

CONCEPT OF BIOHYDROGEN PRODUCTION BY AGRICULTURAL ENTERPRISES

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ABSTRACT

Biohydrogen production in agricultural enterprises is an urgent matter. It is appropriate to utilize two methods of biohydrogen production: a thermochemical method – from crop-based biomass and anaerobic digestion (fermentation) method – from animal-based biomass. It is appropriate to use gasifiers for the thermochemical method and bioreactors for fermentation method.

The theoretical potential of biohydrogen was established with due regard to the amount of biomass which is necessary for utilization in livestock agriculture, for fields fertilization as well as with the consideration of the coefficients of concordance with hydrogen equivalent and loss factor under biohydrogen production. The theoretical potential of biohydrogen from crop-based biomass in Ukraine amounts to 77 billion m³, during the period of three years (on average 25.6 billion m³ per year).

Introduction

Agricultural production mainly focuses on providing the population with foodstuffs (Golub et al., 2017). However, agricultural production can also effectively arrange for production of biofuel from biomass, in particular biogas, diesel biofuel, bioethanol, baled straw, fuel pellets, briquettes and generator gas (Kukharets, 2016; Rzeznik and Mielcarek, 2018; Ovcharuk et al., 2020). Such a production has become traditional, though the production of renewable energy from biomass causes some fear in researchers as to reduction of the level of core product production – foodstuffs, as well as to reduction of the amount of plant food in

soil caused by the use of some cultivated areas for growing bioenergy crops and by the use of straw as fuel (Verdade et al., 2015; Gomiero, 2018; Tryhuba et al., 2021a, Tryhuba et al., 2021b).

For this reason, it is necessary to coordinate the main criterion of functioning of the agricultural production: ecological safety, power supply and economic effectiveness. Such research was conducted and it was concluded that agricultural production can provide itself with energy resources (Yarosh, 2020; Golub et al., 2020b). However, this research was based only on biomass utilization. Thus, the effects of using hydrogen technologies on biological safety and economic effectiveness was not determined.

Though, according to the research, (Gas Decarbonisation Methods, 2020) the EU is planning to produce more than 1700 TWh using hydrogen technologies by 2050. That is why it is appropriate to use hydrogen technologies for energy production in agricultural production.

Two methods of biofuel production are appropriate for hydrogen production in agricultural production – thermochemical (Fig. 1) and biofermentation (Fig. 2).

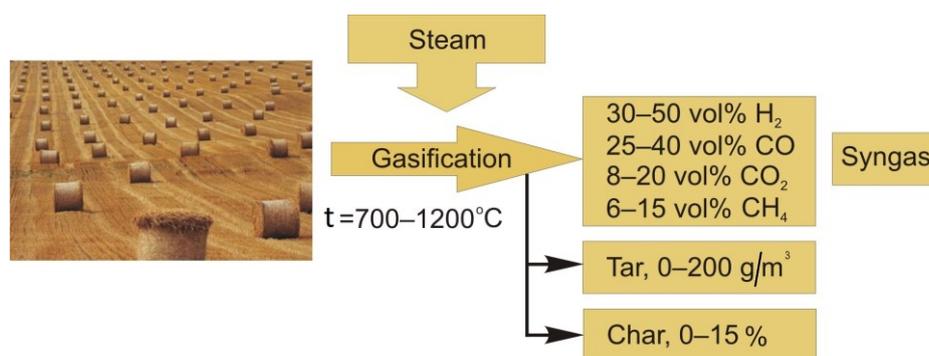


Figure 1. Thermochemical method (Bhoopendra et al., 2019)

