – 500 kW DTU – up-scaling
- 2007 – 100 kW DTU – several fuels
- June 09 – R&D Committee approval
- December 09 – Stoholm agreement

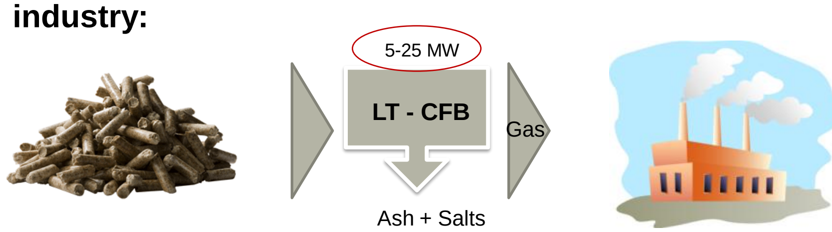
DONG energy

LT-CFB tests at DTU - 35 tonnes in approx 500 hours

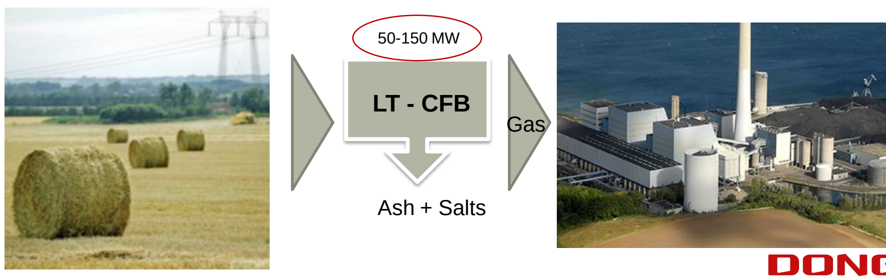
Test plants	Fuels tested	Hours >700°C	Gas cleaning
50 KW 1999-2004	Wood Straw Pig manure Hen manure	2 92 12 16	SC (Sec. cyclone) SC SC SC
500 kW 2004-2006	Straw Swine manure Swine biogas residue Common biogas residue	35 42 59 39	SC SC SC SC & TC (Tert.cyclone)
100 kW 2009-2010	Straw Citrus &Sea weed residue	124 37	SC SC, Cooler, filter

DONG energy

From biomass to gas by a low temperature gasifier in industry:

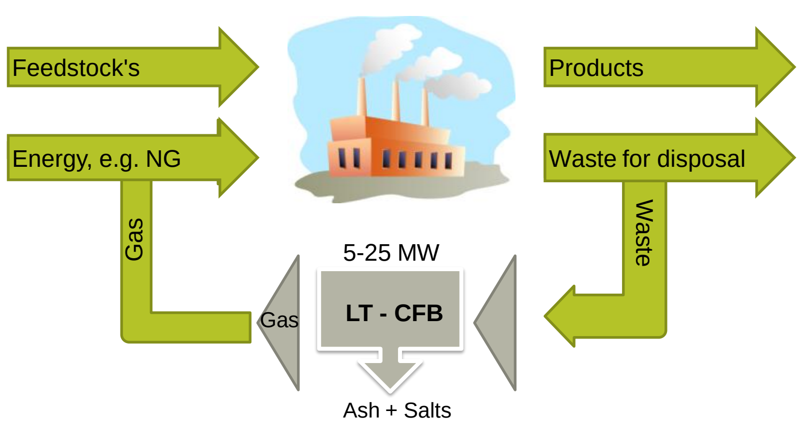


- and in power sector:



DONG energy

LT-CFB in industry: NG is being replaced by local waste fractions

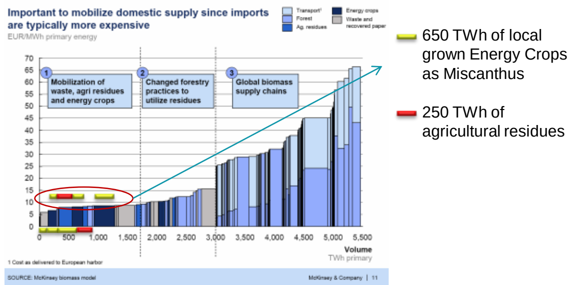


The LT-CFB gasifier can use cheap local waste fractions to replace expensive natural gas

DONG energy

The LT-CFB gasifier is able to utilise high alkali containing biomass fractions for power generation

Potential for Energy Crops in EU-27



Agricultural residues and energy crops have high content of alkaline, and therefore they are difficult to utilise in existing boilers!

- Increase in European biomass demand till 2020 is estimated to 850 TWh (20-20-20)
- Demand can be covered through utilization of low value biomass in competition with imports
- Cost for utilization of local low value biomass instead of imported biomass depends on transport costs, infrastructure and technology for conversion

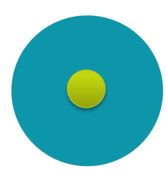
DONG energy

Economy of scale

- Specific CAPEX for large scale makes up for additional transport

• Low density biomass is expensive to transport

• Increasing the transport distance of straw from 50 to 200 km, increases cost with approx. 10 DKK/GJ



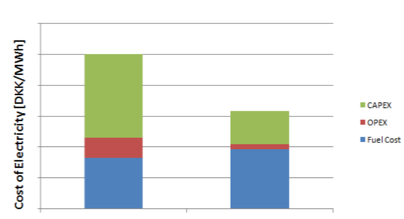
r = 50 km, Area is 7850 km2
r = 200 km, Area is 125600 km2

Plant size is 16 times bigger

2 cases to consider:

	100 MW	6,25 MW
Fuel cost	X + 10 DKK/GJ	X
CAPEX (Total)	100 Y	14 Y
OPEX / per year	100 Z	25 Z
Electrical eff.	46%	42%

Cost of electricity,
Plant size Vs cost of biomass



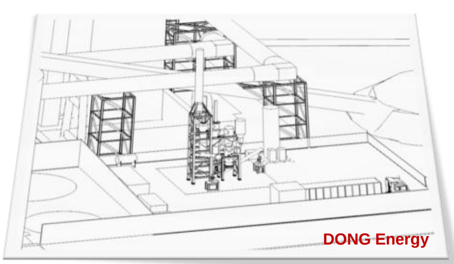
DONG energy

LT-CFB Landmarks II

- 1999 - 50 kW DTU
- 2003 – 500 kW DTU – up-scaling
- 2007 – 100 kW DTU – several fuels
- June 09 – R&D Committee approval
- December 09 – Stoholm agreement
- January 10 – Investment Committee
- March 10 – Energinet.dk Board approval
- March 10 – Start of demo project

DONG energy

From biomass to gas by a low temperature gasifier Construction of 6 MW_{th} demo plant started August 2010



Gasification Demonstration Project

Up-Scaling

Integration

Demonstration

2010	2011	2012	2013

- Total budget 90 MDKK
- Grant from ForskEL and ForskVE 35 MDKK

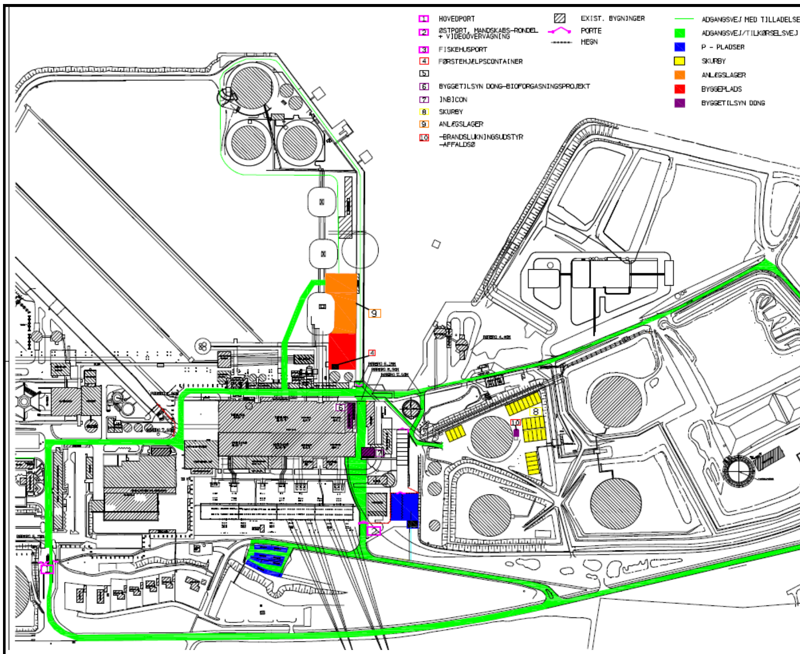
Features:

- Fuel: straw, manure fibres........ local residues
- Operating temperature is around 650 ºC
- Efficiency ~ 95%
- Capacity: 6 MW_{th} / 1,5-2,3 tonnes straw per hour
- Location: ASV 2, Kalundborg
- Construction initiated
- Commissioning during spring 2011

- Conversion of low value biomass and waste fractions into "alkaline free" gas
- Conversion of troublesome alkaline species into useful fertilizer

14

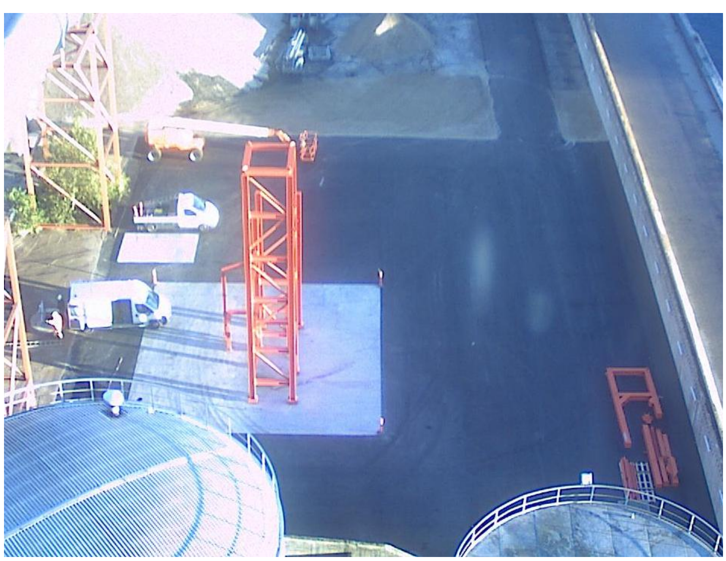
DONG energy



DONG energy

15

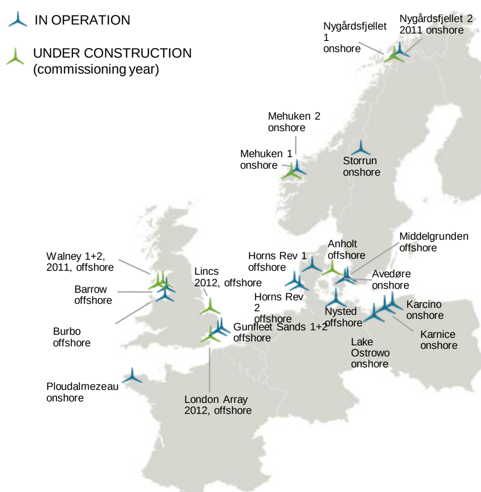
Site status October 1, 2010:



