ENERGY POTENTIAL FROM AGRICULTURAL RESIDUES IN TEXAS

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Fuel shortages, along with dramatic increases in the price of energy, have placed considerable emphasis on the development of new and competitive energy supplies. In irrigated regions, the increased price and threat of curtailed supplies of natural gas have serious economic implications for the farm firm [4, 13]. Agriculture has the potential of replacing part of the energy it uses in the form of agricultural residues. The purpose of this article is to evaluate the use of residues from crop production in Texas as a feasible energy source.

Study Area

To delineate a study area, the leading counties in Texas in terms of agricultural residue produced were distinguished for each of the four major crops of corn, cotton, grain sorghum, and wheat [15]. The High Plains area was found to have the greatest energy potential from crop production in Texas. This area contains all 10 of the counties showing the highest potential energy production from each of the crops considered, except grain sorghum. However, only three of the leading counties in grain sorghum production are not in the High Plains. Therefore, the 54 counties which block off a large portion of this area were selected as a study area for evaluating the feasibility of collecting and transporting residue from wheat, corn, grain sorghum, and cotton to one or more sites for conversion into energy. Because of differences in the methods of collection, however, wheat, corn, and grain sorghum are considered separately from cotton.

Two cities within the study area, Amarillo and Lubbock, were selected as sites for the conversion of residues into energy because of their size and location.[1]

Data Base and Procedure

Average figures for energy from biomass production were estimated throughout the state of Texas over the six-year period 1970-1975. Crop yield data for the major crops were taken from the Texas Crop and Livestock Reporting Service [35]. The data reflecting the ratios of residues to yield for each crop were consolidated from several sources. The ratios for the different crops (Table 1) were used to

TABLE 1. CONVERSION FACTORS APPLIED TO ESTIMATE CROP RESIDUE AND ENERGY VALUE

Crop	Pounds Dry Residue Per Pound Yield	Btu Per Pound Residue
MAJOR CROPS		
Corn	1.07 [c,d,l]	6,000 [e,l]
Cotton (with field trash)	0.9175 [f,s]	7,000 [k]
Gin trash only		
Spindle harvested	0.3 [k,m,n]	7,000 [g,j,k]
Stripper harvested	1.5 [k,m,n]	7,000 [g,j,k]
Sorghum	1.07 [a,b,o]	6,000 [e]
Wheat	2.73 [a,b,p]	7,500 [e,i,l]
OTHER CROPS		
Rice	1.4 [h]	6,000 [q,r]
Barley	2.25 [h]	7,500 [e,h,q]
Flax	1.0 [h]	8,000 [h,i]
Hay	0.8 [q]	7,500 [q]
Oats	2.5 [h]	7,500 [e,h,q]
Peanuts	1.2 [q]	7,000 [q]
Rye	2.25 [h]	7,500 [h,q]
Soybeans	0.85 [q]	7,000 [q]
Sugarcane	0.2 [q]	8,000 [j,q]
Sunflower	5.0 [q]	8,000 [i,q]

[a]Allen and Musick, [b]Allen, Musick, Wood, and Dusek, [c]Arnold, [d]Dugas, [e]Green, [f]Glover, [g]Griffin, [h]Kawoksing and Lapp, [i]Larue, [j]Marks, [k]McCaskill and Wesley, [l]Miller, [m]Moore and McCaskill, [n]Pendleton, [o]Schake, [p]Shipley and Regier, [q]Stanford Research Institute, [r]Steffgen.

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[1]A project was initiated at Texas A&M University in late 1977 to build, test, and evaluate an on-farm energy converter that uses agricultural residues. If economically feasible, such a system would provide more independence for farmers and reduce transportation costs as estimated herein. This research program will establish costs of conversion and efficiency of converting crop residues to energy, i.e., Btu's avilable in crop residue that are actually recovered and made available to the energy consumer by the conversion process.

calculate the amount of energy available from the residues of each crop.

Collection

Stalks (residue) from wheat, corn, and grain sorghum currently are baled by farmers and ranchers for cattle feeding, particularly when hay is in short supply. Thus, experience in collecting these residues is considerable. The objective of this phase of the study was to identify the least-cost collection method. Several methods of residue collection were considered, including conventional rectangular bales, stackwagons, small round bales, and large round bales. Published costs of baling served as the basis for establishing such costs for residues. On the basis of 800 tons per year per machine, the Kansas Cooperative Extension Service quotes costs per ton of hay collected (excluding feeding costs) as approximately $12.41 for conventional bales, $10.75 for stackwagons (6-ton systems), $11.77 for small round bales, and $9.51 for large round bales [17]. These figures indicate that large round bales would be the most economical system for handling residues. If the quantity of crop residue baled annually by a machine differed from the 800 tons, cost per ton would of course be affected.