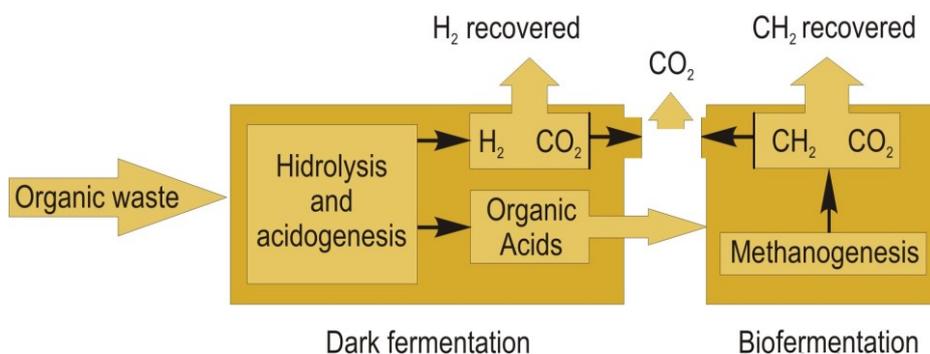


Figure 2. Anaerobic digestion (fermentation) method (Baeyens et al., 2020)

Should be "Hydrolysis" instead of "hidrolisis" in the figure above

When using the thermochemical method, hydrogen is produced as a result of decay of crop-based biomass (Bhoopendra et al., 2019; Pandey et al., 2019). To produce hydrogen from biomass by the thermochemical method it is appropriate to use gasifiers of a new type (Fig. 3) designed by the authors of the paper.

The main obstacle for production of generator gas from crop-based biomass is the formation of solid agglomerates (particles, residues) in the process of generator gas production. To avoid the formation of agglomerates, the authors of the paper have designed the gasifier construction which does not have a fire grate, and gas withdrawal occurs through joints on the side surface of the recovery zone (Golub et al., 2020a).

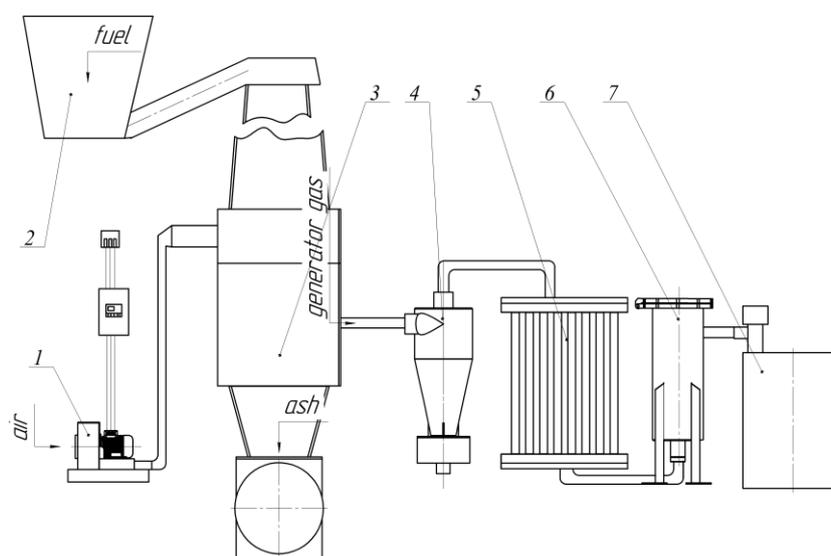


Figure 3. Thermochemical plant scheme: 1 – a fan for supplying air to the gasifier; 2 – bunker for fuel; 3 – gasifier; 4 – prime filter; 5 – cooler; 6 – fine filter; 7 – gas upgrading (Golub et al., 2020a).

In the process of fermentation, hydrogen is obtained by biomass processing with special bacteria (Baeyens et al., 2020).

To provide efficient production of hydrogen by fermentation under conditions of agricultural enterprises we suggest using bioreactors designed by us (Fig. 4).

The authors of the paper (Golub et al., 2019) suggest new engineering solutions in the system of substrate motion in a bioreactor. They insist on using direction change of gravity forces, that influence the movement of organic and mineral fractions of biomass. The bioreactor case is cylinder-shaped which spins around a horizontal axis. The bioreactor rotates in liquid which is in an outside case. Such a construction induces the lift for a rotary bioreactor while discharging the supporting bearings. The friction force reduces and the energy which is used for bioreactor rotation and substrate motion, reduces as well. The bioreactor construction contributes to a steady motion of a substrate and prevents the formation of floating organic particles as well as of immersed sediments.

