Technological advancements in small scale biomass gasification: case study of South Tyrol

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Abstract

Small scale biomass gasification has been a technological option that has raised a lot of interest during the last years in Europe. Alongside the growth in market share, we also observe new optimized technologies that are applied. The scope of this paper is to describe and analyze the most peculiar and innovative technological advancements that were investigated under the framework of GAST project. GAST project stands for "GAsification in South Tyrol" and is focused on analyzing and assessing small scale biomass gasifiers that have been developed in South Tyrol during the last three years. The monitoring activity has been the basis for the thermodynamic analysis in order to assess the potential and limitations of these energy systems. The outcomes imply that the small scale gasifiers that have gained market share have three main characteristics: are automated, have modular form and are based on patents/ specific designs. On the other hand this makes the considered technologies dependent on the specific input and thus, not able to utilize a wider spectrum of the available biomass. In conclusion, small scale biomass gasification is a technological option that is viable in the area of South Tyrol, mainly due to the high economic incentives set by the Italian legislation, to the innovative technologies and to the local conditions that make district heating a suitable option and are characterized by remarkable biomass availability.

Keywords gasification, biomass, CHP, small scale, producer gas

1. Introduction

Utilization of biomass for energy production has raised a lot of attention due to the endeavor to wipe out the utilization of fossil fuels. Solid biomass is one of the most interesting and promising resources for renewable energy production in Europe and represents a key factor for the reduction of greenhouse gas emissions in the energy production sector [1]. Biomass has the advantage of being a renewable energy resource and can be considered as CO_2 neutral [2]. Energy from biomass, also known as bioenergy, is defined as the energy recovered from non-fossilized organic matter [3]. Currently, woody biomass is the largest biomass energy resource worldwide. The most significant biomass sources are agricultural waste (mainly pruning), forest residues or even the organic fraction of the municipal waste [4].

Downscaling electricity production units, results to higher losses mainly due to the drop of the steam turbines isentropic efficiency. Therefore the concept of gasification is becoming more interesting due to the utilization of Internal Combustion Engines or Gas Microturbines in combination with the valorization of heat. Combined Heat and Power units (CHP) result to higher efficiencies, which can make investments on biomass gasification more appealing and economically viable.

Concerning the market penetration of small scale biomass gasification it has to be mentioned that, until recently, it hadn't succeeded to gain a significant market share. The main reasons could be identified as its inability to compete with conventional technologies based on fossil fuel and the lack of commercial options to deliver stable, reliable and efficient solutions. Therefore the technology gained interest only in areas with special characteristics, i.e. secluded areas with high biomass inventories [5]. The scenery shifted during the last decade with new technologies entering the market and gaining market share. One could argue that this bump in utilization of biomass gasification technologies is due to the increased tariffs for renewable energy producers. However, it is the optimization of the gasifiers up to a level of high performance and the stability of operation that made such an investment appealing [6].

2. Development of the GAST project – region of South Tyrol

GAST stands for "GAsifcation in South Tyrol". During the last 3 years, several South-Tyrolean entrepreneurs have decided to invest in the biomass gasification energy conversion technology, clearly conveying a strong interest in the sector of small scale cogeneration plants. The plant owners are both private subjects (i.e., local farmers) and companies (i.e., sawmills) that have access to large amounts of low cost local woody biomass [5]. The situation is quite complex and variegated. In addition, the management of the forests (e.g. removal of pruning, dead branches, small plants, plants attacked by pathogens etc.) can be transformed from a cost to a resource, supporting locally green jobs and, as a whole, green economy. South Tyrol is a region that is strongly supporting green energy and sustainable development. Clearly the autonomous region of South Tirol promotes the development and the utilization of renewable energy systems. In addition to the national plan for renewable energy, the local governments play a crucial role for the establishment of renewable energies, due to their role concerning the authorization of the energy plants [7].

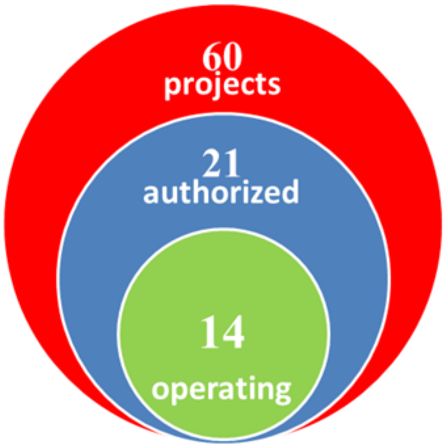

Fig1. Projects developed under the GAST framework until May 2013 [7].

As projected on Fig. 1.from a total of 60 projects that were proposed concerning small scale biomass gasification plants, 21 had been authorized and 14 were already operating by May 2013 [7]. One of the aims of the GAST project is to perform a survey of the actual spreading and development in South Tyrol of small scale biomass-gasification-based CHP plant, selecting some representative plants and monitoring them. Therefore, the deployment and the distribution of the plants that have been developed from May 2013 until May 2014 have been mapped and projected on Fig.2 and Fig.3. The ultimate scope is to understand the state of the art of the gasification technology in South Tyrol, to give an overview of the performance of the local plants and to identify possible ways of improvement. To our knowledge, this kind of survey is, at the moment, unique in Italy. In addition, it can support the local public administration, providing useful tools for the authorization procedures of small biomass plants, which are becoming more and more diffused in South Tyrol. The screening process resulted to the categorization of the gasifiers in nine major types. In addition, all the corresponding technologies are utilizing air as a gasifying medium and in their majority follow the downdraft design approach that will described in detail in the following chapters.

