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GOLDEN, COLORADO 80401

Agricultural Crop Residue Collection Costs

Jan Dauve
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Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

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AGRICULTURAL CROP RESIDUE COLLECTION COSTS

JAN DAUVE
SILVIO J. FLAIM

DECEMBER 1979

PREPARED UNDER TASK NO. 3321.3

Solar Energy Research Institute

1536 Cole Boulevard
Golden, Colorado 80401

A Division of Midwest Research Institute

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FOREWORD

This report, performed under Task 3321.30, is one of a series involving costs and benefits that arise from harvesting agricultural biomass for use as an energy source. Two sample farms, in Iowa and Oklahoma, are used as the basis for estimating collection costs. Data from this and other reports will be used as inputs to a macroeconomic analysis to measure the impacts of large-scale agricultural biomass utilization.

Approved for:

SOLAR ENERGY RESEARCH INSTITUTE

Dennis Costello

Dennis Costello, Chief
Economic Analysis Branch

SUMMARY

Five systems for collecting agricultural crop residues are examined: conventional bales, big round bales, big rectangular bales, stackwagons, and loose chop. Costs are estimated for new machinery and do not represent average charges for the existing stock of harvesting equipment nor opportunity costs for other farm activities. Agricultural crop residue collection increases total farm production costs, and revenues from residue sales will determine the profitability of this activity. Adoption of minimum tillage practices will increase the amount of residue available for energy conversion and also reduce production expenses.

With conventional practices, the stackwagon system had the lowest costs per ton for both a 400-acre corn harvest and a 750-acre wheat harvest. Big round bale systems are less expensive than stackwagons when crop residues are stored over a long period of time. Big rectangular bales are competitive with other systems when large acreages are harvested. Conventional bales are competitive on small fields if on-farm labor is not a constraint. Loose-chop harvesting systems are not feasible unless transportation distances are short. Collection cost estimates varied from a low of $12.63/ton for loose chop harvesting of corn stover to $25.85 for giant rectangular bale systems. Stackwagon systems were the next lowest cost alternative at $15.37/ton. Loose chop systems are not considered a viable alternative because of high storage and handling costs.

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SECTION 1.0

INTRODUCTION

Agricultural crop residues have four potential uses: (1) animal feed, (2) animal bedding, (3) prevention of soil erosion and soil fertility maintenance, and (4) an energy source. The third use is most common because the technology to use residues as an energy source is not well developed and feed values are low. Residues are grazed or harvested for feed by some farmers, but most use them for this purpose only when other forages are scarce. Residues are seldom the primary roughage in an animal's diet. The potential energy that residues contribute to U.S. energy supplies depends primarily on the costs of residue collection. The purpose of this study is to examine the farm-level costs of collecting agricultural residues for use as energy feedstocks.

1.1 CHARACTERISTICS OF AGRICULTURAL CROP RESIDUES

Crop residues are diffuse in nature, owned by many individuals, and, therefore, generally expensive to harvest. Because of their low energy density, crop residues also are expensive to store and transport. Residues are plentiful in some regions, and often the largest concentrations are in areas that are fossil fuel deficient. Advantages of agricultural crop residues include: the large volume presently available (estimates as high as 430 million tons annually have been reported [Alich et al. 1977, p. 11]), renewability, low sulfur content, and the potential for near-term applications. Disadvantages of agricultural biomass include lower Btu content per pound and expensive collection costs. Crop residues have diverse characteristics, and each of these characteristics can affect storing, processing, and transportation costs.

Tillage methods affect residue availability. Reduced tillage practices conserve soils and allow larger amounts of residue to be removed safely (Flaim 1979). Conservation tillage usually reduces production costs because fewer trips are made over a field, but costs may increase for herbicides and pesticides used to kill weeds and insects that are normally destroyed by plowing. Conservation tillage also reduces total energy consumption of the farming activity and increases residue yields, without increasing erosion, by 0.46 ton/acre for corn stover and 0.49 ton/acre for wheat straw in two situations analyzed (Flaim 1979). Overall, the effectiveness of conventional tillage practices depends on soil type and weather conditions (Washington Post 1976).

