PROSPECTS FOR THE GROWING AND USE OF ENERGY CROPS IN UKRAINE

UABio Position Paper N10

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Table of contents

Introduction

UABio Position Paper N10 covers the issues of growing and using energy crops and also prospects for the development of this bioenergy sector in Ukraine. The document contains analysis of energy crops sphere in the European Union including existing support mechanisms. The authors have considered the features of growing several energy crops and fuel properties of the crops. Some mechanisms to encourage the energy crops sector development in Ukraine are suggested.

Growing energy crops in the EU

Energy crops are the plants which are cultivated with the purpose to be used directly as a fuel or as a feedstock for production of biofuels. At present there does not exist a standard (or generally accepted) classification of the crops. Energy crops can be grouped according to the following features (some examples are given in brackets):

- *cultivation cycle* – annual crops (rape, sunflower) and perennial crops (willow, poplar);
- *type* – woody crops[1] (willow, poplar) and herbaceous crops (miscanthus[2], switchgrass);
- *characteristics* and therefore the obtained end product – oil crops (rape/sunflower for biodiesel), starch and sugar crops (sugar beet/maize for bioethanol), lignocellulosic crops (willow/poplar for direct heat and power generation, production of solid biofuels or 2nd generation liquid biofuels);
- *«origin»* – classical energy crops that is crops initially intended for energy production (miscanthus, reed canary grass) and common agricultural crops, which are grown for food production as well as for biofuels production (rape for biodiesel, sugar beet for bioethanol, maize for biogas).

Energy crops are very important for the bioenergy sector of the European Union. European Biomass Association (AEBIOM) estimates the current potential of energy crops in the EU as **44-47** Mtoe/yr [1]. One of the EU 2020 targets is to reach **138** Mtoe of biomass in the gross final energy consumption that corresponds to 14% of GFC [7]. The available potential of energy crops allows covering about 1/3 of the target.

As of 2011, the total area under lignocellulosic energy crops in the EU was about **130-140** th. ha (**Table 1**) [7]. About 37% of the area (50 th. ha) is in Romania with growing switchgrass. Big areas are also in Finland under reed canary grass (nearly 19 th. ha), in the UK under miscanthus (10-11 th. ha), in Sweden and Poland under willow (11 th. ha and 5-9 th. ha respectively).

At the same time the cultivation area for energy crops intended for liquid biofuels production is much bigger and exceeds 2.5 Mha in the EU. The crops are mostly grain crops and rape. Almost 38% of the total is in Germany where 746.5 th. ha are occupied by rapeseed (for biodiesel) and 200

[1] As usual they form short rotation coppice (SRC).
[2] It is also called Elephant Grass.

th. ha are under sugar and starch crops (for bioethanol) (**Fig. 1**). The big area in Germany (1157 th. ha) is also used for cultivating crops, which are feedstock for biogas production.

Table 1. Lignocellulosic energy crops in the EU (2011), ha [7]

EU countries	Willow	Poplar	Miscanthus	Switchgrass	Reed canary grass
Austria	220-1100	880-1100	800		
Belgium	60		100		
UK	1500-2300		10000-11000		
Germany	4000	5000	2000		
Denmark	5697	2807	64		19
Ireland	930		2200		
Italy	670	5490	50-100		
Lithuania	550				
Netherlands			90		
Poland	5000-9000	300			
Romania				50000	
Sweden	11000	550	450		780
Finland					18700
France	2300		2000-3000		

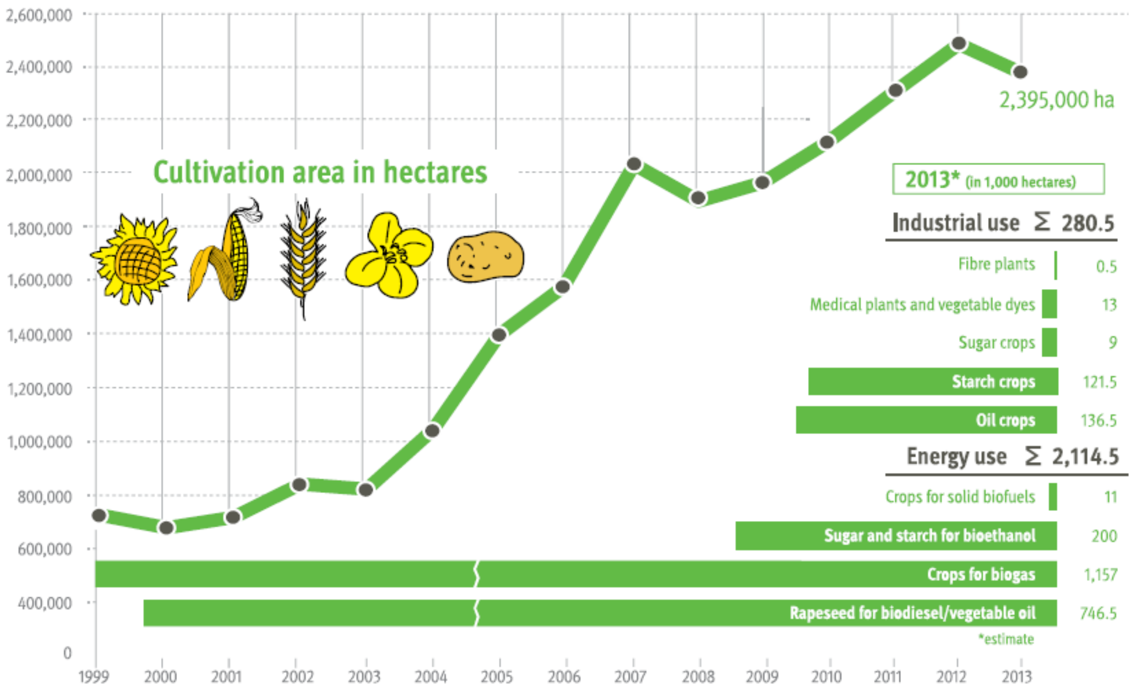


Fig. 1. Crops for energy and industry in Germany [44]

Nowadays, **13.2** Mha are available in the EU for cultivation of energy crops, while in 2020/2030 it is expected to increase and be around **20.5/26.2** Mha respectively. The European Commission calculated that **17.5** Mha of land would be required to reach the 10% biofuels target that would amount to about 10% of the total Utilized Agricultural Area in EU-27 [2].

Regulation and stimulation of energy crops cultivation in the European Union

Different policy levels affect the production of energy crops in Europe [8]:

- Agricultural Policy;
- Energy policy;
- Research and innovation policy.

Agricultural policy

The Common Agricultural Policy (CAP) addresses renewable energy under its second pillar for rural development. The CAP provides the possibility to support investments and infrastructure related to establishment of energy crops such as Short Rotation Coppices (SRC) and grasses for energy purposes (miscanthus, switchgrass, reed canary grass etc.). Concrete figures are not indicated in the relevant documents but some experts observe that pillar II budget is much less than that of pillar I[3]. It should be noted that under CAP pillar I (Single Farm Payment), a specific "energy crop scheme" was introduced in 2003 that provided per hectare subsidies (45 EUR/ha), though this was removed in 2010. Several member states began their own similar schemes [38].

The CAP post-2013 also requires farmers to dedicate at least 5% of their eligible hectares to ecological focus areas (for arable lands above 15 ha) such as land left fallow, terraces, landscape features, buffer strips and afforested areas. This figure could rise to 7% after a Commission report in 2017. Members States have the possibility to grow perennial energy crops on these ecological focus areas, under the condition that no pesticides and chemical fertilizers are used.

