# The "NEXT GENERATION" project: valorization alternatives for char from small scale gasification systems in South-Tyrol

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**Abstract**

Small scale gasification of woody biomass is a technology that has had a rapid development in the whole South Tyrol region in Italy. In few years, up to 40 plants have been authorized by the Autonomous Province of Bolzano, and most of them are already operating. These gasification plants are co-generative systems, because the producer gas (i.e., the combustible gas produced as the main product of this process) is used in an internal combustion engine (ICE) to generate both electrical and thermal power. However, this process produces a solid carbonaceous by-product, known as char. More than 2000 ton of char are produced every year in the whole region, and at present they are managed as waste. However, char presents chemical and physical characteristics that make it a potentially interesting and valuable product in the view of pushing the gasification process from a co-generative to a poly-generative one. Within this context, the NEXT GENERATION project (i.e. NEXT in the followings) was funded by the Autonomous Province of Bolzano, with the aim of getting insights on possible ways for char valorisation. The NEXT project started on June 2016 and lasts at the end of November 2017. In the present paper, preliminary results on eight different chars are presented and discussed.

**Keywords:** small scale gasification, char, valorization, CHP, biomass.

## 1. Introduction

South Tyrol is an alpine region in the North of Italy and almost 42% of the territory is covered by forest. Due to the mountain constraints, South Tyrol is composed by many small cities and towns. This configuration represents the perfect ecosystem for the application of small scale gasification and combined heat and power (CHP) plants, as a sustainable way to provide heat to the houses and to produce renewable energy. In addition, the policies for the wood maintenance have the effect that constantly, high amounts of woody residues are produced and that they have to be managed. In this context, biomass gasification and CHP production serving a local small district heating grid seems to be a really interesting and sustainable solution, capable to address both the need for woody residues management and for renewable energies production and exploitation. Another typical application of this biomass to energy solution is downstream of a joinery industry, in which the woody residues are treated to produce energy and heat to the industry itself. Alternatively, heat can be used in a local small district heating grid. During the last years both the incentives for renewable energy producers and the degree of the technology development of the gasifier systems have guaranteed the economic sustainability of this technological solution [1]. Since 2012 more than 40 gasification plants have been authorized by the local government (i.e., the Autonomous Province of Bolzano) and built in the South Tyrol region, consisting on 13 different technologies. All these plants produce about 7 MW of electric power and 9 MW of heat, although about 2000 ton per year of char is produced and that has to be disposed of at a price of about 150 k€/ton. Char from gasification has chemical and physical characteristics that make it interesting as a exploitable by-product , as it is or post processed, in more than one way, namely for energy production or as a raw material for innovative applications (e.g., for filtering medium, either as is or activated, or for catalyst production). In this case, char valorisation is raising a considerable interest [2], moving from a cogeneration perspective to the "polygeneration" one. In fact, a "polygeneration" system is currently defined as a technology capable to produce at least three different products. In this case, beside energy and heat, a gasification plant could be also able to produce a valuable and effectively exploitable solid stream, represented by the char [3]. From March 2013 to April 2015 the Free University of Bolzano, in collaboration with two South Tyrolean institutions, namely Eco-Research and TIS-Innovation Park (today IDM South Tyrol), along with the RE-CORD consortium, has studied and monitored four different gasification technologies installed in the region, those being a hot-char bed gasifier, a Joos gasifier, a Rising co-current gasifier and a downdraft gasifier. This work was done during the GAST Project (namely, "GAsification experiences in South Tyrol: energy and environmental assessment") funded by the Autonomous Province of Bolzano. The main aims of the GAST project were to perform a survey of the most relevant technologies installed at the moment and to give an overview of their performances. The monitoring activity consists of measuring on-site all the parameters needed for both mass and energy balance, these being mass flows (solid, liquid and gaseous) entering and exiting the plant, electrical and thermal energy production, electrical energy consumption and additional energy inputs. The monitoring activity also allows the chemical analyses of all solid, liquid and gaseous streams. The monitoring activity is well described in [2]. The gasifier configurations studied during the GAST project were the most representative in terms of diffusion in the region and market share. However, in the last years newer solutions have been developed, implying different efficiencies and by-products streams.

