ECONOMIC FEASIBILITY

The various aspects of rice straw incorporation have been discussed in relation to soils, cultural considerations and stem rot disease. It is recognized that unless management is attentive to the technical issues of rice straw incorporation great potential exists for difficulties. Outside of these issues, the rice grower is faced with the management of the machinery system which will facilitate the rice residue disposal operation. Either in conjunction with, or subsequent to, harvesting the rice grain, the farmer will have to deploy labor, equipment, and cash towards preparing his field for the next season's crop. This section of the report discusses the incorporation options which are available to rice growers in terms of management and costs. A cost comparison of standard residue disposal and rice straw incorporation systems is presented.

Management

Rice straw incorporation has been accomplished under experimental field conditions and by interested growers seeking to alleviate pollution problems related to open-field burning. Field studies show distinctly that an incorporation system requires both a straw reduction and spreading operation prior to tillage (Burkhardt et.al., 1975; Miller et.al., n.d.; Wick, 1979). Early incorporation trials employed combine-attached straw choppers which also spread the straw. The best results for straw reduction have been obtained with an Allis Chalmers (AC) Model 782 shear-bar forage chopper, modified with a deflector to spread the chopped straw back onto the field (Burkhardt et.al., 1975). Unlike other machines tested, the AC 782 is able to handle rice straw at any moisture content; although wet straw will cause clogging problems.

A combine-attached chopper results in decreased harvester efficiency. Growers are reportedly reluctant to mount choppers on their combines since most combines don't have the reserve engine power required to handle chopping without reducing harvester performance (Miller et.al., n.d.). Also, the operational problems created by this attachment is burdensome during the very critical harvest procedure. At the present time, new combines are equipped with detachable spreaders. If straw reduction is to be accomplished by a separate operation, there would be no need for spreading behind the harvester unit. The Copley International Corporation survey of rice growers indicated that 87 percent of Sacramento Valley rice farmers spread their straw (Question 15). Only 51 percent of San Joaquin Valley growers are believed to perform this spreading operation.

Many combinations of machinery systems are available to rice growers if they are determined to incorporate their rice straw. Field interviews with rice farmers who had experimented with incorporation revealed that none of them were satisfied with their equipment's ability to produce a good seed bed. Problems related to clogging and downtime for equipment repairs were particularly aggravating. In addition, some fields were so deeply rutted from bankout wagon traffic during harvesting that only large, track-layed equipment could be used for initial seed bed preparation in the spring.

Both the Agricultural Extension Service and the University of California, Davis, have experimented with rice straw incorporation on representative soils under diverse weather weather conditions* (Burkhard et.al., 1975; Wick, 1979). These soils are not the most difficult soils to till in the rice-growing districts; however, Copley International Corporation has rated them as "least suitable" for incorporation. Various incorporation systems have consisted of disking, moldboard plowing and rotovating treatments with or without a prior straw reduction operation. Studies show that incorporation of rice straw is feasible under certain conditions. One study reports that:

> It has been demonstrated that, under the extremely wet weather conditions encountered in 1972-73 or the more favorable conditions of 1971-72, satisfactory incorporation can be accomplished, at least in the two soil types studied, provided the straw is chopped into short lengths (e.g., 1½ to 4 inches) and spread over the field. The type and number of tillage operations can be the same as would be used after burning, and soil moisture requirements are about the same. Chopping must be done at a time when the soil is firm enough to support the equipment. (Kepner et.al., 1973)

The two-year incorporation trials included two tests conducted at separate locations: one in Colusa County and the other in Sacramento County. During the wet year (1972-73), only the straw reduction and spreading operation could be accomplished at the Colusa County site. Additionally, the Colusa grower who initiated the incorporation program could not complete any of

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*Soil types include Stockton clay, Sacramento clay loam and Freeport clay loam.

Table 4.14

SUMMARY OF 1972-73 INCORPORATION TREATMENTS AND RESULTS

Trial	Operations[a]		Final Condition (just before flooding)	
No.	Fall	Spring	Amt. Trash showing[b]	Pulverization
Sacramento County experiment (stubble heights mostly 8-18 cm (3-7 in.), some down flat; all operations done April 11-28)				
1		BD	Moderate	Fair (lots of 8-15 cm (3-6 in.) clods, and high percentage of soil in clods over 1.7 cm (3/4 in.))
2		CD	Moderate	
3		DR	Moderate	A little more finely pulverized soil than in Nos. 1 and 2, but about the same maximum clod size
All above treatments were subsequently disked twice about 10 cm (4 in.) deep, landplaned, and finally chisel cultivated in applying aqua ammonia. The second disking in No. 3 could have been omitted. It has little effect on final coverage or pulverization.				
Colusa County experiment (stubble heights mostly 20-35 cm (8-14 in.); yield = 7800 kg/ha (7000 lb/a): operations done October 27-31 and April 18-25)				
4	B	P	Moderate	Fair (some 13-18 cm (5-7 in.) clods)
5	B	dP	Moderate	Good (not many clods over 13 cm (5 in.))
6	BD	P	Very little	Good
7	C	P	Considerable	Fair
8	C	dP	Moderate	Fair
9	CD	P	Considerable	Fair
10	M	P	Very little	Excellent
11	MD	P	Very little	Excellent
12	MR	P	Very little	Excellent
13	CR	P	Moderate	Good
14	CR	R	Moderate	Excellent
15	CR	RR	Very little	Excellent
16	CR	dR	Very little	Excellent
Treatments 4-13 were subsequently disked once about 10 cm (4 in.) deep, floated and finally spike-tooth harrowed. Spike-tooth harrowing was the only subsequent tillage treatment in Nos. 14-16.				

Treatments 1 and 4 represented the sequences used by these growers in this abnormally wet year.

[a] B = burned; C = straw chopped with AC forage choppers; M = stubble and straw shredded with special flail-type shredder; D = stubble-disked 15-18 cm (6-7 in.) deep; d = regular-disked about 10 cm (4 in.) deep; P = moldboard plowed 18-20 cm (7-8 in.) deep; R = rotary tilled 10-15 cm (4-6 in.) deep, 28 cm (11 in.) bite length.

[b] Pieces of straw and stubble and some small pieces of root clumps.

Source: (Burkhardt et. al., 1975)

the normal fall tillage operations on his other fields due to inclement weather. At the Sacramento Valley test site, all fall burning, chopping and tillage was prevented by wet soil conditions. At both test locations, straw disposal and tillage operations were accomplished in the spring with good results (Burkhardt et.al., 1975).

Table 4.14 provides a summary of final seed bed conditions following the 1972-73 incorporation treatments.

It was concluded that a chopping operation in combination with rotary tillage or disking provided good straw-soil contact during fall tillage operations; however, the rotary tillage promoted better stubble-soil contact than disking. The rotary tillage operation required substantially more energy output than stubble disking. Under wet soil conditions, neither rotary tillage nor disking were possible.

In light of the constraints imposed on incorporation systems such as weather, restrictive soil types and stem rot disease, it is important for farm operators to develop a system that minimizes these problems without a substantial investment in new equipment. The number and size of tractors and implements will vary with farm size. Shown in Table 4.15 is the typical equipment which is used under the present system of open-field burning. In Table 4.16, an equipment list is provided for a representative incorporation system.

A comparison of these tables reveals that the straw incorporation system requires two additional operations not encountered

Table 4.15

EQUIPMENTS LIST REQUIRED FOR RICE RESIDUE DISPOSAL AND SEED BED PREPARATION UNDER OPEN-FIELD BURNING[a]

	Time of Year	Operation	Number of Times	Tractor (DBHP)[b]	Implements
1	October-November	Disk	1	90 HP	Stubble Disk, 10'
2	March	Plow	1	135 HP (4 W D)	Moldboard Plow, 6'x16' (Chisel Plow, 12')
3	March	Disk	2	135 HP (4 W D)	Offset Disk, Heavy Duty, 21'
4	March	Level	2	85 HP (Crawler)	Finish Level, 12'x45' (Triplane, 15' x 35')
5	April	Float	1	90 HP	Float 12'
6	April	Disk	1	85 HP (Crawler)	Tandem Disk, 12' (Spike-tooth Harrow, 32')

[a] Considered to be typical operating conditions for Sacramento Valley for a farm size of 700 acres and rice acreage of 400 - 600 acres.

[b] Tractor requirements rated at draw bar horsepower.

Source: (University of California, Davis, "Budget Generator", 1980)

Table 4.16

EQUIPMENT LIST REQUIRED FOR RICE STRAW INCORPORATION AND SEED BED PREPARATION[a]

	Time of Year	Operation	Number of Times	Tractor (DBHP)[b]	Implements
1	October-November	Straw Reduction	1	90 HP	Forage Chopper, 15'
2	October-November	Plow	1	135 HP (4 WD)	Moldboard Plow, 6'x16'
3	March	Disk	1	135 HP (4 WD)	Stubble Disk, 10'
4	April	Chisel	1	135 HP (4 WD)	Chisel Plow, 12'
5	April	Disk	2	135 HP (4 WD)	Offset Disk, Heavy Duty, 21'
6	April	Level	2	85 HP (Crawler)	Finish Level, 12'x45' (Triplane, 15'x35')
7	April	Float	1	90 HP	Float 12'
8	April	Disk	1	85 HP (Crawler)	Tandem Disk, 12' (Spiketooth Harrow, 32')

[a] Considered to be suitable for farm size of 700 acres and rice acreage of 400 - 600 acres.

[b] Tractor requirements rated at draw bar horsepower.

Source: Adapted from (Burkhardt et.al., 1975) and (Webster et.al., 1979). A combination of tillage operations which correspond to a "fall plow" system. (University of California, Davis, "Budget Generator", 1980) Copley International Corporation in open-field burning. The straw incorporation system corresponds to a "fall plowing" which is suggested to minimize stem rot inoculum levels (Webster et.al., 1974). The incorporation system presented here is slightly different from the system studied by Webster et.al. (1974). It assumes that two less diskings would be required to establish suitable seed bed conditions. Burkhardt et.al. showed that reasonable seed bed conditions can be obtained under a variety of equipment combinations. In any event, there will always be diversity among the types of field operations employed by farmers. The incorporation system presented in Table 4.13 could be employed in most of the rice acreage in California. There will undoubtedly be a substantial number of farm operators who do not own the complement of tractors listed under the "fall plow" incorporation system, particularly those owning small farms.

Costs

If the waste burning of rice straw is prohibited, the most important consideration to rice growers will be whether or not they can afford to incorporate rice straw. A comparison of the costs of rice straw disposal indicate that open-field burning represents a \$43.83 per-acre cost advantage over the rice straw incorporation. (These figures do not include the forgone revenue losses should stem rot disease induce yield declines.) Tables 4.17 and 4.18 show the per-acre costs of rice straw disposal by open-field burning and rice straw incorporation, respectively.

It is shown in Table 4.17 that open-field burning and subsequent seed bed preparation activities cost \$119.87 per acre.

Table 4.17

PER ACRE COST OF RICE RESIDUE DISPOSAL AND SEEDBED PREPORTION FOR OPEN-FIELD BURNING[a]

Operation	Tractor ($/acre)		Implement ($/acre)		Labor[e] ($/acre)	Total Cost of Operation ($/acre)
	Fixed[c]	Variable[d]	Fixed[c]	Variable[d]		
Fall open-field burning						$ 2.10[b]
Fall stubble disk	$ 1.51	$ 2.79	$ 2.33	$ 2.10	$ 2.80	11.53
Spring plow	3.71	6.36	6.68	1.87	3.10	21.72
Spring offset dish (2x)	5.92	10.17	8.94	4.60	5.40	35.03
Level (2x)	10.89	9.78	4.94	1.20	8.80	35.61
Float	.74	1.37	.12	.06	1.54	3.83
Disk harrow	3.25	2.92	.73	.79	2.36	10.05
TOTAL	$26.02	$33.39	$23.74	$10.62	$24.00	$119.87

[a] Figures based on 700-acre farm with 400 - 600 acres of rice. Costs are in 1980 dollars.

[b] Cost for open-field burning obtained 775 observations reported by rice growers. The figure includes all types of burning.

[c] Fixed costs include depreciation, interest (12%), and taxes and insurance (2.5%)

[d] Variable costs include fuel and repairs.

[e] Labor costs at $7.50 per hour

Source: (University of California, Davis "Budget Generator", 1980)
Copley International Corporation

Table 4.18

PER ACRE COST OF RICE STRAW INCORPORATION AND SEED BED PREPARATION[a]

Operation	Tractor ($/acre) Fixed[c]	Tractor ($/acre) Variable[d]	Implement ($/acre) Fixed[c]	Implement ($/acre) Variable[d]	Labor[e] ($/acre)	Total Cost of Operation ($/acre)
1 Straw reduction[b]	$ 2.33	$ 4.29	$ 7.20	$ 4.50	$ 1.50	$ 19.82
2 Fall plow	3.71	6.36	6.68	1.87	3.10	21.72
3 Spring stubble disk	1.51	2.79	2.33	2.10	2.80	11.53
4 Chisel plow	8.83	15.16	.94	.85	2.45	28.23
5 Spring offset disk (2x)	5.92	10.17	8.94	4.60	5.40	35.03
6 Level (2x)	10.89	9.78	4.94	1.20	8.80	35.61
7 Float	.74	1.37	.12	.06	1.54	3.83
8 Disk harrow	3.25	2.92	.73	.79	2.36	10.05
TOTAL	$37.18	$52.84	$31.88	$15.97	$27.95	$165.82

[a] Figures based on 700-acre farm with 400 - 600 acres of rice. Costs are in 1980 dollars.
[b] Implement cost applies to a field forage chopper and are in 1978 dollars.
[c] Fixed costs includes depreciation, interest (12%), and taxes and insurance (2.5%).
[d] Variable costs include fuel and repairs.
[e] Labor costs at $7.50 per hour.