3. Gasification and small scale applications

3.1. Theoretical background

Among all the possible technological options for biomass valorization, gasification has a strong potential due to the high electrical efficiency even in smaller scale applications [8]. Gasification of biomass as a possibility for energy conversion is a concept that is not novel and has been around from mid-19th century. It represents the thermochemical conversion of a carbon-rich feedstock into mainly gaseous products under the presence of sub-stoichiometric oxygen. Although a thermal process, there are fundamental differences when compared to the more familiar concept of combustion. Combustion is a process which releases heat and exhaust gases without any heating value while gasification “packs” energy into chemical bonds, upgrading the inlet feedstock into a gaseous product which is called syngas or producer gas [9]. The main compounds that can be found in the producer gas are mainly carbon dioxide, hydrogen, carbon monoxide and methane. Moreover according to the gasification agent we can have higher or lower amounts of nitrogen.

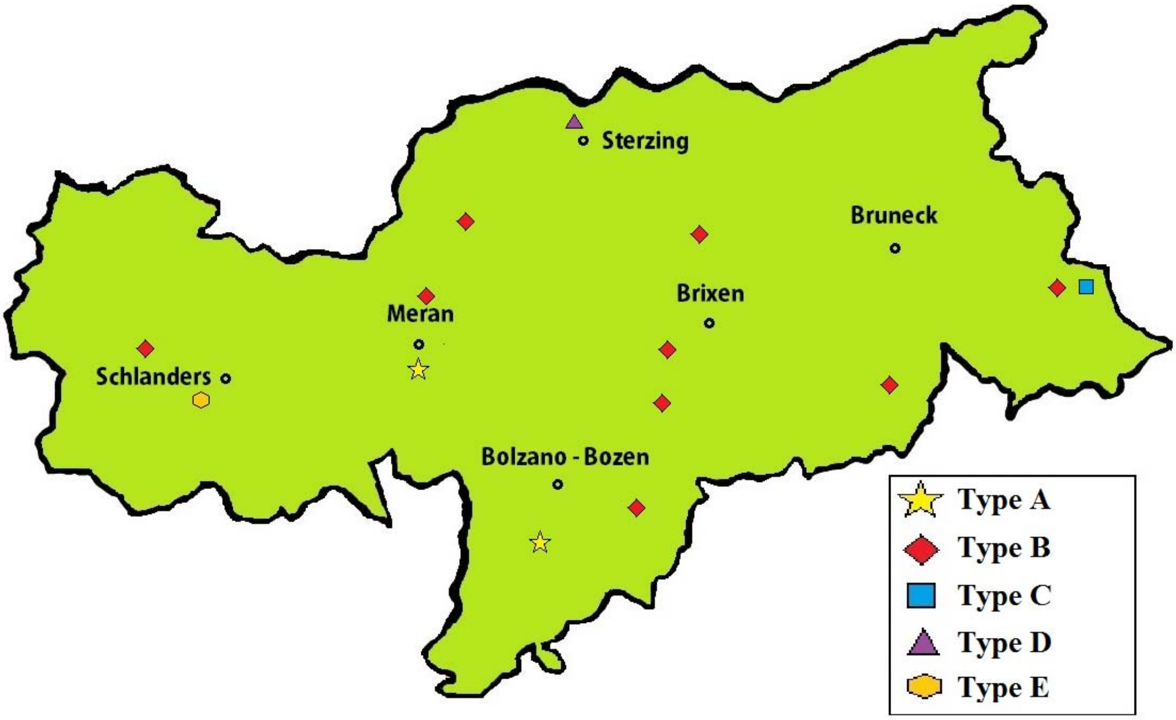

Fig2. Distribution of small scale gasification plants in South Tyrol on May 2013 [7]

The lower heating value of the syngas/ producer gas is directly correlated to the composition of the different compounds on a dry basis. In addition, other properties should be taken into consideration like the knock tendency of the fuel, especially when the gas is utilized in an Internal Combustion Engine [10].The engine 'knock', also known as knocking effect, reflects the abnormal propagation of the flame inside the pistons due to the temperature or the pressure conditions [11]. In the case of fixed bed air gasification, although hydrogen has a very low limit of auto-ignition, the high composition of nitrogen and carbon dioxide in the producer gas is a knocking suppression parameter, due to the fact that these gases are practically inert [12]. A reliable approach to estimate the knocking effect of a fuel is to know the octane rating of the fuel.

Except the producer gas, gasification has also other by-products mainly char, tar and ash. Char can be defined as the solid fraction which results from the pyrolysis of carbon based materials and may have carbon content between 50% and 80%. Char has a very reactive surface and plays a significant role in the gasification process [13]. Tar consists of various heavy organic compounds. It is commonly accepted that all the organics which have a boiling point at temperature higher than of benzene are considered as tar. A high concentration of tar in the gas could result to various problems in the operation of the energy production units whether it is an Internal Combustion Engine or a Gas Microturbine [14]. Finally ash is the solid residue that results from the combustion of biomass. This combustion residue is a complex, heterogeneous and with a variable composition. Although ash usually consists from inert minerals that do not participate in the reactions, we observe slagging effects due to high temperature melting.