Several studies have given the cost of collection through large round baling systems as being from $7 to $15 per ton. Therefore, as no exact cost is available, the Kansas State Extension Service estimate [27] of $9.51 per ton is rounded to $10 per ton and used as collection cost in this study. Because the same machine can be used to bale hay or grain crop residues and bale size and weight are comparable, the cost estimates for hay baling can be applied to grain crop residues. The amount of residue collected and transported is the dry weight inflated by 20 percent for moisture to ensure an accurate estimate of quantity of material handled and associated costs. Energy values were estimated on the basis of dry weight only.

Transportation

Transportation costs were taken from the Railroad Commission of Texas Motor Freight Tariff No. 8-f governing hauling of livestock feedstuff, cottonseed, and grain [25]. These rates are based on a load weight of 20,000 pounds and are given in cents per 100 pounds. It is expected that if the Railroad Commission rates were not applicable to agricultural residues, custom hauling rates would be comparable. Costs of transportation both to Amarillo and to Lubbock were calculated for each of the 54 counties by using the mileage from the center of each county to each of the collection sites and applying the appropriate rate for that distance. The central point in the county represents an average collection cost for all residues in the county.

Results

For purposes of this study, wheat, corn, and grain sorghum were considered collectively because residues of these crops are primarily left in the field. Cotton gin trash was considered separately. Gin trash is located at the gin; hence for the most part it has already been collected.

Wheat, Corn, and Grain Sorghum

Because residues from these crops are in the field, they require a collection phase as well as a transportation phase. Table 2 shows the quantity of corn, wheat, and grain sorghum residue by county, as well as the energy equivalent and costs of the collection and transportation to Lubbock and to Amarillo. Calculations for the 54-county region indicate that $25{,}444{,}424 \times 10^3$ pounds, or nearly 72 percent of the crop residue available in the state, is in this area. In total energy value, this amount accounts for 138.5×10^{12} Btu or over 60 percent of the total energy available from crop residue in the state.

Summary data on costs of transportation of total residue to each collection site are $62,710,046 for Amarillo and $73,827,139 for Lubbock. From this evaluation, Amarillo appears to be the preferable single collection site in terms of cost. This result changes slightly for cotton gin trash because of the proximity of the large cotton production area to Lubbock. Also, transportation cost would be the deciding factor in location because collection costs are constant regardless of the collection site chosen.

Transportation costs show a low cost to Amarillo of $4.93 per ton or $0.45 per million Btu and a high cost to Lubbock of $5.80 per ton or $0.53 per million Btu. Adding collection and transportation costs gives a total cost for wheat, sorghum, and corn residues delivered to each collection site of $189,932,166 for Amarillo and $201,049,259 for Lubbock.

With collecton costs included, the low figure to Amarillo is increased to $14.93 per ton or $1.37 per million Btu. The high figure to Lubbock is increased to $15.80 per ton and $1.45 per million Btu. These condensed values are presented in Table 3.

The energy value of one million Btu is approximately equivalent to one thousand cubic feet (mcf) of natural gas with an energy value of 1000 Btu per cubic foot. Thus, the value per million Btu of fuel produced from crop residues should be equal to the price of natural gas per thousand cubic feet. However, the total equivalent prices of residues would have to be calculated, including the cost of conversion of the residue to a usable energy source and its efficiency in use in relation to the fuel with which it is being compared.

A second alternative approach used to calculate the transportation costs and the feasibility of residue as a fuel source was to divide the 54-county area into two sections according to preselected conversion sites. Residue in each of the 54 counties was assumed to be transported to the site associated with the lowest transportation cost as shown in Table 2. For example, crop residues from Armstrong County were allocated to Amarillo because transportation costs were only $350,918 compared with $827,105 for Lubbock. Conversely, Briscoe

TABLE 2. WHEAT, GRAIN SORGHUM, AND CORN RESIDUE, ENERGY VALUE AND COSTS TO COLLECT AND TRANSPORT TO TWO CENTRAL SITES BY TEXAS HIGH PLAINS COUNTY

