ANALYSIS OF POSSIBILITIES FOR THE PRODUCTION AND USE OF AGRIBIOMASS BRIQUETTES IN UKRAINE

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Summary

Position Paper No. 20 by the Bioenergy Association of Ukraine includes analysis of opportunities for increasing the volumes of production and use of biomass fuel briquettes for the needs of population. Characteristics of different types of briquetting equipment are presented, requirements for feedstock are considered, techno-economic and legislative aspects of briquettes production are analysed. Some successful examples of the introduction of biomass briquetting lines in different regions of Ukraine are described. Feasibility study of several typical variants of the production and consumption of briquettes from agribiomass has been developed.

1. Expediency and advantages of using fuel biomass briquettes

Biomass briquettes are a kind of solid biofuel that is widely used in developing countries, and the interest in which has long existed and is growing in developed countries of Europe and North America.

In Sweden, the first briquetting lines were introduced at several large sawmills in the early 1900's. Large-scale production of wood briquettes started in the 1970s after the first oil crisis and today exceeds 300 kt/yr[1] [2]. An interesting example is the DH system in the town of Floby, which operates fully on wood briquettes annually supplying consumers about 9 GWh of heat[3].

In Germany, the volume of wood and agribiomass briquettes production is more than 1.75 Mt/yr with the total installed capacity of briquetting equipment of 3.25 Mt/yr. The main part of the produced fuel briquettes (about 1.2 Mt/yr) is consumed internally, and the rest is exported to other European countries. In Germany, biomass briquettes are used mainly in domestic and small boilers with manual loading, but a certain amount is also used in semi-automated and fully automated boilers of up to 5 MW capacity. Much attention is paid to the development and improvement of specialized energy equipment, resulting in a low emission of harmful substances during burning of briquettes and high efficiency of up to 90%[4].

Examples from other European countries: the annual production of biomass briquettes in Croatia is more than 60 kt, in Serbia 30 kt, in Bosnia and Herzegovina 35 kt, in Macedonia 5 kt, in the Czech Republic 188 kt of pellets and briquettes together[5]. Agribiomass briquettes production is actively developing in Moldova, and currently it is estimated at more than 86 kt/yr, with new

[1] Susanne Paulrud. Upgrade Biofuels – Effects of quality on processing, handling characteristics, combustion and ash melting. Doctor Thesis, Swedish University of Agricultural Sciences, Umea, 2004 https://pub.epsilon.slu.se/533/1/Agraria449.pdf

[2] Johan Karlhager. The Swedish market for wood briquettes: production and market development, 2008 https://stud.epsilon.slu.se/12071/1/karlhager_j_171108.pdf

[3] http://ukrfuel.com/news-briquettes-used-in-district-heating-in-4.html

[4] https://www.slideshare.net/azeus13/the-fast-growing-biomass-briquettes-market-in-germany-41545601

[5] Data from documents available on website https://www.unece.org/info/ece-homepage.html

producers being able to receive some support from the EU-UNDP "Energy and Biomass" project[6].

The subject of fuel biomass briquettes is extremely topical for Ukraine as well. Since May 2015, natural gas prices for households have increased considerably in the country, which has led the population's active switching to biomass. A large number of domestic boilers for solid fuel was installed, currently they are running mostly on firewood. A considerable amount of firewood is harvested by the people themselves (so-called "self-harvesting") from field shelterbelt forests and other shelterbelt forests, which actually leads to their destruction. Such firewood is of high humidity, low quality and does not meet the passport requirements of energy equipment. The consequence of its use in domestic boilers for solid fuel is low efficiency of the equipment and high levels of emissions of harmful substances.

The way out of this negative situation can be the transition from wood to the use of biomass ***briquettes***, mainly ***agribiomass*** briquettes (straw of cereals and rape, corn/sunflower stalks, etc.) due to its big potential in Ukraine available for energy – about **8.3** Mtoe/yr (data of 2016). Briquettes are improved biofuels with predictable quality, so they are often called "Euro-firewood".

Advantages of using agribiomass briquettes:

- Compliance with boiler equipment requirements, best environmental performance during combustion.
- Ability to be used in existing ovens, domestic (15-30 kW) and small boilers for solid fuels with manual loading (up to ~ 100-150 kW). Briquettes do not require specialized equipment, in contrast to more expensive biomass pellets.
- Potential possibility of using relatively low density ("soft") briquettes in bigger boilers with screw feed (up to ~ 1 MW).
- Availability of a large raw material base, especially for agribiomass briquettes.
- Relatively low price. The price per unit of energy for briquettes is comparable to that of wood at much better combustion performance (**Table 1.1**).
- Briquettes are more convenient and economical than wood for transportation and storage. Due to increased energy density, they require lower labour costs when manually loaded into the boiler.
- Briquettes can act as a cheaper substitute for coal, especially in those regions where coal is expensive (4000 UAH/t and more). The cost per unit of energy for briquettes of straw/ sunflower husk can be up to **2** times less than that of coal (see **Table 1.1**).

[6] http://biomasa.md/ru/piata-de-producere-a-bioenergiei/producatorii-de-biocombustibil/

Table 1.1. Comparison of specific energy cost for fossil fuels and biomass

Type of fuel or energy carrier	Price (April 2018), UAH/t without VAT	Lower heating value, MJ/kg	Specific energy cost of fuel/energy carrier, UAH/GJ without VAT
	A	B	A/B
Natural gas for population	5798 UAH/1000 m^3	34.0	171
Natural gas for industry	8686 UAH/1000 m^3	34.0	256
Coal	**3000-5000***	**25.0**	**120-200**
Fuel oil	9000	42.0	214
Electricity	1.91 UAH/kWh	-	531
Wood pellets/briquettes	2900**	17.0	171
Sunflower husk pellets	1700**	17.5	97
Straw pellets	1800**	16.0	112
Sunflower husk briquettes	**1600****	**17.5**	**91**
Straw briquettes	**1900****	**16.0**	**119**
Firewood (W40%)	**950**	**10.0**	**95**
Wood chips	1000	10.1	99
Baled straw or corn stalks	900	14.6	62

** Approximate price.*

*** Approximate price. Actual price strongly depends on quality of a concrete batch of pellets/briquettes and a region of its production.*

2. Review of Ukrainian solid biofuel market

According to Ukraine's Energy Balance for 2016[7], the production of biofuels and waste was **3348** ktoe, and the supply of primary energy from them was **2832** ktoe (3.1% of TPES). The difference between them was mostly due to export of biofuels (553 ktoe in 2016). The annual increase in bioenergy sector during 2010-2016 on average can be assessed at 45% by the production of biofuel and waste and at 35% by the total production of primary energy from them.

Solid biofuels such as firewood, wood chips, biomass pellets and briquettes, baled straw occupy the biggest part of biofuel market. According to expert estimation[8], the total production of pellets in Ukraine in 2015 was about **1.32** Mt at 494 plants, including up to 390 kt of wood pellets, about 724 kt of sunflower husk pellets, 146 kt of straw pellets, 8.4 kt of peat pellets and 51.8 kt of pellets from other types of feedstock.

[7] Energy Balance of Ukraine for 2016. Express issue of the State Statistics Service of Ukraine N 06/0/08.4вн-17 of 20.12.2017.

[8] Complex analysis of Ukrainian biomass pellets market. UNDP, GEF project, 2016 http://uabio.org/img/files/docs/kompleksnii_analiz_ukrayinskogo_rinku_pelet_z_biomasi.pdf

The volume of production of fuel briquettes in Ukraine is less than that of pellets, the main types of feedstock being wood, husk, straw and reed. The production of wood briquettes in 2015 was 170 kt, the production of briquettes from agricultural crops was 95 kt[9].

At present a big part of pellets and briquettes is exported from Ukraine to Europe because of low demand in the internal market. Thus, the exports of wood pellets in 2015 was over 150 kt (38.5% of the total production), the exports of husk pellets (including re-exports) was almost 822 kt[8]. Despite of a number of problems, this segment of bioenergy continues growing. Creation of favourable conditions in the internal market will help to reorient the solid biofuel from its export to the internal.

Main features of the production of solid biofuel in Ukraine are its regional irregularity, comparative dispersion, and a big number of small production plants dealing with traders. Another feature is location of production plants as close as possible to sources of feedstock. For instance, producers of wood pellets and peat pellets are located mainly in Western Ukraine and only some of them are situated in industrial regions of central and eastern parts of the country (up to 70% of wood pellets is produced in the following 7 oblasts: Zakarpatska, Volynska, Chernigivska, Kyivska, Zhytomyrska, Lvivska, Sumska. Usually producers of sunflower husk pellets are located closer to central and eastern regions where secondary residues of sunflower processing are available due to high concentration of oil extraction plants (for example, just 4 oblasts, namely Dnipropetrovska, Zaporizka, Odeska, Mykolaivska, provide the production of up to 413 kt that is over 50% of all sunflower husk pellets in Ukraine). Producers of straw pellets are located in agricultural regions their number being not so big and concentration of the production being high. The biggest producers of straw pellets in Ukraine are Smart Holding «Vin-peleta», «Bioenergy» Ltd, «Aver-tekh» Ltd, “Creative Agro”, “Berdianski zhnyvarky” (up to 50% of all the production of straw pellets)[8].

Prices of solid biofuels differ significantly from various producers (**Figure 2.1**) and by region of the country. There is also a fluctuation of prices throughout the year. In particular, they grow in the heating period due to change in the balance of supply and demand. The final price is significantly affected by delivery terms and distance of transportation. In addition, certified biofuels (that is biofuels with confirmed quality), are more expensive and are mainly exported. For example, wood pellets certified by EN Plus A1 100 EUR/t more expensive, and certified agro-pellets are 20 EUR/t more expensive than the respective uncertified pellets[8].

Pellets and briquettes are considered "improved" solid biofuels due to their higher calorific value, less humidity and generally higher energy density (GJ/m^3) compared to uncompressed types of biomass and biofuels.

[9] Roadmap for the development of the solid biofuel market in Ukraine. Project UNDP/GEF, 2016. http://bioenergy.in.ua/media/filer_public/b4/bd/b4bda440-5ab8-4c64-943a-a094da7a757f/dorozhnia_karta_z_rozvitku_rinku_tverdogo_biopaliva_ukrayini.pdf

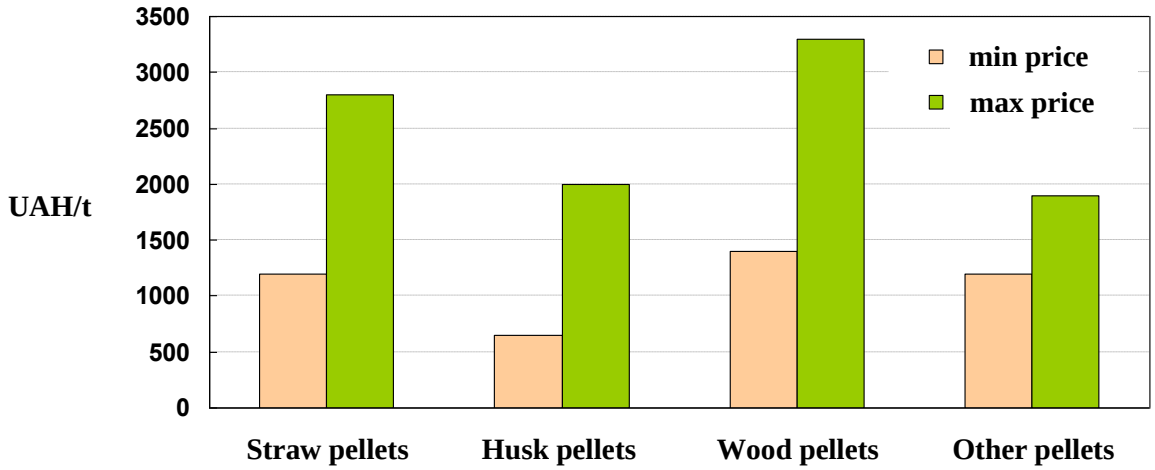


Fig. 2.1. Range of biomass pellets prices in the domestic market proposed by producers in June 2016 (minimal and maximal prices)[8].

The current volume of Ukrainian market of biomass briquettes for population (individual heating) can be estimated as ~**500** kt/yr with the increase to over **3** Mt/yr by 2035 (**Fig. 2.2**)[10].

