IEA Bioenergy, Task 33 – Thermal Gasification of Biomass

Workshop

Thermal biomass gasification in small scale

13-15 May 2014, Ischia, Italy

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Introduction

Combined heat and power generation (CHP) or cogeneration has been considered worldwide as the major alternative to traditional systems in terms of significant energy saving and environmental conservation. The most promising target in the application of CHP lies in energy production for buildings, where small-scale CHP is usually installed.

Generally speaking, the concept “small-scale CHP” means combined heat and power generation systems with electrical power less than 100 kW.

Small-scale CHP systems are particularly suitable for applications in commercial buildings, such as hospitals, schools, industrial premises, office building blocks, and domestic buildings of single or multifamily dwelling houses. Small-scale CHP systems can help to meet a number of energy and social policy aims, including the reduction in greenhouse gas emissions, improved energy security, investment saving resulted from the omission of the electricity transmission and distribution network, and the potentially reduced energy cost to consumers.

Small-scale and micro-scale biomass CHP systems can reduce transportation cost of biomass and provide heat and power where they are needed.

Of all the renewable energy resources, biomass is plentiful and prominent. Wind energy and solar energy have the limitation of intermittent nature and therefore, they can only be used in the diversified systems to contribute where fossil fuel-based power generation provides base-load power when the sun is not shining or the wind is not blowing.

Biomass is the world’s fourth largest energy source, contributing to nearly 14% of the world’s primary energy demand. For many developing countries, the contributions of biomass to their national primary energy demands are much higher, from ca. 20% to over 90%. Biomass energy systems contribute to both energy and non-energy policies. The life cycle of a sustainable biomass energy system has a nearly neutral effect on the atmospheric carbon dioxide concentration.

The workshop “Thermal biomass gasification in small scale” offered interesting information in this field, from research organisations as well as industry. Furthermore, new contacts and areas of cooperation were outlined.

Table 1: Presentations overview

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MARCO FANTACCI, BIO&WATT GASIFICATION S.r.l., Italy

Energy conversion of biomass through pyrogasification process: presentation of an industrial solution

The Bio&Watt gasification plant was presented. Its key characteristics can be seen below:

- Capacity: 200-300 kW_{el} per single module
- Compact design: soil occupancy of the gasification module ca 14 m^2, of the whole plant ca 400 m^2
- Easy maintenance to achieve higher reliability
- Closed cycle: no waste products (the ash from biomass gasification fed into the plant), all the energy potential of the biomass is exploited
- Broad range of applicable fuels (biomass pre-treatment needed)

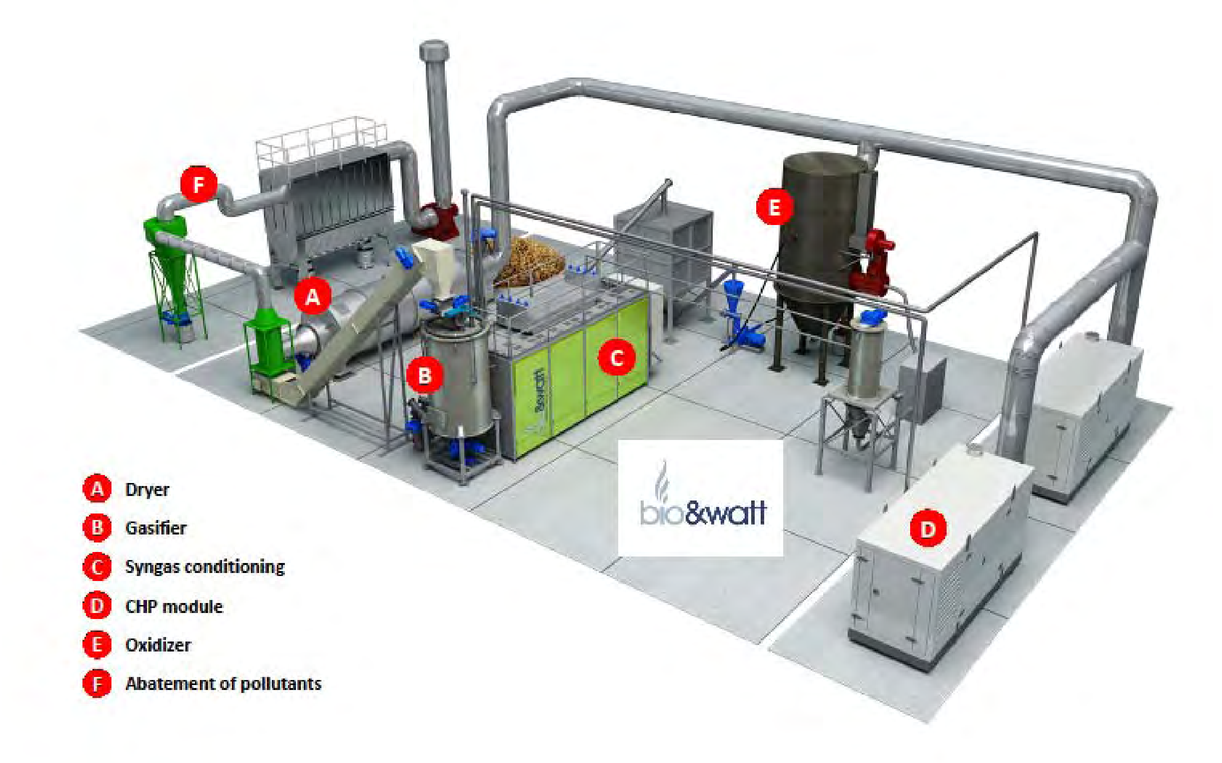


Figure 1: Plant layout and main subsystems

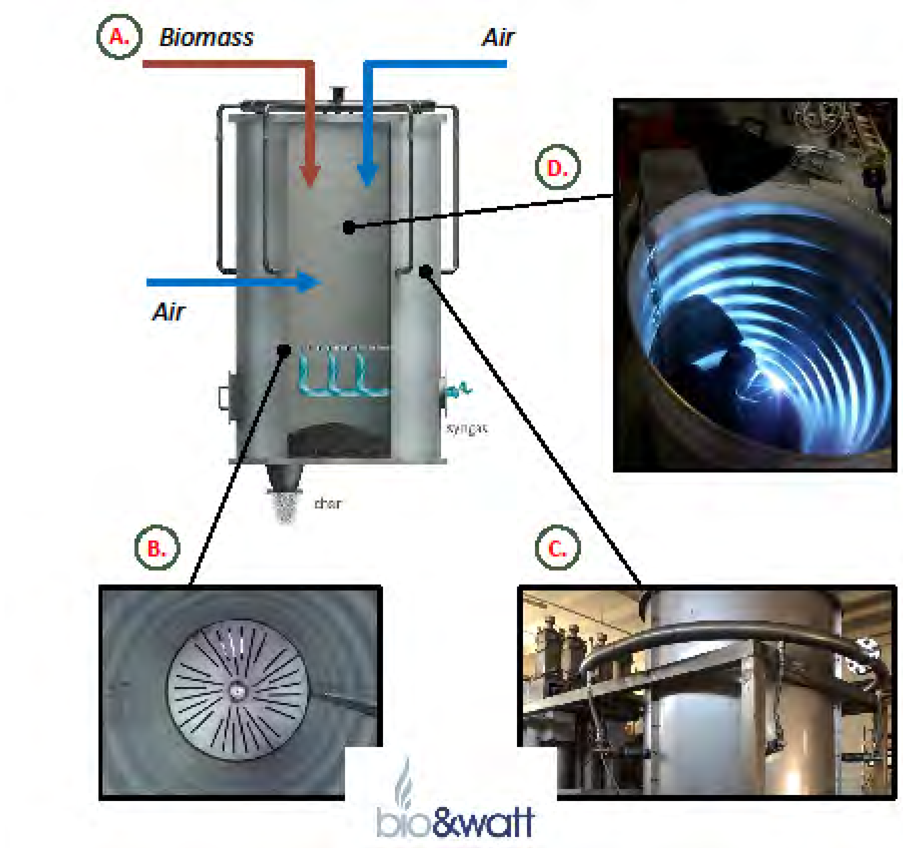


Figure 2: The gasification reactor

A. downdraft
B. fixed bed/stratified
C. double fire
D. no refractory

The gasification reactor design focuses on simplicity, easy maintenance, energy conversion as well as low tar production.