With the aim of updating the overview of the gasification technologies spread in the region and find valorisation pathways for the plants by-products, in 2016 the Autonomous Province of Bolzano have funded the NEXT GENERATION project. This project, named "Novel EXtension of biomass poly-GENERATION to small scale gasification systems in South-Tyrol" and lasting in December 2017, is managed by the Free University of Bolzano and is carried out in collaboration with Eco-Research (Bolzano, IT), IDM South Tyrol (Bolzano, IT) and RE-CORD (Florence, IT). The aims of the NEXT project are to update the list and the survey of the installed technologies, and to investigate the quantity and the quality of the by-products and their environmental impacts. Moreover, within the view of applying gasification in a poly-generative perspective, in particular the char by-product has been investigated as a potential valuable material, likely usable in several applications, according both to its chemical and physical characteristics, and to its availability. As a matter of fact, the gasification systems installed in South Tyrol have different sizes and, consequently, different char production rates. That represent an important aspect to be taken into consideration, being the quantity of char available one of the main parameters when considering the possibility of creating a new value chain for a new product, like char could be. Thus, in the NEXT project the map of the gasification plants authorized in South Tyrol will be updated. Then, all the different technologies will be monitored (at least, one monitoring campaign per technology design), and char will be collected and analysed in laboratory with the purpose of getting insights on convenient exploitable ways to make it becoming a valuable product. Finally, important remarks on the poly-generative potentials of the different technologies will be provided.

During the first months of the NEXT project, eight technologies have been monitored and preliminary analyses have been performed. In the present paper, the results obtained up to now regarding the NEXT project are presented.

## 2. Materials and methods

### *2.1 The NEXT project*

The NEXT project was funded in 2016 by the autonomous Province of Bolzano, with the main aim of investigating the quantity, quality and environmental impact of the by-products of small scale biomass-gasification-based CHP plant in South-Tyrol, and to assess possible routes for their valorisation according to the concept of poly-generation. In particular, both the management of the residues and their valorisation are the two main aspects that are considered. Thus, char/tar interactions before the extraction of the by-products, char toxicity and environmental impact assessment and tar analysis (specific on tar deposition across the producer gas path) are the aspects under investigation. Considering possible valorisation pathways, char is being investigated for energy production, after post-processing such as chemical conditioning and/or densification, and through direct exploitation (pulverized char co-combustion in industrial systems). Moreover, char is being investigated as a raw-material for innovative applications: for filtering medium, either as it is or activated, or for the production of catalysts. Within this framework and focusing on these purposes, the NEXT project has been divided into the following four work packages.

#### *2.1.1 WP1: Evaluation of gasification by-products in South Tyrol and assessment of the environmental impacts*

Within this work package, the identification of novel technologies and the assessment of the recent development in the local gasification sector will be performed, and the gasification plants will be categorized according to the by-products characteristics. Representative plants will be monitored, according to the methodology described in the paragraph 2.3. Moreover, the identification of primary output streams and their potential availability will be assessed.

#### *2.1.2 WP2: Integrated products and by-products sampling in selected representative plants*

The most representative gasification plants will be monitored. All the products and by-products, namely producer gas, tar and char, will be sampled and analysed, according to the methodologies described in the following paragraphs. In particular, chemical and physical characteristics, toxicity, heavy metals content and surface properties of char will be analysed. Finally, an assessment of the correlation between the operative conditions of the different investigated technologies and the characteristics of the by-products will be performed.

#### *2.1.3 WP3: Poly-generation: assessment of valorisation pathways for gasification by-products*

In this work packages, the potential uses of char will be investigated and possible both local and international industrial stakeholders will be identified. In particular, char for energy production, as a raw material for filtering medium and as a precursor for the production of activated carbons will be the main topics of this investigation.

#### *2.1.4 WP4: Thermodynamic analysis of the processes and optimization methds*

The results obtained in WP2 will be finally analysed and used for the development of decision tools for policy implementation through the application of Multicriteria Analysis (MCA). Thus, according to specific parameters and criteria, viable poly-generative optimal scenarios will be suggested, considering the whole spectrum of the process chain.

### *2.2 Survey on gasification technologies*

In collaboration with IDM South Tyrol (Bolzano, IT), the list and the map of authorized small scale gasification plants in South Tyrol was updated, through databases of both the autonomous Province of Bolzano and the GSE ("Gestore dei Servizi Energetici", namely the Italian energy services manager). Data concerning plant localization, gasification technology, type of gasifier, biomass used as feedstock and its characteristics, feeding configuration, gasifier agent, gas cleaning and conditioning system, and type of engine for electricity production were collected. The technologies were subsequently categorized by manufacturing company, authorization year and char characteristics (i.e., dry/wet powder, dry/wet residue).

