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BIOMASS BASED POWER GENERATION

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***Abstract* :** Biomass gasification appears to be an effective strategy not only to avert an impending future energy crisis but also reducing carbon emissions from fossil fuels. Gasification is a technology that has great potential in terms of efficiency of conversion of biomass into both thermal and electric power generation. It is in this context that a comprehensive overview of the biomass technologies available, its potential applications and economic analysis with different design solutions, are discussed in the present communication.

Keywords: Biomass, gasification, thermal energy conversion, fluidized bed gasifier, economic analysis, case study.

1. INTRODUCTION

Considering limited availability of conventional fuels worldwide along with ever increasing energy demand, especially in the developing World, it is imperative to search new alternative sources to supplement or substitute the traditional ones. Due to its strategic role in the sustainable worldwide development, use of biomass for energy purpose has gained a considerable attention over the last couple of years [1]. Amongst different technologies employed for the production of clean energy [2-4], gasification certainly represents one of the most potential and interesting options both as a well-established technology and having a variety of applications [5]. The technology being relatively simple to use as well as versatile is of great interest for both underdeveloped and industrialized countries.
Gasification plants of low-to-medium thermal capacity appear to be of considerable interest since they help to optimize transport infrastructure and distribution of hydrogen locally but eliminate large structural and distribution carriers, generally required in case of conventional energy, as well [6-8].
It is in the above context that in addition to a comprehensive review of the biomass gasification technologies available as on today, a detailed economic analysis has been conducted to investigate the effect of different parameters and variables on the cost of energy produced. Cost estimation for the per unit energy produced under different solutions investigated demonstrates that it strongly depends upon the size and type of the plant used. The value, no doubt, a little bit high compared to the energetic cost of conventional fossil fuels still appears to be interesting, especially in the free-tax situation.

Status of biomass based power generation

An extensive review of gasifier manufacturers in Europe, USA and Canada, identified 50 manufacturers offering 'commercial' gasification plants from which:

- 75% of the designs were downdraft type,
- 20% of the designs were fluidized bed systems,

- 2.5% of the designs were updraft type, and,
- 2.5% were of various other designs.

However, there was very little information on cost aspects, emissions, efficiencies, turn-down ratios and actual operating hours experience. Actual operating experience is limited and there is little confidence on the technology, which is due to the general poor performance of the various prototypes. Atmospheric Circulating Fluidized Bed Gasifiers (ACFBG) have proven very reliable with a variety of feedstocks and are relative easy to scale up from few MWth up to 100 MWth. Even for capacities above 100 MWth, there is confidence that the industry would be able to provide reliable operating gasifiers.

It appears to be the preferred system for large scale applications and it is used by most of the industrial companies such as TPS, FOSTER WHEELER, BATTELLE, LURGI and AUSTRIAN ENERGY.

Therefore ACFBG have high market attractiveness and are technically well proven. Atmospheric Downdraft Gasifiers (ADG) are attractive for small scale applications (<1.5 MWth), not only in developed but developing economies too. However, the problem of efficient tar removal is still a major problem to be addressed and there is a need for more automated operation especially for small scale industrial applications. Nevertheless, recent progress in catalytic conversion of tar gives credible options and ADG can therefore be considered of average technical strength.

Atmospheric Updraft Gasifiers (AUG) have practically no market attractiveness for power applications due to the high concentration of tar in the fuel gas and the subsequent problems in gas cleaning. Atmospheric Bubbling Fluidized Bed Gasifiers (ABFBG) have proven reliable with a variety of feedstocks at pilot scale and commercial applications in the small to medium scale; up to about 25 MWth. ABFBG are more economic for small to medium range capacities. Companies promoting ABFBG are CARBONA and DINAMEC.

Atmospheric Cyclonic Gasifiers (ACG) have only recently been tested for biomass feedstocks and although they have medium market attractiveness due to their simplicity, they are still unproven. Finally, Atmospheric Entrained Bed Gasifiers (AEBG) are still at the very early stage of development.

Pressurized fluidized bed systems either circulating (PCFBG) or bubbling (PBFBG) are complex due to their installation related problems as well as the additional costs related to the construction of all pressurized vessels. No company is presently developing pressurized systems for downdraft, updraft, cyclonic or entrained bed gasifiers for biomass feedstocks and it is difficult to imagine that such a technology could ever be developed into a commercial product due to the inherent problems of scale, tar removal and cost. Bubbling fluidized bed gasifiers can be competitive in medium scale applications. Large scale fluidized bed systems have become commercial due to the successful co-firing projects while moving bed gasifiers are still trying to achieve this.

In conclusion, for large scale applications the preferred and most reliable system is the Fast Internally Circulating Fluidized Bed Gasifier (FICFB) while for the small scale applications the downdraft gasifiers are the most extensively studied.

At present, 87 gasification facilities are active. Fifty-four of them can be found in Task 33 member countries whereas remaining 33 in other countries. (Austria 9, NZ 1, Denmark 7, Norway 0, Italy 0, Sweden 4, Finland 4, Switzerland 4, Germany 7, Turkey 2, Japan 2, Netherlands 6 and USA 8). Co-firing (4 gasification facilities); CHP (37 gasification facilities), Synthesis (34 gasification facilities); Other innovative (12 gasification facilities)

It is worth to note that majority of all 87 gasification facilities are now in operation (59%), an additional 14% are in construction, 3% are in commissioning and 16% are planned. Only 8% of all gasification facilities are on hold. *N*early a half of all gasification facilities (47%) are commercial, 27 % pilot plants and 26% demo plants. Based on the successful operation of Güssing plant, the FICFB gasifier has been commercialized in six plants in Europe in stages of planning, construction or operation.

Status Of R&D Activities On Biomass Gasification At ENEA

Because of the high potential awarded to this energy source, efforts are mainly focussed to sharply increase the utilisation of biomass, in Italy. With respect to the exploitation of biomass, R&D activities, as shown in Fig. 1, are focused mainly on the development of gasification processes for the production of gaseous energy carriers of higher value (suitable for direct application in CHP production) or as synthesis gas of to produce derived fuels (e.g. hydrogen, SNG, Fischer-Tropsch liquids, methanol, DME). Different biomass gasification technologies and gas cleaning / and conditioning, have already been investigated. In order to allow the exploitation of low value feedstocks, such as biomass residues from forest management, agro-industrial and agricultural sectors and wood industries, R&D activities are focused mainly on the development of small to medium size technologies for power production.