Energy policy

The Renewable Energy Directive 2009/28/EC set the goal to provide 10% of RES in transport sector by 2020. Achieving the goal implies the use of agricultural crops for liquid and gaseous biofuels production. At that the European Commission is concerned to limit the impact of indirect land use changes generated by the production of biofuels[4]. That is why the Commission published a proposal that limits the contribution of food-based (conventional) biofuels to 5% to meet the 2020 renewable energy target in the transport sector. This proposal is currently being discussed within the European Parliament and the Council. Another similar suggestion is also under discussion: to limit to 6% the contribution of all energy crops grown on land – including perennial energy crops – to the 10% renewable energy target in the transport sector. The outcomes of pending sustainability discussions will have a significant impact on energy crop production in Europe.

Implementation of research and innovation policy includes the European Strategic Energy Technology (SET) Plan[5] and the EU's new program for research and innovation Horizon 2020[6]

[3] Some figures for comparison: Pillar II budget in 2009 was 13.6 billion EUR, [40], the budget for 2014-2020 is about 85 billion EUR [39]. Pillar I budget in 2009 was 41.1 billion EUR, [41], the budget for 2014-2020 is about 264 billion EUR [42].

[4] Just under 99% of biofuels currently used in the EU road transport come primarily from food and feed crops [19]

[5] http://europa.eu/legislation_summaries/energy/european_energy_policy/l27079_en.htm

(2014-2020). SET Plan is to assist the EU to attain its 2020 and 2050 targets in energy sector. Among others, the Plan includes measures to encourage production and consumption of 2nd generation liquid biofuels. Under Horizon 2020, approximately 5.8 billion EUR is dedicated to research and innovation for secure, clean and efficient energy.

Beside the mentioned above three policy levels affecting the production of energy crops in Europe, a lot of EU countries have their own drivers and support schemes for the sector (Table 2). Typical support schemes are subsidies per hectare of land under energy crops and feed-in tariff (or similar mechanism) for power produced from biomass/biogas. For instance, in Finland agricultural subsidies for cultivating reed canary grass are the same as the subsidies for other field crops (500-700 €/ha/yr) and support scheme for SRF plantations is 500 €/ha . In Austria, producers of power from energy crops has additional commodity bonus to the existing feed-in tariff.

Table 2. Driving forces and support schemes for energy crops in the EU [3, 9, 37].

EU countries	Driving forces	Support schemes
Austria	Markets for biomass/pellets.	Feed-in tariff for electricity produced from biomass/biogas. For energy crops, the plant owners have got an additional commodity bonus of 4 cent/kWh since 2008.
Germany	Biogas in network. Advanced biofuels.	Feed-in tariff for electricity produced from biomass/biogas.
Denmark	High biomass price.	
Finland	Large market/demand for biomass.	Support scheme for SRF plantation: 500 €/ha. Subsidies for cultivating reed canary grass: 500-700 €/ha/yr.
France	Sugar reform fund (64 million EUR). Waste water treatment / table water protection / sewage sludge.	
Italy	Sugar reform.	Feed-in tariff for electricity produced from biomass/biogas.
Poland	Agricultural potential. Legislation on biomass for power (stimulation of agricultural biomass use).	
Sweden	CO_2 tax. Large market/demand for biomass.	Farmers receive a subsidy for establishment costs of willow: 500 €/ha.
UK	Limited wood resources.	Energy crops support schemes: 800-1000 pounds/ha (willow, poplar, miscanthus and others). Renewable Obligation Certificates (ROCs) for electricity are advantage for energy crops.
Romania	Land potential	
Spain	Land potential [2]	Regulated tariff for electricity produced from energy crops.

[6] http://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020

Peculiarities of cultivating energy crops

Yield of energy crops directly depends on the climate, soil and other conditions. The crops have different water requirement, they can differ a lot with regard to frost and drought resistance (**Table 3**). For the EU, bioenergy experts have developed tables and maps with the lists of energy crops recommended for different climate zones. For example, willow, poplar, miscanthus, maize, sunflower, rapeseed, sorghum, flax, reed canary grass are recommended for *the continental zone;* for *the Mediterranean north* poplar, miscanthus, giant reed, maize, sunflower, sorghum, flax, sugar beet, soybean, rapeseed, kenaf are considered to be suitable; for *the Mediterranean south* giant reed, cardoon, eucalyptus, sorghum, flax [9].

Table 3. Main cultivation constrains of some energy crops [9].

Energy crop	Temperature, °C			Water requirement	Frost resistance	Drought resistance
	seed germination	growing				
		min	max			
Annual crops						
Rapeseed	>5	5	30	medium	high	medium
Sunflower	10	5	35	medium	low	medium
Flax	7-9	8	30	medium	medium	medium
Sorghum spp.	12	10	40	medium	low	high
Fast growing trees						
Willow	-	0	30	high	high	low
Poplar	-	0	30	medium	medium	medium
Eucalyptus	-	5	35	high	low	high
Perennial herbaceous crops						
Reed canary grass				high	high	low
Switchgrass				medium	high	medium/high
Miscanthus				medium [22]/ high	medium	low
Giant reed				medium	low	medium/high
Cardoon				low	low	high

Growing energy crops consists mainly of 3 stages: 1) soil tillage; 2) the growing itself (planting, caring the plantation); 3) harvesting (the last operation is reconverting land after the end of the plantation lifetime). Raising every energy crop has its peculiarities. For instance, miscanthus is planted in the form of rhizomes, poplar and willow are planted in the form of cuttings, and rapeseed, sunflower, and flax are seeded.

Below is description of the whole cultivation cycle of some energy crops that are suitable for Ukraine's conditions.

Willow (Salix spp.)

Willow is a fast growing tree that can form plantations of high productivity and long lifetime. Willow is a shrub or shrub-shaped tree of 6-8 m height. Usually a willow plantation is thick, the plant has many shoots, with which it can quite easily propagate. The plant has big increment by length, up to 3-5 cm per day, on average 1.5 m per year. Willow is comparatively light as compared with many other wood species.

Fig. 1. Willow plantation and willow harvesting.

Willow plantation remains productive during 20-30 years, and the plant may be harvested every 2-3 years. Average yield of willow is **10-12** dry t per hectare per year [22-24]. The biggest yield, 16-20 dry t/ha/yr, can be obtained in 4-5 year of the growing. According to some studies, under especially favorable conditions the yield may come to 30-40 dry t/ha/yr [25, 26].

Exhaustion of the soil by willow is 3-5 lower than by grain crops; in addition about 60-80% of nutrients comes back to the soil with abscised leaves [4].

Positive feature of willow is its high resistance to frost, pests and deceases. Willow can grow on a wide range of soil types, on bogged and barren soils, which require reclaiming. On a low-quality soil the plant grows slower than under favorable conditions, but its intensive grows is enabled by the well-developed root system.

Another feature of willow is its ability to evaporate a big amount of water from the soil. It may be the way to drain soils with large quantity of ground water or to protect land from bogging. During the period of intensive vegetation a willow plantation can evaporate 300-800 th. l/ha depending on planting density [21]. Besides, the ability of SRC willow root system to absorb large amounts of trace metals helps to remediate contaminated land and sewage sludge [6].

