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CROP RESIDUES AS A FUEL FOR POWER GENERATION

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ABSTRACT

Crop residues could serve as an alternative energy source for producing electric power and heat in agricultural regions of the United States. Nearly 2 quads of residues are estimated to be available as a sustainable annual yield. These can substitute for up to one quad of conventional fuels used to generate electricity and up to an additional quad of petroleum and natural gas currently used for producing heat. The most promising routes to residue conversion appear to be regional generators sized in the megawatt range, and the mixing of residues with coal for burning in coal power plants. Costing farmers from \$0.70 to \$1.25 per million Btu, to harvest and prepare for use as a fuel, residues can be a competitive renewable energy supply.

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INTRODUCTION

Biomass has been receiving increased attention as a possible source of energy. Much of this attention has been focused on the conversion of biomass to liquid or gaseous fuels such as the fermentation of grain to produce ethanol. However, current processes for converting biomass to high quality liquid or gaseous fuels are expensive and inefficient.^{1,2} This is particularly true for biomass materials characterized by low sugar and high cellulose content, such as residues. Biomass can also be converted to electricity, and many processes for doing so are better developed and achieve greater energy conversion efficiencies than processes for conversion to fuels. Moreover, since electricity generally commands a much higher price than do fuels, conversion of biomass to electricity may possess an inherent economic advantage over conversion to a fuel.

Crop residues, the portions of plants remaining after crop harvest, have several promising features as a fuel for electricity generation. Large supplies are available in major agricultural regions, most of which are not currently marketed; existing crop harvesting equipment can often be modified at low cost for use in harvesting residues; and the use of crop residues is safer and less polluting than the use of equivalent quantities of conventional fuels.

In this report we review the availability and preparation costs of crop residues as fuel and examine the potential of several devices that could utilize residues for generating electricity.

RESIDUE AVAILABILITY

Three crops - corn, soybeans, and wheat - comprise the bulk of the grain and seed oil crops produced in the United States. Seventy-eight percent of the cultivated acreage in the U.S. is devoted to the production of these three crops. The remaining 22% of the acreage produces a large variety of grain and seed-oil crops, each accounting for only a small fraction of total residue production.^{3,4} The total annual production of corn, soybean, and wheat residues alone is more than 300 million dry tons, (see Table 1). About 25% of this -- 80 million dry tons, having an energy content of 1.2 quad (10^{15} Btu)* -- is estimated to be harvestable as a sustainable annual yield.

*Conversion factors are outlined in Appendix A.

Table 1
Annual Production and Energy Availability of Selected Residues

Crop	Production (10 ⁶ dry tons)	Potential residue yield*	
		Physical quantity (10 ⁶ dry tons)	Energy content** (quads)
Corn	112	28	0.42
Soybeans	60	15	0.23
Wheat	156	39	0.59
Total	328	82	1.24

*Based on 1974 crop production³ and 25% yield fraction.

**Assuming average heating value of 15x10⁶ Btu/ton of dry crop residue.

Currently, most farmers turn residues into the soil in order to maintain a favorable balance of organic matter in the soil structure, improve water management, and regain nutrients embodied in residues.⁵ This practice is especially beneficial in the case of soybeans since the residues have a high nitrogen content. Little is known about the long term effects that residue harvest might have on soil quality. The 25% yield fraction used here is an estimate of the amount that could be removed without compromising soil quality. The acceptable yield fraction will vary from region to region depending on soil structure and nutrient content.

Besides the three crop residues discussed here, others should be considered in assessing national residue availability. Crops such as oats, flax, barley, cotton, sugar beets, and sorghum also produce utilizable residues. At 25% yield fraction, these could contribute 0.4 quad/yr of for a total national potential of 1.6 quads/year. This is about 2% of the current U.S. primary energy consumption.

