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FIRST RESULTS OF THE H2020-LC-SC3-RES-11 BLAZE PROJECT: BIOMASS LOW COST ADVANCED ZERO EMISSION SMALL-TO-MEDIUM SCALE INTEGRATED GASIFIER FUEL CELL COMBINED HEAT AND POWER PLAN

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***Abstract* - BLAZE aims at developing Low cost, Advanced and Zero Emission first-of-a-kind small-to-medium Biomass CHP. This aim is reached by developing bubbling fluidised bed technology integrating a high temperature gas cleaning & conditioning system and integration of Solid Oxide Fuel Cells. The technology is characterised by the widest solid fuel spectrum applicable, high efficiencies (50% electrical versus the actual 20%), low investment (< 4 k€/kWe) and operational (≈ 0.05 €/kWh) costs, as well as almost zero gaseous and PM emissions, projecting electricity production costs below 0.10 €/kWh. The paper shows the first project activities: the preliminary economic analysis, the choice of 10 samples and 5 mixtures of representative biomass wastes to be tested in the gasification labs and the bio-syngas representative tar and contaminants to be tested in the SOFC lab scale facilities.**

***Keywords* – Biomass, Gasification, SOFC, CHP.**

I. INTRODUCTION

At present, installed electricity generation capacity by Combined heat and power (CHP) in the EU-28 is about 120 GWe (ST 62 GWe, CC 30 GWe, ICE 15 GWe, GT 12 GWe), which generates approximately 11% of the EU electricity demand (362 TWh, i.e. on average ≈3000 annual equivalent hours) [1]. The CHP heating capacity is about 300 GWth with a heat production of 775 TWh, i.e. an average of ≈2.5 thermal/electrical power ratio and 2500 annual equivalent hours. Renewables, mainly biomass and in particular low-cost biomass or biomass waste, are becoming increasingly important having attained 20% of the market. The bioenergy contribution for heating and cooling has currently the largest share (88%) of all RES used for heat and cooling with 76 Mtoe, not far from the 2020 Member States plan of 90 Mtoe [2]. CHP systems have significant penetration in the EU industry, producing approximately 16% of final industrial heat demand [3]. It is worth noting that cogeneration (CHP) plants account for about 60% of EU-28's bioenergy production from solid biomass [4]. The total EU28 energy demand for Heating and Cooling (H/C) equals 51% of the total final energy demand; the majority of the demand for H/C is due to space heating (52%), followed by process heating (30%) and water heating (10%) with ambitious policy objectives which include, for instance, that all new buildings must be Nearly Zero Energy Buildings (NZEB) from 31st December 2020 The European bioenergy potential derived from residues is 314 Mtoe; the currently consumed share is less than half of this value [5]. Major limitations of the bioenergy potential relate to the facts that S-o-A small-medium solid biomass power plants currently have annual operating time 4000 h, electrical efficiency 25%, high local and environmental impacts and a capital cost 5.000 €/kWe. They cannot compete with the liquid or gaseous fossil fuels CHP where, even if the fuel cost is higher, the CAPEX is lower, the annual operating time higher and local emissions lower [6].

II. BLAZE

The project aims at the development of a compact bubbling fluidised-bed gasifier integrating primary sorbents and ceramic candle filters with Ni catalyst (IBFBG), a high temperature fixed bed sorbents reactor and an integrated solid oxide fuel cell

(SOFC) including first-of-a-kind heat-driven gas recirculation. The technology is developed for a CHP capacity range from 25-100 kWe (small scale) to 0.1-5 MWe (medium scale) and is characterised by the widest fuel spectrum applicable (forest, agricultural and industrial waste also with high moisture contents, organic fractions of municipal waste, digestate), high net electric (50%) and overall (90%) efficiencies as well as almost zero gaseous and PM emissions. Such targets can be achieved by the technology development undertaken in this project that allows to convert with high efficiency low cost fuel, by the currently launched SOFC mass-production (cost projection ≈ 2,000 €/kWe) and by the actual market penetration (and so reduced cost and increased reliability) of small-to-medium scale fluidised bed gasifiers integrating hot gas conditioning and fully automated operation

