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BIOCHAR FROM RESIDUAL VEGETABLE AGRICULTURAL BIOMASS AMENDMENT FOR INCREASING AGRICULTURAL PRODUCTION AND ENERGY STOCK

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Abstract: From residual vegetable agricultural biomass (RVAB) with oxypyrolysis processes, energy and biochar (BC) are produced, without residues and with negative carbon footprints. BC from agripellets contains 65% carbon and has 25% of RVAB energy. Incorporated in the soil ensures a minimum 13% increase in production, sequestering CO2 cheaply in the long term. Safe and cheap of BC stock gasified in miniCHP produces energy with 85% total efficiency substituting natural gas, when and as much as needed. For a negative carbon footprints is gasified 70% of BC. In Romania, from 20 Tg.br.db/year is produced 3.5 Tg.bc/year BC with energy of 28 TWh/year, equivalent to 1.7 billion m^3 of natural gas.
Keywords: biomass residual, energy, biochar, carbon footprint, natural gas

1. INTRODUCTION

In the current energy crisis, using the internet and GPS, machine learning and artificial intelligence applications, the exploitation of green energy resources, biomass renewable annually, is necessary to produce decentralized energy and decarburization, with modern thermo–chemical conversion technologies, safe and efficient economically, energetically and ecological.

Traditionally biomass is used in combustion processes to produce energy. Experiments show that emissions from biomass burning are very high at the point of energy production. As a result, GNDE will no longer support this activity (*Murad E., 2021; European Biomass Association, 2019; Horizon 2020, 2022*).

In order to reduce energy consumption and CO2 emissions from transport, it is economic and ecological to use biomass collected from a limited area, with a radius of less than 30 km with energy installations connected in smart local energy networks, linked to each other and to the national system (*Murad E., 2021; European Biomass Association, 2019; Horizon 2020, 2022*).

Romania is and will be a large producer of plant foods (fb) and meat. Annually, on average, 7 million hectares are cultivated, from which about 40 Tg.fb/y of food biomass is harvested. At the same time, residual vegetable agricultural biomass (RVAB) can be collected, which represents at least 50% of the food. In 2021, a minimum of 20 Tg.db/y with 95 TWh/year energy potential could be collected in Romania.

From RVAB with the process of oxypyrolysis and gasification, energy and biochar (BC) are produced without residues and with negative CO2 emissions, in accordance with the requirements of the Circular Economy and GNDE.

BC produced with oxypyrolysis processes, at temperatures below 850 ºC, contains very few volatiles, has molar ratios O/C < 0.2 and H/C < 0.4, conditions necessary for use as an agricultural amendment, as well in gasification processes for energy production. BC obtained from agripellets has an average carbon content of 65% and has 25% of RVAB energy, it is porous with a specific surface area of 150 – 400 m2/g.bc and with an alkaline pH. It also has over 60 other non–energy uses, of which those as a filter material are dominant (*Conte P. et al., 2021; Hikmet G. et al., 2019; Natural Resources Conservation Service, 2022*).

The main use of BC is as an agricultural amendment to increase the organic carbon content of the soil, as a growth medium for micro–organisms and to retain moisture, which provides an increase in agricultural production by an average of 13% and sequesters CO2 cheaply in the long term, representing a profitable investment in the future (*Hikmet G. et al., 2019; Schmid H–P., et al., 2021a; Schmid H–P., et al., 2021b; European Biochar Industry Consortium, 2020; Lawrence Livermore National Laboratory, 2020*).

BC with 10% moisture can be safely and cheaply stored as an energy stock that can be used when and as much as needed. By gasifying BC with air, CO2 and H2O, a combustible gas is obtained, called gas.bc, with a high HHV and usable for energy production as well as a substitute for the import of natural gas or for that accumulated in pits (*Murad E. et al., 2016; Murad E., 2021; Murad E. et al., 2022; Qiang Hu et al., 2020*).

2. MATERIALS AND METHODS

A synthesis of crop food biomass production and an estimate for RVAB collectable in RO 2021, as well as the main quantities required in the work, is presented in table 1 (*Institutul National de Statistica, 2022*).