Willow should be planted in early spring just after frost as at that moment the soil moisture is the most favorable (**Table 4**). Planting can be performed manually or mechanically. For the manual planting they use cuttings of about 20 cm length; in the course of mechanical planting the cuttings of 1.5-2 m are mechanically cut into the pieces of 18-20 cm. The soil should be properly pre-treated including plowing up, disking and removing weeds. Planting density is 15-20 cuttings per hectare. Weed control is of special importance during first months until the willow shrubs close up and cover the weeds.

Introduction of fertilizer takes account of the loss and reserve of nutrients in the soil. For example, 10 t of dry willow wood contain 46-49 kg of N, 12-15 kg of P, 22-29 kg of K, 40 kg of Ca, 10 kg of Mg. Under a 3-year growing cycle and the yield of 10 t d.m./ha/yr the following rates for introducing fertilizer may be recommended: nitrogen 150 kg/ha, phosphorus 45 kg/ha, potassium 90 kg/ha; calcium 120 kg/ha; magnesium 30 kg/ha (once per 3 years after willow cutting). Barren soil requires 30-40% more fertilizers to reach average yields.

During the first year, introduction of nitrogen fertilizers is not recommended as the root system of the plant should develop. Next years the fertilizer should be introduced by portions in the period of early vegetation and intensive growth.

During a 3-year period the abscised leaves bring 20 kg of nitrogen to the soil that is why it is reasonable to cultivate the soil between rows after harvesting.

After the first year of growth the plant should be cut off at the level of up to 5 cm so that to stimulate its stooling (some studies report that the willow yield is higher by the moment of harvesting if the process cutting had not been performed; also the technical cutting is not recommended in case of slow growth of the plant and big amount of weeds).

Willow is harvested after the end of its vegetation period that is from October-November to March-April but mostly in winter period (after leaves falling). The most energy can be obtained with the harvest from 3 (and more) year cycle plantation. By the moment of harvesting the plant diameter is about 28-31 mm, the height is 5-6 m. Harvesting is carried out by a regular clipper equipped with a reaper for willow. Under the 3-year cycle a willow plantation can be harvested 7-8 times after that it must be reclamated. Elimination of the plantation after the end of its lifetime is a comparatively easy operation as the roots are not deep. In spring when the height of shoots is about 20-30 cm it is necessary to introduce herbicide, to cut sprigs and plow them back into the soil. In fall the land can be used for growing other plants.

Table 4. Approximate timeline for field operations for the 3-year cycle willow plantation [27]

Year	Season	Activity
0	Fall	*Soil tillage:* - mowing, rooting out existing plants (if necessary); - introducing contact herbicides to control perennial weeds; - discing; - plowing; - cultivating; - seeding cover crop[7] (if there is a possibility to make the soil ready for planting during a year); - treating soil by CultiPack[8].
1	Spring	*Planting:* - discing; - treating soil by CultiPack; - planting cuttings; - introducing pre-emergent herbicides; - mechanical and/or herbicide weed control.
1	Winter	Process cutting (if necessary)
2	Spring	Introducing fertilizers (if necessary); weed control (if necessary)
3	round the year	Plantation growth (2-3 years)
4	Winter	1st harvesting
5	Spring	Introducing fertilizers (if necessary); cultivating soil between the rows
6	round the year	Plantation growth (2-3 years)
7	Winter	2nd harvesting
8-22		Repeating the 3-year cycle with 3rd-7th harvesting.
23	Spring/Summer	Elimination of the plantation

According to some experts from the Institute of bioenergy crops and sugar beet of the NAAS of Ukraine, the *Salix* willow is suitable for Ukraine's conditions. It gives opportunity for creating varieties and hybrids for different applications. As usual ***Salix Viminalis*** and its species are used for energy production [32].

Poplar (Populus spp.)

Like willow, poplar is a perennial woody energy crop. The conditions and technologies of its growing are similar to those of willow. Poplar is resistant to pests, it can grow on poor and contaminated soils but it is less frost resistant than willow and therefore is not usually cultivated in

[7] A cover crop is a crop planted primarily to manage soil erosion, soil fertility, soil quality, water, weeds, pests, diseases, biodiversity and wildlife in an agroecosystem.
[8] CultiPack is a new soil cultivation machine http://www.tumeagri.fi/Cultipack.eng.html

the North-European countries. The plant practically does not require pesticides and fertilizers[9]. The yield of energy poplar is 8-15 t d.m./ha/year, and new clones can give up to 16-20 t d.m./ha/year on good soils [29-31].

Fig. 2. General view of a poplar SRC and harvesting operation.

There are three types of poplar SRC [29, 3]: very short rotation system (I), short rotation system (II) and medium rotation system (III). They differ in planting density and harvesting intervals. For system I, planting density is 10,000-15,000 cuttings/ha, the system is harvested at 1-year intervals; stem size at harvest reaches 2-3 cm (cut level). For system II, planting density is 5,000-10,000 cuttings/ha, the system is harvested at 2-3-year intervals; stem size at harvest reaches 10-12 cm (cut level). For system III, planting density is 1,300-3,000 cuttings/ha, the system is harvested at 5-6-year intervals; stem size at harvest can reach 15 cm at breast height. The Claas system is prevalent method for harvesting SRC with very short and short rotation systems. It is based on a modified forage harvester whose standard header has been replaced with a special SRC header. Standard forest technology can be adapted to the harvesting of SRC with medium rotation system. As the

[9] Fertilizers may be introduced when necessary to stimulate growing. For example, in Spain and Italy, they apply a combination of mineral and organic fertilizers before planting to achieve slow release of nutrients. Depending on the expected target productivity, it is also possible to apply nitrogen fertilizers periodically among rows (60-80 kg N/ha) soon after harvesting, in order to promote rapid growth of new shoots [3].

stem size is small compared to the capacity of standard forest machinery, light units should be used whenever possible. European experience shows that usually one can obtain more biomass from the poplar SRC with medium rotation system (III) [33].

The life time of energy poplar plantation is 15-20 years. At the 3-year cultivation cycle one can have 5-7 harvests. Removal of the plantation is more difficult than for willow as poplar often forms a big main root.

There are different kinds of poplar, of which specialists recommend *Toropogrytsky* poplar (the hybrid of euroamerican poplar *I-214* and Lombardy poplar) for Ukraine's conditions. The clone has high yield and is resistant to adverse conditions. Under normal conditions, the average increment of *Toropogrytsky* poplar is 14 m^3/ha/yr. The increment may come to almost 37 m^3/ha/yr on richer and more moistened soils [28].

Miscanthus (Miscanthus spp.)

Miscanthus is a perennial rhizome plant originating from Asia. Once planted it can be yearly harvested during 15 and more years at an average yield of about 10 t d.m./ha. Miscanthus is characterized by a well-developed root system (up to 2.5 m deep), fast growth, rather good resistance to low temperatures[10] and medium water requirement that corresponds to annual precipitation of 600-700 mm. Medium dense soils with low groundwater are suitable for cultivating miscanthus [22, 34].

Miscanthus is planted in March or April. It is important to establish the crop correctly before planting. The first step is the weed control. The soil should be subsoiled if necessary to remove compaction. Two methods of miscanthus propagation are used in Europe – micropropagation and rhizome division. The later one is used more and is more economically viable method. Rhizomes need to be planted to allow for some expansion of the plant during the life of the crop and at a soil depth of 5-15 cm. Planting densities vary from 10,000 to 15,000 or more rhizomes per hectare. Planting can be carried out using by traditional agricultural machines (for example, semi-automatic potato planters or manure spreaders), as well as bespoke planters.