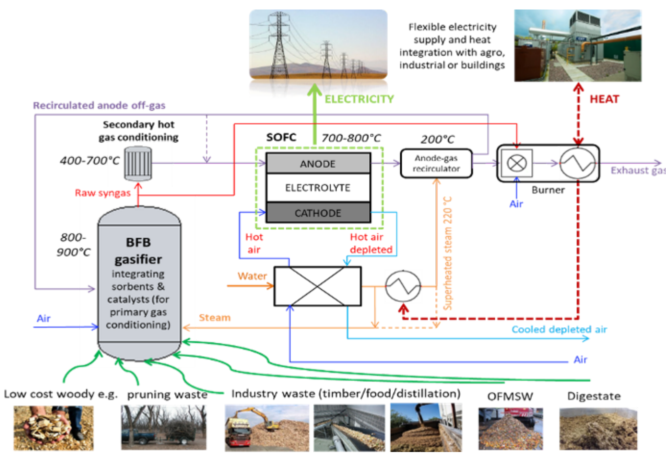

Fig. 1. BLAZE SCHEME

III. First cost estimation

Based on literature data it is possible to roughly compare CAPEX, OPEX and BLAZE cost of electricity to the conventional biomass CHP systems. Owing to the normally thermal base load sizing of the CHP, the cost of a gas boiler with burner, flue tubes and accessories is added to the CHP plants cost. To this item, heating civil works, piping, pump, expansion vessel and regulation system have been added. The conventional biomass systems analysed are biomass combustor coupled to organic fluid cycle (ORC) and biomass fixed bed gasifier coupled to internal combustion engine (ICE), because for sizes below 1 MWe, these systems are the mainly applied to the market. The systems are evaluated for the two cogeneration sectors, assuming, for buildings, to give heat at the price of 0.06 €/kWht (considering average 3000 annual electrical equivalent hours and 2500 thermal) and, for industrial, at the price of 0.04 €/kWht (considering 7500 annual electrical and thermal equivalent hours, as usual in industrial plants). A price of 60 €/ton (similar to the price of high humidity wood chips) has been used for BLAZE, meanwhile a price of 100 €/ton (similar to the price of low humidity wood chips) has been used for ORC and ICE systems. The more difficult small-scale CHP size is analysed, thus BLAZE 100 (100 kWth biomass IBFBG integrated with 50 kWe SOFC) is compared to a 100 kWth biomass combustor coupled to a 15 kWe ORC and a 100 kWth biomass fixed bed gasifier coupled to a 25 kWe ICE. The table below show the CAPEX for the considered biomass CHP systems. Because of this small size (i.e. a production from 45 to 150 MWhe) the CAPEXs are generally higher but the electricity price is also higher. In BLAZE the costs per kWe produced is less than in the conventional solid biomass cases because, even if the gasification and SOFC CAPEX are higher, the electrical efficiency is double.

TABLE I
BLAZE, ICE, ORC CAPEX

CAPEX	BLAZE	ICE	ORC
Input kWth	100	100	100
Biomass storage and feeding (spider, hopper, screw) cost €	6,000	6,000	6,000
Gasification (BLAZE or ICE/GT) or Combustion (ORC) cost €	90,000	90,000	70,000
€/kWth	**960**	**960**	**760**
Power generator size kWe	50	25	15
Power generator size kWth	40	50	65
SOFC-ICE/mGT–ORC cost €	100,000	37,500	30,000
€/kWe	**2,000**	**1,500**	**2,000**
System cost €	196,000	127,500	100,000
€/kWe (considering all CAPEX to only electric power)	**3,920**	**5,100**	**6,667**
100 kWth gas boiler with tubes and accessories €	50,000	50,000	50,000
Electric system cost €	170,000	110,000	82,000
€/kWe	**3,400**	**4,400**	**5,467**
Thermal system cost €	76,000	67,500	68,000
€/kWth	**1,900**	**1,350**	**1,046**

The table below shows the global (electric and thermal) OPEXs.

TABLE II
BLAZE, ICE, ORC OPEX

	€/year		
OPEX cost item	BLAZE	ICE	ORC
Personnel (automated operation - 50 h/yr)	1,000	1,000	1,000
Gasifier/Combustor, Gas Cleaning system, Boiler	1,300	1,300	1,000
Power generation (SOFC or ICE)	1,300	1,300	600
Biomass Cost	4,000	7,000	7,000
Ash disposal cost	500	500	500
Other Costs (e.g. insurance, aux. consumptions)	1,000	1,000	1,000
Total OPEX	9,100	12,100	11,100

As expected the higher OPEX costs for traditional CHP with respect to BLAZE are mainly due to the higher biomass cost..

The evaluation of the costs of the electricity produced is carried out according to the methodology of the "Levelized Cost Of Electricity" (LCOE) with the following equation:

$$LCOE = \frac{C_i + \sum_{i=1}^{20} CO_i(1+r)^{-i} + \sum_{i=1}^{20} CC_i(1+r)^{-i}}{\sum_{i=1}^{20} EE_i(1+r)^{-i}}$$

where:

r interest rate; Ci the investment cost incurred (CAPEX); COi the cost of operating and maintenance incurred during the i-th year; EEi electricity (or thermal energy) produced in the i-th year; CCi fuel cost incurred in the i-th year

The OPEX are the sum of CO and CC. The interest rates is assumed equal to 3.00% owing to the actual 0% of ECB, European Central Bank and a 3% of spread.

