

A STUDY ON CALORIFIC ENERGY VALUES OF BIOMASS RESIDUE PELLETS FOR HEATING PURPOSES

Ioannis Gravalos¹, Dimitrios Kateris¹, Panagiotis Xyradakis¹, Theodoros Gialamas¹,
Spiros Loutridis², Augoustinos Augousti¹, Anastasios Georgiades¹, Zisis Tsiropoulos¹

¹Technological Educational Institute of Larissa, Faculty of Agricultural Technology,
Department of Biosystems Engineering,
41110 Larissa, Greece
e-mail: gravalos@teilar.gr

²Technological Educational Institute of Larissa, Faculty of Technological Applications,
Department of Electrical Engineering,
41110 Larissa, Greece
e-mail: loutridi@teilar.gr

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Abstract: *Combustion is the most developed and most frequently applied process used for solid biomass fuels because of its low cost and high reliability. The interest in using biomass residue pellets for heating purposes is increasing. Clean and dry residue pellets are an ideal fuel for combustion in small-scale installations. This article presents an experimental study on calorific energy values of biomass residue pellets for heating purposes. The fuel samples used, were biomass residues of agricultural (cotton, cardoon, etc.) and forest (pine, fir, beech, etc.) wastes. This research is part of a continuing program to obtain precise thermal analysis data from different kinds of agricultural and forest by-products. A bomb calorimeter (Model C5000, IKA®-Werke) was used to determine the calorific values by the standard ASTM method. The experimental results obtained are encouraging and show that these materials can be used as alternative fuels.*

1. Introduction

The small-scale bioenergy systems are expected to proceed at a faster pace due to the lower investment level. Today bioenergy is the second largest commercial renewable energy source. Current total biomass use for energy is in the range of 12% of world primary energy consumption, mainly in traditional applications for cooking and heating in developing countries. Also in some industrial countries, the interest in using wood for heating purposes is increasing. Domestic wood-burning appliances include fireplaces, pellet stoves and burners, central heating furnaces and boilers for wood logs and wood pellets (IEA Bioenergy, 1998; Janssen et al., 2002).

Biomass can be converted into energy (heat or electricity) or energy carriers (charcoal, oil, or gas) using both thermochemical and biochemical conversion technologies. Combustion is the most developed and most frequently applied process used for solid biomass fuels because of its low costs and high reliability. During combustion, the biomass first loses its moisture at temperatures up to 100°C, using heat from other particles that release their heat value. As the dried particle heats up, volatile gases containing hydrocarbons, CO, CH₄ and other gaseous components are released. In a combustion process, these gases contribute about 70% of the heating value of the biomass. Finally, char oxidises and ash remains (IEA Bioenergy, 2002).

Among the uses of biomass the wood pellet is also included. New techniques are available to turn wood and crop residues into standardised pellets that are environmentally safe and easy to handle (Oberberger & Thek, 2004; Petersen Raymer, 2006; Ravindranath et al., 2006). In the production of fuel pellets and

briquettes, the feedstock has to be mill, pulp and steam before being transformed into a denser product. It is a pure powder form refined wood or crop residues that has been put under high pressure so as to be formed into small cylinders of various sizes. Given the pressure, in the phase of its production, and its reduced humidity, the energetic density of the wood pellet is approximately double than that of the wood. Size reduction is an important treatment of biomass for energy conversion. Particle size reduction increases the total surface area, pore size of the material and the number of contact points for inter-particle bonding in the compaction process (Drzymala, 1993). Owing to the binding capacity of lignin, a natural substance found in firewood, there is no need to add any type of chemical additives. Cellulose crystallinity reduction is required for bioconversion of lignocellulosic feedstock (Schell & Harwood, 1994). A number of properties are commonly known to affect the success of pelleting, including: heating value, moisture content of the material, density of the material, particle size of the material, fiber strength of the material, lubricating characteristics of the material, and natural binders. Ebeling & Jenkins (1985) determined the heating value and performed fuel proximate analysis for 62 kinds of biomass. Samson et al. (2000) were studied combustion characteristics of pelleted switchgrass. They compared the combustion quality of switchgrass pellets with coal and natural gas. They reported that carbon dioxide emission from switchgrass pellet was very much lower than the fossil fuel.

