PROSPECTS FOR THE USE OF AGRICULTURAL RESIDUES FOR ENERGY PRODUCTION IN UKRAINE

UABio Position Paper N7

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Introduction

Position Paper N7 by the Bioenergy Association of Ukraine is another one in a series of the planned publications on the major issues of bioenergy development in Ukraine. The Paper covers an issue of possibility of using plant residues of agriculture for energy production in Ukraine. Such points as generation of cereal straw, residues of grain corn (maize) production and sunflower production as well as existing areas of the residues utilization and preconditions for their use for energy production are analyzed in the Paper.

World experience in the use of plant residues of agriculture for energy production

By now there has been accumulated quite a big world experience in the use of plant residues of agriculture, first of all straw, for energy production. A recognized leader in this field is Denmark. In the country, of the annually generated ~6 Mt of straw about 1.5 Mt are combusted for energy production (~17 PJ/yr). Manufacture and introduction of the first boilers for small straw bales started in Denmark as far back as in 1970s after the first oil crisis. Later there appeared boilers for big and round straw bales[1]. Introduction of the boilers with high efficiency and low emissions was supported by a state subsidy. It was implemented by the Danish Energy Agency in 1995 for the boilers below 200-400 kW and was in force for over 10 years. According to the subsidy scheme, the owner of a boiler obtained reimbursement within 30% of the boiler cost provided that the boiler efficiency and emissions met certain norms.

Now there are over 10,000 straw fired boilers for farms (0.1-1.0 MW) and about 55 DH plants (0.5-12 MW) in Denmark in operation. Besides, 8 CHP plants (2-28 MW_e) and 4 thermal power plants along with straw also use wood chips, MSW or fossil fuels (coal, natural gas) as fuels. The biggest is a 35 MW_e Fyn power plant that consumes 170,000 t/yr of straw [13, 63, 64]. The straw, mostly big bales, is delivered by trucks-trailers from the territory of 20-160 km distance from the plant. Bottom ash from the straw combustion is either delivered to the company that produces organic fertilizers or returned back to farmers to be spread on the fields. Unutilized ash is landfilled [81].

One of the world biggest straw fired power plants of 38 MW_e operates in the UK (Ely). It consumes 200,000 t/yr of straw that is the main fuel. The plant can also burn a range of biofuels and natural gas up to 10% [42]. Another 40 MW_e straw-fueled TPP is planned to be constructed. The power plant will employ technology developed in Denmark and is expected to be operational in early 2016 [62].

At least two straw fired power plants are in operation in Spain. The first is a 25 MW_e plant in Sangüesa that consumes 160,000 t/yr of straw. The straw is supplied by local farmers from the territory within 75 km from the plant. Bottom ash from the straw combustion is used for the

[1] Typical size and weight of straw bales: small bale – 46×36×80 cm (12 kg); medium-size bale – 80×80×240 cm (235 kg); big bale – 125×240×240 cm or 120×130×240 cm (>500 kg); round bale – Ø150 cm × 120 cm (244 kg) [13, 63].

production of organic fertilizer. Straw for the second TPP of 16 MW_e in Bivriesca is supplied by 17 companies in the amount of 102,000 t/yr. Introduction of the power plant led to creation of 100 permanent new jobs [42, 65, 68]. There exists information that Acciona Energía (Spain), which constructed the two straw-fueled power plants in Spain, has long-term plans for construction another 7 TPPs all over the country [81].

Poland started using straw for energy production as far back as in 1990s. The push for it was the decrease in livestock population that resulted in surplus straw of 8 Mt/yr. Now there are in Poland about 100 small straw fired boilers (~100 kW) and over 40 small and medium-scale DH plants (0,5-7 MW) in operation [82-84]. In addition, DP CleanTech (Denmark) together with Polish Energy Partners (PEP) is constructing a 30 MW_e straw-fueled power plant in Winsko. Wood chips will be supplementary fuel for the plant. Commissioning of the TPP is planned by the end of 2014 [85].

It is worth mentioning that until recently Poland actively used straw pellets for co-combustion with coal at coal power plants. For example, PEP alone annually supplied 150,000 t of pellets for the TPPs. In 2013 the situation changed as Polish government abolished the state subsidy for co-combustion of coal with biomass pellets at power plants.

In Sweden, the market of straw as a fuel is emerging and developing. At present there is comparatively limited number of straw fired boilers for farms and DH plants in the country. Lunds Energi is constructing a big CHP plant in Örtofta. The CHPP will consist of a 110 MW wood chips boiler, a 45 MW straw boiler and a 53 MW_e steam turbine. Consumption of straw will be about 80,000 t/yr. Experts establish linkage between the formation of commercial straw market in Sweden with putting the Örtofta CHPP into operation [81].

Straw to energy technologies are also actively developing in China. During 2006-2012 DP CleanTech constructed 34 straw power plants of 1200 MW_e total capacity. A typical plant is the 30 MW_e PP in Liaoyuan that consumes 160,000 t/yr of straw and deliver 200 GWh/yr to the national power grid [66, 67].

Plant residues of agricultural origin are also widely used in Europe and North America for solid biofuels production. For example, straw pellets are produced in Lithuania (Baltic Straw), the UK (Straw Pellets Ltd, Agripellets Ltd), Estonia (BJ TOOTMISE OÜ), Poland (Widok Energia S.A.), Canada (Semican), the USA (PowerStock); straw briquettes are manufactured in Estonia (BaltPellet OÜ), Denmark (C.F. Nielsen A/S), Canada (Omtec), Lithuania (Baltic Straw) and other countries. Next Step Biofuels, Pellet Technology USA, and PowerStock (USA) offer pellets made from corn stubble remains.

Technologies for crop harvesting and ways of agricultural residues utilization in Ukraine

Ukraine has highly developed agriculture, in particular crop sector, which annually generates a big amount of different wastes and residues. Waste products can be divided into primary and secondary. Primary waste arises directly during crop harvesting; secondary waste is generated in the course of crop processing at enterprises. Primary waste products include straw of cereal and other crops, residues of sunflower and grain corn production (stalks, corn cobs, sunflower empty heads etc.). Secondary wastes are sunflower husks, buckwheat hull, rice hull, sugar beet bagasse and so on. Waste products and residues are partly used by agriculture itself as organic fertilizer, litter and fodder for cattle and also by other sectors of economy; the rest is unutilized and often burnt or landfilled without any use. It seems to be reasonable to engage most part of the unutilized biomass in energy production. At that an important question is what part of wastes and residues may be taken for energy purposes without doing harm to soil fertility.

Cereal straw

Production of cereal and leguminous crops[2] in Ukraine has been about 40-50 Mt/yr with the yield of 25-30 centners[3] per hectare. According to some preliminary data, the production of cereal crops in 2013 reached a record figure in 63 Mt with a record yield in nearly 40 centners per hectare (**Fig. 1, 2**). Today the area under the spiked grains in Ukraine makes up 39% of the total sown area that is nearly the same figure as in 1990 while the sown area under corn has increased by 4 times (**Fig. 3**). Another trend is increasing area under sunflower (almost by 4 times as compared with 1990) and decreasing area under the fodder crops.