Miscanthus does not require a big input of fertilizers due to good nutrient use efficiency (the maximum quantity of nitrogen is between 50 and 70 kg N /ha/year) [33]. As miscanthus is highly resistant to pests it does not require chemical protection. Weed control in the establishment phase of the crop is essential because poor control can severely check the development of the crop.

[10] Miscanthus does not grow at temperatures below a threshold of 6 °C. This is considerably lower than for maize which means that the growing season is longer [33]. The major constraint to long season growth is late spring frosts which destroy early spring foliage and effectively reduce the duration of the growing season [34].

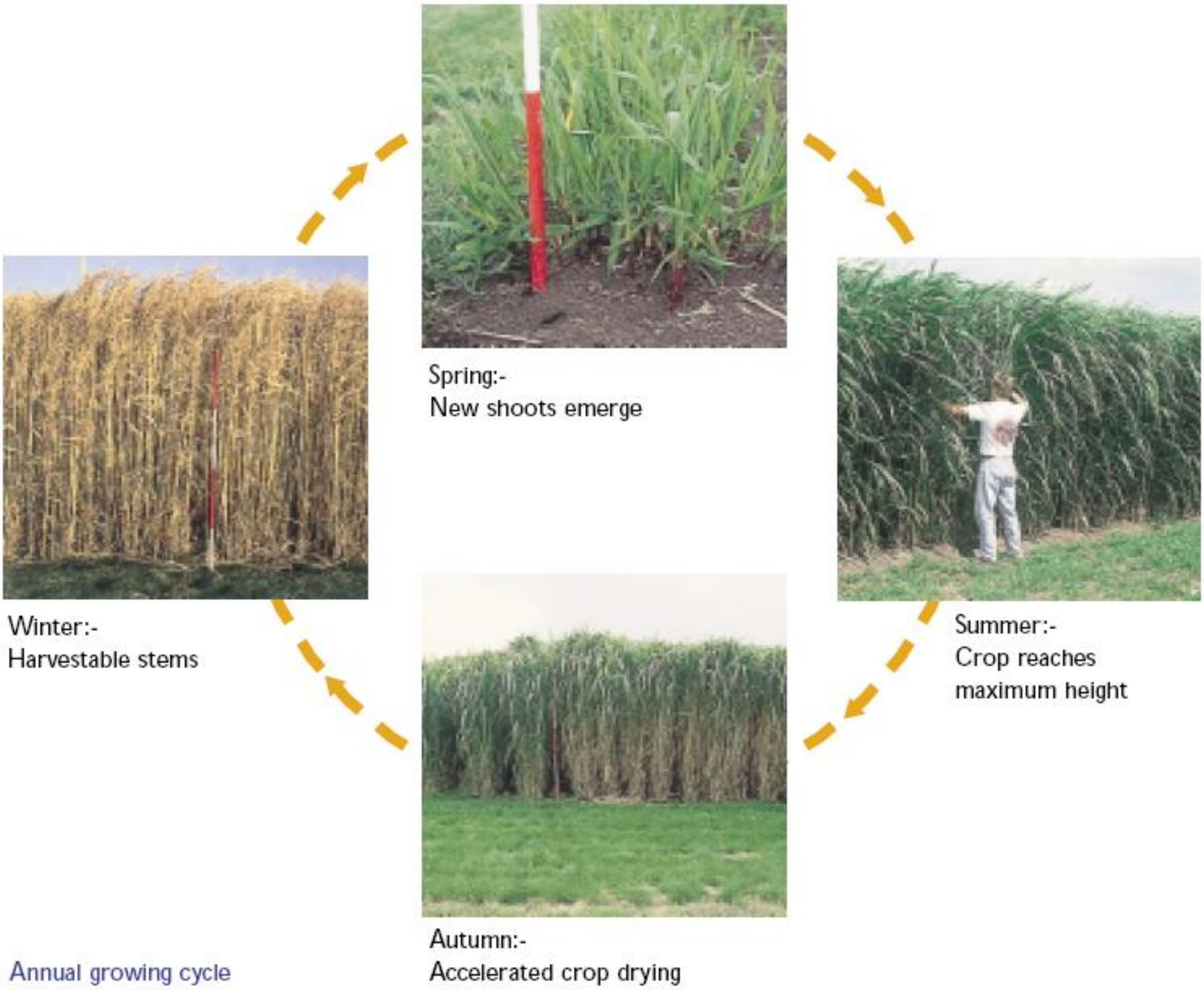


Fig. 3. Annual growing cycle of miscanthus [34]

After planting in spring, miscanthus reaches 1-2 m in height by late August (stem size is about 10 mm), starts drying by late July and is harvested in winter. The crop is not harvested in the first year due to the low yield (up to 8 t d.m./ha), however, the yield of the second year can reach maximum 10 t/ha of dry matter. From the second season onwards the crop can be expected to achieve a maximum height of 2.5-3.5 m. By the third year harvestable yields are between 10-15 t d.m./ha. Peak harvestable yields of 20 t d.m./ha have been recorded. The soil is an important factor for miscanthus productivity. The yield on fertile soils can reach 30 t d.m./ha/year, however, the yield on less productive soils can hardly reach 10 t d.m./ha/year. In order to produce maximum yields *Miscanthus×giganteus* is able to utilize large quantities of water, up to 900 mm/year [33]. In 10 years of lifetime the productivity of plantation starts to gradually decrease.

Miscanthus can be harvested by heavy rotary mowers, balers or self-propelled forage harvesters. Taking in to account the size and solidity of stems, it is recommended to apply special machines designed for hard usage [22].

Fuel characteristics of energy crops

Energy crops are used for the production of solid, liquid and gaseous biofuels. The Position Paper covers energy crops intended for the production of solid biofuels like chips, pellets, briquettes. Fuel characteristics of some crops of the kind are presented in **Table 6**. For comparison, the table also contains the data on grain crops straw and wood chips.

Table 6. Fuel characteristics of energy crops and some other biofuels

Parameters	Miscanthus	Willow	Poplar	Straw of grain crops (*for comparison*) [10]	Wood chips (*for comparison*) [11]
Water content after harvesting , %	15 [33] 15-23 [22]	53 [33] 50 [3]	49 [33] 50-55 [3]	15-20	40
Lower heating value, MJ/kg (d.m.)	17.5 [33] 17-19.5 [22]	18.5 [33]	18.7 [33]	~18	~19 [12]
Volatiles, %	>78 [13]	79 [13]	83 [13]	>70	>70
Ash content, %	3.7 [33] 2.3 [15]	2.0 [33] 1.5-2 [6]	1.5 [33] 0.5-1.9 [3]	3-4	0.6-1.5
Elemental composition, %:					
C	46.97 [13]	50.28 [13]	47.95 [13]	42-43	50
H	5.57 [13]	5.98 [13]	5.92 [13]	5	6
O	45.82 [13]	42.65 [13]	45.29 [13]	37-38	43
Cl	0.04 [13]	0.02 [13] 0.03 [3]	0.03 [13] 0.04 [3]	0.2-0.75	0.02
K*	0,46% [43]	123.3 g/kg of ash [3]	0.21 [35] 28.6 g/kg of ash [3]	0.22-1.18% 0.2-0.98% [35]	0.13-0.35% [14] ~81 g/kg of ash [3]
N*	0,16 [15] 0,57 [43]	0.5-1.0 [6] 0.74 [13]	0.77 [13] 0.9 [3]	0.35-0.41	0.3
S	0.28 [13]	0.34 [13] 0.03 [3]	0.03 [13] 0.2 [3]	0.13-0.16	0.05
Ash melting point, °C	1250 [6] 1385 [13]	>1500 [6] 1528 [13]	1200-1500 [13] 1160 [3]	950-1000	1000-1400

