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## Potential of Production of Energy Crops in Ukraine and their Processing on Solid Biofuels

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### ABSTRACT

Renewable energy sources in Ukraine account for only 4% of the total energy consumption today. At the same time, Ukraine has favorable climatic conditions and fertile soils, as well as areas of agricultural land, which make it possible to meet the demand for food products both for domestic consumption and for export. The tendencies towards the depletion of traditional fuels and their rise in price determine the diversification of the fuel and energy sector and the search for reserves for the production of their own environmentally friendly energy. The paper describes the characteristics of energy crops for biofuel production. The advantages of growing bioenergy crops were presented. The characteristics of energy crops in relation to growing conditions were determined. Ukraine has a great potential for growing the most popular energy crops: miscanthus, switchgrass, energy willow, poplar without endangering food security but this potential has not been realized yet.

**Keywords:** energy crops, solid biofuels, bioenergy policy, miscanthus, switchgrass, energy willow, poplar.

### INTRODUCTION

The rise in energy prices and the degradation of the ecological condition of the environment as a result of the growing consumption of fossil fuels are prompting humanity to use biomass for energy needs – biofuel production. World experience convinces that the production of biofuels provides benefits for the economy of each country, in particular, it makes it possible to create new jobs not only in rural areas, but also in industrial centers, as well as improves the environmental situation in the country, regions, etc. [Pryshliak, Tokarchuk, 2020].

Agriculture has been considered as one of the priority sectors including energy production direction in the research of Kaletnik, Honcharuk, Okhota, 2020. It is the main industry, producing biomass. The biomass of animal origin includes manure and bird droppings; in turn, the biomass of plant origin includes plant waste and energy crops. Unlike other types of biomass, such as energy crops, manure is produced as

by-products of animal husbandry, which require disposal in an environmentally sustainable manner. In addition, manure is a good substrate for biogas production, as it is easily mixed with other feedstock, such as corn silage, plant residues and others [Tokarchuk et al., 2020].

Plant biomass is used for production of various types of biofuels. Two yields can be harvested annually from each field: food and energy. Along with the gradual refusal of food crops for biofuel production, plant biomass energy has become one of the most dynamic aspects of the modern global energy market, on the basis of which governments of the world's leading countries seek to adopt the existing renewable energy policies and regulatory mechanisms to stimulate the development of non-food biomass production. The European bioenergy policy is changing dynamically, following the trend of sustainable development. Ukraine, having a significant agricultural potential and following the European vector of development, strongly depends on the European tendencies [Trypolska, Kyryzyuk, 2018].

In January 2020, the Ministry of Energy and Environmental Protection of Ukraine presented the Concept of “Green Energy Transition of Ukraine until 2050” [Green Energy Transition of Ukraine until 2050]. The concept aims to achieve a climate-neutral economy by 2070. Among the main directions of decarbonization of the economy, including energy as its important component, the following are identified: the development of renewable energy sources (RES) in combination with an increase in energy efficiency; reducing the consumption of carbon-intensive energy resources to zero and maximizing the use of RES so that the agricultural and forestry sector can switch to full self-sufficiency in energy resources; increasing sustainable production of biomass, biofuels and other RES to support the implementation of the “green” transition in other sectors of the economy. Biomass is currently seen as a promising renewable energy source, which can be sustainably utilized in the production of fuels and electric energy, adding no carbon dioxide to the environment [Ramos et al., 2018].

Among the renewable energy sources, biomass can be used to meet a variety of energy needs, including generating electricity, heating homes, fuelling vehicles, and providing process heat for industrial facilities. Biomass energy also generates less air emissions, reduces the amount of waste sent to landfills, and decreases our reliance on foreign oil [Janiszewska, Ossowska, 2020].

The fuels derived from energy crops are not only potentially renewable, but are also reasonably similar in origin to fossil fuels (which also originate from biomass) to provide a direct replacement. Bioenergy crops are easy to store, transport, affordable, and can be converted to a wide range of energy sources using the existing and new conversion technologies, and thus could be a powerful alternative to traditional fuels in the twenty-first century. More and more countries around the world are beginning to prefer high-performance energy crops with high biomass yields and high cellulose content as raw materials for biofuel production. Such crops include miscanthus (*Miscanthus*), switchgrass (*Panicum-virgatum*), willow (*Salix*), poplar (*Populus L.*). Unpretentiousness to soil and climatic conditions of cultivation allows growing these perennial phytoenergetic plants on unproductive soils with rugged relief. In addition to the actual energy benefit, this will help to preserve the soil from water erosion, reduce the nutrient losses with

surface washout and soil degradation. In addition, these plants are characterized by low production costs and do not require significant use of fertilizers and pesticides. This will allow the cultivation of energy plants on lands removed from the crop rotation. If the full potential of the use of untapped lands of Ukraine is estimated, in 2018 it amounted to 4 million hectares [State Statistics Service of Ukraine], which can be defined as the theoretical potential of growing energy crops. With its full use, it is possible to replace about 20 billion m<sup>3</sup> of natural gas. The technically achievable potential is 2 million hectares of land, which is equivalent to the replacement of 10 billion m<sup>3</sup> of gas or 34% of consumption (according to JSC “Naftogaz of Ukraine” Ukraine consumed 29.8 billion m<sup>3</sup> of natural gas in 2019, [JSC “Naftogaz of Ukraine”]). In monetary terms, the use of these lands for growing energy crops will allow import substitution worth about \$1.8 billion.