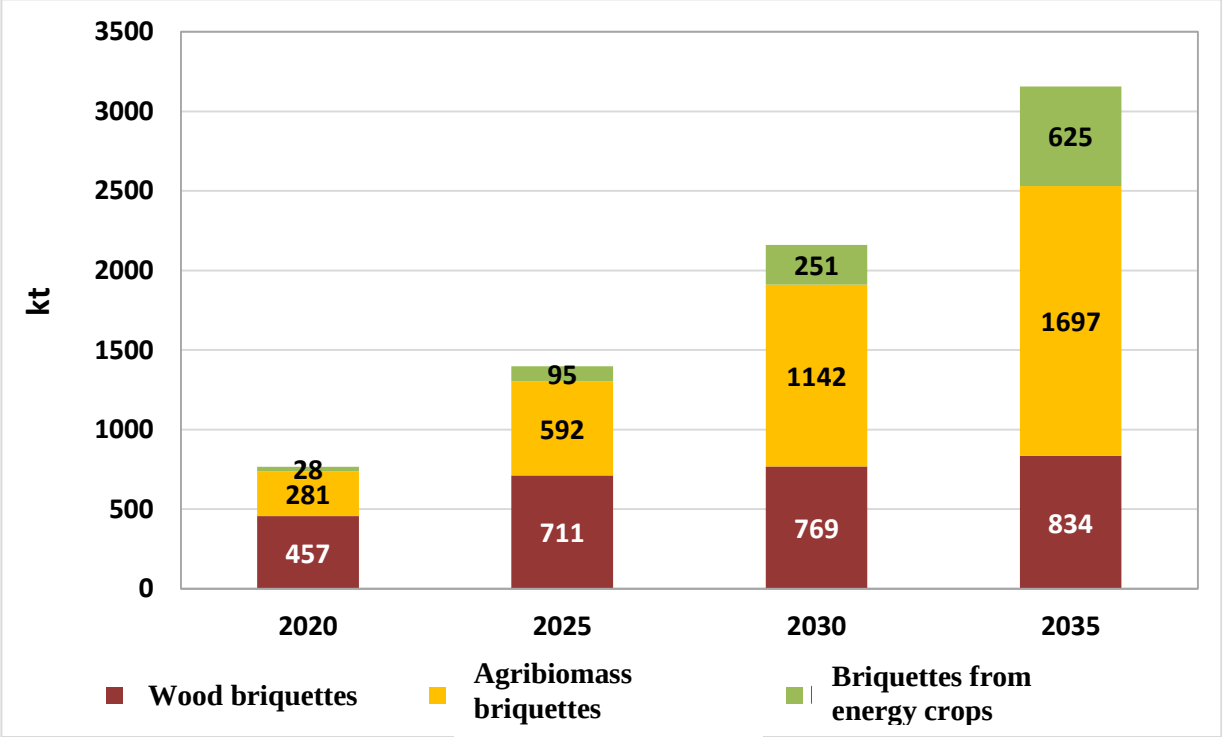


Fig. 2.2. Estimation of Ukrainian market of biomass briquettes for population (individual heating) [10].

[10] The estimation is based on key indexes of the Energy Strategy of Ukraine until 2035, forecast by SEC Biomass for the structure of solid biofuels consumption and forecast for the production of renewable heat in different sectors by 2050.

In Ukraine, there is a ***subsidy*** for population for purchasing ***solid*** stove fuel (coal, firewood, ***briquettes*** etc.[11])[12]. The subsidy is granted if a household is not provided with electricity, heat or gas heating. The subsidy is calculated based on the fuel amount limit of **2 t**[13] per household per year, fuel price limit (which is **2424.16 UAH/t** in 2018[14]) and the total annual income of a family for the previous calendar year.

[11] http://kostvlada.org/priznachennya-subsidii-na-tverde-palivo/
[12] CMU Resolution № 848 of 21.10.1995 (with amendments)
http://zakon3.rada.gov.ua/laws/show/ru/848-95-%D0%BF/page
[13] CMU Resolution № 356 of 23.04.2012 (with amendments)
http://zakon5.rada.gov.ua/laws/show/356-2012-%D0%BF
[14] http://olevsk-gromada.gov.ua/2018/02/16/shhodo-priznachennya-subsidiyi-dlya-pridbannya-tverdogo-paliva-skraplenogo-gazu-u-2018-rotsi/

3. Technological aspects of the production of biomass briquettes

3.1. Feedstock types and requirements to feedstock

Briquetting is the process of compressing the material under high pressure and in some cases under heating up to 250-350 ºC. At the same time lignin is released in the vegetable material, and lignin is a binder for the formation of briquettes. For the production of briquettes from non-wood biomass, environmentally friendly additives (no more than 2%) can be used.

Raw material for the production of fuel briquettes can be softwood and hardwood, straw, cane, husk of sunflower and buckwheat, flax residues, and other vegetable waste. Typical requirements for raw materials are: humidity 6-12%, fractional composition 2-10 mm (**Table 3.1**).

Table 3.1. Characteristics of feedstock for briquettes production[15].

Type of feedstock	Characteristics of feedstock			Characteristic of briquette
	Bulk density, kg/m^3	Moisture content, %	Fraction, mm	Density, t/m^3
Sunflower husk	100	4-9	6-10	1.15
Sunflower husk (comminuted)	260	6-9	2-5	1.09
Buckwheat husk	160	5-12	2-5	1.03
Rice husk	125	5-12	2-6	1.01
Oak sawdust	270	6-12	2-5	1.25
Pine sawdust	125	6-8	2-5	1.15
Chaffed straw[16]	40-60	8-14	5-30	0.7-0.9[17]

The volume of briquette is about 1/10 of the amount of raw material spent on its production. Briquetting of biomass can significantly increase the bulk density and specific energy content of biofuel, which simplifies its logistics (transportation, storage) and reduces the cost of logistics. In addition, the final product (briquettes) has more homogeneous qualitative characteristics compared to uncompressed biomass.

The quality of briquettes depends to a great extent on the moisture content of the raw material. There are optimal and critical humidity. Optimal humidity is 4-10% when the best mechanical characteristics of briquettes are achieved. However, it should be borne in mind that for some types of raw material the upper limit of moisture content is 6-8%. Critical humidity is the humidity at which briquettes can be formed but they have some cracks, so the product loses its marketable condition. The critical humidity is within 10-15%. At higher humidity, the obtained

[15] http://bio.ukrbio.com/ua/articles/1589/
[16] Study of vegetable biofuels in Ukraine and Kyiv region. Report by SEC "Biomass" for «Kyivenergo», 2013.
[17] Bio-briquettes based on straw http://www.gns-halle.de/downloads/info_straw_briquettes.pdf

briquette will be "torn" by the internal pressure of moisture that occurs when compressing the comminuted material[18].

As already mentioned, the production and use of briquettes from biomass of agricultural origin is of particular interest for the Ukrainian conditions. Straw of cereals usually has a relatively low moisture content (within 20%) and can be pelletized/briquetted or baled and burned without additional drying. It should be noted that the optimal relative humidity for straw as a fuel is 11-15%. It is not desirable to use straw with humidity of above 22% as it has a negative effect on the quality of combustion. More detailed characteristics and properties of straw are presented in **Annex 1**.

Table 3.2 gives a comparison of the main characteristics of different sale forms of straw. From the data of the table it is evident that on average the bulk density of straw briquettes is **10** times higher than that of chaffed straw, the density of briquettes is **10** times higher than the density of bales, and the specific energy content is **5-10** times higher.

Table 3.2. Some characteristics of sale forms of straw[19]

Form of straw	Bulk density, kg/m^3	Specific volume, m^3/t	Density, t/m^3 [16]	Specific energy content, GJ/m^3
	A	B=1/A	C	D
Bulk straw	20-50	20-50		0.29-0.72
Chaffed straw	40-60	16-25		0.57-0.86
Round bales	70-110	9-14	0.1-0.14	1.01-1.58
Rectangular bales	70-160	6-14	0.1-0.14	1.01-2.3
Briquettes	300-700	1.4-3.3	0.7-0.9[17]	4.65-11.2
Pellets	500-700	1.4-2.0	1.0-1.4	7.75-11.2

From the economic point of view, the production of biomass briquettes is more attractive than manufacture of pellets as capital costs and operating costs of a briquetting line are significantly lower than those of pelleting line of similar productivity. The average electricity consumption for the production of 1 ton of biomass briquettes is 60-80 kWh, and that for 1 ton of pellets is 90-110 kWh[20]. Requirements to raw material to be briquetted are not as high as for pelleting, so it is possible to obtain briquettes from significantly wider types of biomass.

[18] http://bio.ukrbio.com/ua/articles/2344/

[19] Practical textbook for using biomass as fuel in municipal sector of Ukraine (for representatives of agro-industrial complex), 2017
http://bioenergy.in.ua/media/filer_public/f5/9c/f59c3f7f-8eca-4b6d-94cd-ffda1150f3ae/biofin.pdf

[20] D.P. Kindzera, V.M. Atamaniuk, R.R. Gosovskyi, I.M. Motil. Study of formation of briquettes from vegetable feedstock and determination of their characteristics. Scientific Bulletin of the National Forestry Engineering University of Ukraine, 2013, issue 23.17, p. 138-146
http://nltu.edu.ua/nv/Archive/2013/23_17/138_Kin.pdf

3.2. Types of briquettes and their fuel characteristics

Biomass briquettes are pressed materials of cylindrical, rectangular or any other shape with cross dimension that is not less than 25 mm and with the length of 100-400 mm. The typical diameter of a briquette is 60-75 mm, and its length usually is within 5 diameters. There are no standard sizes for this product.

Briquettes may be of very different shapes but on the whole three types can be distinguished: **NESTRO, RUF** and **Pini&Kay**[15 18 19 21] (the names are based on the names of companies which manufacture well-known presses for the production of briquettes of this type):

- **NESTRO (NIELSEN)** is long briquettes of cylindrical or multiangular cross section mainly without the inner hole (**Fig. 3.1a).** NESTRO briquettes are manufactured with *hydraulic presses*, and NIELSEN briquettes with *mechanical presses* at the expense of high pressure. These briquettes are of unlimited length and can be cut into both "disks" and "logs". The shape of the briquette is ordered by a buyer. The production process is rather simple so highly qualified personnel is not required. **Advantages** of NESTRO (NIELSEN) briquettes are rather low production cost and quite high density (1.0-1.15 t/m^3). **Disadvantage** is poor moisture resistance of the briquettes (therefore secure package is required).
- **RUF** is briquettes of a brick shape (**Fig. 3.1b)** produced with *hydraulic presses* at the expense of high pressure. Dimensions of the briquette depends on the feedstock looseness and applied pressure. Hydraulic presses are considered to be the most reliable briquetting equipment but they are rather expensive. Features of the production process are minimal requirements to the operating personnel and to manufacturing organization. **Advantage** of RUF briquettes is a low production cost. **Disadvantages are** the lowest density compared with other types of briquettes (0.75-0.80 t/m^3); poor moisture resistance of the briquettes (therefore secure package is required); poor mechanical resistance that has a negative impact upon the briquette state after a long transportation.
- **Pini&Kay** is briquettes of cylindrical or multiangular cross section with the inner through hole (**Fig. 3.1c)**. The hole ensures better air movement during combustion. Pini&Kay briquettes are manufactured by extrusion with *mechanical* (*screw) presses* by mixing of high pressure and thermal processing (roasting). The high pressing temperature (250-350 ºC) causes burning-off and strengthening of briquettes surface that ensures transportation of briquettes without damage. Features of the production process are strict requirements to feedstock moisture content (< 8%) and feedstock comminution, high energy-intensity need in highly qualified personnel. **Advantages** of briquettes of this type are high mechanical resistance and moisture resistance, and the highest density compared with briquettes of other types (1.1-1.4 t/m^3). **Disadvantage** is a high production cost.

[21] http://bio.ukrbio.com/ua/articles/7541/

a) NESTRO (NIELSEN) b) RUF c) Pini&Kay

Fig. 3.1. General view of biomass briquettes.

Density is one of the most important indexes of quality of biomass briquettes. Usually it is 0.8-1.3 t/m^3 at the moisture content of the pressed biomass of 8-14%. Density is the main factor that determines mechanical strength and water resistance of a briquette. Heating value of a briquette depends on the type of feedstock used and on the moisture content. Typical range of the lower heating value of biomass briquettes is 16-18 MJ/kg (**Table 3.3**).

Sunflower husk briquettes have high calorific value (LHV comes to 19 MJ/kg) at the expense of comparatively low ash content (2.9-3.6%) and availability of oil in their composition (see **Table 3.3** with experimental data[22]; the table also includes some data from other sources for comparison). On the other hand, due to availability of oil, smoke ducts are sooted more intensely when burning these briquettes and therefore should be cleaned more often. Wood briquettes have low ash content (about 1%) and high heating value (17-19 MJ/kg). Straw briquettes are inferior in quality to sunflower husk/wood briquettes due to higher ash content (5-8%) and lower heating value (about 16 MJ/kg). In addition, straw briquettes have a bit lower density (up to ~1 t/m^3). Of the briquettes types presented in table, rice husk briquettes have the lowest quality due to very high ash content and comparatively low calorific value.

An important advantage of briquettes as fuel is the constancy of temperature during combustion for several hours.

Biomass briquettes can be combusted in domestic boilers and small boilers for solid fuels with manual loading (up to ~100-150 kW), which often are already available in households, state-financed institutions or institutions of social sphere. In the market, there are also automated boilers with a bunker (up to ~240 kW) designed for biomass briquettes. Briquettes of lower density (that is «softer» due to pressing of wetter feedstock) can be used in large boilers with screw feeding. It is expected that the screw manufactured of strong metal will be able to crush briquettes and ensure their uninterrupted feeding into the furnace.