* *The content depends on the amount of applied fertilizers.*

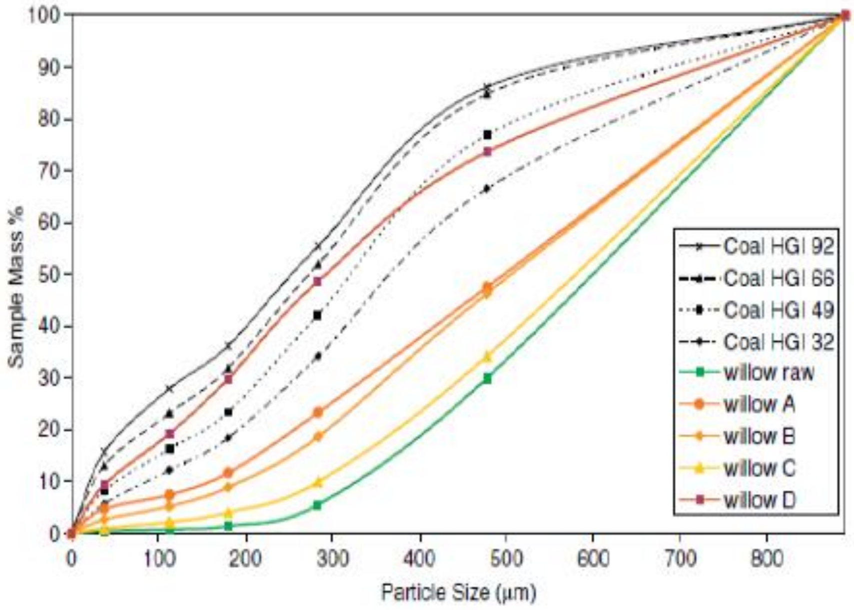
Analysis of the table data shows that characteristics of willow and poplar are, on the whole, close to those of wood chips. The main difference is the higher content of nitrogen that can be explained by applying fertilizers while growing the energy crops. Miscanthus has the higher ash content, close to that of straw. All the considered energy crops have rather high ash melting point that is an advantage in comparison with straw. Results of some papers on the fuel characteristics of energy crops are presented below.

Detailed research of the fuel properties of 6 willow genotypes was done by the author of [6] with the use of laboratory equipment. The work was focused on possibility of co-combustion of willow with coal on the UK power stations. It was found that willow had comparatively low content of ash (1.5-2%) and nitrogen (0.05[11]-0.4[12] % d.m.). When growing willow, introduction of fertilizers should be optimal as it influences the elemental composition of biomass. For instance, combined application of nitrogen and potassium fertilizers results in the higher carbon content in biomass that in turn leads to its higher calorific value. On the other hand, introduction of these fertilizers has an influence on the content of nitrogen and potassium in willow that may lead to the higher emissions of NO_x and lower ash melting point due to high content of K_2O in the ash. Of the six studied willow genotypes, 5 had a very high ash melting point (> 1500 °C) and low slagging and fouling tendencies.

Paper [6] also covered grindability of willow that is important for co-combustion with coal and production of pellets. It was found that raw biomass was very difficult to pulverize while grindability of some torrefied willow samples was close to that of coal (**Fig. 4**). Energy required for grinding torrefied biomass is approximately 10-20% of the energy required for grinding raw biomass material. It is due to the fact that hemicellulose which forms structural linkages in the biomass materials breaks down during torrefaction and forms a material with lower strength and good grinding properties.

Analysis of the elemental and biochemical composition of the willow samples showed that the genotype with the highest content of lignin (27.13% – genotype *F*, **Table. 7**) has the highest ash content (2.88-3.25%). On the contrary, the genotype with the lowest lignin content (15.49% – genotype *B*) has the lowest ash content (1.11-1.37%). The highest calorific value is associated with the genotypes with high carbon content and low oxygen content (for example, genotypes *A*, *B*). On the whole, study [6] reported on quite good fuel properties of willow (except for genotype *S.elaeagnos Scop.*) that implied good prospects for cultivation and use of this kind of biofuel.

[11] No application of nitrogen fertilizers.
[12] Introduction of 150 kgr N/ha as $NH_4(NO_3)$.



A, B, C, D – willow torrefied under four different conditions (A-D represent increasingly severe torrefaction conditions)

Fig. 4. Particle size distribution of coal, raw willow and torrefied willow [6]

Table 7. Fuel characteristics of different willow genotypes [6].

Parameters	*S.aurita L.* A		*S.viminalis x S.schwerinii* B		*S.eriocephala Michx.* C		*S.drummondiana Barratt ex Hook.* D		*S.mielichhoferii Saut.* E		*S.elaeagnos Scop.* F	
	I	II	I	II	I	II	I	II	I	II	I	II
Elemental composition, % daf												
C	53.65	49.33	53.58	49.52	53.68	49.57	51.98	51.00	46.13	50.62	54.27	51.01
H	6.73	6.00	6.81	5.99	6.34	5.95	6.47	6.03	5.80	6.12	6.85	6.36
N	0.95	0.57	0.81	0.45	1.02	0.36	0.86	0.85	0.57	0.66	0.89	1.25
O	38.67	44.10	38.80	44.04	38.96	44.12	40.69	42.12	47.50	42.60	37.99	41.38
Fuel properties												
Moisture, %	6.16	2.73	6.59	2.72	4.96	2.89	4.74	2.72	5.46	2.26	6.05	5.65
Volatiles, %	75.77	78.35	75.89	79.09	77.28	79.53	75.25	76.70	76.00	79.00	73.94	73.31
Fixed carbon, %*	16.57	17.33	16.40	16.82	16.20	15.57	18.31	18.95	16.95	16.97	17.13	17.79
Ash content, %	1.5	1.59	1.11	1.37	1.56	2.01	1.71	1.63	1.59	1.77	2.88	3.25
Higher heating value, MJ/kg d.b.**	21.50	19.28	21.61	19.39	21.33	19.24	20.56	20.00	17.98	19.81	21.41	19.74
Biochemical composition,%												
Hemicellulose	7.35	15.07	13.29	13.95	9.14	14.70	13.77	11.51	15.09	11.47	9.80	n.a.
Cellulose	50.02	43.92	52.98	47.80	54.06	48.03	33.52	38.34	42.22	43.57	46.56	n.a.
Lignin	18.40	18.41	15.49	15.46	18.05	14.79	22.17	18.42	18.62	18.35	27.13	n.a.

** Calculated by difference   ** Calculated value.*

I – data of December 2008, II – data of February 2011.

Authors [15] investigated fuel characteristics of four perennial energy crops – miscanthus, switchgrass, giant reed and cardoon (**Fig. 5**) in comparison with Austrian wood pellets as a reference fuel.