Nowadays, the efficiency of using agricultural feedstock for bioenergy production in discussed widely. A significant number of scientific publications are devoted to the study of the efficiency of growing agricultural and energy crops. Kulyk et al. (2020) investigated the economic and energy efficiency of biomass production, the output of solid biofuel, its energy intensity and energy output. The input and output of energy are two important factors used to determine the energetic and ecological of a fuel or its production technology. Scholz et al. (1998) have investigated the usefulness of a number of different methods for the production of five biofuels which can be produced in agriculture and calculated their energy balance.

The goal of the study is the review of potential types of bioenergy raw materials and the efficiency of their cultivation and processing into solid biofuels.

## THE CHARACTERISTICS OF ENERGY CROPS

The high cost of fossil fuels and the development of technological progress have enabled the emergence of energy systems on biomass, which allow obtaining energy directly or indirectly through combustion, pyrolysis or gasification. These systems are becoming more efficient, more reliable and cleaner. The number of boiler houses operating on renewable energy sources,

mainly solid fuel boilers, began to grow rapidly in Ukraine after a sharp rise in gas prices in 2014. Constantly growing demand has led to the problem of obtaining raw materials at affordable prices. The availability of local resources in a specific area is a prerequisite for a successful transition to solid biofuels and the development of bioenergy in general. In some Western European countries, in Scandinavian countries (Finland, Sweden and Norway), Poland and Denmark, an effective substitute for solid forest biomass has been found – energy crops, wood (willow, poplar, paulownia, etc.) and grass (miscanthus, switchgrass, etc.). The interpretation of the category “energy crops” by scientists differs, which is the reason for the difficulties in approaches to stimulating their production and use. The most widely used is the definition of energy crops as the plants that are specially grown for use directly as fuel or for biofuel production. Thus, these crops are used in energy farming – a new type of agriculture [Koçar and Civaş, 2013]. The general characteristics of energy crops for biofuel production are shown in Figure 1.

The energy efficiency of agricultural crops should be optimized in an era of growing demand for energy, including renewable energy (Stolarzski et al., 2019). The use of energy crops as raw materials for biofuel production has a number of advantages, which include: the possibility of natural gas substitution, reducing the cost of energy, land reclamation, decarbonization, reducing emissions, economic growth (Fig. 2).

Unlike food crops, energy crops do not have special requirements for the soil, they can be

grown on degraded lands. Among the EU countries, Italy is in the lead in terms of the land areas used for energy plantations with 57 thousand hectares (the largest area in Europe). In Poland, 13 thousand hectares are allocated for this purpose, in Sweden – 12 thousand hectares, in Germany – 11 thousand hectares, in Denmark – 10 thousand hectares, whereas in Finland – 8 thousand hectares [Eurostat, 2020]. In addition, the cultivation of energy crops on low-yielding lands will not compete with the possibility of growing food crops on them and will meet the criteria of sustainability, in accordance with the requirements of Directive 2009/28/EC (Fig. 3).

The cultivation and use of special plants for biofuel purposes is an effective measure for the efficient functioning of rural areas. These plants are called energy crops, they are mainly perennial, are well adapted to the growing conditions, and are capable of forming a high yield of biomass. The biomass of energy crops is characterized by a low content of chemical elements, contains a significant amount of lignin and cellulose, sugar and starch in some plants, and is an excellent feedstock for the production of energy-intensive biofuels. The yield of energy crops is the main factor when choosing the type of crop to grow in a particular area and directly depends on the climatic, soil and other conditions. Crops have different water requirements and can differ significantly in terms of their frost and drought resistance (Table 1).

Among energy crops, in terms of biomass yield potential, energy productivity level, a complex of

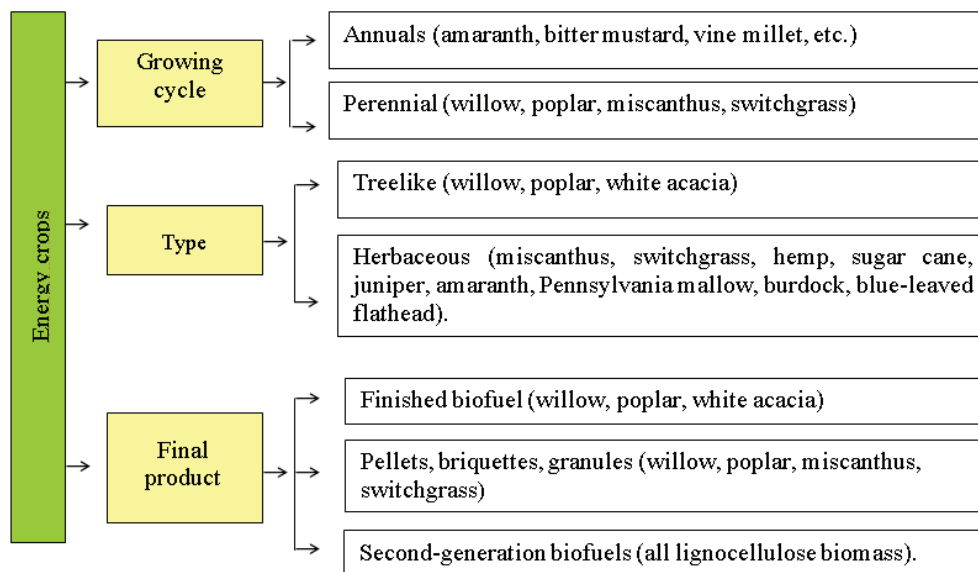


Fig. 1. Characteristics of energy crops on the basis of [Chaika, Yasnolob, 2017, Heletukha et al., 2017]