### *2.3 Plant monitoring*

To calculate both mass and energy balances, several non-invasive measurements and sampling have been performed. The considered mass fluxes have been: feedstock entering the reactor, air flow (or gasifying agent flux), tar, producer gas and residual char. Both the feedstock and the char masses have been measured with a balance and the data have been compared, when available, to those measured by the control system integrated in the plant. Dry mass of both feedstock and char have been calculated, after having determined their moisture, according to UNI EN 14774 in laboratory. The air flow has been calculated measuring its velocity through a Pitot tube of known dimensions, connected to the air input. The mass of tar has been determined by applying a tar sampling system, equipped with six impinger bottles, in accordance to UNI CEN/TS 15439. The system has been used for tar collection, while tar analyses have been performed in the laboratory. In particular, the GC-MS technique has been applied. Subsequently, tar molecules have been separated through a DB5 MS column (J&W Scientific) and then analysed by a mass spectrometer (GC-HRMS, MAT95XL, Thermo Scientific). Finally, the mass of the producer gas has been derived from the input air flow rate, assuming negligible the nitrogen content in the feedstock and measuring the gas composition through a portable gas chromatograph (3000 microGC, SRA Instruments) equipped with two columns, a Molsieve column capable to detect $H_2$, $O_2$, $N_2$, $CH_4$ and CO and a Plut-U column capable to detect $CO_2$, $C_2H_4$, $C_2H_6$ and $C_3H_6/C_3H_8$.

The energy fluxes related to both the input biomass and the exiting char have been determined after having evaluated their lower heating value (i.e., LHV) through a bomb calorimeter (IKA, C200), knowing the respective masses. The energy flux of the producer gas has been calculated on dry basis, knowing its composition through the portable gas chromatograph. Both electrical and thermal power produced by the plant have been extrapolated from the data logging system. Similarly, data on electric power self consumption and possible auxiliary energy inputs have been recorded.

A detailed description of the methodologies applied for the measurements and determination of both mass and energy balances can be found in [2].

### *2.4 Analyses on char*

Preliminary analyses on char have been performed to get insights on its exploitability both as a renewable solid fuel or as new adsorbent material. Thus, moisture and ash content have been determined according to UNI EN ISO 18143-2:2015 [4] and UNI EN 14775:2010 [5], respectively. Elemental analysis has been performed according to UNI EN ISO 16948:2015 [6] using and elemental analyser (Elementar, Vario MACRO cube), while the heating value has been determined according to UNI EN 14918:2010 [7] with an isoperibol bomb calorimeter (IKA C200). Char surface area has been determined through a physisorption analyser (Micromeritics, 3Flex 3500) applying the Brunauer–Emmett–Teller method [8]

## 3. Results and discussion

Figure 1 reports the updated map of all the small scale gasification plants authorized and installed in the South Tyrol region. The plants have been identified with different colours, meaning each colour a different authorization year.

