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Original Research

Plant Biomass Production and Use as an Environmentally-Friendly Local Fuel

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Abstract

We review research on growing and burning herbaceous and woody energy plants, and compare the harmful substance emissions into the air while burning these plants. Research results of biomass combustion and reed usage as an environmentally-friendly fuel grown near lakes is reviewed. The research results of burning the chopped energy plants such as willow and topinambour stems are presented, and compared with ash wood burning. The tests were carried out in a boiler designed to burn wood, wood briquettes, and large chips. After determination of harmful substance emissions into the atmosphere it has been concluded that burning bio-fuels is better because of low pollutant concentrations compared to wood, and sufficiently to coarse-chopped willow stems, i.e. to those types of bio-fuels that are amply mixed with air while burning.

Keywords: energy plants, environmentally friendly fuel, willow, topinambour stems, chaff, burning, pollution, emission

Introduction

Plants under the influence of solar energy, water, and small quantities of minerals are capable of synthesizing organic mass from carbon dioxide. During photosynthesis the amount of organic matter produced within one year is known as phytomass gain. Biomass is a local eco-friendly fuel that contains practically no sulphur. While the carbon dioxide released during burning it is part of the natural carbon cycle, which is absorbed by vegetation in the process of photosynthesis and is converted into oxygen.

Individual plant biomass types can be used to produce heat, electricity, and gaseous fuel. Biomass resources include not only agricultural and forestry products, but also its processing and recycling waste. The solid biomass fuel can be fractionated into wood, chopped wood, shavings, sawdust, bundles, briquettes, pellets, and flour shape.

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Co-firing of biomass and fossil fuels is attractive in the Baltic countries because of permanently rising prices of fossil fuels and comparatively large biomass resources. The most popular co-firing technology is known as parallel combustion. In Lithuania Few Dh companies and one CHP plant use direct co-firing of peat and wood or straw blends [1].

Plant biomass for energy purposes is a major source of renewable energy. Currently, biomass accounts for about half of the renewable energy used in the European Union [2-5]. European Union countries have estimated that the volume of biomass energy will increase 3-3.5 times by 2020, and 3.5-4.5 times by 2030 [3, 6]. It has been predicted that EU renewable energy consumption in 2020 will reach 20% of total domestic consumption, and biomass energy will comprise about 13% of total domestic consumption (65% of total renewable energy) [2, 7]. The target for the amount of energy generated from renewable sources in the final consumption of energy in 2020 for Lithuania is planned to be equal to 23% according to a proposed direc-

Table 1. Amount of carbon monoxide (CO) and nitrogen oxides (NO_x) in smoke while burning energy plants, $mg{\cdot}Nm^{-3}$.

Plant name	Harvest time			
	September		March	
	CO	NO_x	CO	NO_x
Reed canary grass	660	834	356	926
Reed canary grass with sweet clover	1,250	555	978	381
Reed canary grass with perennial lupine	1,664	554	337	267
Reed canary grass with goat's rue	1,472	554	–	–
Awnless brome grass	2,255	414	563	748
Awnless brome grass with sweet clover	1,882	494	867	631
Jerusalem artichoke	2,625	688	2,250	234

tive on renewable energy sources (RES) [7]. As early as 1997 the biomass energy in countries with no significant fossil fuel resources, such as Austria, Sweden, and Finland, was: 12%, 18%, and 23%, respectively [8].

Plant biomass (wood, straw, energy plants) is one of the most important renewable energy sources in Lithuania and now composes a substantial part of the local fuel. The greater use of local fuel began when the National Energy Efficiency Program was launched in 1992 and renewed in 1996. New use of plant biomass for energy and other purposes was defined by future prospects for an agricultural and rural development strategy program in 2007-13. In 2005 the amount of plant biomass fuel was 715 thousand toe (tons of oil equivalent) in Lithuania, which equaled about 94% of the total renewable energy generated [9]. Currently, biomass fuel makes up about 8.2% of all general Lithuanian fuel and energy consumption [2, 10].

Green biomass energy stock consists of quick-growing trees and bushes, willow, and tall perennial grass. There are more than 500 ha of cultivated willow (*Salix Viminalis*) plantations in Lithuania, which are used as hard bio-fuel. Therefore, with the increasing uptake of renewable energy sources, research and development of new technologies is necessary.