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It is possible to collect annually, for a collection coefficient Kcbr = 0.667, a dry mass of RVAB of 19.4 Tg.br.db/y which, related to food biomass, represents about 55%. The collected RVAB has an energy potential of 94.5 TWh/y, with an average HHV of 4.87 MWh/Mg.br.db and an average energy density of 12.97 MWh/ha.

Table 1. Agriculture food biomass production and RVAB mass collectable in RO2021

CROP	Agriculture 2021 7,28 M.ha			Energy potential of RVAB			Carbon from RVAB.db		
	Food biomass	RVAB.db collected Kcol = 0,67		HHV.db	Annual energy potential	Crop part	Carbon content	RVAB carbon /ha	Annual carbon mass
	Mg.fb/y	br/ fb	Tg.br/y	kWh/ kg.br	TWh/y	%	kg.C/ kg.br	kg.C/ ha	Tg.C/y
Maize	14,820	0,83	8,205	4,95	40,614	43,00	0,437	2109	3,586
Winter wheat	10,433	0,60	4,176	4,80	20,043	21,22	0,434	1249	1,812
Sunflower	2,843	1,50	2,845	4,80	13,656	14,46	0,475	1802	1,351
Rape	1,375	2,30	2,110	4,67	9,852	10,43	0,460	3263	0,970
Barley	1,981	0,60	0,793	4,70	3,726	3,95	0,430	1137	0,341
Soy	0,347	1,60	0,371	5,00	1,854	1,96	0,460	1832	0,171
Tomato	0,753	0,50	0,251	5,14	1,291	1,37	0,474	5146	0,119
Vineyard	1,009	0,30	0,202	5,32	1,074	1,14	0,450	823	0,091
Plum	0,819	0,30	0,164	5,42	0,889	0,94	0,480	1769	0,079
Apple	0,602	0,35	0,141	5,37	0,755	0,80	0,477	1870	0,067
Beans	0,161	1,20	0,129	5,40	0,698	0,74	0,460	1163	0,059
Total	35,147		19,386		94,452	100,00			8,646
Average			0,552	4,872	12,97E–6		0,446	1188	

It is found that corn, wheat, sunflower and rapeseed crops produce almost 90% of the energy potential of RVAB collected annually.

Table 2. Mass collected and energy potential of RVAB for RO2021

Feature	U.M.	Value
Annual dry RVAB mass collected	Tg.br.db/an	19,400
Energy potential at RVAB collected	TWh/an	94,500
HHV for RVAB, average	TWh/Tg.br.db	4,871
RVAB mass utilization for pelleting	%	90,00
Mass of agripellets annual produced	Tg.pel.db/an	17,460
Energy consumption for pelletzation	MWh/MWh.pel	0,070
Annual energy consumption for pelletzation	TWh/an	5,954
Annual usable energy from agripellets	TWh/an	79,097

To produce energy and biochar from RVAB, CHAB systems are used, with oxypyrolysis processes where the maximum temperature is below 900°C. Figure 1 shows the block diagram of a thermo–chemical conversion aggregate of RVAB with the oxypyrolysis process. Usable heat and biochar with a positive CFPf carbon footprint are obtained if the carbon in BCH is not sequestered *(Conte P. et al., 2021; Murad E. et al., 2016; Murad E., 2021; Natural Resources Conservation Service, 2022)*.

Since the biochar produced is usable as an amendment for agricultural soils, as a filter material and as a fuel in CHP for the production of electricity, the content of volatiles must be low, with molar ratios O/C < 0.2 and H/C < 0.4, in accordance with the imposed norms *(Hikmet G. et al., 2019; Schmidt H–P. et al., 2021b; European Biochar Industry Consortium, 2020; Lawrence Livermore National Laboratory, 2020; Natural Resources Conservation Service, 2022)*.