A variety of liquid and gaseous fuels can be derived from crop residues. The most cost-effective uses now are either burning them directly either at a power plant or burning them on the farm (in most cases as a substitute for propane) for grain drying and for space heating. Several companies are presently manufacturing residue burners for on-farm use.

In this report, two specific types of crop residues are examined: corn stover and wheat straw. Both are available in large areas of the country and are grown in high enough concentrations to be potential substitutes for conventional fuels. Other crop residues are also available but in smaller quantities.

Crop residues are available in sufficient quantities to make a substantial contribution to the energy requirements of Iowa or Oklahoma, the two sample farming situations included in this analysis. The Ponca City, Okla., power plant has two 515-MW boilers and may be used to demonstrate the magnitude of agricultural residues as a fuel source.* To supply this plant with 10% of its required fuel at full capacity would take 2,768 ton/day of wheat straw, assuming 13×10^6 Btu/ton. Assuming further that one ton of straw could be removed from each acre and that only half the land were in wheat, the maximum hauling radius to fuel this plant at 10% firing rate would be only 22 miles.

1.2 FACTORS AFFECTING CROP RESIDUE COLLECTION COSTS

Land, labor, capital, and management are four basic factors of production. In this section, these factors and the items that influence their costs are examined.

Land is already committed to the production of crop residues. There is no charge in this analysis for land because crop residues are produced in greater amounts than they can be used economically. We define "excess" residues as that amount produced over the minimum required to maintain soil fertility and control erosion. Further, crop residues require additional machine operations for chopping and incorporating them into the soil. Excess residues may require more pesticides per acre because insects thrive in humus-rich environments. A cost may be assessed for replacing nutrients removed when residues are collected, but this will vary with soil types, residue removal rates, weather, and tillage practices.

The value of nutrients lost when residues are removed vary by crop and the soils from which they are removed. Short et al. (1979, p. 2) estimate that the cost of lost nutrients ranges from $2.79 to $5.34/ton in 1978. Alich et al. (1977) estimate that the charges range from $3 to $10/ton. Buchele (1977) takes a credit for residue removal, arguing that the stubble and trash remaining after removal are sufficient for erosion control and that chopping and discing operations are no longer required. We assume that the quantity of residues left after harvesting is sufficient to control erosion and to sustain crop production economically and indefinitely. Hence, no costs are charged for nutrients lost by residue removal.

Labor could be a constraint on crop residue collection. Most labor required would need skills that are utilized during normal farming operations, but timing residue harvests may create a problem. Corn stover should be collected during or shortly after grain harvest and before the arrival of winter snows. This is a relatively short period when farmers often are busy with many other prewinter tasks. Fall plowing can add another activity to this short season. Labor availability for collection of wheat straw in Oklahoma should not be as much of a problem as stover collection in Iowa because of a longer potential collection period.

The discussion of capital is limited to machinery used for preparing, packaging, and on-farm transporting of residues. The machinery complement represents the large amount of capital required for residue collection. Various items affect machinery performance and, thereby, the costs of residue collection. Obviously, the most important consideration is matching the equipment in terms of size and capability to the farm on

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*David Urban 1979: personal communication.

which it is to be used and to other equipment in the complement. The location and packaging preferences of the residue consumer also will be an important determinant of the machine complement. If the consumer is far away, greater density of packaged residue may be very important. Climate will have an effect also. If the collection season is short, machinery with high capacity and efficiency may more than offset additional capital costs for it. The weather in any given year will affect performance in that year. The ability of the operator and his familiarity with the equipment can have a major effect on costs.

In Iowa, farmer-owned haying machinery should be readily available for corn stover collection because the haying season already will have ended. In Oklahoma, this may not be the case. The timing of residue harvest and hay harvest will be situation-specific to an individual farm. If a farmer already owns his equipment, there should be little resistance to harvesting some residues and little or no inefficiency in beginning a new enterprise.

Management, the last factor of production, is the most difficult to deal with in a general manner. The manager must handle the other three factors simultaneously, along with special circumstances that may occur because of location, land configuration, weather, governmental policies, or a variety of other related items. Without government policies to allow for the variability of production choices in response to the items that are beyond management's ability to control, residue prices and quantities will fluctuate similarly to the way that grain prices fluctuate. Residues as an energy source will require the communication and cooperation of managers of farms, power plants, manufacturing firms, and transportation services.

