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COGENERATION WITH BIOMASS IN CHPAB CONCEPT

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Abstract: *The paper analyzes the use of the* ***CHPAB*** *concept to produce from biomass electric energy, thermal energy and biogas by cogeneration with a negative carbon footprint. Cogeneration with biomass in CHPAB concept is easy to incorporate into a Smart Grid energy system to maximize energetic efficiency and security. To maximize the energy efficiency of cogeneration, the gasifier and the thermal engine operate in an optimal regime. From 1870 kg. biomass produces 1 MWhe of electricity, 2.42 MWh of thermal energy and 282 kg. biochar. The energy efficiency for electricity production is 11.5%, for heating is 27.8% and for cogeneration is 39.3%, with a negative carbon foot print –0.282 kg.C/kWhe.*

Keywords*: Cogeneration, biomass, CHPAB concept, carbon foot print, smart grid*

1. Introduction

For sustainable development, it is necessary to make the most of the renewable energy resources: solar, wind and biomass to meet future energy demands for a growing population with growing needs. One problem with systems that harness the solar and wind resource is that they cannot deliver energy immediately and as needed, that is, they are not dispatcable. Biomass is still a cheap renewable source from which energy is produced by direct burning, pyrolysis or gasification when and as needed.
Cogeneration is the most energy-efficient and economical option to produce electric and thermal energy from solid, liquid or gaseous fuels, but also has a positive or near-zero carbon footprint.
For farms and small communities, the intelligent network type **Smart Grid** concept represents the trend of decentralizing power supply from various sources of energy through the organization of energy network. The Smart Grid system identifies the status and charging of all network elements, it can provide basic loading and can prevent real-time overhead from managing network-connected power sources
The production of thermal and electric energy with wood or charcoal gasifiers has been widely used in World War II due to oil fuel shortages. At present, the requirements of sustainable development have brought back the current thermo-chemical gasification processes of biomass to a higher level of knowledge and technology to produce electricity with a negative carbon footprint in a low-power power plants, accessible to agricultural farms and for more isolated areas. [1, 2, 3, 4, 7, 9]
As an alternative to current methods of thermal energy production from biomass it is the **CHAB** (**C**ombined **H**eat **A**nd **B**iochar production) concept which includes also the biochar (BC) generation. BC is a sterile organic material obtained from biomass pyrolysis in an oxygen-free environment or with a sub stoichiometric concentration, with alkaline pH. It has a carbon content of 80-95% and it is characterized by high porosity and adsorption capacity. [3, 4, 6, 7, 8, 14]
The biomass gasification in **CHAB** concept uses the biochar byproduct gasification during thermal power generation, as the carbon store that can be collected and sequestered. Sequestration is much easier than flue stack CO2 gas capture and storage, as char is a solid and easy to handle. Biochar is equally important as a soil amendment, with surprisingly powerful benefits to plant productivity, soil biological activity, water retention, pest management and mineral uptake in plants. And as it is known to be stable in soil for 100s to 1000s of year timeframes, it is a low tech and cheap method for carbon storage, already with a scaled infrastructure via global agriculture. [1, 2, 3, 6, 7, 16, 17]
Biomass-based cogeneration-based on the **CHPAB** (Combined Heat Power and Biochar production) concept that synergistically combine the production of electricity, heat and biochar,

providing the most energy-efficient, economical and environmentally-friendly use of local residual biomass. Cogeneration plants with CHPAB can easily integrate into a Smart Grid energy network by making a valuable contribution to local energy resources by increasing safety and energy independence with low operating costs. [15, 19, 20]

Current combustion plants with internal combustion engines are simpler, smaller in size, displaceable and affordable for small biomass producers in agriculture or forestry. For the use of biomass as a primary energy resource in cogeneration the CHPAB concept is integrated. Examples are the current achievements of: ALL POWER LABS, V-GRID ENERGY SYSTEMS, DIACARBON, ECOERA and EPRIDA. [11, 13, 14, 15]

ALL POWER LABS has developed a cogeneration plant in CHPAB concept with which it is possible to change the proportion of bio-produced produced as needed and biomass used, with high values for real energy efficiency coefficients in cogeneration. It is stated that one tone of dry gas biomass produces 1 MWh with zero production of biochar. Increasing the proportion of biochar reduces the energy resource for cogeneration and produces less electricity. [11, 21, 22]