Although most residues are turned into the soil, a small fraction of corn residues are currently being utilized. Where cattle farming and the growing of corn occur side-by-side, farmers sometimes allow the cattle to glean selected tracts of standing field corn residues soon after harvest.⁵ Also, in some parts of the country, corn cobs from central shelling plants are converted to furfural (a chemical used in the synthesis of adhesives). The price paid for the cobs put to this use is estimated to be \$0.94/10⁶ Btu. The growing use of field shelling equipment -- in which the cobs are left behind in the fields -- will tend to limit growth in this application of residues. A notable aspect of both of these cases is the proximity of the residues with the location of their intended use; neither collection nor transportation of the residues is required. Since there is little growth potential in these uses of residues, they can be expected to be an available resource for the foreseeable future.

ELECTRICITY USE IN AGRICULTURAL REGIONS

About 65% of U.S. corn, soybean, and wheat production occurs in the contiguous 12-state region consisting of Illinois, Iowa, Kansas, North Dakota, Minnesota, Nebraska, Indiana, Missouri, Ohio, Oklahoma, South Dakota, and Texas. Most of the land in this region is devoted to agriculture, primarily for the production of the three crops. Residues could contribute significantly to electric power generation in a number of these states; more than 25% of the electricity consumption in five of these states could be generated by residues (see Table 2).

Table 2
Comparison of Current Electrical Energy Consumption with Potential
Generation from Residues for Twelve States

State	Residue availability and energy content			Total electricity consumed in 1975 (10^9 kWh)	Ratio of electricity from residues to total consumption
	Weight (10^6 dry tons)	Thermal energy (10^{12} Btu)	Electrical energy** (10^9 kWh)		
Texas	2.0	30	1.8	145	0.01
Ohio	2.9	44	2.5	105	0.02
Indiana	3.7	56	3.3	48	0.07
Illinois	7.2	108	6.3	85	0.07
Oklahoma	2.9	44	2.5	30	0.08
Missouri	2.9	44	2.5	33	0.08
North Dakota	5.0	75	4.4	4	1.10
Minnesota	4.5	68	4.0	26	0.15
South Dakota	2.9	44	2.5	10	0.25
Kansas	6.2	93	5.4	18	0.30
Iowa	7.0	105	6.2	20	0.31
Nebraska	4.0	60	3.5	11	0.32

*Assumes 25% yield fraction.

**Assumes 20% efficiency for conversion to electricity.

A farm of average size has the potential for generating far more electricity from residues than is used on the farm. While the annual consumption of electricity on a farm is roughly 12,000 kWh⁶ (including electricity consumed at the farm residence), the electrical energy potentially available from residues on an average farm ranges from 27,000 to 124,000 kWh/yr (see Table 3). Hence, a residue conversion device developed for farm use would easily supply all of the electricity needs with residues harvested on the farm.

Table 3
Comparison of Current Electricity Use on Non-Irrigated Farms with
Electrical Energy Potentially Available from Residues

Crop residue	Current Annual electrical demand at a farm* (10 ³ kWh)	Electrical energy available annually from residues** (10 ³ kWh)	Ratio of potential residue-generated electricity to current consumption
Corn	12	48	4.0
Soybeans	12	27	2.3
Wheat	12	124	10.3

*From Reference 6.

**Assumes 25% yield fraction, 20% efficiency of conversion to electricity, and average cultivated acreages of 150 for corn, 90 for soybeans, and 300 for wheat.

Irrigated farms can consume substantially more electricity than non-irrigated farms and may therefore be a more likely market for residue conversion devices. About 60% of the irrigation pumps used in the U.S. today are electrically powered, and electricity consumption by such pumps can amount to hundreds of thousands of kilowatt-hours per year. Although only about 3% of all corn, wheat, and soybean farms are irrigated, those that are tend to be much larger than average. Irrigated farms are concentrated in Nebraska, Kansas, Oklahoma, and Texas. In these states, 15% of grain farms (some 36,000 out of a total of 240,000) are irrigated. Energy requirements for irrigation vary considerably depending on the depth of the water table and the amount of rainfall; a range of 30 to 150 kWh/acre-year is found in the four states mentioned above (see Table 4). Even in areas requiring heavy irrigation, residues could supply all irrigation and non-irrigation electricity requirements (see Table 5).