Utilization of wood and crop residues as an energy source will serve to reduce consumption of fossil fuels, thereby reducing the emission of greenhouse gases to the environment. Ideal in providing fuel for heating devices, the wood pellet it is pure, non pollutant, and neutral in carbon dioxide (CO₂) emissions. In other words, it doesn't contribute to the destabilization of the ambient, as whatever (CO₂) emissions occur from its combustion they are counterbalanced by equivalent amounts of (CO₂) that have been absorbed from the plant during its life, process of photosynthesis, it burns completely, without producing smoke, leaving minimum residue of ash, always less than 1%, which can be used as a precious fertilizer for the garden too.

The excellent handling properties of pellets mean that the fuel is gaining rapid popularity in Sweden, Denmark, and Austria. In other countries, the interest in pellet burners is starting to increase. The wood pellet can be stocked in little space as far as its energetic density is concerned which is approximately double that of wood. Thanks to its compactness it can be transported more easily and economically. In fact, the cost in € per kW of the wood pellet is much lower than that of diesel oil. Pellet burners are of special interest since they can replace oil-fired boiler. Boilers work on the principle of natural draught. Automatic pellet combustion is a recent innovation in space heating. Technology for biomass use in domestic heating is simple and cheap. The wood pellet is a pure combustible material and its minimum residue of ash can be removed and disposed of easily. The wood pellet is fed in air fun stoves, alternative energy fireplaces and wood pellet boilers and stoves for centralised heating. The use of the pellet in modern heating systems, as it has been mentioned above, with the automatic combustible feeding and the supply of electronic controlled air, it is in a position to render 90 % of the contained energy in firewood used for heating. There are many advantages of densified fuel pellets: a) The fuel is free flowing, which facilitates material handling and rate of flow control, b) The energy density is increased, easing storage and transportation, c) Higher uniformity and stability permits more efficient combustion control, d) There are less particulates produced during the combustion process, e) The capital cost for storage is reduced, and f) Risk of fire is reduced considerably.

In the present study, we focussed on the biomass fuel quality objective, as the residual biomass can be transformed into a fuel useful as an alternative energy source. The thermal analysis of different species is based on the calculation of their calorific values through experiments carried out in a static bomb calorimeter. The rest of the parameters studied were: bulk density, moisture and ash content.

2. Materials and Methods

The fuel samples were used from biomass residues of agricultural crops (Cotton, Cardoon), forages (Typha Angustifolia, Phragmites Australis), and forest (Poplar, Pine, Fir, Beech) wastes. Cotton is primarily an agricultural crop, but it can also be found growing wild. There are more than 30 species of cotton plants, but only few are used to supply the world market for cotton. The leaves are heart-shaped,

lobed, and coarse veined, somewhat resembling a maple leaf. The plant has many branches with one main central stem. Overall, the plant is cone or pyramid-shaped. Vegetative branches grow from the bottom of the plant and produce very little cotton. Fruiting branches on the main stem of the plant produce most of the cotton. The Cardoon (*Cynara cardunculus*) is a plant with very good adaptability and high output, the final height of plant reaches the 2.6 m. The production of dry mass reaches 17÷33 t/ha. It is a naturally occurring variant of the same species as the globe artichoke, and has many cultivated varieties. It is native to the Mediterranean, where it was domesticated in ancient times. Cardoon has attracted recent attention as a possible source of biodiesel. The oil, extracted from the seeds of the cardoon, and called artichoke oil, is similar to safflower and sunflower oil in composition and use. *Typha Angustifolia* plants grow along lake margins and in marshes, often in dense colonies. *Typha Angustifolia* leaves are alternate and mostly basal to a simple, jointless stem that eventually bears the flowering spikes. The rhizomes spread horizontally beneath the surface of muddy ground to start new upright growth. *Phragmites Australis*, the common reed, is a large perennial grass found in wetlands throughout temperate and tropical regions of the world. It is sometimes regarded as the sole species of the genus *Phragmites*, though some botanists divide *Phragmites Australis* into three or four species. The erect stems grow to 2÷6 m tall, with the tallest plants growing in areas with hot summers and fertile growing conditions. The leaves are long for a grass, 20÷50 cm and 2÷3 cm broad. The flowers are produced in late summer in a dense, dark purple panicle, about 20÷50 cm long. Later the numerous long, narrow, sharp pointed spikelets appear greyer due to the growth of long, silky hairs. Figure 1 shows the crop and forage plants that were used in this study. Agricultural crops as Cotton and Cardoon were obtained from a farm near Larissa, Thessalia, Greece. Forages as *Phragmites Australis* and *Typha Angustifolia* were taken from the area of Prespes Lakes, Florina, Macedonia, Greece. They were collected in the form of whole plant with moisture content of 5.0% ÷ 12% (wb). Forest residues (Poplar, Pine, Fir, Beech) were obtained from the local furniture industry.



