Biomass waste wood as new materials for the gasification in CHP plants

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As in Serbia, non-existent official estimates of biomass availability to the internationally recognized methodology, this paper attempts to collect based data from forest harvesting and wood processing, and perform assessment. The paper points out the regions in Serbia, the largest producers of scrap wood forest after logging, as well as the type of timber industries that produce it. In the industrial processing of wood energy consumption is considered in primary wood processing technologies. The consumption of wood waste necessary for obtaining electrical energy is calculated. Estimation of the amount of scrap and the price of kWh of electrical energy is done for the demonstration CHP plant power 200kWe, for heat and electricity, which is under construction on Project No. TR-33049 financed by the Ministry of Education and Science Republic of Serbia. At the end, the two principals of working CHP plant are given, with and without Stirling machine, as a possible solution for the mentioned demo plant.

Key words*:* *wood waste, forest harvesting, wood processing, CHP plant*

1. INTRODUCTION

The Energy envelopment Strategy until 2015.year ([1]) predicts that the share of renewable sources (excluding large hydro) in the total primary energy consumption should rise from zero to 1.1% in 2015.year, while the share of total final energy consumption should increase to 1.5 - 2%.

Biomass is traditionally used for years in the world to the production of heat, but the output in 2008.year in Serbia amounted to only 0.3 Mtoe, which means that only 11% of available energy, biomass utilized. According to the Biomass Action Plan from 2010 to 2012.year ([2]), the annual energy potential of biomass in the Republic of Serbia is about 2.7 Mtoe. The energy potential of biomass from forestry and wood industry (cutting of trees and the remains of trees produced in the primary and / or industrial processing of wood) is estimated to be approximately 1.0 Mtoe, while about 1.7 Mtoe derived from agricultural biomass (agricultural wastes and residues from farming, including liquid manure). As the total annual consumption of primary energy in Serbia in 2009 was 16Mtoe; from this it is clear that biomass derived from forestry and timber industry can cover even 6.25% of primary energy in Serbia, if it is rational and adequately used.

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2. WOOD WASTE IN FORESTRY AND WOOD PROCESSING INDUSTRY

In order to understand the characteristics of wood as waste and talked about his energy evaluation is necessary to know and its chemical composition. Elemental chemical composition varies depending on the type of wood, its age, area, part of the tree, etc. Hardwood: beech, oak, elm, locust, hornbeam, and others, which are dominated by the Serbian forests, contain approximately 50% carbon, 43% oxygen, 6% hydrogen and 1% nitrogen. Of compounds involved in the wood structure the most important are: cellulose, hemicelluloses and lignin. These three compounds make up 80% of the composition of dried wood. Others make up water (about 17%), auxiliary materials (2%) and ash (1%). The dry wood broadleaves, pulp accounts for 43-45%, 19-26% lignin, 21-26% pento, heksozani 3-6%, and while in dry coniferous wood pulp is present 53-54%, 26-29% lignin, pento 10-12% and 13% heksozani.

2.1 In forestry

The average density of forests in Serbia is 939 trees/ha, and the average volume in the forests of Serbia is 161m^3/ha ([3]) . Serbia belongs to the middle forested countries where the forest there is 29.1% of its total territory. In relation to the global aspect of this is covered close to the world that is 30% and significantly lower than Europe, which reaches about 46%. In central Serbia the highest volume of wood harvest is to: Zlatiborski, Raški, Pčinji and Rasinski region, whereas in the case with: Sremski, Južnobački and Južnobanatski district in Vojvodina (Table 1). It is interesting to note that the percentage of cut hardwood stands in the regions rather uniform, while in conifers cut in the Zlatibor and Raška district reaches 70% of the total harvest.