DONG energy

16

Wind is the key to the low-carbon transition – and DONG Energy will continue to be a world leader



STRONG POSITION THROUGH INDUSTRIALIZATION OF OFFSHORE

OPTIMIZED PLANNING AND EXECUTION OF PIPELINE
Strong in-house to secure portfolio synergies construction competences

SIEMENS AGREEMENT
1,800 MW supply agreement with steady supply

OPTIMAL OFFSHORE INSTALLATION
Acquisition of A2SEA world-leading installation vessels and crew

Capacity*	MW
In operation	1,098
Under construction	1,074
Project pipeline	4,000

Note *:
In operation: Annual report 2009 excluding minorities' ownership of Storrun (6 MW)
Under construction: Adjusted by reduced Walney ownership and increased according to Lincs ownership and Anholt
Project pipeline: Strategy document March 2010 (MAS/Renewables)

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DONG energy

Annex 11. The Skive plant (BFB gasification): status and perspectives

Bettina Skjoldborg, Aaen consulting and Henrik Flyver Christiansen, Danish Energy Agency

I/S SKIVE FJERNVARME

BIOMASS GASIFICATION

IEA Bioenergy Agreement:2010-2012 Task 33: Thermal Gasification of Biomass

Optimization of I/S Skive District Heating Biomass Gasification Plant

IEA – Thermal Gasification of Biomass
7th of October 2010
AAEN A/S

I/S SKIVE FJERNVARME

BIOMASS GASIFICATION

AAEN A/S Consulting Engineers

Bettina Skjoldborg

B.Sc. Elec. Eng.
Graduate Certificate in Business Administration

Partner and project manager

Building Consultant for Skive District heating Company

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I/S SKIVE FJERNVARME

BIOMASS GASIFICATION

General information about I/S Skive Fjernvarme

- Consumers 3.294 energy meters (8000 – 9000 households)
- Annual sale of district heating: 120.000 MWh
- Annual sale of electricity: 22.000 MW
- District heating network 67,1 km Main pipelines
  54,4 km Connection pipelines
- Annual turnover: about 120 mill. DKK (16.1mill EUR)before tax
- Annual fuel consumption
  - Natural gas: 4,5 mill. m^3
  - Bio oil: 4.500 ton
  - Wood pellets: 21.000 ton

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7th of October 2010

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BIOMASS GASIFICATION

Project background

Increased heating demand in Skive → Necessary to extend natural gas capacity → Increased heatprice

Increased heating demand in Skive → Biomass CHP Plant alternative → A stable and future-proof heating price

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7th of October 2010

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BIOMASS GASIFICATION

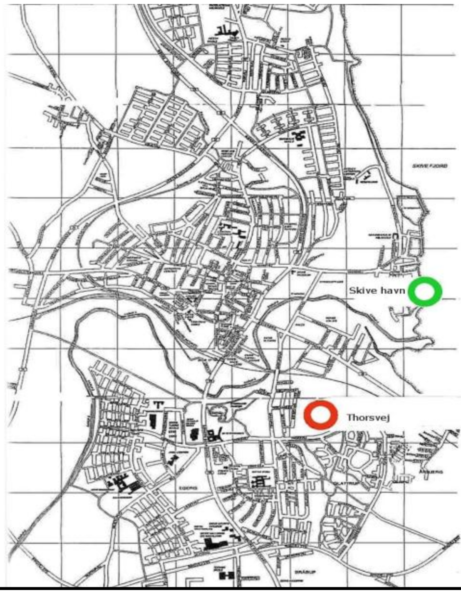
Wood pellets import

Wood pellet transport

- Transport distance is approximately 3 km.

Ship load and depth

- Maximum ship load: 3000 tons
- Maximum ship depth: 4 meter



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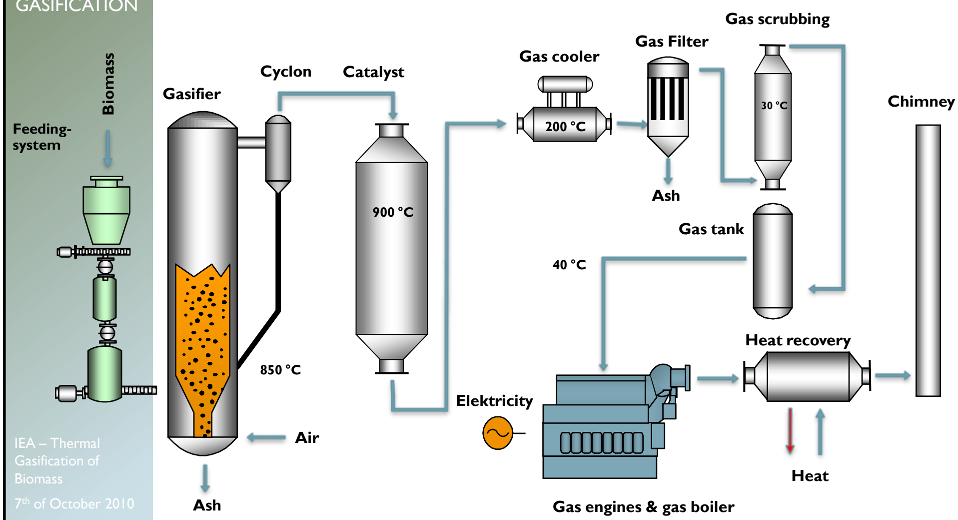
BIOMASS GASIFICATION

Gasification Plant



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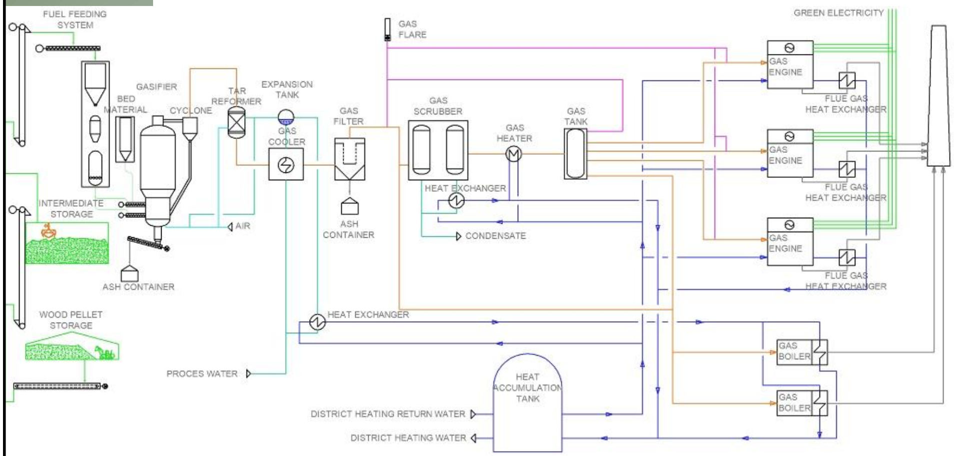
BIOMASS GASIFICATION

The Overall System



Biomass

7th of October 2010

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BIOMASS GASIFICATION

Authority Processing

The political handling of the project

- Preparation of a project proposal about biomass cogeneration plant – posted the 14th of May 2001.
- Approval of the heating plan on City Counsel Meeting on the 19th of September 2001.
- Preparation of district plan proposal for the new facility at Thorsvej. Consultation period was completed the 12th February 2003.
- There were objections to the project because of the location at the residential area.
- On a extraordinary general meeting at I/S Skive Fjernvarme, the 12th March 2003 the consumers was informed about the project.
- The district plan was finally adopted by Skive municipality at City Counsel Meeting 24th of June 2003.

The administrative handling of the project

Environmental Impact Assessment

- Viborg County's processing of the case was closed.
- The County's decision was complained to the National Nature Complaints Board
- The National Nature Complaints Board did on the 9th March 2005 agreed in the decision of the County.

Waste water approval

- Was published together with the environmental approval on the 26th March 2005.

Fire Protection Authority

- The prepared ATEX and HAZOP analyze was approved by the Fire Protection Authority in Skive with assistance from the Danish Technological Institute the 20thApril 2005.

Environmental approval

- The environmental approval was published on the 26th March 2005.

Building permission

- Building permission for the accumulation tank was granted the 19th October 2004.
- Excavating and casting permission for the CHP Plant was granted the 11th April 2005.
- Final building permission for the CHP Plant was granted the 5th September 2005.

IEA – Thermal Gasification of Biomass

7th of October 2010

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BIOMASS GASIFICATION

Above: On 19th April 2005 – Chairman of the Board Mr. Erik Nielsen from I/S Skive District Heating perform the first digging

Left: June 2005 – Accumulation tank completed

IEA – Thermal Gasification of Biomass

7th of October 2010

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BIOMASS GASIFICATION

IEA – Thermal Gasification of Biomass

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BIOMASS GASIFICATION

Gasifier unit produced in Finland while inside brickwork is performed by Finish and Danish Companies

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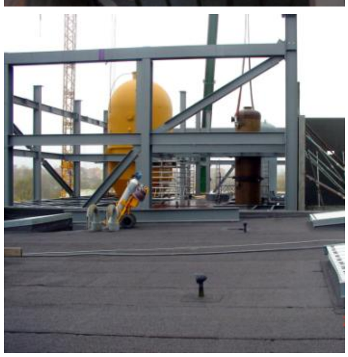
BIOMASS GASIFICATION



Gas cleaning equipment inserted – 27th October 2005

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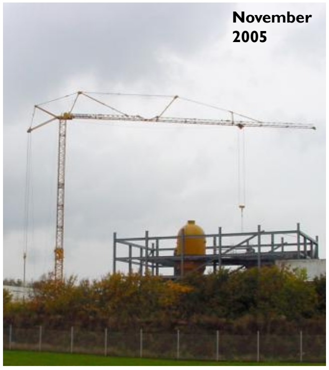
BIOMASS GASIFICATION



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BIOMASS GASIFICATION

Operation and Commissioning

- 20 MW wood-gas is produced on the gasfier
- Analysis of the wood-gas show quality according to expectations
- 4 operators day and night during operation
- Noise problem from Flare
- The equipment in some areas has been too highly classified(ATEX)
- Too many assumed operation parameters in the SCADA system
- The first engine delivered 10 MWh 2nd June 2008
- Engine two and three were starting up between weeks 35 and 41 2008.

- April 2010:
  - Motor: 10.730 number of hours
  - Electricity: 15.257 MWh
  - Heat: 42.257 MWh

Status:
70% output and 50% availability
The objective:
100% output and 90% availability
Unmannered operation during the evening and nighttimes.