The aim of the syngas conditioning is fouling prevention, syngas de-dusting, syngas cooling (from 700°C to < 40°C), and tar separation. No mechanical filtration is provided.

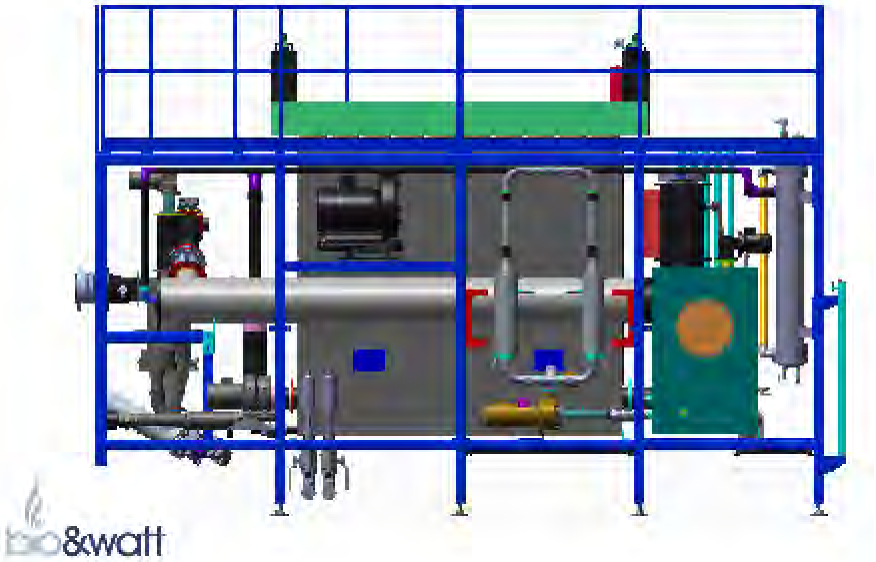


Figure 3: The producer gas conditioning section (cyclone, wet scrubber, electrostatic precipitator)

For tar separation the process water from the wet scrubber and wet ESP is sent to a specifically designed settling tank in order to separate tar. The focus is put on complete tar separation from process water and reuse of water in a closed-loop cycle.

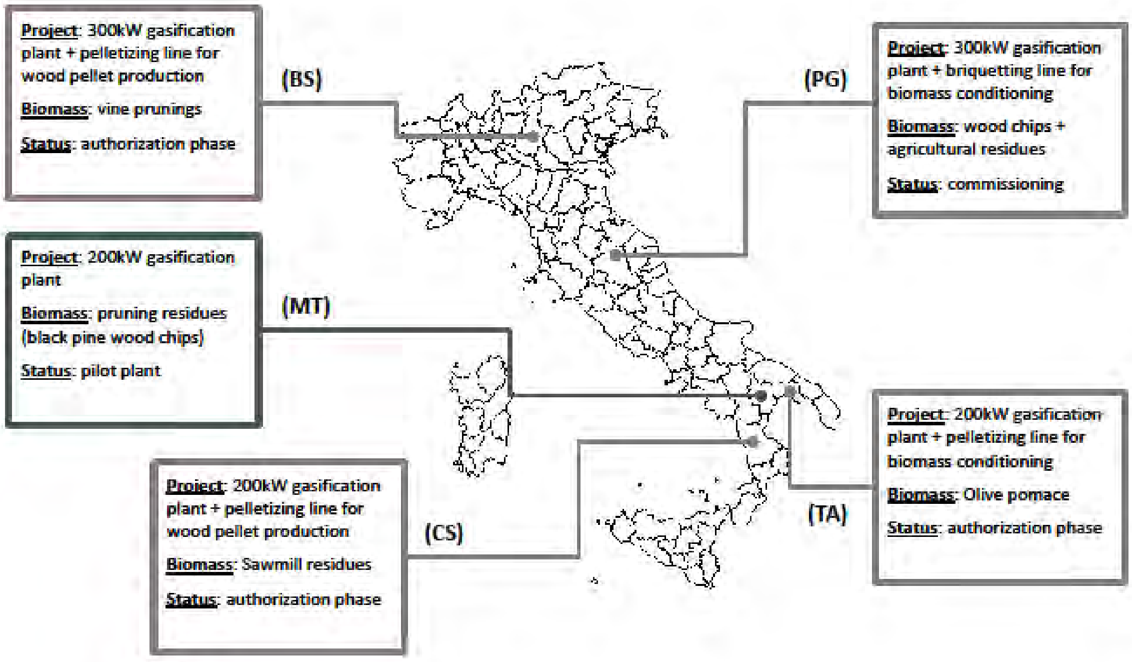


Figure 4: Further Bio&Watt projects under development

ANDREA DUVIA, Gammel Duvia Engineering Srl , Italy

Biomass cogeneration: Activities and experience with plants based on biomass gasification

The company Gammel Duvia Engineering Srl with more than 10 years of industrial experience with leading European partners and customers offers complete engineering service for the tendering, integrated design and realisation of biomass power plants. It has strong technical and commercial background in the biomass cogeneration, geothermal and industrial heat recovery sectors.

Projects

Standard turnkey plant „Pezzolato Energia" based on fixed bed downdraft gasifier

Pezzolato with headquarters in Envie (CN) is a company active since 1976 in the production design and sale of biomass treatment devices (chipping machines, splitting machines, sawmill machines).

In 2013 Pezzolato decided to evaluate the opportunity to enter the energy cogeneration market with main focus on small gasification plants (< 200 kW_{el}).

Gammel Duvia Engineering was selected as consultant for:

- Technology and market analysis of European market for small biomass gasifiers
- Evaluation of potential business models and partners
- Technology and market analysis of European market for small biomass dryers
- Business development strategy and negotiation with specific customers

After evaluation of over 50 potential suppliers, Spanner Re2 (Germany) has been selected as technology provider.

Properties:

- Cogeneration system based on fixed bed downdraft gasifier coupled with dry syngas cleaning and 5,7 l gas motor.
- Standard product with 45 kW_{el} gross power.
- Standard module size suitable for placing into containers.
- > 250 reference plants and > 2.000.000 operation hours runtime.
- High biomass quality requirements for optimal operation (humidity content < 10%, low fines content).
- Preferred scope of supply limited to standard core system (without dryer, installation, building, grid connection, etc).

Figure 5: Standard Spanner gasification module

Pezzolato is proposing a turnkey supply based on Spanner gasification technology and proprietary solutions for drying and conditioning of the Biomass. Plant size 50 – 300 kW$_{el}$.