Source: (University of California, Davis, "Budget Generator", 1980)
(Reed, 1978)
Copley International Corporation

If variable costs are considered alone, the resulting per-acre cost would amount to $68.01. The variable costs refer to all out-of-pocket costs such as fuel, repairs, labor and miscellaneous items. The overhead or fixed costs, including depreciation, insurance, interest on borrowed capital, and taxes, increase the per-acre cost by $51.86.

The cost to incorporate and prepare a seed bed is calculated to be $165.82 per acre. All of the tillage operations can be accomplished with equipment already available on the farm. An investment of approximately $9,000 (1978 cost) would be required for a field forage chopper (Reed, 1979). This forage chopper would facilitate straw reduction from a windrowed condition.

The costs to incorporate and prepare a seed bed were taken from standards derived for normal tillage in rice fields. For instance, the cost to stubble disk for incorporation is the same as the cost under open-field burning. It is likely that this would result in an understatement of incorporating costs, particularly with respect to labor and other variable costs. Additional maintenance and repair on equipment will be necessary, and field efficiency will be lowered in comparison to tillage operations associated with open-field burning.

The potential for incorporation of rice straw is dependent upon grower attitudes to a great extent. It is certain that, unless open-field burning is prohibited, growers will not voluntarily initiate rice straw incorporation practices.

SUMMARY

It becomes apparent from the analysis in this section that rice growers will not voluntarily initiate straw incorporation while open-field remains an alternative disposal method. A number of serious technical constraints would render straw incorporation infeasible for the majority of farms within the rice growing area. Many of the soils have high-clay contents which would play havoc with farm machinery under wetted conditions. A large portion of the remaining soils have shallow underlying layers which would further impede the incorporation process.

The potential repercussions from incorporating rice straw include a variety of cultural considerations. Yield depression in subsequent crops can be caused by nitrogen deficiency, seedling toxicity or a buildup of stem rot inoculum. Additional problems include a buildup of foreign materials throughout the irrigation system and the formation of a matted layer which will hamper farm implements used for the seed bed preparation of subsequent crop.

Economically, there is no incentive for the rice grower to incorporate his rice straw. Although the majority of equipment needed for incorporation would likely be owned by the farmer, an investment of approximately $10,000 for a rice chopper would be required in all cases. Additional costs for fuel, repairs, labor and management make rice straw incorporation an expensive proposition. All things considered, rice straw incorporation appears to offer no advantage over other utilization and disposal methods.

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RICE STRAW COLLECTION AND REMOVAL

Presently, there is very little demand for rice straw as a food, fiber, and energy source due to its limited availability. Conceptually related to the potential demand for rice straw is the development of a collection system by which the rice straw would be removed from the fields and transported for further processing. The development of collection, handling, and transportation systems which would prove both technically and economically feasible is essential if rice straw utilization is to be a reality in California.

COLLECTION AND HANDLING

Rice straw collection systems fall into two major categories: post harvest and total crop harvest. Post harvest collection systems remove the rice straw which is left by the combine either as loose straw or from a windrowed condition. These systems would likely be some type of cubing or baling operation. Alternately, total crop harvesting implies that both grain and stalk are removed in a single operation. The majority of the data presented is based on field trials with post harvest equipment. Total crop harvesting data are rough estimates, as the prototype equipment has not yet been developed. Considerable research concerning equipment design and subsequent field trials would be required to substantiate the available data.

In theory, all of the systems studied are workable. However, several problems must first be solved. Logistics problems exist due to the abrasive nature of the straw. The straw twists and bends around most conventional harvesting equipment and its rough surfaces prematurely wear down machinery. Weather also seriously hampers the use of more traditional harvesting techniques. With the rice straw harvest occurring in late September and October, drying conditions may be poor, and rain is always a possibility. Soil moisture may be high, causing both slow drying and a serious handicap to field harvesters and bankout equipment. Each of the harvesting systems described below, i.e., cubing, baling, and total crop harvest, assumes optimal conditions. In reality, all three systems are at the mercy of weather, with the possibility that much of the straw cannot be harvested.

Cubing

Limited experimental work with a field cuber and subsequent trials with stationary cubers have indicated that rice straw can be cubed. The limits within which a satisfactory cube can be produced have not been adequately defined. Further experimentation will be required to establish the optimum conditions necessary for cubing rice straw.

Technical Feasibility. The Papakube densifying system appears to afford the greatest promise for effective cubing of rice straw. It can cube at a rate of eight to ten tons of rice straw per hour and does not require any type of binder additive.

This cubing system can be utilized effectively in several ways. As a self-propelled cuber, it is driven through the field and cubes directly from the divided windrow left by a combine. The cubes are deposited, by conveyer, to a trailing dump truck and are then ready for storage or transport to a processing plant. The portable (semi-mounted) cuber produces an identical quality cube under a wider variety of operating conditions. The cuber can either be mounted on a flatbed trailer and tractor-pulled or be mounted onto a small cab-driven semi. The latter would prove feasible only where an extensive road system exists on the farm. The rice straw should be spread at the time of harvest by a tractor-pulled swather. The straw will field dry more rapidly under this system, thus eliminating many of the problems of harvesting the rice straw from a windrowed condition. After field drying, the cured straw should be dry chopped, allowing greater ease in handling. The straw is then blown into a bank-out wagon and is hauled and piled up at a convenient location. The cuber is next pulled up to the pile where a conveyer system carries the straw to the cuber. The finished cubes are finally deposited in a dump truck and can be hauled to storage or processing facilities.

Economic Feasibility. Table 5.1 shows the investment, annual overhead and cash operating costs associated with a farmer-owned mobile field cuber. The equipment depicted here

Table 5.1

MOBILE FIELD CUBER

Investment and Overhead Costs

	New Cost	Life	Depreciation	Interest	Other	Total
Cuber[a]	$130,000	12 yrs.	$10,833	$ 7,725	$2,600	$21,158
Dump Truck, 5 ton	35,000	10 yrs.	3,500	2,021	700	6,221
Divide Windrow (Combine Attachment)	2,000	10 yrs.	200	116	40	356
Tractor Mounted Skip Loader	13,286	10 yrs.	1,329	767	266	2,362
Portable Elevator	5,536	10 yrs.	554	320	111	985
Total	$185,822		$16,416	$10,949	$3,717	$31,082

Cash Operating Costs

	Per Hour	Tons Per Hour	Per Ton
Labor[b]	$14.66	9	$1.63
Fuel[c]			
Diesel Tractor	7.92		0.88
Cuber	7.92		0.88
Truck	6.24		0.69
Repairs and Maintenance[d]			
Diesel Tractor	4.59		0.51
Cuber	15.08		1.68
Trucks, Etc.	5.81		0.65
Miscellaneous[e]	3.15		0.35
Total	$70.93	9	$7.27

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[a] System rated at 9 tons per hour (216 H.P. diesel, 4 wheel drive). All costs are expressed in 1980 dollars.

[b] Labor requirements include two men at $7.33 per hour.

[c] Fuel costs include: Diesel tractor, 8 gallons per hour at 99¢ per gallon; Cuber (6V-71), 8 gallons per hour at 99¢ per gallon; Truck, 6 gallons per hour at $1.04 per gallon.

[d] Repairs and maintenance calculated to be 100 percent of new cost over the life of the equipment.

[e] Calculated at 5 percent of the total labor, fuel, and repairs, etc.

Sources: (Mack, 1980)
API Ford Tractor, Denver, Colorado
University of California, 1978
Energy Cube Division, Papakube Corporation
Exxon Oil Corporation, Sacramento, California
(Dobie et al, N.D.)
(Berg, 1980)

could handle large farms under a variety of operating conditions. The cuber has a production capacity of nine tons per hour given average conditions. The limiting factor associated with this system appears to be ability to achieve field drying of the rice straw, as the cuber requires that the straw be of low moisture content. Under normal operating conditions, cash operating costs are expected to be $7.27 per ton. The capital investment required should reach $185,822 with annual overhead costs of $31,082.

Table 5.2 presents the costs for a portable cubing system. The costs associated with this system are higher than those for a mobile cuber but it can operate under a wider variety of conditions. Spread rice straw is field dried much more quickly than the windrowed straw required for mobile cubing. This eliminates much of the risk incurred with field drying which could potentially offset the higher costs involved. Investment costs for this system are expected to be $224,622 while capital costs will be $37,985 annually. Operating costs are assumed to be $8.46 per ton.

Baling

Field baling has been common practice for a variety of straw types for many years. Rice straw baling poses a set of problems not commonly associated with ordinary baling which must be overcome before it can be considered technically and economically viable. Logistics problems include equipment design, handling, and transportation while economic concerns are as diverse as energy, repairs, and management. Baling appears

Table 5.2

SEMI-MOUNTED (PORTABLE) STATIONARY CUBER

Investment and Annual Overhead Costs

	New Cost	Life	Depreciation	Interest	Other	Total
Energy Cube Densifying System[a]	$130,000	12 yrs.	$10,833	$ 7,725	$2,600	$21,158
5th-Wheel Gooseneck (33,000 lb. capacity)	11,500	10 yrs.	1,150	664	230	2,044
Dump Truck, 5 ton	35,000	10 yrs.	3,500	2,021	700	6,221
Tractor Mounted Skip Loader	13,286	10 yrs.	1,329	767	266	2,362
Portable Elevator	5,536	10 yrs.	554	320	111	985
Bankout Wagon (150 cwt)	18,800	10 yrs.	1,888	1,085	376	3,349
Swather (tractor pulled)	10,500	10 yrs.	1,050	606	210	1,866
Total	$224,622		$20,304	$13,188	$4,493	$37,985

Cash Operating Costs

	Per Hour	Tons Per Hour	Per Ton
Labor[b]	$14.66	9	$1.63
Fuel[c]			
Diesel Tractor	7.92		0.88
Diesel Engine	7.92		0.88
Trucks, 2	12.48		1.39
Repairs and Maintenance[d]			
Diesel Tractor	4.59		0.51
Cuber	15.08		1.68
Trucks, Etc.	9.86		1.10
Miscellaneous[e]	3.53	___	0.39
Total	$76.04	9	$8.46

---

[a] System rated at 9 tons per hour (216 H.P. Diesel) and includes: cuber, press wheel, tub mixer, water tank, and metering system. All costs are expressed in 1980 dollars.

[b] Labor requirements include 2 men at $7.33 per hour; includes one man on cuber and one man on truck and trailer.

[c] Fuel costs include: Diesel Tractor, 8 gallons per hour at 99¢ per gallon; Diesel Engine (6V-92), 8 gallons per hour at 99¢ per gallon; 2 Trucks, each 6 gallons per hour at $1.04 per gallon.

[d] Repairs and maintenance calculated to be 100 percent of new cost over the life of the equipment.

[e] Calculated at 5 percent of the total of labor, fuel, repairs, etc.

Sources: (Mack, 1980)
API Ford Tractor Division, Denver, Colorado
University of California, 1978
Energy Cube Division, Papakube Corporation
Exxon Oil Corporation, Sacramento, California
(Dobie et.al., N.D.)
(Berg, 1980)

to afford desirable packaging for utilization by many technologies and although demand for baled straw is uncertain at the present time, the future shows great promise for this system.

Technical Feasibility. Field baling can be accomplished in a number of ways, with an assortment of equipment types, handling systems and final products. The nature of the rice straw dictates, to a large extent, the type of equipment which can be used. Rice straw is rigid and abrasive and is often harvested under muddy field conditions. Balers need to be equipped with flotation gear and reinforced to withstand abrasion. Despite these modifications, they are nevertheless subjected to increased down time and exorbitant repairs.

Baling practices fall into two major categories. The first produces a product which is a rectangular bale. These bales can be bound with either wire tie or twine tie. The wire tie is preferred due to the abrasive nature of the rice straw but either method is acceptable. The second produces large and irregular-shaped bales. Experimentation has been done for several over-sized and high density systems but little data are available. The self-propelled Thompson Baler produces a large round bale and shows the greatest promise.

Custom baling is also an alternative, but perhaps more so from an economic standpoint than as a technologically advanced system. Existing custom baler systems are not specifically suited for rough rice field conditions. Custom baling eliminates the need for the farmer to purchase and maintain his own equipment but this system is inefficient from a technological standpoint. This type of baling is, however, presented in the following economic analysis as an alternative to farmer-owned harvesting systems.

Economic Feasibility. Table 5.3 illustrates the costs associated with custom field baling. Contract baling is performed on a per ton basis with costs expected to average $17.68. It is expected that a price reduction would be available for large farms but, because this would be the result of actual negotiations, a $17.68 price is assumed for all farms. This cost includes roadsiding: piling or stacking the bales at a major road where they could be readily loaded into trucks for transportation.