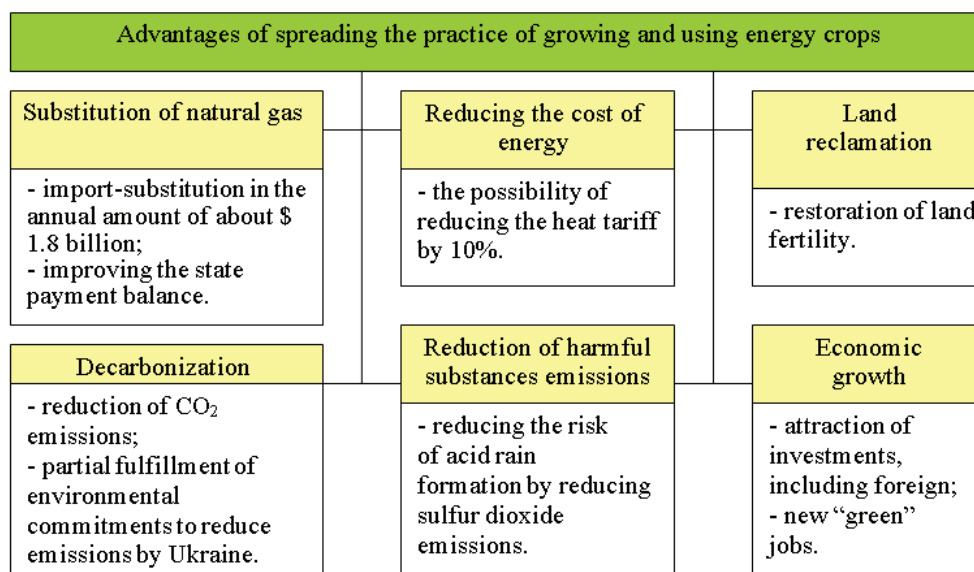


Fig. 2. Advantages of growing energy plants on the basis of [Hanegraaf and Biewinga, 1998; Zegada-Lizarazu and Monti, 2011; Fernando et al., 2010]

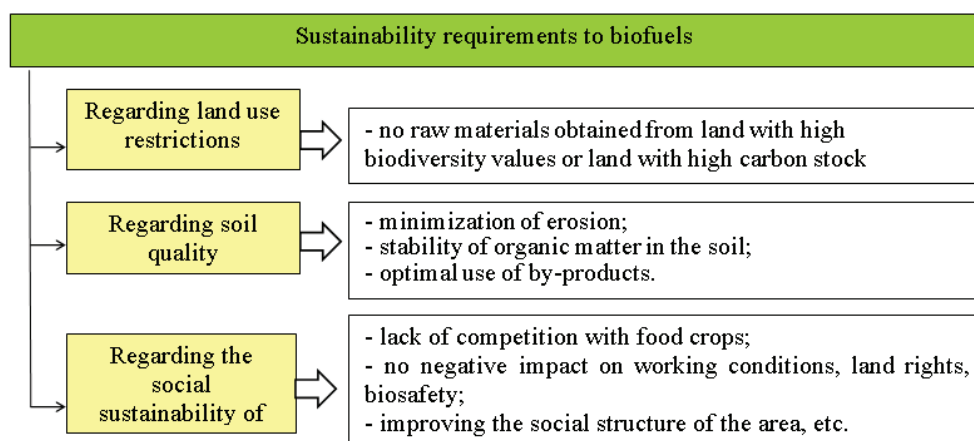


Fig. 3. Sustainability requirements to biofuels according to [Directive 2009/28/EC]

Table 1. Characteristics of energy crops in relation to the growing conditions based on [Alexopoulou et al. 2012]

| Crop                       | Temperature, °C  |                              | Need for water | Frost resistance | Drought resistance |
|----------------------------|------------------|------------------------------|----------------|------------------|--------------------|
|                            | Seed germination | Plant growth<br>min      max |                |                  |                    |
| Fast-growing tree crops    |                  |                              |                |                  |                    |
| Willow                     | -                | 0.1      30.0                | high           | high             | low                |
| Poplar                     | -                | 0.1      30.0                | medium         | medium           | medium             |
| Eucalyptus                 | -                | 5.0      30.0                | high           | low              | high               |
| Perennial herbaceous crops |                  |                              |                |                  |                    |
| Switchgrass                | >15              | 10.0      35.0               | medium         | high             | medium / high      |
| Miscanthus                 | >8               | 10.0      40.0               | medium / high  | low              | low                |
| Artichoke islanskij        | >5               | 5.0      35.0                | low            | low              | high               |

adaptive properties, economically useful traits and productivity potential and the possibility of growing on non-agricultural lands, the following energy crops are distinguished: switchgrass

(*Panicumvirgatum L.*), giant miscanthus (*Miscanthusgiganteus*), energy willow (*Salix L.*) and energy poplar (*Populus*). The choice of an energy crop for industrial cultivation depends on several



**Table 2.** Features of growing bioenergy crops, based on [Ganzhenko, 2017]

| Energy crop | Soil requirements, pH | Precipitation, mm / year | Depth of groundwater | Life cycle, years | Periodicity of harvesting |
|-------------|-----------------------|--------------------------|----------------------|-------------------|---------------------------|
| Willow      | 5.0–7.0               | 650–700                  | up to 2 m            | 20–25             | 1 time in 2–3 years       |
| Poplar      | 6                     | >600                     | up to 2 m            | 20–25             | 1 time in 2–3 years       |
| Miscanthus  | 5.5–7.5               | 500–700                  | 4 m                  | Up to 20          | annually                  |
| Switchgrass | 5.5–7.0               | 380–760                  | 5 m                  | 10–15             | annually                  |

natural factors: soil type, soil moisture/rainfall, landscape type. The requirements for cultivation and the peculiarities of the growing season of the main energy crops are shown in Table 2.