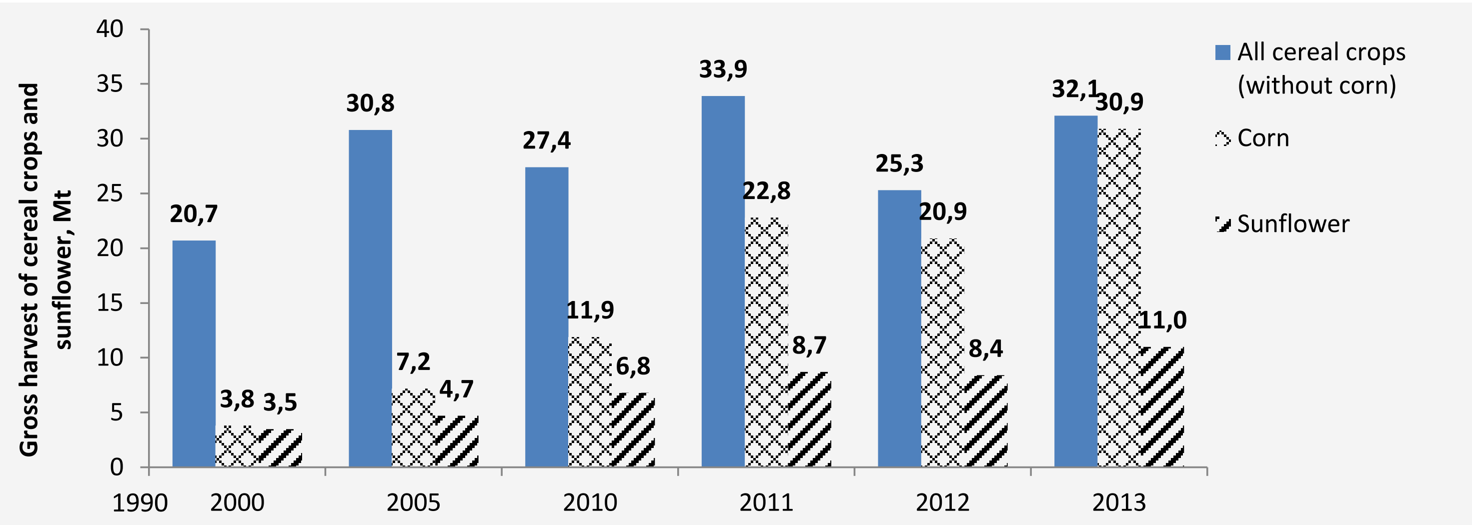

Fig. 1. Production of cereal crops and sunflower [4] in Ukraine, **Mt** [1, 15]

[2] Hereafter the term cereal crops will be used for short.
[3] 1 centner is equal to 100 kg.
[4] Corn is a cereal crop, sunflower is a technical crop.

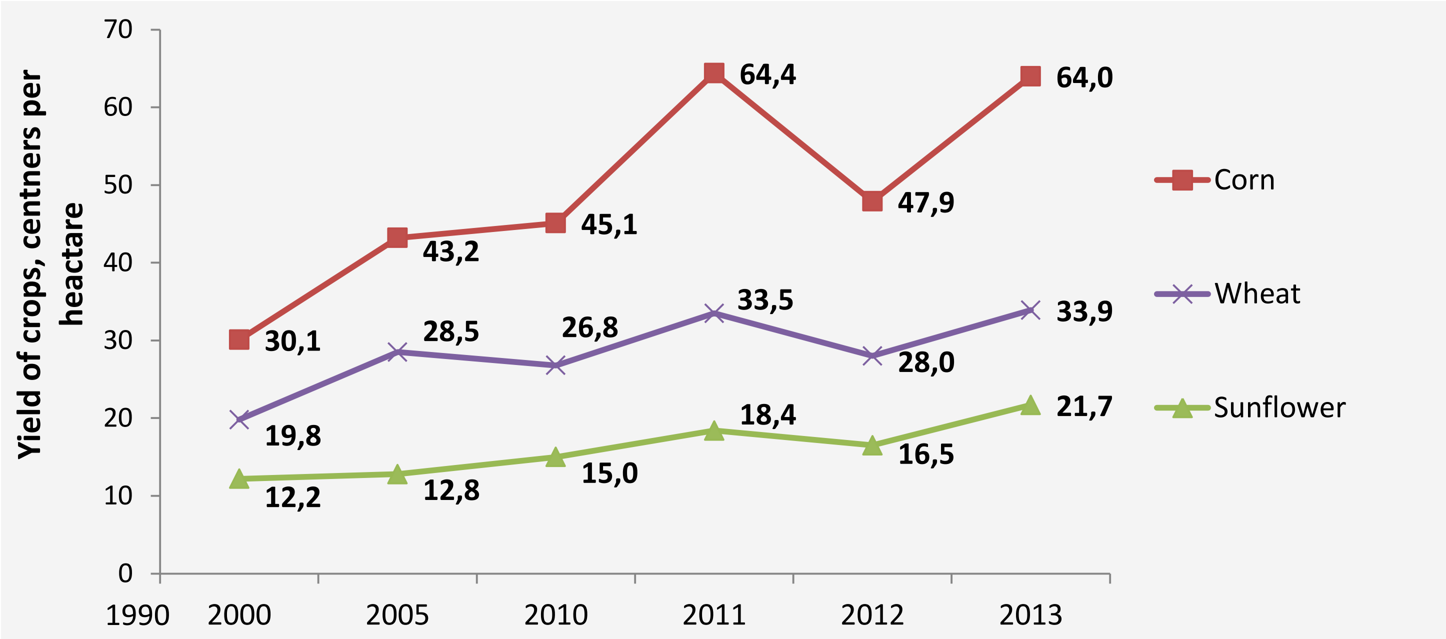

Fig. 2. Yield of cereal crops and sunflower, **centners per hectare** [1, 15]

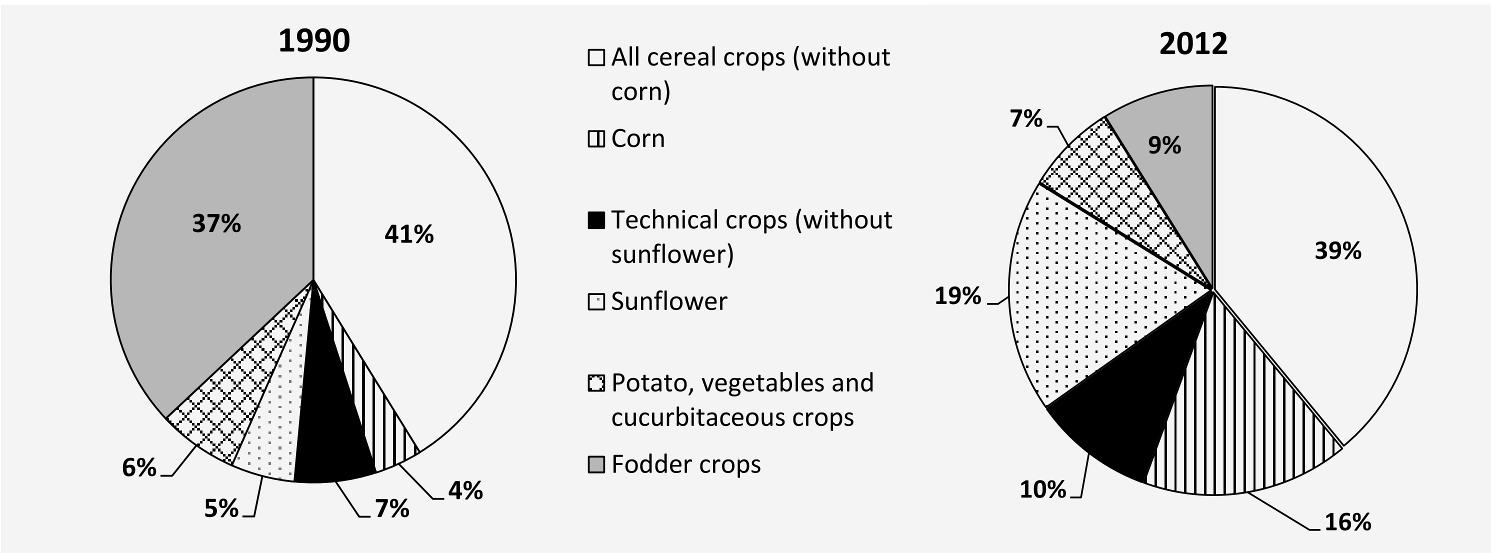

Fig. 3. Structure of sown area under the main crops in Ukraine [1]

Straw is a waste product of cereal crops production. The ratio between the grain part and straw is about 1:1[5] therefore the annual amount of straw is close to the production volume of cereal crops in Ukraine.