A – pelletized switchgrass, B – pelletized cardoon, C – chopped giant reed, D – chopped miscanthus

Fig. 5. Fuels investigated [15]

As compared with wood, the investigated perennial energy crops have much higher ash content, of miscanthus having the least (2.3% d.m.) (**Table 8**). This is partly due to their fast growing metabolism (accumulation of nutrients) and different organic structure (SiO_2-phytoliths) but can also be significantly influenced by the harvesting period and by the mechanical harvesting technique used. Typically, the dominating ash forming elements in the perennial crops are Si followed by K, Ca, Cl and S. It can be seen from **Table 8** that miscanthus has the lowest content of Si, K, Ca as compared with other energy crops.

Besides, in comparison with wood pellets, the considered energy crops (except for switchgrass) are characterized with increased corrosion potential. The indicator of this is the ratio Cl/S > 1. The phenomenon is explained by local release of corrosive Cl-gas on boiler tubes caused by sulphation of alkali or heavy metal chloride in deposits. The corrosion potential is especially high if Cl/S > 1 at a high content of Ca (the case of cardoon). Wood pellets have ratio Cl/S < 1. Compared to wood, the perennial energy crops also contain higher concentrations of N that implies higher emissions of NO_x. The crops are also characterized with slagging and fouling tendencies.

Table 8. Fuel characteristics of herbaceous energy crops [15].

Parameters	Pelletized switchgrass	Chopped giant reed	Chopped miscanthus	Pelletized cardoon	Wood pellets (*for comparison*)
Ash content, % d.b.	8.3	6.1	2.3	17.4	0.50
Content of N, % d.b.	0.67	0.71	0.16	1.1	0.08
Elemental composition, mg/kg d.b.					
Si	14.99	13.92	7.30	21.14	<400
Ca	6.55	3.25	1.77	19.02	938
K	12.75	6.49	1.44	21.54	485
Na	924	331	58	10.33	30
Mg	2.22	1.62	644	3.93	152
Al	763	919	82	4.44	n.a.
S	735	2.16	390	1.56	73
Cl	1.51	2.24	880	17.78	53
Cl/S*	0.002	1.04	2.25	11.39	0.73
Gross calorific value, MJ/kg daf	17.8	19.8	19.6	20.3	20.3
Bulk density, kg d.b./m^3	585	116	117	561	644

* *Indicator for the corrosion potential.*

Despite some disadvantages of energy crops as compared to wood pellets, on the whole they are a good fuel, which requires well thought-out approach to use. In many cases the biofuels can meet existing emission limits (unless they are unduly strict). For instance, it can be seen from **Table 9** that performance of miscanthus combustion is completely within Austrian limiting values for dust, NO_x and CO emissions.

Table 9. Average emission levels during combustion of biofuels from herbaceous energy cops, mg/nm^3 (13% O_2, d.b.) [15].

Pollutants	Switchgrass	Giant reed	**Miscanthus**	Wood (*for comparison*)	Austrian limiting values for wood fired plants of 100-350 kW
Total dust, *including*	58	102	**27**	21	150
< 1 μm (aerosols)	50	67	**16**	16	
NO_x	368	363	**187**	106	350* / 250**
HCl	18	67	**59**	3	
SO_2	91	278	**53**	3	
CO	145	443	**55**	1	250

* *For chemically non-treated wood waste.*

** *For natural wood.*

According to [15], operational measure to mitigate the tendency of slag formation may be decreasing temperature of combustion by using cooled grates and furnace walls in the combustion chamber. Another approach can be upgrading biomass by either separating problematic elements (e.g. through leaching) or trying to neutralize their effects by additives (e.g. addition of lime to increase the melting point of slag). The third possibility may be blending the perennial crops with wood fuels. The measure is expected to decrease the emissions of HCl, SO_2, NO_x and solid particles.

Authors of paper [13] have studied combustion characteristics of some energy crops including willow, poplar and miscanthus. On the whole the obtained results are in line with the conclusions of described above studies (see the fuel characteristics in **Table 6**). Willow has a high ash melting point (>1500 °C) and slight slagging problems as compared with other investigated energy crops. Ash content of miscanthus (6.74%) is much higher than that of willow (1.93%) and poplar (1.71%). The same applies to nitrogen content. Of all the investigated energy crops the worst fuel properties are associated with cardoon. As opposed to paper [15], authors of [13] consider that energy crops (except for cardoon) will not cause any severe slagging problems as they have low content of chlorine (<0,1%).

Growing energy crops in Ukraine

At present a few companies are occupied with commercial growing energy crops in Ukraine. In addition several companies are planning to enter the market in the near future. Some of them are shortly described below.

"Salix Energy" established in 2010 has the largest plantations of willow (Salix Viminalis) in Ukraine which are located in Volyn and Lviv regions (> 1500 ha). The company is raising 6 willow varieties including Polish and Swedish ones. In 2013 the company registered its own willow variety of «Martsiyana» (the only variety officially registered in Ukraine). The plans for 2014-2015 include extending willow plantations up to 2500-3000 ha and beginning of commercial harvesting. "Salix Energy" is planning to use willow chips for the production of heat and power in Ukraine [4, 5].

"Phytofuels" grows a number of energy crops (switchgrass, miscanthus, willow, sugar sorghum and others) on 35,000 ha in Poltava region of Ukraine. Briquettes and pellets manufactured from the crops are supplied by "Phytofuels" to domestic and foreign consumers. The company cooperates with the Institute for biomass and sustainable development (Poltava) and Wageningen University (the Netherlands)[13].

Agricultural holding "KSG Agro" that owns 65,000 ha in Dnipropetrovsk region is developing such a new area of its business as miscanthus growing. A plantation intended to generate the miscanthus cuttings sprouted successfully on 33 ha in 2013. The holding is planning to create a 400 ha

[13] Information from http://www.phytofuels.com.ua (at the moment the website is not available)

plantation in 2014 and to extend it up to 2000 ha a year later. The biomass will be used for the production of solid biofuels [16].

In 2011, "Agrarian Cooperation" Ltd started the project on cultivating willow (Salix Viminalis) and production of pellets from it. The area of land for the project implementation is 2000 ha; design capacity of the pellet plant is 24 kt/yr [17].

Ukrainian specialists also carry out big R&D on energy crops. A major contribution to it is made by the Institute of bioenergy crops and sugar beet of the NAAS of Ukraine [14]. For instance, the Institute studies the gene pool of *Salix L.* willow of different ecological and geographical origin regarding its productivity, suitability for mechanical management and harvest, energy value. Eleven species and three hybrids of *Salix L.* were planted on the test plot of the Institute [32]. The Institute also studies the yield of sugar sorghum, miscanthus and other energy crops. The specialists have created the Atlas of high-yield bioenergy crops [18].

Despite active recent development of energy crop sector in Ukraine, there is a number of problems to be solved. One of them is that energy crops are not included in the classifier of agriculture crops. Now the willow is included there as a technical crop while miscanthus and other energy crops are absent in the classifier. This may cause legal and other problems for producers of the energy crops. Besides, sometimes the producers are demanded to pay VAT when concluding contracts with investors though they have not produced anything yet. This is due to the fact that the cuttings grown by the company for its own needs are considered to be products. Another problem is that a producer of energy crops is not considered an "agricultural producer" and therefore do not have respective benefits (for example regarding equipment lease) until he makes the first sale of the harvest. Taking into account that production cycle of the willow and poplar plantations is 3-4 years, the period till the first harvest sale is rather long.