Table 1- Felled timber regions in Serbia in 2009 ([4], [5], [6])

Region 1)	Broadleaves		Conifers		Wood waste 3)
	m^3	% 1)	m^3	% 2)	m^3
Zlatiborski	122078	5,20	126141	49,20	94323
Raški	144372	6,15	53134	20,72	75052
Pčinjski	118483	5,05	11448	4,46	49374
Rasinski	116400	4,96	8797	3,43	47574
Sremski	220761	9,41	92	0,04	83924
Južnobački	144523	6,16	204	0,08	54996
Južnobanatski	101752	4,33	6472	2,52	41125

1) - the total volume of felled broadleaves in the Republic of Serbia, 2) - the total volume of felled conifers in the Republic of Serbia, 3) - the estimated amount of potential scrap [7]

In considering the structure of wood scrap it is necessary to divide into two main types: technical and stack wood. Technical wood is in possession of further sawmill and gets the final processing, furniture, doors and windows, construction of civil engineering and mining and custom products, while the stacked wood is used as: fuel and industrial. Industrial wood is used for: i.e. chipping board production, chemical processing and production of cellulose and paper. Fuel wood consumption in Serbia is one of the 50% of the total timber harvest. This percentage in the future should certainly be reduced to account adequately valorized waste from forest harvesting and wood processing.

When forest is cut in the total amount of stem wood (no leaves or needles) share certain categories of wood in a climate Serbia about the following (according to [8]): roughly 71% of wood, small twigs 11% and 18% Tree Run. However, the volume of unused parts of the wood, which include: leaves, needles, bark, thin branches, stumps, roots and rotten wood, is as high as about 38% ([7], [9]) of the total volume of timber wood. If you think it is realistic to use about 28%, as stumps and roots no one takes out or collecting leaves and needles, this means that the current cutting trees in forests (data from 2009) about 426 000 m^3 of wood waste, wood waste that is remains unused after cutting. These residues are different in size and shape, and are scattered in the woods. As for the quality of these biomass residues can be used as an energy source. After crushing the crushers, the scrap wood (chopping) could be used either to produce pellets and briquettes or at the plant for the production of combined heat and power (CHP plant).

2.2 In wood processing industry

The wood processing industry is mainly used for electricity, heat and fuel. Energy consumed for three main purposes:

- the need for the operation of production: space heating and lighting, compressed air supply;
- the wood processing and handling operations
- drying and evaporation of sawn timber and semi-finished

Electricity is provided from electro supply network. It is used to drive motors and lighting. This type of energy is sometimes used as a source of heat, but it should be avoided.

Thermal energy is supplied by burning oil, coal, natural gas or waste wood. In this way provides the energy needed for heating plants, industrial drying, steaming, hot presses, etc., and the conversion of heat into other forms of secondary energy.

In Table 2 the data are given, according to the OECD [10], which is related to energy needs for the most important technologies for primary wood processing. In consideration are taken sawmill wood (with or without industrial drying of wood), production of veneer panels and particle board production. The data represent the average values for a number of developing countries rich in forests. Energy consumption is broken down to: electricity, heat and fuel (diesel and gasoline) and reduced to the finished product m^3.

In the four mentioned processes most of the energy consumption makes heat. Heat treatments (industrial drying, steaming, hot presses) are the largest consumers of thermal energy. In sawmill lumber processing for this purpose consumes between 83 and 92% of total energy, in making veneers more than 95%, with 87% of veneer (plywood) boards, and in making particle board from 61 to 62%.

The primary processing factories electricity consumed most electric motors for propulsion machinery and equipment, internal transport and other purposes which include lighting, heating, production and distri-

Table 2 - Energy consumption in primary wood processing technologies ([10]) per volume of finished product (for soft broadleaves and conifers)

Primary wood processing technologies	Electrical energy	Thermal energy	Fuel
	kWh/m^3	GJ/m^3	l/m^3
Sawmill lumber *Natural drying* *Industrial drying*	20 25	- 1,5	4 4
Particle and fiber board production	20	2,0	3
Production of sliced veneer	56-85	10	-
Plywood board production	150	4,0	3

bution of compressed air powered machine maintenance. Fuel is mainly used as a vehicle fuel internal transport of a stock in final wood processing the consumption of electrical energy is more than 90%, mostly for electric motors of machines.