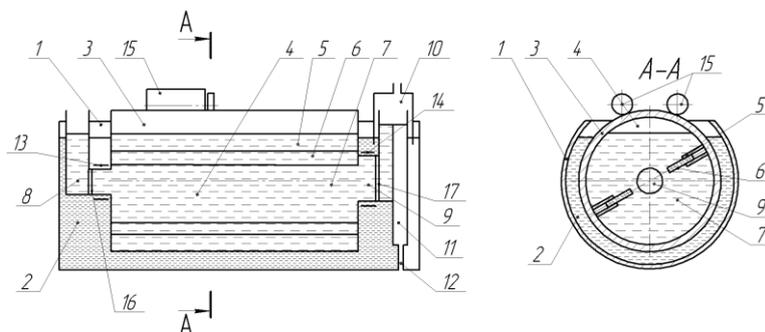


Figure 4. Biohydrogen plant scheme: 1 – horizontal outer housing; 2 – liquid; 3 – cylindrical bioreactor; 4 – fermentation chamber; 5 – partition; 6 – movable plates; 7 – organic mass; 8, 9, 12 – sockets; 10 – gas collector; 11 – the discharge chamber; 13, 14 – bearing joints; 15 – external drive; 16, 17 – interpolator (Golub et al., 2019).

The use of the suggested equipment for hydrogen production requires further economic and technological research.

Material and Methods

The management of crop-based biomass for hydrogen production requires bulk-yield monitoring of grain-crops by-products (straw) and consideration of coefficient of its utilization for energy requirements.

To determine the theoretical potential of hydrogen production from plant raw materials of the agrarian origin when using the thermochemical method, the data on the available gross output of crops in crop farming and the average coefficients of the available, technical and economic potentials of by-products (up to 0.7) were used.

While determining the theoretical potential of biohydrogen it should be taken into account that some amount of straw is required to use in cattle breeding and for fields fertilization. Thus, while determining the potential, it is necessary to use the factor for reducing to by-products. (Avcioglu et al., 2019). It is also necessary to use the factor for reducing to a hydrogen equivalent with the heat value of $119.83 \text{ MJ} \cdot \text{kg}^{-1}$ (Mortensen et al., 2020; Cao et al., 2020).

Biohydrogen yield from 1kg of raw materials (e.g., for the straw from grain crops it equalled up to $2.8 \text{ m}^3 \cdot \text{kg}^{-1}$ (Golub et al., 2018)), the hydrogen content in the received gas (up to 40%) as well as the loss coefficients in the process of gas purification and using (up to 0.3) were taken into account.

To determine the theoretical potential of hydrogen production from the plant raw materials of the agrarian origin by using the fermentation technique, similar to the thermochemical transformation, the data on the available gross output of crops in crop farming and the average coefficients of the available, technical and economic potential of by-products (up to 0.7) were used.

The coefficients of gas yield from 1 kg of dry mass of plant origin (up to $0.13 \text{ m}^3 \cdot \text{kg}^{-1}$) (Kukharets and Golub, 2015) depending on the biomass kind, as well as loss coefficients in the process of purification and using the received gas, were taken into account.

Results and Discussion

With due regard to feasibility of hydrogen production, an advanced method of biofuel production at the agricultural enterprises has been suggested (Fig. 5). Diesel biofuel, bioethanol (in the amount necessary to provide the mobile machinery operation), biogas, biohydrogen, generator gas, solid fuel (rolls, pellets (granules), straw briquettes) are produced according to this method.

A part of plant biomass (straw) is used for the production of pellets (granules). Generator gas is made from granules. Generator gas is used for biohydrogen production. Biohydrogen and biogas are made from animal residues by means of fermentation.

Gross yield of grain crops which are grown on all types of farms in Ukraine is given in Table 1 (without oil plants).

Table 1.

Gross yield of grain crops the products of which are suitable for energetic needs in Ukraine, thous. t.

