# BIOMASS PROPERTIES AND GASIFICATION BEHAVIOR OF 7-YEAR-OLD SIBERIAN ELM[1]

*W. A. Geyer and R. M. Argent*
Department of Forestry

and

*W. P. Walawender*
Department of Chemical Engineering, Kansas State University
Manhattan, KS 66506

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ABSTRACT

Studies were conducted to establish baseline information for use in characterizing Siberian elm as energy or fiber feedstock. Biomass properties were determined. Calorific value (4,698 cal/g) and specific gravity (0.55) of Siberian elm are similar to those of soft elms, and its fiber length is relatively short (1.00 mm). Ash content was 1.65%. Gasification produces a medium energy gas ($3 \times 10^6$ cal/m$^3$) with yield varying from 0.17 to 0.96 m$^3$/kg over a gasification temperature range of 600 to 700 C. Ovendry yields were 9.8 t/ha annually at 700 trees/ha.

*Key words:* Siberian elm, *Ulmus pumila,* gasification, wood energy, specific gravity, calorific value, fiber length, biomass yield.

## INTRODUCTION

Woody biomass is an appealing energy source, and its use in the United States has increased dramatically in the last few decades. It has been projected that 8 to 10% of our industrial and residential heating requirements could be supplied by wood by 1990 (Hewett and Glidden 1982; Zerbe 1981). Much of the timber cut in the Plains states is used for fuelwood. In Kansas, it has been estimated that three-fourths of the annual cut is for fuelwood (Raile and Spencer 1984). Forest plantations of rapidly growing hardwoods, managed intensively for biomass production, could contribute significantly to future alternative energy supplies.

Fuelwood shortages are a national and global problem (Clarke 1985). Numerous tree species should be evaluated to determine their potential to overcome this shortage. Siberian elm (*Ulmus pumila* L.) is one species that appears promising because of its adaptability to harsh climatic conditions, apparent rapid rate of growth, and tolerance to varied site conditions in the Great Plains states (Johnson 1966). Its Asian origin suggests that this species could have wide adaptability and potential importance as a fuelwood in savannah regions worldwide.

Although Siberian elm is a potential tree species for energy production and perhaps other technological uses, many basic properties of this species have not been characterized, thus limiting comparison to other woody plants. The objective of this report is to establish baseline information for characterizing young Siberian elm as an energy or fiber feedstock and to provide limited empirical yield data on upland sites in the Central Plains.

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## MATERIALS AND METHODS

### *Planting site and measurements*

This study was conducted in eastern Kansas on an upland site, which had been in native pasture grasses for 15 years. The soil was classified in the Morril and/or Pawnee series (fine-loam, mixed or fine montmorillonitic, mesic, Typic Argiudolls) and consists of 30 cm of silt loam soils underlain by clay loam on 5% slopes. Numerous broadleaf tree species were planted to determine plant-density yield variations. A Nelder-wheel (Namkoong 1965) consisting of 210 trees per species, replicated twice, was used to provide five planting densities ranging from 1,400 to 7,000 trees per hectare with two border rings. An additional 0.5-hectare plot planted to Siberian elm at 1.2 × 2.4 m (3,470 trees/ha) was established for harvesting studies.

Cultivation was used to control weeds during the first and second growing seasons in the "wheel" density trials, whereas a Casoron/cultivation combination was used in the larger plot. No subsequent weed control practices were applied other than annual mowing for fire prevention reasons. Fourth-year growth results (Geyer and Naughton 1980), production, and harvesting costs (Naughton 1985) have been previously published for these plantings.

Nondestructive annual height and diameter measurements were used with individual tree weight curves (dormant) to determine dry weight area yields. These curves have been developed from destructive sampling of 49 trees at similar spacings, giving the following equation: $\log_{10}W = 1.061 + 0.932 \log_{10}D^2H$, where W is OVD tree weight (kg), D is base diameter (cm), and H is total height (m). Individual tree weights, incorporating survival at 7 years and planting density were used to calculate yield.