Table 5.4 presents the overhead and cash costs incurred with a farmer-owned Thompson Baler. Although the new cost is low the annual overhead costs are predicted to be $16,579, due to its short expected life. Cash operating costs will be $6.97 per ton, providing the farm has an adequate road system. On larger-sized farms added logistics problems could be created by this system. The product is both heavy and difficult to handle, making traditional handling systems impractical. Also special consideration needs to be given to the time-frame involved with harvesting. The production rate for this system is the lowest per hour, which will create problems under difficult weather conditions and may necessitate the purchase of additional balers.

Table 5.3

COST OF FIELD BAILING AND ROADSIDING THE DRY STRAW FROM THE WINDROW

Custom Bailing Operation [a]

Operation	Cost Per Ton
Divide windrow[b]	$ .07
Bale[c]	11.07
Roadside[d]	5.54
Miscellaneous	1.00
TOTAL	$17.68

---

[a] This system involves no improvement of the straw as feed, and is only a system that can be handled for feed or for other purposes. All costs are expressed in 1980 dollars.

[b] The windrow splitter is desirable because the standard baler pickup would not adequately handle the large windrows left by the harvester.

[c] Wire-tie bales are preferable for rice straw due to its abrasive nature.

[d] Costs include a one-mile haul on a bankout wagon.

Sources: (Dobie, et. al., N.D.).
University of California, 1976.

Table 5.4

SELF-PROPELLED THOMPSON BALER (FARMER OWNED)

Investment and Annual Overhead Cost[a]

	New Cost	Life	Depreciation	Interest	Other	Total
Baler	$ 40,882	3 yrs.	$13,627	$2,134	$818	$16,579

Cash Operating Costs

	Per Hour	Tons Per Hour	Per Ton
Labor[b]	$ 7.33	5	$1.47
Fuel[c]	4.16		.83
Repairs and Maintenance	14.20		2.84
Twine[d]	7.48		1.50
Miscellaneous	1.66		.33
Total	$34.83		$6.97

---

[a] All costs expressed in 1980 dollars.

[b] Labor costs include 1 man at $7.33/hour.

[c] Fuel costs include baler, 4 gallons per hour at $1.04 per gallon.

[d] Cost calculated at 68¢ per bale at 2.2 bales per ton.

Sources: (Dobie et. al., 1976).
Exxon Oil Corporation, Sacramento, California.

Total Crop Harvest

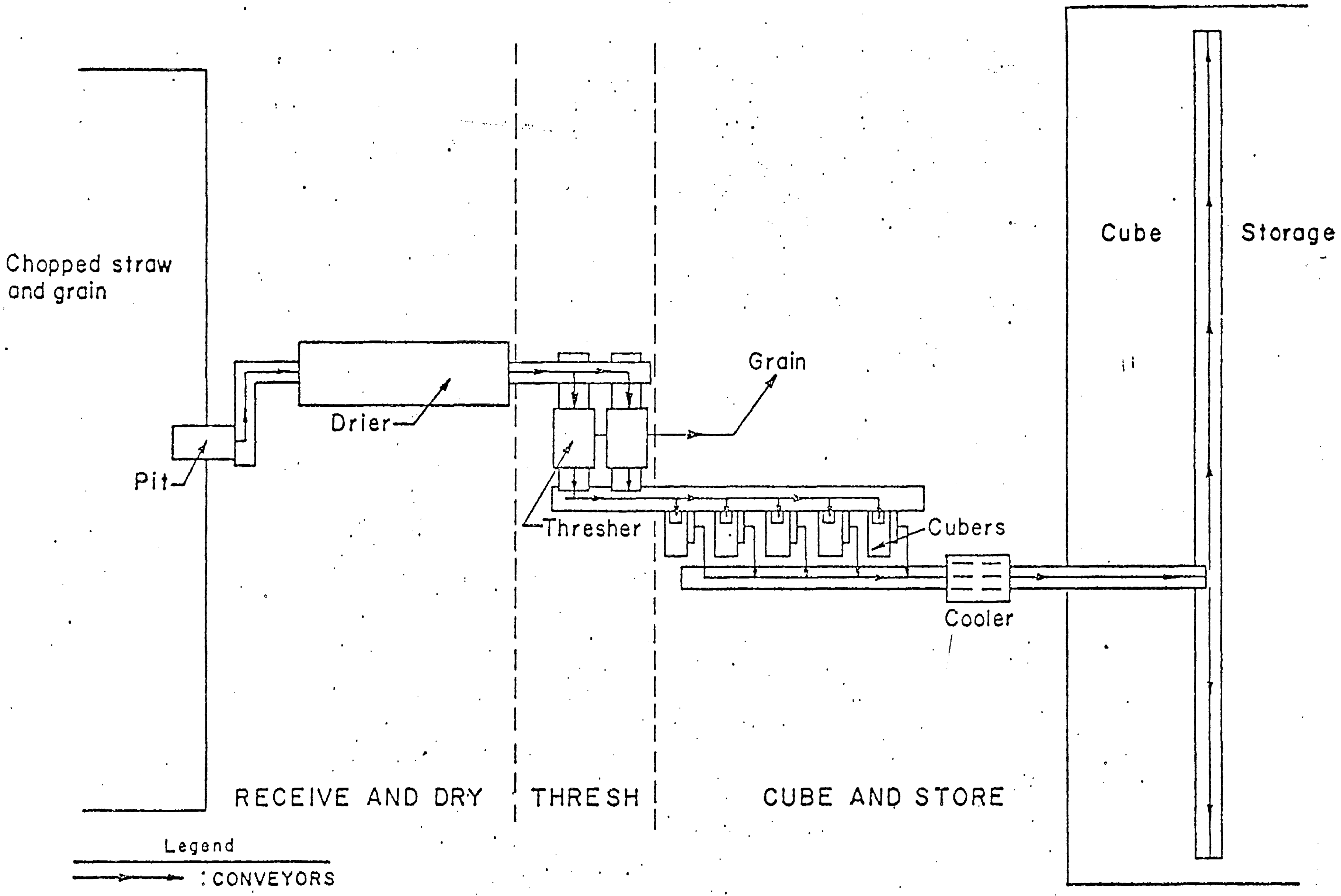
This technique is not presently being practiced in the United States although it has gained a degree of popularity and acceptance in Europe. The premise for this method is that both grain and stalk can be removed in a single operation. In theory, forage choppers could be used to cut the rice stalk very close to the ground. The general plan of the system includes field chopping the standing crop into large vans, hauling it to a central plant, drying and separating the grain from the straw, and processing the straw into cubes. Figure 5.1 illustrates the flow diagram for the total crop harvest system.

Technical Feasibility. As indicated by the flow diagram, total crop harvesting requires several distinct yet interdependent steps. A breakdown at any specific processing point would virtually insure a shutdown for the entire operation. If, however ,troubleshooting and maintenance are practiced at a high level, this system appears to be technically sound from an efficiency standpoint.

Advantages of the total crop harvest include shorter harvesting time, ease of operation under difficult conditions and an opportunity for concentration of management skills. Drying is provided at the facility, thus eliminating the need for field drying, which appears tenuous at best. Experience and published data are unavailable on the use of rotary drum dehydrators for

Figure 5.1

FLOW DIAGRAM FOR TOTAL RICE HARVEST SYSTEM



Source: (Dobie et.al., 1972).

drying large volumes at moderate temperatures but a minimum of head loss is expected. It is anticipated that the forage choppers considered for this practice could operate under a wide variety of operating conditions, perhaps including standing water. Concentration of both labor and management is required for the traditional rice harvest; given that straw removal could subject these facets to additional strain, total crop harvesting presents an appealing alternative.

Economic Feasibility. Ultimately, an economic analysis to determine separate costs and revenues for straw and grain would be desirable. The data presented here are for the system as an entity. Further conclusions as to the actual costs of processing the straw could be drawn by subtracting the actual costs of harvesting grain alone. As this would not depict an accurate representation of the advantages or disadvantages of this system, it is not shown here and the following costs represent those for the total crop.

Table 5.5 indicates the overhead and cash costs for chopping the rice and hauling it to a central plant for processing. The costs are based on a 5,000-acre harvest requiring seven forage choppers and a ten-mile haul to a central processing plant. Initial investment costs are anticipated at $310,000 with a resulting annual overhead of $62,318. Cash operating costs will average $18.47.

Receiving and drying the total rice crop is the most capital intensive of the processes involved. In addition to a

Table 5.5

TOTAL RICE CROP PROCESSED AT A CENTRAL PLANT

Chop and Haul

Ten tons total weight per acre = 50,000 tons handled in 40-day harvest season or 1,250 tons wet (40%) moisture) each 24 hours or 52 tons per hour.

Investments and Annual Overhead Costs[a]

	New Cost	Life	Depreciation	Interest	Other	Total
Seven choppers, self-propelled, direct cut header 165 H.P., flotation gear	\$310,000	8 yrs.	\$38,750	\$17,368	\$6,200	\$62,318

Cash Costs to Chop and Haul (Dry Basis)

	Per Hour	Tons Per Hour	Per Ton (dry)
Labor to Chop[b]	\$51.31	35 (52 wet)	\$ 1.46
Fuel and Repairs			5.54
Haul to Central Plant[c]			10.26
Management			.33
Miscellaneous[d]			.88
Total			\$18.47

---

[a] All costs are expressed in 1980 dollars.

[b] Labor costs include 7 men at \$7.33 per hour.

[c] Calculated at a hauling distance of 10 miles. Cost includes loading and unloading of straw.

[d] Calculated at 5 % of labor, fuel and repairs, hauling and management.

Sources: (Dobie et. al., N.D.).
University of California, 1976.
API, Ford Tractor Division, Denver, Colorado.

substantial amount of core facilities, the peripheral equipment involved is extensive and costly. Capital costs total $1,209,890 or $183,062 annually. Cash operating costs are also high at $13.82 per ton, largely due to the amount of energy required for drying. Table 5.6 illustrates these costs.

Table 5.7 gives annual overhead costs for the threshing operation which separates the grain from the straw. It is important that the thresher be designed with ample capacity and power to reduce the possibility of a breakdown due to the abrasive nature of the straw. New costs for the thresher, conveyers and the power units total $75,286. Annual overhead will be $12,079 while cash operating costs are minimal at $0.51 per ton due to the absence of labor as a requirement.

Table 5.8 represents the costs associated with cubing the straw and storing the cubes. Magnets are included in the system to remove any wire or broken machine parts from the straw prior to its entering the cuber. A Papakube densifying system was chosen for its high production capacity and low maintenance requirement. The Papakube system does not require any type of binder or additive to produce a high quality cubing, lending further economic advantage to its use. Facilities for cooling the cubes prior to storage are an additional necessity. Investment costs are expected to reach $476,951 with annual overhead costs of $82,748. Cash operating costs for cubing and storage will average $6.74 per ton.

Table 5.6

RECEIVE AND DRY

Investment and Annual Overhead Costs[a]

	New Cost	Life	Depreciation	Interest	Other	Total
Blacktop slab 5,000 square feet @ 66¢	$ 33,000	10 yrs	$ 3,300	$ 1,905	$ 660	$ 5,865
Pit feeder for moving into dehydrator, 40 H.P.	166,071	20 yrs.	8,304	10,991	3,321	22,616
Dehydrator and furnace 300 H.P. fans 100 H.P. motors	885,712	20 yrs.	44,286	58,195	17,714	120,195
Tractor scoop (push straw and grain into pit feeder)	44,286	10 yrs.	4,429	2,557	886	7,872
Conveyers-feeder to dehydrator 100', to other facilities 150' 60 H.P. ($111 per linear foot)	27,679	10 yrs	2,768	15,980	554	19,302
Electric controls, 500 H.P., $66/connected	33,214	20 yrs.	1,661	2,182	664	4,507
Scales (30 ton)	19,929	20 yrs	997	1,309	399	2,705
Total	$1,209,891		$65,745	93,119	$24,198	$183,062

Cash Operating Costs (Dry Basis)

	Per Hour	Tons Per Hour	Per Ton (dry)
Labor[b]	$ 14.66	35 dry (52 wet)	$ .42
Fuel to dry	386.40	35	11.04
Repairs:			
Pit feeder	3.80	35	.11
Dehydrator and furnace	20.50	35	.59
Tractor scoop	2.05	35	.06
Conveyers	1.28	35	.04
Controls	.77	35	.02
Blacktop	1.53	35	.04
Scales	.46	35	.01
Electric power[c]	17.50	35	.50
Management	11.55	35	.33
Miscellaneous[d]	23.10	35	.66
Total	$483.70		$13.82

---

[a] All costs expressed in 1980 dollars.

[b] Labor cost include 1 man on scoop and 1 man on dryer at $7.33 per hour.

[c] Cost includes a 500 H.P. motor rated at 1 Kw hour per H.P. at 3.5¢ per Kw hour.

[d] Calculated at 5% of operating costs.

Sources: (Dobie et.al., N.D.).
University of California, 1978.
U.S. Department of Commerce, 1979.

