Biomass and Waste Gasification

Country Report ITALY

IEA Bioenergy Task 33

2018

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INTRODUCTION

Italy has long been involved in the energy exploitation of residual biomass and waste. Among the various processes adopted, the way based on the thermochemical process of gasification has certainly attracted considerable interest. Such process has found favor both in public research organizations and in private companies, which currently supply gasification plants on the market based on their own design.

In the following sections legislative frameworks of reference, research programmes providing economic support to activities of RD&D, and major public and private key players active in the field of gasification at national level, are described.

RD&D PROGRAMMES TO PROMOTE THE RENEWABLE ENERGY SECTOR.

In 2015, Italy defined and adopted a National Research Programme (NRP). The objective of this programme for research, development and demonstration (RD&D) is to ensure the coordination of research with other national policies and the alignment of the Country to the strategic vision defined at European level. The NRP is also intended to favour the conditions for a progressive integration between public and private research.

To this aim, 12 areas of specialization were identified with the aim of giving priority to the most promising applied research initiatives. These areas were identified taking into consideration also the industrial relevance of the production sectors with respect to the national context.

In its first edition, the programme was planned to cover a time horizon up to 2020. Accordingly, during this period, the NRP has gradually been implemented. It is currently in operation and in progress.

The 12 areas identified as having priority and strategic importance for Italy are: Aerospace; Agri-food; Cultural Heritage; Blue Growth; Green Chemistry; Design, Creativity and Made in Italy; Energy; Smart Factory; Sustainable Mobility; Health; Smart, Secure and Inclusive Communities; Technologies for Living Environments. With respect to such overview, actions aimed at giving support and drive RD&D progress for gasification-based technologies are included in the strategic lines of energy and green chemistry.

Other instruments available to promote advances in the area of gasification are the EU funding programmes for R&D. Research bodies and universities are the main players involved in the study and development of gasification, and related subjects, i.e. from the thermochemical process carried out with different technologies, including pre-treatment stages, to the use of the produced gas and its conversion into biofuels. The activities take place within programs carried out at the respective groups and collaborations with other national and international organizations. A description of some of these groups is presented in the “Research institutes” section where activities which most distinguish their work and infrastructures are presented.

THE ITALIAN SUPPORT TO ELECTRICITY PRODUCTION FROM BIOMASS

To facilitate the diffusion of renewable energy technologies for electricity production and achieve the commitments made at EU level, the Italian government had supported over time the sector with public incentives regulated through ministerial decrees. The incentives were granted following the criteria of the technology readiness level (i.e. specific costs of production) for each type (PV, Wind, etc.), and on the basis of the plant size. The incentives were then gradually reduced as a certain technology approached commercial maturity (e.g. PV); the subsidies were granted at a rate inversely proportional to the size of the plant: the larger the plant size, the lower the incentive. These measures also comprised incentives for technologies based on the use of biomass, including gasification.

At the date of preparation of this document, two new government decrees on electricity production from RES are under delivery. The last decree has in fact been divided in two parts in order to take into account the differences still present in the maturity towards the market of some classes of technologies compared to others.

These measures are known under the acronyms “FER 1” and “FER 2”, where the abbreviation FER stand for “Fonti Energetiche Rinnovabili” (Renewable Energy Sources). The “FER1” decree is expected to be published shortly and is aimed at regulating the incentives for technologies considered ready for the market (i.e. wind, hydropower, landfill gas, photovoltaic). The second decree, “FER 2”, is instead intended to regulate the incentives for power production through the most innovative technologies, namely: biomass and biomethane, geothermal, thermodynamic solar. It is currently under preparation.

Besides power production, the thermochemical process of gasification is also included as eligible process in the decree for incentives devoted to the production of biomethane and advanced biofuels for the transport sector. This initiative was undertaken in order to favour the share of biofuels in the transport sector and the fulfilments in accordance with the commitments signed by Italy within the European Union in favour of the reductions of fossil fuels and GHG emissions into atmosphere. The decree currently in force was officially published on March 2018[1].

DIFFUSION OF GASIFICATION TECHNOLOGY ON THE NATIONAL TERRITORY: THE PLANTS CONNECTED TO THE GRID.

With its agricultural crops, agro-industrial activities and woodland and forest areas, Italy has quantities of residual woody biomass[2,3,4,5] suitable for use in gasification processes. The current scenario shows a situation in which, with the exception of Liguria, in all the other Italian regions there is a certain number of gasification plants. Most of these plants are based on commercial fixed bed gasifier technologies, in particular downdraft configuration. The product gas from these plants is typically exploited in internal combustion engines for power production, which is delivered to the national electricity grid (Figure 1)[6] for transmission and dispatching. The installed units are both from abroad and from the manufacturing of Italian companies that have invested and developed their own systems (see dedicated section).

[1] https://www.gazzettaufficiale.it/eli/id/2018/03/19/18A01821/SG

[2] http://atlantebiomasse.brindisi.enea.it/atlantebiomasse/mappe.html

[3] https://www.enama.it/userfiles/PaginaSezione/files/p1c2.pdf

[4] http://www.fiper.it/fileadmin/user_upload/biblioteca/libroFIPER-biomasse-legnose-petrolio-verde-per-il-teleriscaldamento-italiano.pdf

[5] https://www.progettobiomasse.it/it/pdf/studio/sintesi_studio.pdf

[6] This chart is based on data from the Italian Energy Service System Operator (GSE, Gestore dei Servizi Energetici).

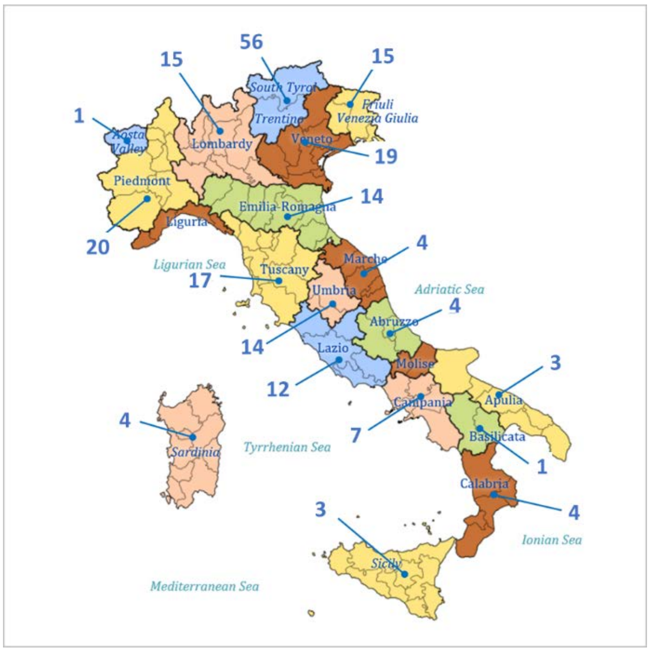


Figure 1. Distribution of gasification plants in Italy (source: data from GSE, 2018[7])

The nominal total installed power amounts to about 43 MWel. Table 1. shows the distribution data among northern, central, southern Italy and islands.

Table 1. Gasification plants installed in Italy.

Geographical area	N° Plants	%	kWel.	%
Northern Italy	140	64.2	32,141	73.8
Central Italy	51	23.4	7,141	16.4
Southern Italy and islands	27	12.4	4,244	9.8
Total	**218**	**100.0**	**43,526**	**100.0**

Most of the plants and installed power are located in the area of northern Italy, in accordance with the fact that in this area of the country the presence of forested areas and companies that work wood is significant. Trentino-South Tyrol is the region with the larger number of gasification plants and power production.

The plant size varies in the range from 20 to 1000 kWel. This range is the result of combination of different factors which take account of logistical and operational aspects, such as the availability of residual biomass from short supply chain and the easiness of plant running (i.e. without the need of dedicated and permanent staff), as well as the availability of incentives by size of produced power.

In Figure 3 the distribution of the number of plants per sub-range of electric power is shown; Figure 3 presents the corresponding distribution in percentage. From these charts, in fact, it appears rather evident that most of these plants are in the power side not exceeding 200 kWel, that is from micro to small size. Altogether they represent over 80% of the total number, while the remaining limited part

[7] See also link Atlaimpianti: https://atla.gse.it/atlaimpianti/project/Atlaimpianti_Internet.html

indicating the plants with dimensions up to 1000 kWel.

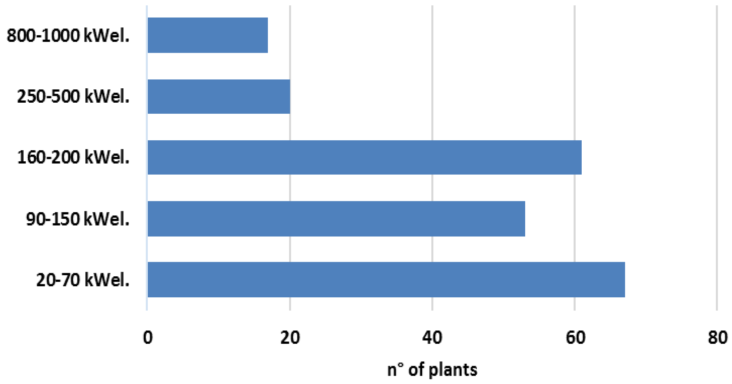


Figure 2. Distribution of the number of plants by size.

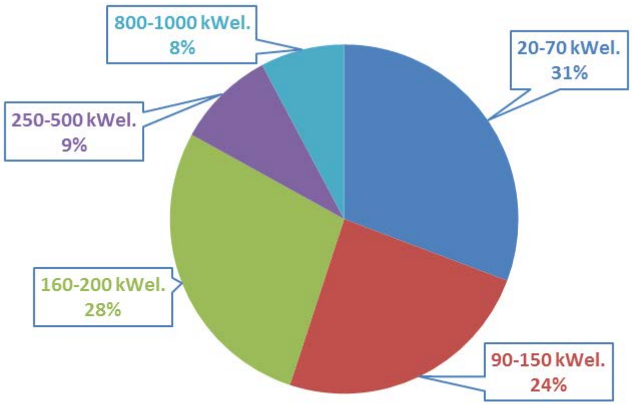


Figure 3. Percentage of number of plants by size.

Based on the identified ranges of electric power, the largest contribution to the total power production comes from the plants in the 160-200 kWel and 800-1000 kWel ranges (Figure 4), which account for 27 % and 36 % of the total (Figure 5), respectively.

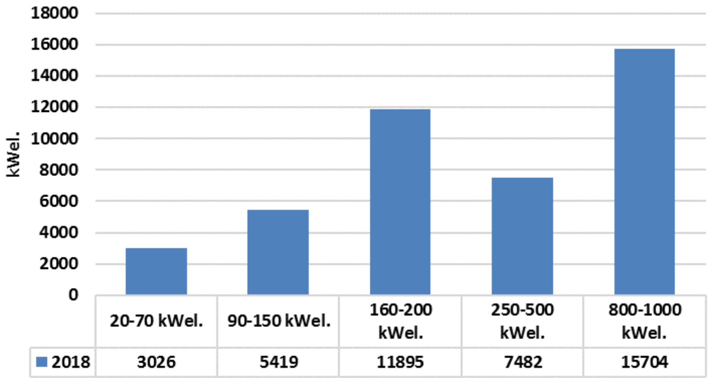


Figure 4. Power distribution by size.

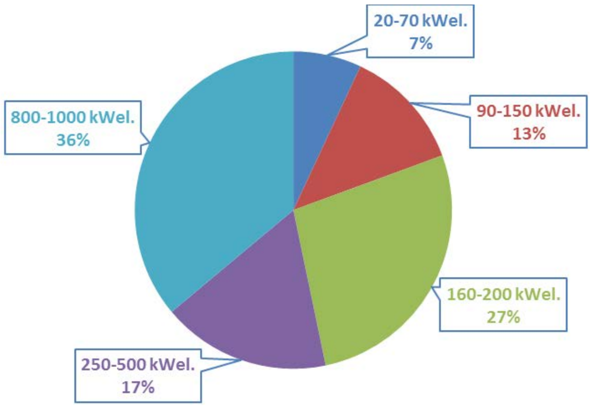


Figure 5. Percentage of power distribution by size.

The total installed power is expected to increase further thanks to the entry into operation of some new plants authorized under the criteria of the decree published by the Ministry of Economic Development on 23 June 2016. As indicated in the section "RD&D programmes to promote the renewable energy sector", this decree is no longer into force.

At the time of writing of this document, a new decree, focusing on power production from renewable energy sources more innovative and with higher specific production costs, is being prepared. When completed, it will contain the next steps in support of bioenergy and technologies for the electrical production from biomass and by-products of biological origin.

R&D INSTITUTES

1. AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE (ENEA; ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT)

Research area:

• Gasification reactor design (Fixed bed and fluidized bed gasifiers),

• High temperature gas cleaning and conditioning,

• Small scale CHP plant,

• Hydrogen and biofuels production from biomass,

• CFD simulation of gasification reactors,

• Process modelling,

• Life cycle and technical-economic assessments

The Agency's activities are mainly focused on Energy Efficiency, Renewable Energy Sources, Nuclear Energy, Climate and the Environment, Safety and Health, New Technologies. R&D activity related to the exploitation of biomass feedstocks and biogenic fractions via thermochemical processes are carried out at Trisaia Research Center (Rotondella, Italy) within the mission and scope of the Division of Bioenergy, Biorefinery and Green Chemistry.

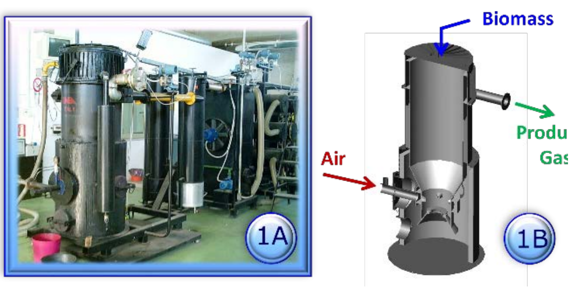
On the subject, at Trisaia a technology park dedicated to biomass gasification is present (Figure 6). The activity of R&D is focused on the development of small to medium sized technologies for power production. This is in order to allow the exploitation of low value feedstocks, such as biomass residues from forest management, agro-industrial sectors and wood industries, and at the same time facilitate the diffusion of decentralized energy production.

Figure 6. Photo of the technology platform site on gasification at Enea Trisaia Research Center.

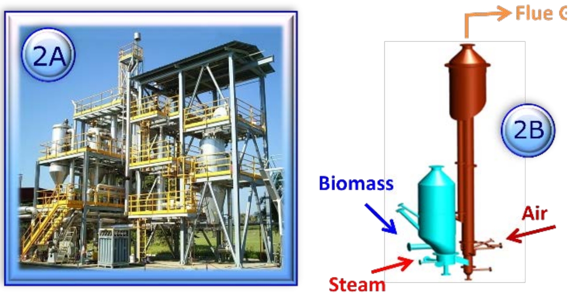
To produce power both the conventional internal combustion engine (ICE) and the more efficient, high temperature fuel cells (i.e. MCFC and SOFC) are mainly considered. Large attention is devoted to aspects which are known be critical for the achievement of full maturity of the gasification technology, such as reactor design, HT gas cleaning and conditioning, gas use/conversion and process integration/intensification, process modelling. In the program of R&D activity, development of innovative processes for production of secondary energy carriers, i.e. liquids and gaseous, such as Methanol, DME, BioSNG and H_2, are also included.

The gasification plant available are based on gasification reactors of different design (i.e. fixed beds, fluidized beds and multi stage), and are equipped with sections for gas cleaning and conditioning (*Figure 7*). To enable the monitoring of the process during gasification test campaigns, the plants are equipped for on-line control of process parameters, such as temperature, pressure, flow rates, and for gas composition and contaminant load measurements. Since the problem of contaminants in the producer gas is still one of the most critical, at Trisaia's facilities both primary and secondary purification methods are investigated depending on the final application. A well-equipped chemical laboratory provides the most relevant analytical techniques for feedstocks characterization and process streams analysis.

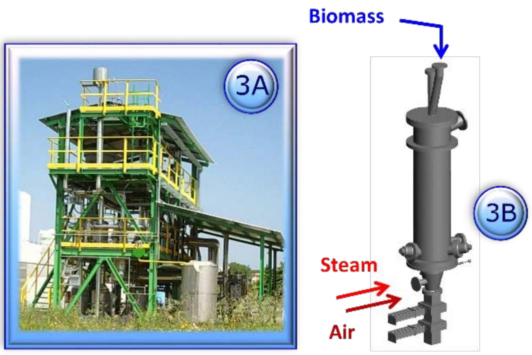
Most relevant facilities are at pilot scale, with sizes ranging from hundreds of kW_{th} to 1 MW_{th}, therefore evaluation of the whole process chain 'Biomass-to-end application' (i.e. BTP, BTG, BTL) can be assessed. Sustainability aspects of the considered processes are taken into account through LCA studies and technical-economic analyses. In order to reduce both investment and production costs, R&D activities for gasification process intensification are underway. Specifically, at Enea-Trisaia Research Center, a high-temperature gas purification system, integrated directly into the freeboard of a 1 MW_{th} bubbling fluidized bed reactor has been implemented and tested. The gasifier in the advanced configuration has been operated in steam/O_2 biomass gasification tests. The experimental campaigns have provided a favorable result with respect to the reactor reliability and the particles removal effectiveness. A particle removal efficiency above 99% was ultimately achieved.