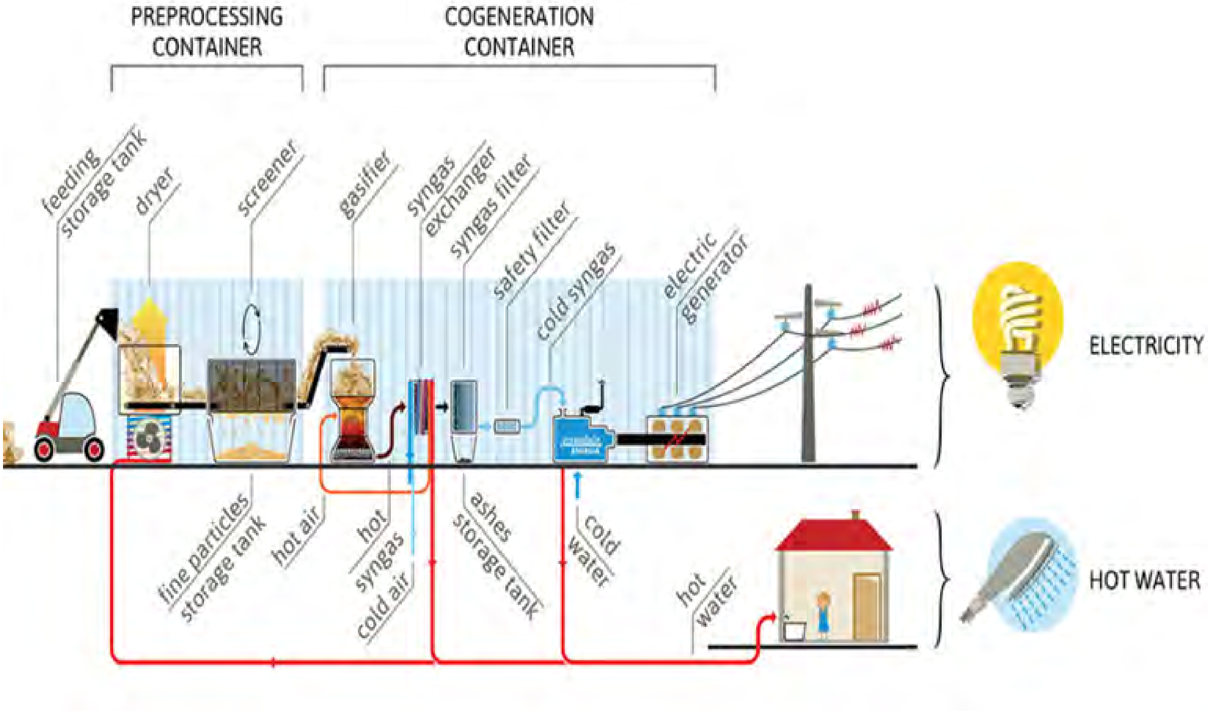


Figure 6: Pelazzo turnkey plant: system concept

Pezzolato has installed a first reference unit (45 kW$_{el}$) at his headquarters in Envie (CN) in Q3/2013. Initially the reference plant has been used for operational tests with different biomass types/qualities and development of proprietary solutions for dryer/ biomass pretreatment. Commercial operation from Q2/2014.

Supply of first customer unit (45 kW$_{el}$) to Prato (turnkey system including gasifier, dryer, biomass pretreatment and special small size chipper Model PTH 250) in June 2014.

Fixed bed updraft gasifier developed by partner Gammel Engineering

Gammel Engineering has more than 20 years of experience in the engineering of bioenergy systems. Among the references there are more than 20 biomass cogeneration plants with different technological solutions and heat uses, e.g. :

- Plössberg (heat for pellet production; 2000 kW; ORC)
- Ruderatshofen (drying of animal food and district heating; 2000 kW; ORC)
- Weissenhorn (heating and high temperature process heat; 600 kW, ORC)
- Cham (district heating and process steam 1500 kW_{el}; steam turbine)
- Taufkirchen (district heating ; 4500 kW; steam turbine)
- Sauerlach (district heating ; 500 kW_{el}; ORC)
- Wolnzach (from heat only to cogeneration; 450 kW;ORC)

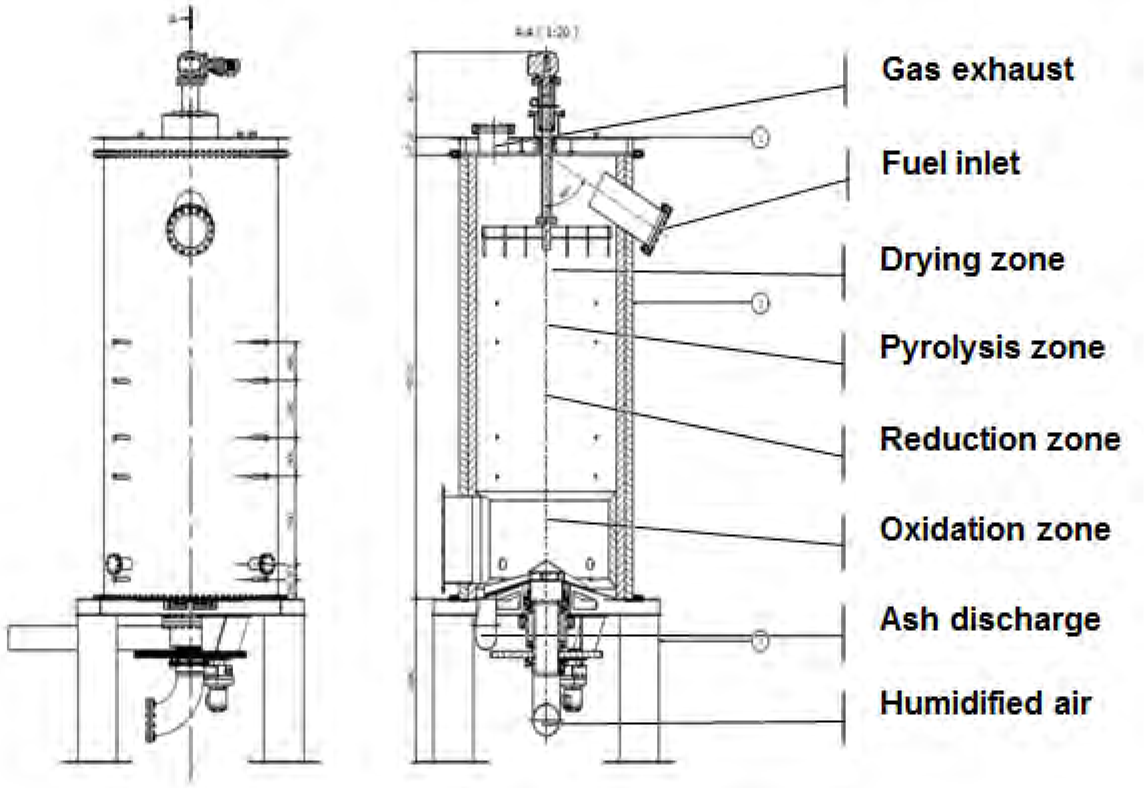


Figure 7: Updraft gasifier – actual design

MARCEL HUBER, Syncraft, Austria

The floating-fixed-bed - status of a unique staged gasification concept on its way to commercialization

The Syncraft Engineering is a high-tech development company for biomass cogeneration plants, as well as planning and implementation of CraftWERK plants.

CraftWERK plants are based on a floating bed technology. The core of the technology is a lifted and propelled against gravity, floating fixed bed. This unique process setup enables to process standard raw material, produces a clean producer gas and simultaneously allows a maximum of efficiency.

- **Highest efficiency**
  CraftWERK as a thermal base load units in existing district heating networks allow maximum utilization of raw materials and overall efficiencies > 70%
- **Low value fuel**
  Wood chips G30 - G50 used without any special requirements, and therefore raw material costs of 90 €/t instead of 200 €/t for pellets or 150 €/t for G100 chips of heartwood.
- **Low operating costs**
  Simple and low-maintenance gas cleaning
  No expensive excipients or process materials needed
- **Low emissions**
  10 times lower emission than actual limits according to TA Luft without expensive gas treatment; 1000 times lower tar-concentration in the product gas as the other reference systems (Güssing)

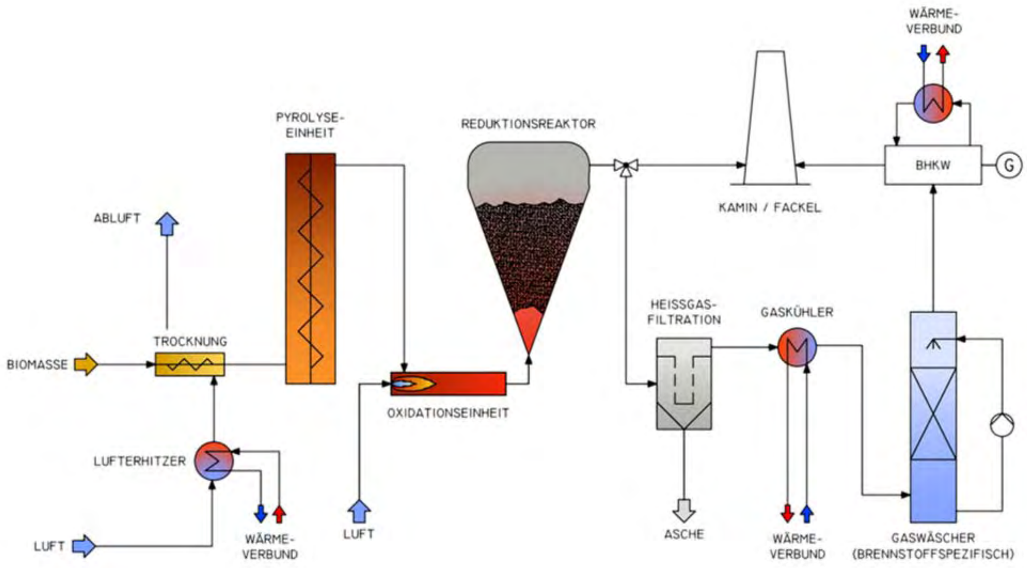


Figure 8: Process scheme of a CraftWERK

Product range:

- **CraftWERK 700** – commercially available

Power: 180 kW_e and 275 kW_{th} @ 0,8 m^3/h
Efficiency: 28% electric
Space requirement: < $200m^2$ / H=8m
Specialty: highly efficient 6-cyl. gas engine from 2G

- **CraftWERK 1200** – prototype in final development stage

Power : 350 kW_e and 500 kW_{th} @ 1,4 m^3/h
Efficiency : 29% electric
Space requirement : $200m^2$ / H=10m
Specialty : adaptable to limit tariff 300kW Italy

- **CraftWERK 1600** – prototype will be built 2015

Power : 475 kW_e and 670 kW_{th} @ 1,9 m^3/h
Efficiency : 30% electric
Space requirement : $250m^2$ / H=10m
Specialty : adjusted to limit tariff 500kW Austria

GIOVANNA RUOPPOLO, CNR – National Research Council, Italy

Fluidized bed gasification and co-gasification of biomass and wastes

The production of chemicals, hydrogen, biofuels and energy by syngas conversion produced from biomass gasification may be considered a very promising route, more efficient compared to combustion and pyrolysis, but for its complete exploitation some technological barriers have to be overcome.

The two main challenges of biomass gasification process are a relevant production of syngas and a relatively low production of TAR. TAR species produced during gasification can be efficiently removed via catalytic methods.

Gasification process carried out in fluidized bed reactors meets these requirements thanks to the uniform temperature and to the high heating rate of the reacting particles (more than 100°C·s-1). In addition this reactor configuration is characterized by good fuel flexibility and by the possibility of using a catalytic bed promoting in turn TAR conversion directly inside the gasifier. It is also reported that fuel pretreatments, such as pelletization, torrefaction and compaction or their co-processing with coal or wastes are suitable options to overcome the limitation of the low energetic density of biomasses. In addition co-gasification can also induce beneficial synergistic effects in tar conversion and in preventing bed agglomeration phenomena.

The presentation offered an overview on the research activity carried out at IRC on gasification of wood and wood/coal/waste pellet in a fluidized bed reactor.

In particular the attention was paid on

- relevance of the use of a suitable catalyst system to reduce tar formation
- the adopting of a conical shape gas distributor and of a central spout as a strategy to decrease the segregation phenomena
- the use of pelletization strategy
- the possibility to use the co-gasification of biomass and plastic to produce a syngas prone for its direct use in the methanol synthesis process.

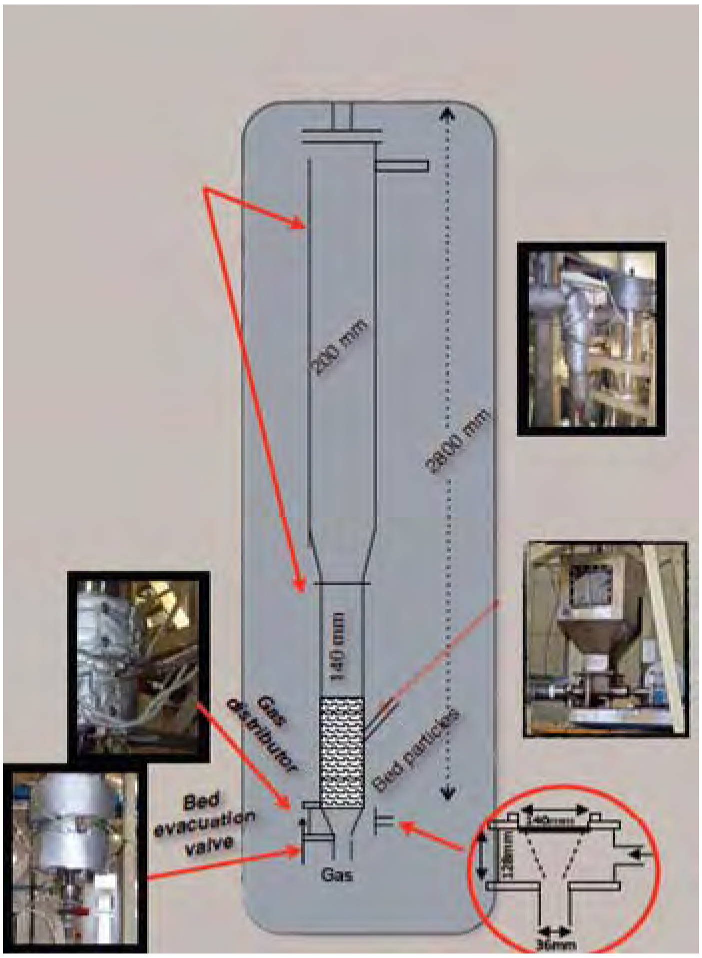


Figure 9: The fluidized bed gasifier

The fluidized bed gasifier consisted of two vertical stainless steel tubes connected by a conical adapter, the lower tube had an Internal Diameter (ID) of 140 mm and was 1010 mm in height, and the upper tube had an ID of 200 mm and was 1800 mm high.

The main results obtained during different experimental campaign and carried out using a fluidized bed gasifier:

- The presence of a catalytic bed, especially in the case when an “ad hoc” reactor configuration is used: adoption of a central jet in addition to the conical distributor, increases hydrogen rich syngas yield and decreases tar production. However some expected negative effects of such configuration on attrition phenomena has been highlighted

- The effect of equivalent ratio and the presence of steam affect the performance of gasifier less than the presence of catalyst provided that the segregation phenomena are negligible

- The use of pellets results into beneficial effects on solid particles emissions but when mixed pellets are used there is an important role played by properties of the parent fuels

- Among the mixed pellet tested, the biomass/plastic pellets exhibited promising results in terms of the hydrogen yield even if they suffered from a higher production of tar

PAOLA AMMENDOLA , CNR – National Research Council, Italy

Development of catalytic systems for tar removal in gasification processes

This research activity focused on a development of a new catalytic system for conversion of tar produced during biomass gasification in order to overcome the typical drawbacks (low activity, coke deactivation) of conventional catalysts.

The innovative catalytic system is a γ-alumina-supported lanthanum-cobalt perovskite (20 wt %) promoted with small amounts of rhodium (0.1 to 1wt%) which was proposed for the high reforming activity of the noble metal and the good oxygen availability of perovskite, respectively. In addition, the large dispersion of rhodium into the $LaCoO_3$ matrix inhibits its possible sintering at high temperatures, typical of biomass gasification (800-900°C).

In order to investigate the catalytic properties by modifying both the catalyst formulation and the operative parameters, an experimental plant at a laboratory scale, which allows the contact between catalyst and a real mixture of biomass devolatilization products, has been set up. It consisted of two connected fixed bed micro-reactors, heated independently in two different electric furnaces and it was equipped with an analysis system for detection and characterization of all gaseous and liquid products. This set up allowed an easy and economic catalytic screening, allowing the use of small amounts of catalytic material.

The activity in biomass tar conversion of the novel catalytic formulation has been compared, in pyrolysis conditions, to that of conventional catalysts (olivine, dolomite, Ni/Al_2O_3). It was found that the novel catalyst was able to completely convert tar and light hydrocarbons contained in the biomass devolatilization products, but also to significantly increase the syngas yield due to prevailing of reforming properties, being by far more active than the Ni/Al_2O_3 catalyst, which was the most effective among the conventional materials.