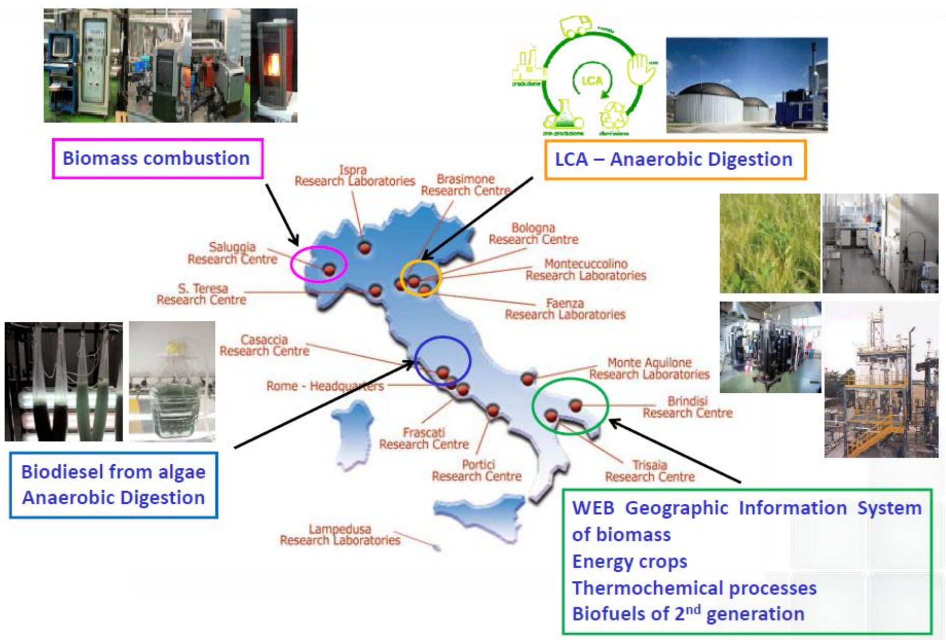


Fig. 1 Research and development activities on Biomass gasification at ENEA

Research and development activities on thermochemical conversion processes are focused on gasification and pyrolysis. The main objective of is to produce power, advanced energy carrier, gaseous streams for synthesis, recover energy and materials, etc. Several projects (hermos-chemical conversion process of biomass via gasification) in co-operation with both national and international institutions have either already been completed or are in progress.

A technology park dedicated to biomass gasification, as shown in Fig. 2, is present at ENEA Trisaia Research Centre.

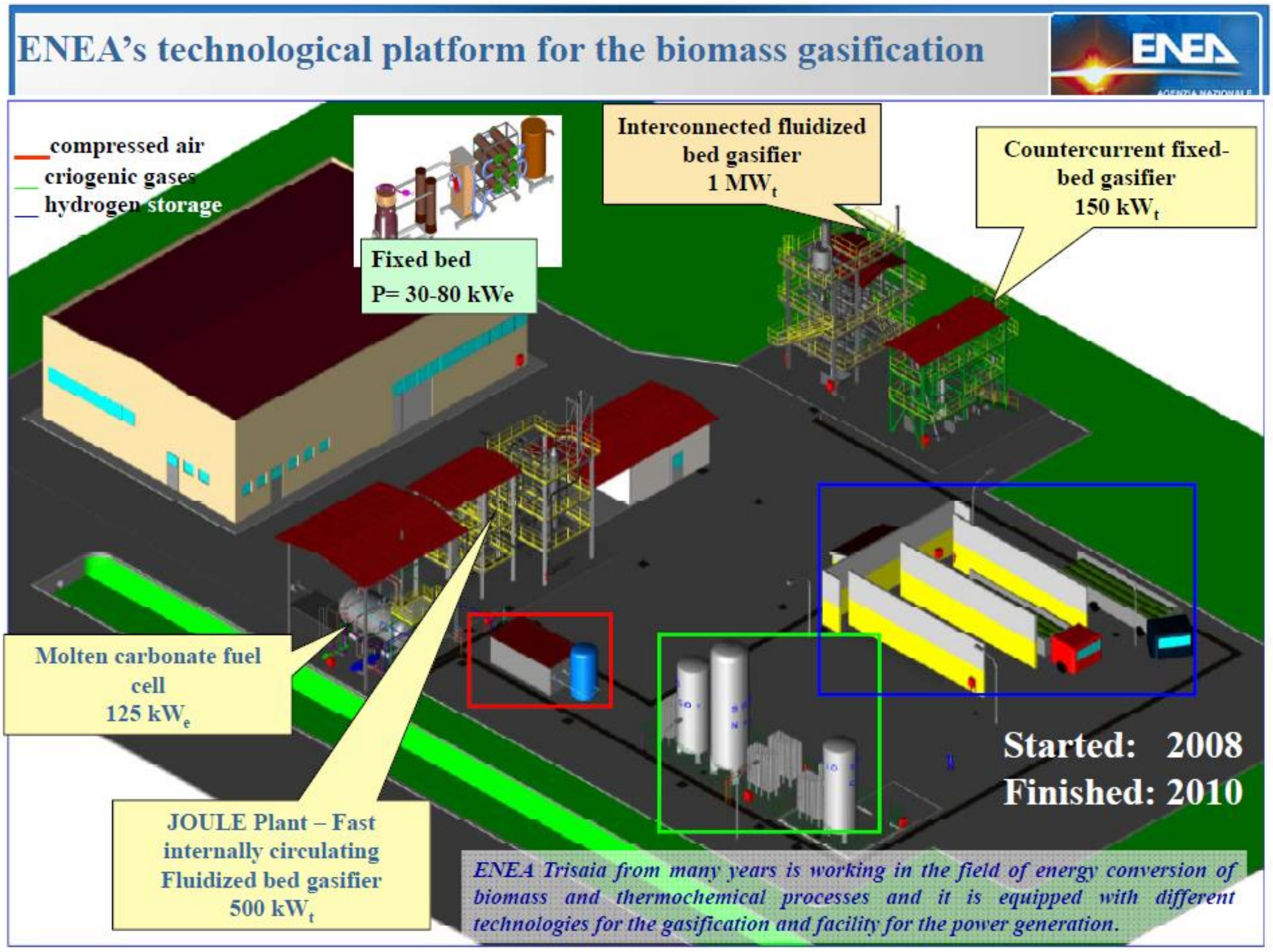


Fig. 2 Technology park dedicated to biomass gasification at ENEA Trisaia Centre, in Italy

Five pilot gasification plants of size ranging between 120 kWth to 1000 kWth, based on different gasification reactor design (i.e. fixed bed, fluidized bed and staged gasifiers) and coupled with advance technique for the achievement of effective gas cleaning and conditioning, are available at the centre. The plants have been investigated experimentally to test the most promising field of application (production of fuel gas for power generation) following different possible ways such as via internal combustion engine, gas turbines and high temperature fuel cell (MCFC).

The use of biomass gasification for syngas production to biofuels conversion has also been considered. $1MW_{th}$ reactor for the production of a fuel gas to be fed to a gas turbine, designed and developed by ENEA, is under thorough investigation. The product gas will be produced by oxygen/steam gasification of biomass by means of a bubbling fluidized bed.

The Internally Circulating Bubbling Fluidized Bed (ICBFB) gasification plant, as shown in Fig. 3 [9], is based on a 1000 kW_{th} reactor and operates a steam/ oxygen gasification process to generate a produced gas of medium heating value (LHV 9-12 MJ/Nm^3dry) [10-12].