### *Sampling*

Ten sample trees were collected for characterization from randomly selected tree bundles (one tree per bundle) during the 1984–1985 dormant season from a recently harvested 7-year-old, short-rotation "energy plantation" growing adjacent to the Nelder-wheel growth plots. Also disks were taken from 15 additional trees for determining specific gravity. Sample trees were chipped using a MORBARK EEGER BEEVER chipper and were thoroughly mixed. Twenty random samples (about 0.5 kg) were taken from the chip pile for wood characterization. The remainder of the chips were ground in a hammermill to pass through a 0.6-cm screen. The ground material then was separated by sieves to collect the <28 to >50 mesh fraction (i.e., the material that passed a 28-mesh screen but was retained on a 50-mesh screen). The separated fraction was used for steam gasification studies in a fluidized bed reactor. Fibrous materials (less than 1%) that would bridge in the gasifier feed hopper were removed and discarded.

### *Calorimetry*

The calorific value was determined for ground, oven-dried, whole tree chips, according to ASTM STANDARD D 2015-77 (1981a). The material used for the evaluation was ground to pass through a 20-mesh screen to achieve complete combustion and good pellet cohesion (Neenan and Steinbeck 1979). Eighty samples, each consisting of approximately 1 g of milled material, were pressed into pellets and combusted in a Parr 1341 adiabatic calorimeter. Correction factors for the formation of acids were not included in the gross heat of combustion calculations (Murphey and Cutter 1974; Barnes and Sinclair 1984). However, calorific values were corrected for moisture regained during storage.

### *Specific gravity*

Disks of 5-cm thickness were taken from 15 additional trees at base, dbh, and middle branch levels for analysis. The specific gravity was determined on the basis of oven-dry weight per green volume of the individual disk segment. Green volumes were obtained by soaking disk segments for 10 days in water until constant volume was achieved. Excess moisture was removed from the surface of the sample with a damp cloth, and each sample's water displacement (volume) was measured. They then were oven-dried to constant weight (3 to 4 days) at 104 C and weighed to determine the dry sample weight. Also, 100 chips were chosen randomly for individual chip determinations.

### *Ash content*

Eighty samples of oven-dried, ground, whole-tree chip particles were ashed in a muffle furnace. The ash content was determined following the ashing procedure described in ASTM STANDARD D 1102-56 (1981b).

### *Fiber length*

Fiber length was determined using a method similar to that of Tsoumis (1968). Matchstick-size slivers taken from chips were placed in a solution of equal parts glacial acetic acid and hydrogen peroxide (30% volume) and were heated in an oven at 60 C for 48 hours. Fibers then were separated, placed on slides, and projected onto a calibrated bullseye ring using a Mark VII micro-projector. Five fibers on each of 20 slides were measured and recorded.

### *Gasification*

Gasification studies were conducted in a 10-cm I.D. fluidized bed reactor over a temperature range of 600 to 700 C. The reactor and its operating procedure have been described in detail by Neogi (1984). The reactor was operated at atmospheric pressure with steam as the sole fluidizing gas. The steam-to-wood mass ratio was maintained at $10.80 \pm 0.85$ for all experiments. Several gasification characteristics, including the dry product gas composition, heating value, volumetric gas yield, and mass yield of gas, were determined as functions of the gasifier operating temperature. The conversion of wood carbon to gas and the percentage of the wood energy content recovered as gas also were evaluated. Regression analyses, using a SAS package, were conducted to find the best fitting polynomial relationships between each of the individual gasification characteristics and temperature. A total of 14 data points (three groups of similar temperatures) were used for the regression analysis of each gasification characteristic.

