ISSN 1454 - 8003
Proceedings of 2022 International Conference on Hydraulics and Pneumatics - HERVEX
November 9-10, Băile Govora, Romania

BIOCHAR FOR EMERGENCY ENERGY STOCK AND NATURAL GAS REPLACEMENT

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Abstract: *Energy and biochar (BCH) are produced from vegetable biomass, with thermo-chemical processes, without residues and with negative CO_2 emissions. Quality BCH with molar ratios O/H <0.2 and H/C < 0.2 contains at least 40% of biomass carbon, has 33% of input energy, is porous with a specific surface area of 150 – 400 m2/g.bc and has many non-energy uses. BCH with 10% moisture can be stored long-term as a carbon and energy stock. BCH as an agricultural amendment cheaply sequesters CO2 in the long term and ensures increased horticultural production. A stock of BCH ensures the production of cheap electricity and heat,* ***when and as much as needed****, with zero or negative CO_2 emissions, without or with low-capacity electric storage. Low-volatile BCH gasified in miniCHP unit produces electricity with 30% efficiency and thermal energy with 56%. For a CO_2 emission below zero, a maximum of 70% of the biochar produced is gasified. From the gasification of BCH with O2 and H2O, gas.bc is obtained as a cheap substitute for natural gas for local use in smart hybrid energy mini-grids.*

Keywords: *Biochar, energy stock, carbon footprint, natural gas*

1. Introduction

In the current period, bio-oil, biochar and pyrolysis gas can be produced from residual biomass through allothermal or autothermal pyrolysis on an industrial scale. On a midi scale, gas.bm and biochar (BCH) are obtained through gasification. Gas.py and gas.bm are burned to produce heat, and biochar for use as an agricultural amendment, filter material, or emergency energy stock [2, 3, 4, 5, 6, 15, 18].

The use of biochar as an agricultural amendment sequesters carbon in the soil for long periods of time with a negative carbon footprint CFP, is used as a filter material. The biochar is stored and gasified to recover energy, the toxic ash is embedded in concrete and stored for the long term, operation with positive CFP [1, 11, 12, 17, 19].

To decarbonize energy production with the CFP = 0 limit, it is necessary that part of the biochar be incorporated into agricultural soils to sequester carbon and contribute to increasing agricultural production, on average by 13% [8, 9, 10, 12].

Depending on the biomass from which the biochar is produced, for CFP =0 it would be necessary for at least 30% of the produced biochar to be used as an agricultural amendment [6, 7, 10].

Biochar with an average moisture content of 10% can be stored in maximum safety, building a decentralized energy stock that can be used – ***when and as much as needed*** – usually in emergency situations, without the grid, without photovoltaics or wind.

The residual or energetic biomass from which energy and biochar are produced is very diverse in chemical composition and ash content. Depending on the pyrolysis or gasification regime, different proportions of biochar with equally different properties are obtained.

In Romania, about 3500 thousand toe of energy is consumed annually for heating homes. 3 million homes are heated by burning wood, with thermal efficiencies below 30%, which represents a major national waste of energy. The efficient gasification of biomass and the use of biochar stocks for emergency situations are economically and ecologically viable alternatives, with great social impact.

2. Material and methods

Heat, bio-oil and biochar result from vegetable biomass with pyrolysis and gasification processes. Bio-oil and BCH can be stored, but the heat must be consumed efficiently and economically. A continuous production does not adapt to the real consumption of heat and electricity, which have a dominant random component. Producing energy when and as much as needed is the optimal economic and ecological option. Systems with the CHAB concept with discretized operation can produce heat when and as much as needed with a very small heat storage capacity [3, 4, 5, 7, 15].
The production of heat and biochar is done with CHAB concept installations equipped with GSIDD gas generators, with thermal power of 100kWth in hot water, called SEB.HW100, which can gasify a wide variety of chopped or pelletized vegetable biomass. The operating regimes are controlled to obtain a share of 20% biochar from dry biomass, i.e. 0.2 Mg.bc/Mg.bm.db, as well as maintaining the temperature in the OZ oxidation zone below the ash softening temperature.
A CHP.BC50 cogeneration unit is used for the production of gas.bc and electricity, it is equipped with a downdraft gasifier GBC.DD to obtain gas.bc with very little tar and high HHV.
For the simulation of biomass gasification, the MER.BM.GAZ.DD simulation program with the MUKMER model, produced by EROLSoft, was used for the oxypyrolysis and gasification processes with stratified downdraft or reversible front processes.
For the simulation of the SEB.HW100 unit, the MER.SEB.MESI simulation program, produced by EROLSoft, was used for the production of hot water/air and biochar.
For biochar gasification, the simulation program MER.BCH.GAZ.DD, produced by EROLSoft, was used for gasification with air, CO2, H2O and O2.
The results obtained have a margin of error of +5% to -10% due to the characteristics of the biomass used which have a large random dispersion due to the pedoclimate conditions and applied agricultural technologies.
Several types of residual, energetic or forestry biomass will be analyzed. Table 1 shows the types of nonwoody biomass, table 2 shows the types of woody biomass.