The creation of industrial scrap wood starts at sawmills. Log the input material which can be downloaded above corps, and the output is lumber. Similar products in the sawmill processing are present outsides and bark. If there is at the sawmill additional elementary part, or it's production of work pieces for final wood processing, as we scrap: scrap pieces, sawdust and any dust. It is believed that the amount of scrap processing sawmill in about 37% of the feedstock that is. Billet within the scope. Tropical comprise about 35% of the total number of timber companies, i.e. there are about 1225 sawmills and timber accounts for about 37.2% of exports of all products from forest wood. Serbia was in 2005. occupied the tenth position in Europe for the production of cut wood, according to the European Commission of the United Nations. Despite their small number, large sawmills have approximately 50% of installed capacity to produce sawn timber. However, level of utilization of their capacity is small due to financial problems incurred as a result of the privatization process, through which pass or have recently gone through all these companies. As for the capacity of sawmills, three mills have individual capacities of more than 15 000 m^3 of logs per year: Lika system-Belgrade sawmill and Simpo: Surdulica and Ćićevac. The greatest number of other mill has a capacity of 3 000 to 5000 m^3 of logs, and many mills in the villages and worked at times, usually during the warmer days, and produce from 100 to 500 m^3 sawn timber per year.

All mentioned technologies in Table 2 produce wood waste. It is believed that the amount of scrap processing sawmill in about 37% of the feedstock that is billet within the scope. In the production of particleboard and fiberboard scrap the estimates up to 45% of the feedstock. The production of veneer and plywood production waste is more than 40% ([7]) from raw material to be processed. In the final wood industry quantity of scrap wood in relation to raw materials is much higher because it comes barely 1 / 3 of sawn timber used. Energy values of some commercial fuels based on wood are given in Table 3.

Using table 2 and table 3 it can be concluded how much wood waste had to be used to obtain electrical energy necessary for the finished product m^3. The results were shown in Table 4. As we could see from Table 4 very low amounts of wood waste are necessary especially in primary wood industry. The amounts of wood waste rise up in final wood industry as it involves more technologies to obtain: particle or fiber boards, veneer or plywood.

Table 3 - Energy values of some commercial fuels based on wood and biomass ([11])

Type of fuel based on wood	Moisture content (%)	Energy value	
		kWh/m^3 compact wood	kWh/kg
Soft broadleaves for heating (wet bulb)	50	2100	2,1
Soft broadleaves for heating (semi-dried bulb, after 2 years)	18-25	2600	3,9
Conifers for heating (wet bulb)	60	1900	2,3
Conifers for heating (semi-dried bulb, after 2 years)	18-25	2200	4,0
Wood residues (after wood processing)	20-30	1900	3,7
Briquettes	7-10	3800	4,7
Pellets	7-10	3900	4,9

Having in mind that these wood processing technologies require a lot of heat, process steam or hot water, in addition to electricity, and at the other side they produce wood waste, so that could be potential users of CHP plant. Practically in a well-organized economy, with organized enterprises, only sawmill sites where there is a surplus of wood residue. It should be noted that these companies are composed of boilers for wood waste, so the plants for cogeneration of heat and electricity for them was interesting from the standpoint of cost savings and rei-nvestment in equipment. The mills are part of the re-mainder is used internally, but a significant amount of residue available for other needs, such as for example the production of pellets or gasification combined to produce electricity and heat.

According to the demonstration facility developed on our project with a capacity of gasification 200 kg/h waste which operates 24 hours, 300 working days of the year, the amount of scrap wood needed for such a plant would amount to1440t wood waste per year. Mentioned sawmill capacity over 15000m^3 ma-terials produced annually to more than: 4800t/year waste, taken account of: wood density of 800 kg / m^3 which corresponds shipping dry bins 10-15% humidity and the amount of scrap in sawmill processing of 40% compared to the input raw material. It is obvious that we planned scrap quantity to meet the needs of 2-3 demo plant mentioned power of 200kWe or one 500kWe power plant which would be more cost effective to make that case. The real price of manufactured chips amounted to 27EU / t, and considering the gasification capacity of 200kg / h waste and projected 200kW of power demo plant, we get the cost per kWh of electricity taking into account only the cost of procuring wood chips as fuel for the plant as:

Price (EU / kWh) = 27x0, 2:200 =
0.027 EU / kWh

Price kWh of electricity thus obtained is lower than about 30% of the energy obtained by using briquettes and pellets ([11]), and it is therefore recommended in areas with a permanent supply of wood chips.