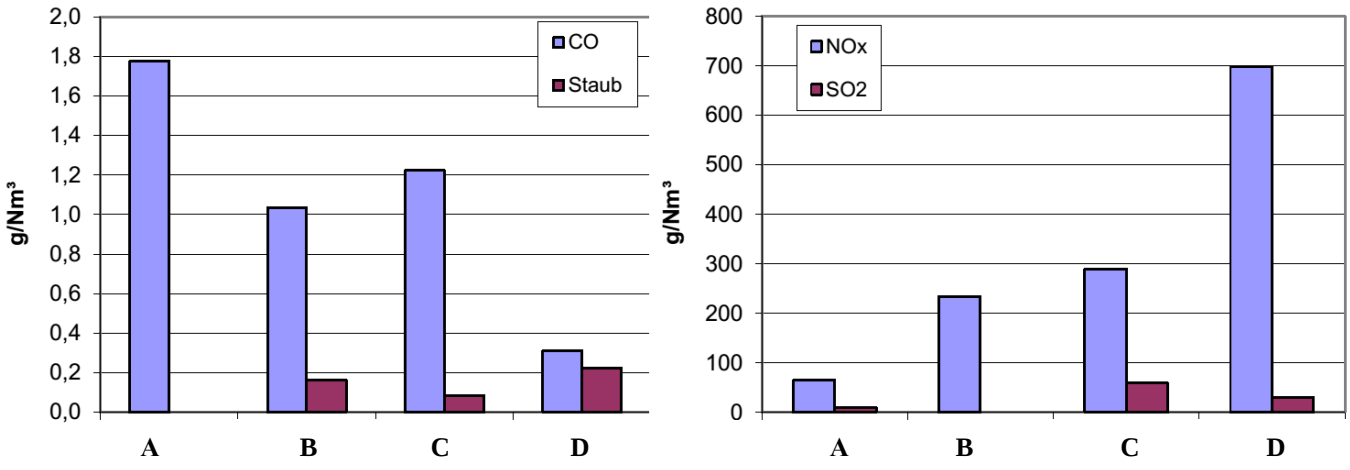
Table 3.3. Characteristics of briquettes produced from different types of biomass[22]

Type of feedstock	Ash content, %	Moisture content, %	LHV, MJ/kg	Density, t/m^3
Straw	7.30 4.86 5.5[23] 8.0[24] 6.1-8.4[17] 4.0[26]	7.80 9.30 6-10[25] 8-10[26]	15.73 15.68 15.4-21.0[25 *] 17.18[24 *] (wheat) 17.60[24 *] (rye) 17.2-17.6[17 *]	1.08 no data 0.7-0.9[17]
Corn cobs and stalks[24 *]	3.0	7.52[27]	15.92 14.13-14.46[27]	0.75-0.92[28]
Sunflower stalks[24 *]	4.3	6-12[20]	18.01	0.85-0.89[20]
Sunflower husk	3.60 2.92	2.70 8.51 6-8[25]	18.77 no data 21.0-21.8[25 *]; 18.85[24 *]	1.15 no data 1.09-1.15[15]
Rice husk	20.2 12.0[24]	7.1 5-12[15]	13.24 13.83[24 *]	1.16 1.01[15]
Sawdust	0.80 1.10 1.16 0.5-1.00[24] 1.0[26]	4.0 10.3 4.1 7-8[25 26]	no data 17.00 18.86 16.8-21.0[25 *] 18.85[24 *] (softwood) 20.53[24 *] (hardwood)	no data no data 0.79 1.15[15] (pine) 1.25[15] (oak)
Grapevine[24 *]	1.5%	no data	14.04	no data
Reed[24 *]	4.0%	no data	16.76	1.12[29]
Miscanthus[24 *]	4.5%; 3.1[30] 3.2[32]	7.5[30]; 3.92[31**] 8[32]	17.5[31**]; 17.6; 17.7[30] 16-18[32 *]	 0.85[32]
Perennial plant stipa capillata[33]	0.7	7.5	18.00	1.37

** It is not specified in the source whether it is LHV or HHV.*
*** Briquette composition: miscanthus 70%, wood– 30%.*

[22] http://term.od.ua/blog/toplivnie-brikety-drevesnie/ (***experimental data***)
[23] http://www.brikk.info/index.php?option=com_content&view=article&id=46:kak&catid=39:articles&Itemid=58
[24] https://bioekoprom.com.ua/ua/novini/teplotvornaya_sposobnost_toplivnyih_briketov_i_nekotoryih_vidov_topliva/
[25] http://agro-business.com.ua/agro/idei-trendy/item/8366-tverde-biopalyvo-tekhnolohichni-vymohy-vlastyvosti-komponentiv-ta-tekhnolohiia-vyrobnytstva.html
[26] O.O. Seriogin, O.O. Osmak, A.V. Bashta. Physical and chemical principles for designing equipment for thermochemical conversion of mixes of biotechnical waste. Bulletin of NTU «KhPI», 2014, № 52, p.125-130.
[27] Józef Kowalczuk, Janusz Zarajczyk, Paweł Sobczak et al. The usefulness of briquettes and pellets from selected plant materials for energy purposes. TEKA. COMMISSION OF MOTORIZATION AND ENERGETICS IN AGRICULTURE – 2012, Vol. 12, No. 2, 311–313.
[28] https://bioresources.cnr.ncsu.edu/BioRes_10/BioRes_10_3_5515_Gong_LWTW_Compress_Charact_Energy_Require_Briquettes_7255.pdf
[29] http://bio.ukrbio.com/ru/articles/4355/
[30] http://www.biofuelmachines.com/miscanthus-pellet-mill-and-miscanthus-pellet-study.html
[31] A.E. Daraban, S. Jurcoane, I. Voicea, G. Voicu. Miscanthus giganteus biomass for sustainable energy in small scale heating systems // Agriculture and Agricultural Science Procedia 6 (2015), p. 538-544 https://ac.els-cdn.com/S2210784315002156/1-s2.0-S2210784315002156-main.pdf?_tid=018af094-fc34-4532-81b4-4f6ce0573588&acdnat=1525331545_e416b2b92fe0aa0a8f52add6eebc56f4
[32] O. Urbanovicova, K. Kristof, P. Findura et al. Physical and mechanical properties of briquettes produced from energy plants. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, V. 65, 2017, p. 219-224 https://acta.mendelu.cz/media/pdf/actaun_2017065010219.pdf
[33] https://en.wikipedia.org/wiki/Stipa_capillata

A group of German companies studied emissions during combustion of ***straw briquettes*** in a 6 kW oven and in a 50 kW boiler with manual loading designed for firewood. The obtained results showed that dust emission was 55-223 mg/nm^3 that in most cases was below the German national limit of 150 mg/nm^3; NO_x emission during combustion of briquettes in the boiler was a bit beyond the existing limit of 600 mg/nm^3; emission of CO and SO_2 was within the national norms (Law 1. BlmSchV) (**Fig. 3.2**). It was determined that the ash melting temperature was > 900 ºC. Based on the results it was concluded that straw briquettes could be used in the existing ovens and small boilers designed for solid fuel[17].



A – 6 kW oven, firewood (for comparison), B – 6 kW oven, straw briquettes with additive to improve the combustion characteristics (sugary solution, max 2%), C – 6 kW oven, straw briquettes without additive, D –50 кВт boiler, 6 kW oven, straw briquettes without additive

Fig. 3.2. Emissions during combustion of straw briquettes (O_2 13% vol.)[17].

A group of researchers from Great Britain, Czech Republic and Poland compared emissions during combustion of ***wood briquettes***, briquettes produced from the mixture of sawdust and coal, coal and wood lumps in a 30 kW boiler. The lowest emission of CO and dust were for wood briquettes, but wood briquettes were inferior in SO_2 and NO_2 emissions to wood lumps (**Table 3.4**)[34].

Romanian researchers studied emissions during combustion of ***briquettes produced from reed, sawdust, the mixture of wheat straw and sawdust, the mixture of sawdust and corn stalks*** in a 40 kW boiler designed for firewood. The results showed that the biomass briquettes were quite suitable for the combustion in such a boiler. In addition, the researchers studied the combustion of briquettes from the mixture of sawdust and corn stalks (50/50) in a *modified* boiler with refractory lining inside the primary combustion chamber and the control of the excess air distribution.

[34] A.B. Ross, J.M. Jones, S. Chaiklangmuang et al. Measurement and prediction of the emission of pollutants from the combustion of coal and biomass in a fixed bed furnace. Fuel 81 (2002), pp. 571-582
http://www.equichannel.cz/data/userfiles/1349325-1-coalBM.pdf

Table 3.4. Measured emissions during combustion of wood and coal in a 30 kW boiler[34].

Substance	Sawdust briquettes (W 9.8%)	Sawdust/coal briquettes (W 5.4%)	Coal (W 3.3%)	Lump wood (W 9.8%)
CO, g/GJ	1760	2140	2990	2400
SO_2, g/GJ	16	110	283	5
NO_2, g/GJ	42	96	162	32
Пил, g/GJ	39	63	294	116

According to results obtained for the modified boiler, combustion efficiency increased up to 96% (for the non-modified boiler it was 91%), boiler efficiency came to 94% (for the non-modified boiler it was 86%), maximal emission of CO decreased from 8292 ppm to 4756 ppm, maximal emission of NO_x fell from 272 ppm to 126 ppm (**Fig. 3.3**)[35]. Nevertheless the achieved emission levels do not meet European standard EN 303-5:2012[36]. *For information: emission limits set by EN 303-5:2012 for boilers below 50 kW with manual loading are 700-5000 mg/m^3 for CO, 60-150 mg/m^3 for solid particles at 10% O_2 depending on a boiler class (classes 3-5 of which 5 is the best)*[37].

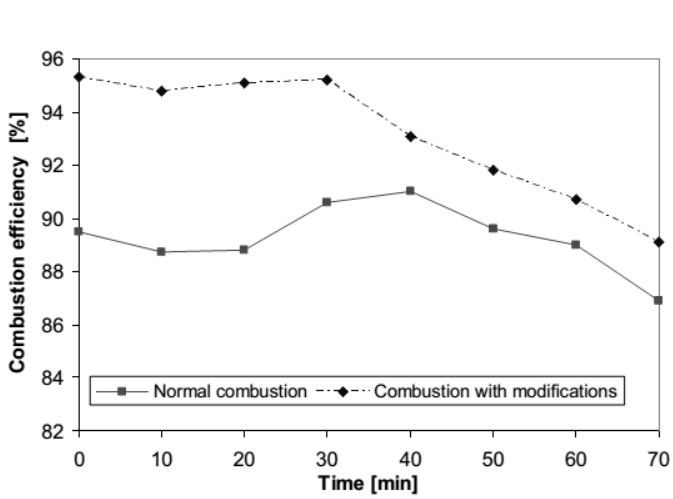
Experiments on the combustion of ***wood briquettes*** in a double-chamber 25 kW VERNER boiler designed for wood chunks and based on the principle of gasification were conducted in Poland (**Fig. 3.4**). Combustion of wood briquettes was compared with combustion of wood pellets in 45 kW VARIMATIK and 22 kW VIADRUS boilers[38]. Obtained results showed that the lowest emission of CO (669 mg/m^3) was measured during the combustion of wood briquettes in VERNER boiler (without primary air) (**Fig. 3.5a**). Emission of NO_x were up to 70-80 mg/m^3 in all the cases except for the combustion of wood pellets in VARIMATIK boiler with primary, secondary and tertiary air (**Fig. 3.5b**).