## RESULTS AND DISCUSSION

### *Wood properties*

All of the wood properties determined are summarized in Table 1. The average calorific value of Siberian elm whole-tree chips was 4,698 calories per gram. This

TABLE 1. *Wood properties of 7-year-old Siberian elm.*

| Property | Mean | Minimum | Maximum | Std. dev. | Sample size |
|---|---|---|---|---|---|
| Calorific value (cal/g) | 4,698 | 4,526 | 4,847 | 62 | 80 |
| Ash content (% ash) | 1.66 | 0.61 | 2.92 | 0.37 | 80 |
| Fiber length (mm) | 1.00 | 0.68 | 1.50 | 0.16 | 100 |
| Specific gravity (gr. vol.) | | | | | |
| Wood | 0.55 | 0.43 | 0.61 | 0.04 | 45 |
| Bark[1] | 0.36 | 0.25 | 0.30 | 0.04 | 45 |
| Combined[2] | 0.51 | 0.40 | 0.57 | 0.03 | 45 |
| Chips | 0.46 | 0.38 | 0.57 | 0.06 | 100 |

[1] Mean values between wood and bark differ significantly at the $<1\%$ level.
[2] Combined weighted average of above based on dry weight percentage.

value is within the range for hardwoods quoted by Arola (1976), which varied from 3,886 cal/g for white ash to 5,728 cal/g for birch. Siberian elm's average heating value was one-half percent lower than the average of 4,722 cal/g reported for hardwoods (Panshin and deZeeuw 1970). However, it was higher than the 4,476 cal/g reported for several Great Plains hardwood seedlings (Geyer 1981).

Siberian elm wood is moderately heavy, with a specific gravity (SG) of 0.55 based on oven-dry weight and green volume of our disk samples. This was higher than other soft elms, i.e., American elm (*Ulmus americana* L.) and slippery elm (*Ulmus rubra* Muhl.) with SG of 0.46 and 0.48, respectively (U.S. For. Prod. Lab. 1974). Panshin (1941) found the specific gravity of Chinese elm to be 0.50 based on oven-dry weight and volume, or about 0.46, based on green volume. The specific gravity of our bark samples was 0.36. While bark and wood values were significantly different at the 5% level, no differences were found between heights. Specific gravity of the whole-tree chips was 0.46, which is nearly 11% lower than the total weighted (by dry weight) value of wood and bark combined (0.51). Cowns (1980) found wood chips to be 2–8% lower than solid wood densities.

The ash content of Siberian elm had a mean value of 1.65% based on oven-dry weight. Normally, ash content of tree species ranges from 0.1 to 0.5% for wood (Panshin and deZeeuw 1970). Bark ash content, however, can be as much as 10 times greater than that of wood (Jenson et al. 1963). Therefore, one can expect the ash content of whole tree chips (containing wood and bark) to be between the two values, depending upon the percentage of each constituent.

The average fiber length of 1.00 mm for young Siberian elm is among the shorter lengths of the hardwoods and shorter than other soft elms. American elm is reported to be 1.50 mm by Rydholm (1965), whereas Panshin and deZeeuw (1970) report American elm fiber length to be 1.55 mm and slippery elm fiber length to be 1.30 mm. This difference may be an age effect.

### *Gasification*

Gasification is a term used to describe the composite of the thermal breakdown of carbonaceous materials (wood) and the secondary reactions of the evolved volatiles. Gasification invariably results in the formation of three major classes of products: 1) a mixture of gases [hydrogen ($H_2$), carbon monoxide (CO), carbon dioxide ($CO_2$), and methane ($CH_4$)]; 2) pryolytic tar; and 3) char (a solid residue). For temperatures exceeding 550 C, the char yield for biomass gasification remains

TABLE 2. *Statistical analysis of Siberian elm gasification characteristics.*

| Dependent variable | Sample size | $R^2$ | Significant regression model* $y = A + BT + CT^2$ A | B | C |
|---|---|---|---|---|---|
| Mole % $H_2$ | 14 | — | 44.27 | — | — |
| Mole % CO | 14 | — | 17.05 | — | — |
| Mole % $CO_2$ | 14 | 0.85 | 764.2646 | −1.5608 | 0.00082587 |
| Mole % $CH_4$ | 14 | 0.63 | −11.9863 | 0.02045 | — |
| Gas vol. yield ($m^3$/kg) | 14 | 0.88 | −3.1022 | 0.0 | 0.00000429 |
| Gas mass yield (g/g) | 14 | 0.91 | −2.6312 | 0.00000364 | — |
| Gas HHV (cal/$m^3$) | 14 | 0.73 | −56.3870 | 0.1257 | −0.0000664 |
| Energy rec. (%) | 14 | 0.92 | −219.5658 | 0.0 | −0.00030139 |
| Carbon conv. (%) | 14 | 0.92 | −197.3126 | 0.002727 | — |

* T is temperature in K.

constant, whereas the gas yield increases and the tar yield decreases with increasing temperature.