Table 1: Nonwoody biomass characteristics

Feature	**U.M.**	**Values**			
Biomass type		**wheat straw**	**corn stover**	**vegetables growing wastes**	**miscanthus**
Biomass price	€/Mg.bm	130.00	130.00	130.00	160.00
Water	kg.w/kg/bm	***0.080***	***0.080***	***0.080***	***0.080***
Carbon	kg.C/kg/bm	**0.4195**	**0.4444**	**0.4119**	**0.4407**
Hydrogen	kg.H/kg/bm	**0.0534**	**0.0476**	**0.0611**	**0.0552**
Oxygen	kg.O/kg/bm	**0.3938**	**0.3692**	**0.4191**	**0.3831**
Azote	kg.N/kg.bm	**0.0000**	**0.0000**	**0.0000**	**0.0055**
Sulfur	kg.S/kg.bm	**0.0000**	**0.0000**	**0.0000**	**0.0051**
Ash	kg.ash/kg.bm	**0.0534**	**0.0589**	**0.0280**	**0.0305**
HHV for BM.db	MJ/kg.bm.db	**18.158**	**18.635**	**18.574**	**19.317**
HHV	kWh/kg.bm	**4.641**	**4.762**	**4.747**	**4.937**
LHV for BM.db	MJ/kg.bm.db	**16.885**	**17.499**	**17.116**	**17.999**
LHV	kWh/kg.bm	**4.261**	**4.418**	**4.320**	**4.546**
Stoichiometric Flow	kg.air/kg.bm	**4.979**	**5.172**	**5.048**	**5.332**
Softening ash temperature	degree C	**840**	**990**	**1000**	**835**

Table 2: Woody biomass characteristics

Feature	**U.M.**	**Values**			
Biomass type		**beech wood**	**energetic poplar**	**vine pruning**	**fruit growing pruning**
Biomass price	€/Mg.bm	**200.00**	**200.00**	**130.00**	**140.00**
Water	kg.w/kg/bm	***0.080***	***0.080***	***0.120***	***0.120***
Carbon	kg.C/kg/bm	**0.4571**	**0.4385**	**0.4174**	**0.4421**
Hydrogen	kg.H/kg/bm	**0.0558**	**0.0526**	**0.0515**	**0.0524**
Oxygen	kg.O/kg/bm	**0.3938**	**0.3757**	**0.3883**	**0.3643**
Azote	kg.N/kg.bm	**0.0038**	**0.0396**	**0.0000**	**0.0079**
Sulfur	kg.S/kg.bm	**0.0002**	**0.0003**	**0.0000**	**0.0008**
Ash	kg.ash/kg.bm	**0.0093**	**0.0133**	**0.0229**	**0.0124**
HHV for BM.db	MJ/kg.bm.db	**19.904**	**18.986**	**18.635**	**20.027**
HHV	kWh/kg.bm	**5.087**	**4.852**	**4.555**	**4.896**
LHV for MB.db	MJ/kg.bm.db	**18.571**	**17.730**	**17.351**	**18.718**
LHV	kWh/kg.bm	**4.692**	**4.477**	**4.160**	**4.494**
Stoichiometric Flow	kg.air/kg.bm	**5.498**	**5.250**	**4.914**	**5.335**
Softening ash temperature	degree C	**1400**	**1200**	**1200**	**1200**

Agricultural residual biomass was chosen for the analysis – wheat straw, corn stover, vegetables growing wastes, vine pruning and fruit growing pruning; energetic biomass – miscanthus and energetic poplar; forest biomass - beech wood [2, 4, 8, 15].
Tables 3 and 4 present the parameters of the biomass gasification regimes in SEB.MESI, from which an average biochar share of 20% of the dry biomass is obtained and the ash softening temperature is not exceeded, in order not to block the propagation of the flaming pyrolysis and reduce the quality of the biochar produced.