Energy plant cultivation and their utilization as a fuel contribute to solving a number of environmental problems [11-14]:

- vegetative plants improve the environmental climate
- plants improve soil structure and allow for a smaller demand of chemical fertilizer
- burning of plant biomass reduces environmental pollution with harmful substances

Energy plants and their plantations are useful because they are grown near residential facilities and farmhouses. Additionally, these plants may improve ambient air quality and the microclimate as they ensure a clean and healthy atmosphere, and absorb carbon dioxide and convert it to oxygen.

From the ecological point of view it is also important for the soil in which they are grown, and the potable water we drink and use for other domestic purposes. The Lithuanian Institute of Agriculture has estimated the impact of various plants on the soil [13]. Numerous studies have demonstrated an undisputed advantage of perennial grasses if compared with annual crops and cereals. The major global environmental problem is the emissions of harmful substances into the atmosphere during burning. Fossil fuel burning leads to many environmental problems both local (except sulphur dioxide, nitrogen oxides, etc.) and global (except carbon dioxide and other "greenhouse effect" gas).

Researchers of the Institute of Agricultural Engineering of Lithuanian University of Agriculture have studied emissions of harmful substances in the atmosphere by burning herbal plants [15]. While burning, the green biomass produced CO and NO_x supply in smoke with an oxygen concentration of O_2=6% (Table 1) [8, 16, 17].

Judging by the amount of CO in the smoke reed canary grass, biomass fuels should preferably be burned. Most of the CO was established while burning Jerusalem artichoke (*Helianthus tuberosus*), awnless brome grass (*Bromus*), and their mixtures with sweet clover (*Melilotus*). The greatest amount of NO_x was noticed in the smoke of reed canary grass (*Digraphis arundinacea*), less in awnless brome grass, and the least in Jerusalem artichokes. The plant biofuel harvested in March showed better burning results, as CO emissions in the smoke were significantly lower. Quantities of NO_x in the smoke ranged from 234 to 926 $mg{\cdot}nm^{-3}$, while the largest was noticed while burning the pure reed canary grass.

As the investigation results suggest, fuel generated more heat and burned better than the plant biomass prepared in late summer or left in the field during winter and cut early in spring. This organic fuel is more appropriate to be widely used for energy purposes in Lithuania [8, 18]. Agricultural waste of green biomass, i.e. multi-grain straw, is used for energy purposes. The appropriate use of this biomass is not only ecological but economical, because the straw is a secondary product of waste. The straw used as a fuel is distinctive because of the amount of CO_2 released into the environment during burning that is absorbed when the cereals are grown the next year. As a result the amount of CO_2 in the atmosphere during straw burning does not increase, and straw is considered one of the renewable energy sources.

It was found that during the burning of herbal plants and straw, dust emissions in the smoke ranged from 600 to 3000 $mg \cdot nm^{-3}$ in continuous furnaces with automatic loading. Cyclones and dust filters are used to separate the dust from smoke.

Limits of emissions from fuel burning equipment are governed by the Lithuanian Ministry of Environment that approved the standards of emissions from fuel burning equipment. These rates are governed by the burning of bio-fuels, including herbage plants and straw, and pollution limit values.

The limit values of contaminants (with the standard concentrations of O_2=6%) released during bio-fuel burning into the atmosphere from new and existing installations (with thermal efficiency of 1-50 MW) are determined as follows [17, 18]:

- $SO_2 \rightarrow$ 2,000 $mg \cdot nm^{-3}$
- $NO_x \rightarrow$ 750 $mg \cdot nm^{-3}$
- CO $\rightarrow$ 1,000-4,000 $mg \cdot nm^{-3}$
- solid particles $\rightarrow$ 300-700 $mg \cdot nm^{-3}$

Burning a ton of straw or grass plants produces 30-40 kg of ash in furnaces and 5-8 kg of dust that remains in a filter. Straw ash contains about 0.09% nitrogen, 1% of phosphorus and 11% potassium. In addition, ashes have a small amount of heavy metals such as copper, zinc, tin, nickel, chromium, and cadmium, etc. These ashes can be used as fertilizer because of phosphorus and potassium.

Foreign countries, especially Western European and Scandinavian countries, apply various measures to promote the production and use of organic fuel – energy plants for energy purposes. Lithuania goes in the same direction. General emissions and emissions when the local fuel is used between countries are varied. Germany and Poland, countries with the largest populations in the region released into the atmosphere the greatest amount of CO_2, SO_2, and NO_x noxious gases [19, 20].