[35] RĂZVAN MAHU, ION V. ION, FLORIN POPESCU. TESTING OF IMPROVED BOILER FOR BIOMASS BRIQUETTES. Symposium "Actual Tasks on Agricultural Engineering", Opatija, Croatia, 2013. https://www.researchgate.net/publication/280157731_TESTING_OF_IMPROVED_BOILER_FOR_BIOMASS_BRIQUETTES

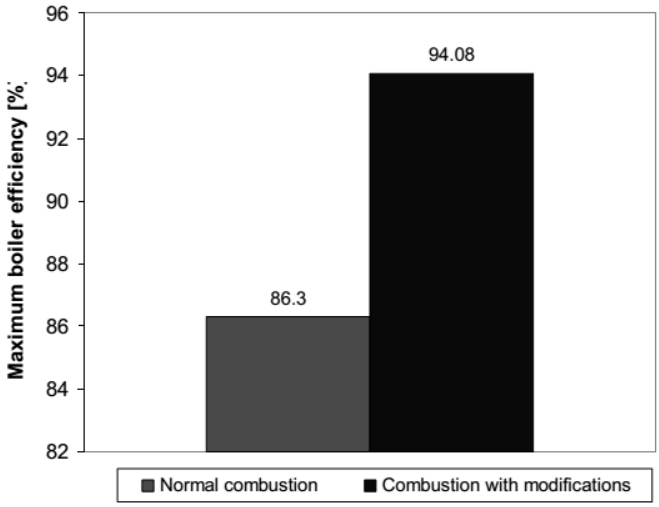
[36] EN 303-5:2012 Heating boilers. Heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500 kW. Terminology, requirements, testing and marking http://store.uni.com/catalogo/index.php/en-303-5-2012.html?josso_back_to=http://store.uni.com/josso-security-check.php&josso_cmd=login_optional&josso_partnerapp_host=store.uni.com

[37] About Nordic Ecolabelled. Boilers for solid biofuel, 2014 http://www.svanemerket.no/PageFiles/11270/biokjel_v3_bkgE.pdf

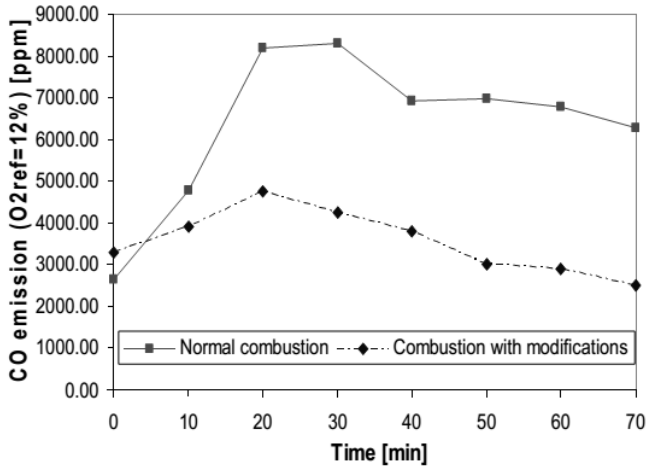
[38] *Martin Polák, Pavel Neuberger.* THE OPTIMISATION OF BIOMASS COMBUSTION IN SMALL BOILERS http://docplayer.net/18261452-The-optimisation-of-biomass-combustion-in-small-boilers.html



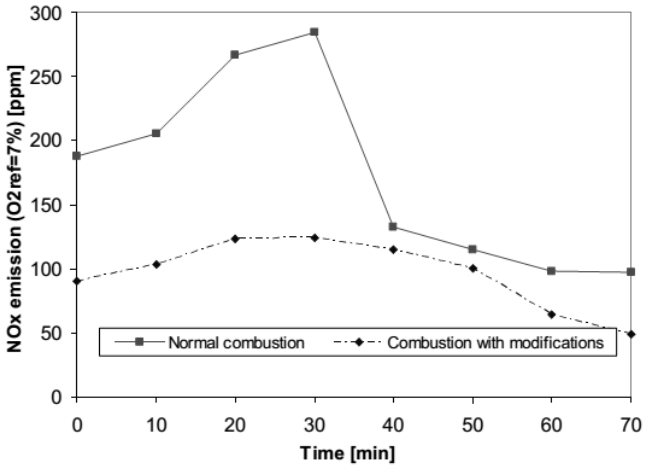
a) Combustion efficiency, %



b) Maximum boiler efficiency, %



c) CO emission, ppm (12% O_2)



d) NO_x emission, ppm (12% O_2)

Fig. 3.3. Operation characteristics of the 40 kW boiler running on biomass briquettes[35].

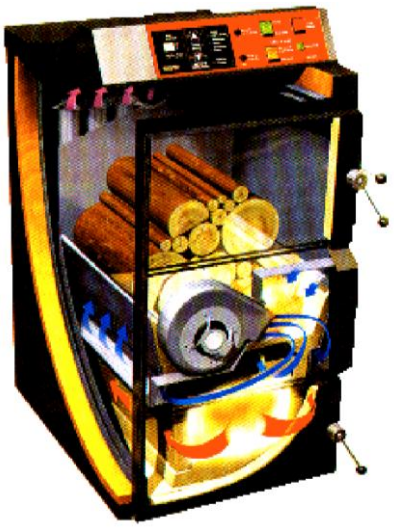
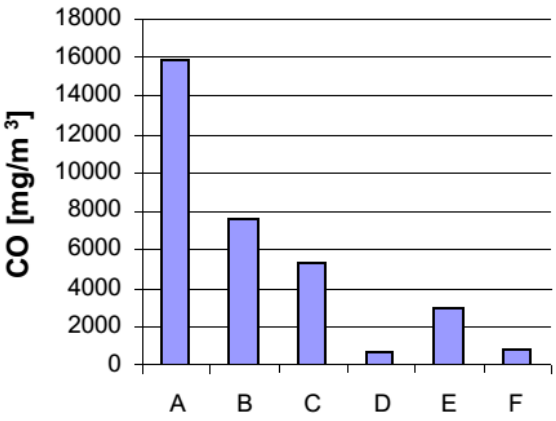
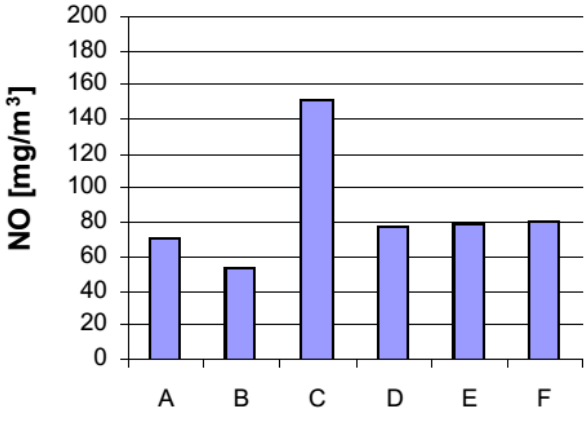


Fig. 3.4. VERNER boiler[38].



a) CO emission, mg/m^3 (11% O_2)



b) NO_x emission, mg/m^3 (11% O_2)

A – wood pellets, VARIMATIK boiler (primary air); B – wood pellets, VARIMATIK boiler (primary and secondary air); C – wood pellets, VARIMATIK boiler (primary, secondary and tertiary air); D – wood briquettes, VERNER boiler (no primary air); E – wood briquettes, VERNER boiler (primary air); F – wood pellets, modified VIARDUS boiler

Fig. 3.5. Emissions during the combustion of wood briquettes and wood pellets in boilers designed for solid fuel[38].

4. Biomass briquetting lines

Typical biomass briquetting process includes 7 stages (**Fig. 4.1**).

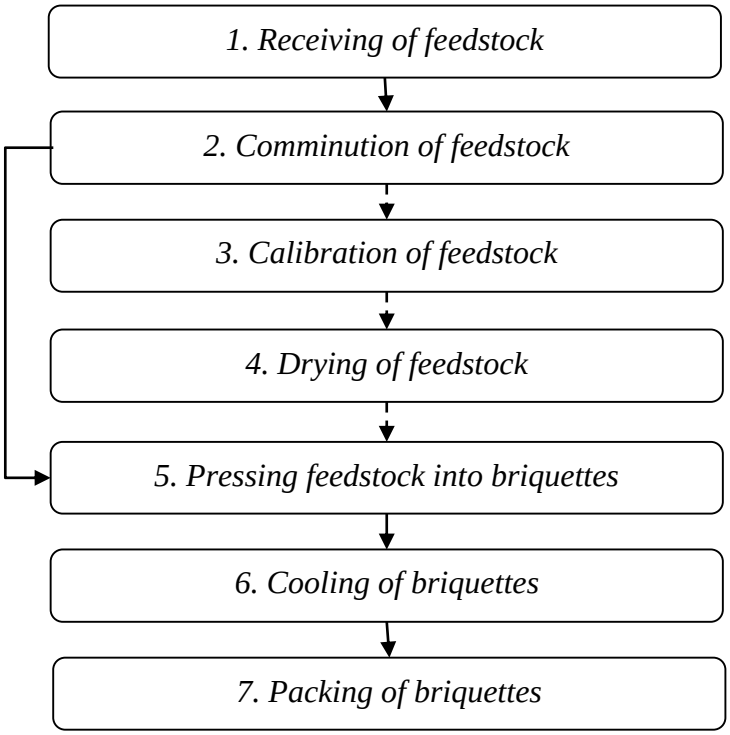


Fig. 4.1. Technological operations for biomass briquettes production[39]

1. Receiving of feedstock

Acceptance of raw material is carried out at the site, the size of which should enable the accumulation of at least a daily biomass supply to ensure its timely and unhindered feed for further processing. It must be taken into account that if straw is used as raw material, it can be packed in rectangular bales or round bales which cannot be moved manually. For this purpose it is expedient to use a load trolley. Consequently, the equipment of the site may include auxiliary equipment for the moving of biomass.

If a briquetting line is of small capacity and is located near the source of raw materials, then the raw material can be delivered in the form of chaffed straw or crushed corn stalks and you can exclude the stage of baling of agribiomass and save on this.

2. Comminution of feedstock

Pretreatment stage includes comminution of feedstock into fractions that meet requirements of a certain briquetting equipment. In addition, such inclusions as metal items, stones and sand must be removed from the feedstock.

[39] Dubrovin V.O. Technological and technical equipping of the production and use of biofuels for industry and heating in agro-industrial complex [Recommendations for agro-industrial enterprises of Ukraine] / Dubrovin V.O., Myronenko V.G., Lobodko M.M., Lut M.T., Sarana V.V., Gudzenko M.M., Gryschenko O.M., Zakharkiv G.S. – K.: Kholtech, 2009. – 32 p.

3. Calibration of feedstock

Calibration is necessary for allocating the feedstock fractions of required dimension. Drum calibrators with sieve holes of up to 5-6 mm are used for this operation. Sometimes comminutors with sieves are used, the sieves performing calibration of biomass.

4. Drying of the comminuted feedstock

The comminuted raw material enters the chamber of the drying unit through the material pipeline. The extraction of excess moisture is carried out by hot air produced by a heat generator that can run both on the biomass itself and on natural gas.

Typically, the raw material should be dried to 8-14% humidity. There are some briquetting presses able to use biomass with up to 30% moisture content. Such humidity can be achieved through the proper storage of biomass, and therefore the drying operation is eliminated.

After that the comminuted and dried material is supplied to the battery cyclone by pneumatic transport; in the cyclone the material is separated from heat carrier. The waste heat carrier is released into the atmosphere, and the dried material is supplied onto the feed device of the press-briquetter.

5. Pressing of feedstock into briquettes

Obtaining of a strong briquette from the comminuted vegetable mass is ensured both physical and mechanical property of the material and conditions of the briquetting process itself. At that certain quality levels must be achieved. They are the briquette density (0.8-1.3 t/m^3), moisture content, dimensions (diameter, length), and regular shape.

6. Cooling of briquettes

In the process of pressing, the raw material reaches temperature of above 70 °C. The higher the pressing force is, the higher the temperature of the briquettes is and the better their quality is. Cooling is necessary for the final hardening of the finished briquettes, which makes them suitable for storage and transportation. In some presses, a briquette after leaving the shaping nozzle moves along the long guide rail while cooling down.

7. Packing of briquettes

Giving marketable appearance to the product is an integral part of the production process. Therefore, at the final stage of preparation of briquettes for their sale, they are packed in bags or plastic bags and placed on pallets.

Thus, the biomass briquetting process can include all 7 manufacturing operations or sometimes only 4 operations (see **Fig. 4.1**): *receiving* of feedstock, *comminuting* of feedstock, *pressing* of feedstock into briquettes and *packing* of finished product.

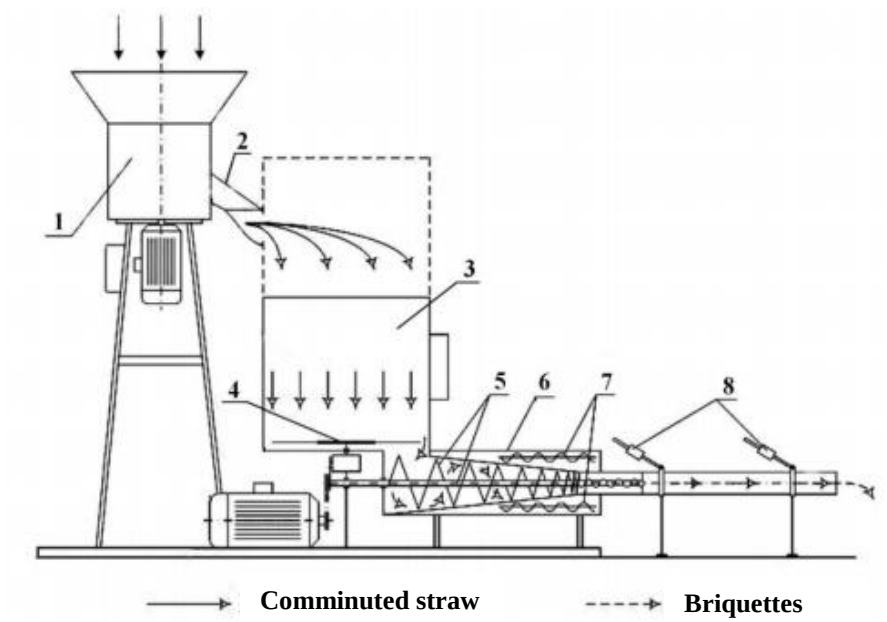
Some briquetting lines do not require comminution of straw into the fractions < 1 cm and can press straw particles of up to 3-5 cm without problems.

The main operation in the technological process of producing biomass fuel briquettes is pressing. This operation is the most energy intensive and determines the quality of the final product. For briquetting of biomass, press-briquetters of two types are used: with a ***piston*** and ***screw*** working organ.