When choosing a site for a plantation, one of the main parameters that needs to be assessed is the soil. Usually, energy crops grow well on medium to heavy loamy soils, well aerated, with acidity in the range of pH 5-7.5. The ability of the soil to retain moisture is also important; therefore, cultivation in light sandy soils is not recommended due to the possible water availability problems. On the other hand, the choice for the area of floodplains and sensitive wetlands can complicate the work of heavy machinery, especially for planting and harvesting. Soil compaction can have a negative effect on wet soils, so the use of heavy machinery for such soils is recommended either in very dry periods or when the soil is frozen. Shallow (i.e. with a thin layer of humus) soils are also not recommended due to low yields. Greater water needs of energy crops compared to agricultural ones can help reduce the leakage of dangerous amounts of nutrients into nearby reservoirs or groundwater in the case of growing energy crops as buffer zones in the areas with intensive agriculture.

### Energy willow (*Salix L.*)

The energy willow is the most widespread crop in the world. This is due to the fact that the willow genotype is one of the richest after rice, and this makes it possible to create new varieties and hybrids for different purposes. The productivity of willow, according to experts, is 10-15 t/ha (under favourable soil and climatic conditions, the yield increases to 25-30 t/ha) of dry weight per year, exceeds the productivity of traditional forest plantations by 14 times [Kulyk et al., 2020]. With sufficient soil moisture, only 1% of humus is needed for the plant to receive the required amount of nutrients and in the future to ensure good yields.

Among a wide range of high-yielding crops, energy willow has significant advantages: a wide range of genetic diversity; easy reproduction; tolerance to a wide range of site conditions; CO<sub>2</sub>-neutrality; 1 ha of energy willow corresponds to approximately 4700 liters of oil; 1 hectare yields from 15 to 25 tons of wood chips per year; willow requires minimal pesticide use and can be grown organically without much difficulty; it cleans waste water; grows by about 2 meters per year - and up to 10 cm per day can be harvested many times, every 2-4 years; 1 liter of oil = 2.5 kg of dry wood chips = 4.5 kg of cod with a water content of 50% energy willow produces about 20 times more energy than is required for growing and harvesting; in comparison, wheat has an energy efficiency of only eight times the cost [Stolarski, et al., 2020; Nordborg et al., 2018; Amichev et al., 2018].

The technology of growing energy willow includes:

- pruning every two to three years using special machines in winter;
- growing for five years, before it gives the best harvest, then it can be harvested until the trees reach 20-25 years, after which they will need to be uprooted and new ones planted;
- harvesting is usually performed in winter, it is also suitable for levelling the sowing season, i.e. the farmer moves part of his usual field work from summer / autumn to winter;
- using specialized equipment for planting and harvesting.

In Europe, small energy willow companies often operate without their own equipment – for certain operations they hire a company that has all the necessary machines. This model works in Poland, Germany, Denmark, Sweden. Every European country has the companies that have special attachments for combines, and they turn to them when it is time to harvest energy willow.

Energy willow is an environmentally friendly feedstock used as a renewable solid biofuel of organic origin, which, when burned in boilers, does

not affect the carbon balance in the atmosphere. It is a type of solid biofuel, suitable for industrial production of heat and electricity at a price that is half that of using gas. The energy willow has a positive effect on the ecology and the environment. One hectare of plantation absorbs more than 200 tons of CO<sub>2</sub> from the air in three years. The calorific value of willow is about 18 MJ/kg of dry matter. One ton of willow with a humidity of 40% provides 1 Gcal of heat [Marchenko, 2012].

Willow does not emit harmful products during combustion and has a high heat transfer: 1 ton of dry biomass replaces more than 500 m<sup>3</sup> of natural gas or 700 kg of brown coal. The biomass can be used to produce both solid granular biofuel in the form of briquettes and pellets, and, if appropriate equipment is available, in the case of oxygen-free combustion, synthesis gas.

### Energy poplar (*Populus*)

Poplar (*Populus*) – willow family (Salicaceae). It is a close relative of the willow, which has also found its way into bioenergy. Like willow, it is grown in Western Europe for heating. In our climatic conditions, among all trees, poplar grows faster than willow, under similar conditions. For growth, it requires a lot of moisture and light, so the greatest biomass yield will be under the conditions close to those in river valleys [Pryshliak, 2021].

The technology of growing energy poplar requires compliance with the following agro-technological requirements: planting density – up to 9000 pcs/ha, and the optimal length of the seedling – 25 cm, when planting at least one bud of the seedling should remain above the ground. The plant is planted only in the spring. 10 tons of poplar cod replaces 2500 m<sup>3</sup> of natural gas.

The main agro-energy characteristics of poplar: yield: 40-60 t/ha, every 3-5 years; annual growth: 16 t/ha; productivity: 20-25 years; the heat of combustion is 18 MJ/kg.

Recently, due to the relatively rapid growth and formation of biomass, poplar plantations are increasingly used as a regenerative energy source for biofuel production. Its wood is quite lightweight and is widely used for technical purposes. Poplar absorbs a large amount of carbon dioxide, owing to which one can obtain an excellent environmentally friendly fuel. In industrial plantings, the yield of dry mass of poplar is up to 6-12 t/ha. Poplar plantations remain productive for 15-20 years or more, and

biomass during this period can be harvested every 3-6 years [Khivrych et al., 2011].