IEA – Thermal Gasification of Biomass

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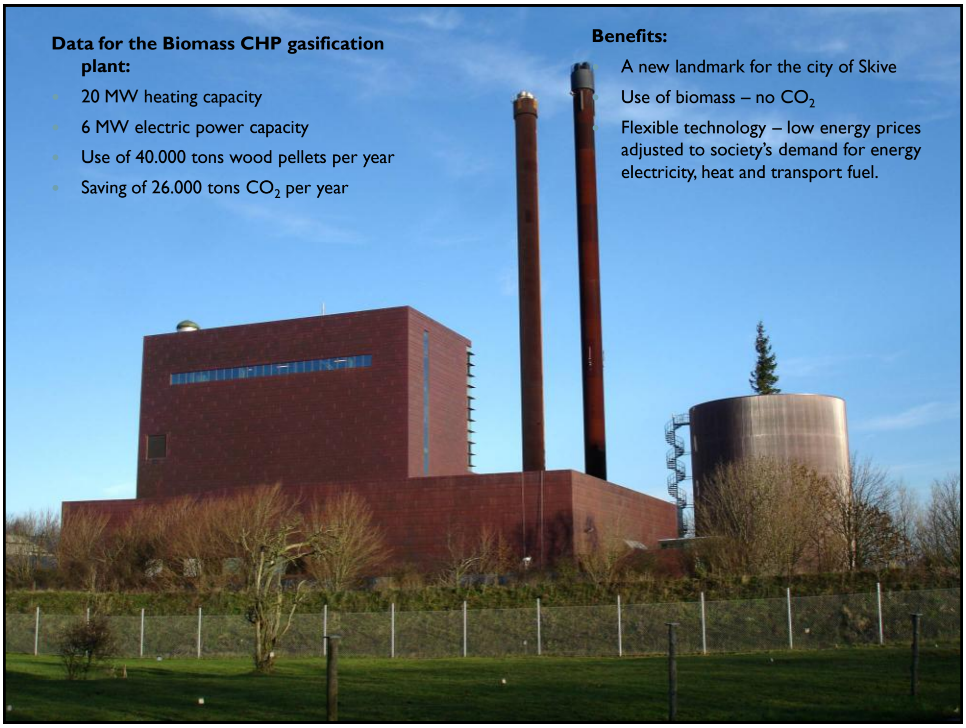

I/S SKIVE FJERNVARME

BIOMASS GASIFICATION

Experiences in General Terms

1. Comprehensive Regulatory and Permission procedures
2. The neighbours were scared of the new "gas factory"
3. The building must be constructed as a commercial CHP plant
4. 40 contracts with different suppliers
5. R&D projects takes a looong time

IEA – Thermal Gasification of Biomass

7th of October 2010

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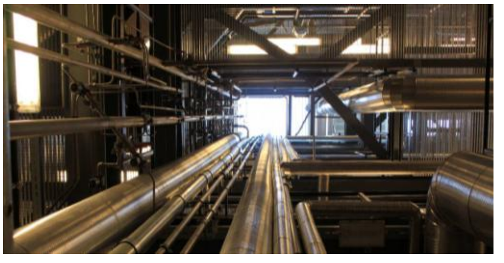
BIOMASS GASIFICATION

R&D Project

- The Danish Energy Agency: — 12 mill. DKK (1.6 mill. EUR)
- EU – 5th Framework Program — 12 mill. DKK (1.6 mill. EUR)
- DOE (Department of Energy) – USA — 11 mill. DKK (1.5 mill. EUR)



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7th of October 2010

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BIOMASS GASIFICATION

Project Process

Situation	Reference 2005	Expectations today
Investment:	161 mill. DKK (21.6 mill. EUR)	248 mill. DKK (33.3 mill. EUR)
Operational cost:	153 DKK/MWh electricity	183 DKK/MWh electricity
Assignment:	Middel 2006	Primo 2011
Fuel price:	700 DKK/tons	1.200 DKK/tons
Electricity transfer price:	600 DKK/MWh	745 DKK/MWh
Interests:	3,5 % p.a.	4,5 % p.a.
Write-off period:	12 year	20 year
Heat price:	278 DKK/MWh	365 DKK/MWh

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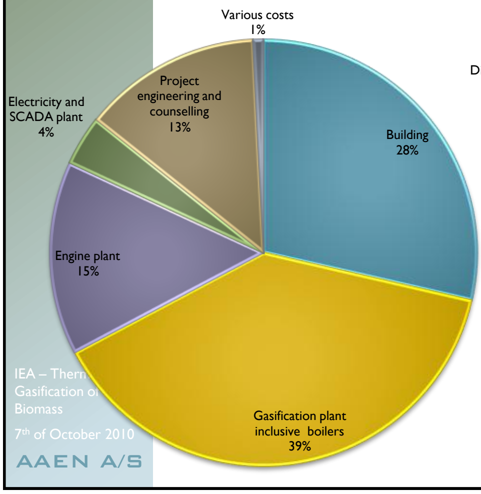
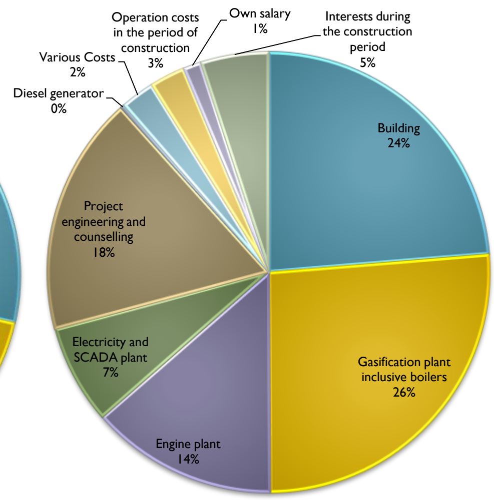
BIOMASS GASIFICATION

Construction Cost-sharing Reference

Reference



70% load & 50% availability



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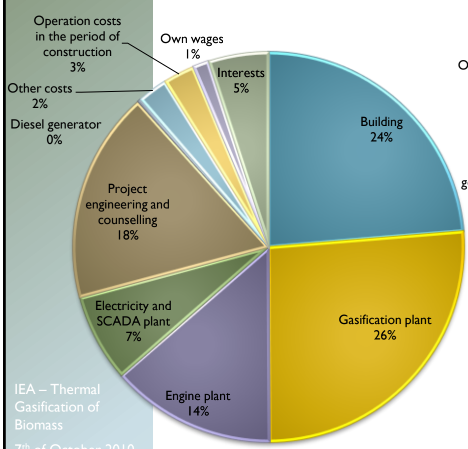
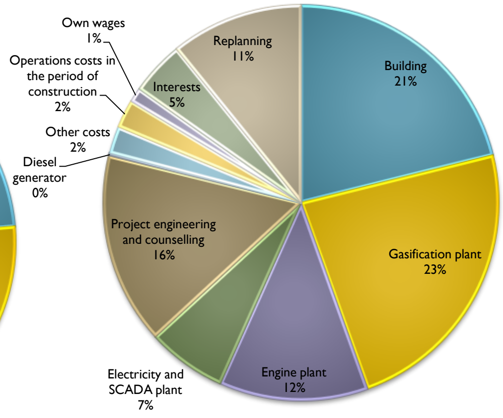
BIOMASS GASIFICATION

Construction Cost-sharing Expectation

70% load & 50% availability



100% Load & 90% availability



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BIOMASS GASIFICATION

Perspectives

	Fuel MW	Electricity MW	Heat MW	Liquid MW	Costs Mio. DKK	Rate Mio. DKK/MW
Skive project	18	6	10	0	250	42
Skive optimised	28	9	16	0	288	32
Skive 2 + fuel	28	10	15		262	26
Skive 2 + liquid	28	10	15	18	302	30
Skive 2 + oxygen	78	28	41		380	14
Skive 2 pressurized + oxygen	98	43	43		608	14
Firing - Ad on gasification: Skive 2 model	28		Gas out =	25	194	
Straw combustion, 2002 costs; Sakskøbing – distant	39	11	23		252	22

Is it possible to bay a such a gasification plant?

What does a guarantee cost?

Will it work?

IEA – Thermal Gasification of Biomass

7th of October 2010

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Annex 12. Steam turbines: what is the lower limit for feasibility, recent developments to reduce costs and increase efficiency in small steam turbine systems

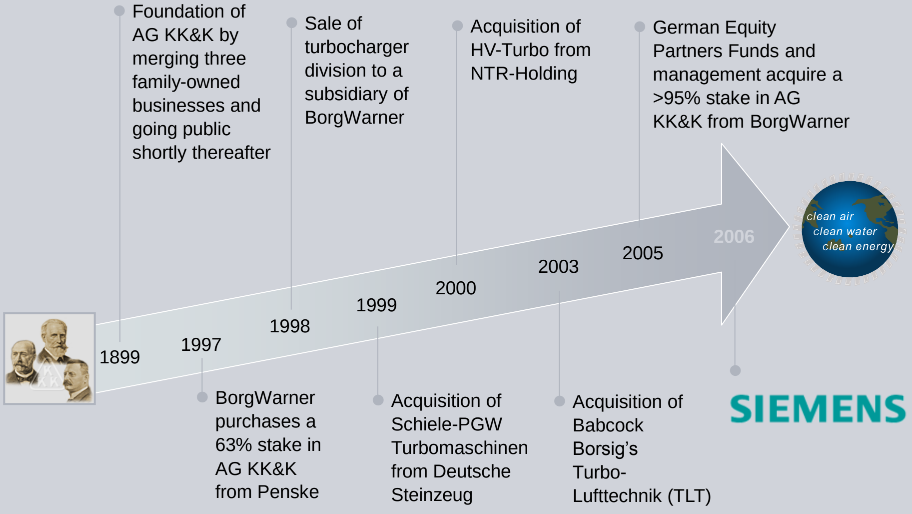
Reiner Schenk, Siemens Frankenthal, Germany

SIEMENS

Siemens Turbomachinery Equipment (STE) GmbH

SIEMENS

Company history



Page 3 28. January 2010 Energy / Pre-designed Steam Turbines

SIEMENS

Manufacturing in Frankenthal: Facts and Figures

Factory site:	**120.000 qm**
Manufacturing:	**30.000 qm**
Employees:	**650**
Machines:	**160**
Manufacturing hours:	**230.000 h**
Skilled workers:	**98%**
Average seniority:	**24 years**
Fluctuation:	**about 0**
	(5 years 4 workers)

Page 4 28. January 2010 Energy / Pre-designed Steam Turbines

SIEMENS

Manufacturing in Frankenthal: Test field

Steam flow: **apprx. 8.5 t/h**

Live steam pressure: **apprx. 35 bara**

Live steam temperature: **apprx. 380 °C**

SIEMENS

1. Overview steam turbines portfolio

SIEMENS

Siemens Steam Turbines Portfolio

Siemens utility steam turbines 200 up to 1900 MW

Siemens industrial steam turbines 5 up to 200 MW

Siemens pre-designed steam turbines 45 kW up to 10 MW

SIEMENS

STE Product Lines

SST-050
up to 750 kW
BF 3,5
BF4/80
BF4/125
AF 3,5 Gs
AF4 Gs

SST-060
up to 5 000 kW
AFA 3,5
AFA 4
CFA 4
CFR 3
CFR 5

SST-110
up to 7 000 kW
TWIN AFA 44
TWIN AFA 46
TWIN CA 34
TWIN CA 36
TWIN CA 54
TWIN CA 56
etc.