The gas can be used for efficient CHP application (i.e. via GT and HTFC) or, thanks to the absence of nitrogen, as starting gas mixture for gaseous and liquid biofuels synthesis (i.e. SNG, FT diesel, MeOH, DME) and for H_2 production for advanced applications, as for instance in FC vehicles.

Fig. 3 Internally Circulating Bubbling Fluidized Bed (ICBFB) gasification plant

The gasifier is based on a patented reactor design that, compared to conventional bubbling fluidized bed reactors, implements a modification to prolong the residence time of the biomass feedstock inside the reaction bed. Recently, at this plant the integration of a filtration system directly inside the gasification reactor, has been implemented. The new system is based on the use of High-Temperature ceramic candles and aims at a simplification of the conventional downstream plant sections for gas purification. During experimental gasification campaigns with this filtration system a dust removal efficiency higher than 99 %wt was achieved.

One 500 kW_{th} staged pilot plant based on a three stages gasification process carried out in different units, is shown in Fig. 4. The process starts with the pyrolysis of the supplied biomass which is performed inside an indirect heated screw reactor, by using part of the product gas as fuel. The pyrolysis gas is then conveyed to a partial oxidation reactor where tars are mostly cracked and converted into lighter gases, while the pyrolysis char is fed to an open core downdraft reactor, with air/steam primary and secondary lines. The char bed also acts as an active carbon filter for raw product gas.

Overall, the ultimate results are a producer gas with a very low tar level content and the possibility of using a wide range of biomass feedstocks (including low value residues, e.g. AD sludge) as solid fuels.

Fig. 4 500 kWth there stages gasification plant

Current state of the technological platform for ENEA's R&D activities on biomass gasification is shown in Fig. 5.

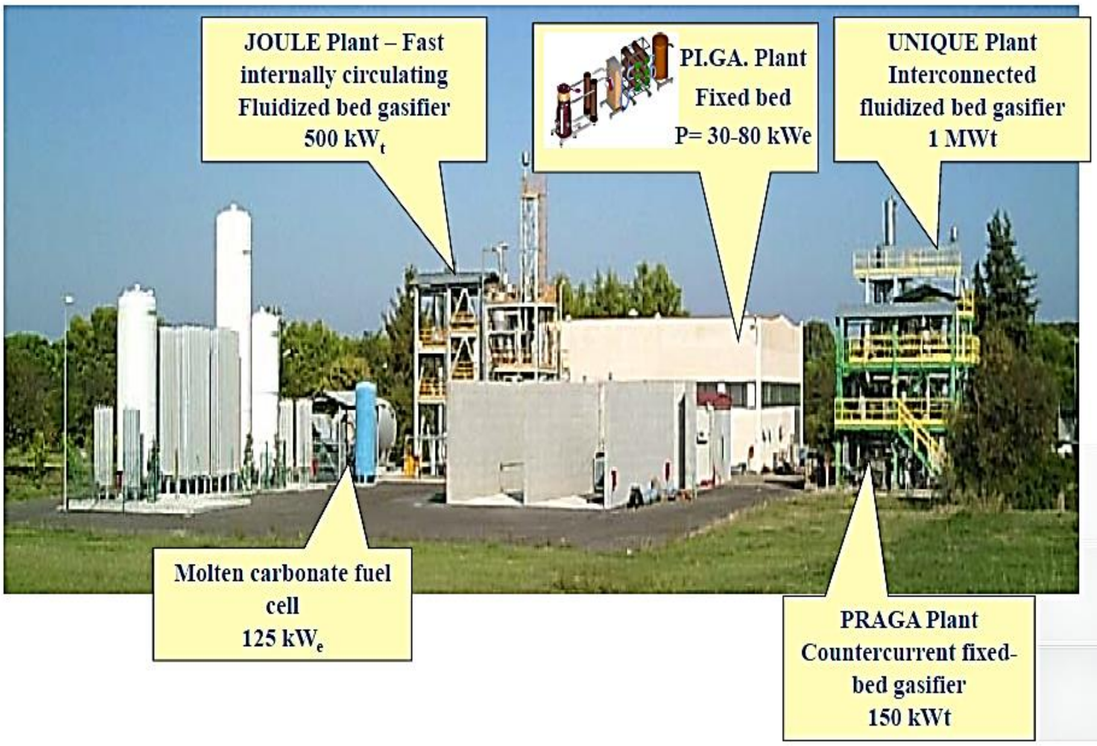
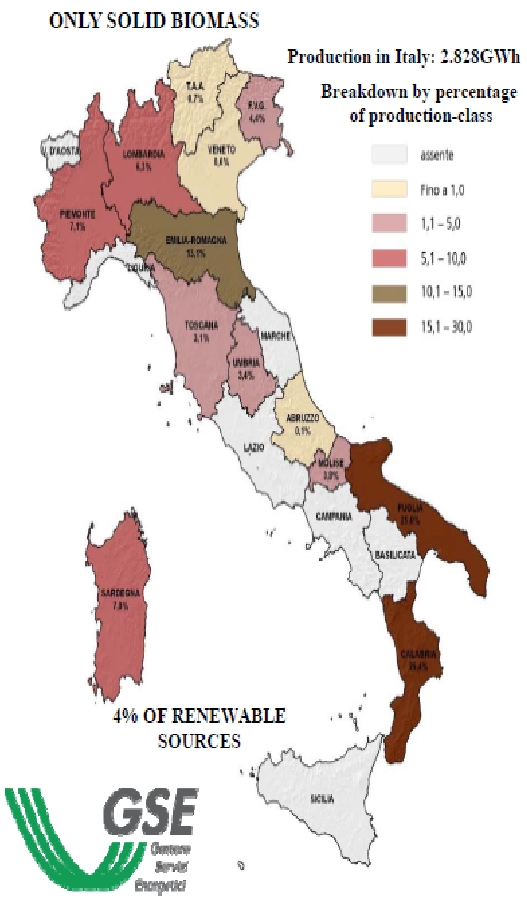


Fig. 5 Current state of the technological platform for ENEA's R&D activities on biomass gasification

Status of biomass gasification plant that are operational, in Italy, is given below (Fig. 6).