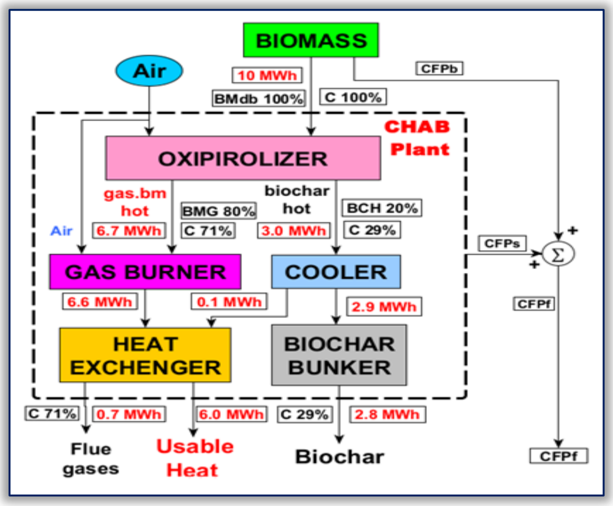

Figure 1 – Block diagram for CHAB plant with oxipyrolysis reactors

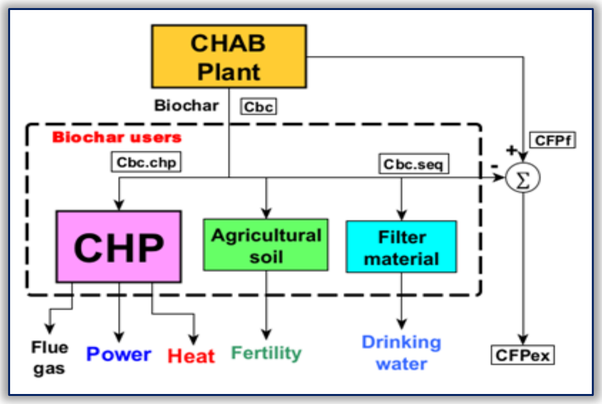

Figure 2 – Bloc diagram of biochar utilization for energy and amendment

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Table 3. Energy and biochar from RVAB

Feature	U.M.	Value
Yield hot gas.bm from RVAB	MWhg/MWh.br	0,670
Annual energy in hot gas.bm	TWh/y	52,995
Average biochar production	g.bc/g.br.db	0,200
Biochar annually produced	Tg.bc/y	3,492
Biochar carbon content	g.Cbc/g.bc	0,644
Carbon mass in biochar	Tg.Cbc/y	2,249
Biochar average H.H.V.	Wh/g.bc	6,590
Annual biochar energy	TWh/y	23,012
CFP CHAB plant operation	kg.CO2/Mg.br	135,00
CFP CHAB plant operation	kg.C/Mg.br	36,818
BCH incorporated for CFP=0	kg.bc/Mg.br	57,171
BCH gasified for CFP=0	%	71,40

Table 3 shows the energy and mass balances for CHAB plant with oxypyrolysis process. The fuel gas produced, called gaz.bm, is obtained with a yield of 67% because part of the input energy from RVAB is found in the biochar produced. The BC produced represents on average 20% of the processed dry mass and has an average carbon content of 64.4% due to the high ash content of the agripellets. Hot gas.bm is burned locally to produce heat.

From the RVAB collected annually, BC is obtained with a mass of 3.5 Tg.bc/y and an energy potential of 23 TWh/y, representing 25% of the input energy. The collection and processing of RVAB produces a positive carbon footprint CFPb, which is added to the CFPs emission due to the system and results in the functional footprint CFPf, which is estimated at 135 kg.CO2/Mg.br. (figure 1) *(Murad E., 2021; European Biomass Association, 2019; Institutul National de Statistica, 2022)*. In order to achieve a final zero carbon footprint CFPex = 0, a minimum of 28.6% of the BC produced must be sequestered. So for energy production with CFPex = 0, a maximum of 70% of the BC produced can be used.

In figure 2 is presented the utilization of BC for energy, as agricol amendment and filter material. The energy from BC is obtained by gasification with agents air, O_2, CO_2 and H_2O, resulting in a gas.bc with high HHV, which, when cooled, can be used to power gas engines, specially designed to operate in the economic pole with very high efficiency, similar engines with those used in hybrid vehicles for recharging batteries. (Table 4)