Table 5.7

THRESH

Investments and Annual Overhead Costs

	New Cost	Life	Depreciation	Interest	Other	Total
Thresher	$31,000	10 yrs.	$3,100	$1,790	$ 620	$ 5,510
Power Units	31,000	20 yrs.	1,550	2,037	620	4,207
Conveyors	13,286	10 yrs.	1,329	767	266	2,362
Total	$75,286		$5,979	$4,594	$1,506	$12,079

Cash Operating Costs

	Per Hour	Tons Per Hour	Per Ton
Labor[b]	---	20	---
Repairs:			
Thresher	$ 1.44	20	$.07
Power Units	.72	20	.04
Conveyers	.62	20	.03
Electric power 150 H.P.[c]	7.56	20	.38
Miscellaneous[d]	.60	20	.03
Total	$10.94		$.51

---

[a] Power units consisting of (2) 150 H.P. electric motors and controls. All costs are expressed in 1980 dollars.

[b] Labor cost is included under "receive and dry."

[c] Electric power calculated at 1 Kw hour per H.P. times 5.04¢.

[d] Calculated at 5% of operating costs.

Sources: (Dobie et. al., N.D.).
University of California, 1978.
U.S. Department of Commerce, 1979.

Table 5.8

TOTAL RICE CROP PROCESSED AT A CENTRAL PLANT

Cube and Store[a]

Investment and Annual Overhead Costs

	New Cost	Life	Depreciation	Interest	Other	Total
Storage building for cubes, 36,000 sq.ft. @ $4.43	$159,480	30 yrs.	$15,948	$11,495	$3,190	$30,633
Papakube cuber	130,000	12 yrs.	10,833	7,725	2,600	21,158
Electric motor, 150 H.P.	5,536	20 yrs.	277	364	111	752
Power controls	9,964	20 yrs.	498	655	199	1,352
Bulk box 25'	26,571	10 yrs.	2,657	1,534	531	4,722
Conveyer to cuber, 150' @ $111/ft.	16,650	10 yrs.	1,665	961	333	2,959
Conveyer to storage 200' @ $111/ft.	22,200	10 yrs.	2,200	1,282	444	3,946
Magnets (2)	2,660	20 yrs.	133	175	53	361
Distribution conveyer	11,071	10 yrs.	1,107	639	221	1,967
Facilities for cooling cubes	66,248	15 yrs.	4,417	6,149	88	10,654
Scoop loader	26,571	10 yrs.	2,657	1,534	53	4,244
TOTAL	$476,951		$42,392	$32,513	$7,823	$82,748

Cash Operating Costs

	Per Hour	Tons Per Hour	Per Ton
Labor[b]	$ 7.33	10	$ .73
Repairs:			
Cuber	16.80	10	1.68
Other equipment	32.70	10	3.27
Electric power	5.24	10	.52
Management	2.21	10	.22
Miscellaneous	3.21	10	.32
TOTAL	$67.49		$6.74

---

[a] One cuber is assumed to operate 24 hours per day at 10 tons per hour. This system can handle up to 21,000 tons in a 90-day season. All costs are expressed in 1980 dollars.

[b] Labor cost is calculated for one man at $7.33 per hour.

[c] Electric power calculated at 1 Kw hour per H.P times $3.49.

Sources: (Dobie et. al., N.D.).
University of California, 1978.
U.S. Department of Commerce, 1979.

TRANSPORTATION

With the exception of the total crop harvest system, transportation costs must also be added to arrive at a cost per ton of straw harvested. These transportation charges will vary with the type of straw packaging as cubes have a considerably higher bulk density than bales. It is assumed that regardless of the packaging method, the product would be transported by common carrier. Table 5.9 enumerates these transportation rates for the appropriate weight classes and distances expected for hauling the packaged rice straw. To apply the rate chart, the weight of the straw is multiplied by the rate given for a specific mileage range and subsequently increased by a constant surcharge. This computation will result in a net cost for hauling, from which the cost per ton of straw transported can be calculated.

SUMMARY

Technically, each of the systems reflects unique merits and considerations. Field cubing appears to have high production but is limited by moisture content. Baling seems feasible under a wider variety of conditions, foresaking high production. Total crop harvesting is considered to have the highest potential but a minimum of evidence is available.

Economic considerations encompass varied aspects of collection, handling, and transportation. Generally, high annual overhead costs will prove economical for large farms. Smaller farms would prove better suited to low overhead systems.

Table 5.9

TRANSPORTATION RATES[a]

Cost = Weight x Rate Increased by Surcharge

Miles[c]	Rate[d] (¢/cwt)	Surcharge (%[e])
	30,000 to 40,000 Pounds[b]	
5-10	22	15.25
10-15	23	15.25
15-20	25	15.25
20-25	26	15.25
25-30	29	15.25
	20,000 to 30,000 Pounds	
5-10	24.5	15.25
10-15	26.5	15.25
15-20	28	15.25
20-25	30	15.25
25-30	32	15.25
	10,000 to 20,000 Pounds	
5-10	37	15.25
10-15	39	15.25
15-20	41	15.25
20-25	43	15.25
25-30	46	15.25

---

[a] Common carrier rates; includes loading and unloading.

[b] Minimum and maximum weights per truckload.

[c] Rates are applicable to all mileages within given range.

[d] In cents per cwt.

[e] Percentage figure.

Sources: Public Utilities Commission, State of California Energy Cube Division, Papakube Corporation, San Diego, California.

Transportation costs appear to be inversely proportional to harvesting costs, with cubing showing the least cost, due to its high bulk density.

Table 5.10 summarizes these costs for various acreages and distances traveled. Rice straw harvesting has been considered for a variety of collection systems. Before such methods can be put into practice, further research is required to identify the parameters within which the systems are workable. Results must be analyzed in light of differences in farm size, type of ownership and management before an accurate determination of feasibility can be made. Harvesting of rice straw would place additional strains on many aspects of the farming operation. A number of these strains are counterproductive to the farming operation as a whole and warrant further identification.

Endogenous Constraints

Several of the problems associated with rice straw collection and removal can be considered as internal for they are farm specific and dependent on farm size, ownership and management. Included in these problems would be a tremendous strain on labor. Due to the limited time frame for harvesting, rice straw collection and removal would have to begin almost concurrently with the grain harvest. Cost studies presented in the majority of the literature on straw utilization and disposal

Table 5.10

SUMMARY OF COLLECTION, HANDLING AND TRANSPORTATION SYSTEMS

Collection and Handling System

	Cost Per Ton of Straw		
	Overhead[b]	Cash[c]	Total[d]
Mobile Field Cubing (Tons)[a]			
1,164 (320 acres)	$26.68	$7.27	$33.95
2,184 (600 acres)	14.23	7.27	21.50
4,368 (1,200 acres)	7.12	7.27	14.39
8,640 (2,400 acres)	3.60	7.27	10.87
Portable Cubing			
1,165 (320 acres)	32.61	8.46	41.07
2,184 (600 acres)	17,39	8.46	25.85
4,368 (1,200 acres)	8.70	8.46	17.16
8,640 (2,400 acres)	4.40	8.46	12.86
Thompson Baling			
1,165 (320 acres)	14.23	6.97	21.20
2,184 (600 acres)	7.59	6.97	14.56
4,368 (1,200 acres)	3.80	6.97	10.77
8,640 (2,400 acres)	3.80	6.97	10.77
Custom Baling		17.68	17.68

Transportation

	Cost Per Ton of Straw		
Distance[e]	Rate[f]	Surcharge[g]	Total[h]
Cubes			
5-10 miles	$4.40	$ .67	$5.07
10-15 miles	4.60	.70	5.30
15-20 miles	5.00	.76	5.76
20-25 miles	5.20	.79	5.99
25-30 miles	5.80	.88	6.68
Thompson Bales			
5-10 miles	7.40	1.13	8.53
10-15 miles	7.80	1.19	8.99
15-20 miles	8.20	1.25	9.45
20-25 miles	8.60	1.31	9.91
25-30 miles	9.20	1.40	10.60
Custom Bales			
5-10 miles	4.90	.75	5.65
10-15 miles	5.30	.81	6.11
15-20 miles	5.60	.85	6.45
20-25 miles	6.00	.92	6.92
25-30 miles	6.40	.98	6.27

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[a] 3.65 tons of straw removed per acre.
[b] Annual overhead divided by production.
[c] Cash operating expenses.
[d] Summary of overhead and cash expenses.
[e] Rates are applicable to all mileage within given range.
[f] Rate categories determined by maximum tonage per truckload.
[g] Amount rate is increased by.
[h] Summary of rate and surcharge.

Source: Copley International Corporation.

presuppose that manpower to operate around the clock would be available.[*] Both straw removal and grain harvesting would require skilled labor and competent machinery operators. It is likely that the prudent farm owner or manager would tend to use the most qualified personnel for grain harvesting. If this were to occur, management of the collection and removal operation would become difficult and efficiency would be sacrificed.

In most cases, straw harvesting would be considered capital intensive. With the exception of custom bailing, all of the systems require a substantial capital investment. Costs for new equipment alone can reach $225,000 for an average-sized farm. If a loan of this magnitude were taken out for equipment purchase, the result would be a substantial decrease in borrowing capacity. The ramifications of a reduction in borrowing capacity include a decrease in the farmer's ability to cope with adversity and expand during prosperous periods.

In addition to overhead costs, cash operating costs are also expected to be high. Should straw harvesting be undertaken, an ample supply of cash must be secured for labor, repairs, transportation and miscellaneous expenses, such as twine or machine oil. The rice farmer incurs high cash costs for normal grain harvesting alone. If costs for rice straw collection and removal are also incurred, a bad year would further weaken the farmer's financial position.

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[*] Confirmed by West Sacramento Employment Development Office

Perhaps the greatest increase in pressure would be placed on management. Copley International Corporation's survey of rice growers indicates that 86% of the farms harvest their own rice grain (Question 14). Grain harvesting requires sound and prudent management. Weather fluctuations demand timely managerial decisionmaking. Even without straw collection and removal, the manager commonly works long days throughout the harvest. If both grain and straw harvesting are to take place concurrently, special considerations must be given to compensating for this added burden.

Depending upon the individual circumstances, these endogenous constraints may adversely affect the decision to harvest rice straw. Should the task of collection and removal be undertaken, it is expected that these constraints will alter the cost effectiveness of such an operation. The degree to which this change may occur will be farm specific and depend largely on farm size and type of present ownership and management.

Exogenous Constraints

There are several external factors which will affect the decision to undertake rice straw collection and removal. Should the decision be made to harvest the rice straw, these same factors could determine the extent and effectiveness of the operation. The principal factors which will determine the producer's decision and ability to produce are: weather, incidence and severity of stem rot, and certain prevalent economic conditions.

Timing of the grain harvest alone is difficult and uncertain. Rainfall bringing harvesting to a halt is commonplace throughout the fall. Table 5.11 gives the probabilities of harvest delays due to rain during October. If the rice straw is to be collected and removed, there are additional delays of operations. Depending on the climate and type of system selected, obtaining adequate field drying may also be a problem. In bad weather years, delays may hamper or make straw collection unfeasible for the selected system.

An increase in the incidence and severity of stem rot disease may result if rice straw collection and removal operations are undertaken. Research has shown that unless rice straw is harvested close to the soil surface (3 inches), an increase in inoculum levels will result, along with corresponding yield losses. However, if the rice straw is harvested low to the ground, then collection and removal systems would be just as effective as burning in terms of stem rot disease control (Webster, 1978).

The low cutting of rice straw will decrease field speeds and increase repairs and maintenance on equipment. Special flail-type choppers such as those employed during straw reduction operations may be required for this procedure. It is, therefore, likely that stem rot disease can be minimized by collection and removal systems, but not without added expense.

Prevailing economic conditions may further influence the decision to undertake rice straw harvesting and affect the cost-effectiveness of such an operation. Many costs of

Table 5.11

PROBABILITIES OF HARVEST DELAYS DUE TO RAIN DURING OCTOBER

Extent of Interruption	Probability of Harvest Interruption During Each Given Week - Percent				
	Week Starting				
	Sept. 27	Oct. 4	Oct. 11	Oct. 18	Oct. 25
Harvest would be interrupted by rain	22	31	38	48	51
At least 1 additional day would be lost	12	14	14	22	28
At least 2 additional days would be lost	7	6	4	8	15
At least 3 additional days would be lost	5	4	1	4	9
At least 4 additional days would be lost	3	2	0	2	4
Average number of good days	6.51	6.43	6.43	6.16	6.03

Source: Machinery Management for Timely Planting and Harvest of Rice in Northern California, University of California, June, 1975.

production are subject to fluctuations in the economy. Inflation could raise the cost of purchasing new equipment or replacing equipment in the future. Energy costs fluctuate under a variety of conditions including foreign trade policy changes. Labor, twine, machine oil and other miscellaneous expenses are all subject to changes in the economy. A sharp rise in price for any combination of these inputs could substantially affect the farmer's cost of production.

Perhaps the greatest economic concern is that there is not an established demand for rice straw at the present time. The substitutability of rice straw as a food, fiber and energy source is presently questionable, pending further research. Without an established demand for rice straw products, growers will obviously be reluctant to invest their time and expertise to harvest rice straw.

Should agricultural wasteburning be terminated, it is expected that rice straw collection and removal will draw a considerable amount of interest. Should this interest culminate in applying present collection and removal technologies, the resultant rice straw supply will encourage industrial demand for this fiber. Rice growers will be reluctant to contribute their resources toward this technology until it is demonstrated to them that their efforts are justified by economic returns.