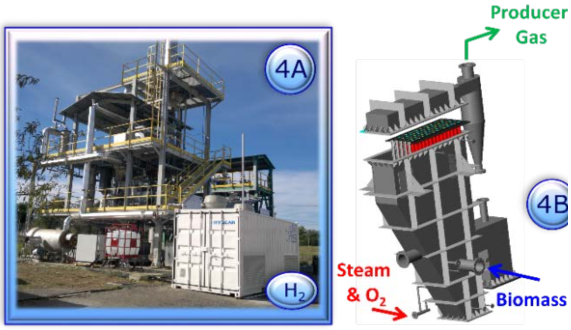
1A) Air-Blown Downdraft Fixed Bed Gasification Plant (120 kW_{th}), with Conventional Gas Cleaning: Filtration Units and Water Scrubber, combined to Internal Combustion Engines (30-80 kW_e). 1B) Scheme of reactor.



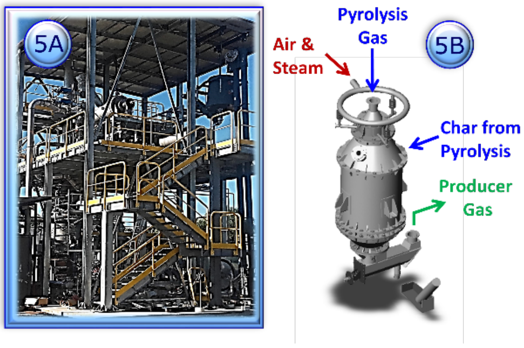
2A) Dual Fluidised Bed Steam Gasification Plant (500 kW_{th}) with Hot Gas Cleaning via an Adsorbing Reactor and a Filtration Unit: Cyclone plus Ceramic Filter. 2B) Scheme of reactor [1].



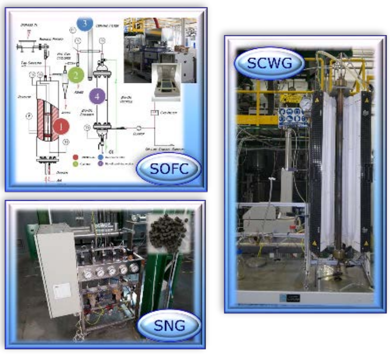
3A) Air/Steam-Blown Updraft Fixed Bed Gasification Plant (150 kW_{th}) with Wet Gas Cleaning: Bio-Diesel Scrubber coupled with Coalescent Filters. 3B) Scheme of reactor.



4A) Internally Circulating Fluidised Bed Steam/O_2 Gasification Plant (1 MW_{th}) with integrated Catalytic Ceramic Candles system for In-Situ gas filtration and conditioning. 4B) Scheme of reactor [2].



5A) Multi-stage air/steam gasification plant (500 kW_{th}) with separate plug flow pyrolysis, partial oxidation of tars (vortex combustion), downdraft gasification and syngas filtration on char bed. 5B) Scheme of gasification reactor [3].



6) Bench scale facilities: 10 kW_{th} gasification plant for tests; Test rig for BioSNG synthesis; Test rig for supercritical water gasification (SCWG);

1) Technology developed in collaboration with Vienna University of Technology and University of L'Aquila; 2) Technology jointly patented by ENEA and University of L'Aquila; 3) Technology developed in collaboration with Ansaldo STS and Varat S.r.l.

Figure 7. Overview of the main pilot plants and bench scale facilities available at the Enea Trisaia Research Center

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2. CENTRO INTERUNIVERSITARIO PER LE RICERCHE SULLE BIOMASSE A SCOPI ENERGETICI (CIRBE; INTERUNIVERSITY CENTER FOR BIOMASS RESEARCH FOR ENERGY PURPOSES) AND UNIVERSITÀ DEGLI STUDI GUGLIELMO MARCONI (GUGLIELMO MARONI UNIVERSITY)

Research area:

• Gasification reactor design (mainly fluidized bed)

• Fluid-dynamic behaviour of fluidized bed chemical reactors, under high temperature and pressure conditions

• CFD simulation of fluidized bed equipment and heterogeneous reaction systems

• Catalytic biomass steam gasification

• Hot gas cleaning and conditioning

• Power plant and process simulation

• Small scale CHP plant

• Technical-economic analysis of innovative systems

CIRBE is an inter-university consortium established between University of L'Aquila and University of Teramo. Together with Guglielmo Marconi University, these three bodies have long been engaged in activities devoted to development of technologies based on fluidized bed gasifiers for biomass and waste gasification.

At University of Teramo the R&D activity on the subject are carried out at the Laboratory of Energy and Environmental Research (EERU). The Laboratory is equipped with a bench-scale fluidized-bed gasifier, able to operate for experimental steam/air gasification tests in steady state up to 850°C. This gasifier is designed to host a filter candle in its freeboard, that allows to carry out particle filtration and to host catalyst pellets for gas conditioning directly inside the reactor. The laboratory is also well equipped with various measurement and analytical instruments, including on-line gas analysis (IR, FID and TCD detectors), dynamic pressure measurements inside the reactor and HPLC tar measurements (*Figure 8*).

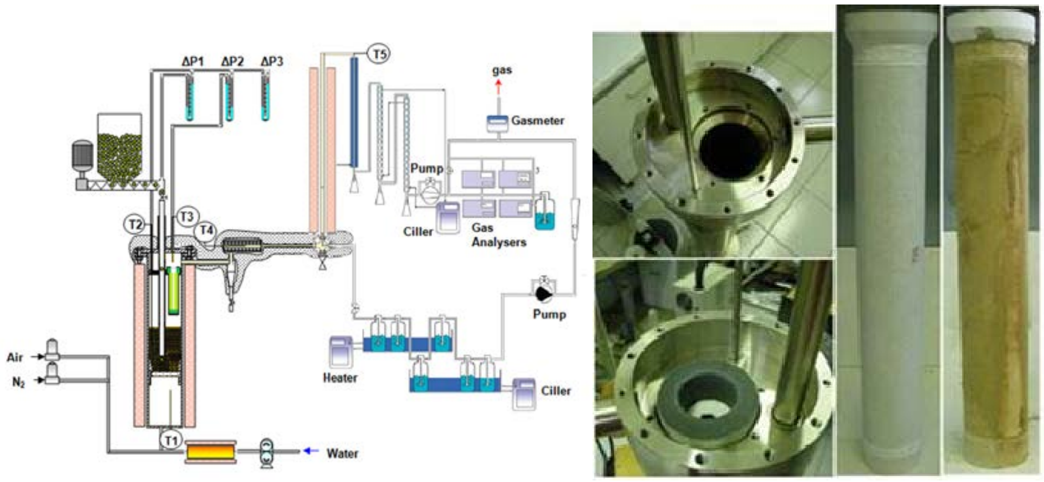

Figure 8. Fluidized bed gasifier bench scale rig with filter candle inserted in the freeboard

Furthermore, the University of Teramo with its spin-off Gassilora realized two fluidized bed gasifiers, one of 200 kWth and the other of 1 MWth as biomass input (*Figure 9*) together with T.M.L. srl.

Figure 9. 200 kWth fluidized bed gasifier realized by the spin-off of the University of Teramo

The laboratory of Chemical Reaction Engineering and Fluidization Dynamics (CRE&FD) of the University of L'Aquila and the Laboratory of Energy and Environmental Research (EERU) of the University of Teramo have been active in fluidized bed biomass gasification research since more than 20 years. Research and innovation projects at lab and pilot scale have been carried out, at the level of both theoretical and experimental research investigations, funded by the European Union and bilateral Organizations. These groups are also member of permanent research networks on "biomass for energy" and "sustainable development" (ARCUS, GDRI, ICTP/TRIL, CIRBE).

The CRE&FD of the University of L'Aquila has experience in the investigation of fluidized bed chemical reactors and multiphase reactors by means of: i) cold model testing and ii) CFD simulations; in particular for fluidized bed reactor and catalytic system for syngas hot gas cleaning and conditioning (*Figure 10*).

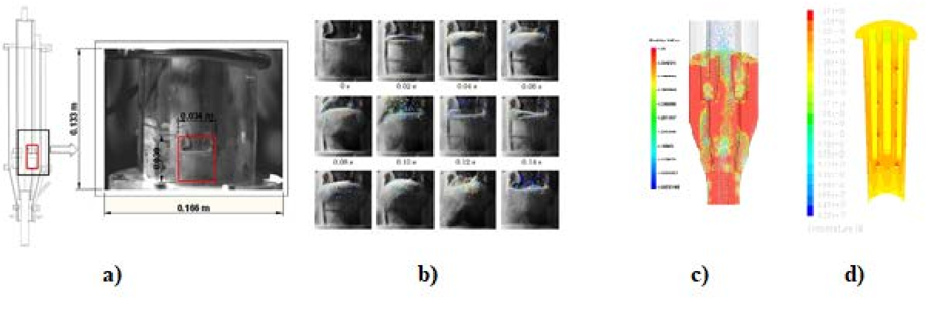

Figure 10. a) Cold model apparatus used for the investigation of an innovative fluidized bed gasifier, b) few snapshots obtained by means of Particle Tracking Velocimetry applied to the fluidized bed, c) Eulerian-Lagrangian simulation of an innovative fluidized bed gasifier, d) 3D CFD simulation of catalytic filter candles inserted in the freeboard of a fluidized bed gasifier

Furthermore, the laboratory of CRE&FD of the University of L'Aquila has a fully automatized test rig composed by a micro-reactor, systems of measurements and control of the flows and analysis instruments for the outlet streams. This test rig is used to carry out long term tests on catalysts and sorbents to be coupled to the gasification process (*Figure 11*). The laboratory is also well equipped with various measurement and analytical instruments, including on-line gas analysis (IR, FID and TCD detectors, GC).

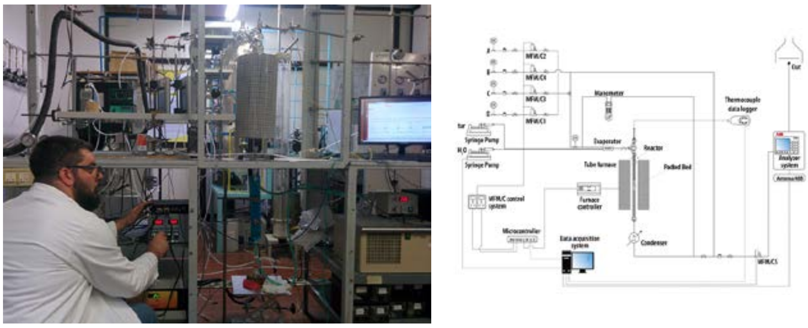

Figure 11. Micro-reactor for experimental test with catalysts and sorbents to be coupled with the gasification process

The Laboratory of Applied Sciences and Technologies of Guglielmo Marconi University is engaged in activities of R&D mainly focused on the themes of 1) renewable sources: potentialities, processes and plants 2) biomass gasification and syngas conditioning systems. In particular, energy simulations of systems and processes are performed through softwares (Excel, Autocad, Trnsys, Chemcad/Aspen, Matlab/Simulink, Labview, Comsol/Fluent, SolidWorks/Simpack, etc.). Well-equipped laboratories support the research activities with instruments for development of innovative catalytic materials, physical characterizations and chemical analysis of organic compounds.

The three research groups of University of L'Aquila, University of Teramo and Guglielmo Marconi University are strongly involved in the development of a 100 kW_{th} dual fluidized bed biomass gasifier (*Figure 12* and *Figure 13*), coupled with a system for hot gas cleaning and conditioning for the production of a hydrogen-rich syngas and the realization of a small scale CHP system (25 kWe, 55 kW_{th}) via the coupling of the gasifier to ICE or SOFC.

Figure 12. 100 kWth dual bubbling fluidized bed gasifier new version

Figure 13. 100 kWth dual bubbling fluidized bed gasifier previous version

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3. CONSIGLIO NAZIONALE DELLE RICERCHE (CNR; NATIONAL RESEARCH COUNCIL)

Research area:

• Study and development of gasification technologies based on slagging entrained-flow, fluidized-bed and fixed-bed reactors;

• Small scale cogeneration (CHP) plant;

• Gas cleaning and conditioning;

• Solid fuel characterization and densification pretreatments;

• Thermochemical equilibrium and kinetic models of biomass gasification and overall energy balance;

• CFD 1D models (phenomenological) of biomass gasification in fluidized and fixed beds;

• Syngas combustion performance characterization and modeling in spark ignition (SI) and compression ignition (CI) engines;

• System analysis of biomass powered cogeneration (CHP): analysis and optimization of integrated processes of syngas production and internal combustion engine powering.

At Consiglio Nazionale delle Ricerche (CNR), studies in the field of biomass and waste gasification are focused on process studies and technologies development and are carried out at both experimental and theoretical levels. The R&D activities cover the whole process chain, from gasification reactors of different configuration and size, also considering local feedstocks availability, to gas end-use.

The main research groups involved on these subjects are the "Istituto di Ricerche sulla Combustione" (IRC), which works in close collaboration with the "Dipartimento di Ingegneria Chimica, dei Materiali e della Produzione Industriale" (DICMaPI) of University of Naples-Federico II and with the "Istituto Motori" (IM), and the "Istituto di Tecnologie Avanzate per l'Energia" (ITAE).

The IRC is active in the study of the hydrodynamics of fluidized bed and slagging entrained-flow reactors with focus on solid fuel segregation patterns. The research activity is devoted to the identification of strategies for tar reduction with particular attention to develop new catalyst also with suitable properties for fluidized bed reactor application or to adopt strategies to limit the segregation phenomena of biomasses. The activities are performed using a fluidized bed gasifier on pre-pilot scale (140mm ID and 4m high) gasifier available at IRC (*Figure 14*) and equipped with all the analysis instrument for the characterization of the output of the process (solid, liquid and gaseous streams).

As concerns the activities on slagging entrained-flow reactors the study, in cooperation with DICMaPI, is focused on the characterization of the fate of char or ash particles as they impinge on the wall slag layer and, in turn, on the establishment of different near-wall segregated phases. The final scope is the development of closure equations for the prediction of near-wall particle behaviour in slagging entrained-flow gasifiers. The studies have been carried out pursuing in parallel experimental and modelling investigations with the aid of an *ad hoc* designed experimental apparatus and numerical simulation codes adopting the hard sphere Eulerian-Lagrangian approach or the DEM soft sphere approach.

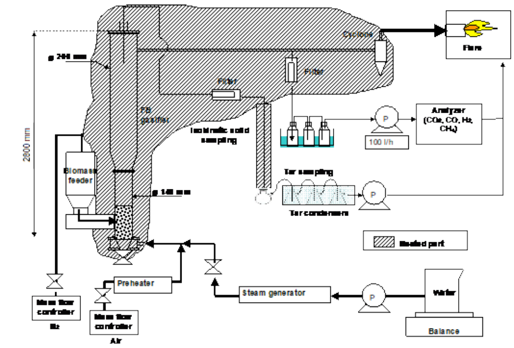
The research activity is also devoted to study the integration of different pretreatment strategies such as torrefaction and pelletization with gasification process. More specifically the activity is devoted to assessing the role played by the main process variables (i.e., temperature and reaction time) and the effect of the reactor configuration (fixed bed vs. fluidized bed reactor) on the properties of residual biomasses pretreated and further employed in gasification processes.

Studies on attrition phenomena of fuel, sorbent and bed materials are performed, in cooperation with DICMaPI, using *ad hoc* developed batch and continuous experimental lab scale facilities operated in fluidized bed as well as in entrained flow conditions. The activity is complemented by the development of predictive submodels of single particle reaction-attrition/fragmentation. Sorption-enhanced gasification conditions, using calcium-based CO2 sorbents, are also investigated with a focus on the sorbent mechanical and chemical stability under cyclic operation.

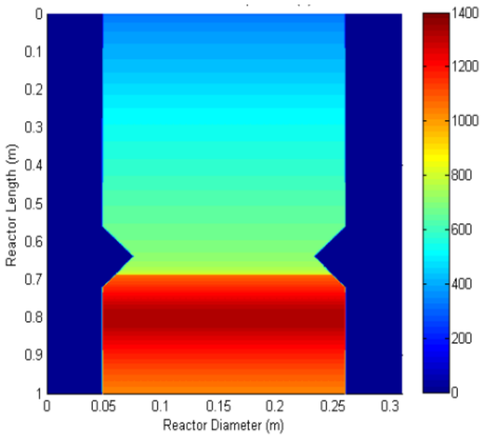
The activities of IRC in fuel characterization include standard methodologies, but also in-house developed analytical methodologies for in situ and detailed chemical analyses. IRC activities on reaction kinetics complement TGA analysis with experiments in microreactors, fluidized beds and heated strip reactor. Particular focus is posed on the effects of temperature and gaseous atmospheres on the particles structure, morphology and reactivity. The activity aims also at the development of predictive submodels of single particle reaction.