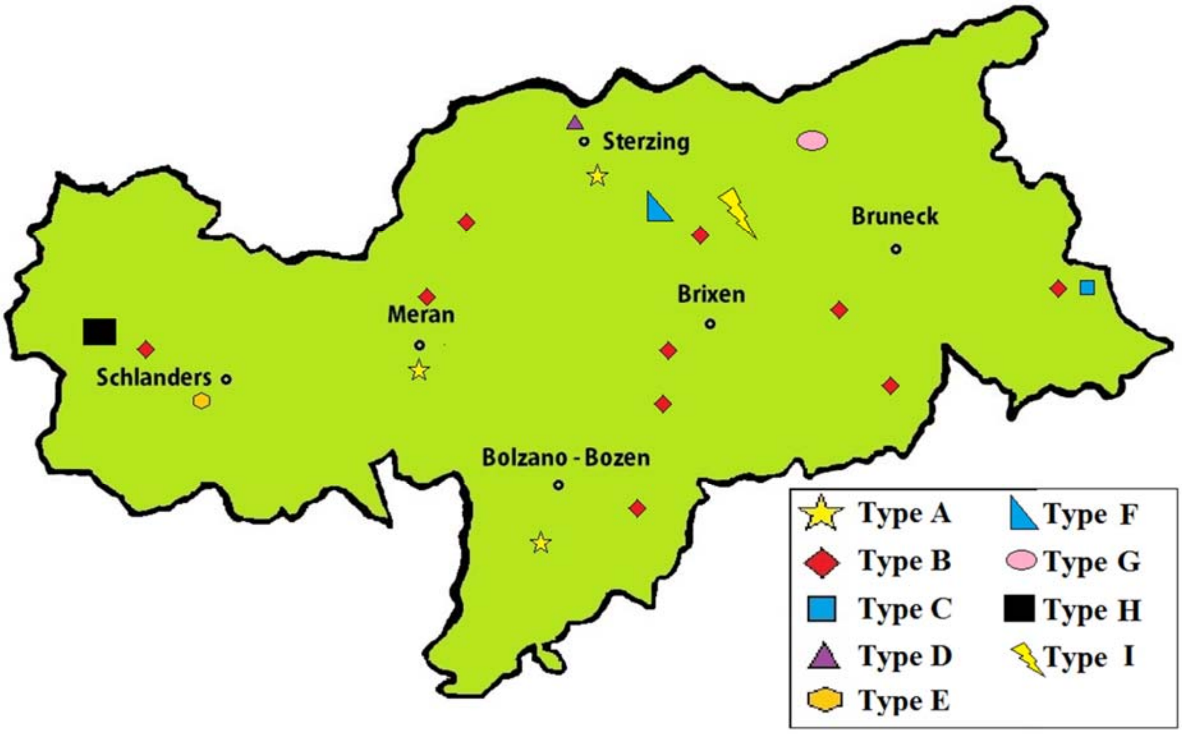

Fig3. Distribution of small scale gasification plants in South Tyrol on May 2014 [7]

3.2. Fixed bed gasifiers

The standard gasification reactors for small scale applications are fixed bed gasifiers mostly downdraft but also updraft designs. There are various types and designs of gasifiers with different characteristics and functional parameters. As a result, different gasifiers are suitable for different characteristics of the feedstock or different designed plant capacity [15]. The basic types are fixed bed (updraft or downdraft), fluidizing bed and entrained flow gasifiers. Moreover, the gasifiers can be also divided in two other major categories: direct or autothermal in which the heat that is needed for the gasification is supplied by the partial combustion of the fuel or allothermal gasification when thermal energy is supplied from an external source [16]. Due to their design characteristics and their operation parameters, autothermal fixed bed gasifiers have significant advantages at small scale [11]. Moreover, their scaling-up is limited from our ability to distribute air homogeneously at the whole reactor [12].

The two most important designs of fixed-bed gasifiers are the updraft (or counter-current) and the downdraft (or co-current) gasifiers. In both cases the biomass is fed from the top and the air in fed to the combustion/ oxidation zone of the gasifier. Usually the product gas from these gasifiers has relatively low heating value because it is diluted with large amounts of nitrogen from the atmospheric air, which is the gasifying medium. Nonetheless the zones are distributed differently in the downdraft and the updraft gasifiers. Even though there are usually no grates or other physical obstacles which separate the gasifier in subsections, a downdraft gasification reactor can be divided in four main zones, each representing a different kind of process occurring: drying, pyrolysis, combustion and reduction. The differences in the zones distribution between the updraft and downdraft gasifiers along with information about their operation are projected in Fig.4.