County	Trash Dry Wt. x 1.2 (1000 lb.)	Energy (million BTU's)	Collection Costs @ $10/ton	Transport Cost to Amarillo	Total Cost to Amarillo	Cost per million BTU's	Transport Cost to Lubbock	Total Cost to Lubbock	Cost per million BTU's
Armstrong	250,656	1,448,995	1,253,280	350,918	1,604,198	1.11	827,165	2,080,445	1.44
Briscoe	265,882	1,464,967	1,329,410	638,117	1,967,527	1.35	664,705	1,994,115	1.37
Carson	882,558	5,044,799	4,412,790	1,235,581	5,648,371	1.12	3,177,209	7,589,999	1.51
Castro	1,692,763	8,906,993	8,463,815	3,724,079	12,187,894	1.37	4,062,631	12,526,446	1.41
Dallam	676,356	3,713,410	3,381,780	1,623,254	5,005,034	1.35	2,975,966	6,357,746	1.72
Deaf Smith	1,667,440	9,253,785	8,337,200	3,001,392	11,338,592	1.23	4,335,344	12,672,544	1.37
Floyd	1,137,468	6,145,076	5,687,340	2,957,417	8,644,757	1.41	2,161,189	7,848,529	1.28
Gray	382,865	2,256,829	1,914,325	765,730	2,680,055	1.19	1,531,460	3,445,785	1.53
Hale	1,691,580	8,786,050	8,457,900	3,890,634	12,348,534	1.41	3,044,844	11,502,744	1.31
Hansford	1,350,884	7,573,159	6,754,420	3,377,210	10,131,630	1.34	6,214,066	12,968,486	1.72
Hartley	628,820	3,555,462	3,149,100	1,196,658	4,345,758	1.23	2,456,298	5,605,398	1.58
Hemphill	117,517	718,059	587,585	305,544	893,129	1.25	552,330	1,139,915	1.61
Hutchinson	399,887	2,286,766	1,999,435	839,763	2,839,198	1.25	1,639,537	3,638,972	1.60
Lipscomb	336,025	2,054,878	1,680,125	1,075,280	2,755,405	1.34	1,680,125	3,360,250	1.64
Moore	1,070,919	5,917,511	5,354,595	2,034,746	7,389,341	1.25	4,176,584	9,531,179	1.61
Ochiltree	1,196,398	6,906,843	5,981,990	3,589,194	9,571,184	1.39	5,862,350	11,844,340	1.72
Oldham	171,114	995,388	855,570	325,117	1,180,687	1.19	444,896	1,300,466	1.31
Parmer	2,275,988	11,950,639	11,379,940	5,917,569	17,297,509	1.45	5,689,970	17,069,910	1.43
Potter	108,690	625,622	543,450	108,690	652,140	1.05	336,939	880,389	1.41
Randall	750,238	4,299,339	3,751,190	825,262	4,576,452	1.07	2,025,643	5,776,833	1.35
Roberts	66,836	400,382	334,180	140,356	474,536	1.19	274,028	608,208	1.52
Sherman	1,053,971	5,928,461	5,269,855	2,529,530	7,799,385	1.32	4,742,870	10,012,725	1.69
Swisher	1,342,213	7,209,987	6,711,065	2,550,205	9,261,270	1.29	3,087,090	9,798,155	1.36
Andrews	14,535	76,211	72,675	69,768	142,443	1.87	40,698	113,373	1.49
Bailey	626,023	3,266,676	3,130,115	1,627,660	4,757,775	1.46	1,377,251	4,507,366	1.38
Cochran	358,707	1,842,874	1,793,535	1,183,733	2,977,268	1.62	717,414	2,510,949	1.37
Crosby	382,385	2,009,971	1,911,925	1,261,871	3,173,796	1.58	611,816	2,523,741	1.26
Dawson	98,534	504,452	492,670	403,989	896,659	1.78	206,921	699,591	1.39
Gaines	272,314	1,433,169	1,361,570	1,198,182	2,559,752	1.79	653,554	2,015,124	1.41
Hockley	465,348	2,374,572	2,326,740	1,535,648	3,862,388	1.63	651,487	2,978,227	1.26
Howard	24,889	128,061	124,445	164,267	288,712	2.26	69,689	194,134	1.52
Lamb	1,204,661	6,110,896	6,023,305	3,493,517	9,516,822	1.56	1,927,458	7,950,763	1.31
Lubbock	535,656	2,739,913	2,678,280	1,660,534	4,338,814	1.59	535,656	3,213,936	1.17
Lynn	149,072	773,219	745,360	536,659	1,282,019	1.66	208,701	954,061	1.24
Martin	37,567	193,659	187,835	176,565	364,400	1.89	105,188	293,023	1.52
Terry	448,570	2,302,563	2,242,850	1,659,709	3,902,559	1.70	762,569	3,005,419	1.31
Yoakim	270,664	1,368,773	1,353,320	1,055,590	2,408,910	1.76	622,527	1,975,847	1.45
Borden	5,687	31,048	28,435	23,317	51,752	1.67	13,080	41,515	1.34
Childress	119,363	730,722	596,815	489,388	1,086,203	1.49	417,771	1,014,586	1.39
Collingsworth	134,125	756,322	670,625	348,725	1,019,350	1.35	509,675	1,180,300	1.56
Cottle	54,446	324,938	272,230	196,006	468,236	1.45	163,338	435,568	1.34
Dickens	72,266	408,152	361,330	260,158	621,488	1.53	151,759	513,089	1.26
Donley	74,144	398,798	370,720	155,702	526,422	1.32	259,504	630,224	1.58
Garza	19,919	103,370	99,595	71,708	171,303	1.66	33,862	133,457	1.30
Hall	50,291	274,801	251,455	120,698	372,153	1.36	176,019	427,474	1.56
Kent	16,624	92,518	83,120	68,158	151,278	1.64	41,560	124,680	1.35
King	19,811	116,834	99,055	77,263	176,318	1.51	49,528	148,583	1.28
Motley	46,942	268,296	234,710	150,214	384,924	1.44	112,661	347,371	1.30
Wheeler	116,807	672,726	584,035	303,698	887,733	1.32	525,632	1,109,667	1.65
Fisher	97,133	568,750	485,665	456,525	942,190	1.66	301,112	786,777	1.39
Mitchell	36,059	190,039	180,295	169,477	349,772	1.84	104,571	284,866	1.50
Nolan	58,307	326,527	291,535	279,874	571,409	1.75	186,582	478,117	1.47
Scurry	52,925	281,198	264,625	227,578	492,203	1.75	132,313	396,938	1.42
Stonewall	62,582	370,983	312,910	281,619	594,529	1.67	194,004	506,914	1.37
Totals	25,444,424	138,484,431	127,222,120	62,710,046	189,932,166	1.37	73,827,139	201,049,259	1.45