Table 4
Irrigation Data for Selected States* (1974)

State	Number of irrigating farms	Total irrigated acres	Irrigation requirements (kWh/acre-yr)
Kansas	6,193	1,327,408	50- 90
Nebraska	20,289	3,046,572	100-150
Oklahoma	1,104	189,951	30- 70
Texas	8,163	1,455,302	45- 85
Total	35,749	6,019,233	

*Derived from Refs. 1 and 4.

The somewhat low annual load factor of irrigation pumping may make it a questionable candidate for the major load to be carried by a farm-based residue conversion device. It is estimated that irrigation systems operate an the average 2000 hrs/yr in Kansas and Nebraska and 3000 in Oklahoma and Texas,⁷ yielding load factors of 0.23 and 0.34, respectively. Since the fixed costs of producing a unit of output are inversely proportional to load factor, this parameter will have a major impact on the economics of capital intensive processes such as residue conversion. Unless winter loads can be developed on the farm to balance the summer irrigation load, a farm-based generator is not likely to be economically attractive.

Table 5
Comparison of Current Electricity Use on Irrigated Farms
and Electrical Energy Potentially Available From Residues

Crop residue	Ratio of Potential Residue Generated Electricity to Total Consumption*			
	Kansas	Nebraska	Oklahoma	Texas
Corn	2.1	1.6	2.5	2.2
Soybean	1.5	1.2	1.6	1.5
Wheat	3.8	2.5	4.6	3.9

*Assumes 25% yield fraction, 20% efficiency of conversion to electricity and average cultivated acreages of 150 for corn, 90 for soybeans, and 300 for wheat.

RESIDUE PREPARATION

Residues can be harvested in much the same way as field grasses. After cutting, chopping, windrowing, and sun-drying, the residues would be gathered for stacking and baling and transported to a storage facility. The specific harvesting procedure chosen will depend on the type of existing crop harvesting equipment, the availability of labor for intense short-term residue harvesting, and the eventual disposition of the residues (i.e., whether they will be used on the farm or transported to a central conversion plant). The labor and energy required for harvesting are comparatively small; about 0.17 man-hrs of labor and 0.45 gallons of gasoline are estimated to be needed per fresh ton of residue.⁸ Assuming an energy content of 15 million Btu per dry ton of crop residue, the ratio of energy input to energy output is less than 0.01 and the labor amounts to less than 0.025 man-hours/10⁶ Btu.

The total cost of residue harvest, including the monetary costs of the above energy and labor requirements, ranges from \$0.67 to \$1.05/10⁶ Btu (see Table 6). The most costly item is the fertilizer required to replace nutrients when residues are harvested. Because of its importance to the cost analysis, fertilizer cost was computed in detail as the sum of the costs of the nitrogen, potassium, and phosphorous compounds removed when residues are harvested (see Appendix B). Although the ash from the burned residues contains some residual nutrients, recycling this ash would result in only a slight reduction in fertilizer replacement cost.

Table 6
Total Additional Cost to Farmer Associated
With Use of Residues as Fuel (1978 \$)

Residue	Preparation costs* (\$/10 ⁶ Btu)	Cost of additional fertilizer** (\$/10 ⁶ Btu)	Total cost at farm (\$/10 ⁶ Btu)
Corn	0.64	0.41	1.05
Soybean	0.40	0.82	1.22
Wheat	0.38	0.29	0.67

*Labor cost @ \$5.15/hr. Sun drying assumed to be feasible at negligible cost.

**Assumes 75% of residues are left on fields to maintain soil conditioning and moisture retention. Consequently, additional costs are not incurred for soil maintenance.

The market prices of corn, soybeans, and wheat as food or feed grains, expressed in terms of their energy value, serve as useful reference points in analyzing the economics of residues. These prices include the cost of greater care in handling which is required when grain is sold as food or feed rather than as a fuel; the cost of marketing residues should be lower than the cost for grain. Another reason why residue prices should be lower is that many fixed costs of farm operation are absorbed in the market price of crops; residues, which are by-products of grain production, would not also incur these costs. The current prices of grains are summarized in Table 7, and show that the costs of residue production, as estimated in this study, are indeed substantially lower than the current prices of the grains.