1.3 CROP RESIDUE COLLECTION SYSTEMS

This report only considers collection systems that are currently available from farm equipment dealers. This subsection describes the activities of collecting residues and hauling them to a central on-farm location. Each system described is based on a common machinery complement. A machinery complement is the set of machines required for the performance of a specific activity, in this case the collection of crop residues. The systems described are based in part on "Hay Harvesting Systems" from Doane's Agricultural Report (1979).

A conventional baling system produces rectangular bales that measure approximately 14 in. x 18 in. x 50 in. and weigh 35 to 100 lb. A conventional baling machinery complement consists of a tractor with of at least 25 hp, a baler, rake, mower, or windrower. Windrows may be made after mowing or with a mower conditioner, depending mostly on the farmers' preferences. To pick up and haul bales, labor-intensive operations are being replaced by automatic bale wagons. Bale wagons permit higher capacity complements including self-propelled windrowers and tandem rakes. Bale wagons have led to a large reduction in labor required by a conventional baling system, but it still is the most labor-intensive system examined here, and it is best suited for smaller farms or farms with small or odd-shaped fields.

Large round balers produce bales that can weigh as much as 3,000 lb and that are 7 ft in diameter and 6 ft wide. The most common dimensions are approximately 6 ft x 5 ft. This system requires less labor than the conventional baling system and is typically used on farms of moderate size (300 to 1,000 acres). The lowest cost per ton is achieved with a total annual tonnage slightly higher than conventional baling systems. A windrower, rake, bale mover, and tractor commonly are used with a large round baler. Machinery choices are flexible for equipment complements and a dual complement may be used with larger balers. Two advantages of the large round bale system are the possibility of one-man collection and the fact that bales do not require covering for out-of-doors storage.

A relatively new collection system is a big rectangular baler that makes bales which are approximately 4 ft x 4 ft x 8 ft. At minimum, a 100-hp tractor is required. Other equipment in the machinery complement could include two windrowers, two sets of tandem rakes, and big bale handling equipment—either an accumulator or grapple fork. Big bales require cover while being stored. This system is the least labor intensive and is practical only for large acreages (600 acres or more).

A fourth collection system presently available is a stacking system. Stacks vary from 1 to 12 tons with dimensions as large as 15 ft x 24 ft. A typical machinery complement will consist of a windrower or mower conditioner, stacker, and stack mover. Some companies have combined the stacker and stack mover into one unit which reduces total capital investment. A stack system compares favorably to a large round baling system except that very large stackers are suited only for fields 50 acres or larger. Only one person is required to operate the machinery. Stacks can be stored unsheltered, and no twine is required. The lifetime of a stack is highly variable but compressed stacks usually have longer lives than loose stacks.

The last harvesting system considered in this report is a loose chop system. This complement consists of a flail-type chopper, wagon, and tractor of at least 50 hp. (A forage harvester is not considered because a flail chopper will harvest the residue for a lower cost.) This system also allows for one-man collection but has one very prominent disadvantage: the material is not compacted or packaged. This system has transportation and storage constraints unless the residue is densified.

SECTION 2.0

COSTS OF CROP RESIDUE HARVESTING

2.1 COST ASSUMPTIONS

The costs estimated in this report are presented on a per-ton basis except where specified. It is assumed that collection equipment (excluding tractors) is only used to harvest residues. Lower per-ton costs should arise if this equipment is used also for haying. Assumptions regarding yields and farm sizes affect the following calculations very little.

The acreages assumed are 400 acres of corn and 750 acres of wheat. These acreages make the cost estimates for wheat straw somewhat cheaper than corn stover on a per-ton basis because total hours of usage will be greater over the 10-year life of the equipment. This effect is negligible because farmers seldom keep equipment for a preplanned length of time. These acreage assumptions provide a reference point rather than a generalization about costs, average farm sizes, or average crop plantings.