V-GRID ENERGY SYSTEMS has developed a 100 kW generator that runs on farm waste biomass and can generate electricity for as ˆ0.02 per kWhe. In contrast, farm utility power in California average ˆ0.15 and diesel costs over ˆ0.20 per kWhe. Solar require a 10 year + commitment whereas our mobile system require just a few month lease trial. Our systems can also co-produce biochar soil enhancers optimized for farm’s needs. [15]

The below is an example of a 500 kW V-Grid Server Array, figure 1, with one month capacity fuel silo for 24/7 on-demand Power V-Grid’s Bioenergy Servers can be both mobile and stationary. Each Bioenergy Server consists of a gasifier and a generator pairing, that can be deployed to remote well sites or be linked together into an array to produce 24/7 on-demand power for large scale operations. [15, 19, 20]

Fig. 1. V-GRID power station generating 500 kW V-GRID on a farm

Internal combustion engines powered by syngas operate at maximum efficiency on the minimum fuel consumption characteristic (MCC) feature at which the power output consumption is minimal. [5, 19, 20, 22]

Also, the yield of the gasifier is determined by the operating mode and biomass properties used, which limits the optimal operating range. Consequently, the combination of gasifier and internal combustion engine has a limited operating range for maximum operating efficiency. [17, 23]

An example of optimal cogeneration with a system consisting of a biomass gasifier and an internal combustion engine is disclosed in patent **FR3016005**, a gasifier energy-production device, with an application for driving an electric + mechanical hybrid propulsion. It is an object of the invention to provide an electrical power generating device comprising an internal combustion engine fueled from syngas produced by a biomass gasifier, an electric motor driven by the internal combustion engine and at least one battery such that at a stationary the production of syngas by the gasifier

and the shutdown of the engine, all the fuel gas produced serves to supply the engine and produce mechanical energy. [18]
Recent development by EPRIDA, Inc. have made this technology more scalable to agricultural industries with two sizes of pyrolysis units. The first processes 1-ton of biomass per hour unit and produces 1 MWhe of electricity, 1 MWhth of usable heat and 136 kg. biochar per hour. The second processes 25 kg of biomass per hour, producing 25 kWth of heat and 25 kWe of electricity and 9 kg. biochar per hour. The Eprida process was developed through research conducted with the National Renewable Energy Labs, Oak Ridge National Laboratory, the Pacific Northwest National Laboratory, U.S. Dept. of Energy, USDA EPRIDA, Inc. Agricultural Research Service, University of Georgia and Iowa State University. [13]
Most gardeners and farmers would excitedly embrace any method that results in increasing their yields by even a few percentage points. The results of Diacarbon's initial growth trials that studied the application of biochar to tomato plants should truly give them reason to celebrate. Recently, Diacarbon's research and development team showcased our biochar in a few landmark growth trials that revealed dramatic improvements in plants survival alongside yield increases of nearly 70%. [14]
The paper aims to analyze the operation regime of a cogeneration plant with CHPAB concept, consisting of a biomass gasification system that produces syngas and biochar, an internal combustion engine that operates an asynchronous electric generator so that the engine can function on the minimum fuel consumption characteristic (MCC).

2. Material and method

For analysis, has been chosen a down-draft stratified biomass gasifier [16] top fed with air and biomass, with flame-controlled pyrolysis air flow and a extractor for biochar near the oxidation and carbon reduction zone working at high temperatures > 1100 °C to obtain a syngas with very little tar. [21, 22]
The block diagram of the cogeneration system analyzed is shown in figure 2.