Table 7
Comparison of Grain Prices and Residue Preparation Cost

Residue	Residue Pre- paration cost (\$/10 ⁶ Btu)	Grain Prices (\$/10 ⁶ Btu)	Price of grain to wholesaler (\$/10 ⁶ Btu)
Corn	1.05	5.64	6.52
Soybeans	1.22	16.38	18.04
Wheat	.67	7.15	8.59

*Based on USDA prices, September 1978. Crop energy content (Btu/lb) from Ref. 9, p. 33.

MARKET POTENTIAL

Although small power systems fueled by wood chips have recently been introduced, devices designed specifically for converting crop residues are not currently being marketed. Such a device could be a fluidized bed boiler followed by a steam turbine (as is the wood chip generator) or a gasifier followed by a piston or turbine gas-engine generator. A number of small, conventionally fueled generators have been on the market for years and several manufacturers have recently introduced cogenerators and total energy systems, devices which could be modified for use in gas-engine residue power systems. Residue conversion devices could make their first appearance on the market in the near future.

An electricity-generating residue conversion device could be located on a farm or in a central location serving a region. In some cases, an existing coal power plant could convert residues to electricity if fed a mixture of coal and residues. What are the advantages and disadvantages of different schemes for sizing and locating the devices? We investigated the market potential, the amount of conventional energy that could be displaced, and the economics for several hypothetical schemes for residue conversion. As used here, the term "market potential" is the maximum possible market size for a device given either market saturation or resource limitations, whichever is the more binding constraint. The estimation of market potential does not include consideration of economic factors. The hypothetical schemes are described below and their technical characteristics are given in Table 6.

Table 8
Characteristics and Market Potential of Hypothetical Residue Conversion Devices

Device	Characteristics				Market Potential		
	Rated Capacity (kW)	Efficiency	Capacity Factor	Annual Energy Production (10 ³ kWh)	Number of Units (10 ³)	Total Annual Energy Output (10 ⁹ kWh)	Annual Fuel Displacement (10 ¹⁵ Btu)
Farm Generator	3	0.2	0.45	12	1300	16	0.16
Farm Total Energy System	5	0.2*	0.28	12 (+59 x 10 ⁶ Btu)+	1300	16 (+0.08 x 10 ¹⁵ Btu)+	0.24
Regional Generator	8000	0.25	0.60	4200	2	91	1.0

*Efficiency of electricity generation only; in addition, some waste heat is utilized.

+Waste heat recovered.

Farm Generator: A residue conversion unit for use on the farm capable of generating 12,000 kWh/yr to meet all the electricity needs of an average farm. A 3 kW power system operating at about 20% conversion efficiency and having battery storage capacity to meet peak loads would satisfy this requirement. (Battery storage for peak capacity is a less expensive way to meet peak loads than adding more generating capacity.)

Farm Total Energy System: A modified version of the farm generator that recovers waste heat and does not require batteries to meet peak loads. This 5 kW generator also produces 167 million Btu of waste heat a year of which about 117 million Btu could be recovered by a heat exchanger operating at 70% efficiency. Only about half of this, 59 million Btu, could be usefully employed because waste heat would be produced year-round with the generation of electricity, while thermal energy requirements are concentrated in the winter months. With a modest thermal storage capacity for daily cycling, the usefully recovered waste heat could provide all domestic hot water needs (19 million Btu) and nearly half (40 million Btu) of the space heating needs (see Appendix C).

Regional Generator: A multi-megawatt generator utilizing the residues collected from hundreds of farms. The power output could be fed directly into utility grids. If located next to a facility requiring thermal energy (e.g., for crop drying) the unit could be operated as a cogenerator.

The market potential of the farm based units, limited only by market saturation, is well over a million units. Only a fraction of the available residues would be utilized even at market saturation. In contrast, the market potential of the regional generator is limited by the availability of residues to 2200 8 MW units.