The numerical activities carried out by IM regard the description of the gasification process through the development of numerical models characterized by different level of accuracy. The inadequacy of 0D thermo-equilibrium models to correlate reactor design parameters, raw material residence time and interaction with gasifying agent with the final product gas composition is overwhelmed by developing proper kinetic or phenomenological models. The knowledge in the field is based on a long-year experience in the numerical simulation of multi-phase reacting flows. As far as numerical analysis is concerned, the IM activity is dedicated to the optimization of fully integrated processes for an efficient biomass valorisation. Syngas combustion in internal combustion engines is also not only modelled to various level of approximation but also experimentally studied to achieve optimal control (Figure 14), for the maximum power output and reduced pollutant emissions from real thermal engines. Instability of combustion related to the low quality of the syngas is also characterised.

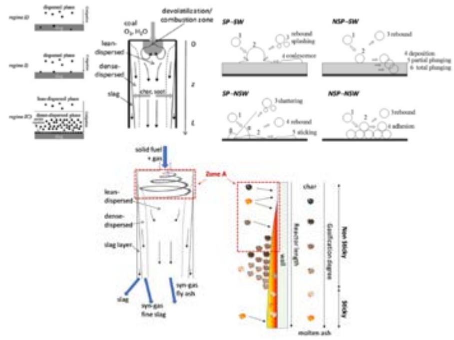
a) 50 kWth Bubbling Fluidized bed gasifier



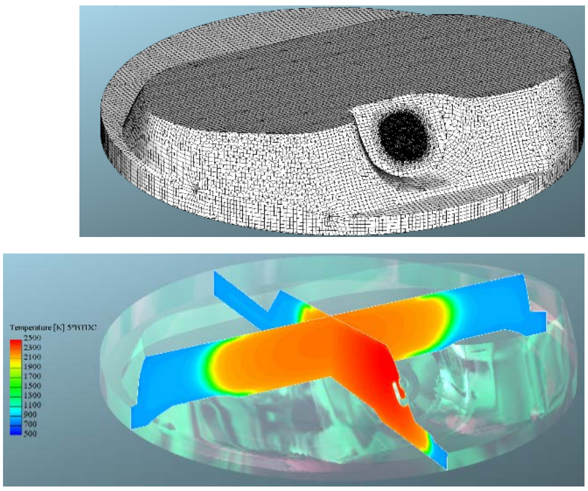
b) Scheme of the pilot-scale biomass fluidized bed gasifier



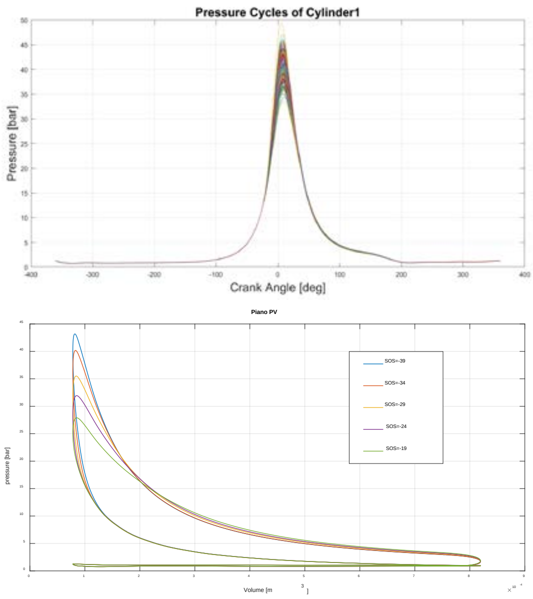
c) Phenomenological 1D model of gasification in a downdraft gasifier (temperature field)



d) Schematic of a slagging entrained-flow gasifier with different near-wall segragation regimes



e) Internal combustion engine simulation as powered with syngas



f) Experimental characterization of syngas combustion in a SI ICE

Figure 14. Photos and schemes of some representative activities carried out by IRC and IM

At ITAE, the R&D activities related to the process of biomass gasification are mainly focused on the study of the most effective approaches to the exploitation and valorisation of local biomass residues such as pruning lignocellulosic biomass and residual feedstocks (e.g. citrus peels, algal materials) for high-efficient power production and syngas conversion. For this purpose, use of different reactor configurations and oxidant agents (oxygen, air, steam), as well as catalysts, are explored (*Figure 15*). Together with experimental activities, simulation models (Computational Fluid Dynamics, composition at equilibrium, steady-state and transient analysis) for fluidized/fixed bed gasifier and integration in CHP or fuel cell systems are development and validation. The R&D programme is finally supplemented with activity of design and development of catalysts, reformers and complete fuel processors units based on SR, ATR, POX and Tri-reforming processes for syngas conditioning to energy vectors (H_2, CH_4, CH_3OH, DME).

a) Fixed bed Gasifier (updraft) 25 kWt equipped with clean-up gas systems

b) Bubbling fluidized bed gasification plant 1,5 kWt

c) Bench scale test plant (left), reformer (right) - Inlet flow range: 1–10 Nm^3/h.

d) Pilot test plant (Inlet syngas flow range: 10–50 Nm^3/h)

Figure 15. Photos of some representative activities carried out at ITAE

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4. LIBERA UNIVERSITÀ DI BOLZANO (FREE UNIVERSITY OF BOZEN-BOLZANO)

Research area:

• Characterization and prototype development of gasification and pyrolysis reactors;

• Innovative filtering systems;

• On-site monitoring and diagnostics of gasification and pyrolysis systems;

• Analysis and optimization of technologies for the combined production of heat and electricity;

• Valorisation of agricultural waste and by-products;

• Biofuels production by means of Fischer-Tropsch synthesis, reforming and methanation;

• Chemical-physical characterization of fuels, catalysts and residues.

The research of the Bioenergy & Biofuels Lab deals with the experimental and modelling characterization of thermochemical conversion processes applied to lignocellulosic biomass. The main investigated processes are gasification and pyrolysis, but also traditional processes such as combustion, as well as innovative valorization pathways such as hydrothermal carbonization. Besides, possible syngas upgrading routes such as reforming, methanation and Fischer-Tropsch synthesis are also investigated.

The research is carried out at different process scales, ranging from the micro scale studied in controlled lab conditions to the real scale studied through the on-site monitoring of plants in actual operation. Extensive experimental activities are currently being carried out in South Tyrol on real small-scale gasification plants (50-250 kWel), coupled with internal combustion engines for onsite energy production.

The laboratory research is comprised by operation of lab- and pilot-scale reactors and by analytical-characterization activities. On the one hand, the Bioenergy & Biofuels LAB is equipped with an open-top gasifier (Betel), for gasification tests at the pilot scale (4 kW, *Figure 16*), a Hydrothermal Carbonization reactor (*Figure 17*), and a reforming reactor for syngas upgrading & Fischer-Tropsch synthesis (*Figure 18*). A char bed reactor has been developed for testing char filtering and catalytic effects (*Figure 19*) and, in addition, a small-scale fixed-bed downdraft gasifier (nominal size 40 kg/h) is in the process of being installed. On the other hand, the LAB is equipped with instruments for the complete characterization of solid and liquid biofuels, such as cutting mill for sample preparation, elemental analyzer (CHNS-O with Cl module), bomb calorimeter, and several apparatus covering a wide spectrum of thermal analysis methodologies (TGA, also coupled with FTIR analysis of the evolved gases, STA, DSC, LFA). A physisorption analyzer allow the measurement of macro and micro-pore size distribution and specific surface area (BET) of solid samples.

The assessment of the performance of biomass CHP generation systems is carried out not only by means of onsite monitoring activities but also by multistage thermodynamic modelling. Engineering tools have been implemented in multistage thermodynamic models. System and scenario analysis on topics such as power-to-gas and biofuels production by means of methane.

Figure 16. Small-scale open top downdraft gasifier coupled with a 4kW single-cylinder dual-fuel diesel engine. The reactor can be used in double stage configuration where primary air flows from the top and secondary air is coming by a nozzle located in the middle of the reactor.

Figure 17. HTC reactor. The reactor allows directly measuring and characterizing in a semi-continuous way the hydrochar and both the liquid and gaseous phases during HTC process. It consists of a 4 liters reactor equipped with an external vessel into which it is possible to extract small amounts of these three phases, without having to wait for the system to be cooled down.

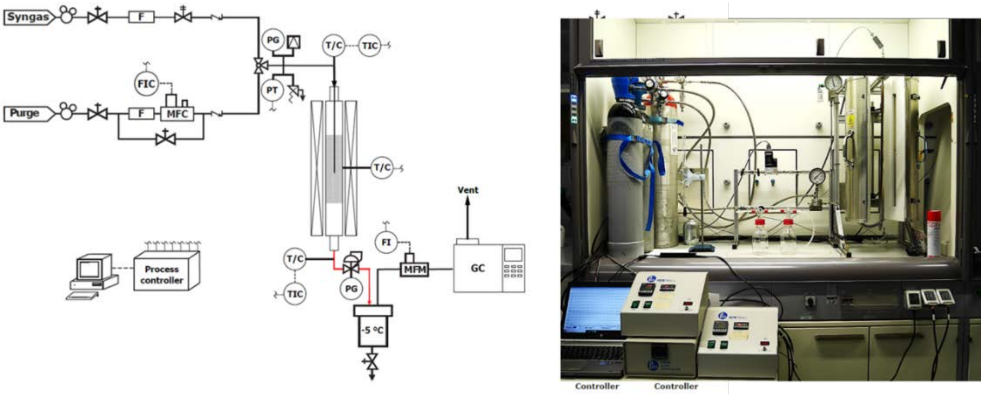

Figure 18. Fischer-Tropsch synthesis & reforming reactor. The catalyst is placed in a fixed bed tubular reactor that is heated with a split-tube furnace controlled with the use of a thermocouple located in the center of the reactor. Gaseous products are analyzed by an on-line gas chromatographer, while products collected in the trap are analyzed off-line by a GC-FID.

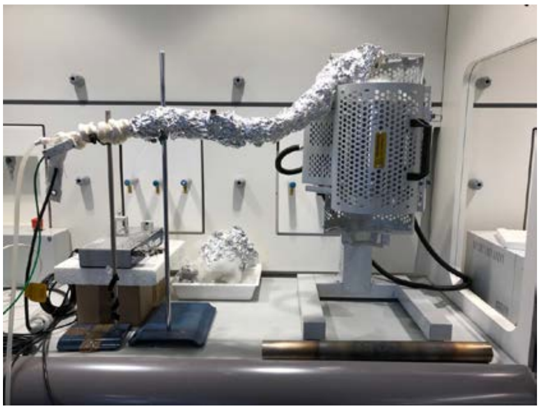

Figure 19. Tar-cracking reactor. The setup consists of a specifically designed quartz tube reactor, filled with an amount of char, a syringe pump for the injection of the tar molecules into the reactor, and a tubular furnace for heating the reactor up to the desired temperatures. At the reactor outlet, tar is sampled both by Solid Phase Adsorption (SPA) cartridges and by following the tar protocol CEN/TS 15439. A calibrated GC-FID is being used for the identification and the quantification of the produced tar compounds. Permanent gases are continuously analyzed with a micro-GC.

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5. RE-CORD - RENEWABLE ENERGY CONSORTIUM FOR RESEARCH AND DEMONSTRATION

Research area:

- Biomass Processing for CHP application and biofuels (gasification, pyrolysis, HTC, HTL);
- Performance assessment of small-scale CHP gasification plant;
- Process for advanced biofuel production;
- Biochar production, functionalization and use;
- EU single-market policy development for biofuels market uptake and deployment;
- Technical-economic analysis and LCA;
- Catalytic conversion processes

The RE-CORD consortium, funded in 2010 under the initiative of CREAR (University of Florence), carries out scientific and technological researches in the field of Renewable Energies and notably in the field of Bioenergy and related policies. RE-CORD is a no-profit independent research body, which merges competences and resources in the field of basic and applied research, engineering, and sustainable land planning and development. Members of RE-CORD are the University of Florence, Az. Agricola Montepaldi, Spike Renewables, ETA Florence, BioEnTech, GAL-START.

RE-CORD has extensive experience on technologies related both to biomass for solid biofuels and energy generation. The specific areas of competence range from technologies for energy generation, thermal and electric, through thermochemical processes, such as gasification and pyrolysis, to those for producing advanced biofuels to technologies for biomass densification (pellets and briquettes).

RE-CORD owns and operates a state-of-the-art chemical and analytical laboratory fully dedicated to biofuels and bioenergy and runs an experimental area where a significant number of research and demonstration facilities are available. Among others, a 70 kWe open-top twin-fire gasifier, a 10 kWe downdraft Imbert-type gasifier, a 100 kg/h indirectly-fired rotary kiln biomass carbonization unit, a 50 kg/h fixed bed autothermal carbonization unit, a 1.5 kg/h intermediate pyrolysis unit, a catalytic methanation unit, as well as batch and continuous set-ups for hydrothermal process development (Figure 20).

RE-CORD personnel participated to International Networks in Bioenergy (as IEA Task 39-Liquid Biofuels), and the Consortium provides consultancy service to the EU Commission, national Ministries, Regions and local stakeholders in carrying out studies or evaluating/monitoring proposals/projects. Examples of such activities carried out for bodies of the European commission are the technical coordination of the ART-Fuel FORUM, or the studies “From the Sugar Platform to biofuels and biochemicals” and the “Template for first-of-a-kind commercial sustainable biofuel project feasibility studies”

In the area of gasification, RE-CORD has been partner of the Indian Institute of Technology of Bangalore in a cooperation project MATT- INDIA, co-funded by the Italian Ministry of Environment and the Indian Ministry for New and Renewable Energies, focused on technology transfer of gasification technologies.

Along with the group of Prof. Baratieri of the Free University of Bozen, RE-CORD joined the most extensive monitoring campaign on small scale CHP units based on gasifiers ever completed in Italy, collecting valuable first-hand information on plant performance data and tar content.

Through its competent but innovative structure, RE-CORD not only bring the research background and expertise of the University of Florence in this field, but also assure a proper implementation of the research work, higher flexibility and faster response to solicitations for new research topics, gather opportunities derived from research results.

a) 70 KWe downdraft twin-fire gasifier

b) 10 kWe downdraft Imbert-type gasifier

c) Test rig for syngas conversion into bioSNG

d) 100 kg/h indirectly-fired rotary kiln biomass carbonization unit

Figure 20. Photos and schemes of facilities in the gasification area

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RE·CORD

UNIVERSITÀ DEGLI STUDI FIRENZE

DIEF DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

C.R.E.A.R.

6. SOCIETÀ TECNOLOGIE AVANZATE LOW CARBON SPA (SOTACARBO SPA)

Research area:

• Fixed bed and bubbling fluidized bed gasification technologies

• Medium- and small-scale CHP generation

• Gas cleaning and conditioning

• Integration with CO2 capture, utilization and storage

SOTACARBO – Società Tecnologie Avanzate Low Carbon SpA is a public research centre (owned by Enea and the Regional Government of Sardinia) active, since 2003, in the field of low carbon technologies, including biomass and coal gasification and CO2 capture, utilization and storage (CCUS).

The R&D activities performed by Sotacarbo are focused on the experimental development of specific gasification technologies for small- and medium-scale commercial applications for combined heat and power (CHP) generation from biomass and mixtures of biomass and coal. Most of the research activity is carried out in three different experimental unit: a bench-scale bubbling fluidized-bed (BFB) reactor, a pilot-scale (500 kWth) BFB unit (*Figure 21*) and a demo-scale (5 MWth) fixed-bed up-draft unit (*Figure 22*).

Fixed-bed up-draft and air-blown gasification technology is tested since 2008 in a pilot-scale unit (200 kWth) and, since 2013, in a demonstration-scale unit (up to 5 MWth), widely tested for more than 2000 hours in different operating conditions with several kinds of biomass and coal/biomass blends. The unit is equipped with a wet scrubber for dust and tar removal, a flare for syngas combustion and a series of analysers for a full process control. The activity, funded by the Italian Ministry of Economic Development (within the "Research on Electric System" programme) and carried out in close collaboration with ENEA, allowed the development of the gasification process and the improvement of the plant performance with respect to the original technology.

The bench-scale BFB gasification plant is part of the carbon-to-fuels facility and is a very flexible unit which allows syngas production from different kinds of biomass. Air, oxygen, carbon dioxide and steam, or combinations of them, may be used as gasifying agents. The process can operate within a wide range of operating conditions: at temperatures of up to 900°C, secondary air in the freeboard, residence time, etc. The gas cleaning system includes a filter to separate solid particles, a condenser to separate tar and water from gases and a scrubber for CO2 and H2S removal. The unit – manufactured by PID Eng&Tech – has been funded by the Regional Government of Sardinia within the "Centre of Excellence on Clean Energy" project and is part of the ECCSEL-ERIC (the European Carbon Dioxide Capture and Storage Laboratory Infrastructure) research infrastructure. A series of experimental campaigns are currently under development to study the gasification performance of different biomass and to set advanced simulation models, in close collaboration with international partners (mainly from USA, UK and India).

