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Electricity production by biomass steam gasification using a high efficiency technology and low environmental impact

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HIGHLIGHTS

- ▶ Integration of biomass gasification and fuel cell with a high conversion efficiency.
- ▶ Experimental results for fluidized bed gasification plant of 500 kWth.
- ▶ Environmental benefits compared to traditional power generation.
- ▶ The MCFC process can be exploited to produce electricity as well as for separating CO_2.
- ▶ Few possible solutions for the capture of diluted gases possibly less prohibitive cost.

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ABSTRACT

The integration of biomass gasification and fuel cell represents in theory an energy effective solution for decentralised CHP production. At the ENEA Research Centre of Trisaia the direct coupling of an existing biomass gasification pilot plant to a molten carbonate fuel cell (MCFC) with a capacity of 125 kWe is in progress.

Being pressurised at 3.5 bar, MCFC shall be combined to a gas turbine in order to establish an efficient process scheme for its industrial scale application. Assuming an optimised gas composition, free of methane and other light hydrocarbons, an overall conversion efficiency minor to 40% is estimated via an appositely developed model based on thermodynamic models. Even this value is one-third higher with respect to conventional gasification for decentralised CHP production, the commercial perspective of the proposed technology still proves to be modest, unless remarkable improvements in stack conversion efficiency, durability and cost are achieved, as well as an impressive plant simplification.

The main goal of the paper is the integration of a biomass steam gasification plant with a molten carbonate fuel cell with the advantage of a power production plant with a low CO_2 emission compared with the traditional power generator fuelled by fossil.

1. Introduction

Combination of biomass gasification and fuel cell technology is generally considered as an effective approach for decentralised combined heat and power (CHP) production. Theoretical calculations show that a significant increase in the overall conversion efficiency from biomass into electricity is achievable with respect to conventional gasification systems for small scale applications (up to 1 MWe of electrical capacity).

Moreover, remarkable advantages for the environment must be added, since greenhouse gases emissions per produced kW h are proportionally reduced and, under certain conditions, downstream separation of the carbon dioxide may be simplified.

Despite its great potential, no integrated biomass gasification and fuel cell system, having a significant capacity, is currently in operation worldwide. Previous studies in this field are mainly aimed at analysing theoretical aspects [1]. Furthermore, several experimental works that have been carried out in this field are related to laboratory-scale facilities [2].

The analysis of the state of the art confirms therefore that the combination of two technologies, such like biomass gasification and fuel cell, which are both still under development, can be presently considered as an innovative concept.

At the ENEA Research Centre of Trisaia the direct coupling of an existing biomass gasification pilot plant to a molten carbonate fuel cell (MCFC) with a capacity of 125 kWe is being carried out. After

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the accomplishment of this project, the first integrated biomass gasification and fuel cell pilot-scale plant will be in operation in Europe. Currently, the MCFC system is almost ready to be run in a stand-alone mode.

Under this condition, the anodic feed stream will be obtained via a mixture of technical gases simulating a typical producer gas from biomass gasification. In the next few months, the implementations, which are still necessary in order to directly use a real fuel gas from biomass gasification, will be started.

The research work carried out by ENEA about the integration of biomass gasification and MCFC is mainly focused on the following topics:

- the investigation of the producer gas quality and the related gas cleaning requirements, in order to use this gas as the anodic feed for the fuel cell assuring an acceptable stack durability;
- the evaluation of the MCFC performance when fuelled by the producer gas of steam gasification instead of pure hydrogen and the identification of the necessary gas upgrading;
- the identification of the auxiliary devices required for the combination of a biomass gasifier to a MCFC, planning the possible optimisation and simplification of the full integrated system;
- the analysis of the economic viability and the related commercial perspectives of the proposed technology, considering the realistic optimisations and developments achievable in the short term.

The full accomplishment of these objectives will be possible after that the experimental tests on the integrated gasification and MCFC system will be performed.

Currently, by applying an apposite developed model of the MCFC to the planned process scheme, a consistent estimation of the overall efficiency in the conversion from biomass to electricity is achievable. Furthermore, basing upon the acquired practice relevant to the installation of the pilot plant, a preliminary cost assessment can be accomplished.