Regional generators feeding power directly into utility grids have several advantageous features compared to farm-based generators. Maintenance shutdowns and mechanical failures can result in a complete power loss to a farm relying only on a farm-based generator unless there is utility backup or multiple units with excess capacity are purchased. A shutdown of a regional generator will have a negligible effect on a utility's ability to meet the demand for power because of the continued availability of other generating units. In addition, maintenance costs per unit of electricity generated can be expected to be lower for a megawatt-sized regional unit compared to a smaller kilowatt-sized farm based unit. Finally, regional generators could in principal, utilize all available residues and, thereby, displace far more conventional fuels -- about 1 quad -- than could the farm based generators (see Table 8).

These features, coupled with the scale economies associated with their larger size, imply that a regional generator would, be more economical and would contribute more toward the achievement of national energy goals than a farm based unit. Although electric utilities might not be interested in purchasing and operating numerous small generating units, it might prove profitable for an independent concern (such as a farm cooperative or a private company) to own such a device and sell its output to a utility. If operated as a cogenerator, the device's thermal output could also be used by the concern or sold. The Public Utility Regulatory Policies Act of 1977 mandates the establishment of rules which require utilities to purchase electricity from such independent concerns. Hence, there should be no obstacles to such an arrangement.

ECONOMICS OF RESIDUE CONVERSION

How much would an economically rational buyer be willing to spend for a residue fueled generator? We estimated the breakeven costs for three hypothetical residue fueled generators -- i.e., the capital cost above which the total annualized costs would be greater than for some realistic alternative. The obvious alternative for the farm-based units is electricity supplied to the farm by a utility. For the regional generator we assume that power was fed directly into a utility grid and competed at the margin with new conventional power plants. A 17% fixed charge rate was employed in the cost calculations (based on a 10 year device life and 10.75% small business loans which are available to farmers). Based on surveys of existing diesel and turbine generator units, operating and maintenance costs were assumed to be about 3.5¢/kWh for the small farm units and between 0.5 and 1.2¢/kWh for the larger regional generators.

The breakeven costs were computed for a range of residue preparation costs and alternative electricity costs. The results are shown in Figures 1 - 3. It seems clear from Figure 1 that the economics of the 3 kW farm generator are not favorable. With residue costs of \$1.00 per million Btu and delivered electricity at the 1978 average of 5¢/kWh, the breakeven cost is less than zero -- i.e., even if the residue conversion device had a zero capital cost, it would still cost more to generate electricity with it than it would to buy electricity from a utility. It is very unlikely that a small residue conversion device could be manufactured at a cost below breakeven for any realistic combination of preparation costs and alternative electricity costs.

Figure 1. Breakeven Capital Cost 3 kW Residue Conversion Unit

The economics of a farm total energy system look much better. Here, the value of the recovered heat (computed from the cost of the fuel oil that would otherwise be used) is added to the cost of utility-provided electricity to obtain the total cost of the most realistic alternative. Assuming a fuel oil cost of \$0.60/gal, a furnace efficiency of 65% and a heat-output to electricity-output ratio of 3:1, the useful waste heat produced for each kilowatt hour of electricity generated by the device is worth 6.4¢. With residue costs of \$1.00 per million Btu and delivered electricity at 5¢/kWh, Fig. 2 shows a breakeven cost of \$900/kW. If electricity prices rose to 7¢/kWh (as they show every sign of doing) and if the device O&M cost could be kept down to 2.5¢/kWh, then the breakeven costs would rise to \$1800/kW. Comparisons with small engines and generators on the market today suggest that this latter performance/cost combination might be a realistic R&D goal for a small residue-fueled total energy system.

In computing breakeven costs for the regional generator, the estimated costs of transporting residues from farms to the regional facility (0.33¢/kWh) and storing them there (0.19¢/kWh) were incorporated into the cost analysis. The value of thermal energy was not included. With a lower O&M costs

Figure 2. Breakeven Capital Cost 5 kW Residue Conversion Unit with Waste Heat Recovery

Figure 3. Breakeven Capital Cost 8 MW Residue Conversion Unit

(0.5¢/kWh), a residue cost of \$1.00 per million Btu, and a cost to the utility of electricity generated from new conventionally fueled plants at 6¢/kWh, the breakeven cost would be \$950/kW. If the device were operated as a cogenerator, and the heat recovered displaced thermal energy produced from fuel oil or natural gas, the breakeven cost would more than double. At these breakeven costs, the likelihood of developing a device at a cost below the breakeven level appears reasonably promising.