This section includes cost estimates and an explanation of their derivation and related information. To estimate costs, each operation was divided into the four factors of production: land, labor, capital, and management. No cost is assessed to land because it is an input into production of grain, oilseeds, etc., and residues are not charged for land to avoid double counting. A $4.00/h return to labor is assumed throughout. This is $0.25 higher than the estimate presented by Edwards and Stoneberg (1979). Operating and fixed costs for machinery were estimated using worksheets from the Cooperative Extension Services of Iowa, Missouri, and Oklahoma (Edwards and Stoneberg 1979; Workman 1975; Nelson and Kletke 1978). A return to management of approximately 8% is also built into the estimates. The costs presented are based on current 1979 prices for new machinery only. These estimates do not represent average charges for the existing stock of harvesting equipment and do not reflect opportunity costs for other farm activities.

Yields of harvestable corn stover, meaning that amount which can be "safely" removed and still be within the soil loss tolerance limits set by the Soil Conservation Service, are assumed to be 1.5 ton/acre. This is a conservative estimate based upon figures of 1.45 ton/acre for conventional tillage and 1.91 ton/acre with conservation tillage which were reported by Flaim (1979). Wheat straw yields are assumed to be 1 ton/acre. This estimate is based on 0.81 ton/acre with conventional tillage and 1.30 ton/acre when conservation tillage practices are followed. Therefore, one may expect potential yields for residues harvested following conventional tillage practices to be slightly lower and the cost per ton to be slightly higher than those estimated here. For conservation tillage one would expect that the estimated yields are understated and, consequently, the costs per ton are overstated for the farm sizes under consideration.

Custom hay harvesters may use their equipment more fully by collecting residues. Custom operators could start collecting residues shortly after the grain harvest begins. Alternatively, if the grain is custom-harvested, the farmer who owns haying equipment could follow the custom operator. Either alternative allows the landowner maximum utilization of his land and equipment and the choice of avoiding a shortage of labor on the farm. Custom rate charges are presented for comparisons with our cost estimates.

Table 2-1 summarizes the cost estimates for harvesting corn stover in Iowa. Table 2-3 summarizes the cost estimates for wheat straw harvesting in Oklahoma. Both tables include all five systems under examination and present average costs per ton for each system. Tables 2-2 and 2-4 present the custom harvest costs of conventional baling, big round baling, and stacking. No custom charges were available for on-farm hauling in Iowa or for stack hauling in Oklahoma. These costs were taken from estimates in Tables 2-1 and 2-3 to provide a total custom collection cost per ton.

2.2 CORN STOVER HARVESTING COST ESTIMATES

The cost per ton of harvesting and transporting corn stover on-farm in Iowa with a 3-ton stacker is estimated to be $15.37 (Table 2-1). The cost of machinery is the largest cost, and this figure would decline as total annual tonnage exceeds 600 tons. Smaller stackers would be more efficient if smaller annual tonnages were collected. Larger stackers are more efficient for larger tonnages and larger fields.

Table 2-1. COST ESTIMATES FOR CORN STOVER HARVESTING[a,b]

Harvesting System	Mow	Rake	Windrow	Package	On-farm Haul[c]	Total Cost ($/ton)	Total Cost ($/MBtu[d])
Three-ton stack	—	—	4.40	6.21	4.76	15.37	1.18
Big round bale	2.80	1.82	—	6.35	5.96	16.93	1.30
Conventional bale	2.80	1.82	—	10.06	9.49	24.17	1.86
Loose chop	—	—	—	6.96	5.67	12.63	0.97
Big rectangular bale	—	2.03[e]	4.44	10.88	8.50	25.85	1.99

[a] If a power unit is required, it is included in the cost estimate.

[b] The machinery complement should be matched to a specific set of circumstances. The use of a complement does not necessarily imply that the authors recommend it.

[c] The hauling distance is assumed to be one mile.

[d] Based on 13 x 10^6 million Btu/ton of residue.

[e] Mow and rake operations usually substitute entirely for the windrow operation. Raking is required in addition to the windrow operation for big rectangular bales because of the large pick-up capacity of this baler.

On-farm storage of stacks would require only land to set them on; no cover is required. This involves little or no cost during the winter. Unless the farmer has idle land normally, the opportunity cost of the land will be prohibitively high in the spring and summer. For the farmer who lacks excess labor, stacks are an excellent option.