Table 3: SEB.HW100 gasification regime for nonwoody biomass

Feature	**U.M.**	**Values**			
Biomass type		**wheat straw pellets**	**corn stover pellets**	**vegetables wastes pellets**	**miscanthus pellets**
Air ratio ER		**0.254**	**0.277**	**0.284**	**0.251**
Temperature in oxyzone	degree C	779	823	823	775
Biochar rate dry BM	kg.bc/kg.bm,db	**0.206**	**0.188**	**0.194**	**0.216**
Biochar rate	kg.bc/kg.bm	**0.189**	**0.173**	**0.179**	**0.198**
Carbon content in BCH	kg.C/kg.bc	**0.660**	**0.612**	**0.785**	**0.779**
Ash content in BCH	kg.ash/kg.bc	**0.281**	**0.339**	**0.156**	**0.153**
Molar ratio O/C	molO/molC	**0.033**	**0.027**	**0.027**	**0.034**
Molar ratio H/C	molH/molC	**0.310**	**0.302**	**0.302**	**0.311**
HHV for biochar	kWh/kg.bc	**6.711**	**6.175**	**8.085**	**8.022**
Biomass price	€/Mg.bm	**130.00**	**130.00**	**130.00**	**160.00**
Operating cost	€/y	**14885.85**	**14885.85**	**14885.85**	**14885.85**

Biomass consumption cost	€/y	29215.43	33847.06	33838.49	30224.28
Production costs	€/y	44101.29	48732.91	48724.34	45110.13
Thermal energy production	MWht/y	485.050	639.687	532.441	397.898
BCH mass production	Mg.bc/y	39.895	42.171	43.545	35.105
Thermal energy cost	€/MWht	58.583	54.142	55.087	66.388
BCH cost production	€/Mg.bc.db	393.168	334.328	445.377	532.533
Carbon from BCH cost	€/Mg.Cbc	595.553	546.448	567.483	683.824
Energy from BCH cost	€/MWh.bc	58.58	54.14	55.09	66.39

The biochar produced with SEB.HW100 unit has molar ratios O/C < 0.2 and H/C < 0.4 which is required for a biochar usable as an agricultural amendment, which produced at temperatures above 750 ºC is sterile, porous and pH >10.00 [1, 11, 12, 17, 18, 19, 20].

Very low volatile biochar is very good for gasification because very little tar is produced which is simple, safe and cheap to dispose of [13].

The prices for the analyzed biomass are estimated from the current supply in the market of pellets and wood chips, which can have large variations depending on the requirement, supply and demand for energy.

Table 4: SEB.HW100 gasification regime for woody biomass

Feature	U.M.	Values			
Biomass type		beech wood pellets	energetic poplar pellets	vine pruning chopped	fruit pruning chopped
Air ratio		0.288	0.287	0.252	0.254
Temperature in oxyzone	degree C	819	823	856	877
Biochar rate dry BM	kg.bc/kg.bm,db	0.198	0.197	0.213	0.215
Biochar rate	kg.bc/kg.bm	0.182	0.181	0.187	0.189
Carbon content in BCH	kg.C/kg.bc	0.883	0.862	0.824	0.883
Ash content in BCH	kg.ash/kg.bc	0.051	0.073	0.122	0.0655
Molar ratio O/C	molO/molC	0.027	0.027	0.021	0.017
Molar ratio H/C	molH/molC	0.302	0.302	0.297	0.293
HHV BCH	kWh/kg.bc	9.172	8.947	8.524	9.177
Biomass price	€/Mg.bm	*130.00*	*130.00*	*130.00*	*160.00*
Operating cost	€/y	14885.85	14885.85	14885.85	14885.85
Biomass consumption price	€/y	48099.39	36562.25	25468.54	25576.92
Production costs	€/y	62985.25	51448.10	40354.40	40462.78
Thermal energy production	MWht/y	516.408	444.043	351.584	353.201
BCH mass production	Mg.bc/y	41.006	37.971	34.338	32.364
Thermal energy cost	€/MWht	70.57	65.44	62.63	62.23
BCH cost production	€/Mg.bc.db	647.29	589.67	533.89	571.10
Carbon from BCH cost	€/Mg.Cbc	732.79	678.91	647.66	646.57
Energy from BCH cost	€/MWh.bc	70.57	65.44	62.64	62.23

Thermal energy can be produced with average costs in the range of 55 – 70 €/MWht depending on the price at which the gasified biomass enters production.

The production cost of BCH is lower for nonwoody biomass, as is the production cost of carbon from BCH, values that depend on the cost of the biomass processed.

BCH from nonwoody biomass contains a lot of ash and less carbon for which the main economically efficient use is as an agricultural amendment intended to increase the fertility of agricultural soils. A biochar with a high carbon content is indicated for gasification [1, 11, 12, 20].