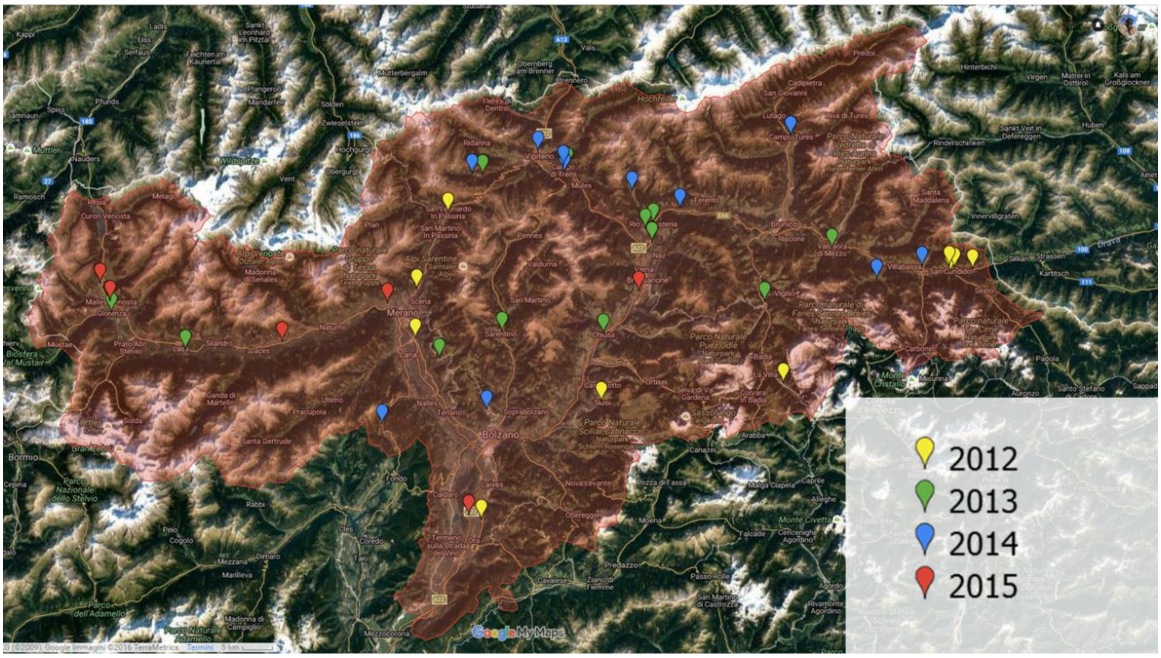


Figure 1. Updated map of the gasification technologies installed in South Tyrol. Different colours identify different authorization years.

The plants are located quite homogeneously in the whole South Tyrol territory. The majority of them are very small plants (45 – 180 $kW_{el}$ and 105 – 270 $kW_{th}$), and bigger scale plants (> 250 $kW_{el}$) started to be authorized since 2014. Some of the plants exploit the heat produced to serve a small district heating system. In most of the cases, the heat is also exploited for drying purposes, for example for drying the feedstock used in the plant or for the production of dry wood chips that are then sold. In some less virtuous cases, the heat is only partially exploited and the drier is mainly used to dissipate the heat, being the governmental incentive for renewable energy production linked to the electric power produced and not on the thermal one. The valorisation of char can be a possibility to improve the poly-generation capabilities of such kind of pants.

Table 1 reports the data obtained from char analyses. The different technologies have been identified with capital letters and not with the name of the manufacturing company.

Table 1. Ash content, ultimate analyses and calorific values of chars from small scale gasification plants; dry basis.

| **Technology** | **Ash** | **C** | **H** | **N** | **O** | **LHV** |
|---|---|---|---|---|---|---|
| | (%$wt_{dry}$) | (%$wt_{dry}$) | (%$wt_{dry}$) | (%$wt_{dry}$) | (%$wt_{dry}$) | (MJ/$kg_{dry}$) |
| A | 27.84 | 68.63 | 0.33 | 0.83 | 2.37 | 23.04 |
| B | 5.47 | 80.23 | 0.49 | 0.23 | 13.57 | 26.53 |
| C | 49.52 | 48.03 | 0.89 | 0.25 | 1.31 | 14.33 |
| D | 19.40 | 66.96 | 0.18 | 0.16 | 13.30 | 18.07 |
| E | 13.34 | 78.97 | 0.68 | 0.20 | 6.80 | 25.38 |
| F | 4.63 | 89.33 | 0.54 | 0.21 | 5.28 | 30.73 |
| G | 25.15 | 69.05 | 0.15 | 0.12 | 5.53 | 22.84 |
| H | 16.03 | 69.49 | 0.20 | 0.46 | 13.82 | 23.99 |

In some of the technologies (namely, D and F), the issues related to char handling – char is usually produced in the form of a very fine powder that can easily spread in the air – and to the risks of fire are overcome by impregnating the char with water. Focusing on the exploitability of char as a renewable solid combustible, this would imply the need of a drying pre-treatment before using char for energy production. In this case, an economic balance becomes essential and the yearly availability of this char represents clearly a threshold limit. However, in the case of technology D, the low heating value of char seems to corroborate the hypothesis that this char could be hardly used for energy production effectively. Similarly, char from technology G has quite high ash content and not so high calorific value. The other technologies presents interesting characteristics that allow to take into consideration their exploitability for energy production. Considering the values reported in Table 1, the best promising char seems to belong to technology F, having a very high calorific value and very low moisture and low ash content. Nonetheless, in this case, the plant should be managed differently, reducing the impregnation of char with water and for example directly feeding the char to an energy densification unit (e.g., pelletizer).  Following a similar evaluation, chars from technologies B, E, H and G follow a decreasing order in terms of chemical and thermal characteristics, focusing on energy production purposes. However, besides the limitations, another important aspect that should be taken into consideration is that they are produced in powder. This fact implies that to be effectively used, a post treatment such as pelletizing should be required for their utilization in traditional combustion units. An advantage is that the powder status open them the possibility to be easily blended with woody materials for the production of new generation pellets with modified calorific value and ash content. In this way, slightly modifications on the pellet performances could be reached.