Source: GSE National Manager of the Energy Services

BIOMASS GASIFICATION PLANT THAT ARE OPERATIONAL IN ITALY

PLANT	POWER (kWe)	MANUFACTURER OF THE SYSTEM	CHARACTERISTICS OF THE PLANT
Belluno(BL)	1000	GAS-1000 MODEL	The plant is fed with 8500t/a of wood
Parma	1000		The plant produces 7.5GWhee 15GWht and it is powered with 9000 t/a of kenaf
Gadesco Pieve(CR)	960	Agroenergia	The pyrogasificator is fed with chopped or chipped vegetable biomass
Alessandria	640		The system is experimental and the process has been developed by poliTO; the plant is fed with 4100 t/a of biomass from forest
Vigevano(PV)	500	Modello GAS-500	The plant produces 3.75GWhe and 7.5 GWht and it is powered with 4100 t/a of wood chips
Caluso(TO)	400	Autogas Nord	The plant is fed with residues of agricultural production, forest biomass, leaves, waste of food industry
Oltrepo Pavese(PV)	300	Bio&Watt	The plant uses an endothermic motor
Castel San Pietro(BO)	250	Bio&Watt	The pyrogasificator is fed with waste prunings, corn stalks, wood chips of poplar
Orzinuovi(BS)	250	Bio&Watt	The pyrogasificator is powered by biomass from forests
Verbania	250	CoVer Energy	The plant is classified as experimental

Gasification is a technology that has great potential in terms of efficiency of conversion of biomass into electricity.
During 2010 requests for qualification that have come to the GSE concern another 20 plants under construction with a total power over 20MWe

Combustion is by far the predominant energy conversion technology

Fig. 6. Biomass gasification plant that are operational, in Italy

CASE STUDY : BIOMASS CHP PLANT IN GÜSSING, AUSTRIA (Fig. 5)

Güssing is a small town with about 4,000 inhabitants and located in eastern part of Austria (Burgerland) near the Hungarian border. It is the capital of a district with 27,000 people. For a long time the Austrian-Hungarian border was called the iron curtain. There used to be huge deficits in infrastructure: lack of highways, roads, railways, therefore no industry settled there. This led to the lacking of industry. The municipality could not get much income from local business taxes. These negative circumstances led to the high rate of unemployment, migration to other cities. More than 70% of the working inhabitants became commuters. The region was very poor until biomass as source of energy was discovered and utilized in the region.

In the year of 1989, the major of Güssing and some experts worked out a concept for the energy supply of Güssing. The point of the concept was to satisfy the local energy demands based on local energy producers who utilize local resources.

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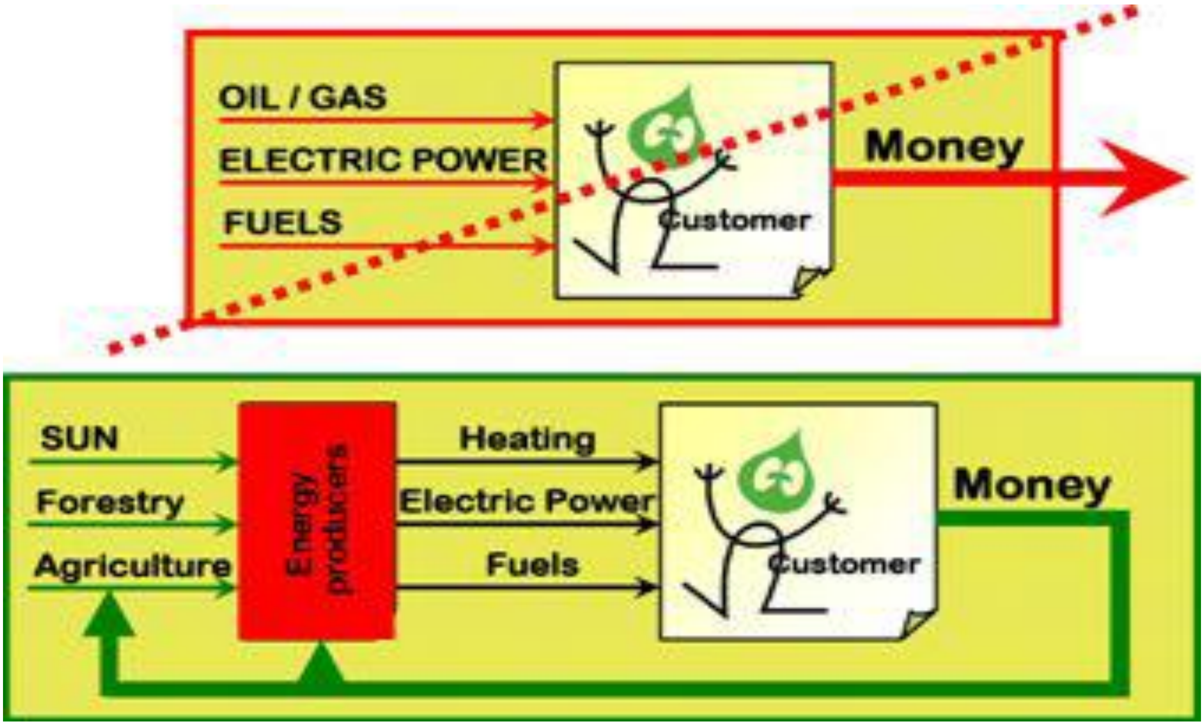
The essence of the Güssing concept is summarized below.



First the energetic optimization of buildings were carried out – reducing local energy demand – then demonstration energy plants were established in the region. The flagship of the most important innovation is the **combined heat and power plant with fluidized bed steam gasification technology**. Apart from the gasification CHP plant there are various research projects are being carried on in Güssing concerning incineration, solar energy, hydrogen generation, fuel cells, the production of methane from syngas, Fisher-Tropsch synthesis etc. The aim of these research projects is to produce heat, electricity, gaseous and liquid fuels to satisfy the energy demands of the region and be as much independent from energy import as possible.

The basic idea of the gasifier concept (Fig. 7) is to divide the fluidized bed into two zones, a gasification zone and a combustion zone. Between these two zones a circulation loop of bed material is created but the gases should remain separated. The circulating bed material acts as heat carrier from the combustion to the gasification zone. The fuel is fed into the gasification zone and gasified with steam. The gas produced in this zone is therefore nearly free of nitrogen. The bed material, together with some charcoal, circulates to the combustion zone. This zone is fluidized with air and the charcoal is partly burned.

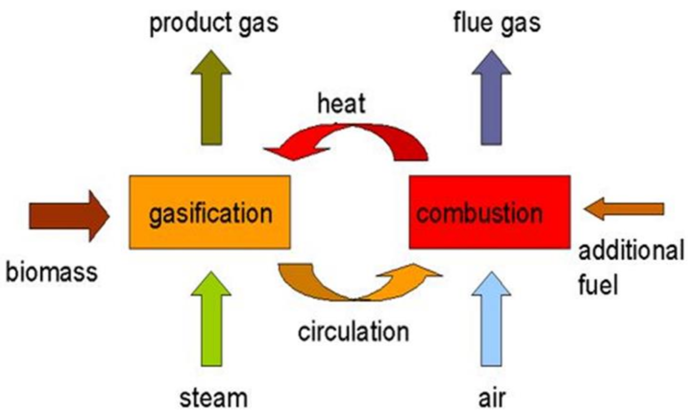


Fig. 7 The basic idea of the gasifier concept

The exothermic reaction in the combustion zone provides the energy for the endothermic gasification with steam. Therefore the bed material at the exit of the combustion zone has a higher temperature than at the entrance. The flue gas will be removed without coming in contact with the product gas. With this concept it is possible to get a high-grade product gas without use of pure oxygen. This process can be realized with two fluidized beds connected with transport lines or with an internally circulating fluidized bed.

<u>Description of the Biomass CHP Güssing</u> (Fig. 8)

In Guessing an innovative process for combined heat and power production based on steam gasification has been successfully demonstrated.