Two representative types of biomass were chosen for the functional and energetic analysis. Poplar from intensive energy crops is used for woody biomass, which has a chemical composition similar to the average of forest resources [14, 16]. From the residual agricultural biomass, corn stover was chosen because it represents in RO and the EU about 40 of the collectable energy potential [5].

Table 5 shows the functional characteristics of the CHP.BC50 cogeneration unit with a nominal electrical power of 50 kWe. The CHP.BC50 produces cold gas.bc that can be used instead of natural gas and LPG, or to feed an electric power generator, when and as much as needed. The relatively low power was chosen to be usable in isolated locations with alternative operating regimes, low load with heat production, gas.bc production for consumption, electricity and heat production.

For maximum efficiency utilization, the generator set only regime in an optimal mode, the specialized heat engine is constructively optimized and extremely driven, with an efficiency of up to 50%, a common variant for hybrid cars with heat engine charging. The 27% electrical efficiency used in the simulation is still modest, but with a real basis.

Table 5: Operating characteristics of CHP.BC50 unit

Feature	**U.M.**	**Values**	
BCH from biomass type		**energetic poplar**	**corn stover**
HHV for BCH	MWh/Mg.bc	***8.944***	***6.175***
Carbon content	kg.C/kg.bc	***0.862***	***0.612***
BCH production cost	€/Mg.bc	***589.00***	***355.00***
Handling and storage	%	***5***	***5***
BCH user cost	€/Mg.bc.db	**618.45**	***372.75***
Cooled gas.bc efficiency	%	***75.0***	***75.0***
Gas.bc specific energy	MWh/kg.bc	***6.708***	***4.631***
Gas engine yield	%	***38***	***38***
Electric generator yield	%	***95***	***95***
Electro engine generator yield	%	***36.1***	***36.1***
Electricity production efficiency	%	***27.1***	***27.1***
Yield heat recovery gas.bc cooling	%	***0.213***	***0.213***
Yield heat recovery gas engine	%	***37.2***	***37.2***
Thermal energy efficiency	%	***58.5***	***58.5***
Cogeneration efficiency	%	***85.5***	***85.5***
Cogeneration Index	%	***46.3***	***46.3***
CFP emitted from operation	kg.CO2/Mg.bc	**35.000**	**35.000**

Table 6 shows the results of the economic estimation of the use of CHP.BC50 for a continuous operation of 7000 h/y and an operating life of 5 years, extendable through successive upgrades.

This results in an hourly operating cost of 7.10 €/h affected by input cost estimation errors of ± 10 %.

Table 6: Operating costs for CHP.BC50 unit

Feature	U.M.	Values
Specific power CHP price	€/kWe	**2500**
Electric power	kWe	**50.000**
CHP.BC50 price	€/system	**125000**
Installation and start-up ratio	%	**20**
Installation and start-up costs	€/system	***150000***
Live Cycle operating time	y/LC	**5.00**
Annual operating time	h/y	**7000.00**
Annual banking interest	%	**5.00**
Annual income from deposit	€/y	**7500.00**
Residual value ratio	%	**30.00**
Installment depreciable value	€/system	**149985**
Annual value to be amortized	€/y	**37497**
Annual maintenance rate costs	%	**15**
Annual maintenance costs	€/y	**5624.55**
Operator cost	€/month	**500.00**
Annual operating costs	€/y	**49121.55**
Hourly operating costs	€/h	**7.017**

3. Results

From the data obtained for operating regimes and production costs, the production costs for the production of electricity and heat, as well as for gas.bc intended for local replacement of PLG and in emergency cases of NG at network blockages, can be estimated accurately enough.

Table 7: Economic evaluation of CHP.BC50 unit

Feature	U.M.	Values	
Biomass type		**poplar**	**corn stover**
HHV for BCH	MWh/Mg.bc	**8.944**	**6.175**
BCH using cost	€/Mg.bc	**618.45**	**372.75**
Specific electricity production	MWhe/Mg.bc	**2.422**	**1.672**
Specific BCH consumption	kg.bc/kWhe	**0.413**	**0.598**
Hourly BCH consumption	kg.bc/h	**20.647**	**29.906**
Hourly BCH cost	€/h	**12.77**	**11.15**
CHP production hourly costs	€/h	**19.79**	**18.15**
Hourly input energy	MWh/h	**184.672**	**184.672**
Electricity production efficiency	%	**0.271**	**0.271**
Thermal energy efficiency	%	**0.585**	**0.585**

Cogeneration Index	%	**0.463**	**0.463**
Hourly electricity production	MWhe/h	**0.050**	**0.050**
Hourly thermal energy production	MWht/h	**107.941**	**107.941**
Equivalent energy produced annually	MWh/y	**108.049**	**108.049**
Specific cost thermal energy	€/MWht	**183.12**	**168.12**
Electricity cost	€/MWhe	**395.33**	**362.94**
ENEL tariff	€/MWhe	**246.00**	**246.00**
Difference from ENEL tariff	€/MWhe	**149.33**	**116.94**