It is to be noticed that solid oxide fuel cells (SOFCs) is considered by the majority of experts as the most suitable technology to be combined to biomass gasification. This evaluation is based upon its higher fuel flexibility, which allows the conversion of carbon monoxide and methane in addition to hydrogen, the enhanced tolerance to both contaminants and corrosion, due to the use of a solid electrolyte, and the potential superior efficiency correlated to the higher operating temperature. In effect, coupling of biomass gasification and SOFC is being deeply investigated on a very small scale facility [3]. On the other hand, the more elevated operating temperature, ranging from 750 to 1000 °C is the main drawback with respect to MCFC, which is still more reliable and from the techno-economic assessment of the integrated gasification and MCFC system may offer useful indications in order to evaluate the alternative combination with a SOFC also economical. Furthermore, MCFC has reached a high degree of commercial maturity, so far, and is available for large scale applications, also. In conclusion, SOFC shows a greater potential in view of the possible developments achievable in the near future, but currently MCFC still appears as a more fitting technology for a pilot plant investigation. However, the results obtained from the techno-economic assessment of the integrated gasification and MCFC system may offer useful indications in order to evaluate the alternative combination with a SOFC also.

2. Residual biomass

The analysis of the residual biomass is an important basic operation for the energy planning; in fact it is important to understand which are the potential energy of an area and if they can significantly affect the energy balance of an area with economically, sustainable and renewable way during the time. The ENEA proposed methodology is based on the use of map data and inventory to produce a geographically detailed on provincial scale that we can use for estimate the size of the power plant with a WEB Geographic Information System [4].

In particular, the residual forest biomass, under these limitation:

– Forests up 1500 m.
– Slope roads major to 40%.
– Accessibility road.
– Protected natural areas.

Considering only the routine maintenance of forests is equal to 2180 ktonn, that corrisponde to 1MTOE (ton of oil equivalent) as you can see at the picture below:

Similar to the Fig. 1.1, you can see the agroindustrial residual biomass, pruning, straws, pomace & marc, with the distribution of different type of agro-industrial biomass:

Fig. 1.2 shows that there is a great potential in term of pruning in the South of Italy, in particular Apulia, Calabria an Sicilia are the regions that have a big concentration of about 251–477 ktonn/year on provincial scale.

At the same time, Fig. 1.3 shows, the distribution of straws on provincial scale:

From Fig. 1.3 is possible note that the great potential is located in north of Italy but the biggest problem in their use for energy

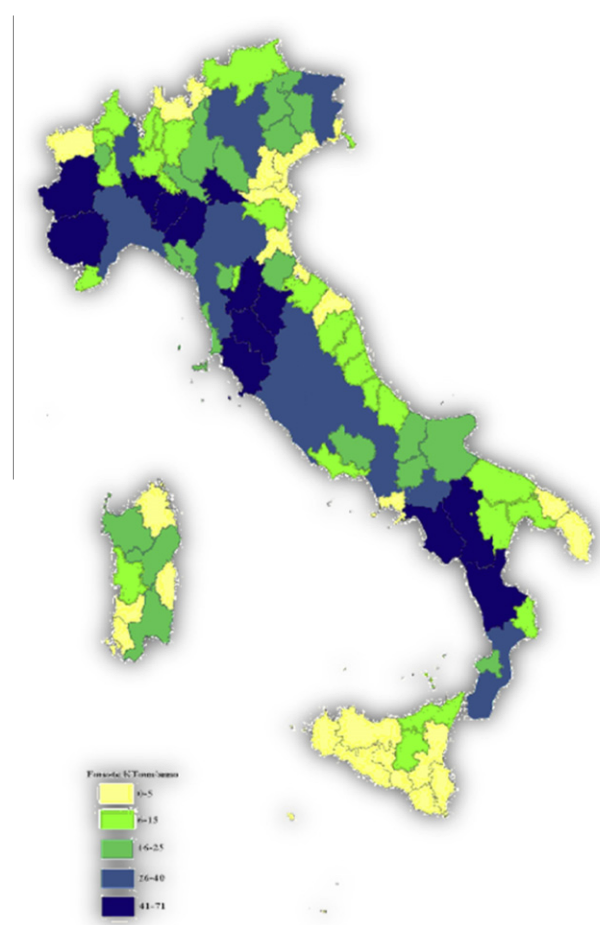

Fig. 1.1. Forest biomass.