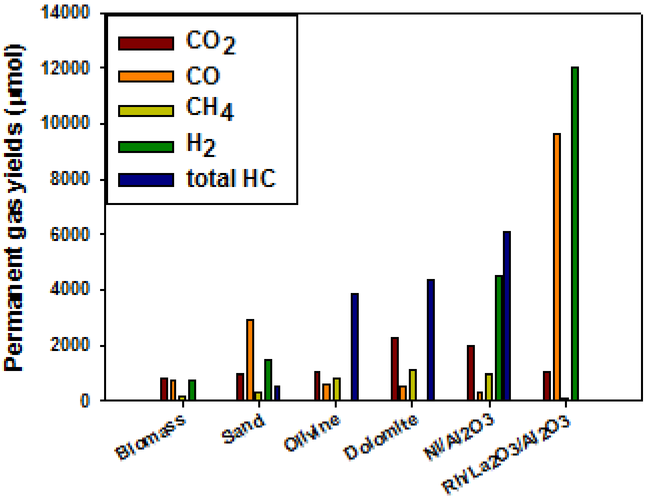


Figure 10: Comparison with conventional catalysts at 700°C (pyrolysis conditions)

Moreover, the catalyst had a limited sensitivity to coke deactivation. These findings were supported by the study of redox properties of the active phases deposited on the alumina support by TPR analysis.

The study of catalytic activity and redox properties also led to define the best catalytic formulation. The best performances were obtained with catalysts containing both rhodium and perovskite due to the synergic effect of the two phases coupling the highest reforming activity with the lowest coke deposition.

In addition, the deposition of the perovskite layer prevents the encapsulation of rhodium into the alumina matrix which led to the formation of a less active rhodium aluminate. The very good performances of the proposed catalyst have been correlated to its easy reducibility under reaction conditions.

A very efficient tar conversion activity was maintained also for rhodium content as low as 0.1 wt% thus strongly limiting the amount of the expensive precious metal. Likewise, the operation temperature can be lowered to 600°C keeping the same performances observed at high temperatures.

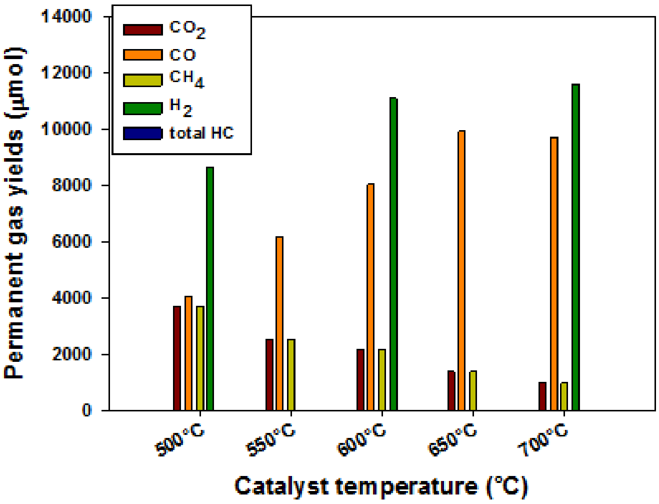


Figure 11: Effect of operating temperature (pyrolysis conditions)

The performance of the alumina supported Rh–$LaCoO_3$ has been also studied for catalytic tar conversion in the presence of H_2S and has been compared with that in the absence of these poisoning agents.

Results showed that the perovskite layer preserves to large extent Rh from poisoning. When saturation limits are overcome highly dispersed rhodium, associated to the reforming centres, is mainly affected and, as a consequence, the formation of reforming products decreases balanced by the production of total oxidation and cracking species.

This catalyst keeps its original reforming properties showed for S-free feed also in the presence of high sulphur concentration. The preservation from sulphur poisoning of dispersed rhodium oxide, active in tar reforming, was confirmed by DRIFT and TPR experiments.

To investigate the thermal and chemical stability of the alumina-supported rhodium-based catalysts repeated cycles of tar conversion at 700°C followed by regeneration of the temporarily deactivated catalyst by oxidation of coke deposited on the surface up to 800°C were carried out in order to test the catalysts lifetime.

The catalysts containing rhodium show a satisfactory physical and chemical stability, dispersion of rhodium on Al_2O_3 surface being preserved even at 800°C. They maintain the original performance and chemical properties of the fresh sample also after several cycles. On the contrary, the significant modification of the redox properties of cobalt in the $LaCoO_3/Al_2O_3$ catalyst after the first conversion/regeneration cycle is related to a partial deactivation due to the irreversible migration of cobalt into the alumina lattice.

The catalytic performance of the rhodium-based catalyst was also evaluated in the presence of different levels of O_2 at 700°C to explore its effect on both the quality of the syngas produced and the extent of coke deposition.

A slight reduction of H_2 yield and a negligible reduction of CO yield, compensated by water and CO_2 formation, respectively, were observed coupled to the total disappearance of coke deposition at 3000 ppm O_2. This represents a good result, since under these conditions catalyst regeneration can be avoided.

A very recent development of this research activity was also the possibility to use this catalytic systems in secondary reactors in the form of honeycombs, reducing the pressure drops across the reactor and its blocking due to solid particulate.

PAOLA AMMENDOLA, CNR – National Research Council, Italy

Relevance of biomass comminution phenomena in gasification processes

This research activity was carried out in a lab-scale fluidized bed apparatus, on fragmentation and attrition by abrasion of two biomass fuels, namely wood chips and wood pellets, under both combustion and gasification conditions.

The aim was to highlight the effect of pelletization, i.e. of their different mechanical strength, on the biomass behaviour during combustion and gasification in a fluidized bed, in terms of fuel particle size distribution and overall carbon conversion.

Indeed, biomass fuels are characterized by a low energy specific content if compared with fossil fuels. Fuel pre-treatments like pelletization or torrefaction/compaction are appealing techniques to increase the bulk density and energy specific content, to improve the fuel properties (e.g. homogenizing, stabilizing and strengthening the fuel particles), and to simplify the design of handling and storage devices.

Fluidized bed (FB) technology is considered as one of the most suitable choices for biomass conversion (combustion, gasification), because of its fuel flexibility.

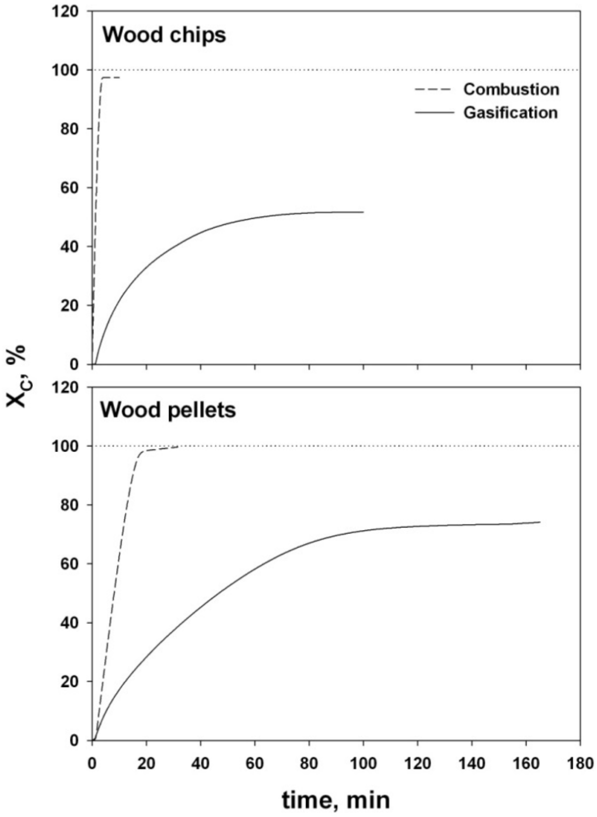


Figure 12: Effect of pelletization - Char attrition tests results – carbon conversion

Upon devolatilization and possible primary fragmentation, a fragile char particle is generated which undergoes attrition by abrasion and fragmentation; with attrition we mean all those phenomena that determine the breakage of the parent particle with generation of a number of fragments.

These phenomena are well known to affect the reliability and efficiency of FB combustion and gasification processes. They may significantly change the particle size distribution of the fuel in the bed which influences the rate and the mechanism of fuel particle conversion, as well as the particle heat and mass transfer coefficients.

On the other hand, attrition may cause the elutriation of fine material from the bed (i.e. the entrainment with the gas flow to the reactor exit) those results in the reduction of fuel residence time and the loss of unconverted carbon, which, in turn, affect the conversion efficiency.