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DRAFT

ALTERNATIVE USES OF RICE STRAW

In both the public and private sectors, research is being conducted to find ways in which to utilize rice straw. The variety of applications being considered range from rice straw as a feed for livestock, rice straw as an energy source, to rice straw as a raw material for the manufacture of paper and allied products. Research has shown that rice straw can be utilized in a myriad of applications. The major utilization schemes which have shown the greatest promise for success are discussed in this chapter.

Presently, there is no commercial or industrial demand for rice straw in California requiring appreciable volumes of this tough cereal straw. In 1979, an estimated 1,900,080 tons of dry rice straw (3.64 tons per acre) were disposed. To the rice grower, the disposal of rice straw by burning is the cheapest and most effective practice in light of all other disposal alternatives. If a demonstrated demand for rice straw arises, then rice growers would have an opportunity to increase their stream of income from rice production and improve environmental conditions due to less reliance on open-field burning.

This chapter assesses the technical and economic feasibility of waste burning alternatives. In some cases it is demonstrated that utilization of rice straw is feasible under the assumed conditions set forth in the analysis. It is recognized, however, that technical and economic feasibility alone does not consider all the external market influences and individual preferences which ultimately determine the allocation of resources and the distribution of goods and services. Therefore, any of the conclusions rendered in this chapter should be considered in light of potential rather than definitive applications for rice straw.

Each major alternative use for rice straw has been evaluated for both its technical and economic merit. Four categories have been developed in order to group the various alternatives. The categories are as follows:

- Rice Straw as a Feedstuff
- Rice Straw as an Energy Source
- Rice Straw as a Fiber Source
- Other Uses for Rice Straw

A summary of the major findings in this chapter includes a ranking of the potential applicability for the use of rice straw in existing industrial and/or commercial processes.

RICE STRAW AS A FEEDSTUFF

There has been ample research conducted on this topic both in the United States and abroad. As stated in Chapter 2, there are several rice producing countries which utilize rice straw as a feedstuff for ruminant animals. Abroad, it is a common occurance to see caribou and other bovine foraging on rice residue either stacked or left in the rice patties. It is known that rice straw in these applications is used as a maintenance level ration and that very little energy and protein is derived from this low quality food source.

The intensive commercial nature of the United States' rice and cattle industries alike preclude the use of rice straw in this manner. The relative technical and economic merits of the domestic use of rice straw as a live stock feed is discussed below.

Livestock Feed

It has been shown that rice straw could be made available to livestock in two ways. First, it could be baled and utilized as straw. Baling can be considered only as a means of packaging and removing the straw from the field. It is unpalatable in this form and further processing is required if used for animal feed. Secondly, it can be processed into cubes. Although cubing facilitates ease of handling, it does not improve the rice as a feedstuff. In order for rice straw to become a viable alternative to more traditional roughages, it must first be analyzed from a technical standpoint. If treatments were technically feasible, these alternatives could then be assessed for their corresponding economic potential.

Technical Feasibility. When fed to ruminant livestock, rice straw is termed a forage. Nutritionally, forages contribute energy, protein, calcium, and phosphorus to the diet. However, rice straw has a very high percentage of cellulose which, when combined with lignin, makes the energy present less usable by the ruminant. This results in a lesser amount of digestible energy and finally in decreased total digestible nutrients (TDN), which determines the ultimate value of the feed. Crude protein percentage is also an important measure of forage quality since protein is the most expensive item to supplement in a ruminant diet. Rice straw is unusually low in protein compared with other feedstuffs, particularly alfalfa. Animals which are producing, such as dairy cattle and growing steers, require increased quantities of calcium and phosphorus. Both are extremely deficient in rice straw and again, they are expensive to supplement. Rice straw also contains a higher percent of silica than any other forage. It is not known what complications this staggering amount of silica can present. It is known that a high silica content decreases the rate at which many other minerals are absorbed.

To evaluate the value of a forage there is a classification system based on the National Research Council (NRC) requirements. Alfalfa hay is the most commonly used forage and will be used here for comparison. Table 6.1 compares the major nutrient values of rice straw with regard to the requirements of a pregnant beef cow and a growing steer calf.

It is evident from this comparison that unsupplemented rice straw is too low in digestible energy, crude protein, calcium, and phosphorus to be used as the only source of nutrients for beef cows or growing cattle. Rice straw is apparently also low in cobalt, copper, magnesium and sulfur, with the possibility of borderline deficiencies of these minerals. Additional analyses are needed, particularly for iron and zinc, to give a more complete picture of the nutritionally essential minerals (Clawson, 1970).

With the nutrient composition of rice straw identified, its value as a feedstuff must be qualified in terms of digestibility. Each of the components of a ration interacts in a complex manner which can only be determined through actual feeding

Table 6.1

COMPARISON OF NUTRIENT VALUES OF RICE STRAW AND ALFALFA HAY WITH NRC REQUIREMENTS

	Typical Composition		Requirements	
	Rice Straw	Alfalfa	Cows with Calves	Growing Steers
Digestible Energy, mcal/kg	1.9	2.5	2.5	2.5
Crude Protein, %	4.5	17.0	9.2	10.0
Ether Extract, %	1.5	2.0	---	---
Crude Fiber, %	35.0	27.0	---	---
Lignin, %	4.5	6.5	---	---
Cellulose, %	34.0	24.0	---	---
Nitrogen-Free Extract, %	42.0	40.0	---	---
TDN	43.0	57.0	57.0	57.0
Ash, %	16.5	10.0	---	---
Silica, %	14.0	1.5	---	---
Calcium, %	0.19	1.3	0.28	0.25
Cobalt, mg/kg	0.05	0.09	0.07	0.07
Copper, mg/kg	5.0	14.0	4.0	4.0
Potassium, %	1.2	1.5	0.7	0.7
Magnesium, %	0.11	0.33	0.1	0.1
Manganese, mg/kg	400	30	20	10
Phosphorus, %	0.10	0.23	0.22	0.20
Sulfur, %	0.10	0.3	0.1	0.1

Source: (Clawson, 1970).

trials. These digestibility trials are conducted by carefully recording feed intake and energy output. Intake is measured in pounds of feed consumed and offset by pounds of gain, heat produced and losses due to excretion of metabolic wastes.

Preliminary digestibility trials done with heifers on rice straw alone or supplemented with various concentrates show that rice is a poor quality roughage with low digestibility and feeding value. Similar disturbances in rumen digestion were recorded in all 12 animals in the trials. The heifers gradually deteriorated in condition and had poor health (Clawson, 1970).

In other trials it was also observed that rumen digestion became disordered when rice straw alone was used as feed. Disordered rumen digestion led to anorexia, constipation, emaciation, lowered calf crop, and in some cases, death (Clawson, 1970).

More research is required to exclude untreated rice straw as a feedstuff. However, from our present knowledge, it can be concluded that untreated rice straw is a poor quality roughage that needs to be fed with supplemental protein, phosphorus, calcium, and possibly some trace minerals before it can be considered for even the maintenance of ruminant livestock. For animals at low levels of production, some additional source of available energy is also required. Rice straw appears completely unfeasible for the higher levels of production required by a competitive livestock industry (Clawson, 1970).

Given that untreated rice straw is not acceptable as a livestock feed, treatments to improve both palatability and digestibility must be analyzed. There are still many unanswered questions about the optimum ration. It must be tested in actual feeding trials to determine animal acceptance and performance. However, a great deal of research has gone into methods used to improve the digestibility of rice straw by physical, chemical, and enzymatic treatments.

Physical treatments include any processes which alter the structure of the feedstuff by impact to increase digestibility. Grinding the rice straw produces a product with a greater surface area. The microorganisms present in the rumen can then more easily break down the cellulose and obtain energy from the feedstuff. However, under practical feeding conditions, forages ground into fine pieces pass through the rumen too quickly to allow time for microbial digestion.

To date, the most promising is treatment by sodium hydroxide. Preliminary treatments by Garrett et.al. (1974) indicated that some NaOH and NH_3 treatments were effective in increasing the performance of lambs fed 65 to 72 percent rice straw diets. The improved performance was due to increased digestion of cellulose and to a greater consumption of the treated straw diets. Similar findings were noted with beef cattle. In another experiment, it was found that diets containing the treated straw were consumed in greater quantities and less feed was required per unit of gain when results were compared. The treated straw diets also had higher net energy values. Digestibility of the organic matter, cellulose and the resulting net energy was higher for most 72 percent treated rice straw diets although not always significantly. The NH_3 treatments approximately doubled the nitrogen content of the straw (Garrett et.al., 1979).

Other alkalies (KOH, $Ca(OH)_2$ and NH_4OH) have also been used but with less efficiency than with NaOH. In a separate trial, treatment of rice straw with 4 percent NaOH for 15 minutes at 100 degrees Centigrade was found to increase digestibility from 30 to 73 percent, whereas treatement with 5.2 percent NH_3 at ambient temperature increased digestibility from 30 to 57 percent. The authors concluded that increasing the heating time and temperature or the concentration of alkali beyond 4 percent NaOH, for 30 minutes did not increase digestibility (Han, Calliham, 1974).

In a feeding trial using wethers, rice straw was treated by grinding, then immersing in 2 percent NaOH for 24 hours, washing free of alkali, and then drying. Treated and untreated straw was then substituted for the alfalfa meal in the ration fed to the control animals. The ground rice straw or alfalfa meal constituted 42.5 percent of the pelleted ration. Average daily gains by wethers for the three types of feed were: Alfalfa, 964.3 grains; treated rice straw, 945.5 grains; untreated rice straw, 774.9 grains (Stone et.al., 1966).

In a similar experiment, paddy straw soaked in eight times its weight of 1 percent NaOH for 24 hours, washed, and dried, was used in a feeding trial with calves. The treated straw lost 70 to 80 percent of its potassium oxalate. It effected better utilization of calcium and protein, increased digestibility of total carbohydrates from 57 to 76 percent, and TDN by about 45 percent. Calves fed the treated straw showed a 77 percent higher growth rate than the controls and grew 19 percent faster. There was also an increase in milk flow from cows fed treated straw (Kehar, 1954).

The conversion of cellulose to digestible protein can be accomplished by microbial fermentation. A number of microorganisms are capable of this, and when properly cultivated, can be harvested for their protein value. To date, fungi have been the subject of greatest interest because of their ease in cultivation and high cellulytic activity. As a source of single cell protein, however, fungi are not as suitable as bacteria or yeast because of their slow growth rate, low protein, and high cell wall content. Continuing experiments, however, reveal that microbial fermentation of rice straw to gain protein is not very economical. Initial results indicated that the cost of production ranges from 20 to 30 cents per pound of protein.

Ensilation is a method which can improve the utilization of rice straw. The usual shortcomings, such as added cost, chemical decomposition which reduces intake, and removal of soluble nutrients, can be offset by ensiling rice straw with such additives as urea and molasses. Organic acids produced by ensiling straw serve as additional nutrients as well as to neutralize the alkali when applied.

Because of the low protein and soluble carbohydrate content of rice straw, nitrogen and carbohydrates need to be added. Because the protein degrades during the process and produces undesirable amines and higher fatty acids, non-protein nitrogen, such as area, biuret, and ammonium polyphosphate is recommended (Han and Anderson, 1974).

Nitrogen additives stimulate formation of organic acids in silage, as well as serving as a nitrogen source for ruminants. A commercial amonia-molasses-phosphate additive can be used successfully. The ensiling of straw with water does not significantly improve the feed value over nonensiled materials, whereas addition of chlorites improves digestion. In feeding trials, the usefulness of rice straw silage was limited by reduced intake. Both digestibility and palatability were improved when 4.5 percent of NaOH:KOH was added at ensiling time.

From the literature cited, it becomes apparent that the most optimistic use of rice straw as a livestock feed is by treating it with NaOH. When this is done, some trials indicate the energy value may be increased to a level equal to or better than alfalfa hay. Since this treatment has no effect on the protein, calcium, or phosphorous content, supplements of these nutrients are necessary.

In summary, there are some factors about the composition of rice straw that are evidently different from most other roughages. On the negative side, the high silica content probably interferes with the utilization of other nutrients and is of no nutritive value. On the plus side, there is a relatively low lignin content and a more digestible crude fraction than is found in other straws and in most average quality hays. The cellulose content is high, and since pure cellulose is readily fermented by rumen microorganisms when treated, this fraction has the potential to furnish a substantial amount of energy to the ruminant.

It can be further concluded that untreated rice straw is a poor quality roughage that needs to be supplemented with protein, phosphorus, calcium, and some trace minerals before it can be considered a suitable feed for even the maintenance of ruminant livestock. Treatment of the straw with small amounts of sodium hydroxide shows great promise as a means of increasing the digestibility of the fraction capable of supplying the ruminant with energy, but the mechanisms and the economics associated with alkali treatment are yet to be determined (Clawson, 1970).

Economic Feasibility. An economic analysis projecting costs and revenues is not possible concerning rice straw as a feedstuff. There is no established demand for untreated rice straw at the present time and widespread acceptance by stockmen is doubtful. If rice straw is to gain popularity as a feedstuff, it must be supplemented and fed in digestion trials to identify its value and palatability. A summary of the research to this point indicates that this untreated straw is a poor livestock feed and it appears that any promise for the future will be dependent on pre-treatment.

The economics associated with alkali treatment are unknown at the present time and the technology for this process is in the prototype stage. It is known, however, that alkali treatment is very expensive, due to the high costs of fuels and caustics. As research in this field is concluded and information concerning both pre-treatments and their subsequent feeding trials is made available, the economics associated with this process will be much more clear.