[5] Except for corn, for which the ratio is 1:1.3. Residues of grain corn production are considered in a separate section of the Position Paper. Detailed information on residue factors is presented in the section "Potential of agricultural plant residues available for energy production".

During harvesting the grain part of a crop is detached from the stalk, and the way of collecting straw depends on the technology applied. Some part of the straw is left in the field as stubble remains to be plough back into the soil later on.

The following technologies for collecting straw of spiked grains are applied in Ukraine [16, 18][6]:

- *"Streaming" technology* (**Fig. 4**). Straw is shredded by a combine harvester, collected in replaceable trailers and transported to a storage place. If the trailer is not available, the straw is scattered over the field.
- *Stacking technology*. Harvester-stacker makes stacks of 150-300 kg and they are discharged onto the field on the stubble remains. The stacks are collected from the field by rope sweeps or by push sweeps. If stacks are formed (shaped) as blocks, they are taken out of the field by stack-movers.
- *Swathing technology*. Straw is swathed by a combine swather. There are different ways for collecting swaths, one of which is baling (**Fig. 5-8**).
- "*Spreading" technology*. During cereal crops harvesting, straw is shredded and spread (scattered) over the field.

Fig. 4. Collecting straw by the *"streaming" technology* [16]

[6] The technologies can be combined [16].

Fig. 5. Swathing non-comminuted straw [16]

Fig. 6. Aggregating swaths

Fig. 7. Lely Welger baler

Fig. 8. KRONE BIG Pack baler

The stacking technology of straw collection used to be widely applied in Ukraine before, and now the “*streaming” technology* is mainly used. According to the latter, a combine harvester makes chaffed straw that is collected in a trailer. Then the chaffed straw is transported to a storage place and stored there usually in the form of big uncovered ricks. That leads to excessive moisture of the straw due to exposure to a lot of rains. Another option of the streaming technology is scattering chaffed straw over the field.

The swathing technology of straw collection provides for further baling. It is important for the case of transporting straw at middle or relatively long distance and the use as a fuel. Baled straw can be stored under a shed or indoors that protects it from moistening and contaminating. Baling considerably reduces the volume of straw and allows mechanizing some operations during straw handling and transportation.

The collected cereal straw is utilized in different ways (**Fig. 9**): as litter and fodder for cattle, as organic fertilizer, for growing mushrooms in hothouses, and also for energy purposes (direct combustion in boilers, production of pellets/briquettes). The unutilized remains, which altogether make up quite big volume all over the country, are often burnt on the field that is legally prohibited in Ukraine and harmful for the environment and soil.

Straw as *organic fertilizer* is used for creating humus in the upper layer of soil. Humus is an organic part of the soil that is formed as a result of decomposition of plant and animal remains and recrements. Maintaining proper humus balance contributes to biological activation of the soil and erosion protection.

It should be noted that due to insufficient introduction of mineral fertilizers during past 20 years, considerably reduced introduction of organic fertilizers[7] (**Table 1**) and burning straw on the fields, the content and stock of humus in the soil has decreased considerably. During 2000-2012, average introduction of organic fertilizers was below 1 t/ha whereas the minimal norm to ensure the deficit-

[7] Introduction of manure decreased from 7-10 t/ha in 1990 to 0.4-0.7 t/ha nowadays [71].

free humus balance is 8-14 t/ha depending on a soil-climatic zone. Today humus loss can be found in all climatic zones of Ukraine. Under the existing structure of the sown area in the country, annual loss of humus is 0.6-0.7 t/ha [24, 75]. Results of agro-chemical investigation of agricultural lands, every 5 years Ukraine's soils loss 0.05% of humus on average [87].

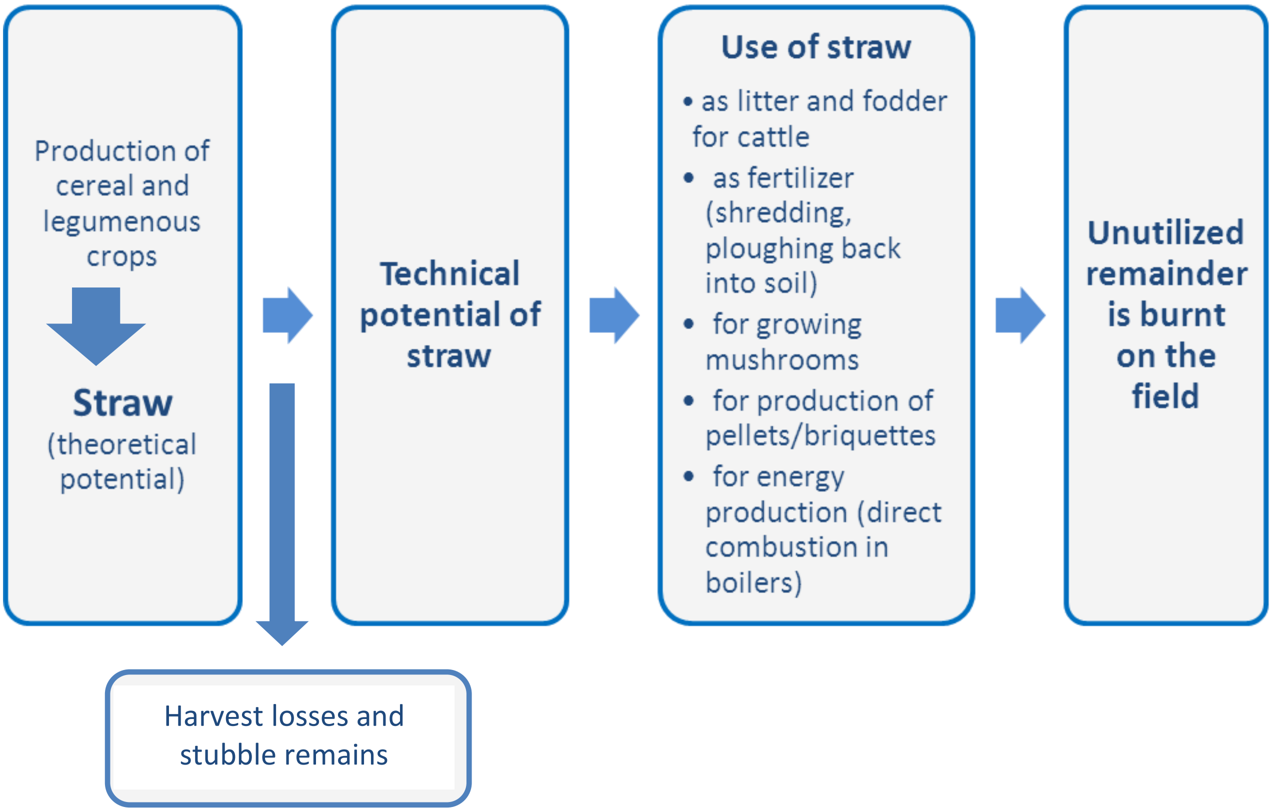

Fig. 9. Production and utilization of straw in Ukraine

Fig. 10. Examples of burning straw on Ukraine's fields
(pictures taken by UABio's specialists)