Table 8: Economic evaluation gas.bc use

Feature	**U.M.**	**Values**	
Biomass type		**poplar**	**corn stover**
CHP.BC50 hourly consume	kg.bc/h	**20.647**	**29.9074**
BCH cost	€/Mg.bc	618.45	**372.75**
Hourly cost BCH consumption	€/h	**12.77**	**11.15**
HHV cooled gas.bc	MWh/Mg.bc	**6.708**	**4.631**
Gas.bc hourly energy production	MWh/h	**0.139**	**0.139**
Gas.bc energy cost	€/MWh	**80.65**	**60.36**
Hourly operating costs	€/h	**4.91**	**4.91**
Hourly gas.bc production cost	€/h	**17.68**	**16.06**
Gas.bc energy cost	€/MWh.gbc	**127.66**	**115.95**
NG average cost in 2022 year	€/MWh	**95.35**	**95.35**
Gas.bc to NG difference energy costs	€/MWh	**32.31**	**20.60**
PLG energy cost in 2022 year	€/MWh	**398.22**	**398.22**
Gas.bc to PLG difference energy costs	€/MWh	**-270.56**	**-282.27**

The cost of the produced electricity of 380 €/MWhe ± 10% is relatively high compared to the current one in the national network of 246 €/MWhe, but lower than that of the electricity produced by the intervention generators. For energetically isolated areas without an electrical network, the use of CHP.BC with biochar produced from locally available biomass is economical, ecological and with a positive social impact.

Table 8 presents the economic evaluation of the use of gas.bc to replace NG in emergency cases and PLG for local use.

The production cost of 120 €/MWh.gbc ± 10% is +25% higher than that of NG, but economically acceptable for emergency situations when the supply of energy for vital consumption is important.

In the case of replacing the local use of PLG with gas.bc, the cost difference is obvious, which is on average +255 €/MWh, that is, the use of gas.bc is 3.3 times cheaper, being an obvious economic alternative. However, the difference is mitigated by the need for a much higher initial investment, but with guaranteed long-term economic efficiency.

4. Conclusions

In the current energy crisis, the production of energy and biochar from residual plant biomass, **when and as much as necessary**, is a complementary solution when it is dark and the wind is not blowing, ensuring economically and ecologically the necessary energy consumption in real time.

This work is a contribution to the development of research and the design of systems for the production and efficient use of biochar produced from vegetable biomass for the production of energy when and as much as necessary and the increase of agricultural soil fertility.

A wide variety of plant biomass can be gasified with SEB.MESI with CHAB concept to produce when and how much thermal energy is needed with an average efficiency of 45% and to obtain 20% high quality biochar.

The biochar produced with SEB.MESI has molar ratios $O/C < 0.2$ and $H/C < 0.4$, which is required for a biochar usable as an agricultural amendment, which, being produced at temperatures above 750 ºC, is sterile, porous and with pH >10.0. The minimum commercial price in EU 2021 was 1250 €/Mg.bc with a maximum of 4000 €/Mg.bc.

The production costs for biochar are 350 – 450 €/Mg.bc for nonwoody biomass and 550 – 650 €/Mg.bc for woody biomass, much below the current prices on the BCH market, which ensures an advantageous capitalization.

It is worth mentioning the production cost of carbon from BCH, which is on average 550 – 650 €/Mg.Cbc for nonwoody biomass and 650 – 750 €/Mg.Cbc for woody biomass, strongly influenced by the cost of the biomass used.

Biochar can be stored as a carbon and energy stock, for long periods, usable as an agricultural amendment, as a filter material, but very important as a source of energy for emergency situations, **when and as much as needed**.

Energy can be produced from gas.bc 3 times cheaper than from PLG, thus being a cheap and safe source of fuel gas for isolated areas without a NG network.

The cost of electricity produced from BCH is higher than that from the network, by about 35-50%, acceptable for emergency situations, but much lower than that of emergency generators.

The biochar produced from residual agricultural plant biomass, which has a lot of ash, is indicated to be used effectively as an agricultural amendment, with which it produces an average increase in agricultural production by 13%, an action subsidized with green vouchers, now with the value of 180 €/Mg. Cbc.

The stock of biochar can be used when and as much as necessary as an agricultural amendment or for the production of energy in emergency situations or for continuous consumption, for a zero carbon footprint it is required that at least 30% of the stock be used as an agricultural amendment.

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