Fuel pellets and briquettes for burning in boilers are made of poplar wood and woodworking waste; part of the wood is burned in its raw form. The use of poplar biomass as an energy raw material can significantly save money and at the same time not harm nature, because the combustion of poplar does not emit toxic components into the atmosphere.

### Switchgrass (*Panicumvirgatum*)

Switchgrass is a thermophilic perennial plant that naturally grows in North America along 45-55° N longitude. Switchgrass is one of the promising perennial plants for biofuel production. The plant has erect stems of different colours, which reach 0.5-2.7 m in height, propagates by seeds and rhizome. Inflorescence – open raceme 15-50 cm long. Its powerful root system can reach up to 3 m in depth [Moser, Vogel, 1995].

The main agroenergetic characteristics are as follows: the frequency of harvesting – annually from the second year of the growing season, the period of use of the plantation – 15-20 years; minimum pending requirements; high temperature resistance. The environmental benefits of growing switchgrass biomass are: no need to use pesticides, it fights against soil erosion, helps preserve natural conditions, improve soil structure and reduce the greenhouse gas emissions. The switchgrass biomass structure has typical components for biofuel feedstock: about 50% carbon, 43% oxygen and 6% hydrogen. Dry biomass has a low ash content – up to 2-4% compared to the low content of potassium and sodium in combination with increased content of calcium and magnesium, contributes to a high combustion temperature and reduces the likelihood of slagging during combustion in boilers. The cost price of switchgrass biomass in different countries ranges from 15 to 40 EUR/t dry matter [Buzovsky, Vytvytska, Skrypnichenko, 2008].

Growing switchgrass for biomass is very profitable from an economic point of view. The crop has a low cost and practically no risks when growing. The switchgrass business is profitable relatively quickly. The plant gives a high yield with very little investment, which means that the money spent will quickly pay off. Switchgrass, as an alternative energy source, is most often used as a solid fuel for boilers. It can be burned

unprocessed, or it can be made into fuel briquettes or pellets. Thus, 1 ton of fuel pellets from switchgrass is equivalent to 1.14 tonnes of wood, 490 m<sup>3</sup> of natural gas, 399 kg of diesel fuel, 437 kg of fuel oil, 779 kg of coal, 418 kg of oil.

**Miscanthus (*Miscanthus*)**

Giant Miscanthus – a close relative of sugar cane, is directly related to the genus of herbaceous perennial plants of the bluegrass family (cereals). Giant miscanthus is characterized by higher biomass yields and higher energy efficiency of biomass production [Dubis, Jankowski, Załuski, 2019]. Other advantages of Miscanthus include [Kiesel., Wagner, & Lewandowski, 2017; McCalmont et al., 2017]:

- can grow for twenty-five years in one place;
- the biomass can be obtained annually;
- accumulates ten tons of underground biomass;
- provides year-round employment;
- provides phytoremediation;
- provides biodiversity.

The technology of growing *Miscanthus giganteus* (Fig. 4) provides for the annual collection

of biomass, starting from the third year of the growing season. At the initial stage, when landing, special technical means are required. The planters that are used to plant potatoes can also be used. Depending on the soil and climatic conditions, the recommended planting density is approximately 18.5 thousand rhizomes per 1 ha. In order to harvest the vegetative mass of *Miscanthus*, one can use the classic silage technique.

Economic calculations of the efficiency of growing miscanthus on one hectare showed that the most invested funds are in the first year – 2046,8 US dollars (USD). However, from the second year onward, there is an opportunity to make a profit (Fig. 5).

Due to the high yield of dry biomass (up to 25 t/ha), high calorific value (5 kWh / kg or 18 MJ/kg (pellets)), low natural humidity of the stems in the collection (up to 15%), miscanthus giganteus is one of the most efficient plants for biofuel production compared to other crops. When the miscanthus biomass burns, less carbon dioxide is released than it was absorbed by plants during photosynthesis, so the use of miscanthus biofuel will not contribute to the greenhouse effect. Its

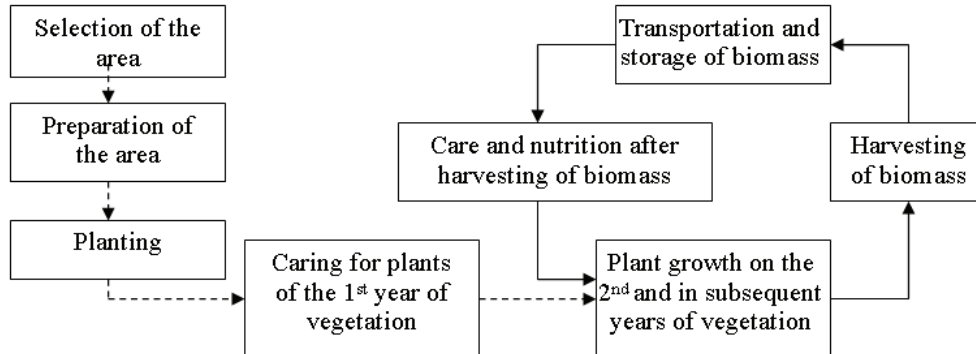


Fig. 4. Technology of growing giant miscanthus, on the basis [Katelevskiy, 2020]