Crop	Years			In aggregate, in the course of 3 years
	2016	2017	2018	
Winter wheat	25320.7	25398.5	23906.6	74625.8
Spring wheat	722.7	759.5	699.2	2181.4
Winter rye	389.2	505.4	393	1287.6
Spring rye	2.4	2.5	0.8	5.7
Winter barley	3637.5	3041	2923.2	9601.7
Spring barley	5798.2	5243.9	4425.9	15468
Oats	499.9	471.4	418.5	1389.8
Millet	189.7	84.4	80.5	354.6
Buckwheat	176.4	180.4	137	493.8
Rice	64.7	63.9	69.2	197.8
Grain maize	28074.6	24668.8	35801.1	88544.5
Sorgo	273.7	198.5	194	666.2

Sources: calculated according to the data of State Statistics Service of Ukraine (Roslynnystvo Ukrainy), 2019

The theoretical potential of biohydrogen was determined with due regards to indices mentioned above (the thermochemical method – Tab. 2, Fig. 6 and anaerobic digestion method – Tab. 3).

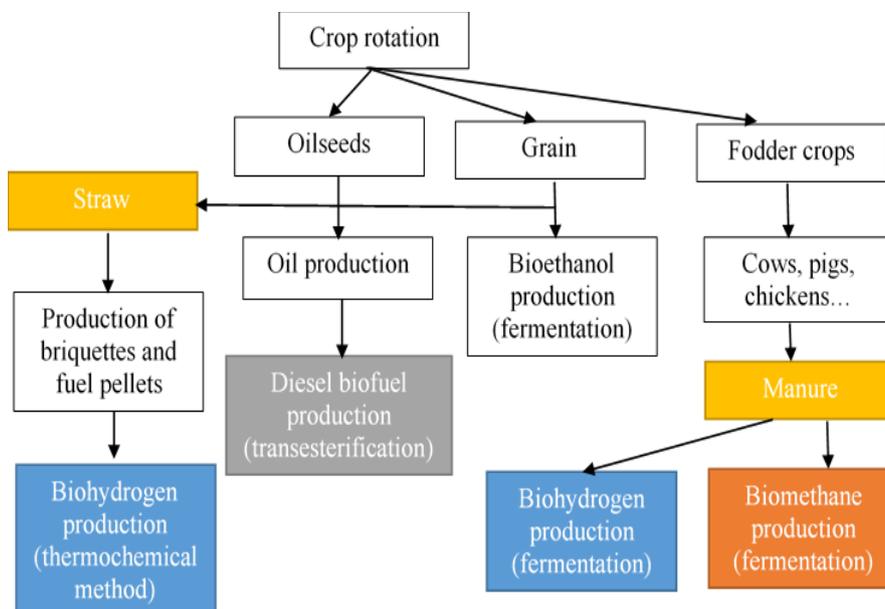


Figure 5. Scheme of biofuel production at agricultural enterprises

Table 2.
Monitoring of theoretical potential of biohydrogen production (thermochemical method) from biomass of plant origin during 2016-2018 in Ukraine, milion. m³

Crop	Years			In aggregate, in the course of 3 years
	2016	2017	2018	
Winter wheat	11431	11466	10793	33690
Spring wheat	326	343	316	985
Winter rye	119	154	120	393
Winter barley	1093	913	878	2884
Spring barley	1742	1575	1329	4646
Oats	98	93	82	273
Grain maize	10721	9420	13671	33812
In aggregate	25529	23964	27189	76682