The 500 kWth BFB pilot unit – named FABER (fluidized air-blown experimental gasification reactor) – has been built to support the fluidized-bed gasification technology for power generation from biomass and residues. The fuel (wood chips) is supplied by a fuel charging system from the bottom of the gasifier (in-bed). The reactor is fed with pre-heated air (about 600 °C) and operates at 0.20-0.45 bar. The gasification agents (air, N2 and steam) are distributed in the bottom of the reactor with nozzles in an inert sand (olivine), to have the right air speed in the reactor (the process can operate at different equivalation ratios (ER). Syngas is sent to the clean-up section, composed by a cyclone, a Venturi scrubber and a second scrubber for tar removal. Downstream from the gas clean-up section, syngas is sent to a 120 kW_e internal combustion engine for power generation. Four different gas sampling lines are installed in the plant to monitor raw gas. A real-time multi-module industrial analysis system is used to monitor the syngas composition. The plant is also equipped with a tar sampler and analyser. The unit –

designed in close collaboration with the University of Campania “Luigi Vanvitelli” and Centro Combustione Ambiente (CCS) – has been installed in late 2017 within the “Centre of Excellence in Clean Energy” project, funded by the Regional Government of Sardinia.

The demo-scale (up to 5 MW_{th}) fixed-bed up-draft gasifier is an air-blown process operating at atmospheric pressure. Fuel is supplied by a semi-automatic system and enters the gasifier from the top. Inside the reactor, fuel is supported by a rotating grate (driven by a double joint shafted motor gear), which allows the distribution of the gasification agents and the discharge of ash. The gasification agents (air and steam) enter the fuel bed at the bottom of the grate at low pressure. In order to ensure better system performance, the grate has been recently modified with respect to the original design, with a significant performance improvement. The gasifier is also equipped with a stirrer and a water jacket to control the surface temperature. The steam, generated in the jacket during operation, reaches the upper steam drum that is connected downstream to a forced air-cooled condenser. Four different gas sampling lines are installed in the plant to monitor raw gas from the gasifier, clean gas downstream of the scrubber, exhausts from flares and venting. A real-time multi-module industrial analysis system and a portable gas chromatograph are used to continuously monitor the syngas composition. The unit, originally designed by Ansaldo Energia, has been significantly improved during more than 2000 hours of experimental tests, carried out in close collaboration with Enea within the “Research on Electric System” programme, funded by the Italian Ministry of Economic Development.

Figure 21. Pilot-scale bubbling fluidized bed unit (500 kWth)

Figure 22. Demo-scale fixed-bed gasification unit (5 MW_{th})

Sotacarbo laboratories are also equipped with several instruments for fuel characterization (proximate, ultimate and calorimetric analyses and kinetic studies through thermogravimetric approaches) and tar analysis.

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SOTACARBO
SUSTAINABLE ENERGY
RESEARCH CENTRE

7. UNIVERSITÀ DELLA CAMPANIA "LUIGI VANVITELLI" (UNIVERSITY OF CAMPANIA "LUIGI VANVITELLI" - DEPARTMENT OF ENVIRONMENTAL, BIOLOGICAL AND PHARMACEUTICAL SCIENCES AND TECHNOLOGIES)

Research area:

- Bubbling fluidized bed gasification technologies,
- Innovative technologies for material and energy recovery from alternative fuels,
- Technological, economic, social, and environmental aspects in the field of resource recovery
- LCA of different management options for municipal solid waste

The Chemical Engineering research group that is active at the University of Campania "Luigi Vanvitelli" since 2000 has a recognized international competence in environmental, technological, economic and social aspects of energy generation from biomass and waste by means of the thermal-chemical conversion processes of combustion, gasification and pyrolysis. It is involved in several studies and research projects about:

- ✓ Innovative technologies for material and energy recovery from alternative fuels (packaging derived fuels, plastic waste, biomass, SRF, tires, etc.), to study process aspects and design solutions, together with their impact on the environment. The activity has been particularly focused on the gasification and pyrolysis processes in fluidized bed reactors of different scale;
- ✓ Technological, economic, social, and environmental aspects in the field of resource recovery from waste, waste management planning, and sustainable manufacturing;
- ✓ LCA of different management options for municipal solid waste, with a particular attention to those of resource recovery by means of thermochemical conversion processes.

The research group manages two laboratories:

- ✓ The laboratory of Chemical Plants for Resource Recovery from Biomass and Waste, which is equipped with a fluidized bed gasifier/pyrolyser with a maximum capacity of about 5 kg/h and an apparatus for experiments on hot syngas cleaning by means of activated carbons. Since 2006, the research group has also managed a pilot scale bubbling fluidized bed gasifier with a maximum capacity of 100 kg/h;
- ✓ The laboratory of Environmental Sustainability of Processes and Services, where some assessment tools, such as Life Cycle Assessment (LCA) and Material and Substance Flow Analysis (MFA/SFA), are utilised with the support of up-to-date software packages and data banks.

At University of Campania, the main pilot plants of relevance for carrying out R&D activities are the *Pilot-scale fluidized bed* reactor, the *Pre pilot-scale fluidized bed reactor* and the *Bench scale apparatus for hot syngas cleaning.*

Pilot-scale fluidized bed reactor

The pilot-scale bubbling fluidized bed gasifier (BFBG) is shown in *Figure 23*, together with the main design and operating parameters. The reactor has an ID of 381 mm and a nominal capacity of about 400 kW. The experimental tests are carried out by injecting air or oxygen-enriched air at the bed bottom while an over bed feeding system is used for fuel. A couple of electric heaters heated up to the desired temperature the fluidizing agent stream before entering the reactor. The desired equivalence ratio is obtained by selecting the fluidizing gas velocity and the solid fuel flow rate. The BFBG is heated up to the reaction temperature by the sensible heat of pre-heated blast gases and by a set of three external electrical furnaces, which are then turned off to allow autothermic operating conditions. The synthesis gas produced in the reactor is sent to a high efficiency cyclone to remove fly ashes and then to a wet scrubber to remove tars, acid gases and residuals.

Geometrical parameters	internal diameter: 0.381 m total height: 5.90 m reactive zone height: 4.64 m wall thickness: 12.7 mm
Feedstock capacity	up to about 100 kg/h
Thermal output	up to about 400 kW
Typical bed amount	145 kg
Feeding system	over-bed air-cooled screw feeder
Gasifying agents	air (but also: oxygen, steam, carbon dioxide)
Bed temperature range	700-950 °C
Fluidizing velocity range	0.3-1.0 m/s
Flue gas treatments	cyclone, scrubber, flare
Safety equipment's	water seal, safety valves, rupture disks, alarms, nitrogen line for making inert the reactor environment

Figure 23. Main design and operating parameters of the pilot scale bubbling fluidized bed gasifier

Pre pilot-scale fluidized bed reactor

The pre-pilot BFBG with a feeding capacity of approximately 5 kg/h is shown in *Figure 24*. It is a 102mmID cylindrical column, 2.5 m high, made of AISI 316L and electrically heated by five shell furnaces, each capable of a maximum power of 3.5kW. All the heating elements are controlled by a data acquisition system connected to five thermocouples, located in the reactor internal wall, which allow to independently set the temperature of each reactor section (blast feeding, air pre-heater, bed and freeboard). The air utilized as fluidizing agent is injected at the bed bottom through a distributor plate composed of three nozzles. These have a truncate pyramidal shape and are specifically designed to ensure a homogeneous distribution of the fluidizing gas in the bed cross-section.

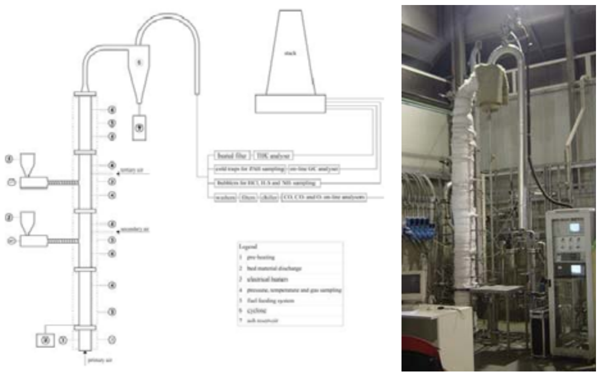

Figure 24. Photo and scheme of the pre pilot-scale fluidized bed reactor

Bench scale apparatus for hot syngas cleaning

The group utilises a bench scale apparatus to study the mechanisms involved in hot syngas cleaning by activated carbons. The apparatus has three main sections: the feeding system, the reactor and the exit line, as sketched in *Figure 25***Errore. L'origine riferimento non è stata trovata.**. The feeding system consists of a rotameter for adjusting the nitrogen flowrate, and a naphthalene (used as tar compound model) saturator to obtain a tar-doped stream. The pipes between the saturator and the reactor are kept above 150°C to avoid naphthalene condensation. The reactor used is a vertical tubular quartz reactor with an internal diameter of 14 mm and a total height of 600 mm. The activated carbon bed is placed above a glass frit inside the reactor, located at 430 mm from the top. The gas at the reactor exit is directed to the sampling device during the tar samplings or, by switching a three-way valve, to the cleaning device for the rest of the time.

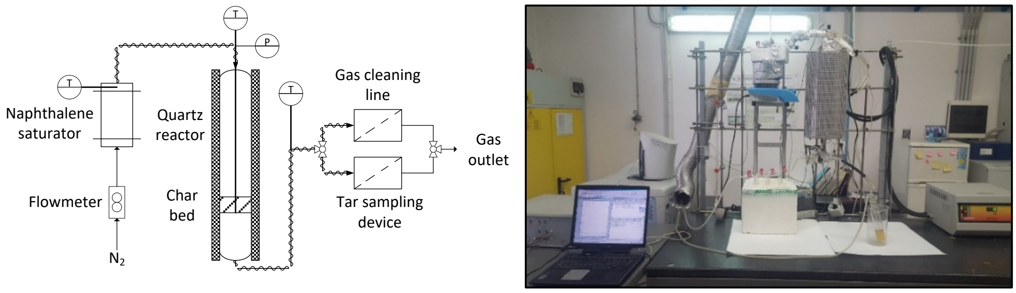

Figure 25. Photo and scheme of the bench scale apparatus

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Università degli Studi della Campania *Luigi Vanvitelli*

Dipartimento di Scienze e Tecnologie Ambientali Biologiche e Farmaceutiche

INDUSTRIES

1. CMD S.P.A

Producer of fixed bed gasifiers.

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Web: http://eco20cmd.com/cmd-eco20/?lang=en

The CMD mCHP plant

CMD ECO20x is a mCHP (Micro Combined Heat & Power) System transforming biomass into syngas (synthesis gas) from which electric energy and heat are produced. Internal combustion engine, connected to a synchronous alternator, can produce $20kW_{el}$ (peak value). Heating system can produce till $40kW_{th}$ of heat power (peak value), using the heating inside cooling liquid of the engine and that released by exhaust. Furthermore, mCHP system is suitable even for a trigenerative purpose (production of electric energy, heating, thermal and refrigerator), coupling with an absorption chiller.

Thanks to an innovative reactor section and specific pre-treatments, the biomass to be used in CMD ECO20x can be selected among a wide range of products and by-products: forestry waste, urban waste wood, waste from mixture of wood, mushroom manure, olive kernel, olive pomace, sawdust, rice husk, hazelnut shells, chestnut shells, almond shells, etc. olive pits, apricot pits, peach pits, tobacco stalks, corn stalks, cane residues. Biomass have been tested according to different combinations.

According to *Figure 26*, the energy box with its innovative design, can include both hopper and equipment in one space, making it more efficient and compact. Moreover, installation times are substantially reduced. ECO2Ox can be used in several applications:

- Forestry: farms, greenhouses, cheese factories, livestock, farming products transformation.
- Industry: logistic platforms for distribution and production of wooden scraps, carpenters'shops, food, paper factories, ceramic industry, glass, chemical, engineering, textile, handcraft industry.
- Residential/Commercial: shopping malls, hotels, swimming pools, urban areas and district heating, wellness centers.
- Public: Municipalities, districts, care homes, public swimming pools, hospitals, schools.

Figure 26. Internal details of ECO20X MICRO CHP SYSTEM.

ECO20x working principles for electric energy production are shown in *Figure 27*. The plant is based on a downdraft fixed bed gasifier of specific design. The cochlea, activated by M1 electric motor, pours biomass into the reactor. Thermochemical decomposition produces syngas needing to be cooled and cleaned before to be used in internal combustion engine. For this reason, it is conducted into a cyclone reactor for ultra faint ashes removal, a cooler able to remove tars inside the syngas by condensation process (obtained through cooling water circulation inside the cooler), a biological filter to further remove ultra faint ashes and residual tars, a cyclone close to the engine allowing the mixture with the external air and the final removal of condensation.

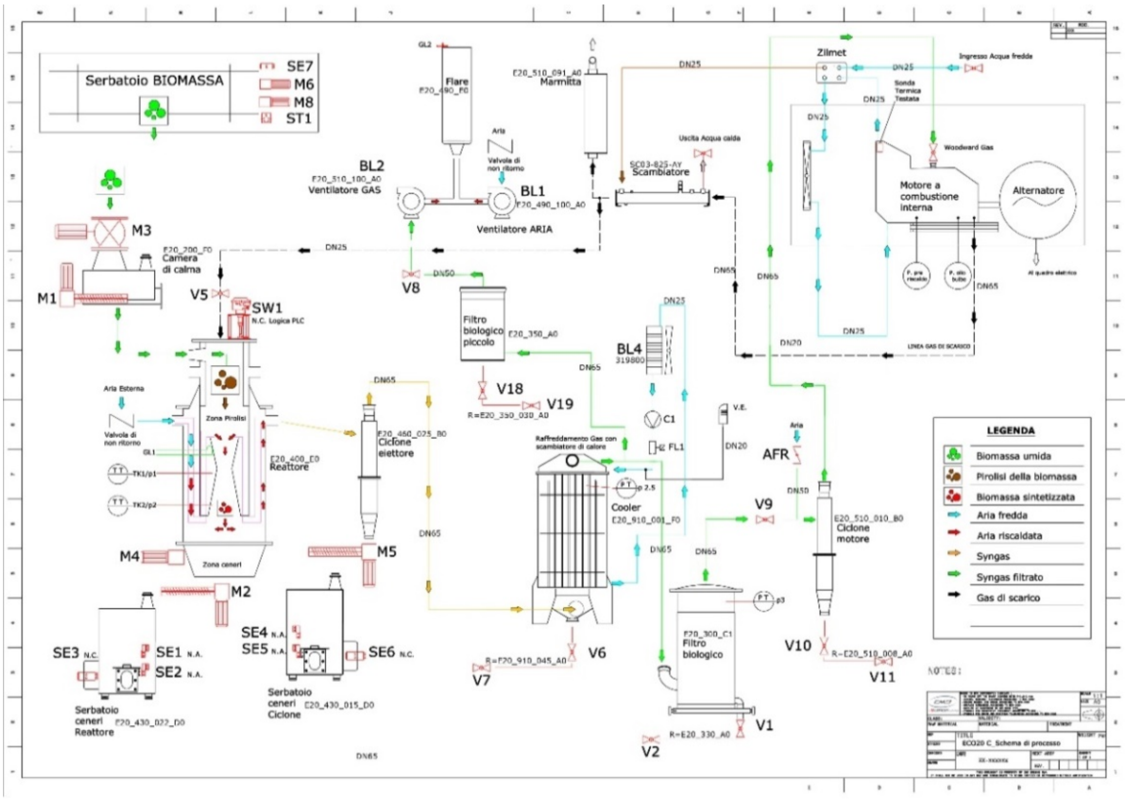

Figure 27. ECO20X MICRO CHP SYSTEM – Plant layout.

Electric energy produced is fully released inside the electric grid, while engine's exhaust gas passes in the thermal recovery section. Concerning thermal recovery section, CHP system can get a first recovery at low temperatures using engine's cooling water by a plate heat exchanger, a further recovery at high temperature using engine's exhaust gas by a shell and tube heat exchanger. CHP system's exhaust gas, after releasing the heat inside the shell and tube heat exchanger, are released in the atmosphere, in line with current regulations on emissions, in conformity with Legislative Decree 152/06.

An overview of the contenerized system is presented in *Figure 28. ECO20X MICRO CHP SYSTEM: containerized version Figure 28*.