Table 4 - The consumption of wood waste for obtaining electrical energy per volume of finished product (for soft broadleaves and conifers)

Primary wood processing technologies	Wood waste for electrical energy (dm^3 waste/m^3 of product)*	
	Soft broadleaves (wet bulb)	Conifers (wet bulb)
Sawmill lumber *Natural drying* *Industrial drying*	13,61 17,01	15,04 18,80
Particle and fiber board production	13,61	15,04
Production of sliced veneer	38,11-57,82	42,11- 63,91
Plywood board production	102,04	112,78

** The values are calculated on efficiency of 70%*

3. DESCRIPTION OF CHP PLANTS

An innovative process for combined heat and power production based on steam gasification is demonstrated [12]. Biomass is gasified in a dual fluidised bed reactor. The producer gas is cooled, cleaned and used in a gas engine. A detailed flow sheet is shown in Figure 1. Biomass wood chips from forestry and wood industry are used. The wood trunks are dried naturally by storage of about 1-2 years in the forest or artifical dried in wood industry. Then they are delivered to the CHP plant and chipped there. When the biomass is used, it has a water content of about 25-40%. The heat produced in the process is partly used inside, e.g. for air preheating, steam production, etc., and the rest is delivered to the district heating system. The net electricity produced is delivered to the grid. The feed in rate should be regulated by law and depends on the type of biomass used and on the size of the plant.

Biomass chips are transported from a daily hopper to a metering bin and fed into the fluidised bed reactor via screw feeders. The fluidised bed gasifier consists of two zones, a gasification zone and a comćbustion zone. The gasification zone is fluidised with steam which is generated by waste heat of the process, to produce a nitrogen free producer gas. The combustion zone is fluidised with air and delivers the heat for the gasification process via the circulating bed material. The producer gas is cooled and cleaned by a two stage cleaning system. A water cooled heat exchanger reduces the temperature from 850°C – 900°C to about 150°C – 180°C.

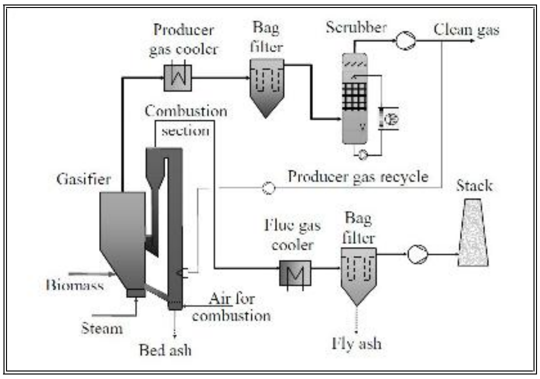

Figure 1 - Schema of the Biomass-CHP ([13])

The first stage of the cleaning system is a fabric filter to separate the particles and some of the tar from the producer gas. These particles are recycled to the combustion zone of the gasifier. In a second stage the gas is liberated from tar by a scrubber. Spent scrubber liquid saturated with tar and condensate is vaporized and fed for thermal disposal into the combustion zone of the gasifier. The scrubber is used to reduce the temperature of the clean producer gas to about 40 °C. The clean gas is finally fed into a gas engine to produce electricity and heat. If the gas engine is not in operation the whole amount of producer gas can be burned in a backup boiler to produce heat. The flue gas of the gas engine is catalytically oxidised to reduce the CO emissions. The sensible heat of the engine's flue gas is used to produce district heat. The flue gas from the combustion zone is used for preheating air, superheating steam as well as to deliver heat to the district heating grid. A gas filter separates the particles before the flue gas of the combustion zone is released via a stack to the environment.

The whole CHP plant is shown on Figure 2. At the left side of the plant is gasifier with combustion section, in the middle are bag filters, coolers and scrubber and at the right sight is gas turbine.

The Figure 3 shows the schematic of small-scale CHP plant based on Stirling engine. The biomass furnace must operate at a high temperature level, in order to achieve high electrical efficiency, but temperatures picks should be impeded in order to keep a risk of ash slagging and fouling low. In addition, high flue gas temperatures may considerably reduce the lifetime of the combustion chamber due to diffusion processes between chamotte and alkali metal which are accelerated at high temperatures and can cause damages in the chamotte bricks.