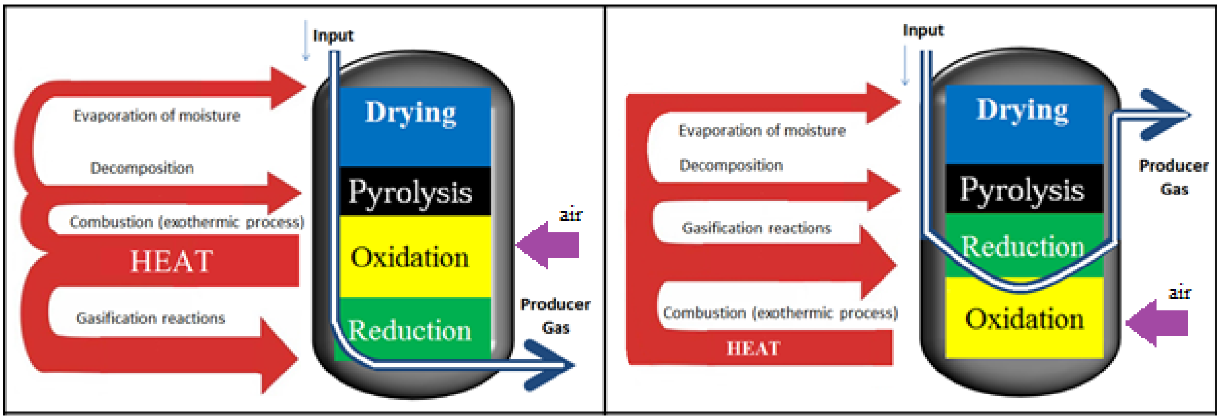

Fig4. Zone separation in downdraft (left) and updraft (right) gasifiers and the 'path' of the input as it is transformed to producer gas and exits the gasifier.

3.3. Reaction zones in fixed bed gasifiers

Drying is the zone that the water content of the feedstock is vaporized. It occupies the area that the input initially comes into contact with, when it enters the gasifier. The decrease in the content of water results to higher heating value of the fuel. On the other hand the latent heat of evaporation is an energy demanding process. The energy demand in the drying zone is higher that the theoretical latent heat of water, mainly due to the fact that the water is usually bound in the biomass when the moisture content is relatively low (i.e. lower than 10-15%), but also due to losses (i.e. heat transfer, irreversibility in processes) [17, 18].

In *Pyrolysis* zone, the feedstock starts to thermally decompose to pyrolysis products (vapor, liquid and solid) by means of heat and almost in absence of oxygen. The type of the feedstock along with the operating parameters (i.e. temperature, pressure, heating rate) define the distribution between the solid, the liquid and the gas pyrolysis product fractions. Pyrolysis can be divided in three main parts –zones which are the endothermic primary decomposition zone, the exothermic partial zone and the endothermic surface char zone. Therefore, although pyrolysis is considered to be endothermic, this only applies for a specific range of the process [13, 17 and 19]. In downdraft gasifiers we observe a transition phase /zone between the pyrolysis and the combustion zone. This edge surface is usually called flaming pyrolysis. The term ‘flaming’ reflects the fact that the combustion is flaming and not glowing due to the operating conditions and the presence of soot. The term ‘pyrolysis’ is utilized due to the sub-stoichiometric presence of oxidation medium along this transition phase /zone.

The *combustion* zone is the area of the gasifier where the oxidation medium (i.e. mainly air or steam) is introduced and pyrolysis products are oxidized. This exothermal process provides the necessary energy (heat) for the pyrolysis, the drying and the reduction of the feedstock. The amount of combusted feedstock is controlled by the equivalent ratio (ER) which is defined as the ratio between the actual oxygen provided to the process versus the stoichiometric amount. The most commercial gasifiers operate within an equivalent ratio range of 0.25 and 0.30 [9].

The *gasification* zone is the area where the reduction endothermic reactions take place and the producer gas is formed. ‘In the reduction zone, temperature is lower than in the combustion zone and the size of the zone depends on designing parameters like the size and the shape of the mantle, the position of the air nozzles and the design of the moving grates’ [5].

A characteristic of the downdraft gasifiers is that the pyrolysis products pass through the combustion zone before the endothermic gasification reactions take place. Thus, part of the liquid pyrolysis products are cracked down by the high temperature of the combustion zone and the producer gas has lower tar content. Finally, the controlled parameters like the specific design of the throat and the air-feeding nozzles ensure that a fraction of the input will be combusted in the combustion zone but the remaining fraction of the feedstock will be converted in the gasification zone [20].

3.4. Energy Conversion Units

In small scale operations, a lot of conventional options are excluded due to their inefficiency and their incompatibility. Internal Combustion Engines are the most common option for converting producer gas to electricity and heat. The gas/ air mixture is compressed in a cylinder by means of a piston in order to create an explosion. Thus, the piston gains kinetic energy, decompresses and rotates the crankshaft. The ignition-explosion inside the piston can be initiated solely by compression (i.e. Diesel engines) or by a sparkle (i.e. Otto engines) [21].

The Otto engines work with the Otto cycle which can be 2-stroke or 4-stroke cycle. At a specific level of compression, the spark ignites creating a flame that propagates and causes the expansion of the piston. After the expansion the products of the ignition are ejected from the cylinder and replaced with a new mixture of air and fuel.
In the Diesel cycle, due to the fact that ignition is caused by compression of the piston, the compression ratio is much higher than the corresponding compression in conventional Otto engines. In the Diesel cycle, air is compressed in the cylinder and the fuel is injected when the compression is complete. In this case only air is compressed in the cylinder, thus there is no risk for the fuel to auto-ignite [22].Characteristic operating parameters of Otto and Diesel engine with product gas can be found in Table 1.

Table 1. Operating parameters of Otto and Diesel engines with product gas [22].