RICE STRAW AS AN ENERGY SOURCE

Energy from agricultural residues has become more important in the last several years. A combination of factors, culminated by the Arab oil embargo in 1973, has made apparent both the short- and the long-term energy problems with which this nation must cope. In a relatively short time the economy has shifted from a position of abundant, low-cost energy to an outlook of impending energy shortages, rising prices, and a fragile supply born of uncertain political ties with foreign sources.

There has been a significant contribution of funding on a federal level to investigate methods of extracting energy from various physical and chemical processes. The most promising energy conversion routes are described in this section.

Direct Combustion

Direct combustion is the most direct method of existing biomass conversion process. Simply stated, it is the burning of matter to produce steam or electricity. The process employs conventional wood-fired boilers which utilize a technology that has existed for over a hundred years. Currently, wood-fired boiler systems are used in the lumber, pulp and paper industries for the generation of process steam. Most conventional wood-fired boiler systems generate process steam only and not electricity.* Systems are available, however, which produce steam at higher pressures than required for process steam and that can be utilized for electric power generation. The Eugene Water and Electric Board of Eugene, Oregon has been producing electricity from wood wastes since 1976.

Technical Feasibility. Several operational factors need to be examined before rice straw can be adapted to a wood-fired boiler. Contacts with wood-fired boiler manufacturers indicate that rice straw would be a suitable feedstock for existing boiler equipment. There are problems however. The silica in rice straw substantially increases the wear factor in wood-fired boilers (Nor'-West Pacific Corporation, 1980). Apparently, increased maintenance on the system is required to prevent efficiency losses due to deposits formed by silica. If rice straw is to be used in place of clean fossil fuels (i.e., low sulfur), a particulate collection system should be considered. A high

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*Boiler systems for process steam operate at pressures of 15 to 150 psi.

efficiency cyclone is the favored device over baghouse cleaners for reducing particulate matter being emitted from boiler stacks.

The overall efficiency of wood-fired systems compares favorably to coal systems (Alich, 1976). The heat given off during the incineration process is related to several operational factors which ultimately determine the thermal efficiency of the combustion system. The feedstock, i.e., rice straw, must be monitored by a control system to keep the influx of biomass at a constant rate. If the loading rate is too rapid, an increase in particulate effluents will result. In addition, greater amounts of residue will be left in the incinerator's combustion chamber. Mixing or tumbling of the residue promotes better aeration and accelerates the burning proces. A proper incinerator temperature must be determined to insure that primary combustion particles have been heated above their ignition temperatures. Lastly, the moisture content of the feedstock should be less than 65 percent; if higher, the feedstock should be dried or supplemented with coal or some other low grade fossil fuel (Alich, 1976).

Direct combustion presents certain advantages over other types of energy-converting processes since quality and packaging of the feedstock is not an overriding concern. Rice straw could be transported directly from the field and utilized. Alternatively, it could be stored as loose straw, as bales, or as cubes and utilized at a later date. Of course, stored rice straw would have to be dry (less than 15 percent moisture content) to prevent a fire hazard. If the rice straw molded, the feedstock could still be combusted. Higher moisture contents will, however, lower the overall thermal efficiency of the process.

Wood-fired boiler systems are capable of handling feedstock at a rate of 5 to 100 tons per hour. The capacity of these systems extend to 22,000 pounds of steam output per hour. Steam is usually generated at low pressures, varying from 15 to 250 psi. Higher pressure systems are available which vary from 400 to 1,450 psi. The higher pressures would be sufficient to propel a steam-powered turbine generator.

Although most applications of wood-fired boilers are for process steam, other applications are feasible. Using rice straw in a coal-fired utility boiler to produce electricity has good potential (Horsefield, 1976 and Stanford Research Institute, 1976). Presently, there are no coal-fired utility plants in California. Moreover, the Air Pollution Control Board has taken a position against construction of such facilities (Stanford Research Institute, 1976). In light of the increased cost of distillate and residual fuel oils and the uncertain future of nuclear power, coal-fired utilities may become a reality in California.

Applications of the steam and/or electricity which can be generated from rice straw are numerous. The most practical uses will undoubtedly be determined by economics. Transportation distances will be a large factor here.

Economic Feasibility. In order to assess the economic feasibility of rice straw as a feedstock for wood-fired boiler systems three major factors must be addressed:

A. collection, transportation, and storage systems;
B. capital and operating system costs;
C. substitutability for existing energy sources.

To address these factors under this section, the economic feasibility of using rice straw in a wood-fired boiler system for a vegetable processing plant will be assessed. In a recent study by Brian C. Horsefield and R.O. Williams (1976), the economics of on-farm power generation was assessed. The study concluded that "direct combustion for steam generation to produce on-farm power was not feasible in the near future." The main deterent was that farmers are apparently unfamiliar with steam processes and that there is a lack of availability of small high-pressure boilers and steam engines or turbines. Given that on-farm direct combustion processes are not currently feasible, it was determined that an off-farm feasibility study of industries which utilize steam for process heat would be appropriate. Horsefield and Williams sought to eliminate the need for expensive transportation, collection, and storage systems inherent in off-farm utilization schemes. There have been improvements in rice straw collection processes since 1976, as noted in the previous chapter. Therefore, off-farm utilization schemes are more cost competitive than several years ago.

A. Collection, Transportation, and Storage. A field cubing system would be adequate to meet the energy input requirements of a steam boiler plant. Rice straw would be cubed on the farm and transported to the plant. Collection and transportation costs would vary by size of farm and hauling distances. A 2,400-acre rice farm would be the upper limit for one field cuber (8,740 tons of rice straw). The cuber would have to operate 24 hours per day, at 9 tons per hour to achieve maximum operating capacity. At this rate, it would take 40 days to complete the cubing operation. It is more reasonable to assume that growers would work for 12 hours per day through the 40-day harvesting season. Therefore, the costs of collection used in this feasibility analysis will be based on employing one field cuber for 1,200 acres of rice.

The transportation of the rice cubes is assumed to be handled by 20-foot dump trucks with a maximum capacity of 30,000 pounds each. The hauling distances are split between 5- to 10-mile hauls and 10- to 15-mile hauls. It is assumed that 50 percent of the cubes are hauled 5 to 10 miles and the remaining 50 percent are hauled 10 to 15 miles. It is estimated that a total 70,200 tons of rice straw would be required to fuel a boiler plant during a 90-day operating period. The transportation charges are calculated for this amount.

A summary of both the collection and transportation charges are presented in Table 6.2.

Table 6.2

COLLECTION AND TRANSPORTATION COSTS FOR A DIRECT COMBUSTION SYSTEM[a]

Collection Costs

Tons	Overhead $/Ton	Cash $/Ton	Total $/Ton	Total $/Season
70,200[b]	$7.11	$7.27	$14.38	$1,009,476

Transportation Costs

Tons	50% 5-10 Miles[c]	50% 10-15 Miles[c]	Total $/Season
70,200	$214,400	$226,535	$ 440,935
Total Collection and Transportation Costs			$1,450,411
Total Cost Per Ton			$20.66

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[a] Costs are in January, 1980 dollars for a 1,200-acre farm.

[b] Rice straw is at 14 percent moisture content.

[c] Rates for hauling are based on rates set forth by the California State Public Utilities Commission.

Some storage of the rice cubes would be necessary to insure a constant inflow of fuel to the boiler plant. If collection operations are curtailed due to inclement weather, the stored reserves of rice cubes will permit a steady flow of fuel to the boiler systems. The capital costs of storage are estimated to be $222,850. A pole-type barn construction was used for estimating the costs of storage ($2.50 per square foot). An 89,140 square-foot building was assumed suitable for storage purposes. The building has a 30-day storage capacity.

B. Capital and Operating Costs. In order for rice straw to compete favorably as a fuel source for a boiler system, the cost of supplying the rice straw and combusting it must compare favorably with the cost of existing fuels. In this section the cost of utilizing rice straw cubes as a fuel source was compared to using natural gas. It was determined that rice straw cubes represented a $1.80 per MM Btu cost advantage over natural gas.

There are several assumptions implicit in the derivation of the average per unit cost for the natural gas and direct combustion systems. It must be emphasized that the costs presented for the direct combustion system are difficult to substantiate. While it is true that equipment costs for the direct combustion system can be reasonably approximated, the operating efficiency, start-up costs, maintenance, and other expenses are relatively unknown. More confidence can be attributed to the capital and operating costs of natural gas systems since these systems have been thoroughly studied.

The hypothetical boiler system is rated at a peak capacity of 250,000 pounds of steam per hour. It is assumed that a three-month period of operation is conducted at or near full capacity. The capital and operating costs are estimated over this time period for both the direct combustion and natural gas systems. A 90-day fuel demand such as experienced in cannery operations is not uncommon. Natural gas could easily be supplied during the off-season. As for the direct combustion system other agricultural wastes could be utilized during those times when rice straw is not available. It is also possible that rice straw cubes could be stockpiled to meet the off-season energy demands although the economics of that have not been studied in this report.

The demand for rice straw cubes is based on the boiler plant's average energy demand. The underlying assumptions are that rice straw cubes can be depended on as a source of fuel at the appropriate time and that farm managers can include the required collection, packaging, and transportation operations during the harvesting period between October 1 and November 30. The energy demand is calculated as follows:

$$\frac{285 \times 10^6 \text{Btu's/hr}}{70\% \text{ efficiency}} \times \frac{1 \text{ lb straw @ } 0\% \text{ moisture}}{7{,}100 \text{ Btu's}} \times 1.14 = 6.5 \times 10^4 \text{ lbs straw/lb}$$

$$\frac{6.5 \times 10^4 \text{ lbs straw/hr}}{2{,}000 \text{ lbs/ton}} \quad \frac{24 \text{ hrs}}{\text{day}} \quad \frac{90 \text{ days}}{\text{season}} = 70{,}200 \text{ tons per season}$$

The capital and operating costs for a direct combustion system utilizing 70,200 tons of rice straw cubes per season are shown in Tables 6.3 and 6.4.

The capital costs for the direct combustion system are shown to be $8,086,688. It was assumed that 100 percent financing would be required for development. Eleven wood-fired boilers (capable of) 22,000 pounds of steam per hour would be required to meet the demands of this system.

The operating costs over the 90-day period amount to $3,201,546. Translated into dollars per MM Btu, the direct

Table 6.3

CAPITAL COST FOR DIRECT COMBUSTION SYSTEM[a]

Site Preparation[b]	$ 862,500
Boilers (11 @ $300,000)	3,300,000
Storage Facility	222,850
Fuel Handling Equipment[c]	1,650,000
Feedwater System and Auxiliary Equipment	434,000
Direct Costs	$6,469,350
Construction Contingency, Fees, and Taxes, etc. @ 15% of Direct Costs	$ 970,403
Engineering and Design @ 10% of Direct Costs	646,935
Total Capital Cost	$8,086,688

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[a] Plant system capacity at 242,000 pounds of steam per hour. Boilers rated at 22,000 pounds per hour. Costs are in January 1980 dollars.

[b] Site preparation costs include clearing, grading, leveling, powerhouse support structures, land and permit costs, plus miscellaneous site work.

[c] Estimated at 50% of boiler costs.

Source: Department of Energy, 1979
Ray Boiler Company

Table 6.4

OPERATING COSTS FOR DIRECT COMBUSTION SYSTEM[a]

Collection of Rice Straw @ $14.38/ton[b]	$1,009,476
Transportation[c]	440,935
Labor[d]	129,600
Maintenance and Repair[e] @ 10%	100,781
Taxes and Insurance @ 3%	421,639
Capital Recovery @ 12% for 30 years[f]	998,168
Credit to Rice Straw Suppliers @ 10% of Collection Cost	100,947
Total Operating Cost	$3,201,546
Cost Per MM Btu[g]	$5.26

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[a] Plant system capacity is at 242,000 pounds of steam per hour. Costs are in January 1980 dollars.

[b] Estimated seasonal Btu requirements of 609×10^9 Btu's/season. At 70% efficiency straw requirements are 70,200 tons at 14% moisture. Assume 7,100 Btu's per pound of straw at 0% moisture content.

[c] Estimated 10- to 15-mile hauls, cubes at 30 pounds/cubic foot, 30,000 pounds per haul.

[d] Assumed five men, three shifts for 90 days at $12 per hour. Hourly rates include overhead, workmen's compensation, state disability, and unemployment insurance.

[e] Includes 5% on capital equipment plus 5% for residue disposal.

[f] Assume 100% financing with 12 monthly payments for 30 years at 12%.

[g] 609×10^9 Btu's per season (MM Btu's/10^6 Btu's) = 609,000 MM Btu.

Source: Copley International Corporation.

combustion system is expected to produce 242,000 pounds of steam at the cost of $5.26 per MM Btu.

To compare the costs of direct combustion with a natural gas system the capital and operating costs of a newly built gas-fired boiler plant must also be determined. The costs of converting an existing natural gas powered system to direct combustion are uncertain. In addition, the feasibility of substituting rice straw cubes as a fuel source in an existing natural gas system would be highly speculative. Moreover, it is certain that the costs to do so would render the utilization of rice straw cubes as an energy source which is uneconomical.