SST-120
up to 10 000 kW
Tandem Machines

SIEMENS

Basic Technical Values

Live steam pressure:	3 – 131 bar_a
Live steam temperature:	dry. sat - 530°C
Exhaust steam pressure:	0.08 – 29 bar_a
Speed:	500 – 23 000 rpm
Power:	Up to 10 000 kW

SIEMENS

Customers and Applications

Our customers

- Producer of Pumps, Compressors …
- IPP / Contracting / Engineering
- Energy-from-waste plants
- Utilities
- Smelters / Steel
- Wood / Paper
- Chemistry
- Petrochemistry / Refineries
- Food
- Sugar / Palmoil
- Ship / Offshore

Main applications

- **Waste-to-energy**
- **Mechanical Drives**
- **Biomass**
- **Cogen / CHP**
- **Heat-recovery**

- Gas expansion
- Geothermal plants / ORC

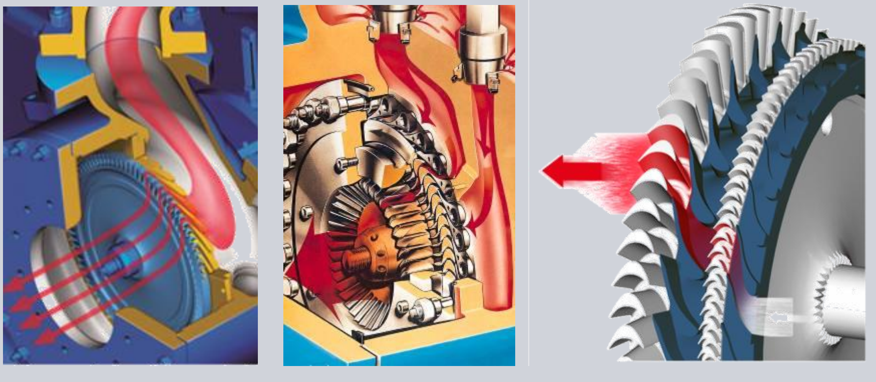
SIEMENS

2. Design of the STE steam turbines

SIEMENS

Operating Principle

Steam flow: SST-060 (AFA / CFR / Condensing Module)



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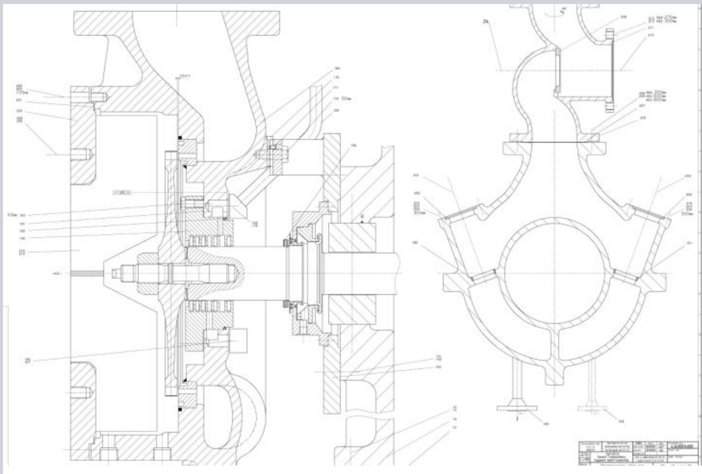
Operating Principle



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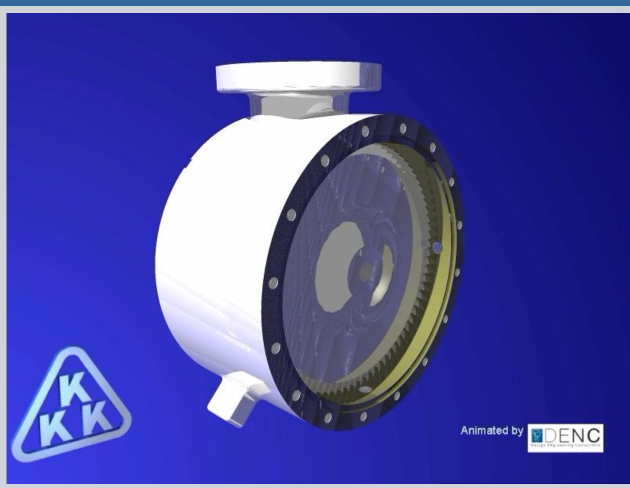
SIEMENS

Operating Principle

Steam Flow: SST-060



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In-house production: Monobloc-design

Turbine wheel manufacturing

In-house production: Monobloc-design

Turbine wheel AFA-type

In-house production: Monobloc-design

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Turbine wheel CFR-type

Page 17 28. January 2010 Energy / Pre-designed Steam Turbines

In-house production: Monobloc-design

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Nozzle ring CFR-type

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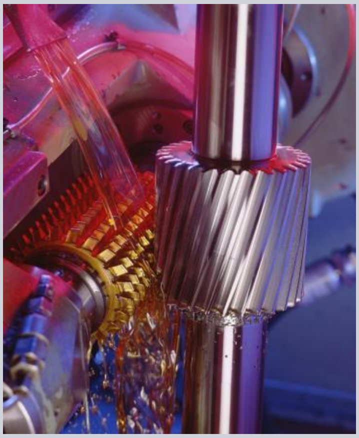
In-house production

Integral gear-box



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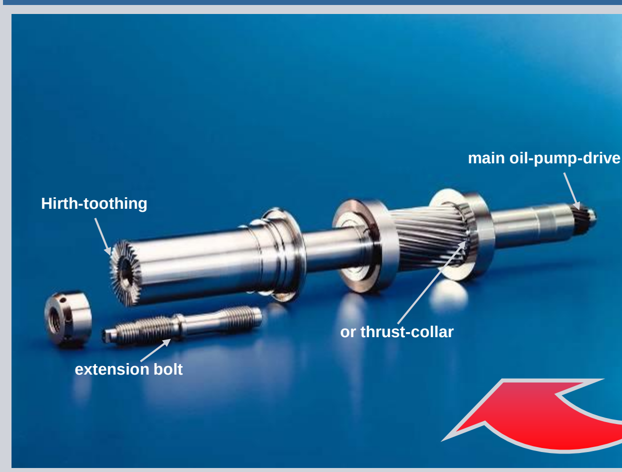
In-house production

Turbine shaft – Hirth toothing – thrust collar



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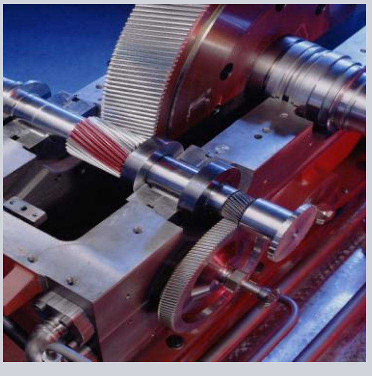
In-house production

Intgral gear-box

SIEMENS

In-house production

Integral gear-box



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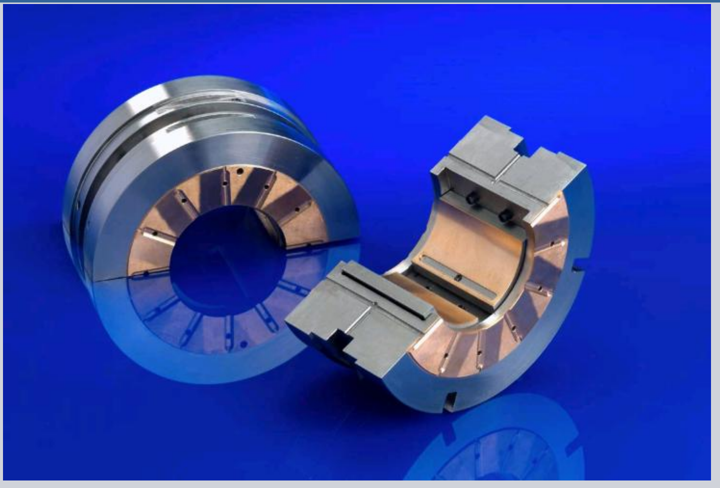
In-house production

Sleeve bearing



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3. Turbines for mechanical drives (SST-060)

+ Turbo Gen Sets (SST-060, SST-110, SST-120)

SIEMENS

Turbine series

Turbine series SST-060 (AFA 3,5 + AFA 4 + AFA 6 + AFA10 and CFA4 type) – up to 5 000 kW

Products:

Application:

- Mechanical drives, Cogeneration, Biomass, Waste-to-energy, Heat-recovery, Gas expansion

Market: *(Examples)*

- Producer of Pumps, Compressors, Fans etc., Chemistry, Petrochemistry / Refineries, Sugar / Palmoil, Wood / Paper, Electricity Supplier / Municipal Utilities, Smelters / Steel, IPP / Contracting / Engineering, Food, Energy-from-waste Plants, Ship / Offshore

SIEMENS

Turbine series

Turbine series SST-060 (AFR / CFR – type)

General

Integral gear design
Overhung design

Technical Data (max)

• Power	5,0 MW
• Live steam pressure	65 bar a
• Live steam temperature	480 °C
• Saturated steam	
• Speed	up to 24 900 rpm
• Exhaust steam pressure	up to 17 bar a
• Turbine wheel diameter	300 / 500 mm
• 5 different gearing sizes	

Typical dimensions

Length 1,5 m
Width 2,5 m
Height 2,5 m
Weight: Turbine inkl. oil reservoir and coupling: up to 12 t

Characteristics

- Exhaust steam pressure type
- Package unit design
- Flexible rotor
- Oil unit integrated in base frame
- Quick start without pre-heating
- Custom made
- Short delivery times

Scope of supply

- Turbine package
- Oil unit
- Electrical scope of supply
- Generator
- Short delivery times

SIEMENS

Turbine series

Turbine series SST-060 CFR 3 + CFR 5 – up to 5 000 kW

Products:

Application:

- Cogeneration, Biomass, Waste-to-energy, Gas expansion

Market:
(Examples)

- Chemistry, Petrochemistry / Refineries, Wood / Paper, Electricity Supplier / Municipal Utilities, IPP / Contracting / Engineering, Food, Energy-from-waste Plants

SIEMENS

Turbine series

Turbine series SST-060 (CFR – type)

General

Integral gear design
Overhung design

Technical Data (max)