With this respect, it has been underlined that the relevance of attrition and fragmentation phenomena is emphasized when using high-volatile fuels instead of coals, since highly porous and friable or even incoherent chars are formed upon devolatilization.

Primary fragmentation tests showed that for wood pellets limited fragmentation occurred during devolatilization, with a fragmentation probability around 30% and particle multiplication factor of 1.4, indicating that the pelletization procedure was able to give sufficient mechanical strength to the particles.

On the contrary, wood chips were subject to extensive fragmentation as witnessed by large values of the particle multiplication factor and of the fragmentation probability, significantly influencing both the average particle size and the particle size distribution of the fuel in the bed.

Results of char attrition experiments carried out under inert, combustion and gasification conditions showed that the carbon loss by elutriation is critical only during gasification, especially for the wood chips char.

A gasification-assisted attrition mechanism was proposed to explain the experimental results, similar to the well-known combustion-assisted attrition patterns already documented for coal under oxidizing conditions. The low reactivity of the generated fines under gasification conditions makes the loss of carbon by fines elutriation much more significant than that typically found under combustion conditions. Approximately half of the fixed carbon of the wood chips char was elutriated away during the gasification experiments, determining a significant loss of conversion efficiency. On the contrary, the higher mechanical strength of the wood pellets appears to be beneficial for reducing carbon elutriation and for obtaining a higher carbon conversion.

Another option to overcome the limitation of the low energetic density of biomasses is offered by their co-processing with coal, because the latter has an almost double energetic density. This measure also turns out to be useful when the primary fuel (i.e., the biomass) is temporarily lacking because of seasonal availability. Of course, the process must be flexible toward the change of the fuel properties. This is the case of fluidized-bed (FB) gasification that is acknowledged to have great flexibility and high efficiency in conversion of several solid fuels.

To this aim a study on the devolatilization, fragmentation, and attrition of three pelletized fuels, one based on wood and the other two based on a mixture of wood and coal, has been also carried out in the lab-scale FB apparatus and under gasification conditions and for comparison under inert or combustion conditions.

Similar and relatively long devolatilization times were observed for the three types of pellets in the range of 90-100 s. Pellet breakage by primary fragmentation upon devolatilization appeared to be rather limited for all fuels, indicating that fuel pelletization gives sufficient mechanical strength to the particles. On the contrary, secondary fragmentation and attrition by abrasion of char particles during gasification were extensive, especially at large carbon conversions, suggesting a gasification-assisted attrition enhancement effect. This mechanism, associated with the low reactivity of the generated fines, made also in this case the loss of carbon by fine elutriation during char gasification much more significant than that found under combustion conditions. Larger carbon losses were associated with fuel pellets with a lower reactivity.

OSVALDA SENNECA, CNR – National Research Council, Italy

Gasification kinetics of biogenic materials and wastes

Biogenic fuels include a rather wide category of materials, ranging from raw vegetal materials to solid refuses of industrial and civil origin. Inorganics and/or metals are often present in biogenic fuels at levels distinctively higher than in traditional fuels. This may produce unusual effects.

The presence of metals and inorganics makes biogenic fuels more or less reactive than conventional solid fuels, moreover it affects the yields in gaseous, liquid and solid products in a way that cannot be predicted a-priori and requires appropriate consideration. Kinetic models of different complexity are required to describe the complex patterns of reaction that can be encountered in some biogenic fuels.

The classical framework of pyrolysis followed by combustion of char and lastly its gasification is in fact oversimplified for many biogenic fuels. A modified framework is proposed to take into account the possibility of overlapping between different processes according to the temperature levels and the alternation of inert/oxidizing gaseous atmospheres..

This presentation offered an overview of experimental results obtained for different biogenic fuels based on thermal analysis and lab-scale reactors. Kinetic models for pyrolysis, oxidative pyrolysis, char combustion and gasification and well as for secondary reactions of tars and volatiles assessed for different fuels are also presented.

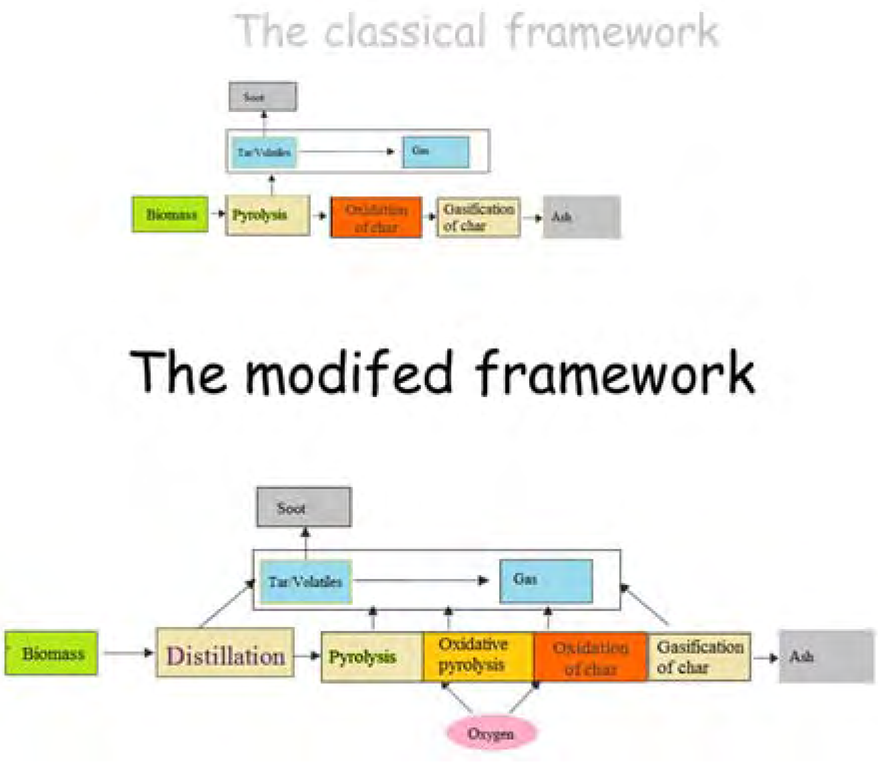


Figure 13: The framework

SIMEONE CHIANESE, University of Naples, Italy and TUV of Vienna, Austria

H_2 4 Industries

Hydrogen production plays a very important role in the development of hydrogen economy. One of the promising hydrogen production approaches is conversion from biomass, which is abundant, clean and renewable. Thermochemical (pyrolysis and gasification) and biological (biophotolysis, water–gas shift reaction and fermentation) processes can be practically applied to produce hydrogen.

This experimental work was provided using FICFB plant in Güssing and an experimental unit for hydrogen production.

The product gas for water gas shift unit was taken after the product gas filter (see the following figure).