Since natural gas systems operate at a higher overall efficiency level, a new seasonal input energy requirement must be determined. At an 85 percent thermal efficiency rating, 716.5×10^9 Btu's per season would be required to fuel the gas-fired system. The seasonal Btu requirements for the natural gas system are lower than the direct combustion system.

The capital costs of the natural gas system are shown in Table 6.5. A total of $5,039,063 is required. This system is rated slightly higher than the direct combusion system although the capital costs are substantially lower.

The operating costs are determined to be $4,301,760 as shown in Table 6.6. Translated into dollars per MM Btu, this amounts to $1.80 per MM Btu higher than the direct combustion system or $7.06 per MM Btu.

Table 6.5

CAPITAL COST FOR NATURAL GAS-FIRED SYSTEM[a]

Site Preparation[b]	$ 862,500
Boiler Equipment[c]	2,087,500
Fuel Handling Equipment[d]	662,500
Feedwater System and Auxiliary Equipment	418,750
Direct Costs	$4,031,250
Construction Contingency, Fees, and Taxes, etc. @ 15% of Direct Costs	$ 604,688
Engineering and Design @ 10% of Direct Costs	403,125
Total Capital Costs	$5,039,063

---

[a] Capacity rated at 300 x 10^6 Btu's per hour. Costs are in January 1980 dollars.

[b] Site preparation costs include clearing, grading, leveling, powerhouse and support structures, land and permit costs, plus miscellaneous site work.

[c] Boiler rated at 250,000 pounds of steam per hour.

[d] Includes storage tank, pumps and piping.

Source: Department of Energy, 1979.

Table 6.6

OPERATING COSTS FOR NATURAL GAS-FIRED SYSTEM[a]

Fuel Supply[b]	$3,286,900
Operating and Maintenance[c]	120,937
Taxes and Insurance @ 3%[d]	272,124
Capital Recovery @ 12% for 30 years[e]	621,999
Total Operating Cost	$4,301,960
Cost Per MM Btu[f]	$7.06

---

[a] Peak capacity rated at 250,000 pounds of steam per hour.

[b] Assumed 716.5 x 10^9 Btu's per season (609 x 10^9 Btu's output at 85% efficiency). Natural gas costs are calculated at $.45874 per Therm ($10^5$ Btu per Therm).

[c] Calculated at 12% of direct costs over 90 days. Includes labor costs.

[d] Calculated at 3% of capital costs.

[e] Assume 100% financing with 12 monthly payments for 30 years at 12%.

[f] 609 x 10^9 Btu's per season (MM Btu/10^6 Btu's = 609,000 MM Btu.

Source: Department of Energy, 1979.

C. Substitutability for Existing Energy Sources. The major point to be made from these analyses is that, theoretically, rice straw can be cubed, transported, and combusted in wood-fired boilers at a comparative advantage over natural gas. This is assuming, of course, that either system under consideration would be newly constructed. Needless to say, it would not be economically feasible to retrofit an existing natural gas-fired boiler system for the purpose of combusting rice straw.

Rice straw is available during the months of October, November, and December. The previous economic analysis is based on using the rice straw during this period. The cost of stockpiling rice straw was not assessed since there would be no incentive to do so on the part of fuel consumers. Other agricultural wastes could be utilized during periods when rice straw is unavailable.

Likely consumers of agricultural wastes would occur within the agricultural industry itself. Food processors, canneries, and millers would be the principal consumers for direct combustion processes. In addition, light industry or manufacturing processes which require process steam might comprise a portion of the market. These industries may be unwilling to utilize agriclutural wastes unless a guarantee of delivery can be made. Due to the uncertainty of weather conditions, rice growers would be reticent to enter into contracts binding them to deliver the rice straw. In light of these constraints, fuel consumers would be more inclined to pay higher prices for fuel (e.g., natural gas) and avoid the risk of interruptible fuel supplies.

Pyrolysis

This process is defined as the thermal decomposition of materials in the absence, or near absence, of oxygen. The decomposed end products consist of char, oil, and low Btu gas.

Pyrolysis systems are designed to serve as either stationary or mobile units. Stationary units have their greatest application where residues are generated on-site. If residues are to be transported to the pyrolyzer, the wastes need to be compact and easily handleable. Otherwise, collection and transportation systems are required which raise the operating costs of the process substantially.

The concept of a mobile pyrolysis system emerged to offset the collection and transportation costs which would be incurred by the stationary system if off-site residues were used. The mobile system, which converts wastes at the site of their production, alleviates having to transport low-density bulk to a thermal convertor unit.

Technical Feasibility. The Engineering Experiment Station (EES) of Georgia Institute of Technology developed an experimental vertical shaft, mobile pyrolyzer in 1976 (Tatom and Calcord, 1976). Peanut shells and sawdust were used primarily as feedstock for this system. EES's system consisted of two sets of trailers approximately 36 feet long. On one trailer a conveyer and dryer system is mounted which picks up the residue and drys it to an appropriate moisture content. The feedstock is then passed through a fuel hopper and into a convertor unit.

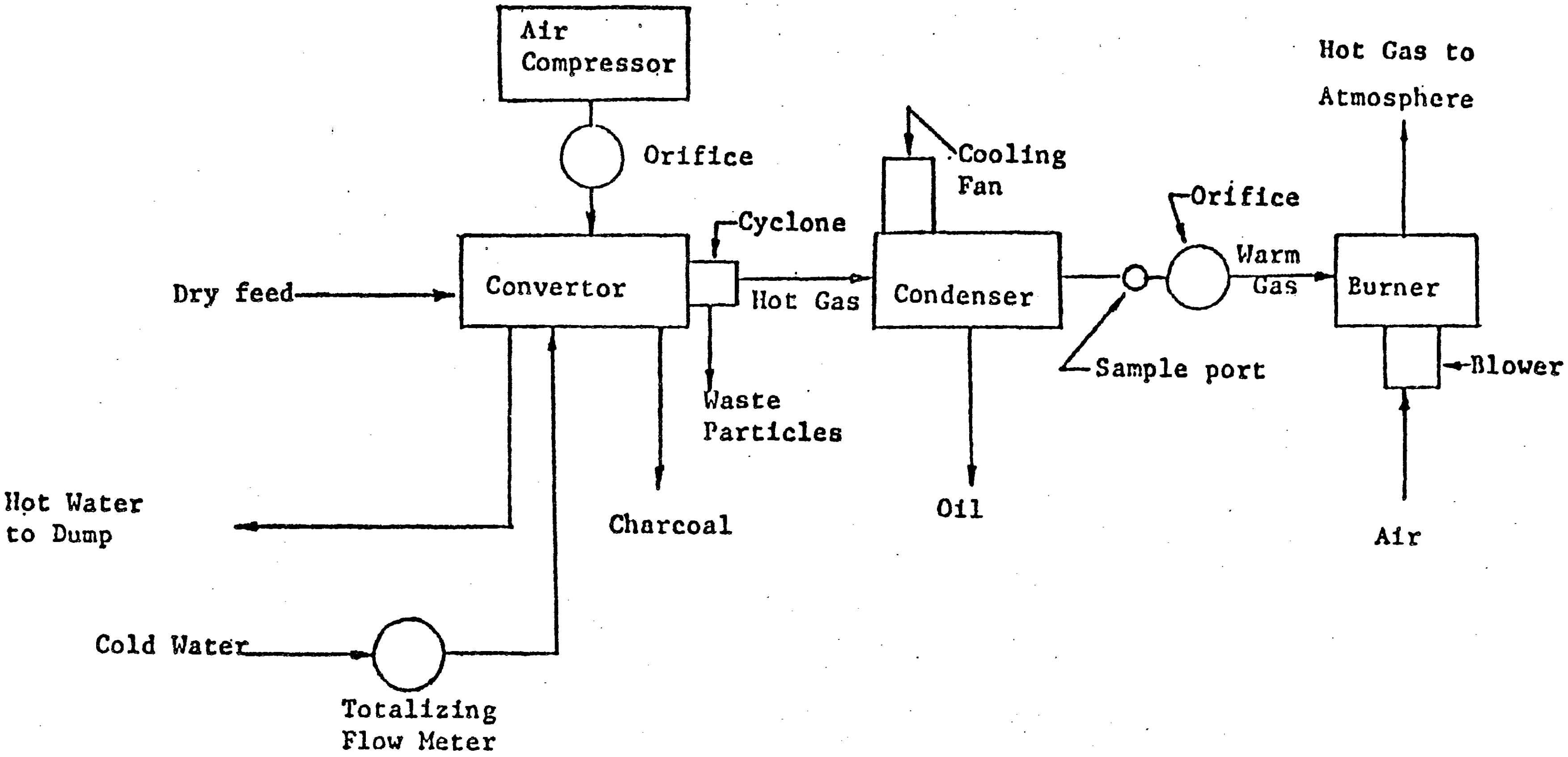
The products of the convertor unit consist of charcoal and hot gas. A portion of the hot gas is condensed to oil while the remainder is used to fuel the unit's dryer and/or engine-generator system. EES's mobile pyrolyzer is capable of converting 200 tons of waste (at 50 percent moisture) per day.

A similarly designed system is being built for field tests in California under a project sponsored by the U.S. Environmental Protection Agency and the State of California, Solid Waste Management Board and California Energy Commission (Kosstun et al, 1979). Energy Resources Co. Inc. (ERCO) is the prime contractor for this project. The ERCO system is designed to employ two 44-foot trailers which support a fluidized bed pyrolysis system capable of converting 180 tons of waste per day (at 50 percent moisture content) into one to two barrels of oil (approximately 336 to 672 pounds) and 200 to 400 pounds of char (Energy Resources Co. Inc., 1979). The system is approximately 80 percent built and field tests will commence some time this year.
Once operative, the pyrolyzer is scheduled to perform field trials on cotton gin trash, logging wastes, lumber mill wastes, rice straw, manure, and orchard prunings (see Figure 6.1 for pictorial diagram of the EES and ERCO pyrolysis systems).

Theoretically, once a prolysis operation has begun it may run continuously for 24 hours. As the char and oil products accumulate at the farm site a service truck would be required to collect the fuel products and transport them to a central thermal conversion plant (i.e., public utility, cannery, etc.).

Figure 6.1

PYROLYTIC UNIT PROCESS FLOW DIAGRAM



Source: (Tatam and Colcord, 1976).

Theoretically, one fuel collection truck could service four pyrolyzer units. Each unit consumes 200 tons of waste at 50 percent moisture per day (Tatom et al, 1976). If four conversion units were operated continuously for a period of one month, approximately 5,300 acres of rice straw could be disposed of (assuming 80 percent efficiency at 3.6 tons of straw per acre). The fuel products could be easily stored and transported since they have a much greater density than their rice straw precursors.

Depending on the moisture content of the feedstock, a pyrolysis system may extract 75 to 80 percent of heat theoretically available from dry waste (Tatom et al, 1976). The system typically converts a pound of dry organic waste to a half-pound of oil and char plus one-quarter pound of gas (Tatom et al 1976). The heating value of the oil ranges from 11,000 to 13,000 Btu per pound. In the following table a comparison of the typical properties of pyrolytic oil is compared to a No. 6 fuel oil.

The heating value of the pyrolytic oil (Btu's per pound) is substantially less than a No. 6 crude oil. The No. 6 oil is the residue left in the still following the oil refining process. The lower amounts of carbon and hydrogen in the pyrolytic oil reflects a lower saturated hydrocarbon content which accounts for the lower Btu rating. If the pyrolytic oil were to be used as a substitute for a No. 6 oil in an oil-fired burner, a greater volume of pyrolytic oil would have to be supplied to the boiler per unit of time to compensate for its lower energy content.

Table 6.7

TYPICAL PROPERTIES OF PYROLYTIC OIL

	No. 6 Oil	Pyrolytic Oil
Heating Value (Btu/lb)	18,000	12,800
Specific Gravity	0.98	1.0
Chemical Analysis (Wt. %)		
Carbon	85.7	58.1
Hydrogen	10.5	7.4
Oxygen	2.0	33.2
Nitrogen		0.35
Sulfur	0.6-3.5	0.04
Chlorine	---	0.02
Ash	0.3	0.82

Source: Energy Resource Co. Inc., op cit p. 10.

The end use applications for pyrolytic oil are numerous. It can be used as a substitute for oil-fired generating plants, a fuel for dehydrators, or at commercial facilities for electric power or process steam.

It is important to recognize, however, that there are technical difficulties involved with substituting fuels across the line. Discussions with boiler manufacturers indicate that boiler equipment must be retrofitted to accommodate new fuels. There are a lot of hidden expenses associated with retrofitting and it is impossible to acquire average estimates of the expenses involved since each boiler system is custom fitted for a particular purpose. The trace elements included in the pyrolytic oil need to be identified before it can be used in a given system. Apparently, oils pyrolyzed from different agricultural wastes have separate or, to a certain extent, unique properties.

A char oil mix also has applications for energy end use. Originally, researchers envisioned using char oil as a coal substitute which could be used in existing suspension or stoker-fired boiler systems. It is now believed that a char oil mix in energy release ratios up to 50 percent may be practical for use in oil-fired boilers (Tatom and Colcord, 1976). Other applications for char and oil products include fuel for on-farm power generation units, for use as a fuel oil extender and for various synthetic products.

Product synthesis of the low Btu gas generated from pyrolysis could be extended to develop methanol, amonia, hydrogen, and synthetic gas.