• Power	5,0 MW
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- Quick start without pre-heating
- Custom made
- Short delivery times

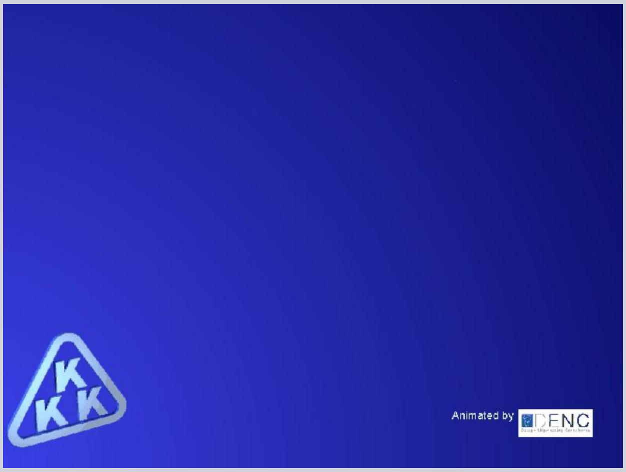
Scope of supply

- Turbine package
- Oil unit
- Electrical scope of supply
- Generator
- Short delivery times

SIEMENS

Turbine series SST-110 (TWIN) and SST-120 (Tandem)

TWIN-Design



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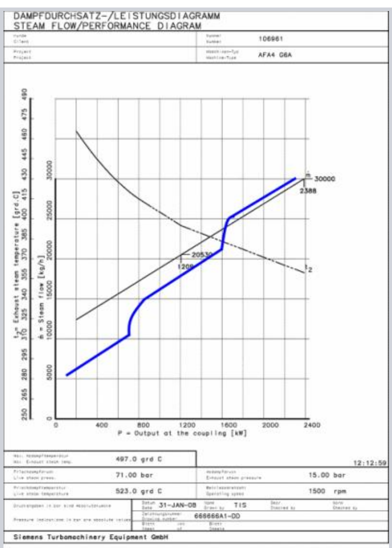
Nozzle Group Control



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Turbine series SST-110 (TWIN) and SST-120 (Tandem)

Turbine series SST-110 / SST-120 (TWIN / Tandem-Typ) – up to 10 000 kW

Products:	 
Applications:	▶ Combined heat and power (CHP), Biomass, Waste-to-energy, Heat recovery
Markets: *(Examples)*	▶ Chemistry, Wood / Paper industry, Utilities, Municipalities, Mills / Steel industry, IPP / Contracting / Engineering, Food & Beverage, Waste incineration plants

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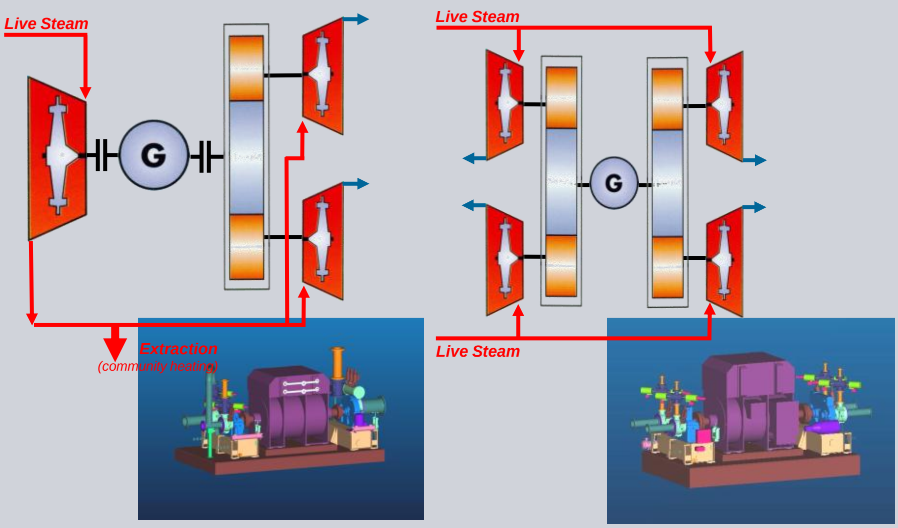
Turbine series SST-110 (TWIN) and SST-120 (Tandem)



SIEMENS

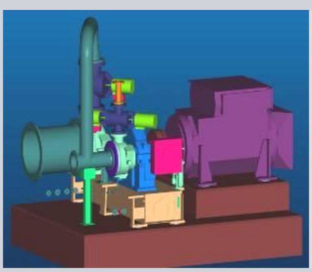
TWIN SST-110 (former CA 56k)

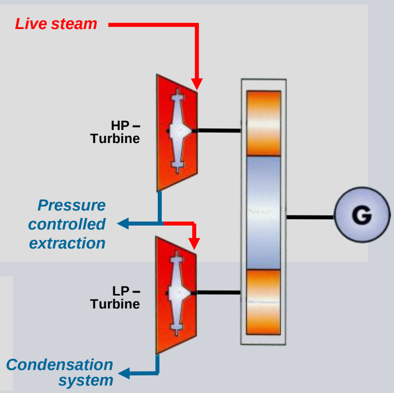
SIEMENS

Technical Details:

SST-110 TWIN - Offer 114790-1A

SST-110 (TWIN-CA 56k)



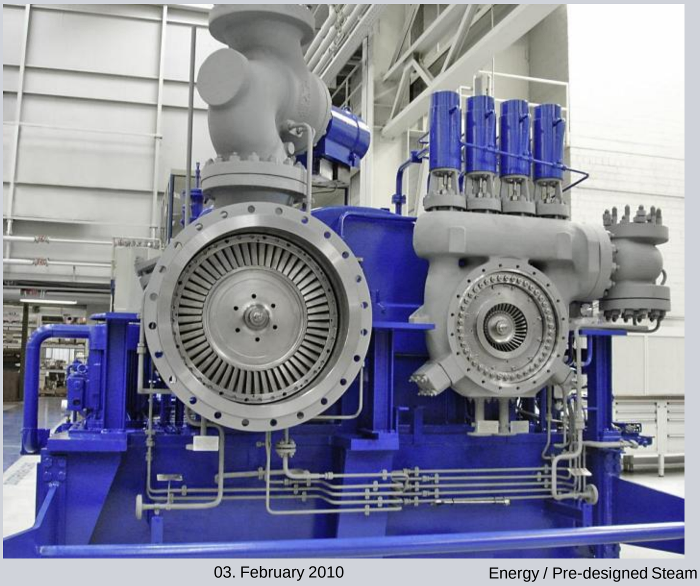


Operating data:

Live steam pressure:	18.0 bar a
Live steam temperature:	445°C
Condensing pressure:	0,12 bar a
Extraction pressure:	3 bar a
Electrical output:	to 2 842 kWe

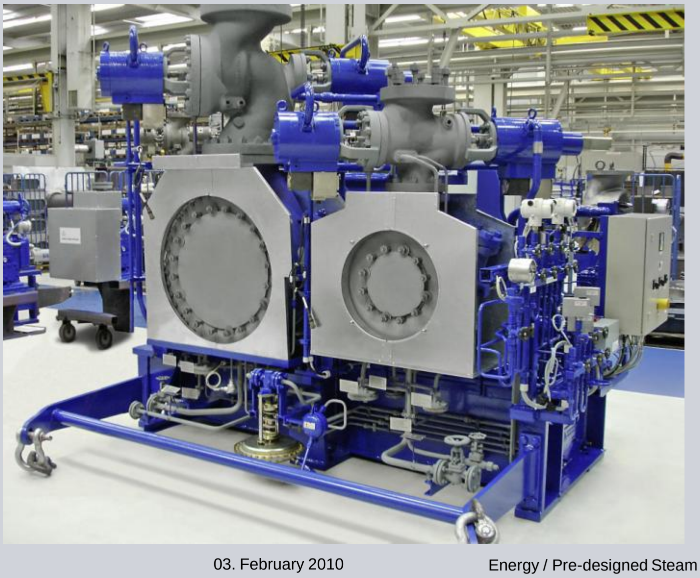
SIEMENS

Technical Details

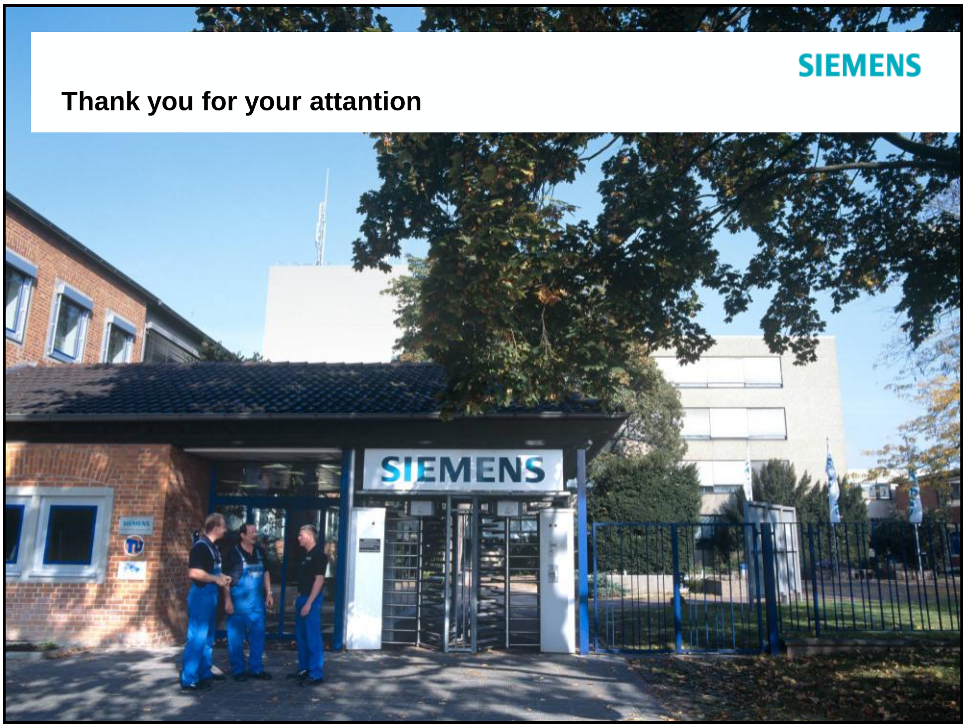


SIEMENS

Technical Details



Thank you for your attention



Annex 13. Perspectives to data collected through the Danish follow-up program for biomass CHP