Big round bales cost approximately $16.93/ton for collecting, packaging, and on-farm hauling. The cost appears to be competitive with stacks unless very large acreages are harvested. Round bales have the advantage of being more dense than stacks and, since they are wrapped with twine, there is less chance of a round bale falling apart. A smaller tractor can be used to pull the baler than to pull a stacker. Capital costs are approximately the same as for the stacker, but operating costs are higher. A farmer who is capital-short may fare better with a big round baler rather than a stackwagon. Storage for both is simply a matter of figuring the opportunity cost of the land for the storage time.

Conventional baling systems are most efficient for tonnages smaller than 600 tons annually. The cost for harvesting 600 tons with conventional bales is $24.17/ton. While costs of the other systems increase as annual tonnages decrease, a conventional baling system will have virtually the same cost per ton whether 100 or 500 tons are collected annually. This system is the most labor-intensive and is best suited for farms with labor available. Storage costs are higher because these bales require cover to maintain their quality except in arid regions. Advantages of these bales are higher density and stackability.

Loose chop collection is the cheapest method of transporting a ton of residue to a central on-farm location. It costs only $12.63/ton. Its disadvantage is its loose form. Problems with storage and harvesting appear too large to overcome unless a densifier can be used on, or near, the farm to facilitate handling, storage, and transport.

The cost of harvesting and on-farm hauling of giant rectangular bales is $25.85. The lowest cost per ton for this system is for an annual harvest greater than 600 tons. It is competitive with the other systems on very large farms that have little or no excess labor. The machinery complement includes an accumulator that can be used for hauling the bales or dropping them in groups of three. These bales require covering similar to conventional bales and have the advantages of being stackable and denser than the other three systems. Pickup capabilities are highest for this system, and labor use is the lowest per ton.

2.3 CUSTOM HARVESTING COSTS FOR CORN STOVER

Two sets of custom rates are examined in this section (Table 2-2). The first is based on Oklahoma custom rates. A custom rate charge for on-farm hauling was available. These rates provide an estimate of the total charge by a custom operation for the collection and on-farm hauling of crop residues. The rates are state averages obtained by the Extension Services.

The cost for collection and on-farm hauling based on Oklahoma rates for a stackwagon, big round baler, and conventional baler are $16.70, $17.53, and $21.77/ton, respectively. No estimates were available for loose chop systems because few farmers hire custom operators for forage harvesting and hauling. There were no custom charges available for the giant rectangular baling system because it is a new machine. One would expect custom charges to be higher than a farmer's out-of-pocket harvesting costs. The reasons for this unexpected result with conventional baling system are the hourly wage rates assumed and the size of the automatic bale wagon used in the previous estimates.

Custom charges for collection and on-farm hauling for stackers, big round balers, and conventional balers in Iowa are $16.86, $20.13, and $21.99, respectively. Comparing custom charges shows how much costs vary between locations. Custom charges for corn stover harvesting in Iowa and Indiana were $23.00 and $18.10 for 3-ton stacks, $11.90 and $7.70 for large round bales, and $8.84 and $9.48 for loose chop harvesting (Abdallah 1978).

Table 2-2. CUSTOM CHARGES FOR CORN STOVER HARVESTING IN IOWA AND OKLAHOMA

Harvesting System	Mow	Rake	Windrow	Package	On-farm Haul	Total Cost ($/ton)	Total Cost ($/MBtu[a])
Iowa:[b]							
Three-ton Stack	—	—	5.60	6.50	4.76[c]	16.86	1.30
Big round bale	—	—	5.60	8.57	5.96[c]	20.13	1.55
Conventional bale	—	—	5.60	6.90	9.49[c]	21.99	1.69
Oklahoma:[d]							
Three-ton stack	3.22	2.05[e]	—	6.67	4.76[c]	16.70	1.28
Big round bale	3.22	2.05	—	9.10	3.16	17.53	1.35
Conventional bale	3.22	2.05	—	9.60	6.90	21.77	1.67

[a] Based on 13×10^6 MBtu/ton of residue.

[b] Edwards and Stoneberg 1979.

[c] Estimated because no custom rates were available.