Figure 1: a) Cotton (Stoneville 474), b) Cardoon, c) *Typha Angustifolia* and d) *Phragmites Australis*

Hammer mill was used for grinding of biomass. The mill consisted of 45 swinging hammers, attached to a shaft powered by a 1.5 kW electric motor. The shaft rotated at a speed of 3600 rpm. The hammer mill reduces particle size of solid materials by shear and impact action. After grinding, samples of grind were placed successively in a stack of sieves arranged from the largest to the smallest opening. The sieve series selected were based on the range of particles in the sample. The set of sieves was placed on the sieve shaker. The duration of sieving was 20 min and was previously determined through trials to be optimal. Sieve analysis was repeated three times for each sample. The geometric mean diameter of the sample and geometric standard deviation of particle diameter were calculated according to ASAE standard S319.3 (ASAE standard S319.3, 2001).

An oxygen bomb calorimeter (Model C5000 Adiabatic Calorimeter, IKA®-Werke, Staufen, Germany) was used to determine the calorific value of the grind. The bomb calorimeter and the metal container surrounding it form the kernel of the calorimetric system, which is placed in a thermally insulated jacket. A primary temperature transducer, placed inside the unit, records the change in the system temperature due to the combustion of the fuel in the bomb. The calorimeter also contains a cooling system. The bomb calorimeter enables a rapid analysis to be carried out, the basic time of which cannot be reduced, since it

is related to the fuel combustion process itself. Calorific value can be defined as the amount of energy released by a mass unit of combustible mass. Two calorific values must be considered: The gross calorific value (GCV) is the amount of energy released by complete combustion of a mass unit of sample, at constant volume in an oxygen atmosphere, assuming that the final products of combustion consist of O₂, CO₂, SO₂, and N₂ in gas phase together with water, that the sample contains and that generated from the combined hydrogen, in a liquid form. Experimentally determination of the gross calorific value in the laboratory conditions: combustion of the sample under specific conditions in a bomb calorimeter according to ASTM D2015-96 standard (ASTM D2015-96 standard, 1998). The net calorific value (NCV) can be calculated from GCV assuming that water in the products remains in the form of vapor. Knowing NCV is very helpful to evaluate crops, forages and forest resources from the energetic point of view. Both calorific values are related through the equation:

$$\text{NCV}=\text{GCV}-(\text{H}_2\text{O}\cdot 24.41) \quad (1)$$

where NCV corresponds to the net calorific value of the dry sample, GCV is the gross calorific value of the dry sample, and H₂O is the percentage of the total water. The heat of vaporization of water is taken as 24.41 kJ kg⁻¹ (Núñez-Regueira et al., 2001; IKA[®]-WERKE C 5000 control, 2004; Núñez-Regueira et al., 2005).

The ash content of the samples was determined based on ASTM standard D 3174-97 for coal and coke (ASTM Standard D 3174-97, 1998). One gram of grind passing through sieve number 60 was placed in a porcelain crucible. The crucible was placed inside a muffle furnace. The temperature of the furnace was increased to between 450°C ÷ 500°C for the first hour and again increased to between 700°C ÷ 750°C for the second hour. For two hours, the same temperature was maintained. After four hours from the start of furnace, the crucibles were covered, removed from the furnace and cooled to room temperature in a glass desiccator. The mass retained in the crucible was expressed as percent ash content. The ash content measurements were repeated five times.

Moisture content of a sample was determined according to ASAE Standard S358.2 for forages (ASAE Standard S358.2, 2001). A sample of 25 g was oven dried for 24 h at 105 ± 3°C. The moisture content was reported in percent wet basis. Moisture content and bulk density after grinding are important properties for downstream processing. The moisture content of the grinds was determined as per the procedure given in ASTM Standard D 3173-87 for coal and coke (ASTM Standard D 3173-87, 1998). One gram of pulverized sample passing through sieve number 60 was taken and oven dried for one hour at 104÷110°C. The moisture content of the grind was determined by weighing and expressed in percent wet basis. Bulk density of the samples was measured using the grain bulk density apparatus. The grinds were placed on the funnel and continuously dropped at the center of a 0,5 l steel cup. The cup was levelled gently by a rubber-coated steel rod and weighed. Mass per unit volume gave the bulk density of the grinds in kg m⁻³. The average bulk density was calculated from three measurement series per sample.