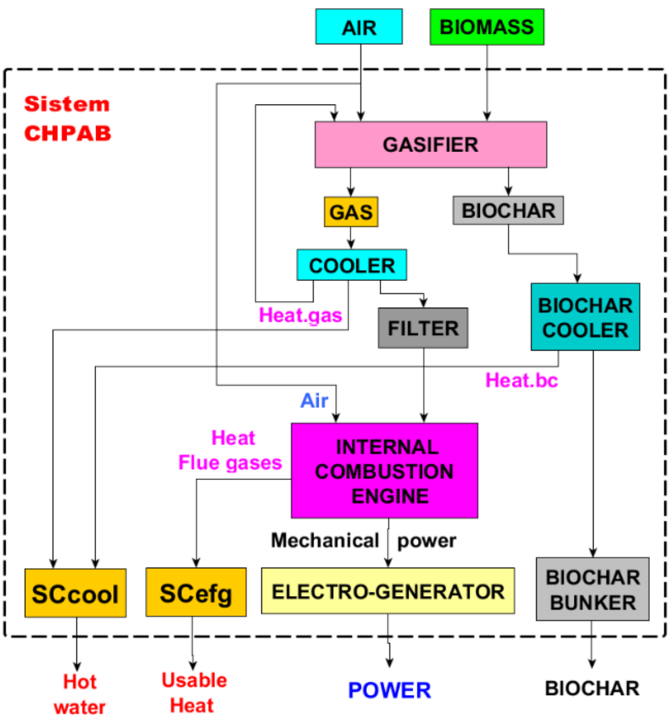

Fig. 2. Block diagram for cogeneration system with CHPAB concept

In the gasifier get biomass (index -bm) and air for gasification and exhaust combustible gas, referred to as syngas, and biochar. The syngas mass is the sum of the mass of air for gasification and the portion of the total gasified biomass (index -bmg). Ash from biomass remains in the biochar. [1, 5, 7]
For the analysis of the cogeneration system in the gasifier is processed M_{bm} = 1 kg. biomass and air for gasification is $M_{air} = K_{dag} * M_{bmg}$. At the exit, a biochar is obtained in the proportion of $K_{bc} = M_{bc} / M_{bm}$ in the range (0-0.20) and mass of syngas $M_{gas} = (M_{bm} - M_{bc}) + M_{air}$.
For different K_{bc} biochar proportions, the useful heat and electricity produced by these inputs and the energy efficiency coefficients for heat, electricity and total cogeneration are determined. [3, 7]
The gasifier operates continuously in optimal energy regimes for biochar in the range proportions $K_{bc} \in$ [0, 0.05, 0.10, 0.15], the final gasification produces hot syngas with very little tar at a conversion efficiency of η_{gas} = 93 %. The syngas is cooled, the humidity is removed, filtered and sent to the thermal engine to produce mechanical energy at a high efficiency, η_{ice} = 25% corresponding to the operation on the MCC characteristic.
Since the engine will operate at a speed, in accordance with MCC characteristic, different from the synchronization with the grid, it operates an asynchronous generator with a ac/ac converter operating in the optimum mode with a yield η_{ge} = 95%.
Syngas is cooled down to 40 °C, heat Heat.gas is transferred from the thermal engine, and the biochar is cooled down to 40 °C, with Heat.bc to storage in the hopper. Heat.gas and Heat.bc are taken over by **SC**cool coolers having water transfer agent and have a medium efficiency η_{cold} = 75%.
A **SC**efg heat exchanger with an average h_{cold} = 90% heat exchanger is used to recover the Heat.efg waste heat of the heat engine. Because the insulation of the system components cannot be ideal, for good thermal insulation, the values in the external environment are estimated to be minus 97%.
Table 1 presents the main data for biomass and cogeneration system analyzed.

Table 1: Main data for biomass and cogeneration system (bm – biomass)

Feature	**M.U.**	**Var.1**	**Var.2**	**Var.3**	**Var.4**
Biomass preparation	type	pellets	pellets	pellets	pellets
Relative humidity	adim	0,00	0,10	0,10	0,10
LHV biomass	MJ/kg.bm	**18,87**	**16,74**	**16,74**	**16,74**
Gasification yield hot syngas	adim	0,93	0,93	0,93	0,93
Thermal loss yield	adim	0,97	0,97	0,97	0,97
Internal combustion engine yield	adim	0,25	0,25	0,25	0,25
Electric generator yield	adim	0,95	0,95	0,95	0,95
Chillers yield	adim	0,75	0,75	0,75	0,75
Exhaust gas SCefg yield	adim	0,90	0,90	0,90	0,90

3. Results and discussions

The operation of the gasifier was simulated with a simulation program developed for the down-draft gasifiers [4] and extended to inverted down-draft gasifiers [5, 6], with which the regimes corresponding to the K_{bc} biochar proportions were selected from the ALL POWER LABS data. Table 2 presents the cogeneration process data for four variants for consumption 1 kilogram of processed biomass.