Table 1. Introduction of mineral and organic fertilizers in Ukraine [1]

	1990	2000	2005	2009	2010	2011	2012
	Mineral fertilizers, kg of nutrient per ha						
Fertilizers introduced under all crops, including:	**141**	13	32	48	58	68	**72**
nitrogen fertilizer	59	10	22	35	43	48	50
potash fertilizer	39	1	4	6	8	9	10
phosphate fertilizer	43	2	6	7	7	11	12
Fertilizers introduced under:							
cereal and leguminous crops	132	15	35	51	63	71	79
technical crops	260	18	39	49	57	67	66
	Organic fertilizers, t/ha*						
Fertilizers introduced under all crops, including:	**8,6**	1,3	0,8	0,6	0,5	0,5	**0,5**
cereal and leguminous crops	6,5	0,8	0,5	0,5	0,4	0,4	0,5
technical crops	17,5	3,1	1,2	0,4	0,4	0,4	0,4

** Manure, different composts, organic-mineral mixtures, poultry excrement etc.*

Expert estimations show that straw is the cheapest source of organic matter for soil. Introduction of straw as a fertilizer with adding 10 kg of nitrogen per a ton of straw is 11 times cheaper than introduction of mineral fertilizers and 4-5 cheaper than the use of manure [71]. Straw as fertilizer should be used first of all for depleted soils [21].

Fertilizing by straw is rather complex agrarian operation. The straw must be shredded, evenly spread over the field and ploughed back into soil. Improper introduction of straw may lead to blocking movable operating elements of tillage machines and sowing machines, may impede embedding seeds into soil, may cause uneven embedding or insufficient contact between seeds and soil, may lead to increased amount of pathogenic agents and plant pests and to reduced effect of herbicides [18].

To become a really effective fertilizer, not just filler that impedes soil treatment, straw must decompose as quickly as possible. Straw decompose quicker in aerobic conditions. In neutral soil well provided with nutrients, straw is decomposing during 3-4 years, in acid soil during 4-5 years. Deep ploughing straw into soil has a negative effect. When straw is decomposing in lower parts of the ploughing layer of the soil, volatile fatty acids are generated. The acids have a negative influence upon plant roots. When straw is introduced into upper third of the ploughing layer, it is decomposing quicker and accumulation of harmful substances does not take place.

As straw is poor in nitrogen (C:N=60-100[8]) it takes 40-50 kg/ha of nitrogen from the soil for its own mineralization until the ratio C:N=20 is reached. That is why the crops are lacking for nitrogen during the initial period of their growth unless nitrogen was introduced into the soil together with straw [20, 24].

A negative feature of straw is depressive influence upon the crop, under which it was introduced. Apart from the wide C:N ratio, inhibitory action is connected with the presence of soluble forms of organic compounds in straw. Aqueous extract from the fresh straw hampers plant growth. A number of derivatives of phenol were identified in straw and products of its decomposition. The derivatives have toxic effect on plants. In soil, the straw decomposition products (acids) significantly inhibit the growth of plants. Phytotoxic effect of the decomposition products lies in delayed growth of roots, metabolic disorders and the occurrence of plant diseases - chlorosis[9]. Especially many harmful compounds are accumulated at anaerobic decomposition of straw. In aerobic conditions and in soils with high biological activity, toxic compounds decompose faster. Experiments revealed that nitrogen was important for eliminating depressive effect of straw on the plants. Its big portions minimize the depressive effect of straw extracts [19].

Straw is widely used as *litter for cattle*. Straw bedding is universal covering; it is convenient and ecologically friendly for animals' health; it can absorb noxious gases like ammonia and hydrogen sulfide. Application of straw bedding contributes to manure collection and increase in its quality. However straw bedding has some disadvantages like quick caking, rather slippery surface, high infestation by mushroom spores, and dusted premises when the bedding is being introduced. Besides straw, the following materials can be used as litter for cattle: peat, sawdust, wood shavings, sand, leaves, and sometimes paper trimmings [8-10, 22, 23].

In livestock sector straw is also used as *fodder* for cattle. Agrarian specialists have already tried a lot of methods to improve the nutritional value of straw. The main conclusion is that for high yielders straw is fodder of little value; it should be only used as food additive in some diets to provide animals with cellulose [30].

Just after harvesting, the moisture of cereal straw[10] is 15-20% (heating value Q = 12-15 MJ/kg). If straw is left on the field for some (rather long) period of time[11], its moisture drops to 14-17% (Q = 14-15 MJ/kg); content of chlorine and potassium decreases due to washing-out that improves the quality of straw as fuel [55]. For combustion in boilers, straw moisture content must be below 20%, for pellets production it should be below 12-14%.

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[8] For information: in manure C:N=20-25, in soil C:N=8-12 [24].

[9] Chlorosis is decease of plants, which causes chlorophyll formation disturbance in the leaves and decrease in photosynthesis activity.

[10] Just after harvesting the straw is called **"yellow"** [63].

[11] So called **"grey"** straw [63].

Ukraine has some experience in *energy and biofuels production* from straw. About 100 boilers and heat generators for straw bales are in operation in rural areas of the country. About 45 of them are the boilers manufactured by UTEM (Ukraine), 10 units are the boilers of Faust and Passat Energi (Denmark) make, the others are heat generators of Brig (Ukraine) make. Total installed capacity of the equipment is estimated as 70 MW_{th}.

The sector of solid biofuel production from straw is also developing. In 2012, 21,700 t of pellets and 2,000 t of briquettes were produced in the country. The first part of Vin-Pelleta, a new factory, started its operation in Vinnytsa oblast (Ukraine) in autumn 2012. Its productivity is 75,000 t/yr of straw pellets. In 2014 the second part of Vin-Pelleta is expected to start its operation, and the factory will reach its design productivity of 150,000 t/yr. Smart Energy, the owner of Vin-Pelleta, is planning to build 20 factories for the production of straw pellets in all Ukraine's regions. Total productivity of the factories is supposed to be 2.5-3 Mt [17]. In addition, KSG Agro (a Ukrainian agricultural holding) is planning to start operation of a factory for straw pellets production in Dnipropetrovska oblast (Ukraine) in 2014. The productivity is expected to be 60,000 t/yr. The agricultural holding is going to use its own feedstock for the pellets production. Further plans include construction of another two factories, in Dnipropetrovska oblast and Crimea.

To increase the production of energy and biofuels from straw in Ukraine, it is necessary to switch over from the "streaming" technology of straw collection to swathing technology with straw baling.

Residues of grain corn production

Corn is one of the most common and most important crops in the world including Ukraine. In 2013, the gross harvest of grain corn in Ukraine reached the highest level since 1990 – 31 Mt with almost a record yield of 64 centners per ha. At that the corn harvested area increased by 4 times as compared with 1990 (**Table 2**) [1, 15].

Table 2. Production and yield of grain corn in Ukraine [1, 15]

Index	1990	1995	2000	2005	2009	2010	2011	2012	2013
Gross harvest, Mt	4,7	3,4	3,8	7,2	10,5	11,9	22,8	20,9	**30,9**
Yield, centners/ha	38,7	29,2	30,1	43,2	50,2	45,1	**64,4**	47,9	**64,0**
Harvested area, th. ha	1223	1161	1279	1660	2089	2648	3544	4372	**4825**

So called "non-grain" part of corn (corn stover or straw) includes mainly stalks and cobs. According to the National academy of agrarian sciences of Ukraine, the ratio between corn straw and grain is 1.3. Based on the figure and the data on grain corn production in the country in 2013, the volume of residues of grain corn production is estimated as over 40 Mt. So, we can state that Ukraine has a very big potential of biomass in the form of corn straw.