County crop residues were allocated to Lubbock.

As shown in Table 3, costs estimated by this method would be \$1.27 per million Btu (total cost of \$105.1 million) for Amarillo; 60 percent of the total residue of the 54-county area is included and the costs are lowered \$0.10 per million Btu (7.3 percent) in comparison with the other method. For Lubbock the costs would be \$1.34 per million Btu or \$74.6 million total; 40 percent of the total residue in the 54-county area is included and the cost is lowered \$0.11 per million Btu (7.6 percent) in comparison with the other method.

A cost for storage of the residues was not included because they would be in round bales which farmers and ranchers have demonstrated to be a convenient form of storage for these materials. Further, a conversion phase was not included in the study and handling cost at the energy sites is part of the energy production costs and beyond the scope of this project.

Cotton Gin Trash

Cotton gin trash as an energy source is considered separately because (1) the method of accumulating gin trash is completely different from that used for other residues and (2) several factors indicate that it is the most likely residue for conversion.

Cotton gin trash from stripper cotton on the Texas High Plains consists of soil, burrs, and all other foreign matter delivered to gins with harvested cotton. Unlike the other crop residues studied, cotton gin trash does not require collection from the field because it is accumulated with the harvesting of seed cotton. The only transportation costs that might be incurred are those to accumulate residue from several gin sites to a central location.

Accumulation from several gin sites is necessary to obtain an adequate amount of residue to accommodate a conversion plant for a large city, as was the assumption for the wheat, corn, and sorghum residue analysis. For cotton gin trash, Lubbock was selected as the central site because of its location in relation to the major cotton producing counties. The 10 counties with the highest production of gin trash listed in Table 4 were used to figure accumulation costs for gin trash as shown in Table 3.

The total energy available from gin trash in the 10 counties is 6.57×10^{12} Btu. In comparison, energy used to gin the cotton is estimated to be 5.80×10^{6} Btu [11]. Thus, although the energy value of cotton trash is small in relation to the energy values of the other crop residues, it is sufficient to provide much of the energy used in ginning operations. Furthermore, cost associated with centralizing cotton gin trash includes only transportation costs with no collection costs. The cost per million Btu of gin trash is significantly lower than that of other crop residues, averaging \$0.25 per million Btu.