Advantages of *piston presses (mechanical, hydraulic)* are that the pressing working body operates for a long time and do not require frequent repairs and maintenance. **Disadvantages** are periodical work process, high material capacity and large dimensions.

Advantages of *screw presses* are continuous work process, low material capacity, less noise and weight, easy maintenance, the possibility to obtain product with higher density (compared with piston presses). **Disadvantages** include deterioration of screw and need in warming up before starting.

For the production of fuel briquettes from *straw*, mechanical *screw* presses are used most often; the principle of their operation is shown in **Fig**. **4.2**. Bulk straw is supplied into a rotary mill 1 for comminution. From there the crushed substance goes to hopper 3 through the guide tray 2. From the hopper, by means of agitator 4 the feedstock is supplied into press-briquetter 6, where the material is pressed by means of a conical screw 5. To facilitate briquetting, straw is heated by heater 7. The density of briquettes at the output is regulated by repressing device 8.



1 – rotary mill; 2 – guide tray; 3 – hopper; 4 – agitator; 5 – cone screw; 6 – body of press-briquetter; 7 – electrical heaters; 8 – device for controlling briquettes density

Fig. 4.2. Straw briquetting equipment[40]

[40] Dubrovin V.O., Kukharets S.M., Polischuk V.M. et al. Development of resource-saving technologies for the production and use of solid biofuels for heating workrooms and personal service rooms in agro-industrial complex. Recommendations for agro-industrial enterprises of Ukraine. Kyiv, 2014.

The market offers equipment of a wide productivity range starting from 50 kg/h. The choice of a particular model depends on the characteristics of the raw material recommended by the manufacturer. **Table 4.1** provides the list of companies offering equipment in Ukraine for straw briquetting lines and briquetting of other types of biomass with a productivity of 150-500 kg/h of the finished product. Nine companies have sent us their commercial offers for the sale of such equipment. The comparative characteristics of these offers are given below.

Table 4.1. List of companies that offer equipment for straw briquetting lines in Ukraine.

N	Company	Region / City	E-mail	website	Date of receipt of the commercial offer
1	"AmeliArt Ukraine" Ltd	Vinnytsia	ameliart@ukr.net	https://ameliart.com.ua/	30.08.2017
2	PE "Bryketuiuchi tekhnologii"	Berdychiv	a_peryan@ukr.net	press-udarnyi.com.ua	30.08.2017
3	Trade house "Toplivo Ukrainy"	Kyiv	eddigood777@gmail.com	toplivo.kiev.ua	30.08.2017
4	"Zerma-Ukraine" Ltd	Kakhovka	sv@tmgreenbull.com.ua	http://tmgreenbull.com.ua/en/home.html	
5	"Trivad"	Kyiv	dp_trivad@ukr.net	http://trivad.com.ua	
6	“Bioekoprom”	Poltava	bioekoprom@gmail.com	http://bioekoprom.com.ua	01.09.2017
7	Private entrepreneur Fediakin	Dnipropetrovsk oblast	sale@pres88.com.ua, pres88@ukr.net	http://pres88.com.ua	01.09.2017
8	"Politrade" Ltd	Kharkiv	bsct@ukr.net, bsct@i.ua	http://www.polytrade.com.ua	30.08.2017
9	«Bronto»	Cherkasy	bronto@bronto.ua	https://bronto.ua	01.09.2017
10	PE «DORA INSTRUMENT»	Lviv	dora-plus@lviv.farlep.net, obladnennya@gmail.com	http://www.doraplus.com/eng/index.php	
11	"COMPANY LTS" Ltd	Mykolaiv	lts.company@ukr.net	http://www.lts.net.ua	
12	PE "Kijko"	Dnipro	vgkijko@gmail.com	http://kijko.com.ua	
13	"EKKO" Ltd	Cherkasy, Khmelnytskyi	ekko.xm@gmail.com, baupres01@gmail.com	http://www.biobriquette.com	
14	«Bioenergia»	Novomoskovsk	bioenergi74@gmail.com	http://zzory.com.ua	05.09.2017
15	PE "Techno-T"	Nizhyn	info@techno-t.net.ua	http://techno-t.net.ua/en	
16	«Inworld» Ltd	Kyiv	vh_inworld@ukr.net	http://www.inworld.com.ua/en/	21.02.2018

Company «AmeliArt Ukraine» (Vinnytsia city) offers Polish equipment (company ASKET) in Ukrainian market, namely *screw* briquetter **BIOMASSER,** type BSX14. «AmeliArt Ukraine» offers a briquetting line BIOMASSER DUO-SET of DS7 type (based on model BSX14) with productivity of up to 160 kg/hr depending on the type, moisture content and comminution degree of feedstock (**Table 4.2**). The line consists of:

– one comminutor TOMASSER of RK7 type for loose straw and small straw bales of 45×45×85 cm. Manual loading, moisture content of the material should be below 35%;

– one briquetter BIOMASSER DUO of BS214C type with two forming bushings along with a filtration bag mounted on the bunker of the briquetter. Consumption of power is about 70-80 kWh/t of briquettes;

– an elastic pipe of 1.5 m to connect the bunker with the comminutor.
Specification of feedstock to be loaded into the briquetter:

- ***non-wood biomass such as straw, hey, cane***. The best type is grey straw (that is straw which was under the influence of atmospheric conditions like rain and sun. Such straw becomes fragile and convenient for comminution and briquetting;
- particle length: from 1 to 5 cm;
- moisture content: from 10 to 30%;
- temperature: from +5 to +30 ºC.

The briquetting line can operate at the environment temperature from +5 to +30 ºC. The line manufactures **Pini&Kay** briquettes of 80 mm diameter and of different length with the inner hole; briquette density can be regulated (the briquettes are called «Golden Coal»).

Fig. 4.3. Briquetter BIOMASSER DUO with comminutor TOMASSER RK.

Company «AmeliArt Ukraine» also offers a briquetting line BIOMASSER MULTI-3 Stationary of 480 kg/hr productivity. The line consists of:

- feeding table od SP4 type;
- comminutor for bales TOMASSER® of PR18 type;
- base ray of 614 type;
- briquetter BIOMASSER® of PB614 type with 6 forming bushings;
- module filters of 614 type;
- electric cabinet.

Table 4.2. List of equipment for the production of biomass briquettes according to the obtained commercial offers

N	Name of equipment	Company	Productivity, kg/hr	Cost, UAH incl. VAT*	Notes regarding straw as feedstock
1	BIOMASSER DUO-SET, type DS7	"AmeliArt Ukraine" Ltd (Vinnytsia) https://ameliart.com.ua/	160	598 950	chaffed straw, small bales of 45×45×85 cm
2	BIOMASSER MULTI-3 Stationary, type BMPB614-PR18-SP4		480	2 870 600	bales of 1.20-1.50 m
3	Press ПБУ-060-400 dosing bunker of 1.5 m^3, dryer САД-0.4-0.8 and comminutor ИТС-1	PE "Bryketuiuchi technologii" (Berdychiv) http://press-udarnyi.com.ua/	300–350	1 190 000	bales of up to 1.8 m
4	Press ПБУ-060-400 dosing bunker of 1.5 m^3, dryer САД-0.4-0.8 and comminutor ИТС-0,5		300–350	1 060 000	bales of up to 0,5 м
5	Press ПБУ-070-800М with dryer САД-0.6-1.2 comminutor ИТС-1		500–600	1 470 000	bales of up to 1,8 м
6	Briquetting line ЛІПТБ-200	Trade house "Toplivo Ukrainy"	150–250	234 000	no comminutor for bales
7	Briquetting line ЛІПТБ-350		350–400	312 000	
8	Briquetting line БЕП-15, BT-60 Wektor	“Bioecoprom” (Poltava) www.bioekoprom.com.ua	350–500 (по соломі)	1 165 200	small bales of 10-20 kg or loose straw; the press is renovated
9	Press SCORPION-SP 50-350M, dryer СП-500	Private entrepreneur Fediakin (Stepove village, Dnipropetrovsk oblast) http://pres88.com.ua	200–400	621 600	no comminutor for straw
10	Briquetting line AGL 300 with comminutor	«Politrade» Ltd www.polytrade.com.ua	200–280	812 462	moisture content of the feedstock should be 7-20%
11	Press PB-500	Bronto (Cherkasy) http://www.bronto.ua	400	732 000	moisture content of the feedstock should be 8-15%
12	Press with dryer	Individual entrepreneur Kulikova N.D. («Bioenergia») http://www.agroteplo.com.ua/ http://zzory.com.ua/	200–400	660 000	no comminutor for straw
13	Briquetting press BP 500 A	«Inworld» Ltd (Kyiv) http://www.inworld.com.ua/en/	450-500	1 730 040	---

** Price as of date of receipt of the commercial offer (see **Table 4.1**).*

The platform of the line can be placed on a trailer (mobile option) or on the floor of a shop (stationary option). Specification of feedstock and characteristics of finished briquettes are the same as for the briquetting line BIOMASSER DUO-SET of DS7 type.

*Important **advantage** of briquetters BIOMASSER is their ability to use feedstock **with moisture content up to 30%;** and as a result it is necessary to dry the feedstock.*

PE "Bryketuiuchi technologii" (Berdychiv) offers 3 variants of briquetting line for ***straw*** with *mechanical* press **ПБУ** (briquettes of **NIELSEN**[41] type with 60 mm diameter).

The first commercial offer includes complete briquetting line of 300–350 kg/hr productivity:

- press ПБУ-060-400 with the module for cooling and heating of oil;
- dosing bunker of 1,5 m^3 attached to the press;
- dryer САД-0.4-0.8;
- cutter for straw bales with comminutor ИТС-1 of up to 1200 kg/hr productivity, which can process bales of up to 1,8 m.

Specification of feedstock to be briquetted: moisture content is 8-12%, particle sizes are up to 5 mm.

Fig. 4.4. General view of press ПБУ-060-400 with dosing bunker.

The difference between the second and the first commercial offer is a smaller cutter with the bales comminutor ИТС-0,5 of up to 500 kg/hr productivity, which can process bales of up to 0.5 m. The third commercial offer includes a briquetting line of 500-600 kg/hr productivity, which consists of the press ПБУ-070-800М with a module for cooling and heating of oil and cooling of fingered bushings, dryer САД-0.6-1.2 and bales cutter with comminutor ИТС-1.

[41] Manufacturer of the equipment defines the type of briquettes as NESTRO.

Trade house "Toplivo Ukrainy" offers a briquetting line ЛПТБ-200 with the *screw* press-extruder **ПШ**-190 of 150-250 kg/hr productivity and a line ЛПТБ-350 of 350-400 kg/hr productivity. Feedstock can be ***wood and agricultural residues*** (moisture content should be 8-12%, particle size should be up to 5 mm). The line also includes a calibrator, a drying unit, a screw transporter, a press-extruder and an outdraught unit. A comminutor for straw must be purchased separately. The line is designed for producing **Pini&Kay** briquettes with the tetrahedron cross section and 60 mm diameter.

Group of companies «BIOEKOPROM» (Poltava) has sent us a commercial offer for the straw briquetting line with *mechanical* press **Wektor** BT-60 of 350-500 kg/hr productivity. The line is intended for manufacturing **NIELSEN** briquettes of 50, 60 and 70 mm (standard size) diameter, and for manufacturing pellets of 7-8, 11-12 and 17-18 mm. Density of briquettes is 0.8-1.5 t/m^3, the length is 25-200 mm (can be regulated). Press BT-60 can operate with a variety of feedstock of 8-15% moisture content: ***straw of grain crops and soya, hey, sawdust, sunflower husk, rice husk, stalks/cobs of corn, stalks of sunflower, peat***.

Fig. 4.5. Straw briquetting line with press Wektor BT-60.

Private entrepreneur Fediakin (Stepove village, Dnipropetrovsk oblast) manufactures *mechanical* press **SCORPION-SP** 50-350M of 200-400 kg/hr productivity intended for the production of **NIELSEN** briquettes from ***straw***. If the feedstock moisture content exceeds 14%, it is recommended to use the aerodynamic dryer СП-500 of up to 500 kg/hr productivity. A comminutor for straw should be purchased separately from other manufacturers. Specification for the feedstock: moisture content should be up to 14%, particle size up to 5-8 mm.

"Politrade" Ltd (Kharkiv) offers a briquetting line for ***straw*** and ***hey*** **AGL** 300 with a *screw* press AG D, comminutor for straw, cyclone and ventilator. The line can manufacture **Pini&Kay** briquettes of 85 mm diameter and 50-500 mm length. Moisture content of the feedstock should be within 7-20%, particle size up to 2 cm.

Fig. 4.6. Straw briquetting line AGL.

«CherkasyElevatorMash» («Bronto», Cherkasy) has sent us a commercial offer for *mechanical* press **PB-500** of up to 400 kg/hr productivity. The briquetting line also includes a storage bin HB-4 with the agitator, two feeders, the cooling device for briquettes and the device for packing briquettes into big bags (**NIELSEN**[41] briquettes**)**. Moisture content of the feedstock (***straw, sawdust, sunflower husk***) should be within 8-15 %.