Corn is known as the culture that forms a large vegetative mass during the season and accumulates a lot of organic matter. Due to intensive removal of nitrogen, phosphorus, potassium and microelements from the soil by this plant, traditional farming methods are used, which consist in the mass introduction of big amounts of fertilizers to compensate for the losses [27]. The most effective is a joint application of mineral and organic fertilizers. As organic fertilizers they use corn stubble remains, cereal straw, and manure. Crop remains (stems, leaves) play an important role for the balance of humus as they replenish the stock of organic matter. When plowing corn stubble remains and introducing fertilizer, humus content in the soil is gradually increasing. Thus, when plowing 5 t/ha of dry matter of stalk-leaf mass, up to 750 kg/ha of humus is created [26]. It is believed that straw and corn stalks are 2.3 times more effective than manure. It is an effective and readily available fertilizer, but you have to apply it correctly [25].

Corn stalks as well as cereal straw are fodder for animals that is widely used in winter period. In summer time green fodder is preferred [29, 31].

The corn can be harvested with the purpose of corn or silage production. There are different technologies for grain corn harvesting. Depending on the applied technology, they can collect (a) peeled corn ears, (b) not peeled ears or (c) ears are threshed during the harvesting process. At that the residues of grain corn production can be (1) comminuted and collected in trailers, (2) comminuted and spread over the field to be ploughed into soil or (3) stalks and leaves without ears may be left on the field. The latter technology is widely used in the USA. Later on the stalks are mown down, comminuted and ploughed into soil. Another possible option is baling corn stalks.

With regard to energy conservation and resource-saving, harvesting all biological mass of corn during one operation (that is without leaving stalks in the field) and combine threshing ears in the field is considered the most reasonable technology.

In Ukraine, the most common harvesting technology includes combine threshing ears in the field, comminuting and scattering corn stover over the field[12]. Collection of the comminuted stubble remains is not performed. Only seed factories collect non-threshed ears and then perform threshing in stationary conditions that gives an opportunity to collect the cobs. The reason is that the seed factories grow corn to obtain (hybrid) seeds as planting stock.

To use corn residues as a biofuel it is necessary to ensure their collection. This is possible with the use of harvesting technology providing collection of stalk-leaf mass in vehicles[13] or/and stationary threshing ears in stationary conditions[14].

Another option is development of baling technology for the case when only ears are collected and stalks are left on the field[15]. There exist examples of the use of high-pressure balers (Massey Ferguson, Vermeer) for corn stalks in the USA. As usual the stalks are baled at the moisture content

[12] Combunation of the mentioned above technologies **b)** and **2)**.
[13] Mentioned above technology **1)**.
[14] Mentioned above technologies **a), b)**.
[15] Mentioned above technology **3)**.

below 20-25%[16] to avoid problems during storing bales. American farmers use the collected corn stalks as litter and fodder for cattle [35, 38, 76, 77].

At present there are no balers for corn stalks in Ukraine as the technology has not been needed by now.

An important issue for energy production is moisture of corn stalks and cobs. Immediately after harvesting the moisture content of stalks is 45-60% (heating value is 5.8 MJ/kg). After drying in the air the moisture can drop to 15-18% (Q = 15-17 MJ/kg) [55]. They start harvesting corn without thrashing ears when moisture of seeds is below 40% and with threshing ears when the moisture is 30%. Cobs are always more moist than grain (35-45 %), but during drying they evaporate moisture more intensively [2-6]. Typically, corn grain is harvested in October-November. Some farms have been doing it in December, January and even later last years, but it is not due to agro-technical requirements but due to production needs and economic feasibility [74].

Fig. 11. Corn harvesting

Massey Ferguson (USA) baler [36]

Vermeer (USA) baler [37]

Fig. 12. Balers for corn stalks

[16] American experts estimate that baling corn stalks should be performed in 2-7 days after corn harvesting depending on weather conditions [77].

 

Fig. 13. Corn stalks and bales made from them

At present in Ukraine there are few examples of energy production from grain corn residues. One of them is Cherkassyteplocomunenergo (the state company responsible for heat supply in Cherkassy city) that produces heat from corn cobs. The cobs are supplied by Cherlis factory (Cherkassy city). Another example: corn stalks are being considered as a possible fuel (alternative to wood chips) for the second unit of 12 MW_e TPP in Ivankiv urban village (Kyiv oblast). Agrarian companies of Ivankiv district state that 90,000 t/yr of this kind of biomass are available.

To make the use of corn stover for energy production possible we can suggest switching over to the "American" technology for corn harvesting. That means that the stalks will be left in the field and baled after proper drying in the air. The collected stalks then can be used for production of pellets/briquettes or directly combusted in boilers.

Biogas production by anaerobic digestion and using the fermented mass as a valuable organic fertilizer may be an alternative to effective utilization of corn residues. Unlike the introduction of ash after combustion of plant residues, it allows you to renew soil fertility at a level that was before harvesting, since almost the entire mass of biogenic elements and compounds in a transformed form is returned to the field.

However, it should be noted that the use of plant residues for biogas production after ripening and harvesting a target crop (grain) has certain limitations. This plant mass in a large proportion composed of lignocellulosic complexes that are difficult to biodegradation. This plant mass in a large proportion is composed of lignocellulosic complexes which with difficulty lend themselves to biodegradation. The destruction of such complexes requires the use of special measures, such as heat or thermo-physical treatment, fine mechanical grinding, chemical treatment, introduction of special enzyme preparations, etc. [86]. However, these methods are often too costly compared with the resulting effect that limits their use in practice. Therefore, biogas is traditionally produced from the plant biomass (stalks, leaves and cobs of corn, sorghum, miscanthus, spiked grains before the beginning of grain ripening, when the plant is still green) that do not require additional pre-treatment, except for ensiling. In addition, some studies show low efficiency of mono-fermentation of plant feedstock after ripening because of too high ratio of C: N and deficiency of certain microelements. Biomass is usually fermented with animal manure.

Residues of sunflower production

Sunflower is also one of the main agricultural crops in Ukraine. Like corn, in 2013 Ukraine harvested a record volume of sunflower – 11 Mt with the highest over past 20 years yield of 21.7 centners per ha. The sunflower harvested area increased by 3 times compared to 1990 (**Table 3**) [1, 15].

Table 3. Production volume and yield of sunflower in Ukraine [1, 15]

Index	1990	1995	2000	2005	2009	2010	2011	2012	2013
Gross harvest, Mt	2.6	2.8	3.5	4.7	6.4	6.8	8.7	8.4	**11.0**
Yield, centners per ha	15.8	14.2	12.2	12.8	15.2	15.0	18.4	16.5	**21.7**
Harvested area, th. ha	1626	2008	2842	3689	4193	4526	4717	5082	**5089**

The potential of sunflower production residues (stalks, heads) is very big. Based on the gross harvest in 2013 and approximate ratio of residues (straw) to seeds (2.0), the potential is assessed in 22 Mt.

Sunflower seeds are used for the production of edible and technical oil; oilcake is feed for animals; sunflower stalks can be ensiled[17].

Sunflower is harvested in September-November. When harvesting sunflower in its optimal phase of ripeness, the moisture content of heads is 70-75%, stalks – 60-70% [57].