Costs not considered in this study are those of preparing gin trash for transportation and storage at the energy conversion site. Such costs would depend on the amount of preparation. A possible preparation would be grinding the material to make the loads more compact. If the cotton trash were put in modules there would be very little storage cost. Finally, the opportunity cost from using gin trash for fuel rather than for some other purpose should be considered to reflect fully the cost of operation.

TABLE 3. COST OF COLLECTING AND TRANSPORTING AGRICULTURAL RESIDUES TO CENTRAL SITES ON THE TEXAS HIGH PLAINS

Item	Tons of Residue[a]	Energy (millions of BTU's)	Percent of 54 County Total	Cost (\$/million BTU's
Wheat, Corn, and Sorghum				
Fifty-four county total transported to each site				
Amarillo	12,722,212	138,484,431	100	\$1.37
Lubbock	12,722,212	138,484,431	100	\$1.45
Fifty-four county total divided by minimum cost per million BTU's to 2 sites				
Amarillo	7,394,199	82,664,282	59.7	\$1.27
Lubbock	5,328,013	55,820,149	40.3	\$1.34
Cotton Gin Trash				
Top 10 counties				
Lubbock	563,368	6,572,613	NA	\$0.28

[a]Dry tons increased for 20 percent moisture.

TABLE 4. COTTON GIN TRASH QUANTITY, ENERGY VALUE, AND COST TO TRANSPORT TO LUBBOCK FOR THE TOP 10 PRODUCING COUNTIES

County	Trash Produced (1000 lb)	Energy Value (Mil. Btu)	Total Cost Hauling (dollars)	Cost/ Mil. Btu (dollars)
Lubbock	176,097	1,027,231.0	176,097	.17
Lynn	144,989	845,768.0	202,985	.24
Dawson	136,990	799,107.0	287,679	.36
Hockley	113,207	660,371.6	158,490	.24
Crosby	104,787	611,256.6	167,659	.27
Hale	101,232	590,519.6	182,218	.31
Gaines	99,573	580,841.0	238,975	.41
Terry	91,462	533,528.6	155,485	.29
Lamb	87,098	508,074.0	139,357	.27
Floyd	71,300	415,915.6	135,470	.33
Total	1,126,735	6,572,613	1,844,415	(Avg.).28

Energy Implications

Total energy value of the residue from the five major crops in Texas represents more than 65 percent of total energy used by agriculture and forestry in Texas in 1973 and about 1.7 times the energy demand for irrigation in Texas (Table 5). The energy in these residues is also equivalent to the on-farm fuel purchases by Texas farmers and ranchers in 1973. The energy value of the residue from the five crops of the 54 counties on the Texas High Plains is more than 60 percent of that available across the entire state. Of total energy use in Texas in 1973, 7 percent was by agriculture. Thus, energy available from residues is 4.5 percent of Texas total energy use. It is certainly significant in relation to total energy use and particularly agricultural energy use [23].

TABLE 5. ENERGY USE IN TEXAS FOR 1973 AND POTENTIAL OF AGRICULTURAL RESIDUES

Item	Energy Use (10^{12} BTUs)	Percent Available From Agricultural Residues[a]
State	5,934	4.5
Agricultural and Forestry	416	64.9
Irrigation	163	165.6
On-Farm Fuel Purchase	273	98.9

[a]This includes only residues from the five major crops in Texas based on average yield from 1970-75.

Conclusions

Although the energy potential from crop residues is great, the costs included in the study do not include conversion costs. The residues such as corn, wheat, and grain sorghum which involve considerable costs for transportation and collection would have to be converted very inexpensively to be competitive with other fuels. In both methods of collecting the corn, wheat, and grain sorghum residues, the lowest costs were $1.27 and $1.37 per million Btu's to collect the residues at a central metropolitan site. Only the direct costs of collection and transportation were included. Indirect costs such as payments to entice farmers to sell the residue or possible impact on land productivity were not included. Therefore, the estimate given here is, in actuality, low.

According to a Trans-Pecos study [4] and the study on deregulation of gas [13] the current price of natural gas in Texas ranges from about $1.25 to $2.00/mcf. On the basis of the $2.00/mcf price for natural gas, as much as $0.63 to $0.73 could be expended per million Btu for conversion and purchase of the residue from the farm and still leave crop residue cost competitive with natural gas.