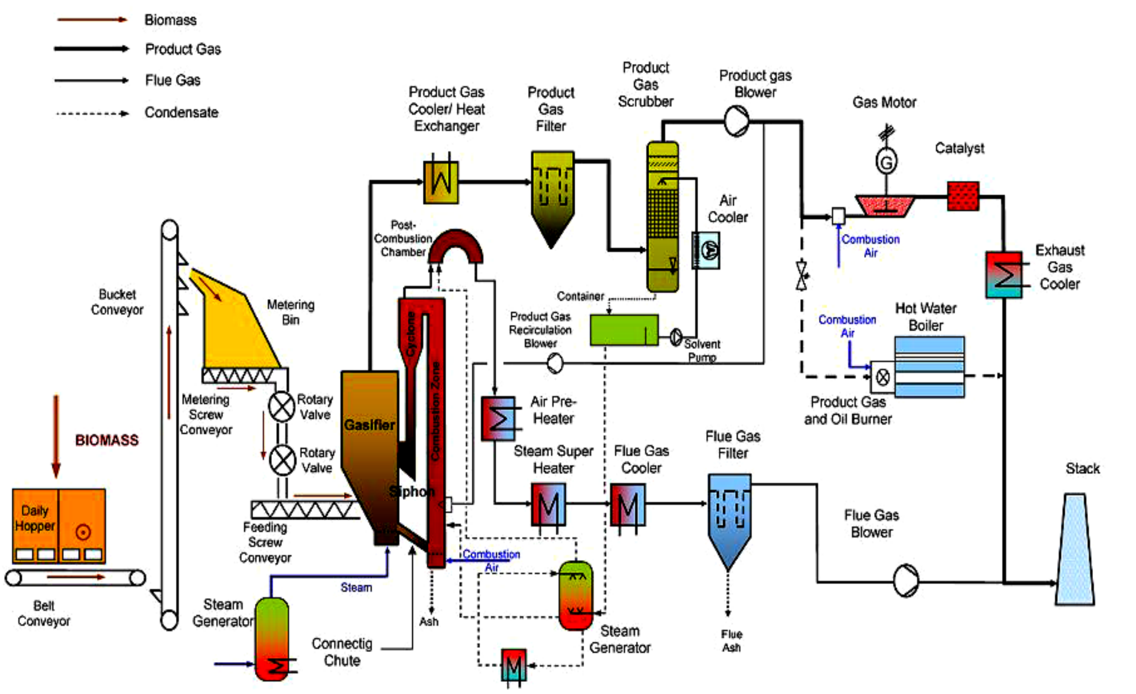


Fig. 8 Schematic flow diagram of the biomass power plant in Guessing

The system consists of the following main components

- biomass feeding system,
- gasifier (gasification and combustion zone),
- product gas cooler,
- product gas filter,
- product gas scrubber,
- product gas blower,
- gas engine,
- water boiler,
- flue gas cooler,
- flue gas filter, and
- flue gas (gas engine) cooler.

The fluidized bed gasifier consists of two zones, a gasification zone and a combustion zone. The gasification zone is fluidized with steam which is generated by waste heat of the process, to produce a nitrogen free producer gas. The combustion zone is fluidized with air and delivers the heat for the gasification process via the circulating bed material.

A water cooled heat exchanger reduces the temperature from 850°C – 900°C to about 150°C – 180°C.The producer gas is cooled and cleaned by a two stage cleaning system. The first stage of the cleaning system is a fabric filter to separate the particles and some of the tar from the producer gas. These particles are recycled to the combustion zone of the gasifier. In a second stage the gas is liberated from tar by a scrubber. Spent scrubber liquid saturated with tar and condensate is vaporized and fed for thermal disposal into the combustion zone of the gasifier. The scrubber is used to reduce the temperature of the clean producer gas to about 40 °C.

The clean gas is finally fed into a gas engine to produce electricity and heat. If the gas engine is not in operation the whole amount of producer gas can be burned in a backup boiler to produce heat. The flue gas of the gas engine is catalytically oxidized to reduce the CO emissions. The sensible heat of the engine's flue gas is used to produce district heat. The flue gas from the combustion zone is used for preheating air, superheating steam as well as to deliver heat to the district heating grid. A gas filter separates the particles before the flue gas of the combustion zone is released to the environment.

The plant fulfils all emission requirements. The operation experience shows that there is only one solid residue which is the fly ash from the flue gas. This fly ash fully burned out, the loss of ignition is lower than 0.5 w- %. The plant produces no condensate which has to be disposed externally.

The plant uses a special **fluidized bed steam gasification technology** which was developed at Vienna University of Technology in cooperation with AE Energietechnik and RENET. The plant started operation in 2001 and after the optimization phase it still working perfectly.

It is the first utility-scale power plant of its kind in the world, with a rated capacity of **8MW**, producing on average about **2MW** of electricity and **4.5MW** of heat per hour.

Operating at **8,000 hours per year** for the last several years, the Güssing facility, together with a network of smaller district heating plants and other renewable energy units, produces more energy than the town consumes (industrial demands not included) on an annual basis.

2. Optimization And Further Development of Biomass CHP Plants

Research in the biomass plant Güssing also includes the further development of feedstock conveyance, the variation of the bed material, and the use of additives for targeted control of gas quality. Other goals consist in extending the range of usable feedstock, simplifying gas cleaning, and the optimization of the gas engine in order to reduce capital and operating costs.

The favourable characteristics of the product gas (low nitrogen content, high hydrogen content, H2:CO ratio of 1.6 – 1.8) allow also other applications of this producer gas.

Research projects concerning the production of electricity in a SOFC (solid oxide fuel cell), the synthesis of SNG (synthetic natural gas), and Fischer-Tropsch liquids and have been started.

The figure 9, gives an overview about possible applications of the producer gas from a steam blown gasifier.

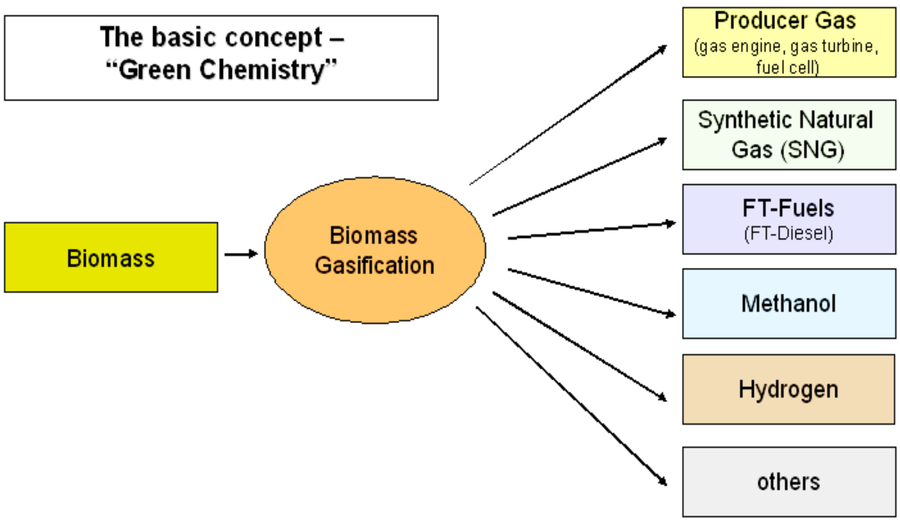


Fig. 9 Overview about possible applications of the producer gas.