The regression analyses conducted on the gasification characteristics for Siberian elm as a function of temperature are summarized in Table 2. Table 3 presents point values extracted from the regression models for each gasification characteristic at selected temperatures. The gas volumetric and mass yields, carbon conversion, and energy recovery are highly temperature-dependent. The gas composition and heating value, however, show only small variation over the temperature range examined. The results for Siberian elm are typical of the gasification behavior of most biomass materials.

### *Biomass yield*

Planting density substantially affected all tree growth characteristics, except total height and survival (Table 4). Survival remained nearly 100% after 7 years. Annual oven-dry weight yields increased with greater planting density. The highest planting density (7,000 trees/ha) produced more than twice the yield of the lowest tree density (1,400 trees/ha). Because of the limited sample size, confidence intervals were calculated only for yield at the widest and narrowest spacing. They did not overlap at "*t*" 0.05 value, thus indicating that the difference is significant. The mean annual increment (MAI) growth rate of dry wood at 7 years is still increasing (50% greater than at 4 years). This indicates that the biological harvest age has not been reached. Average annual growth rates are greater than those previously reported for several younger-aged hardwood species in Kansas (Geyer 1981).

TABLE 3. *Gasification behavior of 7-year-old Siberian elm at various temperatures.*

| Temp. (°C) | Gas composition (mole) $H_2$ | CO | $CO_2$ | $CH_4$ | Gas vol. yield ($m^3$/kg) | Gas mass yield (g/g) | Gas HHV (cal/$m^3$) | Energy rec. (%) | Carbon conv. (%) |
|---|---|---|---|---|---|---|---|---|---|
| | (%) | | | | | | | | |
| 600 | 44.3 | 17.1 | 31.1 | 5.9 | 0.17 | 0.14 | $2.71 \times 10^6$ | 10.1 | 10.5 |
| 625 | 44.3 | 17.1 | 28.7 | 6.4 | 0.36 | 0.30 | $2.91 \times 10^6$ | 23.5 | 22.6 |
| 650 | 44.3 | 17.1 | 27.2 | 6.9 | 0.55 | 0.47 | $3.02 \times 10^6$ | 37.2 | 35.0 |
| 675 | 44.3 | 17.1 | 26.8 | 7.4 | 0.75 | 0.64 | $3.06 \times 10^6$ | 51.3 | 47.8 |
| 700 | 44.3 | 17.1 | 27.5 | 7.9 | 0.96 | 0.81 | $3.01 \times 10^6$ | 65.8 | 60.9 |

TABLE 4. *Mean tree growth characteristics for plant density trials of 7-year-old Siberian elm grown in eastern Kansas on upland loamy prairie soils.*

| Tree density (no./ha) | Survival (%) | Total height (m) | Stump diameter at 10 cm (cm) | Annual oven-dry yield of dormant material (tonne/ha) |
|---|---|---|---|---|
| 7,000 | 100 | 6.2 | 9.0 | 9.8[1] |
| 4,700 | 100 | 6.2 | 10.2 | 8.8 |
| 3,200 | 98 | 6.3 | 10.8 | 6.6 |
| 2,100 | 100 | 6.3 | 11.2 | 5.2 |
| 1,400 | 100 | 6.4 | 13.3 | 4.7 |

[1] The confidence intervals at the "t" 0.05 level for the lowest and highest two densities did not overlap, thus indicating a significant difference.

## CONCLUSIONS

The data presented for Siberian elm suggest that: 1) whole-tree chip properties are similar to those of other soft elms, except fiber length is shorter than most hardwoods; 2) steam gasification in a fluidized bed yields a medium energy gas, which increases in quantity while maintaining a fairly constant heating value with increasing gasifier operating temperatures; and 3) this species can produce high biomass yields when grown in short-rotation forestry plantations; however, maximum biological growth rates have not yet been achieved at 7 years, even at a close planting density of 7,000 trees/hectare.