3. Results and Discussion

The results of calorific energy analysis in Cotton, Cardoon, Typha Angustifolia, and Phragmites Australis could be helpful to turn crop and forage residues into standardised pellets. Figures 2, 3 and 4 presents calorific energy (J/g) distribution in different organs of the above mentioned plants: root, main stem, terminal, vegetative branches, fruit branches, leaves, bolls or flowers. There were significant differences in calorific energy in the different plant organs. For the root and main stem, calorific energy varied between 16.943–17.733 J/g. This result suggests that root and main stem had the same calorific energy values for all type of plants. The differences between main stem and branches were very little significant. Specifically for Cotton plants, the vegetative branches measured 17.070–17.598 J/g, while for the fruiting branches calorific values varied between 17.065–17.548 J/g. Great interest is the relatively low amount of energy observed in the cotton leaves (15.955 J/g). Cotton and Cardoon seeds or Typha Angustifolia and Phragmites Australis flowers have higher energy values compared to other plant organs. This higher energy value of seeds (22.750–23.078 J/g) and flowers (17.716–18.555 J/g) might be due to higher lipid

content which reflects optimal environmental condition for the plants. The energy stored in this part is used to support growth and reproduction of plants in the following season.

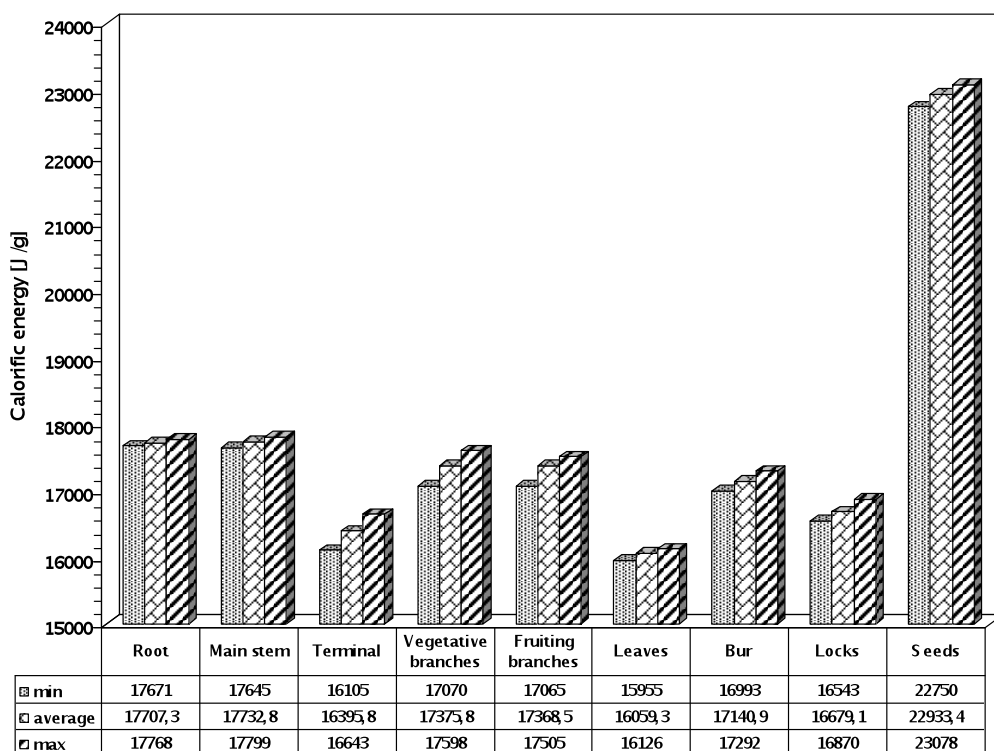


Figure 2. Calorific energy distribution in Cotton plant organs

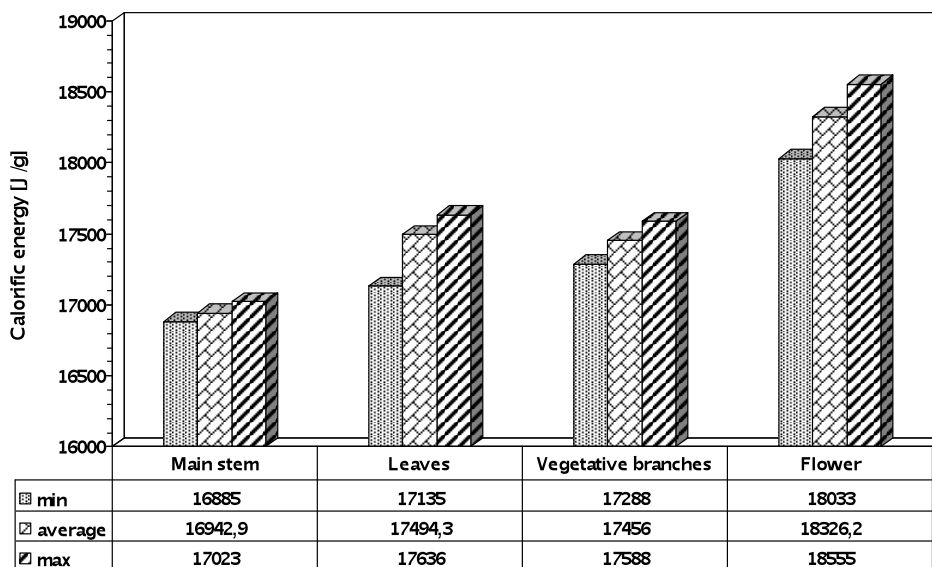


Figure 3. Calorific energy distribution in Phragmites Australis plant organs