In order to investigate the possibility to exploit char as an adsorbent material to be used as a filtering medium or as a precursor for activated carbons production, its surface area has been measured through BET analysis. Figure 2 shows the results of BET analyses performed on the chars from the different technologies, while showing the ranges of values for both filtering materials and activated carbons. As a matter of fact, the range of surface area values for adsorbent materials is from 200 to 2000 $m^2/g$, while an activated carbon should have a surface area of more than 500 $m^2/g$ [9].

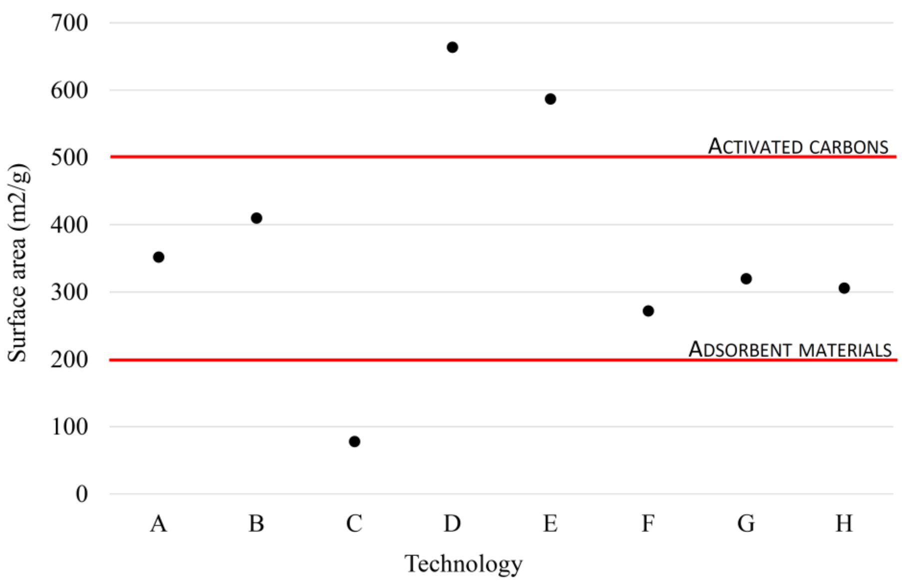


Figure 2. Surface areas of chars and threshold limits for both adsorbent materials and activated carbons.

As it is possible to see in Figure 1, all chars have a quite interesting surface area that makes them possibly exploitable at least as filtering medium (i.e., adsorbent materials), a part from the char belonging to technology C. Technologies D and E produce chars that have surface areas higher than the lower limit of 500 $m^2/g$ for activated carbons (hereinafter, ACs). This represent an interesting result, being activated carbons a very interesting and valuable material. As a matter of fact, in 2018 it is expected an ACs demand of up to 2.1 million of tons. Hence, the market is big and the possibility to have cheap precursors, like char could be, represents a very interesting business opportunity. However, specific tests on ACs from char by-products are needed to establish the pathways for their commercial and industrial application.

## 4. Conclusion

Within the framework of the NEXT project, started on June 2016, the list and classification of the authorized and existing small scale gasification plants in South Tyrol has been updated. Many data have been collected, namely plant localization, gasification technology, type of gasifier, biomass used as feedstock and its characteristics, feeding configuration, gasifier agent, gas cleaning and conditioning system, and type of engine for electricity production. Furthermore, the chars obtained as by-product in different technologies have been analysed in the laboratories of the Free University of Bolzano, with the main purpose of getting insights on the exploitability of char as a renewable solid combustible or as a porous material, to be used as a filtering medium or as a precursor of activated carbons. The preliminary results reported in this paper show that five of eight chars analysed could be likely used for energy production, because their quite high LHV (22.84 – 30.73 MJ/kg) and their low ash content (4.63 – 16.03 %). These chars are produced in powder. This can represent an advantage when considering the possibility to pelletize them alone or blended with wood. In this case, char could be used as a corrective material, capable to improve the characteristics of pellets. On the other hand, BET analyses show that all chars have interesting characteristics in terms of a possible application as filtering materials and, in particular for two of them, as precursors for the production of activated carbons. However, because the gasification plants have small size, the yearly availability of the chars must be considered in order to evaluate the economic feasibility of creating a sustainable value chain of chars.

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