	Diesel engine	Otto engine
Fuel	diesel	gasoline
Compression ratio	16-24	5-10
Ignition	compression	spark
Efficiency	25-35 %	15-25 %

4. Methods of analysis

The methodology that has been followed for the analysis of gasification units for the GAST project consists of the application of technical standards along with other methods that can assess the distribution of the streams along with the thermodynamic performance, such as Material Flow Analysis, Exergy and Energy Analysis.

4.1. Technical standards

The measurements and the analysis that have been implemented in the framework of the GAST project, have been done in compliance with the corresponding technical standards. Alongside the existing technical standards, novel standards and guidelines are under development in order to embrace innovative co-generation plants like small scale biomass gasification units, which until recently were considered to belong to the refinery industry [23].
The Italian Committee of Thermal engineering has issued a draft guideline, known as 'Guideline CTI 13', which is 'highlighting the aspects that have to be carefully evaluated during the contracting and commissioning of gasification systems (i.e. classification, requirements, rules for bidding, ordering, construction and testing) for which produce and utilize producer gas obtained by gasification of lignocellulosic biomass' [7].
The sampling of the wood chips feedstock has been implemented according to the standard EN 14778:2011, which describes methods for preparing sampling plans and the procedures for collecting solid biofuels samples. It includes both manual and mechanical methods.
Tar and particles in the producer gases were sampled in agreement with the technical specification CEN/TS 15439. A heated probe equipped with a particle filter sampled in a quasi-continuous regime under isokinetic conditions the gas stream containing the tar and the impurities. The volatile tars are trapped in impinger bottles which contain 2-propanol of 99% purity [5, 24]. Gas Chromatography – Mass spectroscopy (GC-MS) along with gravimetric techniques have been applied on and off-site for the analysis. The producer gas composition is one of the main focuses of the monitoring campaign. Therefore, the measurements took place in two different sampling points: downstream of the gasifier in order to assess the raw gas and upstream the CHP motor to sample the filtered gas. The on-site analysis was implemented by mobile GC units. Moreover - in order to have measurement redundancy and test the GC calibration - producer gas was also sampled and analyzed off-site with a MS unit). The major technical standards that were followed for analyzing the biomass feedstock are projected on Table 2.

Table 2. Technical standards that were followed for the analysis of biomass feedstock.

Technical Standards	Type of analysis
CEN/TS 15289	Determination of total content of sulphur and chlorine
CEN/TS 15105	Methods for determination of the water soluble content of chloride, sodium and potassium
CEN/TS 15290	Determination of major elements
CEN/TS 15296	Determination of minor elements
CEN/TS 15297	Calculation of analyses to different bases
CEN/TS 14775	A ash content
CEN/T S 15104	C total carbon content
CEN/TS 15289	Cl total chlorine content
CEN/T S 14918	Net calorific value at constant pressure (J/g)
CEN/TS 15104	H total hydrogen content
CEN/TS 14774	M moisture content
CEN/TS 15104	N total nitrogen content
CEN/T S 15289	S total sulphur content

4.2. Material Flow Analysis

As ‘Material Flow Analysis’ or else MFA we define the method that keeps the record of all the input and output streams. It is the main concept behind not only material but also energy balances. With this method we numerically track every different stream (or else flow) of the process. By means of this tool it is much easier to find out in which part of the process chain are specific materials or substances accumulated. Thus, we can develop more efficient strategic management tools [25]. Furthermore, MFA is very useful tool to assess the sustainability of a process. Usually this happens by means of assessing the environmental degradation due to accumulation of pollutants [25].

Material Flow Analysis, like any method, has pros and cons. On the positive side, by means of MFA we have the quantitative representation of the input and output flows along with accumulated stocks in the different steps of the process. Thus, the tool enhances our ability to identify potential environmental threats. This assists not only the efficiency of the monitoring but also the ability to develop precautionary measures. The MFA can take into consideration the economic aspect because the flow of materials is correlated to economic activity. Therefore, MFA can be a great tool for decision making [26]. On the other hand, the quality and the accuracy of the provided data are crucial to the result. This requires global standardized methods that could take place only if MFA is adopted on a global scale. [26]

4.3. Energy Balances

It is also important to investigate not only the different streams of materials that enter and exit from every process, but also the energy that is required for each process to take place. In our case we have energy produced by gasification processes, which tend to be more efficient in comparison to conventional technologies. Nonetheless, an amount of energy is required in order to prepare the feedstock for the gasification process but also to gasifiy the feedstock. An energy balance should be implemented in order to know the net energy production of a system.

We have to point out that this method of analysis is not a Life Cycle Analysis. We are not trying to calculate the impact of the whole life cycle of biomass. Therefore, the energy demand for the land-use and the production of the biomass is not considered. This would also be of no-use in our case because the differences between the different sets of processes are spotted on the type of gasifier, filters and energy production and not in the production part. Furthermore, the other factor that is not considered in this study is the energy demand for distribution of the produced energy.

4.4. Exergy Analysis

In order to evaluate the quality of the streams and measure the overall efficiency, we have implemented analysis of the exergy. We could say that exergy is a way to assess the quality of the energy. In our case, exergy is a good indicator for the maximum amount of work that we can theoretically obtain from a process. Therefore we calculated the exergy of the output streams for different gasification systems. There are two main different types of exergy. The one depends on the difference of the temperature and the pressure between the system and the surrounding environment and is called physical exergy. The other is called chemical exergy and is correlated to the type of the elements (and molecular structure) of the products [27].