Table 4. Technical characteristics of CHP with biochar

Feature	U.M.	Value
Biochar mass annually produced	Tg.bc/an	3,492
Biochar relative mass gasified	%	100
Energy efficiency cooled gas.bc	%	75
Gas.bc engine yield	%	38
Electric generator yield	%	95
Electroengine generator yield	%	36,1
Electricity production efficiency	%	27,1
Electricity annual production	TWh.e/y	*6,231*
Yield heat recovery from gas.bc	%	21,3
Yield heat recovery gas engine	%	37,2
Heat recovery yield	%	33,2
Recovered heat cooling gas.bc	MWh.th/Mg.bc	1,400
Recovered heat gas engine	MWh.th/Mg.bc	2,451
Heat production in CHP	MWh.th/Mg.bc	3,852
CHP heat production efficiency	%	58,5
Heat annual production	TWh.th/y	13,451
Cogeneration efficiency	%	85,5
Annual energy production	TWh/y	19,681
CFP from CHP operation	kg.CO2/Mg.bc	35,000
Annual CFP CHP operation	Mg.CO2/y	122,220

Cbc carbon from biochar is distributed according to use. For gasification in CHP Cbc.chp is consumed, which is added at CFPf. For uses as an agricultural amendment and as a filter material, Cbc.seq is consumed, which is subtracted from CFPf, contributing to decarbonization (figure 2).

Biochar–fired CHPs produce electricity with an efficiency of 27%, thermal energy with 58%, and the total energy efficiency is 85%. If all the biochar produced annually is gasified, 6.23 TWh.e of electrical energy can be obtained, as well as 13.45 TWh.th of thermal energy. CHP operation with biochar produces a positive CFPf carbon footprint; can be brought to zero or 0 negative value by using more than 30% of BC as agricultural amendment.

3. RESULTS

The valorization of biochar produced from RVAB in several variants is analyzed. First variant consists in the gasification of the entire mass of BC produced annually, in the second variant only 70% of BC is used for energy production which ensures CFPex = 0, in the third variant only 50% of BC is gasified, and in the fourth OPTION all BC mass is used as an agricultural amendment.

Table 5 shows the thermal energy and electrical energy values possible to obtain through the energy recovery of RVAB for the four analyzed variants.

The thermal energy produced is the sum of the energy produced by burning gas.bm resulting from the oxypyrolysis of RVAB and that produced by CHP. If all the BC produced is used as an agricultural amendment, 53 TWh.th/year can be produced, if all the BC produced is gasified, 66.5 TWh.th/year is obtained, with about 25% more.

In variant one, in which 100% of BC is gasified, 6.23 TWh.e/year of electricity is produced with CHP. In warrant four, BC is not gasified and no electricity is produced. The total energy efficiency of the energy conversion of RVAB falls within the limits of 77–81% depending on the mass of BC sequestered in the soil. BC stored as stock represents useful energy. Energy, thermal and electrical production is done with a total efficiency in the range of 56–77%.

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Table 5. Energy balance for RVAB gasified with CHAB systems

Feature	U.M.	Value 1	Value 2	Value 3	Value 4
Biochar mass gasified	%	100	70	50	0
Annual heat production	TWh.th/y	66,445	62,410	59,720	52,995
Annual electrical energy	TWh.e/y	6,231	4,361	3,115	0,000
Annual energy production	TWh/y	72,676	66,772	62,835	52,995
Energy production efficiency	%	76,91	70,66	66,49	56,08
Biochar production efficiency	%	0,00	7,31	12,18	24,35
CHAB system efficiency	%	76,91	77,96	78,67	80,43

The use of BC as an agricultural amendment produces a long–term carbon sequestration of BC, contributing to the decrease in CO2 emissions. If 100% of the BC produced is used as an amendment, 2.25 Tg.C/year corresponding to 8.25 Tg.CO2/year can be sequestered. It follows that the energy use of RVAB can be done with a negative footprint CFPex << 0. (Table 6)

Table 6. Utilization of agribiochar

Feature	U.M.	Value 1	Value 2	Value 3	Value 4
CFP Carbon Footprint		≥ 0	≤ 0	< 0	<< 0
Biochar mass gasified	%	100	70	50	0
Biochar energy for CHP	TWh/y	23,012	16,109	11,506	0,000
Biochar Mass not gasified	Tg.bc/y	0,000	1,048	1,746	3,492
Annual carbon mass sequested in soil	TgC/y	0,000	0,675	1,124	2,249
Annual mass of CO2 sequested in soil	TgCO2/y	0,000	2,474	4,123	8,246

The main use of RVAB is energy production, table 7 shows the coverage level of energy consumption for 2020 in Romania. The INS data for 2021 has not yet been published, but the evolution of previous years indicates variations below 5%.