Table 2: Data for cogeneration processes (bm – biomass; bc – biochar; gas – syngas)

Feature	M.U.	Var.1	Var.2	Var.3	Var.4
Cogeneration process load	type	full	partial	partial	partial
Biomass processed	kg.bm	**1,00**	**1,00**	**1,00**	**1,00**
Biochar (BC) production	kg.bc/kg.bm	**0,00**	**0,05**	**0,10**	**0,15**
Carbon content in BC	kg.C/kg.bm	**0,000**	**0,032**	**0,078**	**0,124**
LHV full gasified biomass	MJ/kg.bmg	18,87	14.62	13.93	13.17
LHV biochar	MJ/kg.bc	0,00	19.6	24,58	26.20
Specific flow hot syngas	kg.gas/kg.bm	3,000	2,850	2,700	2,550
Energy in hot syngas	MJ/kg.bm	**17.023**	**12.500**	**11.254**	**10.015**
Gasification yield cold syngas	adim	0,860	0,819	0,817	0,806
Energy in cold syngaz	MJ/kg.bm	**14,346**	**10,899**	**8,913**	**6,868**
Specific flow cold syngas	kg.gas/kg.bm	2,760	2,280	2.160	2.040
LHV cold syngas	MJ/kg.gas	5,305	4.493	4,258	3,959
Potential energy in BC	MJ/kg.bm	0,000	0,980	2,458	3,930
Energy from BC cooling	MJ/kg.bm	0,000	0,029	0,058	0,086
Energy from syngas cooling	MJ/kg.bm	**2,380**	**2.258**	**2.057**	**1.938**
Useful energy in warm water	MJ/kg.bm	1.731	1.664	1.538	1.473
Mechanical energy produced	MJ/kg.bm	**3,661**	**2,561**	**2,299**	**2.019**
Energy in engine exhaust gases	MJ/kg.bm	6,589	4,609	4.138	3.634
Useful energy from exhaust gas	MJ/kg.bm	5,753	4,024	3,613	3.173
Electric energy produced	MJe/kg.bm	3,478	2,433	2,184	1,918

Table 3 presents the energy balances and the energy efficiency coefficients for the four analyzed alternatives. For variant 4, which also provides a large amount of biochar, 15%, figure 3 shows the corresponding inputs and outputs for a **1 MWhe** output cogenerated. Electricity is produced with 11.5% efficiency, 282 kg. biochar is produced with a 23.5% efficiency and is consumed **1.877 tons** of biomass with 10% moisture for produced and **2.24 MWh** of thermal energy with a 27.8% efficiency. Global cogeneration efficiency is 39.2% for CHP regime and 62.7% in CHPAB concept, with a negative carbon foot print of -0.233 kg.C/kWhe, which indicates a very good utilization of the potential energy of the biomass used.

Table 3: Energy balance and efficiency for cogeneration system

Feature	M.U.	Var.1	Var.2	Var.3	Var.4
Useful energy in warm water	kWth/kg.bm	0,481	0.462	0.427	0.409
Useful energy from exhaust gas	kWth/kg.bm	1,598	1,118	1.004	0.881
Total useful heat	kWth/kg.bm	**2,079**	**1,580**	**1,431**	**1.291**
Electric energy	kWhe/kgbm	**0,966**	**0,676**	**0,607**	**0,533**
Potenţial energy in BC	kWhth/kg.bm	0,000	0,272	0.683	1.092
Specific consumption of biomass	kg.bm/kWhe	**1,035**	**1,480**	**1,648**	**1.887**
Electrical energy efficiency	adim	0,184	0,145	0,130	0,115
Thermal energy efficiency	adim	0,397	0,340	0,308	0,278
CHP energy efficiency	adim	**0,581**	**0,485**	**0,438**	**0,393**
BC production efficiency	adim	0,000	0,059	0,147	0,235
CHPAB energy efficiency	adim	**0,581**	**0,544**	**0,585**	**0,627**
Electric energy Carbon foot print	kg.C/kWhe	**0.00**	**-0,047**	**-0,129**	**-0,233**

For cogeneration systems produced by A.P.Ls in the CHPAB concept, 1 MWhe is produced from 1 tone of biomass consumption is specified as the performance for electricity generation. The analysis shows that for the same amount of biomass it is obtained 0.966 MWhe, which confirms the announced performances, with a CHP efficiency of 58.1%, very good value, given a carbon footprint close to zero.