5. Factors of innovation on small scale gasifiers

Downdraft gasifiers have been traditionally the most common and widely used. The first commercial applications had been fed with coal as input. The utilization of biomass gasifiers has taken place only through periods that oil was not abundant. Therefore after World War II, biomass gasification went out of the picture for more than 30 years. But during the oil crisis in the middle 1970's, United States and other western countries investigated again the possibility of using gasification for energy production [17].

5.1. Downdraft gasifiers – Common designs

There are several designs downdraft gasifiers' designs that have been widely applied. As most important designs we could identify the Imbert Hourglass, the V-hearth, the Constricted Flat Plate, the Straight Reduction Tube, the Stratified Downdraft, the Multipoint air injection, the Buck Rogers and the J-Tube. The main differences can be denoted in the design of the throat, the size of the hearth mantle and the position and design of the air nozzles. In each case a specific design can provide different set of advantages and disadvantages. Therefore, efforts have focused on preheating the air in the air nozzles that enters the gasifier, to increase the retention time, increase the size of the reduction of the reaction, provide air in all parts of the combustion and reduction zone, and finally to scale up the process while maintaining a sufficient performance [17]. In the framework of the GAST project newer and more innovative designs have been identified and analyzed.

During the last decade, the main driver of innovation was the multi-stage approach to fixed bed gasification (Milena, Viking, Fraunhofer). Staged systems for biomass gasification are based on the separation of the sub- processes of thermo-chemical conversion (drying, pyrolysis, oxidation, reduction) occurring in different reactors. The separation of the process steps permits the partial steps to perform, which results in higher concentrations as well as very little load in the form of condensable hydrocarbon compounds (tar loads) [3].The two - stage process is usually the case pyrolysis and combustion/gasification occur in different reactors . As a result each different process propagates in a more complete and integrated way [11]. Although multi-stage gasification results to products of higher quality, it is the case that the process is not anymore autothermal and thus it becomes a matter of scale and mass production of units that will ultimately make a multi-stage fixed bed gasifier economically viable. The cost of materials along with additional equipment and reactors are factors that make the design of such a gasifier inherently expensive.

As a result of the above, contrary to the intuitive approach of developing multi-stage better-performing small scale gasifiers, the main factors that drive the innovation of small scale biomass gasifiers have been the modular form of gasification solutions, the automation of the process and the ability to optimize the efficiency of the gasification zones either by utilizing specific input or by applying patents. Finally the sizes of the units along with the 'renewability' of the fuels are issues of high significance due to their correlation with the amount of the feed- in tariffs.

5.2. Modular form and Automation control

Modular system could be defined as a compact 'boxed' system that aims to provide an integrated solution. The modular form approach includes all the equipment that are necessary to operate a gasifier and produce electricity and heat. Alongside the gasifier, the appropriate filtering system, heat exchangers, energy production unit(s) even the pumps and the loading augers have been chosen by the manufacturer. What is purchasable from the market is not a single reactor but the whole module, an integrated solution that covers the whole chain of energy production. Usually all the equipment is stacked in a box-container, something that makes the transportation of the module much easier and reduces the required space. In addition, by means of electronics and automation control the gasification unit can self-regulate and run without any external assistance. Parameters like input of biomass or input of air are automatically adjusted to the quality of the fuel and the parameters of the gasifier. Moreover the indicative operation parameters are accessible not only on-site but also via mobile/ smartphone applications, thus enhancing the ability of the operator to constantly observe the units' performance. Both the above features can be helpful not only by improving the efficiency but also by simplifying the handling, the operating and the maintenance operations.

5.3. Patent based

The appealing feed-in tariffs gave an incentive to manufacturers to invest in patents in order to improve the efficiency of their systems. The result is a new breed of gasifiers that perform significantly higher but are optimized for a very specific range of input characteristics. The most representative patents that can be met in gasifiers located in the region of South Tyrol are mainly developed around three 'pillars': Drying of the input, increasing the retention time and maximizing the char-gas reactions. The most characteristic patents are described in the following paragraphs.

5.3.1. Joos gasifier

The type of gasifier is called Joos gasifier, from the name of the inventor of this design (i.e. Bernhard Joos). It is constituted from two separate vessels that are air-tight and connected with a loading auger. The input is first dried in the first vessel and then transported to the main reactor – gasifier. This technology represents a downdraft biomass gasifier that functions in a scale smaller than 50 kWe. The characteristics of this approach is that in the final composition of producer gas, hydrogen is relatively high (~20%) and high temperatures occur in the oxidation zone. These phenomena take place because the majority of the water content evaporates s in the drying vessel. Separate streams of steam and biomass enter the reactor. In the combustion zone much less heat is utilized as latent heat therefore higher temperatures occur. In addition, this assists the tar cracking and the faster start-up of the gasifier. Moreover the water is already evaporated when it enters the gasifier and part of the excess heat from the oxidation zone that otherwise would be lost due to heat transfer is utilized to break down steam to molecular hydrogen and oxygen [28].