Dugas [6] gives three methods of converting biomass to energy. The costs presented are $0.31 for aerobic bacteria conversion, $1.45 for pyrolysis, and $4.33 for yeast fermentation per million Btu's. Of these conversion methods, conversion by aerobic bacteria is the only one that would yield a total cost lower than the Btu equivalent price of natural gas. The costs of conversion may be slightly understated because the Dugas study is almost five years old. Nevertheless, even with the most economical conversion method, the use of crop residues would be infeasible if the indirect costs were higher than $0.42 per million Btu.

In contrast, for cotton gin trash residue, the cost of transportation to a central site is the only major cost involved ($0.28 per million Btu). Therefore as much as $1.72 per million Btu can be expended in the conversion process and still leave gin trash fuel competitive with natural gas priced at $2.00/mcf.

A better alternative for gin trash residue is to use it at the gin where it is accumulated. Estimates by Cotton Incorporated [5] indicate that there is sufficient heat in 170 pounds of gin trash to dry and gin one bale of cotton; thus, a gin with an annual volume of 8000 bales paying $1.20 per bale for drying could afford to invest up to $40,000 in a system to utilize gin trash as an energy source.

Researchers at the U. S. Cotton Ginning Research Laboratory at Stoneville, Mississippi, have done considerable work on systems to capture heat from incineration of gin trash. In a system developed for 30 percent heat recovery, McCaskill and Wesley [18] show that in all cases, at a processing rate ranging from 6 to 30 bales per hour, the heat recovery for drying was in excess of the heat required for drying.

The specific problem of this system is its effect on the environment. For an incinerator unit of this type at the Kiech-Shauver Gin Company in Monette, Arkansas, it was shown that the stack gases contained six times the level of pollution allowed in Arkansas without a filter and three times the allowable level with a filter in place. Studies are needed to determine whether the value of the energy produced from an incinerator system is great enough to outweight the cost of meeting Environmental Protection Agency standards.

Nevertheless, of the crops studied, cotton gin trash seems to be the most feasible agricultural residue to use as a fuel. Costs of collection are low enough to allow a large portion of the total expenditure to be used on conversion processes rather than collection, and thus the costs can be competitive with those of other fuels.

Limitations

Many questions remain about agricultural residues. One major concern is the scheduling of removal of residues and the timing of availability of residues to correspond with energy needs. In most cases, the demand for energy in municipal areas occurs in a constant flow, and thus the use of seasonal energy sources is limited. However, if residue is used to provide energy for an individual farm or industrial site, especially in the case of cotton gin trash used at the gin, the supply would be needed only on a seasonal basis. This factor would reinforce the idea that cotton gin trash is one of the best sources of energy among the residues discussed because it is brought to the gin with the seed cotton.

The relative benefits lost by not returning residue to the soil are not considered in this study. Residues have been shown to be effective in reducing wind and water erosion. Direct effect on crop yield is much less certain. However, Shipley and Regier [28] calculated a nine-year yield average for wheat for different residue management treatments in the High Plains of Texas. The treatments used were (1) incorporation into the soil, (2) mechanical removal (simulation bailing), and (3) burning. The resulting yields were 50.7, 50.3 and 51.7 bushels per acre, respectively. Significant yield variation was found among years but there was no evidence that this yield variation could be attributed to the straw management practices. It is not stated whether this is the rule or an exception, but the study shows the uncertainty of the benefits lost from removal of residue and the need for future study in this area. The long-term impact of crop residue removal on soil productivity is unknown at this time.

Another item not considered is the actual value of residues. The amount that would have to be paid to entice farmers to sell crop stubble rather than incorporate it would add to costs already established. This amount would probably be related also to the price of stubble in the form of roughage for cattle or to the price of nutrients that might have to be replaced in the soil. The price paid would have to be competitive to gain control of residues.

The nature of farmers and of farming areas would be another factor to consider in the total program. For success, nearly 100 percent cooperation by the farmers would be necessary. About 209,000 farms [34] in the State of Texas would be involved. Timing of the removal of residue must conform to tillage practices of the farm firm. Time and manpower costs for such a large undertaking would need evaluation.

Storage of such a large quantity of residue over long periods raises questions of maintaining residue energy potential, costs, and possible health or environmental hazards.

This analysis applies to current prices only. Adjustments in the cost and supply (possible curtailment) of traditional energy sources would affect economic feasibility of using agricultural biomass as an energy source.

In this study no consideration is given to crop yield variability which would determine residue availability over time. Also, variation in cropping patterns and fallow land would affect quantity, timing, and type of crop residue that would be available. However, for feasibility analysis, use of expected values is appropriate.

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