[d] Nelson and Kletke 1978.

[e] Mow and rake operations substitute for windrow operations.

Large amounts of corn stover can be collected for less than $20/ton and, as harvested acreage increases, fixed costs decrease on a per-ton basis. This is also true of custom rates. Generally, higher custom rates are charged because of travel time involved in transporting machinery to someone else's land. If the acreage to be harvested is very small, custom operators may even decline to come unless they are paid a premium above their usual charge.

2.4 WHEAT STRAW HARVESTING COST ESTIMATES

The systems that were examined for the collection of corn stover in Iowa are examined for the collection of wheat straw in Oklahoma, including the three systems used in the section on custom rates. Costs for the stack system are $15.99/ton (Table 2-3). The advantages and disadvantages of stack systems for wheat straw harvesting parallel those for corn stover harvesting. Straw stacks do not hold together well, however, which may lead to higher storage losses. The cost for the big round bale system is $16.52/ton. The costs for harvesting with the conventional system, loose chop, and giant rectangular bales are $21.49, $14.11, and $20.43, respectively. Harvesting costs reported by Koelsch ranged from $18.60 to $21.00/ton in Kansas because of lower yields (Koelsch et al. 1977). The cost per ton for giant rectangular bales declined more than $5.00 with an 150-ton increase in annual tonnage harvested. The big bale system is particularly advantageous for large acreages and users that handle a large volume of hay.

Table 2-3. COST ESTIMATES FOR WHEAT STRAW HARVESTING[a,b]

Harvesting System	Swath ($/ton)	Package ($/ton)	On-farm Haul[c]/$/ton	Total Cost ($/ton)	Total Cost ($/MBtu)
Three-ton stacks	4.89	6.48	4.62	15.99	1.23
Big round bales	3.18	6.03	7.31	16.52	1.27
Conventional bale	3.18	9.28	9.03	21.49	1.65
Loose chop	—	9.25	4.86	14.11	1.09
Big rectangular bale	4.89	9.14	6.40	20.43	1.57

[a] If a power unit is required, it is included in the cost estimate.

[b] The machinery complement should be matched to a specific set of circumstances. The complement used is not meant to imply that the author recommends it.

[c] The hauling distance is assumed to be one mile.

2.5 CUSTOM HARVESTING COSTS FOR WHEAT STRAW

Harvest and on-farm hauling cost per ton of wheat straw by custom operators using a stackwagon, big round baler, and conventional baler in Oklahoma are $16.24, $19.36, and $23.99, respectively (Table 2-4). For the same three systems the Iowa costs are $16.72, $23.05, and $22.30. Cost for conventional bales was $0.09 less per bale (approximately 50 lb) in Iowa.

Table 2-4. CUSTOM CHARGES FOR WHEAT STRAW HARVESTING IN IOWA AND OKLAHOMA

Harvesting System	Mow	Rake	Swath	Package	On-farm Haul	Total Cost ($/ton)	Total Cost ($/MBtu[a])
Iowa:[b]							
Three-ton stack	3.10	2.50	—	6.50	4.62[c]	16.72	1.29
Big round bale	3.10	2.50	—	10.14	7.31[c]	23.05	1.77
Conventional bale	3.10	2.50	—	7.67	9.03[c]	22.30	1.72
Oklahoma:[d]							
Three-ton stack	—	—	4.95[e]	6.67	4.62[c]	16.24	1.25
Big round bale	—	—	4.95	10.70	3.71	19.36	1.49
Conventional bale	—	—	4.95	10.67	7.67	23.29	1.79

[a] Based on 13 x 10^6 MBtu/ton of residue.

[b] Edwards and Stoneberg 1979.

[c] Estimated because no custom rates were available.

[d] Nelson and Kletke 1978.

[e] Swath operations substitute for mowing and raking.

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SECTION 3.0

CONCLUSIONS

Costs presented in the previous section are based upon assumptions concerning acreages harvested and common operating practices. These figures should give a close approximation of costs and a range of prices that farmers should be willing to expect from custom harvesting crop residues. A farmer who treated residue collection as another enterprise in its own right would raise total farm production costs, including the cost of residue collection, but adoption of minimum tillage practices would offset these cost increases. Costs also could be reduced below the estimates presented here if combines were adapted to windrow the residue that they throw out. That would save at least one trip through the field and eliminate the need for a mower and possibly even a rake. This could lower costs between $3.00 and $5.00/ton.