COMBUSTION IN COAL POWER PLANTS

In addition to their possible use in specially designed residue conversion devices, residues would also appear to be a possible partial replacement for coal in coal power plants. When transportation costs of about \$0.40/10⁶ Btu are added to the cost of residues at the farm, the estimated cost of delivered residue fuel is in the range of \$1.10-1.60/10⁶ Btu (excluding farmer's profit). In comparison, the delivered cost of coal varies from about \$0.80 to about \$1.60/10⁶ Btu so that residues are, on average, roughly competitive with coal in this application. Reduced sulphate emissions when residues are mixed with coal could lower the effective cost of residues to a utility by facilitating compliance with emissions regulations. However, since residue combustion, either alone or in combination with coal, has not yet been demonstrated in the field at coal plants, there is as yet no clear understanding of the technical problems or the additional costs or benefits (e.g., lower environmental emissions) that might be associated with burning residues with coal.

CONCLUSION

The current emphasis in federal efforts to spur the use of biomass resources is on the development of processes to produce liquid fuels to displace the consumption of refined petroleum products and natural gas. In particular, alcohol production for use in gasohol has captured the political and popular imagination and is growing rapidly. However, the fermentation of grain to produce alcohol has a poor energy balance (and consequently may save little petroleum or natural gas in the short run), receives a government subsidy of \$4 per million Btu, and uses a raw material, the availability and cost of which depend on the vicissitudes of a volatile grain market. In contrast, residue fueled regional cogenerators or farm total energy systems would have a highly favorable energy balance and could save up to one quad of refined petroleum products and natural gas. They would not require a subsidy to be competitive. In addition, they would also generate electricity, further reducing the need for conventional fuels.

Not all biomass-to-fuel schemes fare as badly as grain fermentation when compared with the conversion of biomass to power. However, the advantageous features of the latter, as exemplified in this assessment of residue power systems, are not generally appreciated. A reappraisal of the emphasis on biomass-to-fuel processes might be worthwhile before government subsidies and incentives encourage large investments in alternative fuels technologies which do not make the most effective use of our agricultural and economic resources.

REFERENCES

1. Chambers, R.S. et al., Science, 206, #4420, Nov. 16, 1978, p. 789.
2. Anderson, E.V., Chemical and Engineering News, 56, #30, July 31, 1978, p. 8.
3. 1974 Census of Agriculture, U.S. Department of Agriculture.
4. 1976 Statistical Abstract of the United States, U.S. Department of Commerce, Bureau of the Census.
5. Kidder, E.H., Stauffer, R.S., and Van Doren, C.A., Effect on infiltration of surface mulches of soybean residues, corn stover, and wheat straw, Agricultural Engineering, 00 00 (May 1943).
6. Wind Energy Mision Analysis, Final Report, Appendices, General Electric Co., Feb. 1977.
7. Anderson, C. (USDA Eng. Div.) Oral communication, 1978.
8. An Evaluation of the Use of Agricultural Residues as an Energy Feedstock - A Ten Site Survey, Vol. II, Study Area Analysis, Stanford Research Institute, July 1977.
9. Effective Utilization of Solar Energy to Produce Clean Fuel, Stanford Research Institute Project 2643, June 1974.
10. Starr, P.J., Finn-Carlson, D.W., and Nachtsheim, C.J., Crop residues as energy sources: Assessing the cost and energy feasibility of direct firing, Energy Sources, 3, (3/4) (1978).
11. VanArsdall, R. (USDA), Oral communication, 1978
12. 1975 Annual Statistical Report, Rural Electric Borrowers, U.S. Department of Agriculture, Rural Electrification Administration.