The comparison of emission intensity in various countries, i.e. the ratio of emissions to energy consumption, disclosed that the highest CO_2 emission intensities are in Poland, Estonia, Denmark, and Germany. These countries satisfy the energy needs of fossil fuels. Norway and Sweden, compared with other European countries, use mainly hydro and nuclear energy, and emit into the environment the least amounts of CO_2 and SO_2 gases (in relation to absorbed energy content) [20].

Lithuania also struggled with environmental pollution, and carried out various studies for burning fossil fuel and green biomass. An example is a project of the Lithuanian Beautification Society carried out in Simnas township. The project was an innovative use of wetlands to produce biomass used for Simnas township heating, while simultaneously improving Zuvintas Biosphere Reserve and the state of ecosystems of other lakes [15]. The main objective of the project was to reduce the impact of climate change through local fuel resources – bio-fuels (reeds), thereby enhancing Zuvintas Biosphere Reserve and protecting bird species and habitats. For this task the special machinery for preparation of bio-fuels was acquired and used to harvest broken reeds on the lake shore and on ice in winter. During the three heating seasons, 15.86 hectares of reed area was harvested, 47.500 tons of biomass was burned, and 214.513 MWh of thermal energy was produced. Research results of bio-fuel and reed burning in the Simnas township boiler-house for heating showed that after combining the Simnas special boarding school heating system with Simnas boiler-house, air pollution decreased: solid particles – 3.679 tons, carbon oxides – 2.703 tons, nitrogen – 0.569 tons, and sulphur – 1.34 tons [15].

Similar environmental pollution studies are available for burning of energy crops (willow, Jerusalem artichoke stalks), the production and use of which as a fuel is increasing in Lithuania.

Our study objective is to determine the harmful emissions of noxious substances into the atmosphere while burning energy plants.

Experimental Procedures

In boilers that use solid bio-fuels, fuel combustion and emission levels depend on fuel type, quality, and shape. These fuel parameters are important in the design of new fuel delivery and burning equipment.

One important parameter of fuel quality is plant stem chaff fineness. This parameter must be determined by refinement on the basis of boilers used in the combustion chamber, chaff transportation or delivery equipment, and storage requirements. Furnaces with the required fineness of chaff obtained high combustion efficiency.

Three-year-growth willow (*Salix Viminalis*) and Jerusalem artichoke (*Helianthus tuberosus*) stem chaff, chopped by the drum chopper were used in the tests. The quality of stem chaff and chaff fineness was defined by methodology and used in EU countries (the stem chaff fractional composition determination methodology) [20, 21]. The application of this methodology for fractional composition determination is based on European Standard (DD CEN/TS 15149-1:2006) [21, 22]. About 5 kg of chaff sample was transferred *via* 40 mm diameter sieves with round holes, the diameters of which were 63 mm, 45 mm, 16 mm, 8 mm, and 3.15 mm. While screening each sample the set of sieves was rotated 30 times within a semicircle in a horizontal plane. The mass remaining on sieves was weighed separately. The mass left on the different sieves was weighed and calculated in percentages. Each test was replicated 3 times.

Tests were carried out to find the influence of the fuel type and fuel quality parameters on formation of contaminants. The investigation to choose the best low-power solid-fuel boiler adapted to burn fuel in large groups, for instance large wood chips, firewood, and sawdust briquettes, was carried out in the Lithuanian Energy Institute with a thermal equipment testing facility using the stan-

Table 2. Analyzers of combustion products and their main parameters.

№	Dimensional parameter	Measuring instrument	Measuring range	Measurement error
1.	CO_2 concentration	Products of burning analyzers Datatest 400CEM	to 20%	±0.2% (abs)
2.	CO concentration		0-100,000 ppm	±2%
3.	O_2 concentration		0-21%	±0.2% (abs)
4.	C_iH_j concentration	C_iH_j analyzer VE7	0-10, -100, -1,000, -10,000, -100,000 ppm	±2%

Table 3. Plant chaff fractional composition (according to EU methodology).

Plant	The chopped stem mass left on the sieve, %					
	Ø 63 mm	Ø 45 mm	Ø 16 mm	Ø 8 mm	Ø 3.15 mm	Dust
Willow	1.58±1.53	2.19±2.02	89.54±2.98	6.19±1.14	0.81±0.37	0.20±0.06
Jerusalem artichoke	0.52±0.61	4.35±7.99	90.39±7.37	3.99±1.71	0.63±0.59	0.11±0.11

dardized methods [23]. Boiler rated capacity during the investigation amounted to 27 kW, and efficiency was 82%. Pollutants generated while burning were measured by burning analyzers for special products or noxious substances (Table 2).