As an energy source, crop residues could be collected immediately and relatively common methods of hay harvesting could be used. These costs do not account for any adaptation of equipment, skills, or knowledge to residue collection. Because adjustments would be made in the future to better handle residues, it is unlikely that these costs would rise substantially in the near-term. Before any collection begins, a market for the residues must be established, whether it is farms, utilities, or industrial conversion into liquid fuels.

Residue harvesting machinery can be greatly improved. These cost estimates are based on four separate machine operations over the field for harvesting. Packages could be more densified; i.e., stackers with compression chambers would likely create stacks that are more weather resistant and would hold up better under transport. Whole crop harvesting systems could be developed which could lower residue collection costs. Companies could become involved in material standarization by leasing equipment or acting as a custom operator.

Collection cost estimates varied from a low of $12.63/ton for loose chop harvest of corn stover to $25.85/ton for the giant rectangular bale system. Although loose chop is examined in this report, it is not presently considered a viable alternative because of high storage and handling costs. If loose chop harvesting is not considered, the lowest cost system is $15.37/ton of corn stover harvested by the stackwagon system. A system similar to this has already been used experimentally in Iowa for corn stover and in Kansas for wheat straw (Buchele 1976; Center for Energy Studies 1977). This system, given the present situation, offers what appears to be the best alternative for beginning large scale harvest of residues. The next most expensive systems are big round bales and large rectangular bales. Big round bales are likely to be used on small to large size farms. Giant rectangular bales are probably the best choice for very large farms. Conventional baling is a feasible option only on small acreages.

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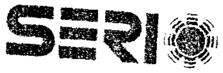
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APPENDIX

Table A-1. MACHINERY COSTS AND CHARACTERISTICS FOR HARVESTING AGRICULTURAL CROP RESIDUES

August 1979

Machine[a]	Package Size[b]	Companies[c]	Approximate List Price[d] (in $000)	Approximate Cost of Operation ($/ton[e])			Minimum Horsepower Tractor[g]	Pickup Capability (ton/h)[g]	Labor (man-h/ton)[g]	Fuel Usage (gal/h)[g]
				Fixed	Variable	Total				
Stackers (compressed)	_3 ton	Hesston, Owatonna, Moeller	9.0-14.0	3.69	3.72	7.41	60	6.5	0.15	3.0
Stackers (compressed)	_3 ton	Hesston, John Deere, Moeller	20.0	4.83	1.81	6.64	90	7.5	0.13	4.2
Stackers (loose)	_4 ton	Haybuster, Farmland, Owatonna Lundell	12.0-14.0	3.65	3.79	7.44	60	6.5	0.16	3.0
Stackers (loose)	_4 ton	Haybuster, McKee, Farmland, Moeller, Owatonna, Gehl	20.0	4.60	1.84	6.44	90	7.5	0.14	4.2
Big round balers	_1,400 lb	Vermeer, Hawkbilt, Hesston New Holland	5.5- 6.5	2.42	1.77	4.19	40	6.5	0.14	3.0
Big round balers	_1,400 lb	Vermeer, Gehl, New Holland International, Hesston, Massey Ferguson, John Deere	7.5- 9.0	2.42	2.08	4.50	50-60	7.5	0.13	3.6
Conventional rectangular balers (medium-duty)	_90 lb	Owatonna, John Deere, Hesston, International, New Holland, Freeman, Massey Ferguson	5.0- 6.5	1.92	1.64	3.56	25-35	6.4	0.16	2.8
Conventional rectangular balers (heavy-duty)	_70 lb	Owatonna, John Deere, Hesston, International, New Holland, Freeman, Massey Ferguson	6.0- 7.0	1.92	2.98	4.90	40	8.0	0.13	3.2
Big square baler and accumulator	_1,500 lb	Hesston, Howard Rotovator	30.0	8.34	1.54	9.88	100	14.0	0.1	6.0
Flail chopper	—	International, John Deere, New Holland	4.0	3.21	1.92	5.13	40-50	4.8	0.22	1.7
Forage Wagon[i]	_6 ton	International, John Deere, Massey Ferguson, New Holland	4.0- 7.0	2.36	2.41	4.77	40-50	—	—	—
Stackmover[h,i]	_4 ton	Hesston, John Deere	3.0- 4.0	1.49	2.24	3.73	60	5.0	0.15	3.9
Stackmover	_4 ton	Hesston, John Deere, Farmland	9.0	1.70	2.48	4.18	65		0.13	4.5
Round bale mover (single)[i]	any	Hesston, International	0.1- 0.3	1.81	3.61	5.42	20-80	2.5	0.40	2.4
Multiround bale mover[i]	any	Hesston, Farmland, Schwartz, Dow Eze	4.5	1.75	2.41	4.16	55	2.5	0.40	3.5
Bale wagon	conventional bale	Freeman and others	12.0-14.0	3.17	1.73	4.90	50-100	7.0	0.17	3.89