In order to push the development of energy crop sector in Ukraine the Bioenergy Association of Ukraine suggests introducing some state support mechanisms. One of them may be the subsidy for energy crop plantations in the amount of **10,000** UAH/ha. Another instrument may be partial paying off commercial interest on a credit by the state. It is recommended to provide the respective financing from the state budget of Ukraine in 2015-2017.

By UABio's estimate there are 3-4 Mha of unused agricultural land in Ukraine (according to estimate for 2012 the figure is 3.5 Mha[15]), which can be used for growing energy crops. We recommend using for that purpose up to 2 Mha according to the one of the possible scenarios[16]: 1 Mha under the maize for biogas production, 0.5 Mha under willow, 0.2 Mha under poplar and 0.3

[14] Website of the Institute http://sugarbeet.gov.ua/
[15] Method for the estimate: arable land (32.5 Mh) – sown area (27.8 Mha) – fallow (1.2 Mha) = 3.5 Mha [20].
[16] Possible scenarios for growing energy crops in Ukraine are considered in UABio Position Paper N9 in more detail [20].

Mha under miscanthus. Implementation of the scenario will give an opportunity to obtain about 3.3 bill m^3/yr of biomethane from maize silage and 6.3 Mtce/yr from willow, poplar and miscanthus.

Some agricultural experts estimate that there are about 8 Mha of land available for cultivating energy crops in Ukraine. They suggest using most area for growing maize for biogas production. We consider such estimations overrated. In our opinion not more than 1-2 Mha of land may be allocated under energy crops.

Taking into account UABio's conceptions for the development of different bioenergy sectors we suppose that the total area under energy crops may be about **200** th. ha in 2020 and up to **1** Mha in 2030 (**Table 10**). The energy crop harvest will be **1** Mtce in 2020 and about **5** Mtce in 2030.

Table 10. Conception for growing energy crops in Ukraine

Parameters	2014	2020	2030
Total area under energy crops (commercial plantations), th. ha	**3**	**200**	**1000**
Structure of the area under the energy crops, th. ha:			
- willow	2	50	250
- miscanthus	~0	30	150
- poplar	~0	20	100
- maize (for biogas production)	1	100	500
Total harvest of the energy crops, Mtce/yr	**0.017**	**1.00**	**4.98**
Structure of the harvest, Mtce/yr:			
- willow	0.013	0.33	1.66
- miscanthus	~0	0.19	0.94
- poplar	~0	0.11	0.54
- maize (for biogas production)	0.004	0.37	1.84
Parameters used in the conception			
Allocation of the total area under energy crops, %			
- willow		20	25
- miscanthus		10	15
- poplar		6	9
- maize (for biogas production)		64	51
Yield*, dry t/ha/yr:			
- willow		12	
- miscanthus		12	
- poplar		9.5	
- maize for biogas production (fresh matter)		30	
Heating value (dry matter), MJ/kg [20]:			
- willow		18	
- miscanthus		17	
- poplar		18.5	
- maize (for biogas production)		yield of CH_4: 100 m^3/t of silage* concentration of CH_4 in biogas: 60%	

** Conservative approach [20].*

An important question is economic indexes of energy crops cultivation such as specific cost of the creation and care of a plantation, income from the harvest sale, payback period and other. Results of a pre-feasibility study for growing poplar on a 2-year rotation cycle plantation in Ukraine are presented in **Table 11**.

Table 11. Performance characteristics for growing poplar on a 2-year rotation cycle plantation in Ukraine (calculation per 1 ha)

Parameters	No subsidy	Subsidy of **620 EUR/ha** creation of the plantation
Planting (purchase of 6000cuttings, refinement of the soil), EUR/ha	1191	571
First rotation cycle (years 1-2):		
- looking after plantation (weed control, harrowing, watering), EUR/ha	306	
- harvesting and delivering biomass to a consumer*, EUR/ha	335	
- yield**, t/ha	40	
- sale price of the biomass, EUR/t	25 (**400 UAH/t**)	
- income from the biomass sale, EUR/ha	994	
Rate of return after 1st harvesting (total income/total expenditures)	*0.54*	*0.82*
Second rotation cycle (years 3-4):		
- looking after plantation (harrowing, watering, application of pesticides), EUR/ha	265	
- harvesting and delivering biomass to a consumer, EUR/ha	353	
- yield, t/ha	42	
- sale price of the biomass, EUR/t	25 (**400 UAH/t**)	
- income from the biomass sale, EUR/ha	1049	
Rate of return after 2nd harvesting (total income/total expenditures)	*0.83*	*1.12*
Rotation cycles 3-7 (years 5-14):		
- looking after plantation, EUR/ha	1323	
- harvesting and delivering biomass to a consumer, EUR/ha	1766	
- yield, t/ha	42	
- sale price of the biomass, EUR/t	25 (**400 UAH/t**)	
- income from the biomass sale, EUR/ha	5245	
- elimination of the plantation, EUR/ha	100	
Lifetime of the plantation (14years):		
- average annual yield , t/ha	27	27
- total expenditures, EUR/ha	5639	5019
- total income, EUR/ha	7288	7288
- total profit (difference between income and expenditures), EUR/ha	1649	2269
- total income/total expenditures	*1.29*	*1.45*

** Here and then in the table the delivery is assumed to be within 30 km.*

*** Here and then in the table the moisture of biomass is that of just harvested biomass (W 55%).*

It can be seen from the table that at the biomass sale price of **400 UAH/t** the rate of return (ratio of the total income to the total expenditures) is 0.54 after the first harvesting, 0.83 after the second harvesting, and 1.29 for the whole lifetime of the plantation (14 years, 7 cycles). It means that the simple payback period of the project on poplar growing is about 6 years (**Fig. 6**). Under the state subsidy of **10,000** UAH/ha (**620** EUR/ha) for the creation of a poplar plantation the rate of return is 82% after the first cycle, 112% after the second cycle, and 145% for the whole lifetime of the plantation. In this case the simple payback period of the project is below 4 years.

Fig. 6. Return of investment for the poplar plantation with the 2-year rotation cycle at the biomass sale price of 400 UAH/t

To ensure the full return of investments after 2nd harvesting and sale of the harvest (that is within 4 years) the price of the biomass must be **480** UAH/t without a subsidy and **360** UAH/t at the subsidy of 10,000 UAH/ha (620 EUR/ha) (**Fig. 7**).