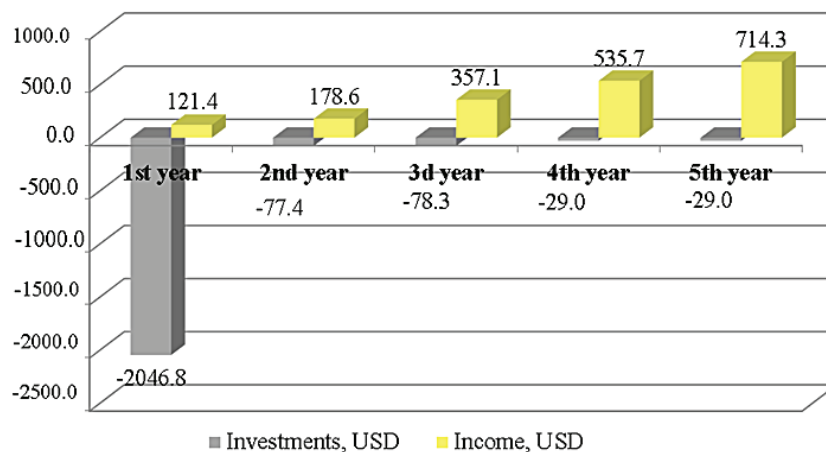


Fig. 5. Economic calculations of the efficiency of growing miscanthus on one hectare, USD

stems contain 64-71% cellulose, which provides a high energy value. The total yield of solid biofuel from 1 hectare of plantation is 20-25 tons. In order to support the choice of the most suitable biomass crops for a specific environment and end use destination, besides biomass yield, biomass quality should also be considered [Amaducci et al., 2017].

### PRODUCTION AND USE OF SOLID BIOFUELS

The most important fuel and technological characteristic of biomass used as a solid biofuel is its calorific value, which depends on many factors: genetic characteristics of energy plants, environmental impact, storage conditions, humidity, etc. The practical calculations of the efficiency of using solid biofuel are carried out using the values the lowest calorific value in the working state of the fuel, which is formed when burning a unit mass of fuel. The comparative characteristics of energy plants for the production of solid biofuel are given in Table 3.

The quality of biofuels is determined by the three phases that the biomass for energy purposes undergoes (Fig. 6).

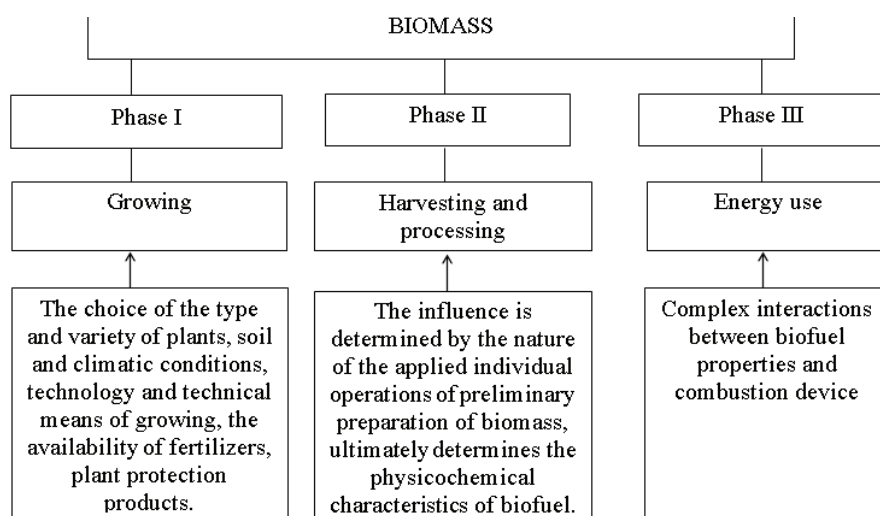
There are several cost-effective technologies for the preparation and processing of biomass for solid fuel in the world today. The most common are pressing, resulting in pellets, briquettes or granules. The process of producing solid fuel from biomass is quite simple and usually includes the following technological operations (Fig. 7).

The use of biomass for fuel production is associated with certain difficulties in comparison with traditional fuels. This is due to the fact that biomass is characterized by: lower density and calorific value; seasonality of formation; additional moisture content; a variety of thermochemical characteristics and chemical composition, depending on the type of biological raw materials, weather and climatic conditions and agrotechnological factors; large dimensions and cost of systems for storage, transportation, preparation and supply of fuel to a copper. The SWOT analysis of using energy crops for biofuel production is given in Table 3.

There are different variants for growing and further use of energy crops as fuel, which includes such options as growing crops and their sale to enterprises, producing solid biofuels; use for energy autonomy (direct combustion or production of briquettes, pellets, granules and their

**Table 3.** Comparative characteristics of energy plants for the production of solid biofuels, according to data of [Kulyk et al., 2020]

| Crop        | Yield of dry mass (t/ha) / year | Heat of combustion, MJ/kg of dry weight | Energy production, GJ/ha | Water content at harvest, % | Ash, % |
|-------------|---------------------------------|-----------------------------------------|--------------------------|-----------------------------|--------|
| Miscanthus  | 8.0–32.0                        | 17.5                                    | 311.9–419.0              | 15.0                        | 3.7    |
| Switchgrass | 9.0–18.0                        | 17.0                                    | 266.8–312.2              | 15.0                        | 6.0    |
| Willow      | 8.0–20.0                        | 18.5                                    | 280.0–315.0              | 53.0                        | 2.0    |
| Poplar      | 9.0–16.0                        | 18.7                                    | 1700–300.0               | 49.0                        | 1.5    |