The energy recovery of RVAB can produce energy that covers at least 8 times the consumption in agriculture in option four and 11 times in option one. This aspect is mainly due to the overall energy efficiency of agricultural production, which for corn is EFEN=17, for wheat it is EFEN = 7.2 (*Murad E., 2021*).

The annual energy consumption of the population can be covered 56 – 77 %, depending on how much BC is used as an agricultural amendment. This energy input can substantially reduce the consumption of natural gas and LPG in urban and rural environments.

At the national level, on average, 15% of all energy consumed in 2020 can be covered, which in the current energy crisis can represent a substantial support for a stable and sustainable development.

BC gasification produces gaz.bc, which cooled and filtered can be used as a substitute for natural gas (NG). Table 8 presents the possibilities of compensating NG consumption from 2020 with locally produced energy from BC. In option one, when 100% of the BC produced is gasified, it is possible to produce cold gas.bc equivalent in energy to 1.7 billion m3 of NG, which would replace 86% of the annual import of NG.

Table 7. Energy cover with RVAB energy potential in RO 2020

Feature	U.M.	Value 1	Value 2	Value 3	Value 4
AgriBiochar mass gasified	%	100	70	50	0
AGR + SILV annual energy consumption 2020	ktep	566	566	566	566
AGR + SILV annual energy consumption 2020	TWh	6,583	6,583	6,583	6,583
Cover of Agriculture Energy consumption 2020	%	9,06	9,86	10,48	12,44
Cover of Agriculture Energy consumption 2020	%	1104	1014	954	803
Annual energy population consumption 2020	Mtep/y	8,100	8,100	8,100	8,100
Annual energy population consumption 2020	TWh/y	94,203	94,203	94,203	94,203
Cover of population energy consumption 2020	%	77,15	70,88	66,70	56,26
Annual energy consumption in RO 2020	Mtep/y	37,233	37,233	37,233	37,233
Annual energy consumption in RO 2020	TWh/y	433,02	433,02	433,02	433,02
Cover of energy consumption in RO 202	%	16,78	15,42	14,51	12,24

Table 8. Energy from gas.bc versus natural gas

Feature	U.M.	Value 1	Value 2	Value 3
Biochar mass gasified	%	100	70	50
Energy efficiency gas.bc cooled	%	75,0	75,0	75.0
Annual energy from gas.bc cooled	TWh/y	17,259	12,081	8,630
HHV of natural gas	kWh/m^3	10,000	10,000	10,000
Volume of NG with equal energy	$Gm^3.ng/y$	1,726	1,208	0,863
Annual energy from imported NG	ktep/y	1726	1726	1726
Energy equivalent	GWh/ktep	11,63	11,63	11,63
Annual energy from imported NG	TWh/y	20,073	20,073	20,073
Cover of annual NG import	%	85,98	60,19	42,99

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Decarburization of the economy is a primary objective of the current stage of development. When achieving this objective, the use of BC produced from RVAB as an agricultural amendment ensures CFPex << 0 and contributes to increasing the fertility of the treated agricultural lands. Table 9 shows the effects of using BC as an agricultural amendment. Recent metastudies have concluded that on average biochar used as an agricultural amendment correlated with soil properties and base crop provides an average 13% increase in agricultural production.

Table 9. Biochar as agricultural investment

Feature	U.M.	Value 2	Valu e 3	Value 4
Biochar mass gasified	%	70	50	0
Agriculture production average growth	%	13,0	13,0	13,0
Biochar Mass not gasified	Tg.bc/y	1,048	1,746	3,492
Average BCH mass incorporation ratio	Mg.bc/ha	2,000	2,000	2,000
Surface with BCH amendment	Mha/y	0,524	0,873	1,746
Average food biomass production RO2021	Mg.fb/ha.y	4,828	4,828	5,828
Plus of food biomass production RO 2021	Tg.fb/y	0,3288	0,5479	1,3228
Agriculture food biomass production 2021	Tg.fb/y	35,15	35,15	36,15
Production relative growth 2021	%	0,94	1,56	3,66