TABLE III

BIOMASS CHP COST PER kWh_E

	BLAZE		ICE		ORC	
Equivalent annual hours	3000	2500	3000	2500	3000	2500
OPEX €/kWh	0.06	0.03	0.16	0.04	0.20	0.04
CAPEX €/kWh	0.08	0.03	0.11	0.02	0.13	0.02
Tot CAPEX+OPEX €/kWh	0.14	0.06	0.27	0.06	0.33	0.06
Equivalent annual hours	7500	7500	7500	7500	7500	7500
OPEX €/kWh	0.04	0.02	0.12	0.03	0.14	0.03
CAPEX €/kWh	0.06	0.02	0.07	0.01	0.06	0.01
Tot CAPEX+OPEX €/kWh	0.10	0.04	0.19	0.04	0.20	0.04

The table shows that BLAZE is the only system that, in case of lower annual equivalent hours, has a competitive electricity generation cost, and that BLAZE, in case of high annual equivalent hours, can have electricity generation cost of 0.05 €/kWh.

IV. GASIFICATION AND SOFC LAB SCALE SETUP

The project started the first of March 2019. In the first 6 months the consortium:

- undertake a preliminary cost analysis, showed in the section before,
- chose 10 samples and 5 mixtures of representative biomass wastes to be tested in the gasification labs,
- chose bio-syngas representative tar and contaminants to be tested in the SOFC lab scale facilities,
- set up the experimental gasification, conditioning and SOFC labs that will undertake a comprehensive lab activities in the next 12 months

Regarding the bio-syngas representative tar and contaminants to be tested in the SOFC lab scale facilities the project done an open access literature overview (www.blazeproject.eu/resources) analyzing 83 papers (mostly experimental). It has been decided to focus on 1 representative syngas composition (owing to the decision to focus only on the steam gasification tested at pilot scale, on wet basis: 45% H_2, 24% CO, 11% CO_2, 2% CH_4, 18% H_2O) and 2 organic (toluene and naphthalene) and 3 inorganic (H_2S, KCl; HCl) representative contaminants levels. In particular, Naphthalene has been selected to represent so-called slow tars, i.e. tars with slow conversion kinetics. In order to make meaningful tests, the investigated contaminant levels will be aligned with those reported in literature regarding experimental work on SOFCs, i.e. 25 mg/Nm3 (5 ppm) and 75 mg/Nm3 (15 ppm) naphthalene. Toluene has been selected to represent so-called fast tars, i.e. tars with relatively fast conversion kinetics. Tolerable toluene levels are less clear than for naphthalene, and thus will be aligned with those expected from BFB steam gasifiers with catalytic filters, i.e. 250 mg/Nm3 (to be expected from clean biomass such as almond shells) and 750 mg/Nm3 (feedstock emitting high toluene concentrations). H2S has been selected to represent sulfur compounds. In order to make meaningful tests, the investigated contaminant levels will be aligned with those reported in literature regarding experimental work on SOFCs, i.e. 1 ppm and 3 ppm H_2S. KCl has been selected to represent both halogens and alkalis. Although it is unclear whether KCl will actually reach the SOFC in this form, other compounds like HCl and alkali hydroxides might reach the SOFC, and therefore investigating the impact of halogens and alkalis is relevant. Thus, KCl is considered a suitable representative to simultaneously assess the impact of halogens and alkali metals. Investigated contaminant levels are 50 ppm and 200 ppm KCl. The following photos show gasification and SOFCs lab scale facilities fitted for the experimental activities.

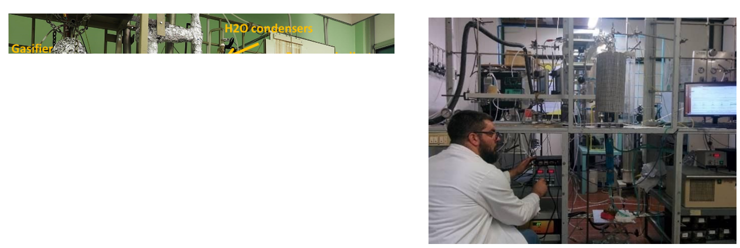

Fig. 2. UNITE gasification and UNIVAQ catalyst and sorbent test rig

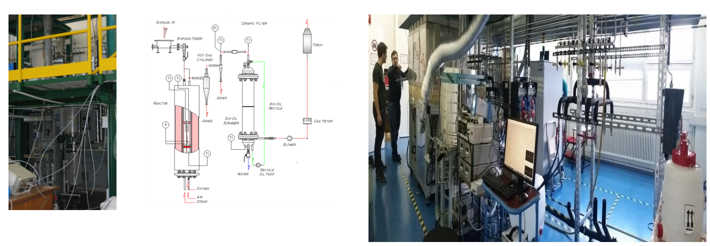

Fig. 3. ENEA gasification and EPFL/SP stack SOFC test rig

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