Fig. 4.7. Biomass briquetting line with press PB-500.

An individual entrepreneur Kulikova N.D. (Novomoskovsk) offers a *mechanical* press of 200-400 kg/hr productivity and an aerodynamic dryer СП-500. Feedstock for briquettes production can be ***sawdust, wood chips, sunflower husk, residues from elevator, straw***. Moisture content of the feedstock should be up to 12%, particle size up to 25 mm. The line can produce briquettes of **NIELSEN** type of 50 mm diameter, 20-300 mm length and 1-1,26 t/m^3 density.

«Inworld» Ltd (Kyiv) offers a *hydraulic* briquetting press **BP** 500 A of Lithuanian make of 450-500 kg/hr productivity. The press is designed to manufacture **RUF** briquettes from ***sawdust*** of up to 15% moisture content. Briquettes sizes are: length 40-105 mm, width 150 mm, height 60 mm.

Fig. 4.8. Briquetting press BP 500 A.

5. Legal aspects of biomass briquettes production

Legal basis for the production of biomass briquettes can be found in the Law of Ukraine **«On alternative fuel types»**[42]. According to the Law, biomass briquettes are defined as solid biofuels:

> *«Biofuel is **solid**, liquid and gaseous fuel produced from biologically renewable feedstock (biomass), which can be used as fuel or component of other fuels»* (Article 1)*;*
> and they are classified as a type of alternative fuels:
> *«Alternative solid fuels include products and wastes of agriculture (crop production and animal husbandry), forestry and technologically related industries, as well as pellets, **briquettes** and charcoal produced from these products and wastes, which are used as fuel…»* (Article 5-1).

The Law «On alternative fuel types» defines that the fact that a fuel is alternative should be confirmed by a document on fuel identification issued by an authorized organ of executive power in accordance with order established by the Cabinet of Ministers of Ukraine (Article. 6).

Biofuels for sale must be *certified* according to existing legislation (Article 6).

Producers of alternative fuels are considered to be economic entities of all types of ownership, which manufacture solid, liquid and gaseous fuels from non-traditional sources and types of energy feedstock. Economic entities that sell their products, on request of purchasers should provide the document confirming fuel quality and the fact that the fuel is alternative.

[42] Law № 1391-XIV of 14.01.2000 (with amendments) http://zakon5.rada.gov.ua/laws/show/1391-14
Summary in English (as of 14.01.2000) http://zakon5.rada.gov.ua/laws/anot/en/1391-14

Activity in the field of production and use of biofuels can be carried out by economic entities of all forms of ownership in accordance with the legislation of Ukraine. Economic entities using different biofuel production technologies have equal rights to access the market of biofuels. Biofuel manufacturers are obliged to keep a record of their biofuels and biocomponents in accordance with order established by legislation (Article 8).

The standards that set the requirements for the quality of alternative fuels should ensure the efficient and economical use of the energy potential of the fuel. The indices of consumer quality of each alternative fuel are set in the relevant standards. These indicators should be the basis for all calculations related to alternative fuels (production and sales volumes, techno-economic, commercial and other indicators). Environmental safety standards for alternative fuels and safety indicators for human health and labour must be within the limits established by law for traditional fuels (Article 11).

CMU Resolution **«Order for issuing the certificate that a fuel is alternative»**[43] determines that the document confirming that a fuel is alternative is issued by the State Agency on Energy Efficiency and Energy Saving according to the established order. The certificate is issued for two years. The State Agency on Energy Efficiency and Energy Saving should provide keeping a *alternative fuels registry*.

In 2014, the exemption from VAT for sales of biofuels, including firewood, chips, granules, briquettes, was cancelled, so there is currently no need for a mandatory certificate of fuel belonging to an alternative type. But such a certificate should be provided at the request of the buyer.

According to the Law of Ukraine **«On licensing of economic activities»**[44], the production of solid biofuels *is not subject to licensing* (Article 7).

6. Certification and standardization of biomass briquettes

As mentioned earlier, biofuels for sale are subject to mandatory certification in Ukraine[42]. Certification is a procedure for confirming the stable quality of products; in the procedure the accredited certification bodies, audits and laboratories are involved. Certification envisages constant quality control in production and thorough compliance with the rules for the production, storage and transportation of solid biofuels[45].

Certification is closely connected with standardization issues. Expert opinion is that Ukraine should introduce certification according to ENplus norms, which meet the world best quality

[43] CMU Resolution №1307 of 5.10.2004 (amended) http://zakon2.rada.gov.ua/laws/show/1307-2004-п
[44] Law № 222-VIII of 02.03.2015 (amended) http://zakon3.rada.gov.ua/laws/show/222-19
[45] Documentation of the best practices of the application of bioenergy technologies in municipal sector in Ukraine. Project UNDP, GEF, 2015. http://bioenergy.in.ua/media/filer_public/2a/3d/2a3da499-5057-4a5f-8e5b-565a52daf34c/dokumentuvannia_naikrashchikh_praktik_zast_bioenerget_tekhnologii.pdf

standards of solid biofuels EN 14961 and ISO EN 17225. ENplus certification system is based on a number of European standards that concern first of all the improved wood biofuels.

There is not a uniform European standard for pellets and briquettes produced from agricultural feedstock, therefore European countries use standards adopted in other EU countries. For example, France has standards AGRO+, AGRO.

The international standard ISO EN 17225 is used as the uniform standard for various types of solid biofuels in the world. It came into force in 2014 and defines fuel quality classes and specifications for solid biofuels produced from raw materials and processed materials originated from forestry and breeding forests, agriculture and horticulture, aquaculture[45].

For a long time there have been in Ukraine the only state standard for solid biofuel, namely ДСТУ (State Standard of Ukraine) 7124:2009 **«Sunflower husk pressed granulated. Specifications»**[46] (came into force on 01.01.2012, amended in 2014).

Technological regulations for the production of briquettes and pellets from sunflower husk[47] are also valid in Ukraine. According to the Law of Ukraine **«On technical regulations and conformance evaluation»**[48], technical regulation is a legal act which defines characteristics of products or related processes and methods of production, including the respective procedural provisions, which are mandatory.

ДСТУ (State Standard of Ukraine) 8358:2015 **«Briquettes and pellets from wood feedstock. Specifications»** was adopted in 2015 and came into force on 1 July 2017[49]. State standards for briquettes produced from other types of biomass (straw and other stubble remains) still are not available.

According to the Law of Ukraine **"On Standardization"**[50], national standards are applied on a voluntary basis, unless the mandatory application of them is established by regulatory acts (Article 23). Currently, Ukrainian producers of biomass briquettes use mainly their own *specifications* or are guided by European standards (in case of export of the products to Europe).

The Law "On Standardization" stipulates that technical specifications are a normative document that specifies the technical requirements that a product, process or service must meet and defines the procedures by which it can be established whether such requirements are met. Enterprises, institutions and organizations have the right to organize and perform work on standardization, in

[46] http://auek.kpi.ua/Standarts_energy/%D0%94%D0%A1%D0%A2%D0%A3%20EN%207124-2009.pdf
[47] Textbook «Economic justification for passing to heating based on solid biofuels. Harmonization of Ukrainian standards and EU standards», 2014
http://saee.gov.ua/documents/Posibnik_for-web-UUP-2014%20(1).pdf
[48] Law № 124-VIII 15.01.2015 http://zakon2.rada.gov.ua/laws/show/124-19
[49] Order by State Enterprise "Ukrainian research and education center for standardization, certification and quality issues" № 101 of 21.08.2015 http://www.leonorm.lviv.ua/p/NL_DOC/UA/2015/Nak_101.htm
[50] Law №1315-VII of 05.06.2014 (amended) http://zakon4.rada.gov.ua/laws/show/1315-18

particular, to develop, accept, review, apply, cancel their technical specifications, and also have the right to own these specifications in the respective spheres of activity and taking into account their economic and professional needs. Specifications adopted by enterprises, institutions and organizations are applied on a voluntary basis (Article 16).

Currently, there are several dozens of specifications developed by enterprises producing briquettes from different types of biomass in Ukraine. Some examples of such specifications (the list) are given in **Annex 2**.

It should be noted that Ukraine has already adopted a number of standards (harmonized with European ones) that deal with general quality issues and methods for determining the quality of solid biofuels, including briquettes. These standards relate to research methods and are not based on the basic standards that provide technical, physical and environmental requirements for the quality of solid biofuels. Some selected examples of such standards (the list) are given in **Annex 3**.

According to expert opinion, Ukraine has an urgent need to implement 36 European standards for solid biofuels and equipment. They are necessary for the introduction of modern certification systems (e.g. ENplus) at enterprises that manufacture solid biofuels, for protecting the rights of solid biofuels consumers, for meeting environmental norms and sustainability criteria[9].

7. Successful examples of the production of biomass briquettes for domestic and other sectors[51]

Production of straw briquettes in the village of Kinski Rozdory (Zaporizhia oblast)

A plant for the production of straw briquettes was build and put into operation in 2016 in Kinski Rozdory village (Zaporizhia oblast) within the EU/UNDP program on the development of rural areas. The villagers elaborated a business plan, organized a ***cooperative*** and applied to the official office of the organization in Zaporizhia oblast. As a result they were granted 80% of the project investments, the rest was covered by the cooperative itself. Total expenditures on the introduction of the briquetting line with a mechanical press were about 750,000 UAH [52] [53] [54].

Productivity of the plant is 250-300 kg of briquettes per year. The produced briquettes are not big in size so that to be able to be placed inside any boiler, oven or fireplace. The briquettes are consumed by local population, which mostly has heating provided by ovens. Members of the cooperative (50 persons at present) purchase the briquettes by their production cost. In the future, the cooperative is planning to produce briquettes from sunflower husk, weed stalks and dry needles of used New Year's tree.

Mini-plant for the production of biomass briquettes in Kamianka village (Odesa oblast)

A pilot mini-plant for the production of biomass briquettes started its operation in the South of Odesa oblast (Kamianka village, Izmail district) at the end of 2016. The main investor of the project is «Izmail production company» Ltd. Annual productivity of the plant is 2 kt of briquettes, the main feedstock being straw. Besides, the plant is planning to produce briquettes from grapevine and orchard pruning[55]. The mini-plant is a model enterprise where local enthusiasts worked out technology for briquetting different types of biomass including

[51] Based on information from mass media.
[52] http://ecotown.com.ua/news/U-zaporizkomu-seli-za-koshty-OON-zbuduvaly-fabryku-z-vyrobnytstva-solom-yanykh-bryketiv-/
[53] http://bioenergy.in.ua/uk/news/novini-bionergetiki/selo-na-zaporizhzhi-peretvoriuie-solomu-i-burian-u-palivni-peleti/
[54] http://www.kp.org.ua/soloma-gritis-ta-zhiti-dopomagaye/
[55] https://odessitua.com/news/54333-v-odesskoy-oblasti-otkryt-mini-zavod-po-proizvodstvu-toplivnyh-briketov-iz-solomy.html

grapevine. It should be noted that grapevine is a specific feedstock for briquettes and requires specific equipment for its comminution before pressing.

Now the manufactured briquettes are sold to local population, in the future they may be supplied to some social sphere consumers like swimming pool and school. According to project manager, demand of the district for biomass briquettes may reach 5 kt/yr[56] [57].

In April 2018 within the framework of Horizon 2020 project «uP_running – Take-off for sustainable supply of woody biomass from agrarian pruning and plantation removal»[58], a batch of last year's grapevine was delivered to the mini-plant at Kamianka village for the test production of briquettes. The feedstock was comminuted and partly used for the production of NIELSEN briquettes with mechanical press of 350 kg/hr productivity. Trial combustion of the briquettes was carried out in a boiler of the Bolgrad first aid center. The trial combustion proved good fuel characteristics of grapevine briquettes.

[56] http://agroportal.ua/news/ukraina/v-odesskoi-oblasti-zapustili-proizvodstvo-solomennykh-briketov/
[57] http://agroportal.ua/news/rastenievodstvo/v-odesskoi-oblasti-stroyat-minizavod-po-proizvodstvu-biotopliva/#
[58] http://www.up-running.eu/

Straw briquetting lines in Vinnytsia oblast

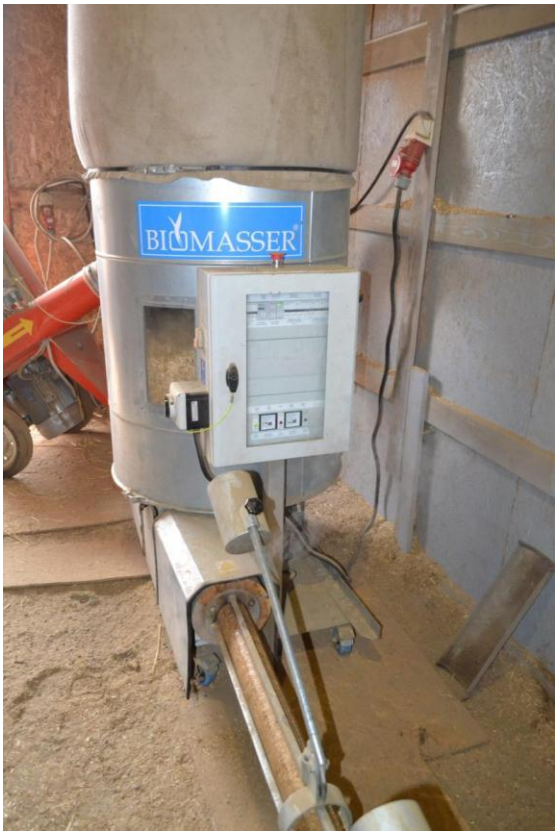
In February 2016 «Svitanok» Ltd introduced a straw briquetting line in Nepedovka village of Koziatyn district. Investments into Polish equipment of company ASKET were 5.6 million UAH. The equipment operates double shift, productivity by the finished product is up to 5 t per shift[59]. Another briquetting line with similar equipment was put into operation in Obukhiv village of Murovanokurylovetskyi district at farm «Vyscheolchedaivske» in July 2017. Operation staff include 6 persons working double shift. The briquettes are supplied to social sphere consumers in Murovanokurylovetskyi district and other districts of the oblast[60] [61] [62].