The use in option four can ensure an increase in food biomass production by 1.32 Tg.fb/y, i.e. an increase of 3.7% of the total production. It's not much, but extra food is produced and CO2 emissions are substantially reduced. Table 10 shows the climatic effects obtained from the energy recovery of RVAB. In variant one of the analysis, the final specific emission is small but positive 0.122 Mg.CO2/Mg.br. In option four with all BC sequestered in the soil, a negative carbon footprint of –5.89 Tg.CO2/year is obtained. The difference compared to the value of 8.25 Tg.CO2/year from table 6, corresponding to the mass of carbon sequestered in the soil, is due to the addition to the positive emissions produced during the processing of RVAB and the operation of energy systems.

Table 10. Carbon footprint

Feature	U.M.	Value 1	Value 2	Value 3	Value 4
Biochar mass gasified	%	100	70	50	0
CFP from CHAB plants	Mg.C/Mg.br	0,037	0,037	0,037	0,037
Annual CFP from CHAB plants	Tg.C/y	0,643	0,643	0,643	0,643
Annual CFP from CHP operation	Tg.C/y	3,33E–02	2,33E–02	1,67E–02	0,00E+00
Annual CFP energy from RVAB	Tg.C/y	0,676	0,666	0,660	0,643
Carbon in soil amendment	Tg.Cbc/y	0	0,675	1,124	2,249
Annual CFP energy from RVAB	TgC/y	0,643	–0,032	–0,482	–1,606
Annual CFP energy from RVAB	Tg.CO2/y	2,357	–0,117	–1,766	–5,889
Specific CFP energy from RVAB	Tg.CO2/Tg.br	0,122	–0,006	–0,091	–0,304
Annual CFP from agriculture 2021	Tg.CO2/y	15,000	15,000	15,000	15,000
Cover of agriculture 2021 CFP	%	+15,70	–0,80	–11,80	–39,30

In agriculture, the annual energy consumption has small variations and as a result it can be estimated that the CO2 emissions are also relatively constant. Taking the basis of 2020, an emission of 15 Tg.CO2/year can be estimated for agriculture in 2021, which indicates that it could be reduced by about 40%.

4. CONCLUSIONS

In the current energy crisis, from residual agricultural biomass RVAB, collectable in 2021, with a mass of 20 Tg.br/y and an energy potential of 95 TWh/y, energy and biochar can be produced that would cover 15% of the annual energy consumption in RO 2021.

The results of the AgroBioHeat Project 2019 – 2022 show that RVAB can be safely and economically collected in Romania and in other EU countries where heat is produced for local consumption in rural areas through combustion. The alternative to the combustion process, more efficient energetically, ecologically and economically, is the thermo–chemical conversion through pyrolysis and gasification, electricity, heat and ecological amendment for agriculture are produced

With oxypyrolysis processes from the collected RVAB, thermal energy 53 TWh.th/y and 20% biochar is obtained, which contains energy of 23 TWh/y. Biochar with a moisture content of 10% can be stored safely and cheaply, constituting an energy stock, corresponding to 6% of the national reserve of energy resources RO 2021, a stock of usable energy when and as much as necessary, in areas without access to NG, in the winter and in peak loads in the national system.

Biochar used as an agricultural amendment can annually produce an additional 1.323 million tons of food vegetable biomass, i.e. an additional 3.6% of agricultural vegetable production and in the next 20–30 years, justifying itself as a very profitable long–term investment.

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At the same time, 2.25 Tg.C/y are sequestered in the long term, corresponding to a decrease of –5.889 Tg.CO_2/y or about –6% of the national annual CFP. By gasifying the BC produced, energy equivalent to that of 1.7 billion m^3 of natural gas can be produced, i.e. 86% of annual imports.
The biochar obtained from RVAB and used in CHPs can annually produce electricity of 6.23 TWh.e/y and usable heat 13.45 TWh.th/y, which can contribute to reducing the energy poverty of small towns in RO.
Although biomass does not appear explicitly in the PNRR, the allocation of European and private financial resources can contribute to accelerating the exploitation of the real green energy resource contained in the RVAB.
The economic evaluation of the energy recovery of RVAB is ongoing and will be the subject of future published papers

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