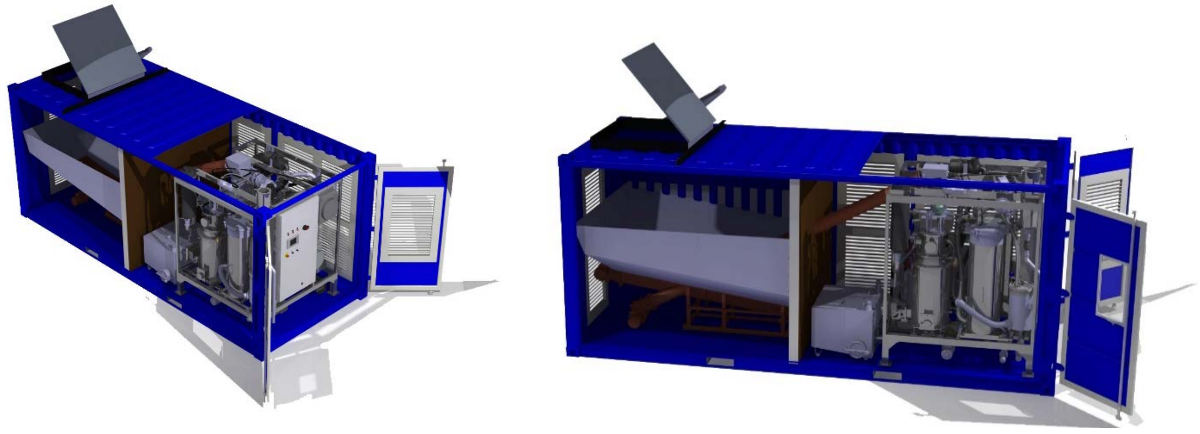

Figure 28. ECO20X MICRO CHP SYSTEM: containerized version.

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Table 2. Reference list of gasification plants by CMD S.p.A

Supplier	Technology	Project/Location	Year of commissioning	Feedstock		Input/ Feedstock	Output El./Th.	Usage/ Product	Start up/ Status
				Wood chips	Off-cuts				
CMD SpA	Downdraft Fixed bed (Mod. ECO20x)	Via A. Pacinotti, 2 - 81020 San Nicola La Strada (CE) - Italy	05/2013	x		87.70 kW/ Wood chips	20 kWel (off-grid)	mCHP production	Demonstration Plant
		Via A. Pacinotti, 2 - 81020 San Nicola La Strada (CE) - Italy	05/2014	x		87.70 kW/ Wood chips	20 kWel (on-grid)	mCHP production	Demonstration Plant
		Via A. Pacinotti, 2 - 81020 San Nicola La Strada (CE) - Italy	06/2015	x		87.70 kW/ Wood chips	20 kWel (on-grid)/ 40 kWth	mCHP electric and thermal suppliers	2015/operational
		Via A. Pacinotti, 2 - 81020 San Nicola La Strada (CE) - Italy	06/2016	x		87.70 kW/ Wood chips	20 kWel (on-grid)/ 40 kWth	mCHP electric and thermal suppliers	2016/operational
		Via A. Pacinotti, 2 - 81020 San Nicola La Strada (CE) - Italy	01/2019	x	x	87.70 kW/ Wood chips	20 kWel (on-grid)/ 40 kWth	mCHP electric and thermal suppliers	2019/operational
		Manni Energy Via Augusto Righi, 7 - 37135 - Verona - Italy	01/2017	x		87.70 kW/ Wood chips	20 kWel (on-grid)/40 kW_{th}	mCHP electric and thermal suppliers	2017/operational
		Lavuri Contrada Camami, Piazza Armerina (EN) - Italy	05/2017	x		87.70 kW/ Wood chips	20 kWel (on-grid)/40 kW_{th}	mCHP electric and thermal suppliers	2017/operational
		Roveroni Localita' Ostia Parmense - 43043 Borgo Val Di Taro (Parma) - Italy	11/2017	x		87.70 kW/ Wood chips	20 kWel (on-grid)/40 kW_{th}	mCHP electric and thermal suppliers	2017/operational

2. ESPE SRL

Producer of downdraft fixed bed gasifiers.

Address: Via Dell'Artigianato, 6, 35010 Grantorto (PD), Italy

Email: espe@espe.it

Web: http://www.espegroup.com/en/biomass/cogenerator/

The CHiP50 Cogenerator

The company has developed CHiP50 Cogenerator, a gasification plant designed for small and medium sized businesses that need both heat and power. The gasification technology used in CHiP50 is the "Downdraft (DG)" reactor. ESPE has made use of this technical solution because it allows for extremely clean synthesis gas without a need for filters, and therefore allows for increased system reliability over the long term and simplifies daily management. The biomass used by such cogenerator is virgin wood chips, or rather very tiny pieces of wood. This chipped timber is generally obtained via local supply chain. Each component of the system is designed, tested and assembled within ESPE. The Syngas produced by wood biomass is conveyed into a cogenerator equipped with an Otto cycle motor for electrical production. The CHP asset allows to maximise biomass energy output with total efficiency (electricity + heat) that reaches as high as 90%. A typical scheme of process implemented in the CHiP50 Cogenerator plant layout is presented in *Figure 29*.

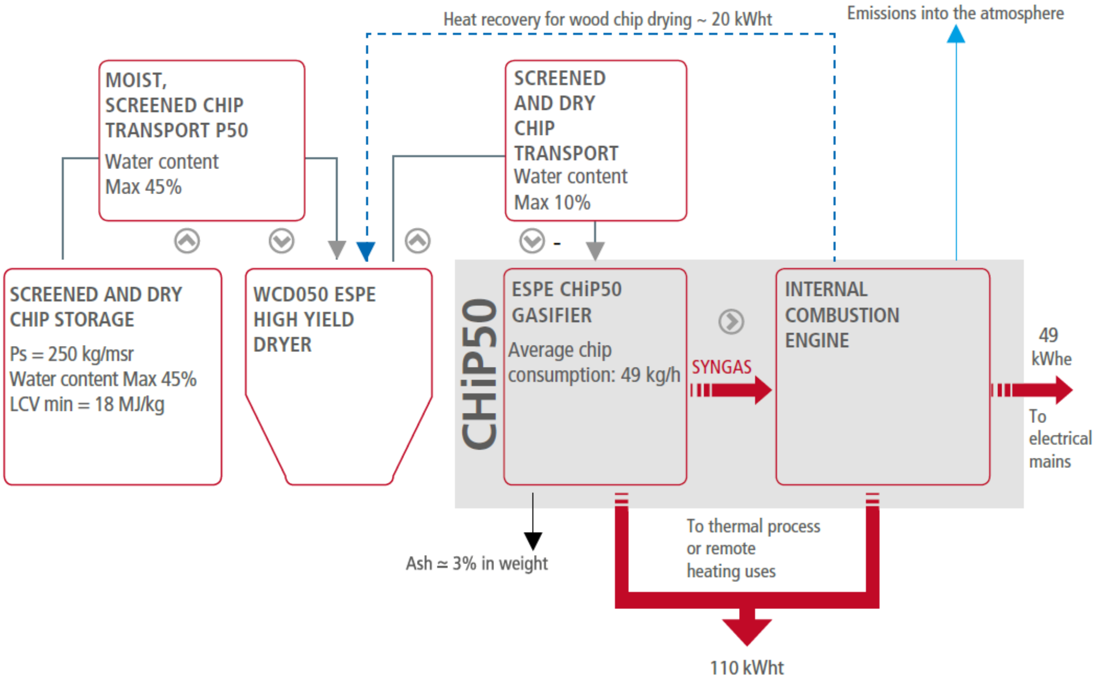


Figure 29. CHiP50 COGENERATOR SYSTEM – Process diagram

During operation, each phase is kept under constant control to maintain high levels of efficiency and reliability: temperature, pressure, and flows are continuously measured and recorded. Thanks to the insertion of a post-reformer, gas coming out from the gasification chamber is further purified with a simultaneous increase in the calorific value.

CHiP50 is equipped with proprietary software for controlling processes both locally and remotely. The ESPE CHiP50 cogenerator is equipped with a single centralised control unit (*Figure 30*) which automatically manages and controls all the functions of the gasification and cogeneration sub-units, allowing the entire process to be controlled and monitored without the need to access the panel installed on the machine. Through the general panel the entire machine can be controlled using a user-friendly and intuitive touch screen interface.

Figure 30. 49 kW electrical and 110 kW thermal cogeneration system for a greenhouse.

Figure 31. 196 kW electrical and 440 kW thermal cogeneration system containerized unit for heating and drying processes

Contact person: Matteo Vecchiato (m.vecchiato@espe.it)

Web: http://www.espegroup.com/en/biomass/cogenerator/

Table 3. Reference list of gasification plants by ESPE SRL

Supplier	Technology	Project / Location	Year of commissioning	Feedstock		Input / Feedstock	Output El. / Th.	Usage / Product	Start up / Status
				Wood chips	Off-cuts				
ESPE S.R.L.	Downdraft Fixed bed (Mod. CHiP50)	Santo Stefano Belbo (CU;Piedmont) Italy	2017	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2017/operational
		Incisa Scapaccino (AT; Piedmont) Italy	2017	X		880 kW/ Wood chips	196 kWel./440 kWth	Micro-CHP production	2017/operational
		Messima (ME;Sicily) Italy	2015	X		220 kW/ Wood chips	49 kWel./110 kWth	Micro-CHP production	2015/operational
		Lunano (PU; Marche) Italy	2016	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2016/operational
		Belluno (BL; Veneto) Italy	2016	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2016/operational
		Gubbio (PG; Umbria) Italy	2015	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2015/operational
		Peveragno (CN; Piedmont) Italy	2015	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2015/operational
		Roma (Lazio) Italy	2016	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2016/operational
		Cogne (AO; Valle d'Aosta) Italy	2015	X		220 kW/ Wood chips	49 kWel./110 kWth	Micro-CHP production	2015/operational
		Piacenza (PC; Emilia-Romagna) Italy	2014	X		220 kW/ Wood chips	49 kWel./110 kWth	Micro-CHP production	2014/operational
		Ravenna (RA; Emilia-Romagna) Italy	2015	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2015/operational
		Perugia (PG; Umbria) Italy	2014	X		220 kW/ Wood chips	49 kWel./110 kWth	Micro-CHP production	2014/operational

		Padova (PD; Veneto) Italy	2014	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2014/operational
		Lucca (LU; Toscana) Italy	2014	X		220 kW/ Wood chips	49 kWel./110 kWth	Micro-CHP production	2014/operational
		Pesaro (PU; Marche) Italy	2014	X		440 kW/ Wood chips	98 kWel./220 kWth	Micro-CHP production	2014/operational
		Mantova (MN; Lombardia) Italy	2014	X		220 kW/ Wood chips	49 kWel./110 kWth	Micro-CHP production	2014/operational
		Vicenza (VI; Veneto) Italy	2014	X		880 kW/ Wood chips	196 kWel./440 kWth	Micro-CHP production	2014/operational
		Cuneo (CN; Piedmont) Italy	2014	X		880 kW/ Wood chips	196 kWel./440 kWth	Micro-CHP production	2014/operational

a) ESPE SRL has installations also abroad (e.g.in UK and Japan).

3. RESET S.R.L.

Engineering and manufacturing of small scale, containerized biomass gasification and cogeneration systems.

Highlights

Small scale plants from 50 kWe to 200 kWe; Fully automatic, integrated, plug and play solution; Containerized and modular;No syngas cleaning waste production; High grade biochar.

Registered office: Viale Giulio Cesare, 71 – 00192 Rome, Italy

Headquarters: Via delle Industrie snc - 02015 Cittaducale (RI)

Email: info@reset-energy.com

Web: www.reset-energy.com – www.syngasmart.com

RESET
Renewable Energy Solutions Environmental Technology

The RESET SyngaSmart microCHP

RESET is a cleantech company founded in 2015 that has developed and marketed SyngaSmart, a range of containerized micro CHP systems (from 50 to 200 kWe) based on a proprietary biomass gasification technology. SyngaSmart plants allow to generate electricity and heat by first converting organic feedstock (i.e. woodchips or dry organic briquettes) into producer gas. The fuel generation process is based on multiple downdraft fixed bed gasifier specifically designed, engineered and developed by RESET R&D dept.

SyngaSmart typical layout is reported in *Figure 32*.

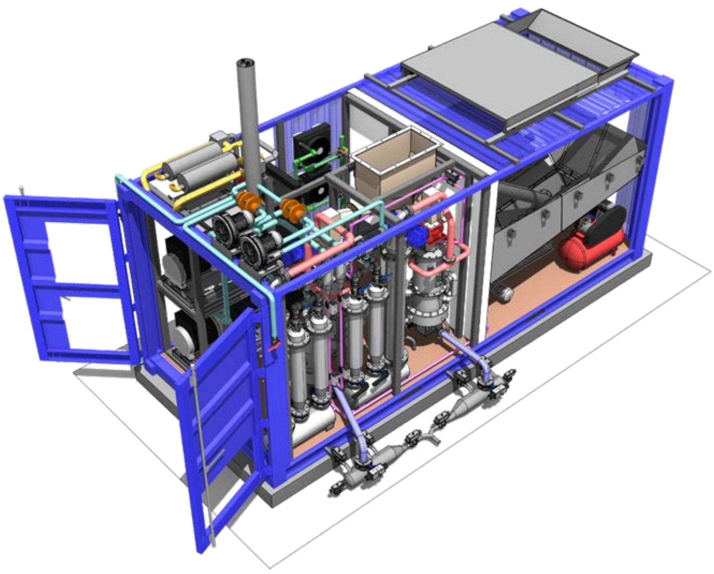


Figure 32. SYNGASMART 50 CHP SYSTEM – Plant layout

SyngaSmart plants enclose all the equipment required for 24 hrs continuous operation inside standard shipping containers: biomass storage and pretreatment (drying), gasification unit, syngas cleaning, biochar collection, genset, thermal recovery and automation/power panel. SyngaSmart can be operated both on site and through remote connection using a proprietary SCADA interface, thus minimizing plant supervision. The generation process is carbon negative since it is capable of storing carbon from biomass into a stable form of high-grade biochar, whose properties as soil amendment are universally acknowledged.

In Figure 33 drawings of a multi-gasifier module are shown.

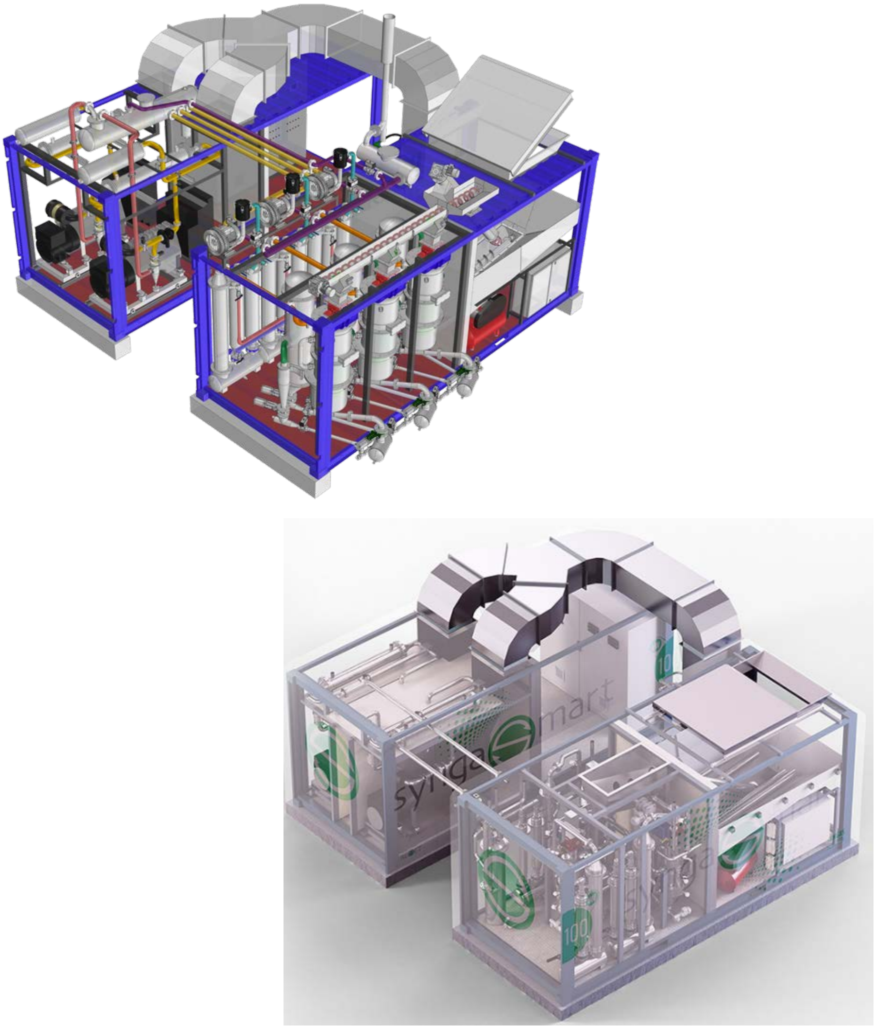


Figure 33. Sketches of a multi-reactor system, four gasifiers are visible.