**Fig. 6.** Phases of biomass passage, on the basis [Blum et al., 2010; Elbersen, 2001]

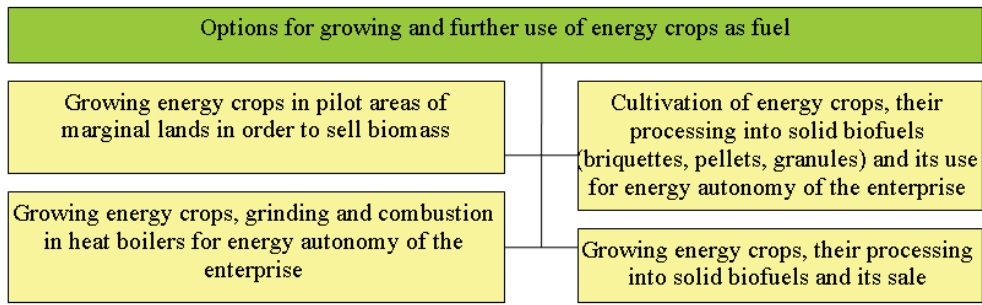


Fig. 8. Options for using energy crops (sales/energy autonomy)

combustion), and sale of secondary energy products on the market (Fig. 8).

The calculation of economic efficiency of energy crops on the example of energy willow and its use for the production of solid biofuels for energy autonomy and sale on the farm (from 5 years of cultivation) showed that under the current Ukrainian market conditions, it is more profitable for companies to sell products than to use for energy autonomy (Table 4).

Growing energy crops needs the state support. Compensation to farmers reaches 50% of the cost of planting in the EU, in addition, there

Table 4. Economic efficiency of willow cultivation and its use for the production of solid biofuels on the farm (the theoretical area of plantations on the farm is 300 hectares)

| Indicator                                        | Indicator value |
|--------------------------------------------------|-----------------|
| Dry mass yield, t/ha                             | 23.0            |
| Dry biomass yield, t/year                        | 6900.0          |
| Solid biofuel yield (10% moisture), t/year       | 62100           |
| Self-sufficiency profitability, %                | 67.3            |
| Average cost of 1 ton of solid biofuel, USD      | 103.6           |
| Profit per 1 ton of solid biofuel, thousands USD | 25.1            |
| Sale profitability level, %                      | 72.5            |

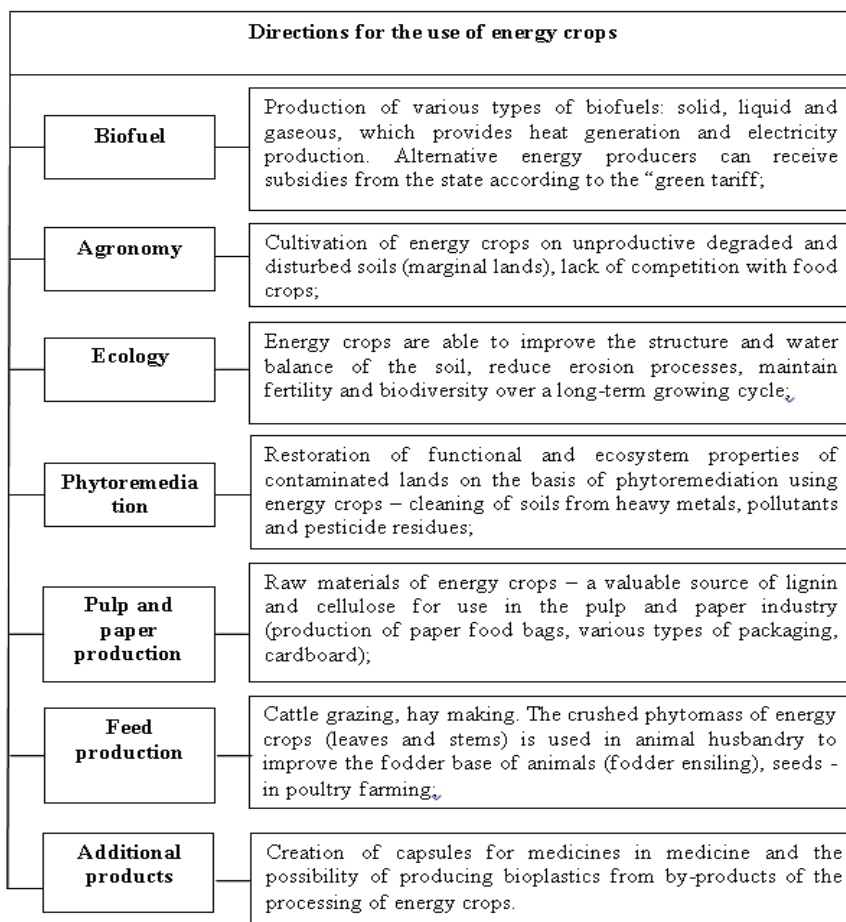


Fig. 9. Directions for the use of energy crops, according to the data from [Kalinichenko et al., 2017]

are tax incentives. It is advisable in Ukraine to introduce exemptions from rent for unproductive and abandoned land, which are put into circulation for growing energy crops for 5 years, i.e. until the receipt of revenue; the application of tax benefits for VAT and income tax; simplified land allocation. In addition to biofuel benefits, energy crops have the following uses (Fig. 9).