The emissions of harmful substances into the atmosphere were defined and the comparison of different fuel types used for burning was made. Investigations were carried out using several types of different bio-fuels and ready-made mixes, and for a comparison with Ash (*Faxinus*) firewood:

1) firewood (ash wood)
2) willow stem chaff produced with a drum chopper
3) willow and Jerusalem artichoke stem chaff mixture produced with a drum chopper
4) Jerusalem artichoke stem chaff produced with a drum chopper

An electrical branch chopper was used for energy plant chopping. Samples of chopped plant stems (about 50 kg each) were delivered to a research laboratory, where burning and emissions tests were carried out for use with the above-mentioned stationary equipment.

Results

Assessing the quality of willows and Jerusalem artichoke stem chaff in accordance with the methodology of EU countries (using a set of sieves with round holes of different sizes), disclosed that the middle-length chaff was received by chopping with a drum chopper (Table 3).

Chaff fineness was shown by accumulated chaff fraction on Ø 16 mm sieve: willow and Jerusalem artichoke stems were chopped with a drum chopper. 89.5% of the willow chaff mass and 90.4% of Jerusalem artichoke chaff mass was left on the sieve. A little amount of dust (0.2% of willow and 0.1% of Jerusalem artichoke chaff mass) was left on the sieve and the chaff mass particles of larger than 63 mm length (1.6% of willow and 0.5% of Jerusalem artichoke chaff mass), which is not desirable for the bio-fuel of high-quality chaff. It was found that Jerusalem artichoke stem chaff has been chopped into smaller pieces than willow stems (Table 3).

The experimental test results of burning of chopped energy plants (e.g., willow and Jerusalem artichoke stems, and ash wood for comparison), are presented in Table 4 and Fig. 1. The test is carried out in a boiler that is designed to burn wood, wood briquettes, and large wood chaff.

The study identified the following periods of burning:

1) ash wood burning period from 0 to 39 minutes
2) willow chaff prepared with the drum chopper, burning period from 39 to 71 minutes
3) willow chaff and chopped Jerusalem artichoke stem mixture, burning period from 71 to 79 minutes
4) Jerusalem artichoke stem chaff burning period from 79 to 105 minutes

Test analyses reveal that the burning of willow chaff resulted in small (less than for ash wood burning) emissions of harmful substances into the atmosphere (CO=1,247.47 $mg \cdot m^{-3}$ and C_iH_j=205.32 $mg \cdot m^{-3}$), while burning of ash wood resulted in (CO=1,641.81 $mg \cdot m^{-3}$ and C_iH_j=713.26 $mg \cdot m^{-3}$). However, the combustion of willow chaff resulted in higher CO_2 emissions of 9.65% (if compared with the burning of ash wood: 8.01%).

Burning Jerusalem artichoke stem chaff resulted in the lowest CO_2 emissions equal to 5.6%, but emissions of other harmful substances were many times greater if compared with the combustion results of willow chaff and ash wood (CO=13,179.28 $mg \cdot m^{-3}$ and C_iH_j=2,803.1 $mg \cdot m^{-3}$).

Once the emissions of harmful substances (for instance CO, CO_2, and C_iH_j) into the atmosphere revealed that bio-fuel burning generated low concentrations of pollutants when better mixing with air was used in combustion processes, and wood and sufficiently coarse chopped willow stems were used. Combustion efficiency of Jerusalem artichoke stems was not high, and as a result a large amount of emissions of harmful substances into the atmosphere was

Table 4. Concentration of burning products.

Bio-fuels	Parameters		
	CO_2, %	CO, %/(mg·m^{-3})	C_iH_j, %/(mg·m^{-3})
Ash wood	8.01	1004.25·10^{-6}/1,641.81	332.53·10^{-6}/713.26
Willow chaff	9.65	919.27·10^{-6}/1,247.47	115.32·10^{-6}/205.32
Willow chaff and chopped Jerusalem artichoke stem mixture	10.09	460.23·10^{-6}/597.31	25.87·10^{-6}/44.05
Jerusalem artichoke stem chaff	5.6	5,635.94·10^{-6}/13,179.28	913.65·10^{-6}/2,803.1
Average	8.08	2,087.47·10^{-6}/3,383.16	388.88·10^{-6}/826.9

found, because these plants were chopped into smaller pieces than willow stems. Therefore, they were not sufficiently mixed with the air during the burning process. Jerusalem artichoke stems revealed significant emissions of harmful substances into the atmosphere.