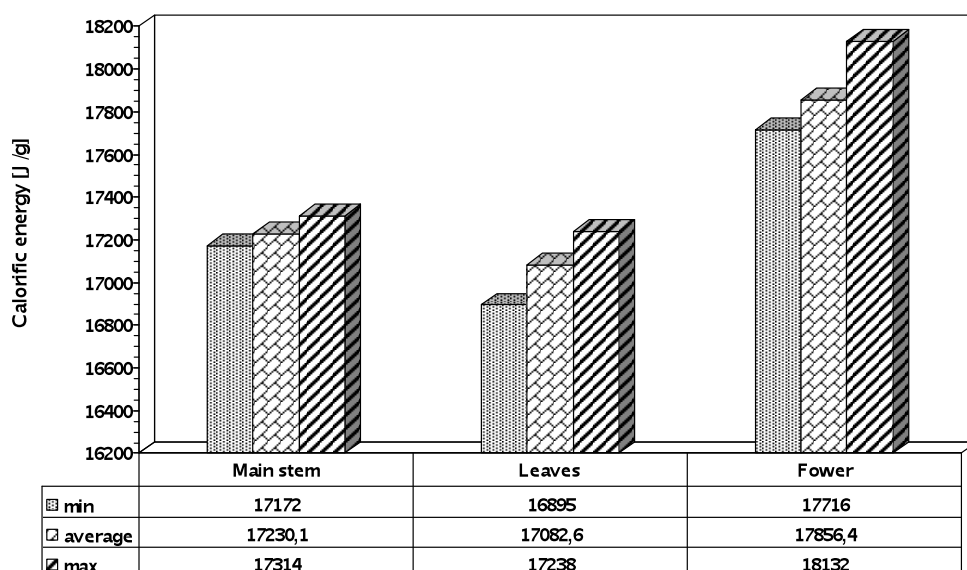


Figure 4. Calorific energy distribution in *Typha Angustifolia* plant organs

After grinding of agricultural crops and forages, the grinds from the hammer mill screen size of 3.2 mm were distributed in large range and produced particles with geometric mean particle diameter of 0.67 and 0.52 mm for forages and agricultural crops, respectively. According to Mani et al. (2003; 2004), wider particle size distribution is suitable for compaction (pelleting or briquetting) process. During compaction, smaller particles rearrange and fill in the void space of larger particles producing denser and durable compacts. Gross and net calorific values, ash content, moisture content and bulk density of biomass grind from different crops and forages are given in Table 1. Grinds from Cotton produced higher gross and net calorific value of 17.731 kJ/g and 18.754 kJ/g, respectively. The lowest calorific values gave the grind from Cardoon (GCV=14.986 kJ/g; NCV=16.028 kJ/g). Similar results were observed for *Typha Angustifolia*, and *Phragmites Australis* grinds. The ash content of Cotton grinds was lower than that of Cardoon, *Typha Angustifolia*, and *Phragmites Australis* grinds. According to Ebeling and Jenkins (1985), the higher ash percentage in these materials is one of the reasons, which influences the heating values. They obtained similar results for wheat and barley straws. Bulk density of agricultural crops grind was higher than that the forages. Cotton grind had the highest bulk density of 167 kg/m³. Moisture content of crop and forage grinds was observed similar. *Typha Angustifolia* grid had slightly lower moisture content than that the other grinds.