An efficient model for the production and energy conversion of biomass provides for the cultivation of energy crops, the production of biomass, its processing and the supply of energy to consumers. At the same time, it is recommended to adhere to a closed waste-free production cycle – the supply of energy. For the rational use of biofuels from biomass of energy crops (obtained on marginal lands) and providing alternative energy to consumers in rural areas, the following scheme is proposed (Fig. 10).

The creation of an infrastructure that provides the attraction of the resource of agricultural

enterprises for the cultivation and processing of energy crops with the participation of energy service companies will make it possible to provide stable supply of the transformed energy resource to consumers.

The total production of pellets in Ukraine in 2020 amounted to about 3.6 million tons of oil equivalent at 494 enterprises (Fig. 11). Currently, a large share of pellets and briquettes are exported from Ukraine to European countries due to the insufficient demand in the domestic market and higher prices for products in foreign markets.

### RECAPITULATION

Bioenergy crops are an important component of the bioenergy potential of Ukraine. Their cultivation has a number of positive effects, including: replacement of natural gas, which will help improve the balance of payments of our state; the

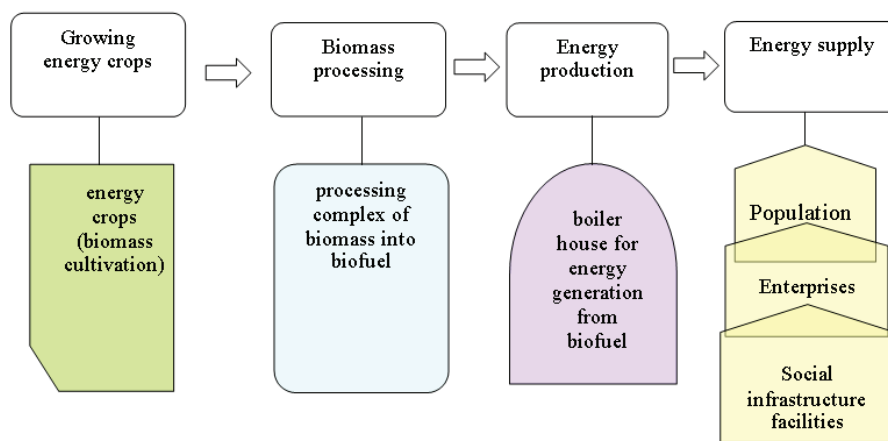


Fig. 10. An integrated logistic model for the production, processing and use of biomass from bioenergy crops, according to the data from [Kulyk et al., 2019; Kulyk et al., 2020]

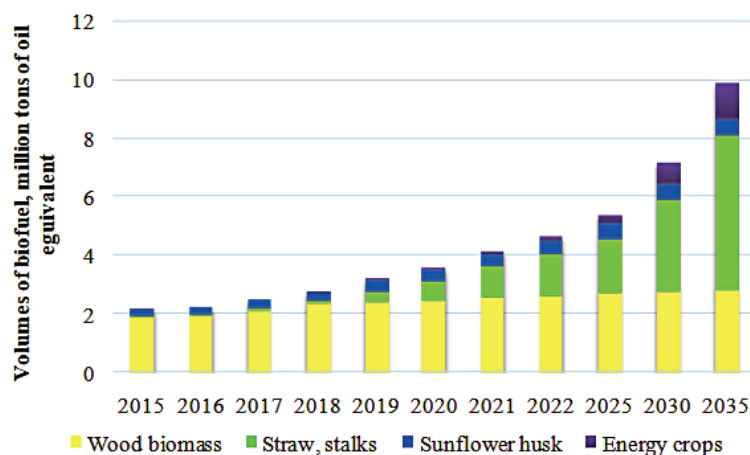


Fig. 11. Dynamics of solid biofuel production in Ukraine [Energy Strategy of Ukraine until 2035]

possibility of reducing the heat tariff for the population by 10%; land reclamation and restoration; decarbonization of the economy and the beginning of the transition to a bioeconomy based on the use of biological resources as energy carriers; economic growth in rural areas due to the creation of new jobs, an increase in revenues to local budgets in the form of taxes from the enterprises engaged in the cultivation of energy crops and their processing into biofuels, etc. At the same time, it is important to create an infrastructure for the cultivation, processing and use of bioenergy raw materials, which provides for the attraction of agricultural resources for the cultivation of energy crops, the collection and processing of biomass, the supply of the transformed energy resource to consumers.

The technologies for growing energy willow, poplar and miscanthus differ, but they share the ability to grow on unproductive degraded lands. There are various options for the cultivation and subsequent use of bioenergy crops - the sale of raw materials (biofuel) or use for energy autonomy (direct combustion, production and combustion of solid biofuel). It is advisable for enterprises to carry out the calculations of the most economically profitable option in accordance with specific business conditions and take into account market conditions.

One of the reasons that hinder the development of growing bioenergy crops in Ukraine is the imperfection of the regulatory legal regulation of the renewable energy industry in Ukraine. In addition, the lack of mechanisms for providing incentives and subsidies to the companies that are ready to invest in “green energy” creates significant financial burdens for the investor at the initial stage of plantation laying and, in turn, significantly slows down the development of such a business in Ukraine.

Significant agricultural land areas and geographic location make Ukraine one of the most attractive countries in Europe for the sustainable cultivation of energy crops without harming recreational or nature conservation areas. We need an initiative on the part of the state, the creation of favourable conditions at the legislative level and the attraction of investors, to promote the development of the production of solid biofuels from bioenergy raw materials. The use of an efficient logistic scheme for the production and use of biofuels from biomass of energy crops will provide the population with alternative energy and contribute to the sustainable development of the bioenergy sector in rural areas.

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