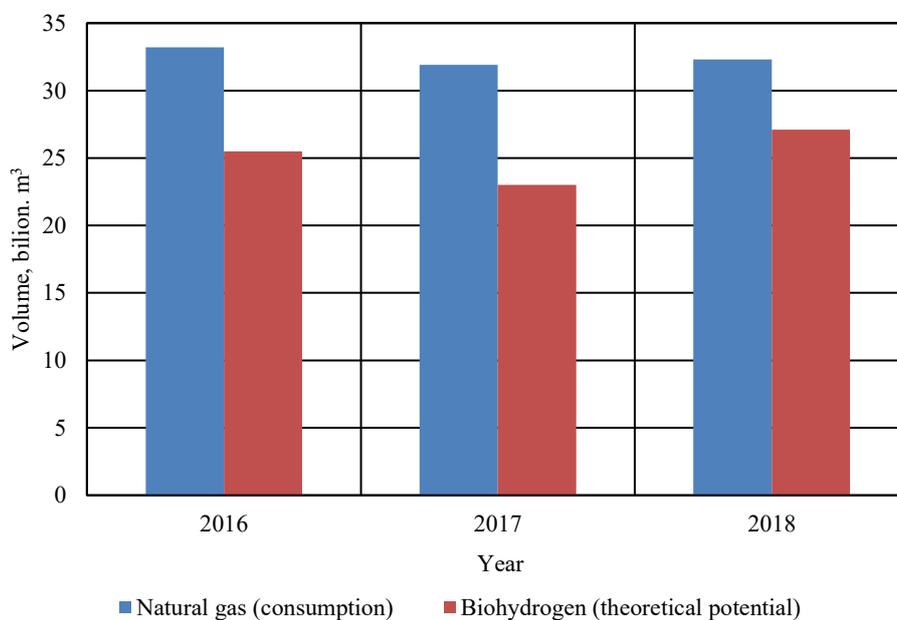


Figure 6. Biohydrogen potential on the basis of biomass of plant origin in the agricultural production of Ukraine

Table 3. Monitoring of theoretical potential of biohydrogen production (anaerobic digestion method) from biomass of plant origin during 2016-2018 in Ukraine, milion. m³

Crop	Years			In aggregate, in the course of 3 years
	2016	2017	2018	
Winter wheat	1170	1174	1105	3449
Spring wheat	33	35	32	101
Winter rye	12	16	12	40
Winter barley	112	94	90	295
Spring barley	178	161	136	476
Oats	10	9	8	28
Grain maize	1098	965	1400	3462
In aggregate	2614	2454	2784	7851

The potential of hydrogen production in the agricultural production by using the technique of thermochemical transformation is approximately 10 times higher than the potential of hydrogen production when using the fermentation method. However, the hydrogen production by using the fermentation method makes it possible to receive organic fertilizers and is appropriate for using in animal husbandry.

Thus, theoretical potential of biohydrogen from crop-based biomass in Ukraine is 77 billion m³, during 3 years (25.6 billion m³ on the average).

The further theoretical and experimental analysis of both methods of hydrogen production under conditions of agricultural production are required for the practical realization of hydrogen potential.

Acknowledgments

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Conclusions

1. It is expedient for the agricultural production to produce biohydrogen with the thermochemical method from crop-based biomass and with the fermentation method from biomass of animal origin.
2. It is appropriate to use the improved gasifiers without a fire-grate for biohydrogen production with the thermochemical method. And it is expedient to use bioreactors for biohydrogen production with the fermentation method.
3. Theoretical potential of biohydrogen from crop-based biomass in Ukraine is 77 billion m³, during 3 years and 25.6 billion m³, on the average.

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POJĘCIE PRODUKCJI BIOWODORU PRZEZ PRZEDSIĘBIORSTWA ROLNICZE

Streszczenie. Kwestię produkcji biowodoru w przedsiębiorstwach rolniczych należy traktować jako pilną. Powinno się stosować dwie metody produkcji biowodoru: metodę termiczno-chemiczną z biomasy rolniczej i metodę fermentacji beztlenowej z biomasy pochodzenia zwierzęcego. W przypadku metody termiczno-chemicznej odpowiednie jest zastosowanie generatora gazu, a w przypadku metody fermentacji – bioreaktora. Teoretyczny potencjał biowodoru został określony biorąc pod uwagę ilość biomasy potrzebnej do hodowli zwierząt, do nawożenia pól, a także przy uwzględnieniu współczynników zgodności z odpowiednikiem wodoru i współczynnika strat w produkcji biowodoru. Teoretyczny potencjał biowodoru z biomasy pochodzenia roślinnego na terenie Ukrainy wynosi 77 miliardów m³ w ciągu trzech lat (średnio 25,6 miliarda m³ na rok).

Słowa kluczowe: bioreaktor, gazogenerator, potencjał, biomasa