Figure 2 - The whole module of the biomass-fired CHP plant ([14])

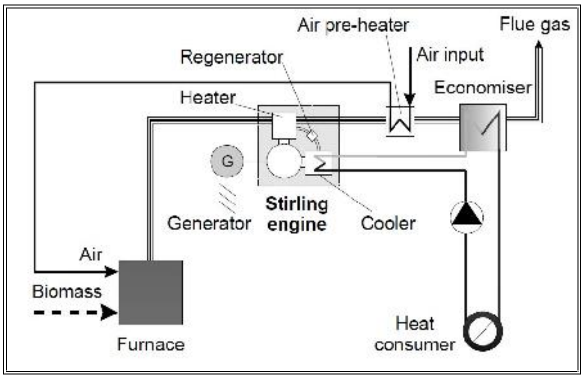

Figure 3 - Schematic of a Stirling CHP plant ([15])

The combustion is realized in two stage design (primary and secondary combustion chamber are geometrically separated) in order to achieve low NOx emissions. The CHP plant developed is designed for furnace temperatures of approximately 1300^{0}C. The Stirling heater designed for this high flue gas temperature and is directly connected to the surface. The surface temperature of a heater is typically between 750^{0}C and 790^{0}C. In order to obtain high temperatures in combustion chamber and high electric plant efficiency the combustion air is preheated to 450-550^{0}C in an air pre-heater situated downstream the Stirling heater. Then the flue gas is cooled in an economizer to approx. 120-150^{0}C.

Many small scale fired plants on the similar principals like Stirling engine are given in literature: [16], [17] and [18]. The paper [19] concerns numerical prediction of relationship between operating speed and shaft power output of Stirling engine and the paper [20] is aimed at development of a numerical model for a Stirling engine with rhombic-drive mechanism. Six systems comprising different technologies have been analysed in literature [16]. Also, a thermo-economic study has a great interest for CHP systems ([21], [22]). In addition to that, some countries like Portugal ([23]) and China ([24]) have they own strategy of utilization biomass in energy purpose in order to achive high efficiency.

4. CONCLUSION

Since the thermo chemical gasification process of converting carbon-rich fuels into carbon monoxide and hydrogen, the wood waste would be one of the most suitable fuels for such purposes. The amount of accumulated carbon in wood is about 50% of the weight of dry substance, while in some agricultural crops e.g. Corn is significantly lower around 44.6%. It should also be noted that the wood waste by-product of forest harvesting, primary and final wood processing, and for remaining in the forest is not necessary to restore the land as is the case with agricultural crops.

It can be concluded that the raw materials for biomass gasification most certainly be required where the largest volumes of wood waste and that is precisely cut wood in the forest and large sawmills, the annual capacity of over 15000m^3. The price kWh of electricity obtained in that way is very low in compare with other types of fuels. Other wood processing enterprises, especially the small, wood residues are available as well, but they are mostly used for their energy needs, and what remains is insufficient for continuous operation of a CHP plant.

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REFERENCES

[1] Ministry of Mines and Energy of the Republic of Serbia, Development Strategy of Serbia until 2015.th, Belgrade, 2005, pp. 50.

[2] Action plan for biomass from 2010th to 2012th, Official Gazette of the Republic of Serbia, 56, 2010, pp. 5-176.

[3] Banković S., Medarević M., Pantelić D. and Petrović N., National Forest Inventory of the Republic of Serbia, Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia, Belgrade, 2009.

[4] Statistical Office of Serbia, 2010, Municipalities in Serbia, ISSN 1450-9075, pp. 210-214.

[5] Statistical Office of Serbia, 2010: Announcements, vol. LX, no. 135, ISSN 0353-9555, pp. 1-4.

[6] Statistical Office of Serbia, 2011: Statistical Yearbook for 2010.year, ISSN 0354-4206, pp. 224-233.

[7] Danon G., Dedić A., Evaluation of waste wood from forestry and industrial processing, in: Improving the technology of wood properties in correlation with the chemical constituents of wood, Faculty of Forestry, Belgrade, 1995, pp. 115-130.

[8] Nikolić S., Forest biomass as a significant component in solving the global energy crisis, in: Combustion of biomass for energy purposes, JDT, Scientific Book, Belgrade, 1992, pp. 45-59.

[9] nergy Saving Group, Feasibility study of the use of wood waste in Serbia, Study Company for Energy Efficiency "Energy Saving Group", Belgrade, 2006, pp. 43-48.