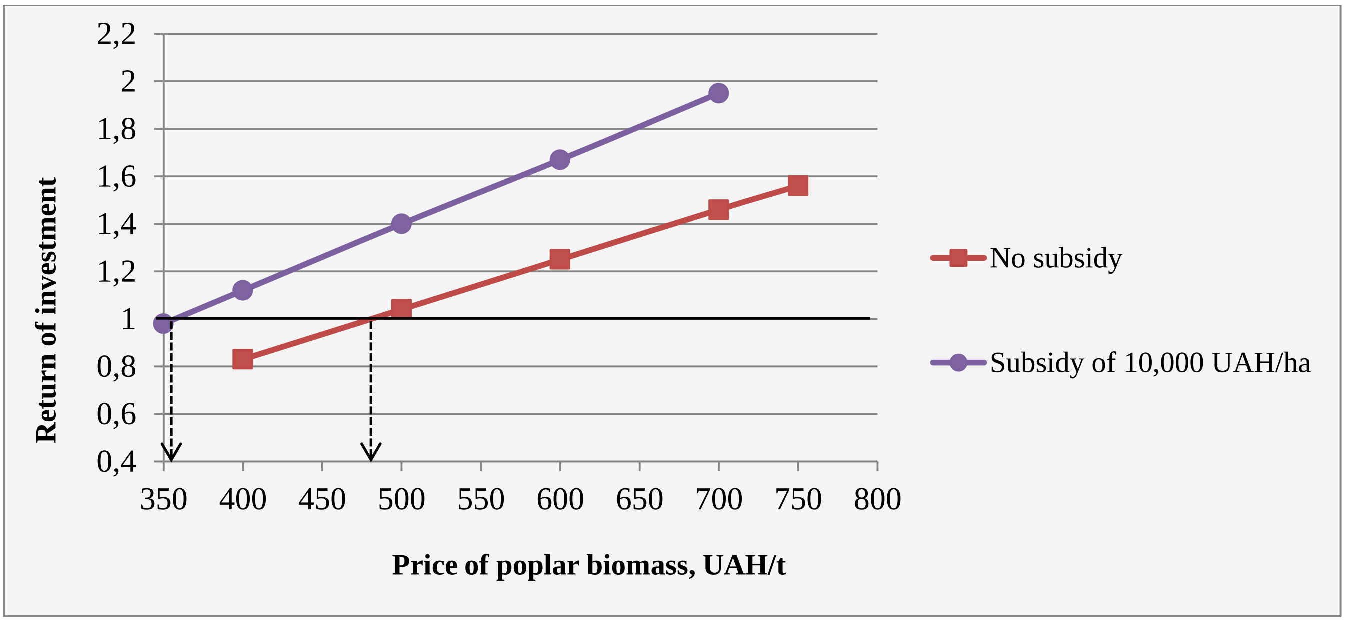


Fig. 7. Correlation between the rate of return and the biomass sale price after the 2nd harvesting for the 2-year rotation cycle poplar plantation

Estimation of a state subsidy for growing energy crops has been made for willow for the period of 2014-2016 based on the forecasted replacement of natural gas with biomass for heat production: 250 million m^3 (2014), 500 million m^3 (2015), 1 billion m^3 (2016). The results show that if energy crops make up 20% of the total amount of the biomass used then the total required subsidy is **84-338** million UAH/yr (**Table 12**). At that the share of the subsidy in the replaced natural gas cost is **38%**.

Table 12. Estimation of the state subsidy for growing energy crops (for willow as an example).

Indexes	2014	2015	2016
Forecasted replacement of natural gas with biofuel, million m^3	250	500	1000
Calorific value of biofuel (wood chips) (W 40%), MJ/kg	10	10	10
Boiler plant operation period, days	185	185	185
Consumption of biofuel (W 40%), kt	844	1688	3375
Share of energy crops (willow) in the total volume of the used biofuel, %	20	20	20
Willow yield (fresh matter), t/ha/yr	20	20	20
Required area of the plantation, th. ha	8.4	16.9	33.8
Required state subsidy for creation of the plantation, th. UAH/ha **million UAH**	10 **84.4**	10 **168.8**	10 **337.5**
Cost of natural gas replaced with the willow (at the natural gas price of 380 $/1000 m^3), **million UAH**	**225**	**450**	**900**
<u>Share</u> of the required state subsidy in the cost of natural gas replaced with willow	**38%**	**38%**	**38%**

W – moisture by mass.

Conclusion

Energy crops are an important area of the European bioenergy. About a third of the EU target for bioenergy consumption in 2020 (**45** Mtoe/yr) can be covered at the expense of energy crops.

At present 13.2 Mha are available for cultivation energy crops in the EU countries. By 2020 the figure may rise to 20.5 Mha, and by 2030 to 26.2 Mha. According to estimation by the European Commission, to achieve the 2020 target (10% of RES in transport) 17.5 Mha (about 10% of the EU agricultural land) must be used for growing energy crops.

In addition to general regulation mechanisms each EU country has its own drivers and instruments to promote growing energy crops. Typical instruments are state subsidy for energy crops plantations (per hectare) and feed-in tariff (or a similar mechanism) for the power produced from biomass.

Now in Ukraine there are a few companies occupied with commercial cultivation of energy crops. Some other companies are planning to enter the marker in the near future.

To push development of the sector in the country the Bioenergy Association of Ukraine considers it necessary to introduce state support for growing energy crops. One of the possible mechanisms is a subsidy for energy crop plantation in the amount of **10,000** UAH/ha. Another instrument may be partial covering commercial rate interest by the state. It is recommended to include the respective budget items in Ukraine's state budget for 2015-2017.

UABio estimates that there are 3-4 Mha of unused agricultural land in Ukraine that may be employed for the cultivation of energy crops. For that we recommend to use up to **2** Mha divided (according to one of the possible scenarios) between maize for biogas (1 Mha), willow (0.5 Mha), poplar (0.2 Mha) and miscanthus (0.3 Mha). Implementation of the scenario will give an opportunity to obtain about 3.3 billion m^3 of biomethane from the maize silage and 6.3 Mtce from the willow, poplar and miscanthus every year.

According to UABio's conception, the total area under energy crops may come to about **200** th. ha in 2020 г. and **1** Mha in 2030 (**Table 13**). The respective harvest of the crops will be **1** Mtce in 2020 and about **5** Mtce in 2030.

Table 13. UABio's conception for growing energy crops in Ukraine.

Energy crop	2014		2020		2030	
	area, th. ha	harvest, Mtce/yr	area, th. ha	harvest, Mtce/yr	area, th. ha	harvest, Mtce/yr
Maize for silage to produce biogas	1	0.004	100	0.37	500	1.84
Willow	2	0.013	50	0.33	250	1.66
Miscanthus	~0	~0	30	0.19	150	0.94
Poplar	~0	~0	20	0.11	100	0.54
Total	**3**	**0.017**	**200**	**1.0**	**1000**	**4.98**

Estimation of the necessary state subsidy for the cultivation of energy crops is carried out for the willow as an example for 2014-2016. The estimation is based on the predicted amount of natural gas that is replaced with biomass for heat production: 250 million m^3 (2014), 500 million m^3 (2015), 1 billion m^3 (2016). The results show that if energy crops make up 20% of the total biomass used then the total required subsidy for energy crop plantations is **84-338** million UAH/yr. At that the share of the subsidy in the cost of natural gas replaced with the energy crops is **38%**.

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Abbreviations

GFC – gross final energy consumption;
NAAS – National Academy of Agrarian Sciences of Ukraine;
RES – renewable energy source;
SRC – short rotation coppice;
SRF – short rotation forestry;
daf – dry ash free;
d.b. – dry basis;
d.m. – dry matter;
n.a. – not available;
tce – tons of coal equivalent.

Previous publications by UABIO

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

1. *Position Paper N 1* "Position of bioenergy in the draft updated energy strategy of Ukraine till 2030".
2. *Position Paper N 2* "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* “Barriers to the development of bioenergy in Ukraine”.
4. *Position Paper N 4* “Prospects of biogas production and use in Ukraine”.
5. *Position Paper N 5* “Prospects for the electricity generation from biomass in Ukraine”
6. *Position Paper N 6* “Prospects for heat production from biomass in Ukraine”
7. *Position Paper N 7* “Prospects for the use of agricultural residues for energy production in Ukraine”.
8. *Position Paper N 8* “Energy and environmental analysis of bioenergy technologies”
9. Position paper N 9 “State of the art and prospects for bioenergy development 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.

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