Sunflower is harvested by combine harvesters equipped with reapers. If the unit “combine-reaper" is equipped with a shredder, it provides cutting plants, threshing heads, collecting seeds in the bin, grinding the thrashed heads and stalks followed by their spreading over the field or collecting in a trailer. Another option is to collect non-shredded thrashed sunflower heads in the stacker, followed by their unloading onto the field in the form of small ricks. The remained stalks are cut and shredded by disc plows. Then they are raked into swaths, of which ricks are made [58-60]. This very technology (leaving the stalks in the field) is applied in Ukraine.

To use sunflower production residues for energy purposes one should ensure their collection. Like corn, sunflower residues have high natural moisture content. That is why as the strategic area, with certain limitations, we can recommend ensiling sunflower stalks, followed by the production of

[17] **Silage** is fermented, high-moisture stored fodder which can be fed to ruminants (cud-chewing animals such as cattle and sheep) or used as a biofuel feedstock for anaerobic digesters. It is fermented and stored in a process called ensilage, ensiling or silaging, and is usually made from grass crops, including maize, sorghum or other cereals, using the entire green plant (not just the grain). Silage can be made from many field crops, and special terms may be used depending on type.
http://en.wikipedia.org/wiki/Silage

biogas. The alternative is baling stalks dried in the field, followed by their combustion in boilers or the use as feedstock for the production of pellets/briquettes.

Now in Ukraine there are no examples of the use of sunflower stubble residues for energy production. Only sunflower husk is actively utilized as a feedstock for making pellets/briquettes and as a fuel for boilers operating at oil extraction plants and other enterprises of oil and fat industry.

Fig. 14. Sunflower harvesting

Fig. 15. The field after sunflower harvesting[18]

Properties of plant residues as fuel

Plant residues as a fuel have a number of adverse properties, so its utilization requires more accurate approach. Foe example, straw can contain chlorine and alkaline metals (**Table 4**), thus its combustion can lead to formation of such chemical compounds as sodium chloride and potassium chloride. These compounds cause corrosion of steel parts of power equipment, especially at high

[18] http://pluga.net/media/photogallery/

temperatures. Another property of straw as a fuel is its relatively low melting point of ash – 800-950 °C (compared to wood ~1200 °C) that can result in slagging of parts of energy equipment.

Table 4. Chemical composition and some characteristics of biofuels of vegetable origin

Indexes	Yellow straw [63]	Grey straw [63]	Wheat straw* [80]	Corn stalks* [72]	Sunflower stalks* [80]	Wood chips (for comparison) [63]
Water content, %	10-20	10-20	No data	45-60 [55] (after harvest) 15-18 [55] (dried in the air)	60-70% [57] (after harvest) ~20** (dried in the air)	40
Net calorific value, MJ/kg	14.4	15	17 (Gross calorific value)	16.7 (d.m.) 5-8 (W 45-60%) [55] 15-17 (W 15-18%) [55]	16 [14] (W<16%)	10,4
Volatile-matter content, %	>70	>70	73	67 78 [79]	73 [14]	>70
Ash content, %	4	3	9,6 2.6 [73]	6.7 6-9 [73] 3.5 [79]; 5.3 [80]	10 12.2 [14]	0.6-1.5
Elementary composition, %:						
Carbon	42	43	43.1	45,5	44,1	50
Hydrogen	5	5,2	5.3	5.5	5.0	6
Oxygen	37	38	39.8	41.5	39.4	43
Chlorine	0.75	0.2	0.8	0.2 [80] 0.984 mg/g; 2-3 mg/g [78]	0.7 0.81 [14]	0.02
Potassium (alkali metal)	1.18	0.22	6.1 mg/kg d.m.	cobs: 6.1 mg/kg d.m. [80]	5.0 [14]	0.13-0.35 [14]
Nitrogen	0.35	0.41	0.6	0.69; 0.3 [80]	0.7	0.3
Sulphur	0.16	0.13	0.2	0.04	0.1	0.05
Ash melting point, °C	800-1000	950-1100	1040-1250	1050-1200 1100-1200 [78]	800-1270 [14]	1000-1400

d.m. – dry matter; W – water content.

* Data on volatile-matter content, ash content, elementary composition are in % of dry weight.

** Expert assessment of UABio.

But today the world has found design and other technological solutions that minimize these adverse impacts and allow utilization of straw successfully as fuel. Examples of such solutions are co-combustion with coal, wood and other fuels, or utilization of “grey” straw with long open-air drying period instead of “yellow” (fresh) straw. “Grey” straw contains significantly less chlorine and potassium, compared to “yellow” one, because of “washing” by rains.

As for Ukraine, it is possible to assume that content of chlorine and alkali metals in its straw is less than in the straw of other countries. It is associated with significant reduction of mineral fertilizer input for crops over the past 20 years. (see **Table 1**).

Corn stalks also contain chlorine and alkali metals. According to data [80], chlorine content amounts 0.2% of dry weight, which is close to the index of “grey” straw. According to available data on corn cobs, potassium content is the same as in straw (6.1 mg/kg d.m.). Ash melting temperature for corn stalks is higher, than for straw – 1050-1200 °C [72]. This is a positive factor for its utilization as a fuel. Besides, corn stalks contain one order less sulphur, than straw.

Carried out research [73] demonstrated the possibility of successful combustion of corn stalk bales in a boiler[19], designed for combustion of straw bales of grain crops. One of the differences was formation of a larger amount of ash – 9.2% for corn stalks against 2.6% for straw. To reduce the amount of ash it is recommended not to use bales of corn stalks with high density (~ 105 kg d.m/ m^3), but with low and medium ones (~ 80 kg d.m./m^3). In this case, the amount of ash is reduced to 6.2%. Average CO emissions during corn stalks combustion was higher than for straw (2725 mg/m^3 vs. 2210 mg/m^3) and for NO_x and SO_2 emissions was lower (mg/m^3): 9.8 vs. 40.4 and 2.1 vs. 3.7, respectively.

There is little information on utilization of sunflower stalks as fuel. According to [80] elementary composition of stalks is close to that of straw and corn stalks, but ash content is higher - about 10% of dry weight. The content of alkali metal potassium is also significantly higher - up to 5% of dry weight. For today no examples of energy production from sunflower stalks are found.

Share of agricultural plant waste that can be used for energy production

One of the major issues is what proportion of potential straw and other agricultural plant waste can be used for energy production, taking into account first of all needs of crop farming and cattle breeding. To answer this question let's consider existing research on the issue and practical experience of other countries.

In the European Union and generally in the world the most experienced country in energy production from straw is Denmark. In this country, from average 5.5-6 million tons of produced straw about 1.5 million tons (**27%**) are utilized as fuel, 1 million tons (18%) is used as feed for cattle, 0.7 million tons (13%) goes to the litter for cattle, and free residue is about 2.3 million tons

[19] Boiler “Farm 2000" (United Kingdom)
http://www.farm2000.co.uk/farm2000.co.uk/Fuels_%26_Boiler_Type.html

(42%) (data for 2004-2008[20]). Numerous studies conducted in the country showed that the current and expected future volume of straw far exceeds the needs of all existing areas of consumption [13]. In the UK, 40% of wheat straw yield is crushed and ploughed into soil, 30% is used as litter and fodder for livestock, the left 30% are sold by farmers to other users, including **3%** (about 200,000 t/yr) - for the needs of power plant with capacity 38 MW_e [32, 42]. In China annually 600 million tons of straw is produced, about 6.4 million tons (**1%**) of which is used as fuel in power plants [66, 67].

In Ukraine according to estimates of UABio experts performed for 2012, **0.6%** of the collected amount of straw was used for production of energy and solid biofuels.