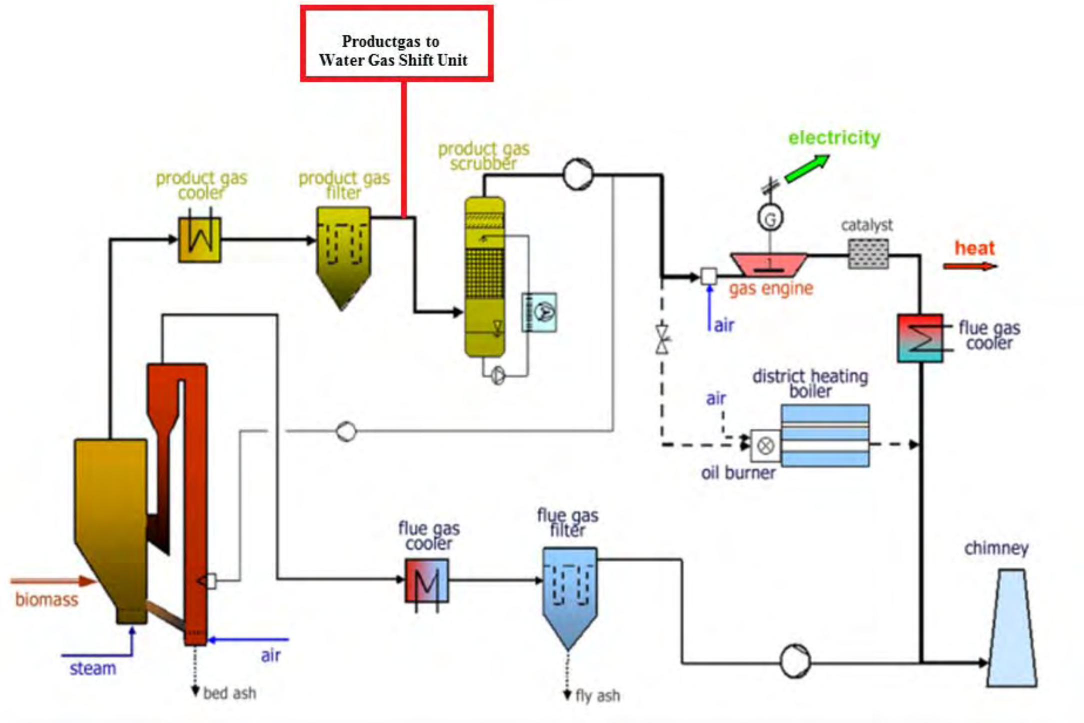


Figure 14: Güssing biomass gasification plant

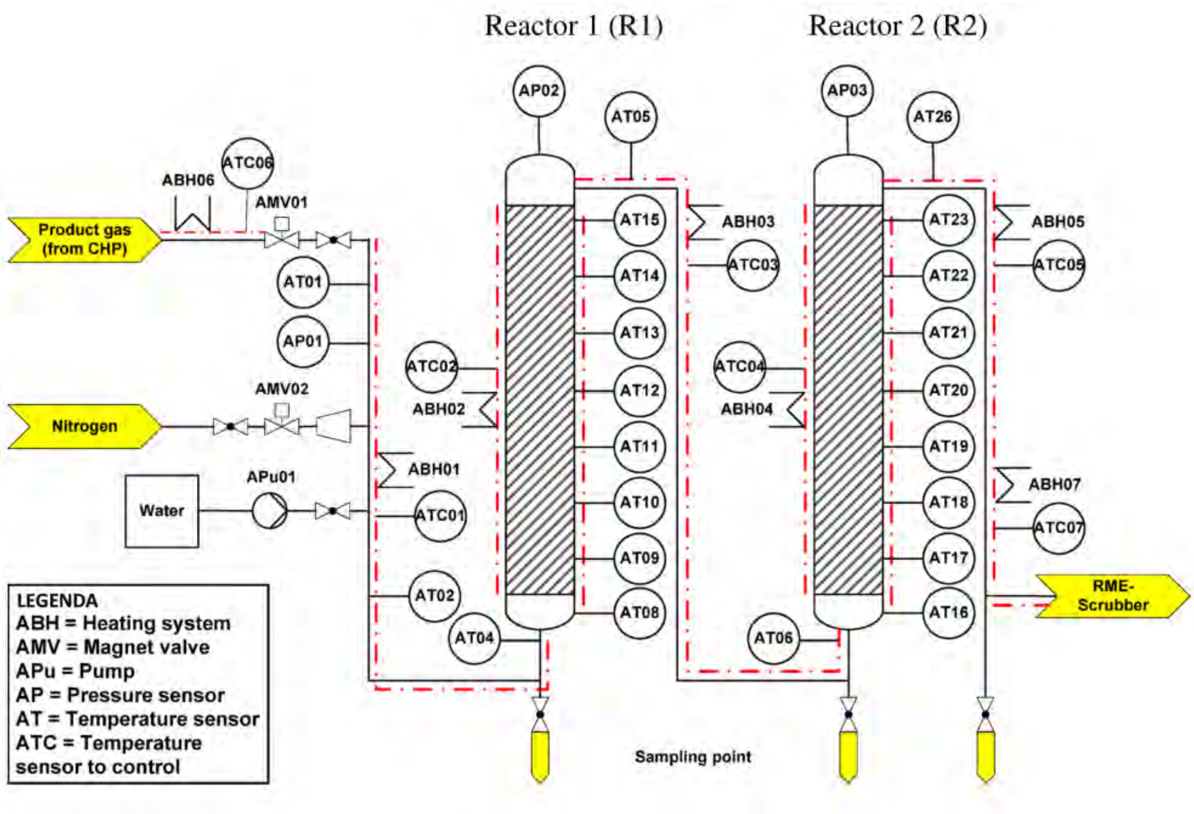


Figure 15: Experimental unit for hydrogen production

Parameters for Catalyst Evaluation

- CO Conversion (X_{CO})

$$\mathbf{X_{CO}}(\%) = \frac{\mathbf{[CO|_{in} - CO|_{out}]\ (mol/h)}}{\mathbf{CO|_{in}\ (mol/h)}} \times \mathbf{100}$$

- Water Gas Shift Reaction Selectivity (WGSR Selectivity)

$$\mathbf{WGSR\ Selectivity}\ (\%) = \frac{\mathbf{[CO_2|_{out} - CO_2|_{in}]\ (mol/h)}}{\mathbf{[CO_2|_{out} - CO_2|_{in}] + [CH_4|_{out} - CH_4|_{in}]\ (mol/h)}} \times \mathbf{100}$$

Conclusions:

- An increase in CO conversion was observed as the temperature increased and the space velocity decreased
- The hydrogen sulphide loading effect was investigated, where a decreased catalytic activity was observed as the H_2S concentration increased, although the catalyst showed a good resistance to hydrogen sulphide poisoning deactivation
- The selectivity of the water gas shift reaction was evaluated and a methanation reaction was detected

SIMEONE CHIANESE, NADIA CERONE, ENEA, Italy

Gasification of fermentation residues from second generation ethanol for production of hydrogen rich syngas in a pilot plant

The gasification of lignin takes place in updraft reactor – PRAGA plant. The process scheme can be seen in the following figure.

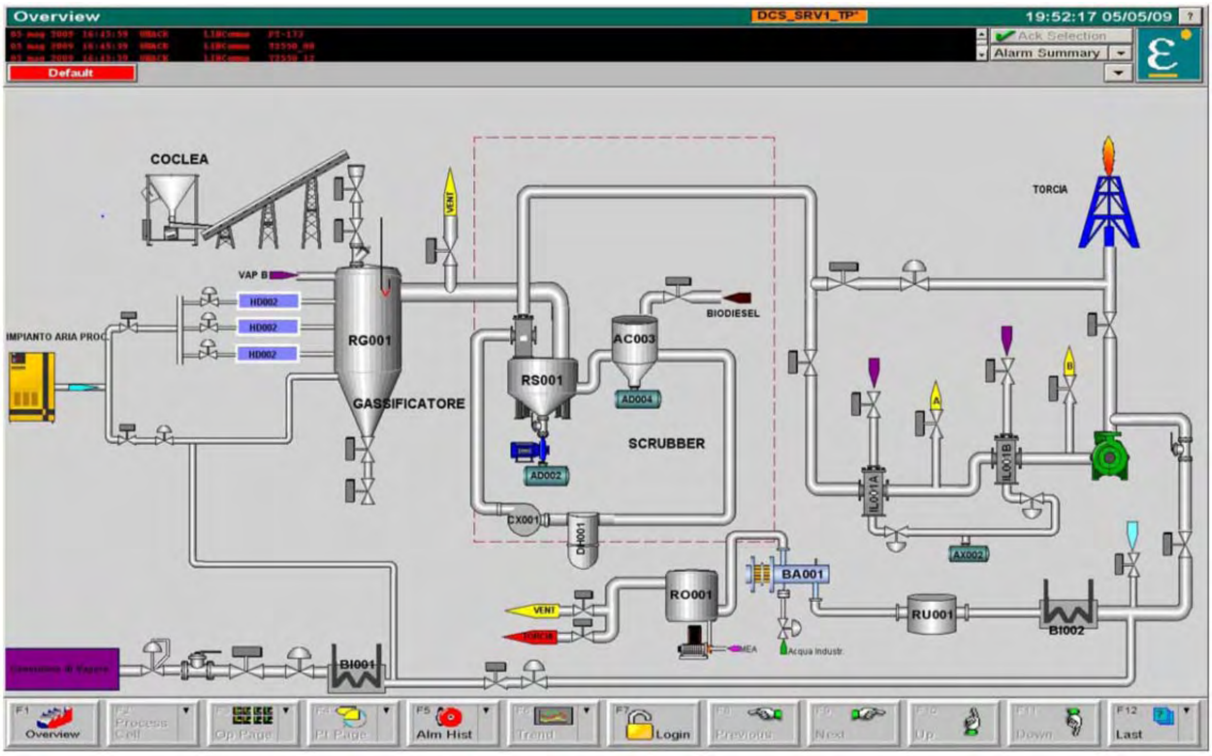
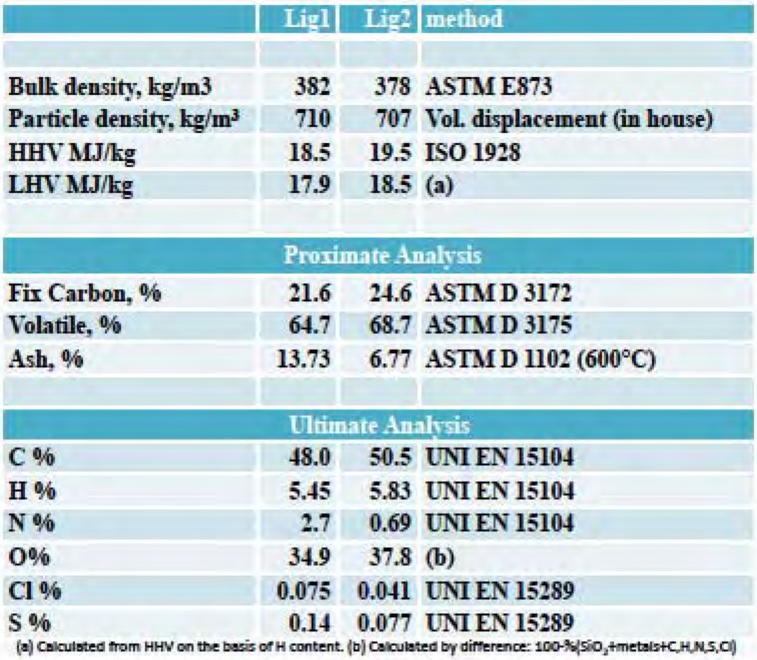