In principal, all products can be obtained from the synthesis gas as this is the case for coal or crude oil. All the necessary chemical pathways are well known since many decades. Therefore, in analogy to coal or oil chemistry one can say now "green chemistry" if the original material is renewable (e.g. biomass).

All this advanced applications need an ultra-clean synthesis gas. To cover with these requirements further cleaned up and conditioning steps are necessary. For this purpose a slip stream of the synthesis gas is taken, treated in a suitable way, and fed to the research installations. The Figs. 10-11, shows a principle scheme of this arrangement.

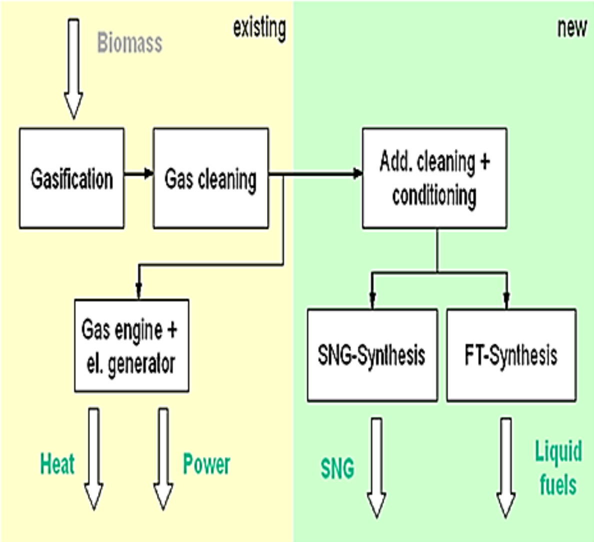


Fig. 10 Extension of the Güssing Plant

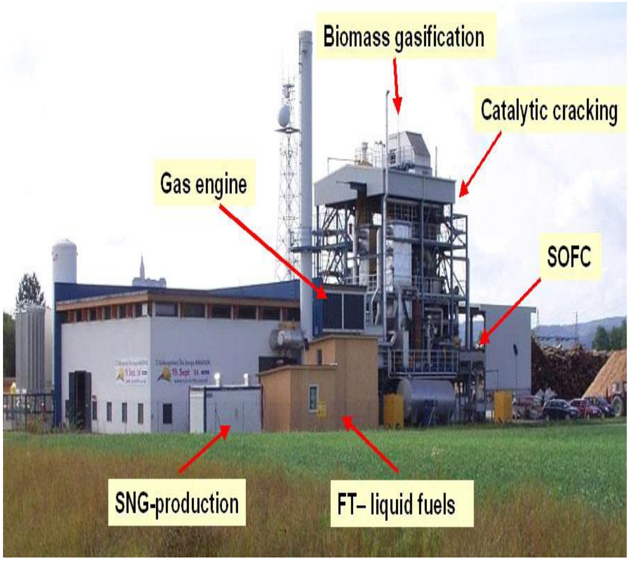


Fig. 11 Principle scheme of this arrangement

The generated Heat is delivered to a district heating grid which has a length of more than 20 km. The consumers are mainly private houses (300pcs), public offices, schools, and a hospital (50 pcs). Furthermore, there is a growing demand of industrial heat which is needed the whole year around. Also wood drying chambers have been installed in the vicinity which are additional heat consumers. Electricity is sold to the electrical grid operator with a feed-inrate of 16 Cents/kWh.

2.1 Economic Analysis With Different Design Solutions

The economic investigation has been conducted by analysing various cost terms associated with configurations of the plant studied. Plants of three different sizes have been considered.

- Plant with thermal power of nearly 1.3 MW_{th}, using a biomass flow rate of nearly 330 kg/h.
- Simulated plant similar to (i) above, but with thermal power of 10 MW_{th} and biomass feed rate of nearly 2500 kg/h.
- Simulated plant similar to (i) above, but with thermal power of 20 MW_{th} and biomass feed rate of nearly 5000 kg/h.

The economic analysis was done in a classical mode considering cost of investment, operating and maintenance costs, depreciation and financing charges.

Cost of Investment (CI)

Cost of investment is sum of both direct and indirect costs. These are broken down as follows:

Costs of Direct Investment (CID):

Direct cost comprises of all costs relevant to construction of the plant (cost of the land, preparation of land, different components of the plants for its construction, electro-mechanical work etc.).

The costs have been evaluated considering the data available in literature and based upon the values provided for various components by the manufacturers. These are broadly divided into two groups, namely plant components and civil works. Plant components include system for the receipt and storage of biomass, system to feed gasifier, system for the distribution of auxiliary fuels, gasification section, filtering section, thermal recovery section, metallic structure and accessories, treatment of feed water, supply and assembling of electrical, instruments, mechanical assembling and piping, separation section, O_2 feeding section.

On the other hand civil works comprise of building of control room and offices, floors for the machine and cemented network, preparation of area, roads and platforms, wall enclosure, sewage of water, fire-fighting network, etc.

Cost of Indirect Investment:

Indirect costs include expenses for the plant designing (engineering aspects), testing, etc. The cost of engineering and supervision is taken as 10-20% of the total cost of direct investment. General costs constitute 5-20% of the total cost of direct investment.

Total Installation Cost

Total of cost investment (CI) is equivalent to 135-123% of CID. The above-mentioned costs have been stimulated by the summation of cost of investment for gasification section, shift section, separation section, oxygen production section, energy recovery section, etc. Cost of direct investment as a function of plant's potential variation, can be obtained using an exponential relationship based on the existing cost data. If C1 is the cost of equipment or a part of plant of output M1, then the cost of a similar device, of output M2, can be calculated using the relationship: [13-16]:

$$C_2 = C_1 \cdot \left(\frac{M_2}{M_1}\right)^S$$

where the value of the exponential factor **S** depends on the type of equipment or plant. The correlation of exponential cost has been developed for specific parts and/or sections of plant. In many cases the cost has to be correlated in terms of parameters related to the plant output.

Direct cost for gasification plant

Cost of gasification plant on pilot scale, including section for heat recovery and cleaning, has been calculated based on the analysis of the cost of pilot plant 1.3 MW_{th}. The cost calculation relevant to the plant on large-scale has been done using values obtained from the exploitation of the pilot plant as well as literature data [16, 17].

Direct cost for shift section: Prices used have been taken from the data available in literature [] providing a relationship between the plant cost and actual molar flow rate of $CO+H_2$.

Direct costs for PSA separation section: Costs for the separation section have been taken from the data available in literature [14, 18], that provide a relationship between cost of the plant and actual molar flow rate of gas, in addition to data provided by companies that supply separation systems.

***Compression section* :** Cost for the compression section appears to be nearly 70.900 k€ per kWe, multistage cooling compressor b=15-18.