Straw briquettes produced by company «AgroK» (Mykolaiv oblast)

Farm «AgroK» (Mykolaiv oblast) produces briquettes from own straw of grain crops and other vegetable residues[63]. The equipment used is that of Polish company ASKET. No binding material or adhesive is added into the briquettes. Current productivity of the briquetting line is rather low, 90 kg/hr, but there are plans to increase it up to 160-180 kg/hr by adding another trunk to the equipment. Comminutor for biomass is a device consisting of separate parts which allows to increase its productivity by adding extra parts without any sizeable upgrading. The briquetting line can operate at the environment temperature above 5 ºC. The stock of own straw is enough for a year of uninterrupted operation.

First attempts to sale the briquettes in the local market were made in spring 2017. To arouse the interest of potential consumers, «AgroK» conducted advertising and marketing campaign, which included free of charge distribution of product samples among the local population during summer and the sale of small production-runs at a fair that took place at the district center at the beginning of autumn. At present the company has enough purchase orders from neighboring villages, most of which do not have gas supply. The company considers that the existing demand will be enough even if the productivity of the briquetting line increases up to 300 kg/hr.

[59] http://ecotown.com.ua/news/Na-Vinnychyni-pochaly-vyroblyaty-solom-yani-brykety-/
[60] https://news.agro-center.com.ua/ru/plant-growing-ru/zolotoj-ugol-dobyvajut-v-vinnickoj-foto.html#.WrpWyC7FKUk
[61] http://www.zerno-ua.com/news/v-vinnickoy-oblasti-iz-solomy-proizvodyat-toplivnye-brikety
[62] http://topnews.vn.ua/society/2017/07/27/59807.html
[63] http://elektrovesti.net/59234_v-nikolaevskoy-oblasti-proizvodyat-ekologicheski-chistye-toplivnye-brikety



Briquettes from grain residues of agro-holding «Nibulon» (Mykolaivska oblast)

First briquetting line for grain residues of III category obtained from cleaning of oil crops was constructed at «Kolosovskyi elevator» (Mykolaivska oblast) at the end of 2017. Pretreatment of the feedstock includes oil extraction during a short thermal processing in a dryer running on biofuel of own production[64]. By the beginning of February 2018, 40 t of briquettes and 477 kg of technical vegetable oil were produced from 50 t of residues.

[64] http://elektrovesti.net/58928_ukrainskiy-agrokholding-proizvodit-toplivnye-brikety-i-sekonomil-na-etom-500-tys-grn-za-neskolko-mesyatsev

Biomass briquettes are used in boilers designed for solid fuels at Nibulon's affiliated branches such as «Novoodeskyi», «Prybuzhanovskyi», «Bashtanskyi», and «Kamianets-Podilskyi». The affiliated branches obtained 24 t of briquettes, which allowed them to save 15,000 m^3 of natural gas and 12,000 l of diesel.

Now Nibulon is considering a project on the introduction of a briquetting line for grain residues at one of its affiliated branches in Vinnytsia oblast.

Production of briquettes from raspberry stalks in Losiatyn village (Ternopil oblast)

Losiatyn villagers at Kremenets district of Ternopil oblast united into two cooperatives with the purpose to grow raspberry and strawberry. Later the ***cooperative*** «Yagidnyi krai» was converted into ***energy*** cooperative. At the beginning of 2017, the cooperative started production of briquettes from the raspberry production residues (cut stalks), which before had just been combusted in field[65].

The introduction of the briquetting line was supported by the EU/UNDP project. Members of the cooperative bring the feedstock (raspberry stalk bundles) to the briquetting shop and then take their briquettes from there by the production cost. In such a way all the Losiatyn villagers are provided with the biofuel of own production, which is much cheaper than natural gas (at that a part of the villagers still has gas heating).

Production of reed briquettes in Vylkove town (Odesa oblast)

Company "Eko-Delta" has been manufacturing briquettes from reed residues at Vylkove town (Odesa oblast) since 2014. Productivity of the line is 400 kg/hr. The feedstock for the production is supplied by companies engaged in reed harvesting. Respective activity of nine companies

[65] https://www.epravda.com.ua/publications/2017/02/1/619225/

results in the generation of nearly 300 t of residues. The briquettes are used for heating administration buildings and are sold to local population[66] [67] [68].

The briquetting line was introduced within the framework of Ukraine-Romania-Moldova project on "Climate Proofing of the Danube Delta through Integrated land and Water management" financed by the EU.

[66] http://ecotown.com.ua/news/Na-Odeshchyni-pochaly-vyroblyaty-palyvni-brykety-z-vidkhodiv-ocheretu/
[67] http://odessa-life.od.ua/article/5471-v-vilkovo-topyat-trostnikom-i-zarabatyvayut-na-nemcah
[68] http://otkat.od.ua/vilkovskie-chinovniki-i-ekologi-budut-gretsya-szhigaya-kamysh/

8. Preliminary feasibility study of the production and use of biomass briquettes in Ukraine

The production and use of biomass fuel briquettes is an important and promising segment of bioenergy development in Ukraine, taking into account the economic, environmental and social benefits it can provide. Briquettes are made from the available local biomass, which is a renewable source of energy and is CO_2-neutral. The introduction of business for the production and sale of briquettes contributes to increasing the energy independence of the regions, creating new jobs in rural areas and developing the local economy.

For Ukrainian conditions, several options for the production and use of biomass fuel briquettes can be proposed, for which a *pre-feasibility* study has been developed. First, let's look at some typical variants of projects for the ***production*** of this type of biofuels.

Option 1. An enterprise in a rural area produces briquettes from agro-biomass and sells them as a substitute for expensive coal to the local population and other consumers using small boilers with manual loading. Such consumers can be objects of the social sphere, for example, schools, hospitals. ***Advantage***: the ability to sell briquettes at their market value.

Option 2. Residents of a village or several villages create an energy cooperative, which produces biomass briquettes for their own consumption. Such a cooperative may be either newly created, or the activity of an existing cooperative (e.g., a cooperative engaged in berries production) expands to the production of fuel briquettes. ***Advantages***: the possibility of using cheap (or even free of charge) local biomass, no rent payment for the production premises, the possibility for the members of the cooperative to buy briquettes at a price close to their production cost.

Option 3. A large agrarian enterprise (agro-firm, agro-holding) produces briquettes from its own raw materials (agricultural by-products and wastes) and sells them to its employees at the briquettes production cost as a component of the "social package". ***Advantages***: the possibility of using raw material (biomass) at its production cost, no rent payment for production premises, the possibility of selling part of briquettes to own employees at a price close to the briquettes production cost (as part of the company's "social package").

Results of the comparative feasibility study of the indicated variants of briquettes production for the case use of using straw as a raw material are presented in **Table 8.1**. The results show that all options are economically viable with a discounted payback period of less than **4** years.

Table 8.1. Preliminary feasibility study of the production straw briquettes.

Indexes	**Option 1**	**Option 2**	**Option 3**
	Enterprise	***Energy cooperative***	***Agro-holding***
	Basic input data: Salary is 400 UAH/day, administrative staff is available, straw is purchased at its market price of 780 UAH/t incl. VAT, rent payment is 20 UAH/(m^2·month), briquettes are delivered to consumers in bags at 2450 UAH/t incl. VAT	Basic input data: Salary is 400 UAH/day, no administrative staff, straw is free of charge, no rent payment, briquettes are sold to the cooperative members in bags at 1450 UAH/t incl. VAT	Basic input data: Salary is 400 UAH/day, administrative staff is available, straw is purchased at its production cost of 450 UAH/t, no rent payment, briquettes are sold to consumers in bags without transportation at 2300 UAH/t incl. VAT (70% of the volume) and to own employees at 1900 UAH/t incl. VAT (30% of the volume)
Productivity, kg/hr	320.0	160.0	640.0
Annual productivity, t/yr	1536.0	640.0	2560.0
Price of feedstock (straw), EUR/t excl. VAT	20.2	0.0	14.0
Capital costs, th. EUR	40.5	23.4	136.7
Operating costs, th. EUR/yr	86.7	18.5	112.2
Credit costs (as part of the capital costs), %	60	60	60
Interest rate, %	7	7	7
Sale price of briquettes, EUR/t excl. VAT	64	38	60 (70%) та 49 (30%)
Simple payback period, yr	3.3	2.9	2.8
Discounted payback period, yr	**3.7**	**3.3**	**3.3**
Internal return rate (IRR), %	**26%**	**35%**	**36%**

Next, consider the technical and economic indicators of some typical projects for the ***use*** of biomass fuel briquettes:

Option A: The population consumes biomass briquettes in an existing boiler as a substitute for coal (option A1) or in a newly purchased boiler for solid fuel (option A2) with a capacity of up to 50 kW.

Option B: A shop/hotel or other similar facility consumes biomass briquettes in an existing boiler as a substitute for coal (option B1) or in a newly purchased boiler for solid fuel (option. B2) with a capacity of 50-100 kW.

Option C: Use of fuel briquettes at an industrial or other enterprise in an existing boiler as a substitute for coal (option B1) or in a newly purchased boiler for solid fuel (option B2) with a capacity of 500-1000 kW.

Results of the comparative feasibility study of the indicated consumption options for straw briquettes are presented in **Table 8.2**. The results show that all variants are economically feasible with a discounted payback period of up to **3** years for options B2 (a new boiler of 100 kW), C2 (a new boiler of 1000 kW) and up to **5** years for option A2 (a new boiler of 20 kW). All options for the use of briquettes instead of coal in existing boilers designed for solid fuel lead to significant savings in the purchase of fuel.

Table 8.2. Preliminary feasibility study of using straw briquettes.

Indexes	**Option A: population, 20 kW boiler**		**Option B: organization, 100 kW boiler**		**Option C: enterprise, 1000 kW boiler**	
	A1	A2	B1	B2	C1	C2
	existing boiler	*new boiler*	*existing boiler*	*new boiler*	*existing boiler*	*new boiler*
Installed capacity, kW	20	20	100	100	1000	1000
Capital costs, EUR		900		3500		30000
Saving associated with purchase of fuel, євро/рік	408	408	409	2307	10207	29190
	compared with coal	*compared with coal*	*compared with coal*	*compared with natural gas*	*compared with coal*	*compared with natural gas*
Credit costs (as part of the capital costs), %		60		60		60
Interest rate, %		7		7		7
Simple payback period, yr		3.9		2.4		1.5
Discounted payback period, yr		**4.7**		**2.7**		**1.6**
Internal return rate (IRR), %		**26%**		**43%**		**68%**

Conclusions

Biomass briquettes are a kind of solid biofuel that is widely used in developing countries, and the interest in which has long existed and is growing in developed countries of Europe and North America.

The production and use of biomass fuel briquettes is an important and promising segment of bioenergy development in Ukraine, taking into account the economic, environmental and social benefits it can provide. First of all, it is necessary to increase the volume of production of briquettes from biomass of agricultural origin, given the presence in the country of significant energy potential of such biomass.

Advantages of using agribiomass briquettes:

- Compliance with boiler equipment requirements, best environmental performance during combustion.
- Ability to be used in existing ovens, domestic (15-30 kW) and small boilers for solid fuels with manual loading (up to ~ 100-150 kW). Briquettes do not require specialized equipment, in contrast to more expensive biomass pellets.
- Potential possibility of using relatively low density ("soft") briquettes in bigger boilers with screw feed (up to ~ 1 MW).
- Availability of a large raw material base, especially for agribiomass briquettes.
- Relatively low price. The price per unit of energy for briquettes is comparable to that of wood at much better combustion performance.
- Briquettes are more convenient and economical than wood for transportation and storage. Due to increased energy density, they require lower labour costs when manually loaded into the boiler.
- Briquettes can act as a cheaper substitute for coal, especially in those regions where coal is expensive (4000 UAH/t and more). The cost per unit of energy for briquettes of straw/ sunflower husk can be up to **2** times less than that of coal.