## REFERENCES

AMERICAN SOCIETY FOR TESTING AND MATERIALS. 1981a. Standard test method for gross calorific value of solid fuel by the adiabatic bomb calorimeter. ASTM D 2015-77, Philadelphia, PA.

———. 1981b. Standard test method for ash in wood. ASTM D 1102-56, Philadelphia, PA.

AROLA, R. A. 1976. Wood fuels—how do they stack up? Forest Products Research Society Proc. (14), Madison, WI.

BARNES, D. P., AND S. A. SINCLAIR. 1984. Gross heat of combustion of living and spruce budworm-killed balsam fir. Wood Fiber Sci. 16(4):518–522.

CLARKE, ROBIN. 1985. Forest, trees and people. Forestry Topics Report No. 2. FAO United Nations, Rome. 40 pp.

COWNS, D. J. 1980. A note on the estimation of basic density of fresh woods chips. New Zealand Forestry Sci. 10(3):502–503.

GEYER, W. A. 1981. Growth, yield, and woody biomass characteristics of seven short-rotation hardwoods. Wood Sci. 13(4):209–215.

———, AND G. G. NAUGHTON. 1980. Biomass yield and cost analysis (4th year) of various tree species grown under short-rotation management scheme in Eastern Kansas. *In* Proc. Central Hardwood Forest Conference, Columbia, MO. 465 pp.

HEWETT, C. E., AND W. T. GLIDDEN, JR. 1982. Market pressures to use wood as an energy resource—Current trends and a financial assessment. Resources Policy Center, Thayer Sch. of Eng., Dartmouth College, Hanover, VT. 24 pp.

JENSON, W., K. E. FREMER, P. SIERLA, AND V. WARTIOVAARA. 1963. The chemistry of bark. *In* B. L. Browning, ed. Chemistry of wood. Interscience Publishers, New York, NY.

JOHNSON, E. W. 1966. Ornamental and windbreak trees for the southern Great Plains. USDA Agr. Res. Ser. 34-77. 52 pp.

MURPHEY, W. K., AND B. E. CUTTER. 1974. Gross heat of combustion of five hardwood species at differing moisture contents. Forest Prod. J. 24(2):44–45.

NAMKOONG, G. 1965. Application of Nelder's designs in tree improvement research. Pages 24–37 *in* Proc. 8th South Conf. for Tree Improvement, Savannah, GA.

NAUGHTON, G. G. 1985. Production and harvesting costs of an 8-year-old energy plantation. *In* Proc. of 22nd Annual Meeting of the Popular Council of the US, 25–27 June, Lawrence, Kansas. 63 pp.

NEENAN, M., AND K. STEINBECK. 1979. Caloric values for young sprouts of nine hardwood species. Forest Sci. 25(3):455–461.

NEOGI, D. 1984. Coal gasification in an experimental fluidized bed reactor. M.S. thesis in Chemical Engineering, Kansas State University, Manhattan. 137 pp.

PANSHIN, A. J. 1941. Strength properties of Chinese elm grown in Michigan. Michigan Agr. Expt. Sta. Quart. Bull., Nov.

———, AND C. DEZEEUW. 1970. Textbook of wood technology, vol. 1, 3rd ed. New York, NY.

RAILE, G. K., AND J. S. SPENCER, JR. 1984. Kansas forest statistics, 1981. USDA Forest Service N.C. For. Expt. Sta. Resource Bull. NC-70. 124 pp.

RYDHOLM, S. A. 1965. Pulping processes. Interscience Publishers, New York, NY.

TSOUMIS, G. 1968. Wood as raw material. London, England. 275 pp.

U.S. FOREST PRODUCTS LABORATORY. 1974. Wood handbook—Wood as an engineering material (USDA Agr. Handbook 72, rev.). U.S. Government Printing Office, Washington, D.C.

ZERBE, J. J. 1981. The contribution of wood to the energy picture. Presented at Conference on Wood—An Alternate Energy Resource for Appalachian Industry and Institution. *In* Proc. Published by School of Eng., North Carolina State University.