***Direct costs for the section producing oxygen* :**Costs for the separation section have been taken from the data available in literature [14] that report a relationship between plant cost and actual daily O_2 production. The data has been compared with data provided by market analysis of a small O_2 generating set based on PSA system [19].

***Direct cost for energy recovery section* :** Costs for the energy recovery section have been taken from the data provided by market analysis of a micro and mini generating set based on micro/mini turbine system [19]. All investment costs of a plant, in general, are summarised in the table. It is, however, to be noted that the direct cost depends upon the type of the plant under investigation. The same is evident from the insignificant difference between the cost of hydrogen produced, irrespective of the fact whether the oxygen is produced onsite or elsewhere.

***Operational and Maintenance Costs* :** Operational and maintenance costs have been defined as the costs necessary for the functioning of the plant. The items considered include: fuels, electric energy, chemicals, different materials consumed, personnel involved, etc.

***Fuel cost* :** The quantity of biomass needed annually to run the plants at their normal load of 330 kg/h, 2500 Kg/h and 5000 kg/h is approx. 2500, 19500 and 39000 T/year, respectively. The biomass is furnished using: husk (nearly 20%), almond-shell (nearly 15%), waste from the sawmill (nearly 65%). The total cost comprises of the material cost (approx. 20 Euro/t) and the transport cost, which depends upon the distance, type of material and the conveyance used. Considering average distance of approx. 50 km, the overall cost of biomass inclusive of supply and transport is approx. 26 Euro/t.

***Cost of man-power involved* :** Cost of labour involved depends on so many factors such as size of the plant, automatic dependency, different existing norms relevant to the use of different machines, possibilities of realising plants in the already existing industrial areas, etc. It is hypothesized that the plants are autonomous i.e. do not belong to other industrial plants with number of persons engaged for the plant (i) equal to 9 while for the plants (ii) and (iii), are 11 and 15 respectively. The average specific cost for the specialised technical staff is of the order of 30 k€.

***Electric energy* :** Electric energy (cost approx. 10 c€/kWh) consumed by the plant is considered jointly for the three sections with major electric power engaged:

- gasification section around 40 kWh/t biomass
- oxygen section is nearly 0.3 kWh/kg oxygen
- compression section for PSA at 15-18 bar.

***Oxygen cost* :** Cost of oxygen for industrial purposes supplied by the manufacturing companies depends on various factors, in particular, annual consumption, and the distance from the main producing centre. On the whole, it varies between 4-9 c€/kg. In the present analysis oxygen cost of 6 c€/kg is applied.

***Other relevant costs* :** Other relevant costs include the cost of chemicals, additives and consumables, mechanical and maintenance operations, etc. On the whole, such cost has a fixed value equivalent to nearly 4% of the cost of investment for the realisation of the plant.
***Fiscal and Financial rate* :** The main fiscal and financial rates adopted in the present study are the inflation rate 2%, discount rate 5% and taxation level 35%.
***Depreciation* :** Depreciation of the plant under investigation is regulated for its fiscal effects under the existing norms of law. The percentage values considered appears to be constant over a period of 10 years.
***Benefit derived* :** The benefits obtained are associated to the sale of electric energy produced and the Green Certificates. The gain derived from the sale of electric energy produced has been assumed to be 0.05€/kWh, whereas the gain relevant to the Green Certificates has been assumed to be nearly 0.08 €/kWh.

Investment cost [k€]	1.3 MWt	10 MWt	20 MWt
Direct cost			
Gasification section	921.0	4483.0	7765.8
Shift section	105.0	395.0	630.0
Separation section	500.0	1195.0	1620.0
Compression section	57.0	433.0	866.0
Oxygen section	196.0	1329.0	2300.0
Energy recovery section	150.0	900.0	1750.0
Total direct cost	1929.0	8735.0	14931.8
Indirect cost	289.4	1310.3	2239.8
Start cost	96.5	436.8	746.6
Total investment cost	**2314.9**	**10482.1**	**17918.2**

3. Operation Performance Of The Biomass CHP Gussing

The Güssing plant is in operation continuously since the middle of the year 2002. Of course during this time there were several periods of maintenance and also periods for improvement of the construction. The production of electricity started in the middle of the year 2002. Heat is fed into an existing district heating system and electricity into the power grid. Below given data shows the cumulative production of heat and power since January 2002. It is evident that there were only a few periods when the plant was not in operation. Furthermore, also an increase of the heat and power output can be observed.

Main characteristics data of the CHP plant

Technology	: Fluidized bed steam gasification
Feedstock (type and consumption/h)	: wood chips 2,300 kg/hr
Feedstock volume	: 18,400 t/y ; Average WC : 30.0%
Plant Power	: 8 MWth
Output Thermal Power	: 4,5 MWth
Output Electrical Power	: 2 MWe
Thermal Efficiency	: 56.3 %
Electric Efficiency	: 25.0 %
Total Efficiency	: 81.3 %
Total operational hours till 2006	: 30000 (gasifier); 25000 (engine)
Total operational hours in 2006	: 8000 (gasifier); 7000 (engine)

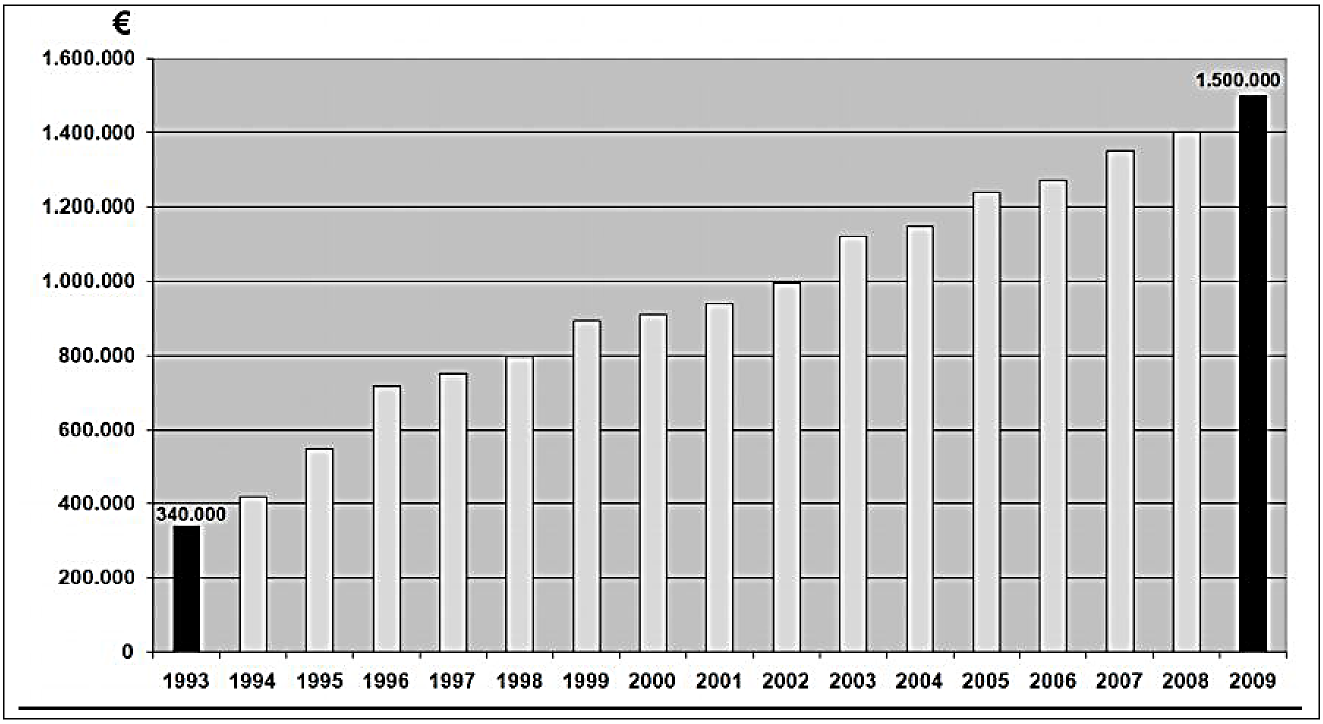
Costs and economics:

The biomass CHP plant in Güssing can be operated economically under the specific Austrian frame conditions. Despite of the quite high costs for the biomass feedstock, the operation of biomass CHP plants are currently quite well due to the high fixed feed-in tariffs for green electricity (up to 16,00 €-cents / kWh_{el} for solid biomass).

Summary of economic data sets for the Güssing power plant is given below.

Cost category	**Amount**
Investment cost	: 10 Mio €
Funding (EU, national)	: 06 Mio €
Operation cost / year	: 1,3Mio €/yr
Price for heat (into grid)	: 2,0 €-cents/ kWh_{th}
Price for heat (consumer)	: 3,9 €-cents/ kWh_{th}
Price for electricity	: 16,0 €-cents/ kWh_{el}

For a next plant 25% reduction of the investment cost can be expected due to the experience and learning gained from the demonstration plant. The operation costs can be reduced as well by unmanned operation and further operation optimization (bed material, gas cleaning).



Growing Income from business taxes (1993-2009)

Total heat power	: app. 50 GWh (households, public utilities, industry)
Electricity	: app. 20 GWh (households, public utilities)
Synthetic gas	: app. 120 m3/h
Synthetic fuel	: 1 barrel/day

Actual added value with 47% self-sufficient use of renewable energies is 20 million €.

Potential added value with 100% self-sufficient use of renewable energies is 38 million €.

4. CONCLUSIONS

Several economic studies have been made on biomass gasification regarding the feasibility and long-term prospects. The first demonstration projects are mostly far too expensive to become profitable. Investment figures of more than 5,000 €/kW electric are not exceptional. However, it is expected that due to the learning curve, the investment costs can be reduced to approximately 2,000 €/kW electric within the coming decade.

- Operational experience and value engineering is needed to achieve this goal.
- Another aspect is the operational costs, in particularly the price of the feedstock. These can be expensive like short rotation coppice (SRC) or cheap (negative) like waste residues. Transportation, fuel handling and processing adds to the cost of the feedstock.
- Furthermore, labour costs must be minimised through process control and automation.
- Practical experience is needed to determine the maintenance costs.

- Remuneration of electricity and heat can also be decisive in the overall economics.

For the short to medium term, biomass gasification can't compete with fossil fuel produced power. Therefore, comparison must be made to alternative renewable energy sources. Studies showed that biomass gasification can compete with other RES when capital costs can be reduced and favourable conditions are created.

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REFERENCES

- Klass, D.L., "Biomass for renewable energy, fuels and chemicals". New York, Academic Press, 1998.
- M. Momirlan and T.N. Veziroglu, 2002., "Current status of hydrogen energy". Renewable and Sustainable Energy Reviews 6, 141-179.
- E. Greenbaum and J.W. Lee, 1999., "Photosynthetic hydrogen and oxygen production by green algae". Symposium on Hydrogen Production, Storage and Utilization. New Orleans, Louisiana.
- D. Wang, S. Czernik and E. Chornet, 1998., "Production of hydrogen from biomass by catalytic steam reforming of as pyrolysis oils". Energy & Fuels, 12, p19-24.
- T.A. Milne, C. C. Elam and R.J. Evans, "Hydrogen from biomass state of the art and research challenges". IEA Report 2001.
- G.Riva, J. Calzoni and A. Panini, 2000., "Impianti a biomasse per la produzione di energia elettrica". Rapporto CTI Energia e Ambiente.
- J.M. Ogden, 1999.,"prospects for building a hydrogen energy infrastructure". Annu. Rev. Energy Environ., 24, 227-79.
- C. E. G. Padro and V. Putsche, 1999., " Survey of the economics of hydrogen technologies". NREL.
- R. Avella, G. Braccio, P. Marzetti, D. Matera and V.K. Sharma, 2003., "Investigation of air gasification process with a bubbling fluidized bed gasifier for electricity generation". Proc. International Conference: Energy and Environmental Technologies for Sustainable Development.
- Y. Wang and C.M. Kinoscita, 1992., "Experimental analysis of biomass gassification with steam and oxygen". Solar Energy, 49, pp. 153-158.
- G. Schuster, G. Loffler, K. Weigl, H. Hofbauer, 2001., "Biomass steam gasification an extensive parametric modelling study". Bioresource Technology 77 ,pp. 71-79.

- V. Addabbo, 2002., "Analisi e fattibilità economica di un processo di gassificazione di biomasse per la produzione di idrogeno". Thesis Università Degli Studi di L'aquila Facoltà di Ingegneria chimica e materiali-ENEA.
- V. Ka and S.M. Walas, "Chemical process equipment", Butterworth-Heinemann, 2001.
- C.N. Hamelinck and A.P.C. Faaij, 2002., "Future prospects for production of methanol and hydrogen from biomass". Journal of Power Sources ,111, pp. 1-22.
- B.M. Jenkins, 1997., "A comment on the optimal sizing of a biomass utilisation facility under constant and variable cost scaling". Biomass and Bioenergy, 13, No. ½, pp. 1-9.
- A.V. Bridgwater, A.J. Toft and J.G. Brammer, 2002., "A techno-economic comparison of power production by biomass fast pyrolysis with gasification". Renewable and Sustainable Energy Reviews 6, pp.181-248.
- V. Dornburg, A. P.C. Faaij, 2001., "Efficiency and economy of wood-fired biomass energy systems in relation to scale regarding heat and power generation using combustion and gasification technologies". Biomass and Bioenergy, 21,pp. 91–108.
- J.M. Ogden, T.Kreutz and S. Karta, "Hydrogen energy systems studies". Centre of Energy and Environment Studies, August 13, 1996.
- M. Mori, 2004., "Produzione di energia elettrica distribuita da impianti di gassificazione". Thesis Università Degli Studi di Trieste, Facoltà di Ingegneria Dipartimento di Energetica – ENEA, Italy.