5.3.2. Hot char bed

This patent describes also a downdraft gasifier. The operating conditions of this reactor allow the development of a hot char bed inside the gasifier that enforces the surface char – gas reactions. The gas reacts with the char in a zone which is rather distant from the combustion zone before it exits the gasifier. Therefore the temperature of the gas is lower than 650 °C and also the temperature in the char zone is also low. Thus the Boudouard reaction ($C + CO_2 \leftrightarrow 2\,CO$) shifts also to the side of char and carbon dioxide and thus produce high amounts of CO2 in the final producer gas. It is rather significant for this technology to utilize dried biomass in order to have optimal conditions for char production in the pyrolysis zone. The active surface of the char bed allows more reactions to propagate with less gasifying medium as the other technologies. As a result the molar fraction of nitrogen is below 50% [29].

5.3.3. Rising co-current

The characteristic of this technology is the design of the gasifier which is called rising co-current. It has the exact zone distribution like a downdraft gasifier. On the other hand the input biomass (pellets) is fed from the bottom by means of a loading auger and the producer gas exits the gasifier from the top. Additionally the way that the air is fed in the gasifier, creates a vortex above the combustion zone, a behavior similar to the term commonly known as fluidized bed. Although other reports [30, 31] have used the term updraft to define the type of this technology, such a term is not sufficient to describe the nature of this technology, although the gas exits from the top. The term that is more accurate and describes the full range of this technology is the term 'rising co-current'. The nature of a gasifier that is not gravity-driven increases the retention time of the input and thus the reactions propagate for longer. Therefore the final product can be much closer to thermodynamic equilibrium. Moreover the char that is created in the pyrolysis zone is acting like a fluidized bed in the reduction zone, so more active char surface participates in the solid-gas reactions. Finally the temperature of the reduction zone is much higher. This shifts the Boudouard reaction and the water gas reaction to produce more carbon monoxide and hydrogen. The composition of carbon monoxide due to these ideal conditions is above 30% [32].

5.3.4. Double-fired bed

Another interesting reactor is the double fire bed gasifier. The zone distribution and the working principle are following the pattern of downdraft gasifiers, with an additional combustion zone at the bottom of the reactor. Thus, the reduction/ gasification zone is 'squeezed' between two combustion zones. The concept of the bottom zone is to utilize the combustion of char at the grate as an additional heat source in order to provide more energy to the endothermic gasification reactions to propagate. Therefore, by means of a double fire bed reactor we have an almost complete conversion of the feedstock to producer gas. These advantages given by joining downdraft and updraft gasification are obtained at the price of a considerably higher producer gas outlet temperature [3].

5.3.5. Heat pipe reformer

A heat pipe reformer is, in principle, an allothermal – pressurized fluidized bed – steam gasifier. The gasifier is divided into the combustion and the reduction chamber. The heat that is produced by exothermic reactions in the combustion chamber is transferred via heat-pipes to the reduction chamber. The working fluid in the heat pipes, which can be Sodium or Potassium, evaporates in the combustion chamber and condenses in the reduction chamber. The fact that the technology is allothermal and produces BioSNG and not producer gas categorizes it not in the same cluster with the previous technologies. Nonetheless it is really interesting that working principles from nuclear engineering are applied to gasifiers. The principle of heat transfer via heat-pipes is similar to molten salt reactors [34].

5.4. Size

A critical factor that allows a small scale gasification technology to gain market share is the profitability of the investment. Usually it is the case that larger scale operations have competitive advantage and thus higher rate of return than smaller ones (i.e. economy of scale). Contrary to that we observe a hyper-concentration of technologies smaller than 200 kWe and even some that intentionally are smaller than 50 kWe. This happens due to the high feed-in tariffs which, along with new taxation schemes, have been deployed during the last years and have raised the incentives for small scale applications that combine production of heat and power [35,36]. The all-inclusive tariff is managed by the energy services regulator of Italy, the GSE. The support mechanism differs according to the technology used. Biomass and biogas have a feed-in tariff as high as 28 cents per kWh. These incentives last for 20 years and the normalized data for the whole period that are projected in the following figure (Fig. 5) show clearly that Italy has by far the most attractive incentives in comparison to any other EU country. Nonetheless we do observe that the incentives are also high for Germany and the same applies also for other countries of Central Europe.

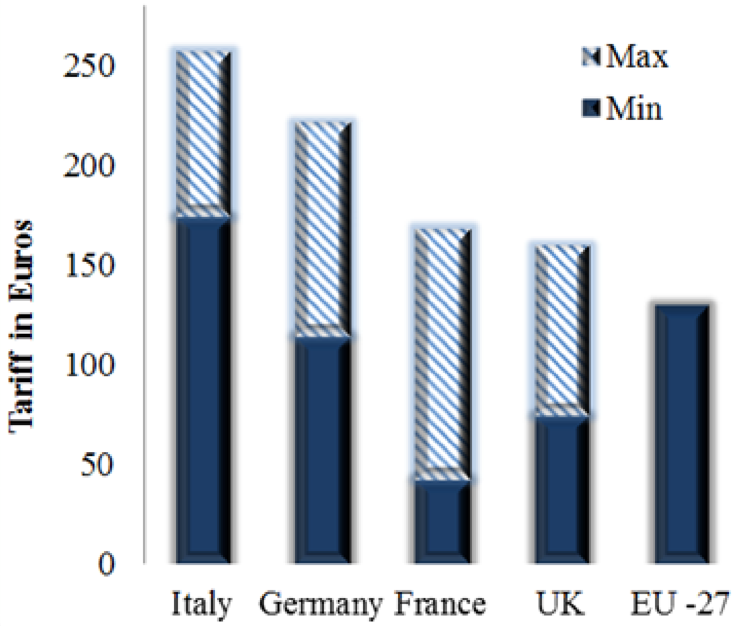

Fig5. Feed-in tariffs for 1 MW electricity from solid biomass in EU when normalized for a 20 year period [35, 36].