Henrik Flyver Christiansen, Danish Energy Agency, Denmark

Small scale biomass co-generation Danish experience and perspective

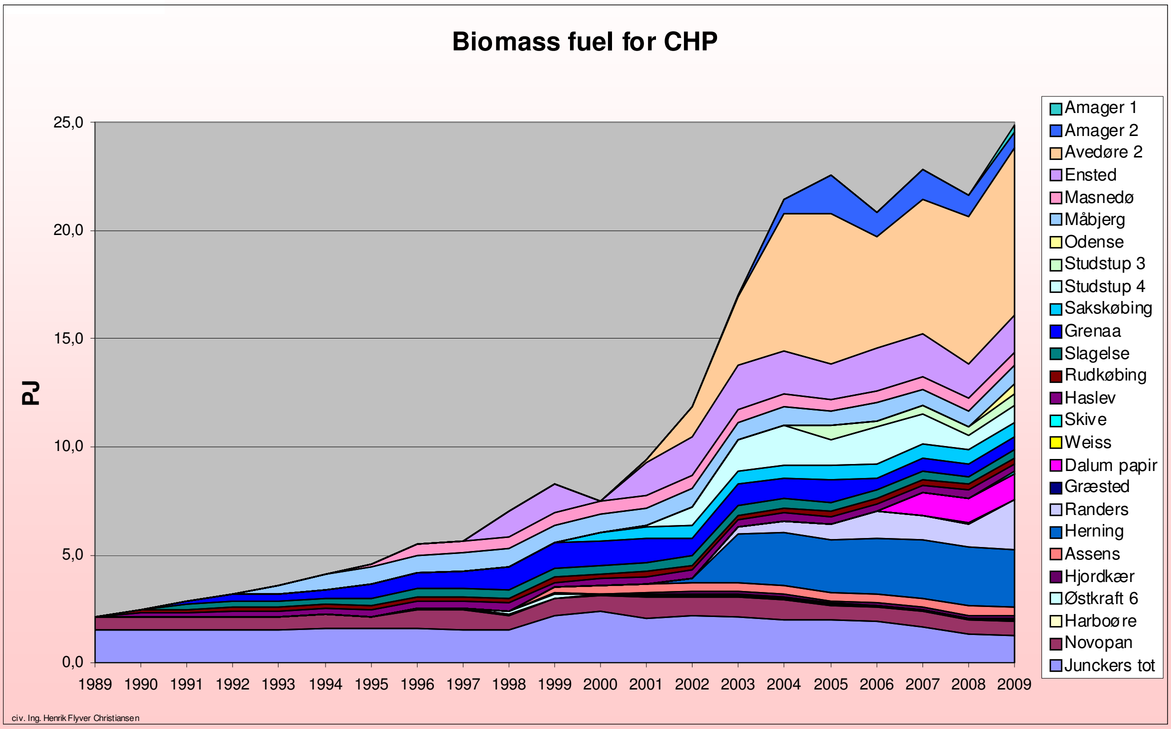
IDA workshop October 7. 2010

Henrik Flyver Christiansen
Danish Energy Agency

DK Follow-up programme

- Started 1993 continued to 2005 on full load.
- Process-, fuel-, energy-, environment-, waste water-, ash-, chemical- and economy analysis
- Monthly data collection
- Continues reporting.
- Task group

Danish Follow-up Programme for Solid Biomass CHP Plants



DANISH ENERGY AGENCY

Danish Follow-up Programme for Solid Biomass CHP Plants

Fundamental consideration

- Saving – reduced consumption
- Efficiency – reduced consumption
- Renewable energy – reorganize production
- Long term - Biomass become only carbon resources.

DANISH ENERGY AGENCY

Energy Supply, Bioenergy, Civ. Ing. Henrik Flyver Christiansen

Danish Follow-up Programme for Solid Biomass CHP Plants

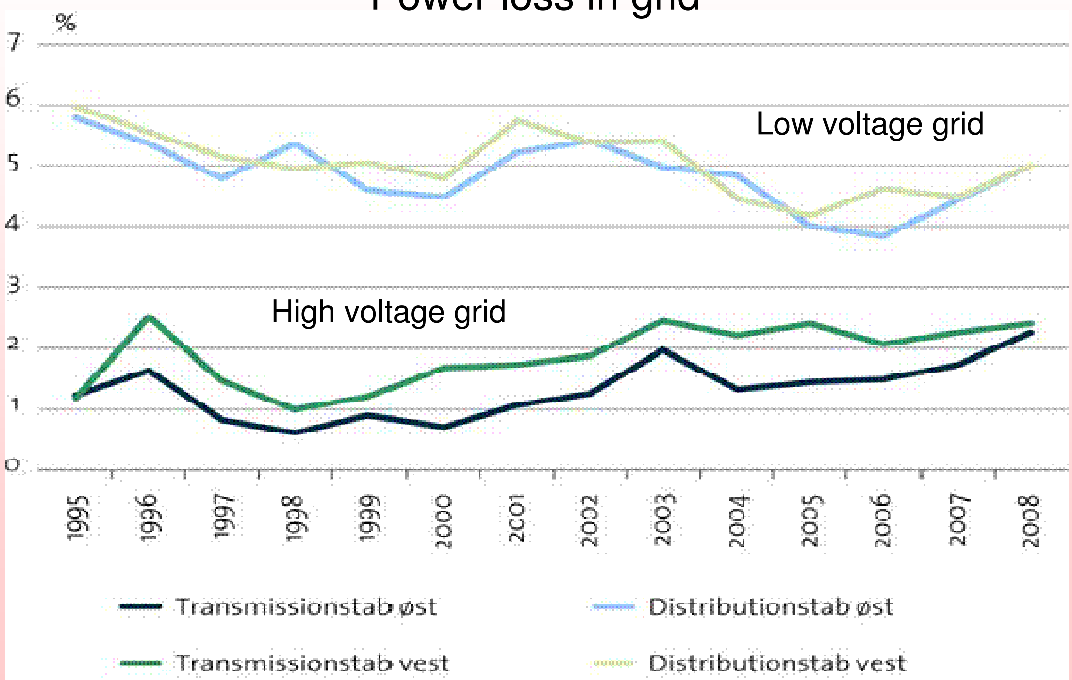
Unique Danish position

Consumption <=> Production

- National power grid – partly storable
- National natural gas grid – partly storable
- Local district heating – storable
- Transport of fuel / product - storable
- Information transport – storable

Danish Follow-up Programme for Solid Biomass CHP Plants

Power loss in grid



Source Miljørapport 2009, Baggrundsrapport, Energinet.dk

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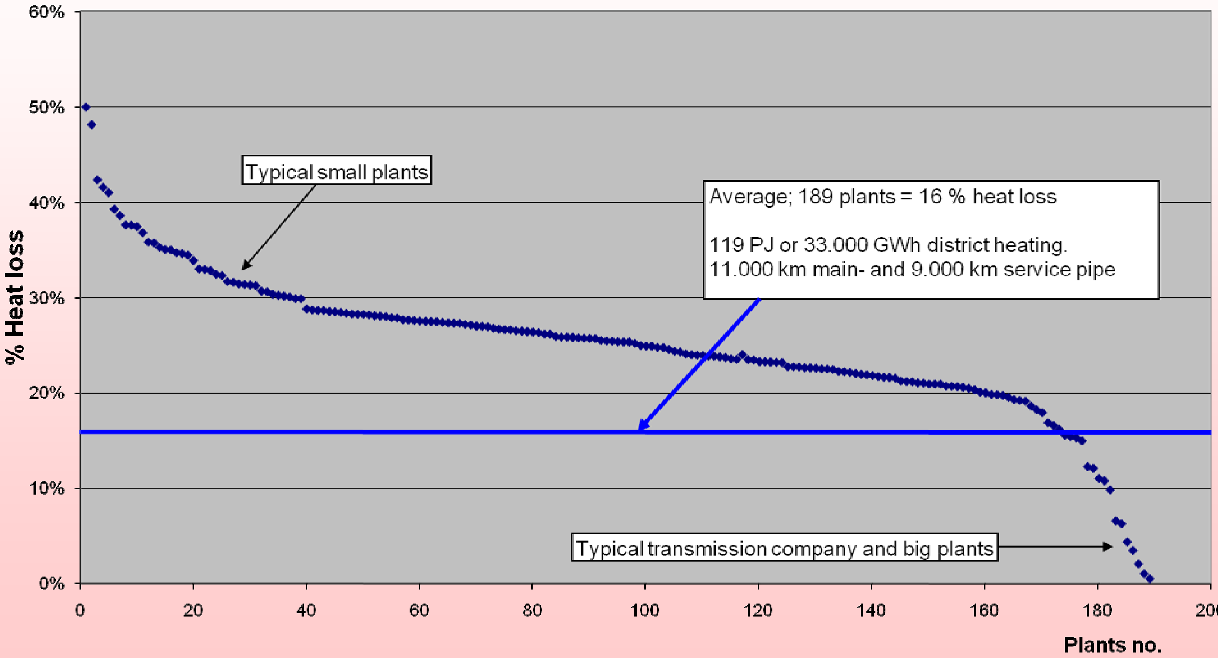
Danish Follow-up Programme for Solid Biomass CHP Plants

Heat loss in district heating



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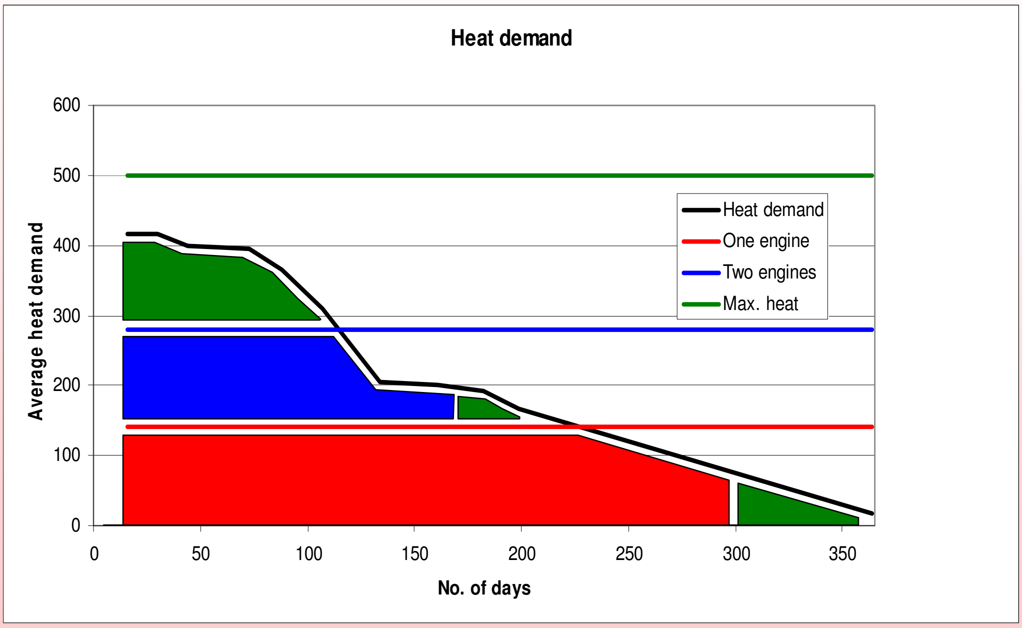