Contact person: Valerio Manelfi (valerio.manelfi@reset-energy.com)

Table 4. Reference list of gasification plants by CMD S.p.A

Supplier	Technology	Project/Location	Year of commissioning	Feedstock		Input/ Feedstock [a)]	Output El./Th.	Usage	start up	status
				Wood chips	Off-cuts					
RESET s.r.l.	Downdraft Fixed bed	SAN COSMO ALBANESE (CS)	2018	X		50 kg/hr	50 kWe / 75 kWth	Micro cogeneration	2019	operational
		STRANGOLAGALLI (FR)	2016	X	X	50 kg/hr	50 kWe / 75 kWth	Micro cogen/waste wood processing	2017	operational
		RIETI (RI)	2016	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	2018	operational
		TERNI (TR)	2016	X		50 kg/hr	50 kWe / 75 kWth	Micro cogeneration	2017	operational
		CERRETO DI SPOLETO (PG)	2017	X		50 kg/hr	50 kWe / 75 kWth	Micro cogeneration	2018	operational
		SASSOFERRATO (AN)	2017	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	2018	operational
		MENFI (AG)	2018		X	100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		SIRACUSA (SR)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		BISIGNANO (CS)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		ROMA (RM)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		ROMA (RM)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		ROMA (RM)	2018	X		50 kg/hr	100KWe/150 kWth	Micro cogeneration	-	under construction
		CITTADUCALE (RI)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		SIGILLO (PG)	2018	X		50 kg/hr	50 kWe / 75 kWth	Micro cogeneration	2019	operational
		PIACENZA (PC)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		PIACENZA (PC)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		PIACENZA (PC)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		PIACENZA (PC)	2018	X		100 kg/hr	100 kWe / 150 kWth	Micro cogeneration	-	under construction
		LODI (LO)	2018	X		50 kg/hr	50 kWe / 75 kWth	Micro cogeneration	-	under construction

a) LHV in the range 16-19 MJ/$kg_{Biomass}$, on dry basis.

IEA Bioenergy

GASIFICATION PLANT DEVELOPMENT BY ENTERPRISES

Driven by the interest the biomass gasification technology has received, nationally and internationally, as well as by the government actions aimed at promoting the development of electricity production from residual biomass, several small Italian companies have undertaken activities for the development of own know-how. Reference technology has been that based on the downdraft gasification reactor, in some cases anticipated by a pyrolysis stage, developed for electricity production in the small to medium range. Descriptions of some of these companies that have agreed to provide original information on their activities and plants under development are given in the following sections.

1. BIOSYN

Address: Via Alessandro della Seta, 20, 00178 Rome, Italy

Email: info@biosyn.it

Web: http://www.biosyn.it

The BIOSYN facility

BIOSYN started their activities in biomass utilization sector in 2015. In early 2016 BIOSYN acquired a downdraft gasification reactor with the water wash system of the produced syngas together with the patent for a special air feeding system to operate the gasification reactor.

The gasification reactor has the capacity to handle 200 kg/h of chopped woods with a recommended humidity of 10% and a maximum content of ashes of 5% by weight. The plant is completed by the synthesis gas treatment to achieve a quality adequate to feed endothermic engine. The production of syngas is approximately 400-450 Nm^3/h. Test have been conducted demonstrating a cold gas efficiency over 76% and an overall tar production of less than 50 mg/Nm^3_{dry}.

The plant is currently used to make tests on different kinds of materials; through the various experimental campaigns a total of 2000 hours of operation has been gathered.

Several tests have been conducted with the aim to evaluate flexibility; chopped woods, various types of nuts, simulated FORSU adequately treated and mixed up with chopped wood like for muds from waste water treatment facilities and plastics have been evaluated.

Type of gasifier

The gasifier is of the downdraft type, but with the so-called two-fired conformation, which is characterized by two oxidation areas, the first one between the pyrolysis section and the oxidation section, in which the primary process air is introduced, and the second one located below the movable grid, where secondary oxidation air is introduced (see Figure 34 A)). This area represents in fact a post-oxidation chamber, in which the gasification processes of the compounds that were not fully involved in the primary process are terminated at high temperature, through the introduction of an adequate amount of air. The advantage of this process component lies in the elimination of unwanted organic compounds, escaped from the process, and in the greater production of syngas. Overall, the adopted solution makes the oxidative phase very efficient, because it allows a homogeneous distribution of the oxidizing agent, keeping the temperature constant and uniform the "blast velocity" in the whole oxidation section.

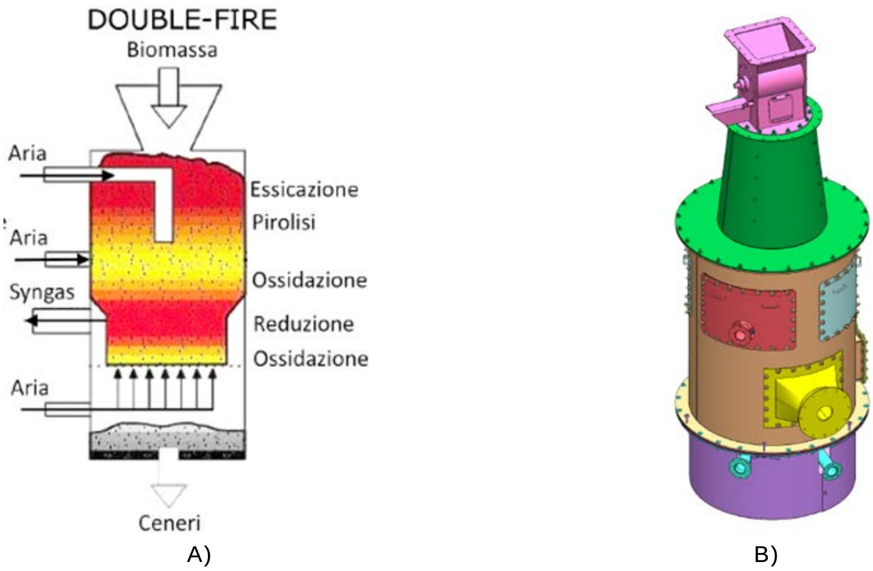
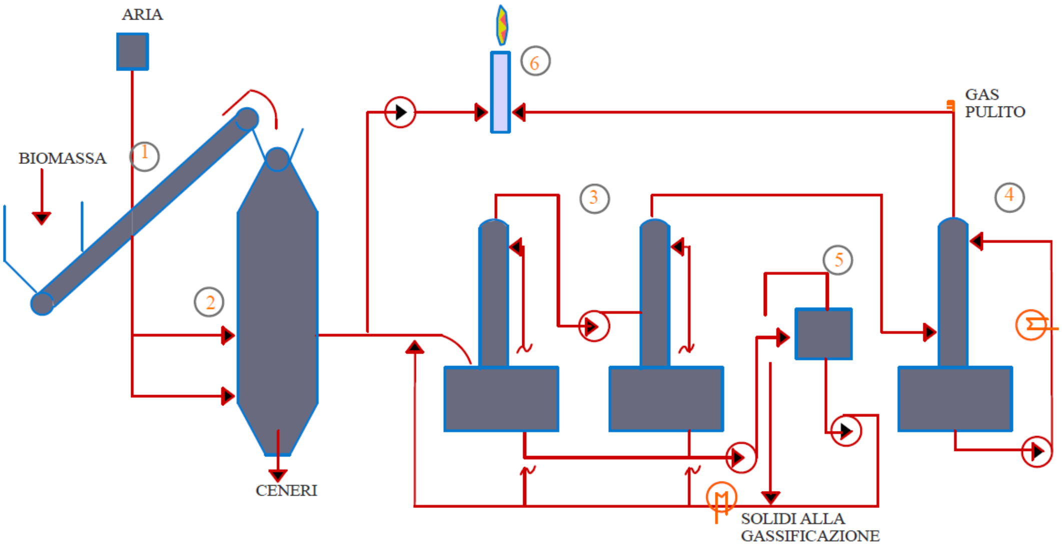


Figure 34. A) Section of the process areas across the gasifier body; B) drawing of the gasifier body.

The gasification section is operated in depression, so that air is sucked from the environment and the produced gas pass through the reaction zones towards the reactor outlet.

Treatment of synthesis gas

The synthesis gas is extracted just below the oxidation zone at a temperature between 550 and 650 ° C and addressed to the gas cleaning section. This section can be considered divided into three conceptual zones, i.e. solid particle removal, high boiling tars removal and low boiling tar removal. A summary scheme of the gasification plant sections is presented in Figure 35.



1) Biomass feeding system; 2) gasification reactor; 3) first stage of tar removal; 4) second stage of tar removal; 5) gas filtration section; 6) flare.

Figure 35. Main plant components in the 1000 kW_t BIOSYN gasification system.

The cooling of the gas is based on a water process, this also allows to obtain a great dust removal efficiency but above all a definitive condensation and separation from the gaseous flow, by filtering, of the various types of tar produced by gasification. The company is currently engineering and manufacturing a system for treating water produced by the process, which eliminates the need to resort to the disposal of special wastewater leaving the system.

A picture of the 1000 kW_t, 200 kW_e, gasification plant located in Nave San Rocco (Trento, Trentino) is presented in Figure 36.

Figure 36. Photo of the 1000 kW_t, gasification facilities. Electrical output: 200 kW_e.

Contact person: Pietro Sica (pietro.sica@biosyn.it)

Implementations

Table 5. Small-scale gasification facility by BIOSYN

Supplier	Technology	Input / Feedstock	Output El. / Th.	Usage / Product	Start up / Status
BIOSYN	Fixed bed/Two-Stages	1000 kWth/ Wood chips/waste/etc.	Between 160 kWe/200 kWe	CHP production on 260 kWth overall	2020 first complete unit (including motor) operational

2. ENERITALY SRL

Address: Via dell'Industria, 17, 27010 Cura Carpignano (PV), Italy

Email: info@eneritaly.net

Web: https://www.eneritaly.net/

The RET ENERITALY Facility

ENERITALY SRL is a SME company founded in 2013. It deals with consulting services in the field of energy efficiency and production from renewable sources. ENERITALY gives support to private businesses and public administrations to identify targeted solutions from both a technical and economic point of view.

The group is engaged since 2014 in a private R&D programme aimed at the development of a first prototype 72 $kW_{el.}$ gasification plant based on a two-stage process of specific proprietary design. The plant was originally meant for CHP application, further possible applications in the evaluation phase are for the production of biochar to be used for filtration of the gas produced from anaerobic digestion.

Each process stage is carried out is a dedicated reactor in order to have a better control of the process conditions. The operation of the first stage is based on the principle of flaming pyrolysis, that is: a high-temperature sub-stoichiometric air flow passes through the biomass thus dragging the extracted pyrolysis gases towards the exit of the reactor. The outlet temperature of gases and c.a. 650 ° C while the air is sucked in c.a. 300 ° C.

Before entering the second stage reactor, the high temperature pyrolysis gases are sucked, through a connection pipe, into an intermediate reactor where some superheated air is added. The pyrolysis gas is then partially burned at a ratio such as to reach a minimum temperature of 900 ° C.

The high temperature gases feed the second stage whose input is formed by a regenerative accumulator. Through the accumulator, which stabilizes the flow temperature, the gases are injected into a previously produced char bed, triggering the reactions that lead to the production of CO and H2 by means of the reactions of CO2 and H2O with char, and decreasing at the same time the temperature of the outgoing syngas. From this phase the gas passes through a primary exchanger, a bag filter and a secondary exchanger. Downstream of the secondary exchanger, it supplies the internal combustion engine (ICE) that produces electricity and thermal energy. The gaseous emissions of the ICE are in accordance with the regulations on emission limit standards imposed by ARPA Lombardia referred to DGR IX/3934 Lombardia, therefore no further abatement treatments are required. In *Figure 37* plant layout of the 72 kW_{el} RET ENERITALY facility is presented.

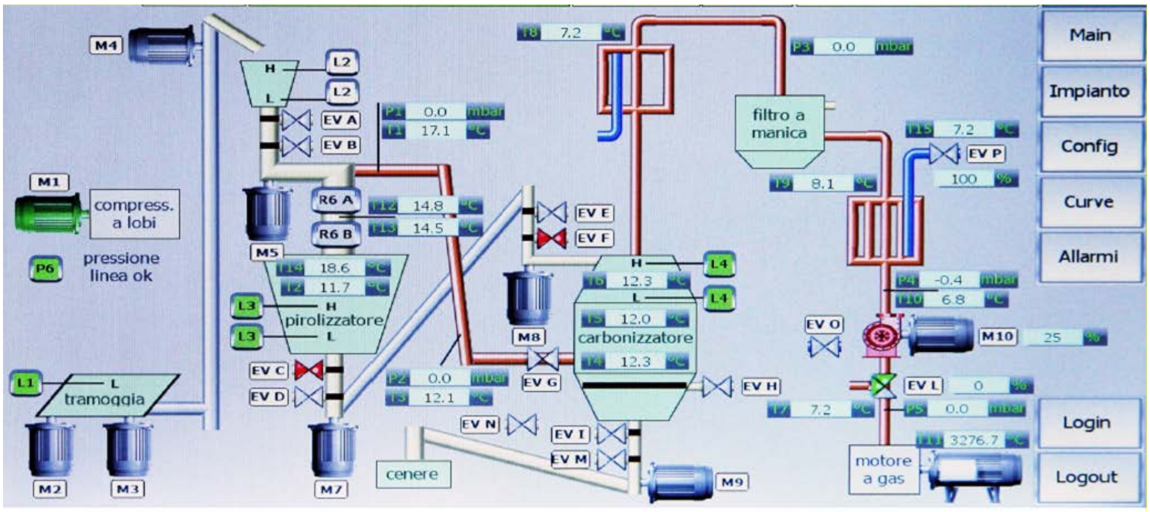


Figure 37. Plant layout of the RET ENERITALY prototype system.

Figure 38 shows a picture of the plant installed in Cura Carpignano (Padua, Northern Italy) ready for connection to the national power grid:

Figure 38. Photo of the 72 kWe assembled RET ENERITALY System

Contact person: Raffaele Menditto (r.menditto@eneritaly.net, amministrazione@spinesrl.com)

Web: https://www.eneritaly.net/prodotti.html

Implementations

Table 6. Small-scale gasification facility by ENERITALY

Supplier	Technology	Input / Feedstock	Output El. / Th.	Usage / Product	Start up / Status
ENERITALY SRL	Two-Stage	200 kW/ Wood chips	72 kWel/ 140 kWth	CHP production, Biochar production	2018/ operational

3. INTERNATIONAL POLYFUEL MACHINES

Address: Piazza Filodrammatici, 1 - 31100 TREVISO (TV) - ITALY

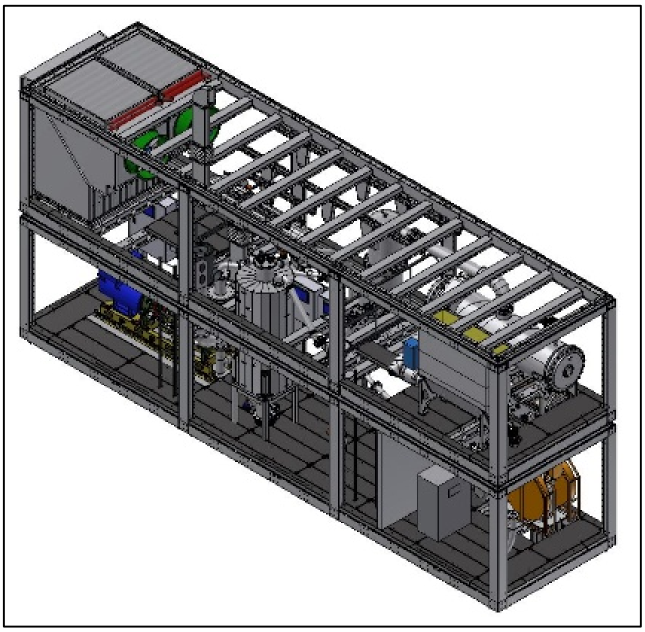
Email: com@ipmindustry.it

Web site: www.ipmindustry.it

IPM

The ITM Gasification Facilities

International Polyfuel Machines is an Italian company focused on the construction of pyrolysis and gasification systems for the production of electricity and heat by means of combined heat & power machines with reciprocating or turbine engines. In 2005 the first steps were taken acquiring the project and the construction rights of a Downdraft plant combined with a reciprocating Otto cycle engine of 280 kW electrical power. In 2007, a first modified reactor was built to power a 25 kW Otto cycle engine. This model was essentially useful for testing the geometry of the reactor and the material used to build the parts at temperatures above 950° C. In the subsequent years the first complete plants from 180 to 330 kW of electricity for power production from wood chips and agro-industrial waste were built. In addition to Downdraft-type reactors and Otto cycle co-generation units, dryers and gas synthesis dry cleaning systems were also realized. In 2010 the first ALFA model reactor was built. Drawing and picture of the of the modular ALFA system under development are presented in Figure 39.



a)

b)

Figure 39. ALFA modular gasification system by IPM: a) drawing of the ultimate version of the complete 200 kW CHP with ALFA model reactor, b) first ALFA model under construction.