Briquettes are made from the available local biomass, which is a renewable source of energy and is CO_2-neutral. The introduction of business for the production and sale of briquettes contributes to increasing the energy independence of the regions, creating new jobs in rural areas and developing the local economy.

The results of the feasibility study of some typical variants of the production and consumption of agro-biomass briquettes indicate that all these projects are economically feasible with a discounted payback period within **5** years.

Annex 1. Characteristics of straw as fuel

Straw of cereals is one of the main types of agricultural raw materials for the production of briquettes. There may be fresh straw (just harvested, "yellow") and straw which lay in the field and was washed by rains ("grey") (**Fig. A1**).

a) *b)*

Fig. A1. General view of straw: a) yellow straw; b) grey straw.

Wheat straw is characterized by high volatiles yield and high heating value (**Table A1**). Since straw can contain chlorine and alkali metals, chemical compounds such as sodium chloride and potassium chloride are formed in the process of its burning. These compounds cause corrosion of steel elements of power equipment, especially at high temperatures, so it is necessary to take this fact into account when using straw as a fuel.

Table A1. Main characteristics and elementary composition of wheat straw (experimental data)[69].

Parameter	Min value	Max value	Median[70]	Average value	Standard deviation	
Moisture content, % mass (working)	0.00	50.00	8.93	**13.07**	11.37	87%
Ash content, % mass (dry)	0.07	13.50	0.83	**2.11**	2.63	125%
Volatiles, % mass (combustible)	64.56	94.92	83.47	**83.30**	3.41	4%
Fixed carbon, % mass (combustible)	5.08	35.44	16.53	**16.70**	3.41	20%
Elementary composition, % mass (combustible)						
C	42.62	58.46	50.15	**50.27**	1.85	4%
H	3.20	8.90	6.06	**6.10**	0.47	8%
N	0.02	2.93	0.22	**0.39**	0.44	113%

[69] https://www.ecn.nl/phyllis2/
[70] Statistical index that reflects sample.

Parameter	Min value	Max value	Median[70]	Average value	Standard deviation	
S	0.00	0.88	0.05	**0.09**	0.12	136%
O	34.54	51.07	43.27	**43.12**	2.08	5%
Cl, mg/kg	0.0	48 048.5	301.6	**1 956.3**	6118.5	313%
LHV, MJ/kg (combustible mass)	15.04	21.83	18.54	**18.67**	1.02	5%
HHV, MJ/kg (combustible mass)	10.35	26.54	19.80	**19.72**	1.36	7%

The composition of wheat straw ash is also important because it can be used as fertilizer (**Table A2**).

Table A2. Wheat straw ash composition[69].

Ash composition, % mass	Min value	Max value	Median	Average value	Standard deviation	
SO_3	0.43	11.36	2.57	**3.34**	2.09	63%
Cl	0.00	7.23	0.80	**1.88**	2.08	111%
P_2O_5	0.10	29.11	2.85	**4.18**	4.48	107%
SiO_2	0.80	72.50	42.79	**42.23**	20.15	48%
Fe_2O_3	0.06	9.30	0.70	**1.26**	1.69	134%
Al_2O_3	0.09	14.74	0.80	**2.33**	3.41	146%
CaO	2.60	65.00	10.79	**15.68**	13.61	87%
MgO	0.13	11.96	2.48	**3.33**	2.59	78%
Na_2O	0.06	9.77	0.62	**1.27**	1.94	153%
K_2O	0.16	36.70	15.70	**15.60**	7.92	51%
TiO_2	0.01	0.60	0.09	**0.12**	0.13	114%
Pb (mg/kg)	1.0	350.0	3.5	**79.8**	136.3	171%
Cd (mg/kg)	0.0	10.0	0.1	**2.8**	4.6	166%
Cu (mg/kg)	13.0	400.0	35.0	**88.2**	114.8	130%
Mn (mg/kg)	0.0	9 340.0	0.1	**1 481.9**	3 186.8	215%
Cr (mg/kg)	70.0	70.0	70.0	**70.0**	0.0	0%

Wheat straw ash has a relatively low melting point (**Table A3**), which needs to be taken into account when choosing straw energy production technology, as this feature may lead to the slagging of energy equipment.

There are no special requirements for straw as a raw material for briquetting: it should have a moisture content of 10-30% and a size of fractions of 5-30 mm (depending on the type of equipment). In addition, it is desirable (but not compulsory) that the straw should be grey (washed by rains) and have an above-zero temperature.

Table A3. Temperature characteristics of wheat straw ash, oxidizing medium[69].

Parameter	Min value	Max value	Median	Average value	Standard deviation	
Temperature of the beginning of ash deformation, °C	780	1 482	995	**1 050**	218	21%
Temperature of ash softening, °C	800	1 482	1 025	**1 074**	204	19%
Temperature of semi-sphere, °C	1 040	1 482	1 155	**1 183**	123	10%
Temperature of fluid state, °C	1 080	1 500	1 263	**1 290**	108	8%

Annex 2. Technical specifications for biomass briquettes (selected)[71]

Vegetable feedstock:

TU U 20.1-36474791-001:2009 Solid fuel. Fuel briquettes from chopped herbaceous feedstock (Vinintertreid Ltd);
TU U 20.1-36474797-001:2009 Fuel briquettes from chopped herbaceous feedstock (Alekmir Enerdzhi Ltd);
TU U 38.1-37474379-002:2014 Pellets and briquettes from wood residues and agriculture crops (Ekoresurs-T Ltd);
TU U 19.2-32886226-001:2013 with modification № 1 Fuel briquettes from herbaceous feedstock (PC Poltava - Konsaltynh);
TU U 20.1-1470313117-001:2011 with modification № 1 Briquetted fuel from herbaceous feedstock residues (PE Koltunov Ihor Volodymyrovych);
TU U 38.1-1700201376-002:2016 Fuel briquettes from vine (PE Mohylnikov Valentyn Dmytrovych);
TU U 38.1-1700201376-002:2016 Fuel briquettes from straw of agricultural crops (PE Mohylnikov Valentyn Dmytrovych).

Sunflower husk:

TU U 15.6-30842484.007:2006 Biobriquettes from sunflower husk (PC LVK)
TU U 15.6-30842484.007-2006 with modification № 1 Briquettes from residues of the agricultural industry (sunflower husk) (PC Spetszovnishkomplekt).

Wood biomass:

TU U 20.1-34920361-001:2009 Pressed briquettes from sawdust (EO Biotemp Ltd);
TU U 20.1-31072232-001:2012 Pressed briquettes from sawdust (RGSN Ltd)
TU U 20.1-36831840-001:2010 Fuel briquettes from sawdust (Eko-Bleiz Ltd);
TU U 16.2-37677902-001:2012 Pressed fuel briquettes from wood residues (UKRBIORESURS Ltd);
TU U 24.1-30817332-003-2002 Fuel briquettes from hardwood (Ekobrykety Ltd);
TU U 19.2-36318023-001:2013 Solid biofuel. Fuel briquettes from wood (PC Torfvud);
TU U 16.2-38244430-001:2012 Briquettes from alder of 1 sort and 2 type (K. R. Enedzhi Ltd);
TU U 16.2-38244430-001:2012 Briquettes from oak of 1 sort and 3 type (K. R. Enedzhi Ltd);
TU U 37.2.34827522-001:2010 Fuel pellets and briquettes from woody feedstock (Rikon-Treid Ltd);
TU U 16.2-34037185-001:2015 Fuel briquettes from wood residues in the form of a rectangular quadrangular prism (PC Dary zemli).

Reed:

TU U 38.1-1700201376-002:2016 Fuel briquettes from reed (PE Mohylnikov Valentyn Dmytrovych).

[71] All the examples (except one) are taken from *Registry of alternative fuels* prepared by the SAEE, 2017 (http://saee.gov.ua/sites/default/files/Reestr_24.05.2017.xls). Validity of each TS must be checked.

Annex 3. State standards related to solid biofuel (selected)[72]

DSTU EN 14588:2013 Solid biofuels. Terminology, definitions and descriptions (EN 14588:2010, IDT);

DSTU EN 14774-1:2013 Solid biofuels. Determination of moisture content. Oven dry method. Part 1. Total moisture. Reference method (EN 14774-1:2009, IDT);

DSTU EN 14774-2:2013 Solid biofuels. Determination of moisture content. Oven dry method. Part 2. Total moisture. Simplified method (EN 14774-2:2009, IDT);

DSTU EN 14774-3:2013 Solid biofuels. Determination of moisture content. Oven dry method. Part 3. Moisture in general analysis sample (EN 14774-3:2009, IDT);

DSTU EN 14778:2013 Solid biofuels. Sampling (EN 14778:2011, IDT);

DSTU EN 15103:2013 Solid biofuels. Determination of bulk density (EN 15103:2009, IDT);

DSTU EN 15104:2013 Solid biofuels. Determination of total content of carbon, hydrogen and nitrogen. Instrumental methods (EN 15104:2011, IDT);

DSTU EN 15105:2013 Solid biofuels. Determination of the water soluble chloride, sodium and potassium content (EN 15105:2011, IDT);

DSTU EN 15148:2012 Solid biofuels. Determination of the content of volatile matter (EN 15148:2009, IDT);

DSTU EN 15210-2:2013 Solid biofuels. Determination of mechanical durability of pellets and briquettes. Part 2. Briquettes (EN 15210-2:2010, IDT);

DSTU EN 15234-1:2013 Solid biofuels. Fuel quality assurance. Part 1. General requirements (EN 15234-1:2011, IDT);

DSTU EN 15234-3:2013 Solid biofuels. Fuel quality assurance. Part 3. Wood briquettes for non-industrial use (EN 15234-3:2012, IDT);

DSTU EN 15289:2013 Solid biofuels. Determination of total content of sulphur and chlorine (EN 15289:2011, IDT);

DSTU-II CEN/TS 15370-1:2013 Solid biofuels. Method for the determination of ash melting behaviour. Part 1. Characteristic temperatures method (CEN/TS 15370-1:2006, IDT).

[72] Road Map for the .development of solid biofuels in Ukraine. Project UNDP/GEF, 2016. http://bioenergy.in.ua/media/filer_public/b4/bd/b4bda440-5ab8-4c64-943a-a094da7a757f/dorozhnia_karta_z_rozvitku_rinku_tverdogo_biopaliva_ukrayini.pdf

Abbreviations

CMU – Cabinet of Ministers of Ukraine
DH – district heating
HHV – higher heating value
kt – thousand tons
LHV – lower heating value
Mt – million tons
PE – private enterprise
SAEE – State Agency on Energy Efficiency and Energy Saving
TPES – total primary energy supply
TS – Technical Specifications

Previous publications by UABio

http://www.uabio.org/en/activity/uabio-analytics

1. *Position Paper N 1* (2012) "Position of bioenergy in the draft updated energy strategy of Ukraine till 2030".
2. *Position Paper N 2* (2013) "Analysis of the Law of Ukraine "On amending the Law of Ukraine "On Electricity" No5485-VI of 20.11.2012".
3. *Position Paper N 3* (2013) "Barriers to the development of bioenergy in Ukraine".
4. *Position Paper N 4* (2013) "Prospects of biogas production and use in Ukraine".
5. *Position Paper N 5* (2013) "Prospects for the electricity generation from biomass in Ukraine"
6. *Position Paper N 6* (2013) "Prospects for heat production from biomass in Ukraine"
7. *Position Paper N 7* (2014) "Prospects for the use of agricultural residues for energy production in Ukraine".
8. *Position Paper N 8* (2014) "Energy and environmental analysis of bioenergy technologies"
9. *Position paper N 9* (2014) "State of the art and prospects for bioenergy development in Ukraine"
10. *Position paper N 10* (2014) "Prospects for the growing and use of energy crops in Ukraine"
11. *Position paper N 11* (2014) "Prospects of biomethane production and use in Ukraine"
12. *Position paper N 12* (2015) "Prospects for the development of bioenergy as an instrument for natural gas replacement in Ukraine"
13. *Position paper N 13* (2015) "Analysis of energy strategies of the EU and world countries and the role of renewables in their energy systems".
14. *Position paper N 14* (2016) "Analysis of tariff setting in the district heating sector of EU countries".
15. *Position paper N 15* (2016) "Analysis of additional sources of wood fuel in Ukraine".
16. *Position paper N 16* (2016) "Opportunities for harvesting by-products of grain corn for energy production in Ukraine".
17. *Position paper N 17* (2016) "Analysis of criteria for the sustainable development of bioenergy".
18. *Position paper N 18* (2017) "Creation of the competitive biofuel market in Ukraine".
19. *Position paper N 18* (2017) «Opportunities for wood fuel harvesting in forests of Ukraine».

Civic union "Bioenergy Association of Ukraine" (UABio) was established to create a common platform for cooperation on bioenergy market in Ukraine, as well as to provide the most favorable business environment, accelerated and sustainable development of bioenergy. General constituent assembly of UABio was held on September, 25, 2012 in Kyiv. The Association was officially registered on 8 April 2013. Among UABio members there are over 10 leading companies and over 20 recognized experts working in the field of bioenergy.
http://uabio.org/en/

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