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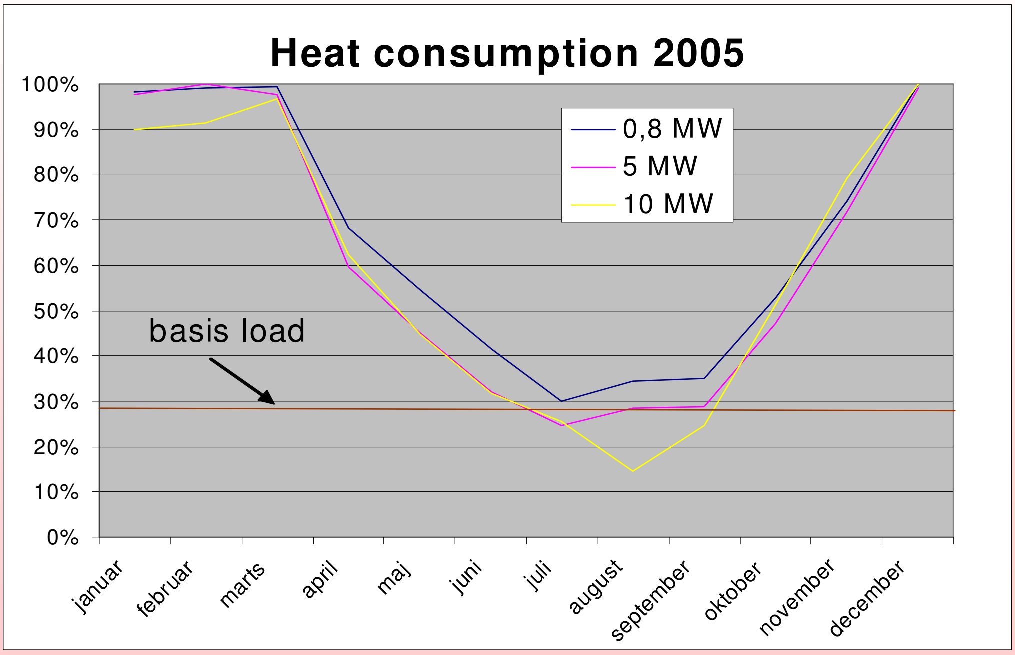
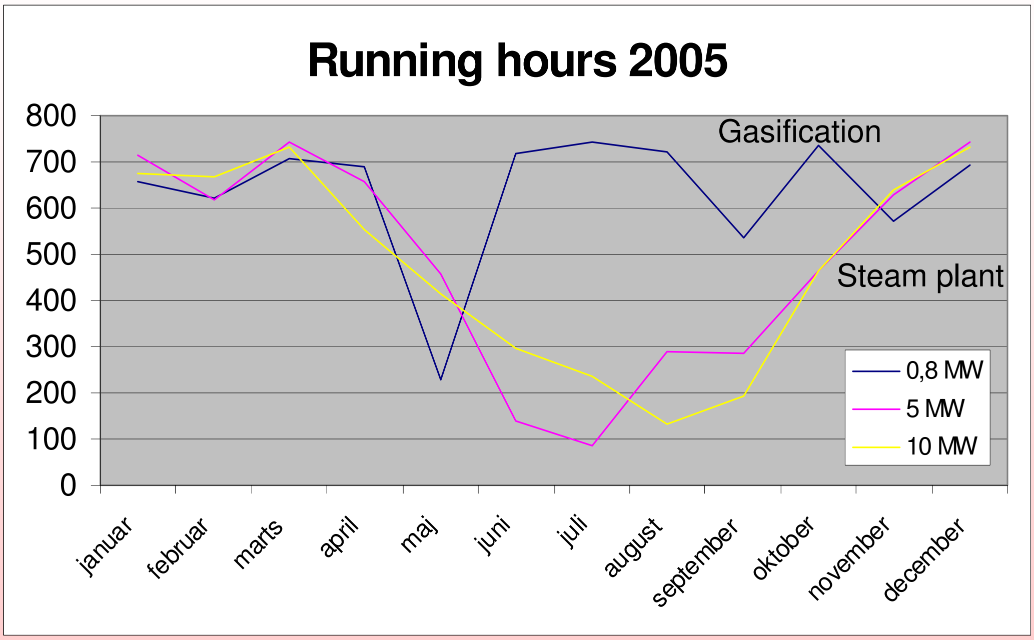
Danish Follow-up Programme for Solid Biomass CHP Plants

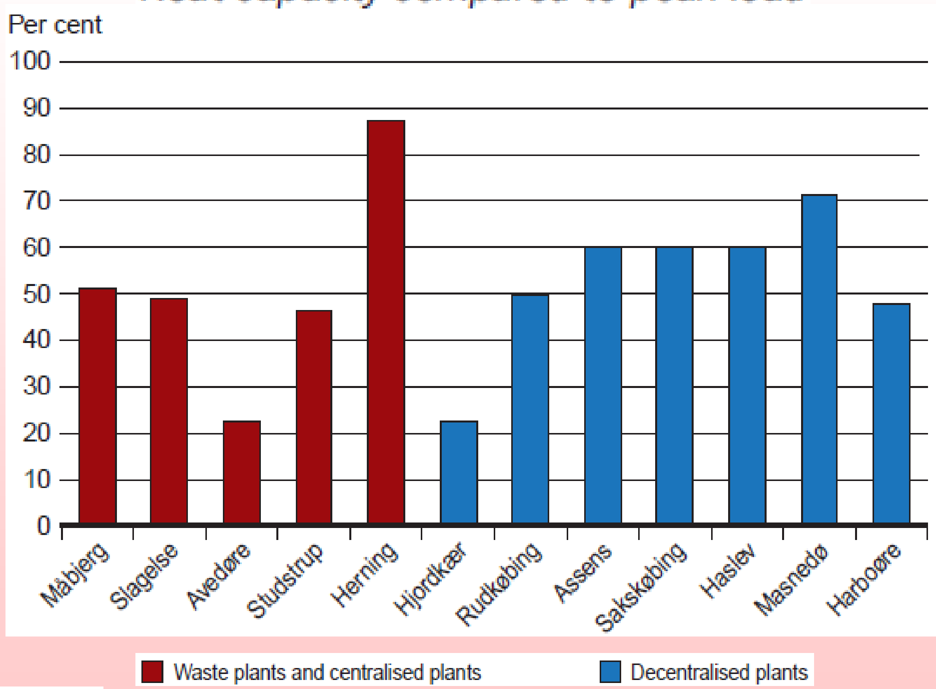


Danish Follow-up Programme for Solid Biomass CHP Plants



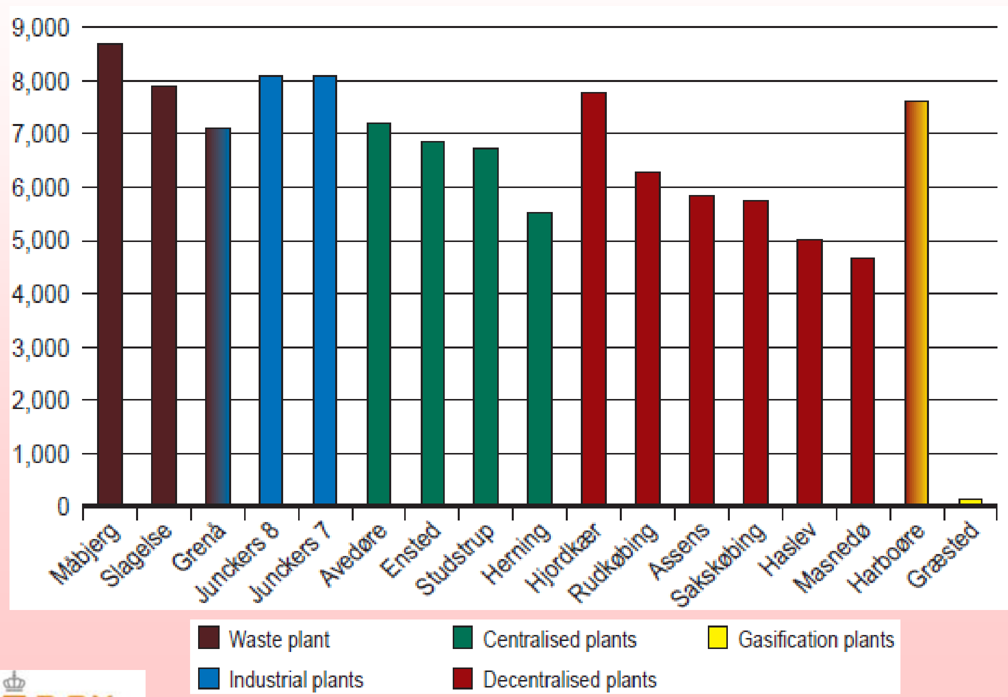
Danish Follow-up Programme for Solid Biomass CHP Plants

Heat capacity compared to peak load



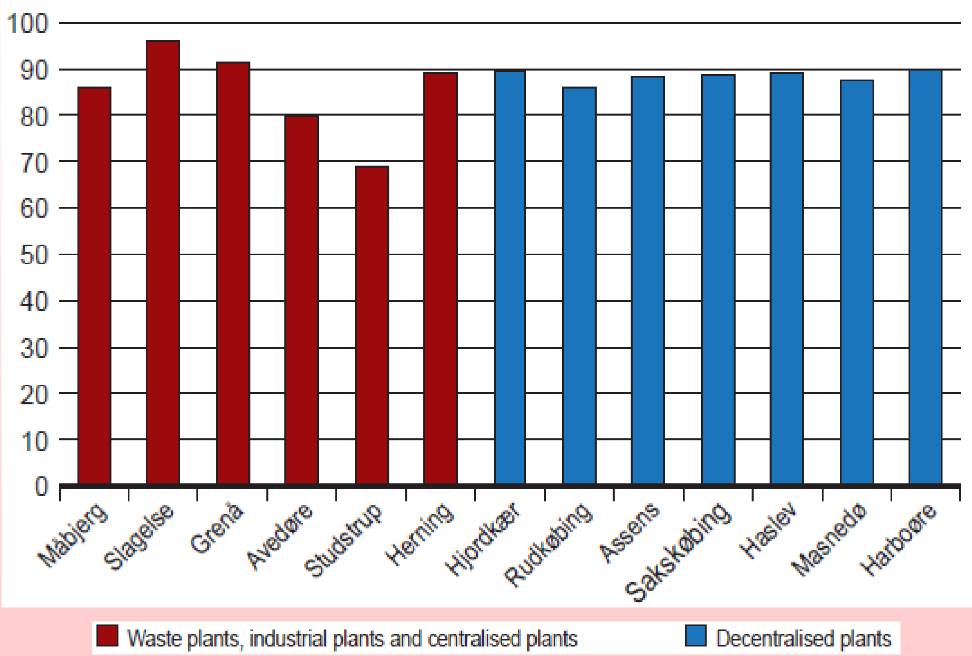
Danish Follow-up Programme for Solid Biomass CHP Plants

Operation hours in 2005



Danish Follow-up Programme for Solid Biomass CHP Plants

The average total efficiency for the plants in 2005.