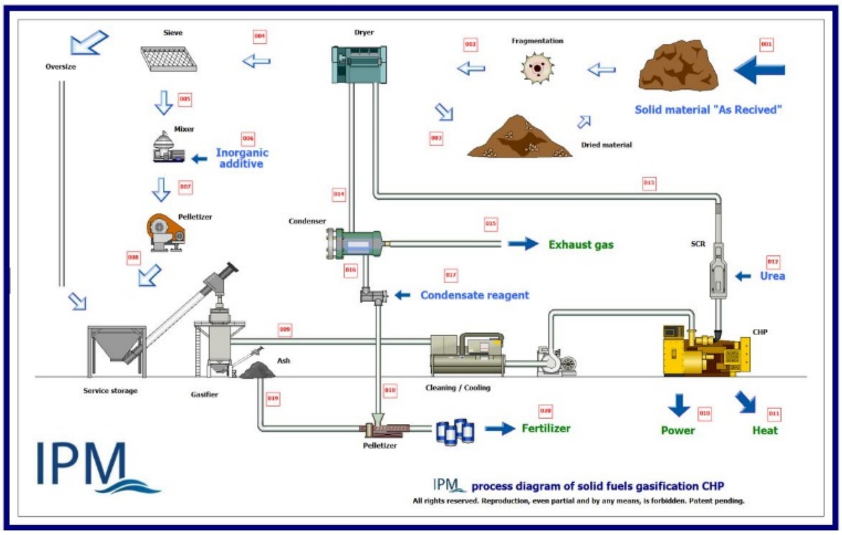
This was a Downdraft type gasifier completely modified compared to the project acquired in 2005, which allowed to achieve very promising results in terms of carbon conversion into gaseous products, the variety of input fuels and low presence of TAR in the produced gas. With this reactor, prolonged pyrolysis and gasification tests of 28 different organic materials[8] were carried out and it was possible to identify and test the solution of the melting ash problem found in the high temperature process of several biomass feedstocks.

[8] Wood chips, White wood pellets, Virgin wood sawdust, Virgin wood curls, Forest pruning, Vine pruning, Olive pruning, HDF panel chips, HDF panel sawdust, Leaves, Grass, Wheat straw, Grape peels, Grapes, Exhausted olive pomace, Virgin olive pomace, Egg hens manure, Broiler litter with wood curls, Broiler litter with rice husk, Broiler litter with wheat straw, Horse litter with wood curls, Cow litter with wheat straw, Urban sludge, Cotton textile scraps, Spent coffee, Corn stalks, Coal powder, Virgin wood biochar.

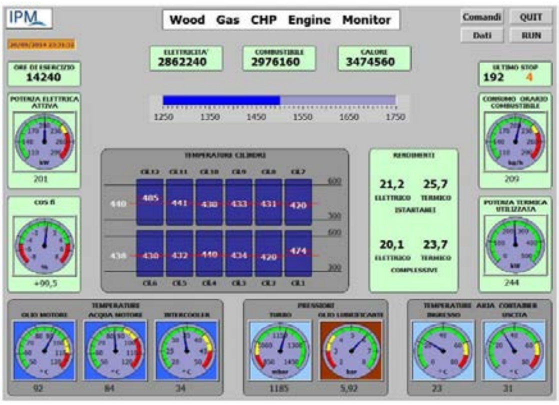
The ALFA model was the forefather of a series of gradually improved reactors in construction materials and concept, architecture and the fluid dynamic process that led to the creation of the BRAVO Series and DELTA Series reactors. These can be combined with Otto, Diesel (dual fuel) or Brayton cycle engines. The latter are state-of-the-art reactors whose project has incorporated the observations resulting from the tests conducted with the ALFA Model and which are characterized by the carbon conversion ratio of over 99.3%, the absence of TAR in the synthesis gas, the broad range of usable organic materials and the absence of klinker in the ashes. In summary, the technology originally used was that of Imbert Downdraft reactor, but currently the BRAVO and DELTA series reactors are based on two innovative pyrolysis and gasification processes for which invention patents are being filed.

The ALFA plant

The plant consists of a modified ALFA Model reactor coupled to a cogeneration unit with an Otto cycle engine producing 200 kW electric power. The system is completed with input material preparation system and producer gas cleaning and cooling devices. Currently the ALFA plant is located in Treviso and is used as a laboratory station to conduct gasification tests of different organic materials rather than for power production in continuous duty with only one specific biomass. An overview of the process chain, from as received feedstock to power production, of the gasification facility based on the ALFA reactor is presented in Figure 40.



a)



b)

Figure 40. a) P&ID sketch of a complete CHP with ALFA model reactor, b) engine control page of HMI

Contact person: Roberto Andreatta (com@ipmindustry.it)

Implementations

Table 7. Small-scale gasification facility by International Polyfuel Machines

Supplier	Technology	Input / Feedstock	Output El. / Th.	Usage / Product	Start up / Status
IPM	Modified Imbert	830 kW/Several matrices	200 kWel/ 280 kWth	CHP production	2012/ Laboratory

4. LEGNO ENERGIA SRL

Address: Strada di Fort, 16 - 23037 Tirano (SO), Italy

Email: info@legnoenergiasrl.com

Web: http://www.legnoenergiasrl.com/

legnoenergia

The TIRANO Gasification Facility

LEGNOENERGIA was founded in 2014 and is based in Tirano (Sondrio, Lombardy). The company is engaged in the production and supply of energy from biomass, both electric and thermal. The process of reference is that of wood pyro-gasification. In Figure 39 the schematization of the four main process stages are represented.

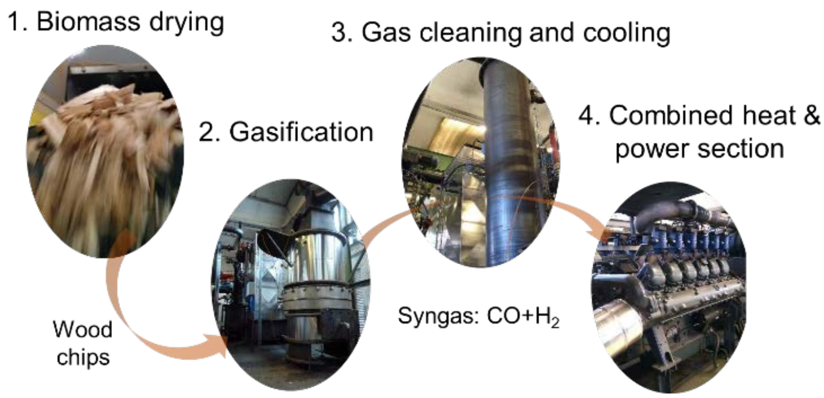


Figure 41. Plot of the main steps required for the gasification process

After three years of study and in-depth analysis of existing technologies, the company developed an innovative pyro-gasification system allowing the combined production of electricity and heat.

- A downdraft gasifier (e.g. imbert gasifier) shaped in a way to grantee the correct residence time of the wood chips into the reactor. This is proved by the high biomass conversion rate (larger than 99.5%) and from the very small size of ashes coming out from the reactor, with a size distribution around 0.5-3 mm;

- A purification step optimized to remove ashes suitable for utilization as biochar (certification is in progress) and a gas cooling down to 30°C. The cooling of the gas allows to remove all TAR formed during the reaction as well as the water still present into the wood chips. This helps to preserve the engine from contaminants prolonging its life and diminishing the maintenance costs;

- Additionally, Legno Energia srl self-developed all the aspects required to operate the gasification line, ranging from the design of the gasifier, the PLC to operate the lines as well as the process of drying wood chips and manage the thermal energy.

Legno Energia srl developed an automatic and highly efficient biomass gasification line which transforms very efficiently (99.5% rate of biomass conversion) wood chips in a syngas with good high calorific value (2kWh/Nm^3_{dry}) and very low tar content (<0.35 g/Nm^3_{dry}).

The syngas is fed in a cogeneration unit-CHP (combined heat power generation) that achieves very high conversion rates: 1 kWhel (electrical) and 1.83 kWhth (thermal) per 1kg biomass gasified. Thus, every 150kg biomass fed into the line will produce (with an overall efficiency of the line of 83%) 150kWhel and 290 kWhth. The whole process is fully automated and controlled with a self-developed PLC. Such characteristics allow to keep the hours worked per year over 90%.

Legno Energia is highly committed to exploit all the thermal energy produced from the plant. For instance, in the operated facilities the heat is used for: a) wood chips drying to feed gasifiers, b) extra wood chips drying for pellet or briquettes production c) supply the local district heating.

In *Figure 40* a schematic plant layout is presented.

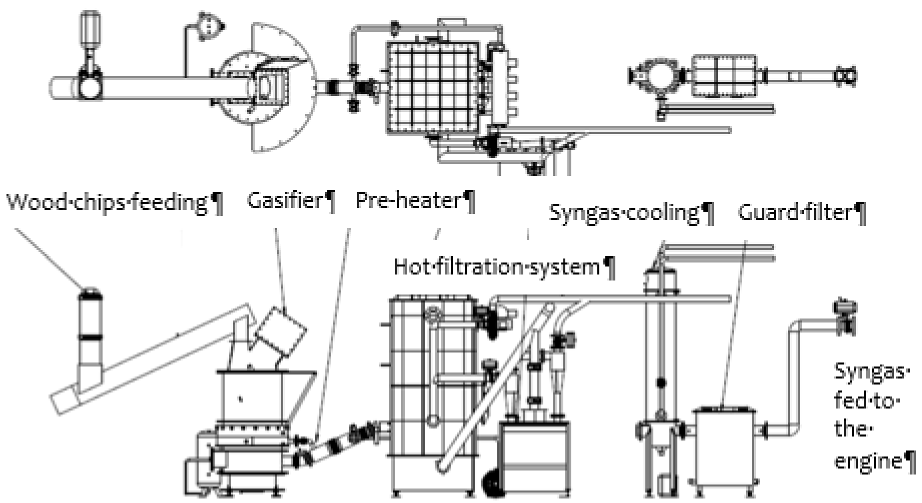
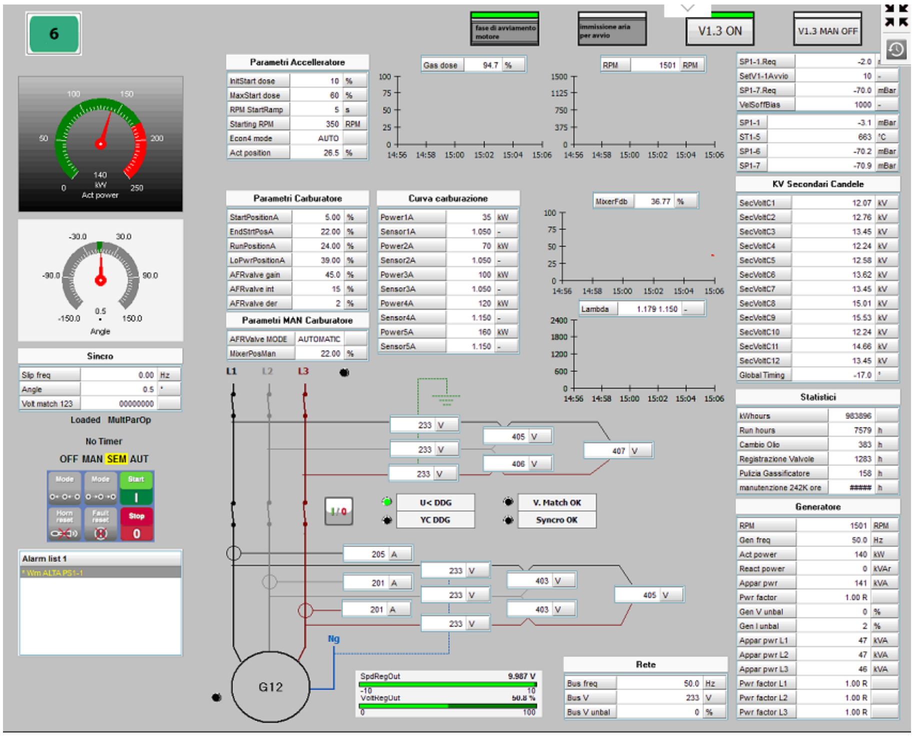


Figure 42. LEGNOENERGIA plant layout

Legno Energia now operate two facilities of 900 kWel each. Each facility is composed of 6 gasification lines of 150kWel and 270kWth each. This means Legno Energia is overall operating a plant of 1.8 MWel and 3MWth, integrated with the local district heating. Thus, the plant requires a total amount of 43 tons of dried wood chips per days that means around 72 tons of wood chips per day.

Images about one of the LegnoEnergia gasification line located in Tirano (SO, Lombardy) are shown in *Figure 41*.

b)



c)

Figure 43. Gasification line implemented in Tirano: a) plant under construction, b) SCADA of the engine (7577 hours of operations, activated in October 2018, 12 month of operation)

Contact person: Raffaele Ferrari (r.ferrari@legnoenergiasrl.com)

Implementations

Table 8. Reference list of small-scale gasification plants by LEGNO ENERGIA SRL

Supplier	Technology	Project / Location	Year of commissioning	Feedstock		Input / Feedstock	Output El. / Th.	Usage / Product	Start up / Status
				Wood chips	Off-cuts				
LEGNOENERGIA	Downdraft fixed bed	Tirano (casa del legno 1)	2016	X		700 kWt/ Wood chips (150 kg/h)	150 kWel./270 kWth	CHP, process heat, district heating	2016/operational
		Tirano (casa del legno 2)	2016	X		700 kWt/ Wood chips (150 kg/h)	150 kWel./270 kWth	CHP, process heat, district heating	2016/operational
		Tirano (casa del legno 3)	2018	X		700 kWt/ Wood chips (150 kg/h)	150 kWel./270 kWth	CHP, process heat, district heating	2018/operational
		Tirano (casa del legno 4)	2018	X		700 kWt/ Wood chips (150 kg/h)	150 kWel./270 kWth	CHP, process heat, district heating	2018/operational
		Tirano (casa del legno 5)	2017	X		700 kWt/ Wood chips (150 kg/h)	150 kWel./270 kWth	CHP, process heat, district heating	2017/operational
		Tirano (casa del legno 6)	2017	X		700 kWt/ Wood chips (150 kg/h)	150 kWel./270 kWth	CHP, process heat, district heating	2017/operational
		Tirano (frama 1)	2019	X		700 kWt/ Wood chips (150 kg/h)	150 kWel./270 kWth	CHP, process heat, district heating	2019/operational
		Tirano (frama 2)	2019	X		700 kWt/ Wood chips (150 kg/h)	150 kWel./270 kWth	CHP, process heat, district heating	2019/operational
		Tirano (frama 3)	2019	X		700 kWt/ Wood chips (150 kg/h)	150 kWel./270 kWth	CHP, process heat, district heating	2019/operational
		Tirano (frama 4)	2018	X		700 kWt/ Wood chips (150 kg/h)	150 kWel./270 kWth	CHP, process heat, district heating	2018/operational
		Tirano (frama 5)	2018	X		700 kWt/ Wood chips (150 kg/h)	150 kWel./270 kWth	CHP, process heat, district heating	2018/operational
		Tirano (frama 6)	2018	X		700 kWt/ Wood chips (150 kg/h)	150 kWel./270 kWth	CHP, process heat, district heating	2018/operational

5. OFFGRID-4.0 SRL

Address: Via Paratino Nr 1 CECINA (LI) 57023, Italy

Email: info@offgridstorage.it

The QuattroPuntoZero Facility

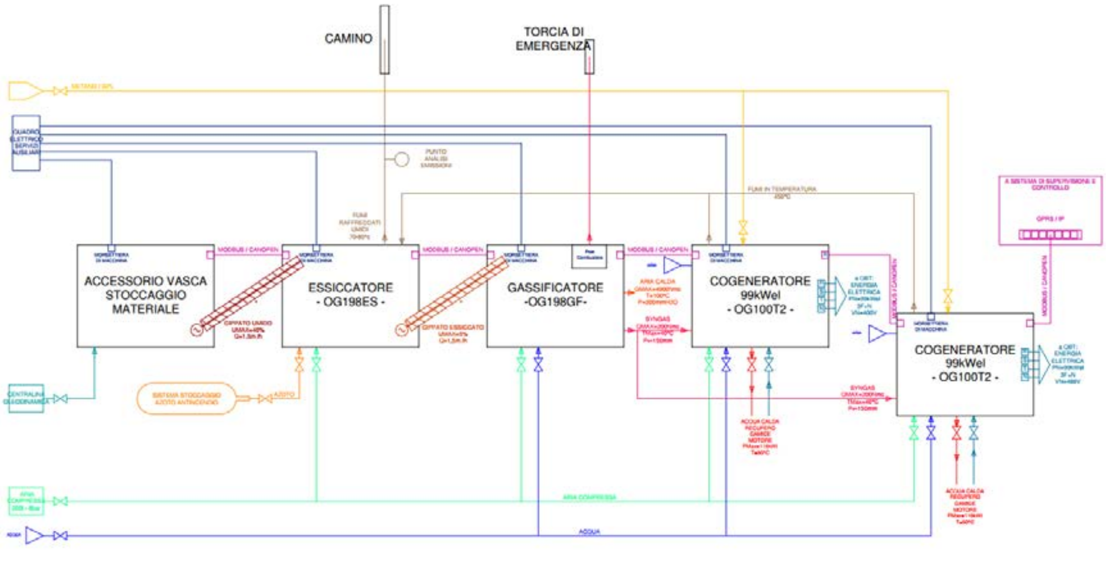
OFFGRID-4.0 srl, was constituted for research, development and construction of plants for the production of energy from biomass. The firma was first established in 2010 starting from the co-instituting company COOP TEA. Together with ENEL Research, OFFGRID has been involved in the field of pyrogasification to develop new filtering systems.