Figure 16: Gasification of lignin in updraft reactor; PRAGA plant – process scheme

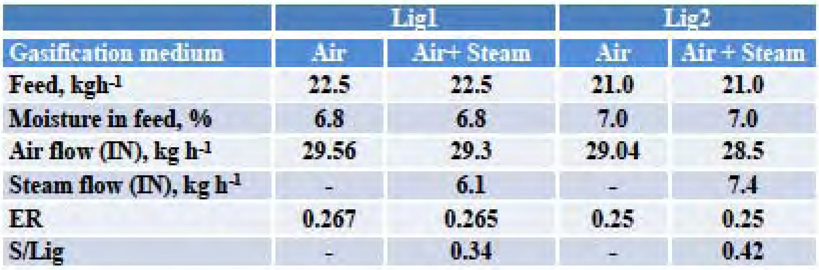
The tests were carried out using lignin as a feedstock and operating the gasification at the following conditions and atmospheric pressure.

Figure 17: PRAGA plant



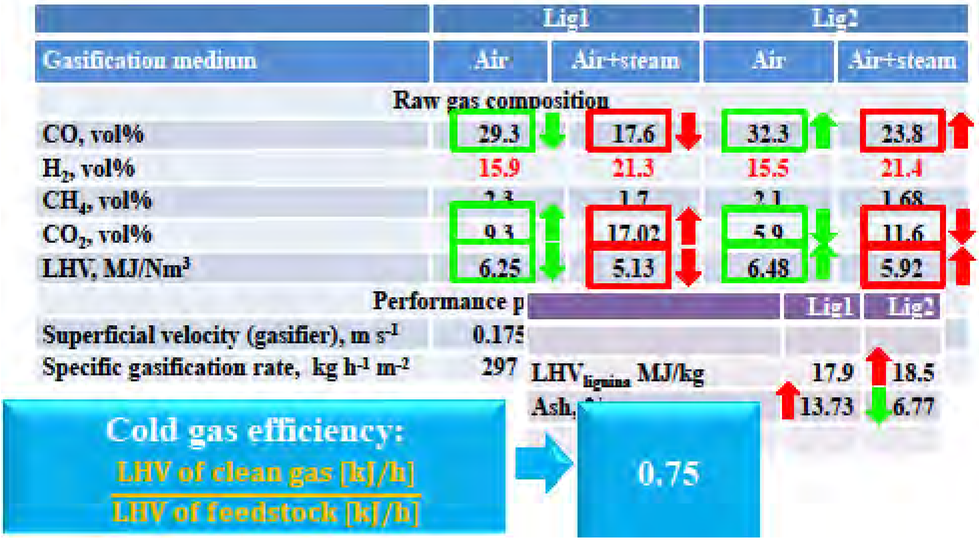
	Lig1	Lig2	method
Bulk density, kg/m3	382	378	ASTM E873
Particle density, kg/m³	710	707	Vol. displacement (in house)
HHV MJ/kg	18.5	19.5	ISO 1928
LHV MJ/kg	17.9	18.5	(a)
Proximate Analysis			
Fix Carbon, %	21.6	24.6	ASTM D 3172
Volatile, %	64.7	68.7	ASTM D 3175
Ash, %	13.73	6.77	ASTM D 1102 (600°C)
Ultimate Analysis			
C %	48.0	50.5	UNI EN 15104
H %	5.45	5.83	UNI EN 15104
N %	2.7	0.69	UNI EN 15104
O%	34.9	37.8	(b)
Cl %	0.075	0.041	UNI EN 15289
S %	0.14	0.077	UNI EN 15289

(a) Calculated from HHV on the basis of H content. (b) Calculated by difference: 100-%(SiO_2+metals+C,H,N,S,Cl)



	Lig1		Lig2	
Gasification medium	Air	Air+ Steam	Air	Air + Steam
Feed, kgh^{-1}	22.5	22.5	21.0	21.0
Moisture in feed, %	6.8	6.8	7.0	7.0
Air flow (IN), kg h^{-1}	29.56	29.3	29.04	28.5
Steam flow (IN), kg h^{-1}	-	6.1	-	7.4
ER	0.267	0.265	0.25	0.25
S/Lig	-	0.34	-	0.42

Table 2: Gasification of lignin: parameters



	Lig1		Lig2	
Gasification medium	Air	Air+steam	Air	Air+steam
Raw gas composition				
CO, vol%	29.3 ↓	17.6 ↓	32.3 ↑	23.8 ↑
H_2, vol%	15.9	21.3	15.5	21.4
CH_4, vol%	2.3	1.7	2.1	1.68
CO_2, vol%	9.3 ↑	17.02 ↑	5.9 ↓	11.6 ↓
LHV, MJ/Nm^3	6.25 ↓	5.13 ↓	6.48 ↑	5.92 ↑
Performance p				
Superficial velocity (gasifier), m s^{-1}	0.175			
Specific gasification rate, kg h^{-1} m^{-2}	297			

	Lig1	Lig2
$LHV_{lignina}$ MJ/kg	17.9	↑ 18.5
Ash,	↑ 13.73	↓ 6.77

Cold gas efficiency:

$$\frac{\text{LHV of clean gas [kJ/h]}}{\text{LHV of feedstock [kJ/h]}} \rightarrow 0.75$$

Table 3: Gasification of lignin – results

The future work in this field

- To optimise of gasification parameters (ER, steam/biomass, feeding rate)
- To improve the analytics of tar determination
- To maximize the hydrogen content
- To model in ChemCad the process by using the kinetic parameters (TGA) and comparison with experimental output

Summary

Small scale biomass gasification has been a technological option that has raised a lot of interest during the last years.

The security of supply and climate change issues and the linked recent growth of the local power generation by means of renewable energy technologies are providing real opportunities for the development of small scale biomass gasification systems.

The workshop offered a good overview and important information on small scale biomass gasification in Italy and Austria. The research organisations as well as the representatives of industrial companies active in this field participated on the workshop.

All the presentations can be found at the Task 33 website. (www.ieatask 33.org)