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August 1979

Machine[a]	Package Size[b]	Companies[c]	Approximate List Price[d] (in $000)	Approximate Cost of Operation ($/ton[e])			Minimum Horsepower Tractor[g]	Pickup Capability (ton/h)[g]	Labor (man-h/ton)[g]	Fuel Usage (gal/h)[g]
				Fixed	Variable	Total				
Rake	—	New Holland and others	1.8	0.47	1.53	2.00	20	5.2	0.19	1.00
Mower (PTO)	—	Many	1.5	1.10	2.13	3.23	20-60	3.7	0.27	1.30
Windrower (PTO	—	Hesston, Owatonna	5.0	2.27	2.13	4.40	30	4.9	0.20	2.94
Windrower (SP)	—	Hesston, Owatonna	14.0	3.61	0.83	4.44	-	6.9	0.15	4.20
Tandem rake	—	New Holland and others	4.6	1.92	0.75	2.67	60	10.0	0.10	1.20
Swather (SP)	—	Massey Ferguson and others	15.0-22.0	3.93	0.97	4.90	-	11.0	0.16	4.40
Swather	—	Massey Ferguson and others	—	1.12	1.39	2.51	30	8.9	0.11	4.90

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[a] If the implement does not contain a power source, a power unit is added for all cost estimates.

[b] These are based on maximum capacities. In virtually all cases smaller packages can be made.

[c] This list is not all inclusive. It merely mentions firms that have provided literature, cost, or other information.

[d] These prices will vary between retailers, companies, and optional equipment selected.

[e] Costs will vary with tonnage, optional equipment, type of crop, and field sizes.

[f] Diesel fuel price is assumed to be $0.80 per gallon.

[g] Based on manufacturer specifications, Missouri Farm Planning Handbook (Missouri Cooperative Extension Service 1979), Nebraska Tractor Tests (Nebraska Cooperative Extension Service), and Doane's Agricultural Report (1979).

[h] Hesston manufactures stackmovers designed for highway use.

[i] On-farm hauling distances are assumed to be one mile.

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

Five different systems for collecting agricultural crop residues are examined: conventional bales, big round bales, big rectangular bales, stackwagons, and loose chop. The stackwagon system had the lowest costs per ton for both a 400-acre corn harvest and a 750-acre wheat harvest. Big round bales are less expensive than the stackwagon system under certain circumstances. Big rectangular bales are competitive when larger acreages are harvested. Conventional bales appear competitive on small acreages where on-farm labor is not a constraint. Loose-chop harvesting systems are not feasible unless transportation distances are short. Custom rates for three systems (conventional bale, big round bale, and stackwagons) are examined to confirm the ordinate ranking of system costs. The custom rates and cost estimates are based on farms located in central Iowa and central Oklahoma, the sample farming situations that are examined in other research in the Analysis Division of SERI. Costs only represent costs for new equipment. These estimates do not represent average charges for the existing stock of harvesting equipment and do not reflect opportunity costs for other farm activities.

17. Document Analysis

a. Descriptors Crop Residues ; Agriculture ; Harvesting ; Cost ; Wheat ; Maize ; Labor ; Management ; Capital

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