The gasification plant developed by OFFGRID is basically composed of a high-temperature drying system, a torrefaction system, a reactor, a post-combustor, a ceramic candle filtration system, a cooling system and an additional separation system for organic vapor removal with a gas output at around 9 °C. In Figure 42 a general scheme of the gasification plant, with detail on the gasification section, is presented.

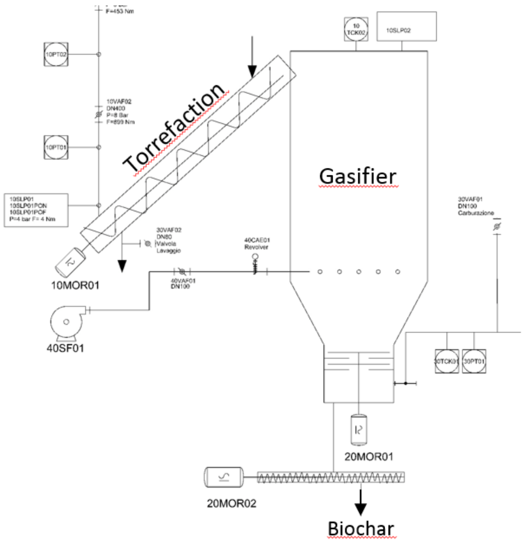
The plant is designed as a whole to ensure the highest conversion efficiency in terms of feedstock conversion in producer gas and cold gas efficiency (CGE). Specifically, starting from the drying part, a component allowing to have a very low consumption of electricity was designed, making the most of all the sensible heat available from the exhaust gases of the engines; afterwards, the process of gasification was divided in controllable and modular sections. The pre-stage of torrefaction was adopted to condition the plant feeding material, thus anticipate the stage of pyrolysis outside the gasification reactor. With the aim of improving the overall plant performances, a post-combustor was adopted to take advantage from the heat in the flue gas to condition the downstream ceramic system.

A first gasification plant has been connected to the national grid starting from December 2017. The plant is sized to process a biomass input of 200 kg/h dry wood chips, corresponding to a nominal thermal input of 850 kWt. Starting from a raw feedstock with a maximum humidity content of 50 %-wt, through the drying system the feedstock is addressed to the reaction inlet section at a final moisture content of about 10 %-wt.

Under proper operating conditions, with an input of 850 kW on thermal base, a syngas production corresponding to 650 kWth is obtained. Supplied to an ICE the produced syngas turns into 200 kWe and 230 kWth (i.e. water at 80-90 degrees and 185 kWth as flue gas at 580 °C). As a whole, the gasification plant has an electrical and overall efficiency of 23 % and 70 %, respectively.



a)



b)

Figure 44. Overview scheme of The OFFGRID 4.0 gasification facility: general plant scheme, b) the two-stage process reactor.

A picture of the 850 kW_{th} gasification plant based located in Vicenza is presented in Figure 43.

Figure 45. Picture of the OFFGRID 4.0 gasification *plant in* Vicenza (Veneto)

Contact person: Fabio Giusti (fabio.giusti@offgridstorage.it)

Implementation

Table 9. Small-scale gasification facility by OFFGRID-4.0 SRL

Supplier	Technology	Project Location	Year of commissioning	Feedstock		Input / Feedstock	Output El. / Th.	Usage / Product	Start up / Status
				Wood chips	Off-cuts				
OFFGRID 4.0	Two-Stage	Vicenza	2017	X		847 kWth /Wood chips	198 kWel/232 kWth	CHP production	2018/ Operational

6. RONDA ENGINEERING SRL

Address: via Vegri, 83, 36010 Zané (VI), Italy

Email: info@ronda.it

Web: http://www.ecogasgenerator.com/

ECOGASGENERATOR

The ECOGASGENERATOR Facility

Ronda Engineering is the startup of the Ronda Spa group which is engaged in research and development of pyrogasification systems for the production of electricity and thermal power from biomass and/or municipal waste, agricultural and industrial waste. According to this aim, Ronda Engineering has developed over time its own gasification plant named Ecogasgenerator.

The Ecogasgenerator system was designed to allow continuous operation and low environmental impact. In *Figure 44* an overview of the plant layout and site arrangement is presented; several section can be recognized.

In short, a first section for the storage of biomass is arranged to serve the gasification plant. In this area the feedstock is stored and refined with an appropriate mill to ensure a suitable size. The reduced material is then automatically addressed to the dryer for humidity reduction. The drying phase is performed in airtight compartment. The accepted maximum humidity of the incoming biomass is 80%. The evaporated water is condensed without any emission into the atmosphere.

The preliminary treated feedstock is then addressed to the section for thermochemical conversion. The whole process takes place in two phases and in a completely airtight environment. The first phase of pyrolysis consists in leading the material to a temperature of about 900 °C to extract the volatile part of organic matter. In the second stage the residual material – consisting of carbon and ash – is further raised to a temperature of about 1300 °C in order to gasify the remaining carbon. To drive this stage, air is used as a gasification agent.

The produced Ecogas is sent to a separator cyclone of coarse dust then to a section for tar removal, where the organic contaminant load is converted into simple gas thanks to a technique developed by Ronda Engineering. Therefore, the gas achieves technical specifications, in terms of gas composition and tar load, that make it suitable for use in Otto cycle engines with very superior efficiency to steam turbines commonly used in similar plants.

Before its feeding to the combustion engine, the gas is cooled at the thermal recovery section. The energy contained in the purified Ecogas is achieved by a pre-heating of the combustion air in the first exchanger, and in a second heat exchanger, by heating of the fluid convector used for drying the biomass and for the supply of thermal energy for external use.

All the condensation water from the gas cleaning and cooling stages, together with that from the feedstock drying, are sent to an electrolytic purifier plant (Ronda Engineering design) to bring their values according to the law.

The cooled gas is fed into an Otto engine suitably adapted by Ronda Engineering for production of electrical energy as to confer on the grid and for own consumption. All of the cogeneration unit is housed in a special soundproof container to reduce noise emissions. Based on an average calorific value of 3-4 MJ/Nm^3_{dry} for the producer gas, a 38 % of electrical efficiency is typically achieved.

The plant is operated and controlled by a single person through PLC and PC with an appropriate interface. All electromechanical controls, the control power, and man/machine interface, are housed in a specially equipped container. The control system is also provided for the WEB connection for remote assistance.

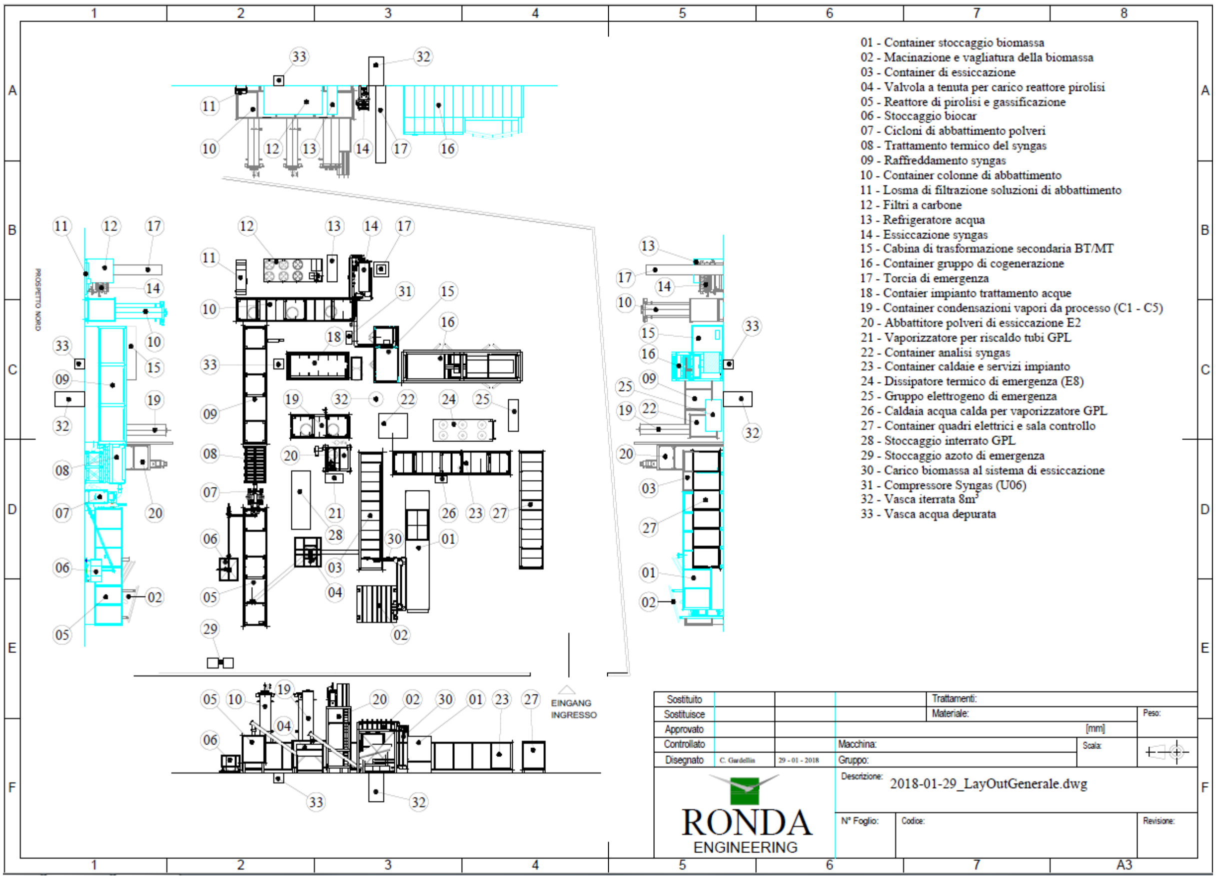


Figure 46. General ECOGASGENERATOR plant layout

In Figure 45, picture of a 3 MWth industrial plant based on the Ecogasgenerator system is presented. The plant is located in Val di Vizze (Bozen, South Tyrol) and is next to be put into operation.

Figure 47. Picture of the 3 MW_{th} industrial plant in Val di Vizze (BZ)

Contact person: Gianantonio Ronda (gronda@ronda.it)

Implementations

Table 10. Small-scale gasification facility by RONDA ENGINEERING SRL

Supplier	Technology	Input / Feedstock	Output El. / Th.	Usage / Product	Start up / Status
Ronda Engineering SrL	Reactor with external heating	3 MW_{th} / Wood chips	999kWel. /1320 kWth	CHP production	2018 Operation

Table 11. Reference list of gasification plants by ENGINEERING SRL

Supplier	Technology	Project / Location	Year of commissioning	Feedstock		Input / Feed stock	Output El. / Th.	Usage / Product	Start up / Status
				Wood chips	Off-cuts				
RONDA ENGINEERING SRL	Reactor with external heating	Zanè (Vicenza)	2006	x		80 kW_{th}/ Wood chips	20 kWe	Pilot plant for testing campaigns	2007, operated for experimental programmes
		Breganze (Vicenza)	2013	x		3 MWth/ Wood chips	999kWe/ 1320 kWth	Tests Industrial Plant	Moved to other location in 2018
		Val di Vizze (BZ)	2019	x		3 MWth/ Wood chips	999kWe/ 1320kWth	Industrial plant for CHP [a)]	In operation by 2020

a) This installation was realized by transferring the upgraded test industrial plant located in Breganze (Vicenza).

7. SITE SPA

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Email: site@sitespa.it

Web: http://pirogass.it/

The PIROGASS Gasification Facility

SITE Spa has promoted and developed systems for the production of energy from renewable sources and for energy saving. After three years of study and analysis of existing technologies, the company has developed and patented an innovative pyrogasification system that allows the combined production of electricity and heat. This system was launched on the market with the PIROGASS brand in 2016 with its first working prototype installed at its branch in Treviso.

PIROGASS is a highly innovative fixed bed gasifier: downdraft type plant is based on the use of wood chips of multitype-biomass (e.g. crops, trees, vineyard scraps) with an open chamber and a proprietary reduction system that can produce tar-free syngas at source. Through a process of pyro-gasification, biomass from trees and crops is converted into syngas, which in turn is converted into electricity and thermal energy. A typical plant layout is presented in *Figure 46*.

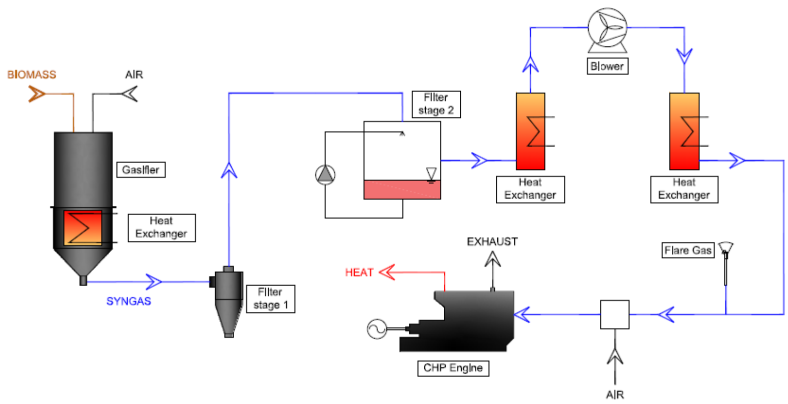

Figure 48. Plant layout of the 800 kWth installed in Treviso

According to the scheme above presented, downstream the gasifier the plant is characterized by a proprietary system for gas purification constituted by: a) reduction system comprising a patented catalytic zone, b) a patented heat exchange system allocated right after the catalytic zone, that allows the rapid cooling down of the produced gas (syngas) and reduces the possibility of reaction and recombination of the gas itself. This solution cuts drastically the formation of TAR and allows to have a gas at a relatively low temperature that facilitates the construction of the downstream equipment, c) a proprietary first stage filter that reduces radically the content of char dragged by the gas flow; d) a second, ad hoc designed and constructed, stage of humid filtration, that, in different steps, furtherly reduced the content of TAR and char from the gas, e) a double step of heat exchangers to condensate the water gas content up to the optimum level acceptable by the engines. After the proper gas cleaning and conditioning the gas is then addressed to the CHP Engine that produces electrical power as well as heat easily usable either inside the plant itself (as refrigeration through an evaporative system, lowering the self-consumption of the system) or outside the plant itself. The facility is finally completed by a safety system constituted by a flare gas coupled with an easy changeable, ultimate filter (not shown).

Pictures of the gasification facility in Treviso, based on the above described layout are presented in *Figure 47*.

a)

b)

Figure 49. Photo of the 800 kWt PIROGASS facility: a) location at San Biagio di Callalta (TV), b) overview of the gasification plant

Overall, the high level of cleanness and low humidity of the gas feeding the engine allows a low requirement for the CHP units maintenance. Thanks to different stages of PLC, the plant is characterized by a high level of automation.

The plant design is such as a scalability from 70 to 150 kW of electricity is possible. A good efficiency of the conversion from wood to gas can be achieved. Diversified biomass in chips form, from p31.5 to p45 in sizes[9], can generally be supplied to the open chamber gasifier. In these operating conditions from 1 kg of biomass consumption per 1 kW of electricity is produced. By

[9] Chip size classes, defined according to the standard UNI EN ISO 177225-4, the International Standard determining the fuel quality classes and specifications of graded wood chips.

exploiting the producer gas at an ICE “Otto Cycle”, in CHP mode, an electrical yield of 32 % and a thermal yield 57 % are attained.

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Website: http://pirogass.it

Implementations

Table 12. Small-scale gasification facility by SITE SPA

Supplier	Technology	Project Location	Year of commissioning	Feedstock		Input / Feedstock	Output El. / Th.	Usage / Product	Start up / Status
				Wood chips	Off-cuts				
PIROGASS	Downdraft fixed bed	San Biagio di Callalta (TV)	2016	X		805 kWt / Wood chips (267 kg/h)	150 kWel/ 307 kWth	CHP production	2016 operational

IEA Bioenergy

Further Information

IEA Bioenergy Website
www.ieabioenergy.com

Contact us:
www.ieabioenergy.com/contact-us/