A comprehensive study on the possibility of sustainable use of straw for energy purposes was recently completed in Germany by the Thuringian Regional Institute for Agriculture (TLL), the German Biomass Research Center (DBFZ) and the Helmholtz Centre for Environmental Research (UFZ) [33, 34]. This is one of the few existing studies of this kind for a particular EU country. According to its results 30 million t/yr of straw is produced in Germany, 4.8 million t/yr (16%) of which is used for stock farmng needs, and 8-13 million t/yr (~ 30%) can be used for energy purposes on the basis of sustainability criteria (the study processed data of 1999-2007). Similar studies for Greece and Sweden have shown that it is possible for energy sector to use 15% and 60% of collected straw, respectively, while the rest should remain on the field to maintain soil fertility [46, 49].

In Poland, 23 million tons of cereal straw is produced annually, according to the data of [69] 4.5 million tons (20%) of this straw can be used for energy needs. The rest goes to the personal needs of agriculture. Estonian experts consider that 10% of the total amount of produced straw should be used for bedding for cattle, 25-75% - to maintain soil fertility, and respectively 15-65% remains for energy production [70].

One of the conclusions of the German study [33, 34] authors is that the straw as fuel in the country isn't utilized completely. The Dutch specialist, professor of Copernicus Institute of Sustainable Development of Utrecht University, Martin Dzhundzhynreha made a forecast that soon a number of European countries will switch from the use of woodfuels to agricultural ones. The reason is that many world renown experts do not consider wood to be a quick renewable energy source, unlike straw and other biomass of agricultural origin [61].

Up to ten studies have been performed for the EU on the issues of energy use of plant waste. According to the results, 25-50% of the total amount straw and crop residues of corn, 30-50% sunflower production waste, while the remaining biomass should be left in the fields [40-42, 47, 50, 52]. Studies performed for the U.S. showed that 30-60% of the total amount of straw and crop

[20] In 2012 situation was mostly the same [39]

residues of corn can be used for energy/biofuels production. With the No-Till[21] technology share of crop residues of corn available for energy needs can increase to 60-80% [43-45, 48, 51, 53, 54].

In Ukraine there are different, sometimes directly opposite positions on the possible use of straw and other plant residues. Many experts in the field of soil science and agriculture think that almost all straw should be left in the field to maintain soil fertility and reproduction. In contrast, according to other specialists[22] in Ukraine there is a surplus of straw that can be used in the energy balance. Practical experience of developments shows that on the one hand Ukraine is gradually picking up the process of introducing straw fired boilers; volumes of pellets and briquettes production increase. On the other hand information about the lack of straw for energy production in the regions comes quite often. For example, almost all requests about the possibility of straw supply for energy submitted by UABio to agroholdings in Kyiv and neighboring regions in 2013, received the answer that all farms used straw for own needs. And in almost all responses of agro-enterprises to similar requests for corn stalks and cores mentioned that leaf and stalk mass of corn during harvesting is chopped and spread across the field.

There is a number of scientific studies performed by Ukrainian experts on the possibility and feasibility of using straw and other agricultural residues for energy production. Consider some of them.

In [7] a computer simulation model of the agricultural enterprise is developed. It uses some share of straw for the production of pellets/briquettes and direct combustion to produce heat. This model helps to establish individually for each company a possible share of straw that can be used for energy purposes in compliance with humus balance. For the potato-grain-livestock enterprise considered in the research this share is 38%.

Similar study [12] considered another type of agricultural enterprise (sugar-grain-livestock direction). It determined proportion of straw that can be used to produce energy without harming soil fertility to be 86%. So, we resume that amount of straw or other plant waste available for energy production depends on particular agro-enterprise characteristics and business environment. According to the assessment method developed in [7, 12], this share can vary from 30% to 100% of the total amount of waste [56]. Further development of this approach can be found in the study [11]. It developed a detailed decision making algorithm on the possibility of using plant residues for energy or biofuels production by particular enterprise.

[21] Zero tillage system, also known as No-Till, is a modern system of farming, in which the soil is not ploughed, and its surface is covered by specially milled plant residues - mulch. Since the top layer of the soil is not turned up, this farming system prevents water and wind erosion of the soil, and retains water much better.

[22] **Example**: M. Bezuglyi, Vice President of Ukraine's NAAS, academician of NAAS; V. Bulgakov, academician-secretary of Department of Mechanization and Electrification of NAAS, corresponding member of NAAS: «According to preliminary calculations, Ukraine has the ability to use **up to 10 million tons of grain straw and arouabout 7 million tonnes of rape straw for energy purposes annually**» http://a7d.com.ua/weekend/others/1461-naukovi-j-praktichni-aspekti-vikoristannya-solomi.html

Study [56] developed a model and established a relation for calculating a maximum limit of straw that can be used for heat demands of agro-enterprises. Available amount of straw depends on the annual humus deficit (kg/ha). The proposed relation takes into account indicators which characterize agricultural production in Ukraine in recent years. According to the study, if general deficit of humus is more than 67 kg/ha, then straw utilization for heat demands is impossible, because positive balance of humus doesn't take place. The maximum amount of straw that can be used for heat demands with a zero balance of humus is about 40%. According to developed model the author [56] calculated the potential of straw for energy purposes in Zhytomyr oblast according to 2005-2011. Share of available straw for the whole oblast is about 30%, while in some regions it ranges from 0 to 49%.

Utilization of straw and other crop residues for agricultural and energy purposes is described in the study [30]. In particular, it points out that Denmark, Sweden and the most Central European countries actively develop energy production from straw. These countries annually use from 5% to 20% of produced straw for heat purposes. 45-50 million tonnes of cereal and legume straw is produced annually in Ukraine. 17-20 million tons (~ 40%) of this amount should be used as organic fertilizer and 10 million tons (20%) can be taken for energy needs. In the livestock farming straw should be used primarily as a bedding (daily requirement, e. g. for cows - 2-8 kg per day for 1 head, depending on the type of keeping and productivity). Straw as a feed is of low value for highly productive stock and should be used only as a supplement. The study [30] also emphasized that the most efficient way of straw and other plant residues utilization requires an individual approach for each sector, based on the principle of economic and agricultural feasibility.

Considering these issues it is important to remember that besides the straw, which is specifically introduced into the soil as organic fertilizer, stubble[23], left in the field after harvest, also gets into the soil, and so does the straw used for litter and fodder.

These studies contain only general (qualitative) recommendations concerning waste from corn production and sunflower waste. Thus, the author of the study [12] believes that stubble[24] of corn and sunflower should be left shredded in the fields, and their combustion in boilers is inappropriate in the current environment. The study [26] concludes that part of grain harvest of corn together with leaf and stalk mass can be used for energy purposes.

The results of the practical experience of the European countries and of Ukrainian and foreign studies are summarized in **Table 5**.

[23] Stubble is included into theoretical potential of straw (i.e. the total amount of production). Technical potential (one, that can be practically collected) is calculated by subtracting stubble amount and losses of straw collection (e.g. baling) from the theoretical potential. Actually, all straw losses at harvest remain in the field and get into the soil.
[24] Stubble – stalks and leaves of plants.