Table 1: Results analyses from biomass residues of agricultural crops and forages

Parameters	Units	Biomass residues of agricultural crops and forages			
		Cotton	Cardoon	Phragmites australis	<i>Typha angustifolia</i>
Bulk density	kg/m ³	167	152	107	112
Moisture content	%	4.40	4.27	4.06	3.43
Ash content	%	4.56	9.42	8.21	7.72
Gross calorific value (GCV)	kJ/g	17.731	14.986	16.943	17.230
Net calorific value (NCV)	kJ/g	18.754	16.028	17.933	18.117

Table 2 lists the gross and net calorific values, ash content, moisture content and bulk density of biomass grind from different residues of forest (Poplar, Pine, Fir, Beech) obtained from the local furniture industry. From the results, it can be said that the forest grinds had higher heating values from agricultural crop and forage grinds. The heating values of Pine and mixture of Pine with Fir grinds were slightly higher than that of Poplar and Beech grinds. Pine grind had the highest NCV of 20.082 kJ/g. From these heating values, it can be said that the differences between GCV and NCV are significant. This might be due to the high moisture content that absorbs forest grinds. Poplar and Pine grind determined 24.18 % and 24.59% moisture, respectively. Bulk density of forest residue grinds was significant higher than that of crop and forage grinds. Low ash content is also crucial to the combustion process, just as very strict ash deposition limits in some countries have adopted. Forest residue grinds had significant lower values of ash deposition in comparison with the forage grinds.

Table 2: Results analyses from biomass residues of forest

Parameters	Units	Biomass residues of forest			
		Poplar	Beech	Pine	Fir+Pine (50%+50%)
Bulk density	kg/m ³	626	635	654	652
Moisture content	%	24.18	15.83	24.59	22.9
Ash content	%	0.81	0.85	0.68	0.73
Gross calorific value (GCV)	kJ/g	14.432	16.202	14.589	15.684
Net calorific value (NCV)	kJ/g	19.371	19.225	20.082	20.042

Eight different types of pellets were used in this work, the properties being presented in Table 3. The first four pellets were made by agricultural crop and forage grids. The other four were made by forest (wood) residues. All these pellets have the recommended diameter. It can be seen that all pellets from forest residues have a similar high calorific values and ash content. Pellets from agricultural crop and forage residues show lower calorific values and higher ash content.

Table 3: Results analyses of pellets from agricultural crop, forage, and forest residues

Pellets	Diameter	Length	Net calorific value	Ash content
	mm	mm	kJ/g	%
Cotton	6.20	21.75	16.988	3.49
Cardoon	6.20	21.76	14.590	8.33
Phragmites australis	6.20	21.76	16.471	7.46
Typha angustifolia	6.20	21.75	16.584	6.78
Poplar	6.20	21.75	17.814	0.79
Beech	6.20	21.75	18.050	0.77
Pine	6.20	21.75	18.754	0.64
Fir+Pine (50%+50%)	6.20	21.75	18.367	0.71

4. Conclusion

The main conclusions that may be drawn from the present study on the calorific energy values of biomass residue pellets for heating purposes are listed below:

- Quantitative calorific energy analysis in crop and forage plants showed that significant differences exist in calorific energy distribution on different plant organs. Root and main stem had the same calorific energy values. The lowest mean calorific energy value in all plant organs was observed at Cotton leaves. Also seeds and flowers have the highest energy values due to higher lipid content.
- After grinding of agricultural crops and forages, the higher gross and net calorific value produced by grinds from Cotton and the lowest calorific values gave the grind from Cardoon. Also Cotton grinds gave the lowest ash content. Bulk density of agricultural crops grind was higher than that of the forages. Moisture content of crop and forage grinds was observed to be similar.
- Pine and mixture of Pine with Fir grinds produced slightly higher net calorific values than that of Poplar and Beech grinds.
- Forest residue grinds in comparison with crop and forage grinds demonstrated significant higher bulk density and significant lower values of ash deposition.
- Pellets from forest residues show higher calorific values and lower ash content in comparison with pellets from agricultural crop and forage residues.

The experiments have verified that the residual biomass can be adapted to a wide variety of solid fuels.

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