[10] Organization for Economic Co-operation and development (OECD), www.oecd.org

[11] Glavonjić B., Guide for wood biomass: species, characteristics and convenient for heating, Ministry for agricultural and forestry Republic of Serbia, Belgrade, 2008.

[12] Hofbauer H. et al., Six Years Experience with the FICFB-Gasification process, 12th European Conference and Technology Exhibition on Biomass for Energy, Industry and Climate Protection, Amsterdam, 2002.

[13] Rauch R et al, Steam gasification of biomass at chp plant guessing – status of the demonstration plant, Institute of Chemical Engineering, Vienna, Austria, 2007, p. 4.

[14] Leilei D., Hao L., Saffa R., Development of small-scale and micro-scale biomass-fuelled CHP systems – A literature review, Applied Thermal Engineering, 29, 2009, pp. 2119–2126.

[15] Marintsch G. et al, Development of a hot gas heat exchanger and a cleaning system for a 35kWe hermetic four cylinder Stirling engine for solid biomass fuels, Austrian Bioenergy Centre GmbH, Austria, p.12.

[16] Wood S.R., Rowley P.N., A techno-economic analysis of small-scale, biomass-fuelled combined heat and power for community housing, Biomass and Bioenergy, 35(9), 2011, pp. 3849-3858

[17] L., May B., Herr A., O'Connell D., Biomass assessment and small scale biomass fired electricity generation in the Green Triangle, Australia, Biomass and Bioenergy, 35(7), 2011, pp. 2589-2599.

[18] Puig-Arnavat M., Bruno J.C, Coronas A., Review and analysis of biomass gasification models, Renewable and Sustainable Energy Reviews, 14 (9), 2010, pp. 2841-2851.

[19] H.C., Yang H.S., Analytical model for predicting the effect of operating speed on shaft power output of Stirling engines, Energy, 36, 2011, pp. 5899-5908.

[20] Chin-Hsiang Cheng Ying-Ju Yu, Numerical model for predicting thermodynamic cycle and thermal efficiency of a beta-type Stirling engine with rhombic-drive mechanism, Renewable Energy, 35 (11), 2010, pp. 2590-2601.

[21] Brown D., Gassner M., Fuchino T., Marechal F.,Thermo-economic analysis for the optimal conceptual design of biomass gasification energy conversion systems, Applied Thermal Engineering, 29, 2009, pp. 2137–2152.

[22] Caputo A.C., Palumbo M., Pelagagge P.M., Scacchia F., Economics of biomass energy utilization in combustion and gasification plants: effects of logistic variables. Biomass Bioenergy, **28,** 2005, pp. 35–51.

[23] Fernandes U, Costa M., Potential of biomass residues for energy production and utilization in a region of Portugal, Biomass Bioenergy, 34, 2011, pp. 661-666.

[24] Zhoua X, Wang F, Huc H, Yang L, Guod P, Xia B., Assessment of sustainable biomass resource for energy use in China, Biomass Bioenergy 35, 2011, pp. 1-11.

SAŽETAK

OTPACI OD DRVNE BIOMASE KAO NOVI MATERIJALI ZA GASIFIKACIJU U CHP POSTROJENJIMA

Kako u Srbiji ne postoje zvanične procene raspoloživosti biomase prema međunarodno priznatoj metodologiji, ovaj rad predstavlja pokušaj da se na bazi prikupljenih podataka iz šumske seče i prerade drveta te procene izvrše. U radu se ukazuje na oblasti u Srbiji sa najvećom sečom i drvnim otpatkom, kao i na vrste drvne industrije koje ga proizvode. U industriji prerade drveta razmatrana je potrošnja energije u primarnim tehnologijama. Izračunata je količina drvnog otpatka neophodna da dobijanje električne energije za potrebe primarne prerade. Izvršena je procena količine otpatka i cene 1kWh za rad demonstracionog CHP postrojenja snage 200kWe, za kombinovanu proizvodnju toplotne i električne energije, koje je u izgradnji u okviru projekta TR-33049, koje finansira Ministarstvo prosvete i nauke Republike Srbije. Objašnjena su dva principa rada CHP postrojenja, sa i bez Stirlingove mašine, kao moguća rešenja za pomenuto demo postrojenje.

Ključne reči: *drvni otpadak, šumska seča, prerada drveta, CHP postrojenje.*