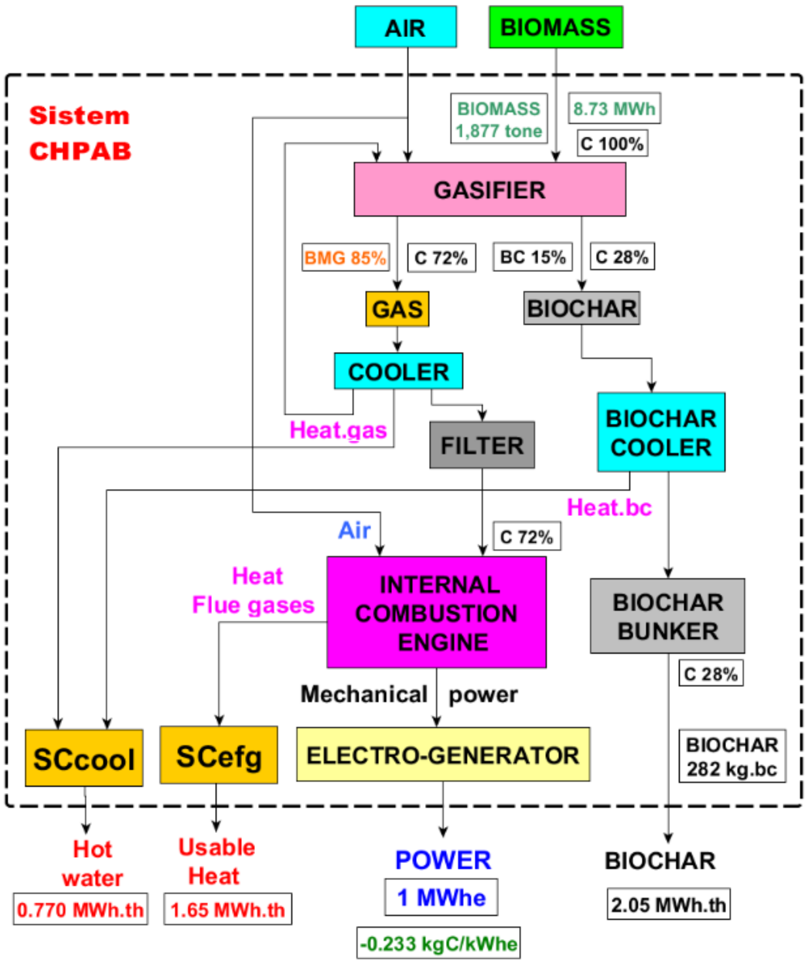

Fig. 3. Energy balance, efficiency and foot print for **1 MWhe** cogenerated

4. Conclusions

For produce thermal energy and biochar from biomass most used **CHAB (**Combined Heat and Biochar production) concept, to produce energy in cogeneration systems with internal combustion engine can be used **CHPAB** (Combined Heat Power And Biochar production) concept for produce electrical, thermal energy and biochar with a negative carbon foot print in environment.
The **CHPAB** concept is usable for low-power cogeneration systems, easy to integrate into a small energy intelligent network type Smart Grid that manages all available energy sources, renewable or classical, which increases energy efficiency and reduces the cost of use
Low-power cogeneration systems with **CHPAB** concept have low weight, are mobile, blended with biomass from local sources, produce biochar incorporated in agricultural land, contribute to their productive potential, contribute to sustainable development and are financially accessible for agricultural farms and isolated communities.
The system analyzed to produce **1 MWhe** with an efficiency of 11.5% and **282 kg**. biochar with 23.5% efficiency consumed 1,877 tons biomass with humidity of 10% and produced **2.24 MWhth** of thermal energy with an efficiency of 27.8% on a negative carbon footprint of **-0.233 kg**.C/kWhe.
Only in CHP mode, the cogeneration energy efficiency is 39.2%, comparable to other commercial CHP systems, and with CHPAB concept is 62.7%, which indicates a very good capitalization of the local biomass energy potential for increasing energy safety and independence in agriculture and in isolated communities.

The plethora of current patents relating to the use of the CHPAB concept in cogeneration with biomass indicates a new direction of efficient use of the energy potential of biomass and, in particular, of agricultural waste which occurs annually in very large quantities, helping to reduce agricultural production costs with a negative carbon foot print.
Combined CHPAB Cogeneration plants with biomass in CHPAB concept have a direct use to consumers with continuous heat and power requirements such as greenhouses, plants for drying and processing agricultural products that can be optimally disposed of the power grid and can use biochar to increase the productive potential of cultivated land.

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