5.5. Developments in Internal Combustion Engines

In the case of using producer gas as a fuel in an Internal Combustion Engine, since the generally poor quality of the product gas and its lower heating value compared to that of traditional fuels, the highest possible compression rate should be achieved in order to have an acceptable thermal efficiency. In Fig. 6 is projected the thermal efficiency of an Otto engine utilizing producer gas in correlation to the compression ratio. In order to achieve higher efficiencies the engines have followed two different paths. For this example the producer gas has the following composition (in molar fractions): H_2: 17%, CO_2: 10%, CO: 22, N_2:52% and a specific heat ratio (γ) of 1.4.

The most common approach until recently has been to reciprocate diesel engines and operate them in dual fuel mode. The dual combustion cycle is officially referred as Sabathè but it is also known as Trinkler, Seilinger or mixed cycle. It could be described as a combination of Diesel and Otto cycles and it takes place in five steps. The fact that heat is added partially at constant volume and partially at constant pressure, allows the combustion to propagate during bigger time steps.

On the other hand, the alternative solution is the utilization of Otto engines in much higher compression ratios. When product gas is utilized solely, the risk of self-ignition is minimized. So far there has not been any extensive research of octane rating test conducted on producer gas fuel, although relatively high compression ratios have been applied and no knocking effect has been observed [11]. Practically this is due to the fact that the producer gas is composed mainly from knocking – suppressing compounds (N_2, CO_2) and the compression ratio that is required in order to reach a knocking point surpasses the point of maximum thermal efficiency in the engine. Therefore, the identification of the knocking point would have more theoretical than practical value. In order to achieve higher compression ratios inside the cylinders of the Otto engines, turbo compression/injection is applied. We could define this combined cycle not any more as Otto cycle but as a combined Brayton- Otto cycle were the first step is a compression stage, like in the gas turbines.

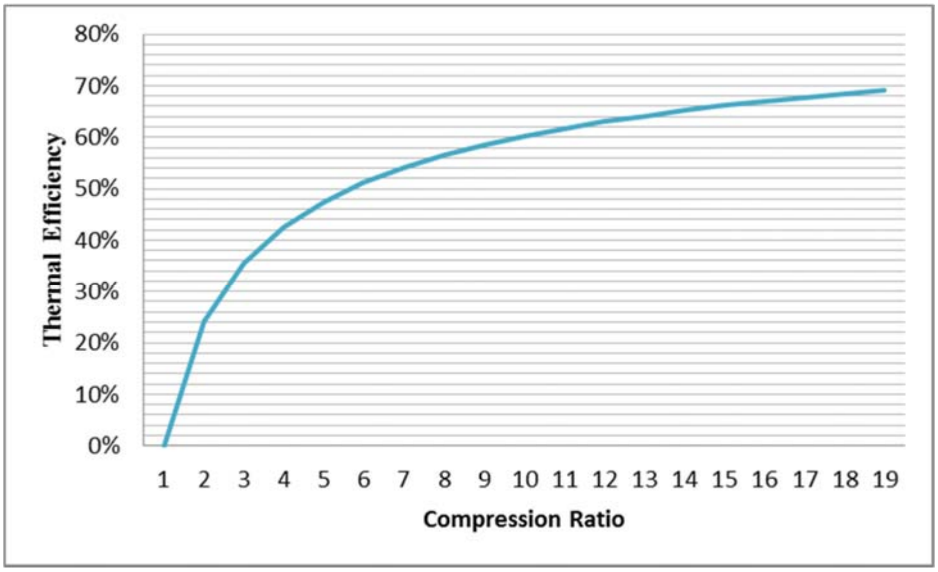

Fig6. Correlation of thermal efficiency and compression ratio of an Otto engine utilizing producer gas (γ=1.4).

6. Discussion and conclusions

On one hand it is evident that economic incentives do assist the development of novel technologies, but one has to argue that the incentives should be clear and not contradicting. A characteristic example is the case of anaerobic digestion plants that receive gate fees for the amount of waste that they process but also they receive feed-in tariffs for the electricity and the heat produced. The gate fees that are received from the amount of input are countering the efficiency of the plant. Therefore, this could be a matter of serious consideration if biomass gasification units utilize agricultural waste for fuel.

In conclusion, there has been a rapid growth of small scale biomass gasification units in the area of South Tyrol the last three years. The economic incentives have played a significant role in the establishment of this technological possibility in the market, but the crucial factor has been the development of efficient and reliable technologies that produce high-quality and reliable products. The main features that are met in most of the innovative gasification technologies are the modular form of the units, the automated control and operation, the application of innovative patents beyond the conventional concepts and finally the optimal size in order to benefit from the increased feed-in tariffs for the units that produce less than 200 kWe. The integration of patents and of novel designs have led to the production of a gas that has much higher heating value than the conventional technologies did. The technological advancements in the design of the reactors have been coupled with more efficient engines that utilize combined cycles in order to increase the thermal efficiency. Due to the higher gas quality and additional innovations, reciprocate gas engines can be utilized and electrical efficiencies at the range of 23% -25% can be reached.

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