Table 5. The share of agricultural plant residues available for energy production

Country / region	Waste type*	Share of total amount (theoretical potential), available for energy needs
Germany [33, 34]	straw	30%
Greece [46]	straw	15%
	C, S	60%
Sweden [49]	straw, C	60%
Poland [69]	straw	20%
Estonia [70]	straw	15-65%
EU-15 + Norway and Switzerland [41]	straw	50%
	C	25%
EU-27 [40]	straw, C, S, O	30%
EU-27 [42]	straw	45%
	C, S	40-50%
EU [47]	straw, C	25%
EU [50]	straw, C, S	30%
EU [52]	straw	50%
USA [51]	straw	40%
USA [54]	straw, C	30-40%
USA [43]	C	30-60%
		76-82% (under technology No-Till)
USA [44]	straw	40-50%
	C	40%
		35-70% (under technology No-Till)
USA [45]	straw	60%
	C	60-70% (under technology No-Till)
USA [48]	V	30-70% (under technology No-Till)
USA [53]	C	30-40%
Ukraine [7]	straw	38% (enterprises of potato-grain-livestock direction)
Ukraine [56]	straw	40%
Ukraine [12]	straw	86% (enterprises of sugar-grain-livestock direction)
Ukraine [30]	straw	20%**
Ukraine [92]	straw	≥ 50% (after 2008)
	C, S	100%

** C – waste of grain corn production, S – waste of sunflower production, O – other plant waste.*
*** Calculated by the authors of the Position Paper according to data of the study [30].*

Critical analysis and synthesis of all the above data in this chapter allows to create the following position of UABio:

1. The issue of the share of straw and other crop residues that can be used for energy or biofuels production should be addressed individually for each farm. At the same time, all relevant agro-economic factors should be taken into account.
2. For Ukraine as a whole only following general reccomendations on the share of straw and other crop residues available for utilization as fuel, subject to own needs of agriculture, can be offered:

   *to use **up to 30%** of the theoretical potential of cereal straw and **up to 40%** of the theoretical potential of waste from grain corn production and sunflower production.*

Energy potential of agricultural plant residues

Based on the recommended shares of plant waste available for energy production, we calculate the potential of relevant biomass types according to data on production of the corresponding agricultural crops in 2013. Calculation results are presented in **Table 6**.

Table 6. Energy potential of agricultural plant residues (**2013**)

Biomass type	Crop yields, Mt	Total amount of waste (theoretical potential), Mt	Waste share for energy needs	Energy potential			
				Mt	W, %	LHV, MJ/kg	**Mtce**
Straw of cereal crops	*grain crops (without corn):* 32.1	30.6	**30%**	**9.2**	20	14,5	**4.5**
Residues from grain corn production: total, including* - stalks (with leaves) - cobs	*corn:* 30,9	40.2 30.3 5.6	**40%**	**16.1** 12,1 2,2	50	8	**4.4** 3.3 0.6
Residues of sunflower production: total, including - stalks (with leaves) - baskets	*sunflower:* 11.0	20.9 14.3 6.6	**40%**	**8.3** 5.7 2.6	60	6	**1.7** 1.2 0.5
Total	74.0	91.8		**33.6**			**10.6**

** The rest is husk leaves with shanks.*

The following ***residue factors***[25] [88] have been used in the calculation:
wheat – 1,0
barley – 0,8
other grain crops – 1,0
grain corn – 1,3
sunflower – 1,9.

It should be noted that experts have different views on the value of the residue factors; in different studies one can find a range of values. In a number of scientific papers, e.g. [89-91], the ratio of the grain to straw is determined using regression equations based on the crop yield that allows obtaining the most accurate results.

The data in the **Table 6** show that in values of conditional fuel (coal equivalent) the biggest potential falls on cereal straw (4.5 million tce) and grain corn production residues (4.4 million tce). The potential of sunflower residues is 1.7 million tce. The total potential amounts to **10.6** million tce or in natural tons – 33.6 million tons.

If we compare these results with previous UABio estimates of all biomass types potential available for energy production in Ukraine (**30-35** million tce/yr), we see that plant agricultural waste in the form of cereal straw, waste of grain corn production and sunflower waste make up about **a third** of the total potential.

Conclusions

Today the world has accumulated a large enough experience of plant agricultural waste for energy production. Commercial straw power plants successfully operate in such countries as Denmark, China, Spain, UK.
Plant waste as a fuel has a number of negative features that require quite thorough approach to its use. Thus, the straw can contain chlorine and alkali metals leading to corrosion of steel elements of power equipment, especially at high temperatures. Besides, straw has a relatively low ash melting point and can cause slagging of energy equipment elements. But today, design and other technological solutions are already found to minimize these negative impacts and allow to use straw as fuel.

World experience of corn stalks utilization for energy production is significantly less. They are known to have relatively high ash content (approximately 2-fold higher than straw), but - quite a high melting point of ash, which is a positive factor for the fuel. Today there are no examples of energy production from sunflower stalks. There are data that their elementary composition is close to the composition of straw and corn stalks, but ash content is higher -10-12% by weight of dry

[25] According to information from the Crop production Department of NAAS obtained by the letter N 5-2/256 of 16.11.2012.

matter. In addition, content of alkali metal potassium is significantly higher - up to 5% by weight of dry matter.

Ukraine has a large number of plant waste through highly developed agricultural sector. The main ones are cereal straw, residues of grain corn production and sunflower residues. Agricultural biomass can be used for energy purposes, if collection of the relevant waste is organized. Ukraine has all neccessary equipment to collect straw, the only need is to switch from the “streaming” technology of straw collection to swatching ones, followed by straw baling. The decision to use swathing or other technology is taken directly by agro-enterprise. It seems that, under wide introduction of straw fired boilers in Ukraine and a stable demand for straw, it will be economically profitable for agricultural enterprises to use swathing technology to collect straw, bale it and sell to relevant consumers.

Harvest technologies for corn that are used in Ukraine now, do not include collection of corn residues. Leaf and stalk mass is shredded and spread across the field. The following options can be offered: collection of shredded residues into transport vehicles and/or stationary trashing of ears. Then collected waste is siloed and used for biogas production. Alternative approach is to use corn collection technology, widespread in the USA, which collect only corn ears and leave corn stalks in the field. Then stalks are dried in the open air to moisture content of about 20%, and then baled. There is no such equipment in Ukraine today, but appropriate balers are produced and used in the USA.

Similar approaches can be recommended also for residues of sunflower production: collection of chopped waste for silo and biogas production or baling of dried in the field stalks with further combustion in boilers or utilization as raw material for production of pellets/briquettes.

Certainly, agro-enterprises will collect residues of corn production for grain and sunflower residues only at stable demand and favorable prices. The next step is energy utilization of the waste (biogas production, direct combustion or pellets/briquettes production), which depends on the moisture content of waste and estimated technical and economic performance of technologies.

On average the following shares of theoretical potential (i. e. total amount of production) are recommended for Ukraine: cereal straw – **up to 30%**, residues of grain corn production and of sunflower production – **up to 40%**. Considering these recommendations energy potential of the corresponding types of biomass is estimated in **33.6** million t or **10.6** million tce (as of 2013). This amounts about **one third** of total biomass energy potential in Ukraine.

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Abbreviation

CHP – combined heat and power
CHPP – combined heat and power plant
DH – district heating
MSW – municipal solid waste
PP – power plant
TPP – thermal power plant
NAAS – National Academy of Agrarian Sciences
d.m. – dry matter
tce – ton of coal equivalent (calorific value of 1 tce is 29.3 GJ)

Previous UABIO's publications

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

1. Position Paper N1 "Position of bioenergy in the draft updated energy strategy of Ukraine till 2030".
2. Position Paper N2 "Analysis of the Law of Ukraine "On amending the Law of Ukraine «On Electricity" No5485-VI of 20.11.2012".
3. Position Paper N3 "Barriers to the development of bioenergy in Ukraine".
4. Position Paper N4 "Prospects of biogas production and use in Ukraine".
5. Position Paper N5 "Prospects for the electricity generation from biomass in Ukraine"
6. Position Paper N6 "Prospects for heat production from biomass in 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

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