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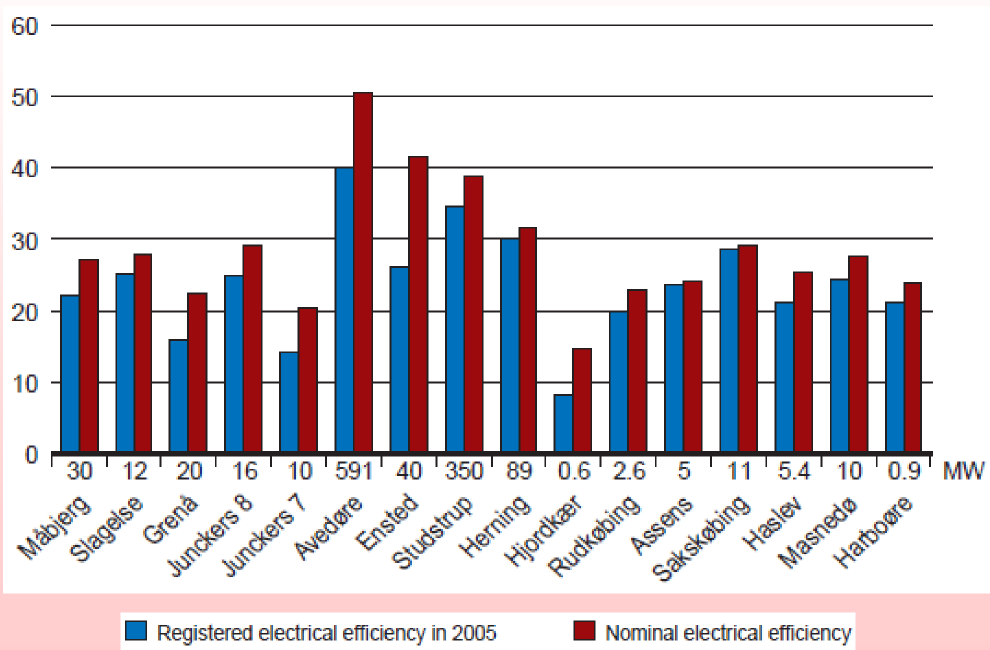
Power efficiency in 2005



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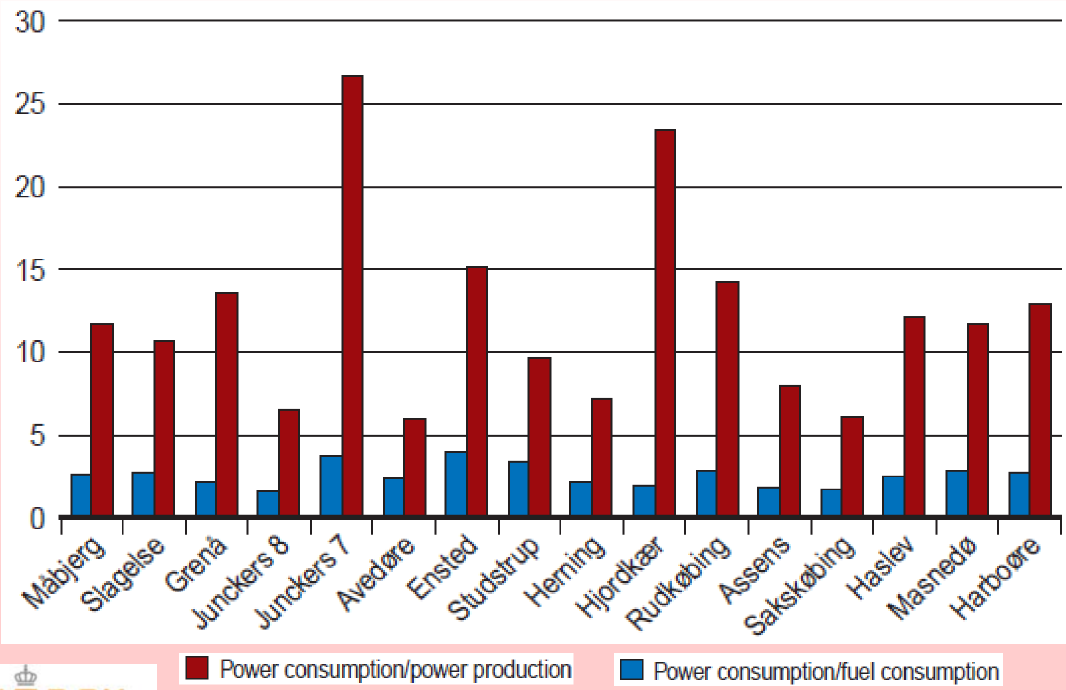
Power consumption in 2005



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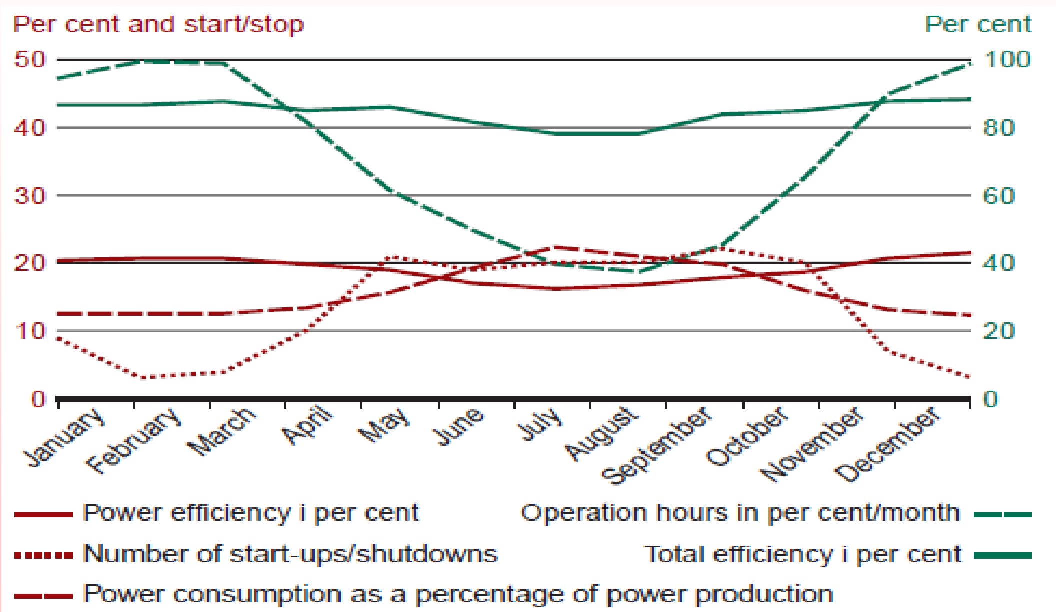
Rudkøbing 2,3 MW steam in 2005



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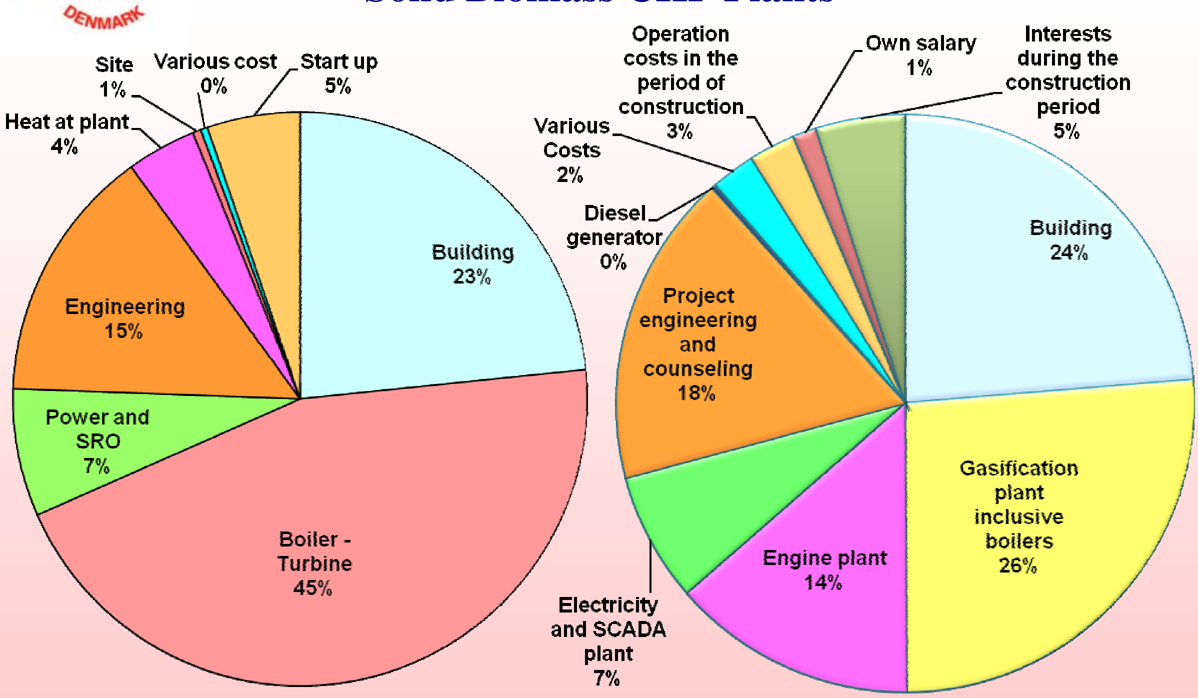

Steam Plant. Straw

Gasification Plant. Wood

Plant Investment

Danish Follow-up Programme for Solid Biomass CHP Plants

Key no. and Plant Investment

	Fuel MW	Electricity MW	Heat MW	Liquid MW	Costs Mio. DKK	Rate Mio. DKK/MW
Skive project	18	6	10	0	250	42
Skive optimised	28	9	16	0	288	32
Skive 2 + fuel	28	10	15		262	26
Skive 2 + liquid	28	10	15	18	302	30
Skive 2 pressurized + oxygen	98	43	43		608	14
Straw combustion, 2002 costs; Sakskøbing	39	11	23		252	22

DK Follow-up programme

Some results:

- **Combustion**: fuel- and ash handling. Plant guarantee. Plant consumption – cut down.
- **Gasification**: Tar- and dust measurement. Guarantee for engine. Basis research.
- **Common**: Standard for fuel. Standard for preforment test.

How to make success

- Secure delivery of homogeneous fuel
- Step by step – don't do every thing at same time
- Development takes time – often more than 10 years for new technology
- National network of developer and supplier
- New plant don't work
- The staff at the plant
- Long term program and a lot of money

Danish Follow-up Programme for Solid Biomass CHP Plants

Development of Straw Fired CHP Plants