After finishing the investigations we can propose to continue the study in the similar research field, and we suggest improving this study. For future research we propose using special boilers adjusted for the burning of wet willow chaff (the moisture content of which is 45-55%), and for higher burning efficiency to choose the optimal chopping quality parameters and to define the continuous chaff supply to the boiler.

Discussion of Results and Conclusions

1. Energy plant growth and their usage for energy purposes help to solve a number of ecological problems. One of them is that burning of plant biomass reduces environmental pollution with harmful substances.
2. Research results of chaff fineness show that the biggest amount of chaff fraction was accumulated on Ø 16 mm sieve: 89.5% of the willow chaff mass and 90.4% of Jerusalem artichoke chaff mass, respectively. A little amount of dust was left on the sieve and the chaff mass with particles larger than 63 mm length. It was found that Jerusalem artichoke stem chaff had been chopped into smaller pieces than willow stems
3. It was defined that burning of willow chaff resulted in small (less than ash wood burning) emissions of harmful substances into the atmosphere: CO=1,247.47 mg·m^{-3} and C_iH_j=205.32 mg·m^{-3}, and during Ash wood burning: CO=1,641.81 mg·m^{-3} and C_iH_j=713.26 mg·m^{-3}. However, the burning of willow chaff resulted in higher CO_2 emissions of 9.65%, and during Ash wood burning 8.01%.
4. The lowest CO_2 emissions were received while burning the Jerusalem artichoke stem chaff (5.6%), but emissions of other harmful substances were much greater than those resulting from willow chaff and Ash wood burning: CO=13,179.28 mg·m^{-3} and C_iH_j=2,803.1 mg·m^{-3}.
5. Harmful substances such as (CO, CO_2, and C_iH_j) emitted into the atmosphere revealed that bio-fuel burning generated low concentrations of pollutants when better mixing with air was used in combustion processes, and wood and sufficiently coarse chopped willow stems were used.

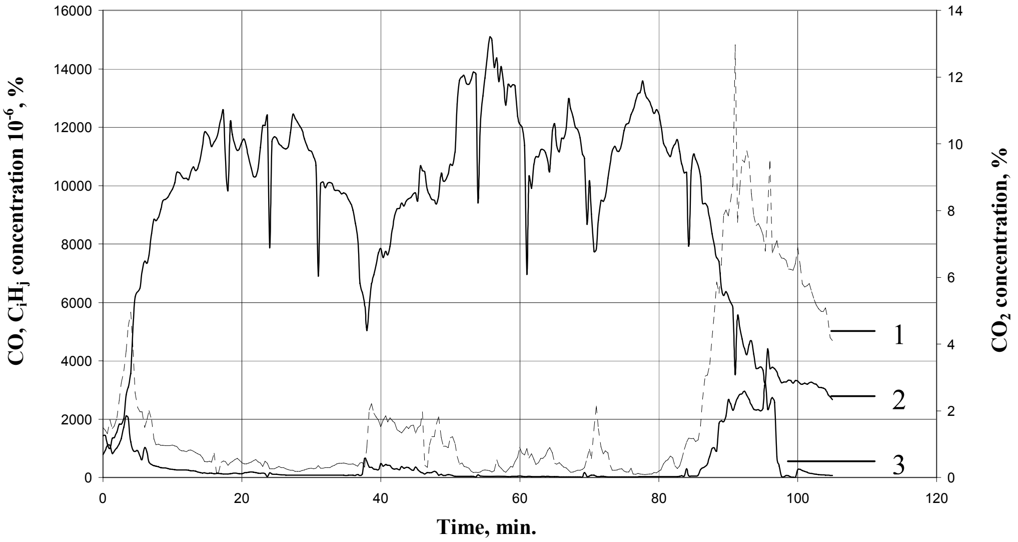

Fig. 1. Concentration of burning products: 1) concentration of CO, 2) concentration of CO_2, 3) concentration of C_iH_j.

6. Future research should use special boilers adjusted for the burning of wet energy plant chaff, and for higher chaff burning efficiency in the boiler, to choose the optimal chopping quality parameters and to define the continuous chaff supply to the boiler.

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