A review of literature on pyrolysis revealed no laboratory or prototype operations using rice straw as a feedstock. Inquiries at Georgia Institute of Technology indicated that rice straw may be a viable feedstock for pyrolysis, however, technical difficulties would need to be ironed out (Georgia Institute of Technology, 1980). It is possible that rice straw could prove to be a difficult feedstock as a result of its high silica (14 percent) and ash content (16.5 percent). ERCO's fluidized-bed pyrolyzer is believed capable of digesting rice straw and other wastes with no expected difficulties (Energy Resources Co. Inc., 1980). Field trials which will be performed on rice straw sometime this year should demonstrate rice straw's suitability as a feedstock for mobile pyrolysis.

Economic Feasibility. To assess the economic feasibility of converting rice straw to a pyrolytic fuel, a hypothetical system has been evaluated. This system employs 14 mobile pyrolyzers at separate locations throughout the rice growing community. It is assumed that the fuel consumer (i.e., food processing plants, canneries, etc.) would provide both capital and labor for the collection and handling of the pyrolysis end products.

The development of the pyrolysis system will ultimately be determined by economics. Given that the conversion technology is available, pyrolysis oil will be competing in the marketplace with other fuels. For the purpose of this analysis the cost of supplying pyrolytic oil will be compared with the cost of supplying a No. 2 fuel and No. 6 crude oil.

A. Collection and Transportation of Rice Straw. In order for the mobile pyrolysis concept to succeed, the collection of rice straw and timing of operations must be coordinated around harvesting activities. The collection of rice straw is assumed to be conducted during the fall. In the spring, growers are preoccupied with preplant preparations. Growers attempt to plant their rice crop on or about May 1. Many growers state that planting one day later than this (on the average) results in two days later harvesting in the fall. During the fall, growers would have to hire additional labor to conduct and/or manage the collection of rice straw since they would most likely be involved in harvesting activities. After the harvest season is over (approximately November 30) growers would have about 40 days to collect rice straw from their fields.

The pyrolyzers can handle straw in moisture contents up to 50 percent. It is assumed that rice straw is baled and collected from the fields at 14 percent moisture. The self-propelled Ben Thompson Baler is capable of baling straw in approximately 1,000-pound bales. Lower moisture contents are optimal; however, the loose packed bales produced from this baler will not present problems if baled at higher moisture contents. The bales are expected to be utilized almost directly as they are retrieved from the field, therefore, the moisture content of the bales are not an issue. The baler is believed to be capable of yielding five tons per hour under normal field conditions. This rate includes field maintenance and loading of bales onto a truck. At this rate, one baler must be utilized at least 20 hours per day to keep up with the mobile pyrolyzer. For the sake of analysis it is assumed that these requirements can be met. Indicated in Table 6.8 are the costs for the Ben Thompson Baler.

Table 6.8

ON-FARM COLLECTION COSTS
FOR A MOBILE PYROLYSIS SYSTEM
(Ben Thompson Baler)[a]

Collection Costs

Tons	Overhead $/Ton	Cash $/Ton	Total $/Ton	Total $/Season
97,850[b]	$7.59	$6.97	$14.56	$1,424,696

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[a] Costs are in January, 1980 dollars for a 600-acre farm.

[b] Rice straw is at 14 percent moisture content.

As shown in Table 6.8 the total collection cost per ton amounts to $14.56. These costs include both bankout and off-loading. Assuming that the pyrolysis process is conducted on a farm size of 600 acres, the total cost to the farm for collection would be $31,799.

The transportation of the pyrolysis oil generated on-farm would be managed by three 7,300 gallon tanker trucks. It was assumed that the hauling distance would average 15 miles per load. The costs of this system are shown in Table 6.9.

Table 6.9

COMPARISON OF TRANSPORTATION COSTS[a]

Type of Fuel	cwt	$/cwt	Surcharge	Total Season
Pyrolysis Oil[b]	528,646	$0.15	15%	$ 94,231
No. 2 Diesel[c]	351,009	0.46	15%	185,684
No. 6 Crude[d]	368,756	0.44	15%	186,591

---

[a] Requirements of 609 x 10^9 Btu's per season. Fuel oils burn at 90 percent efficiency.

[b] Hauling distance at 15 miles. Estimated 12,800 Btu's per pound.

[c] Hauling distance at 105 miles. Estimated 17,350 Btu's per pound.

[d] Hauling distance at 105 miles. Estimated 18,350 Btu's per pound.

Sources: Public Utilities Commission.
Exclusive Transportation Corporation.

Also included are the comparative costs of hauling No. 2 and No. 6 fuel oil. It was assumed that the fuel oil would be hauled approximately 100 miles by common carrier. The varying amounts of oil being hauled are a result of the variation in Btu content of each oil and their respective densities.

B. Capital and Operating Costs. The theoretical mobile pyrolysis system requires 14 mobile pyrolyzers. In addition, modifications to an existing oil-fired boiler facility is required. These costs are shown in Table 6.10. An estimated $12,529,939 is required to pay for all capital costs. The system is capable of supplying energy at the rate of 282 x 10^6 Btu's per hour. The steam boiler is rated at 250,000 pounds of steam per hour. The boiler rating corresponds to the average load which might be required at a cannery or food processing plant.

It was assumed that the heat from both the char oil would be utilized in converted oil-fired boilers. Therefore, the derivation of total seasonal straw requirements is lower than if the oil alone was used. Through the remainder of this section reference is made to the oil only. The units and conversions used to derive rice straw demand is shown below:

$$\frac{282 \times 10^6 \text{ Btu's/hr}}{50\% \text{ yield}} \times \frac{1 \text{ lb straw @ } 0\% \text{ moisture}}{7{,}100 \text{ Btu's}} \times 1.14 = 90.6 \times 10^3 \text{ lbs straw/hr}$$

$$\frac{90.6 \times 10^3 \text{ lbs straw/hr}}{2{,}000 \text{ lb/ton @ } 14\% \text{ moisture}} \times \frac{24 \text{ hrs}}{\text{day}} \times \frac{90 \text{ days}}{\text{season}} \times \frac{\text{acre}}{3.64 \text{ tons}} = 26{,}881 \text{ acres}$$

Table 6.10

CAPITAL COST FOR MOBILE PYROLYSIS SYSTEM[a]

Pyrolyzer (14 mobile units @ $759,050)[b]	$10,626,700
Modifications to Existing Plant[c]	688,875
Handling and Conveyance System[d]	417,500
Storage (30 days)[e]	220,270
Transportation[f]	300,000
Direct Costs	$12,253,345
Construction Contingency, Fees, and Taxes, Etc. at 15% of Direct Costs	165,956
Engineering and Design at 10% of Direct Costs[g]	110,638
Total Capital Costs	$12,529,939

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[a] Utilizes 1,086 tons of straw per day (14 percent moisture) Costs are in January, 1980 dollars.

[b] Cost includes engineering, design, fabrication, and installation.

[c] The costs of retofitting an existing steam generating plant were approximated by taking one-third the new cost of a 250,000 pounds per hour boiler.

[d] Estimated at 20 percent of the new cost of a 250,000 pounds per hour boiler.

[e] Assumed 30-day storage for 220,270 gallons at $1,000 per 10,000 gallons

[f] Three diesel/tank trailers with 7,300 gallon holding capacity.

[g] Does not include pyrolyzer, transportation, or storage facility.

Sources: Adapted from Energy Resources Co. Inc., 1979.
Copley International Corporation.

The amount of acreage required to supply the rice straw is calculated to be 26,881 at 3.64 tons per acre (14 percent moisture content). The system is anticipated to run for a 90-day period. The 90-day period corresponds to seasonal demand by agricultural industries which this system is intended to supply. Table 6.11 lists the operating costs for the mobile pyrolysis system.

The costs which are shown in Tables 6.10 and 6.11 reflect the amount of money that is required to supply pyrolysis oil to an existing oil-fired boiler system. No operating costs of the boiler system itself are included in these tables. Since this economic analysis is based on the costs of operation, the boilers themselves are irrelevant.

C. Substitutability for Existing Fuel Sources. The same constraints face the mobile pyrolysis system as the direct combustion system. Namely, the likelihood of adopting the pyrolysis oil into industrial processes will be based on cost and reliability of supply. As shown in Table 6.12 the cost per therm of pyrolysis oil is at least 34 percent higher than the next best alternative.

The ability of rice farmers to supervise and maintain labor crews for the collection of rice straw is somewhat unclear. Rice growers hire labor during the harvesting season, yet the amount and availability of excess labor for collection processes is uncertain. Moreover, the uncertainty of weather conditions during the fall increases the risk associated with

Table 6.11

OPERATING COSTS FOR MOBILE PYROLYSIS SYSTEM[a]

Collection of Straw	$1,424,696
Labor[b]	2,166,800
Transportation (fuel and repairs)[c]	101,750
Supplies[d]	23,100
Maintenance and Repair (5% of Capital Cost)[e]	196,100
Residue Disposal	20,000
Taxes and Insurance @ 3%	470,643
Capital Recovery @ 12% for 30 years[f]	1,546,614
Credit to Rice Straw Suppliers @ 10% of Collection Cost	142,469
Total Operating Cost	$6,092,172
Cost Per MM Btu	$10

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[a] Utilizes 1,086 tons of straw per day (14 percent moisture). Costs are in January, 1980 dollars.

[b] Estimated 2 supervisors, 14 loaders, and 14 system operators for 90 days each, 4.2 shifts per week. Wages include workman's compensation, state disability insurance, etc., plus clerical and administrative.

[c] Estimated 905 trips at $94,250 (tanker capacity is 7,300 gallons). Repairs estimated at $2,500 per tanker per year for three tankers.

[d] Suppliers include moving pyrolyzers 42 times at $500 per move, plus LPG for startup at $2,100.

[e] Calculated for 90 days.

[f] Assumed 100 percent financing with 12 monthly payments for 30 years at 12 percent.

[g] Total Btu required are 609,000 MM Btu's.

Sources: Adapted from Energy Resources Co., Inc., 1979.
Copley International Corporation.

purchasing pyrolysis oil derived from rice straw. While it is true that other fuels have been in short supply at times, over the long run these fuels have proven to be reliable.

Table 6.12

COMPARISON OF FUEL COSTS

	Gallons	Total Cost[a]	Cost/MM Btu [b]
Pyrolysis Oil	6,608,075	$6,091,020	$10.00
No. 2 Diesel[c]	4,387,608	4,573,292	7.50
No. 6 Crude[d]	4,524,614	2,238,499	3.70

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[a] Includes all costs, including transportation for No. 2 and No. 6 fuel oils.

[b] Cost per MM Btu as output at 609 x 10^4 therms per season.

[c] Cost at $0.91 per gallon.

[d] Cost at $0.435 per gallon.

Sources: Shell Oil Company, San Rafael.
Exclusive Transportation Corporation, San Diego.
Copley International Corporation.

Given that the cost per MM Btu of pyrolysis oil is greater than the other fuel oils considered in this section, this alone precludes its use as a substitute fuel oil. As the environmental pressures mount to restrict burning, the market for pyrolysis will improve. It is likely that the capital costs for the pyrolysis units will substantially decrease as more units become available. Presently, however, it must be concluded that the comparative costs of substituting pyrolysis oil for either a No. 2 or No. 6 fuel oil are not favorable.

Gasification

Gasification is the reaction of solid fuels with steam and oxygen or air to yield a low Btu gas. Gasifiers were first introduced in the late 1800's as stationary operations to gasify coal or coke. It was later found that, in addition to low grade fossil fuels, biomass could be converted into gas. During World War II fuel shortages in Europe generated a renewed interest in gasifiers for the replacement of coke, and natural gas as fuel for furnaces and boilers. Following World War II interest in gas producers declined as fossil fuels once again became more abundant. A few countries including England, France, and especially Sweden have continued to develop gas-producer technology since the mid-1940's. Du Vant Motors in France manufactures gas producers and diesel engines which operate with a diesel-producer gas mix (Horsfield, 1976). Sweden developed the famous Inbert downdraft gas producer which is used to power farm equipment today.

Original gas producer technology employed an updraft design. In updraft gas producers the air flow travels upwards through the residue-fuel; this process tends to generate more tar and charcoal than downdraft gas producers. Large, stationary updraft gas producers have been successfully operated. Recent testing on gasifiers has been conducted on Swedish-styled downdraft gasifiers. Downdraft gas producers tend to eliminate tar from the gas and are better suited to crop residues (Goss, 1979).

A schematic diagram of a downdraft gas producer is shown in Figure 6.2. This particular gas producer can be converted to an updraft mode if desired. Very simply, the fuel material (straw, wood chips, prunings, etc.) is combusted in the fuel chamber with a limited supply of air or oxygen. Steam is generated which passes through the reaction zone to produce a low Btu gas at low pressure.* The gas which is produced roughly consists of the following elements:

Table 6.13

ANALYSIS OF GAS OBTAINED FROM A DOWNDRAUGHT RESIDUE-FUELED PRODUCER*

Gas	Amount
CO_2	100%
CO	20
H_2	18
CxHy	5
O_2	1
N_2	46
	100%

Source: (Williams et al, 1978).

The overall thermal efficiency estimated for crop residue conversion is between 65 and 75 percent of the theoretical energy available from the feedstock (Alich et al, 1976). In

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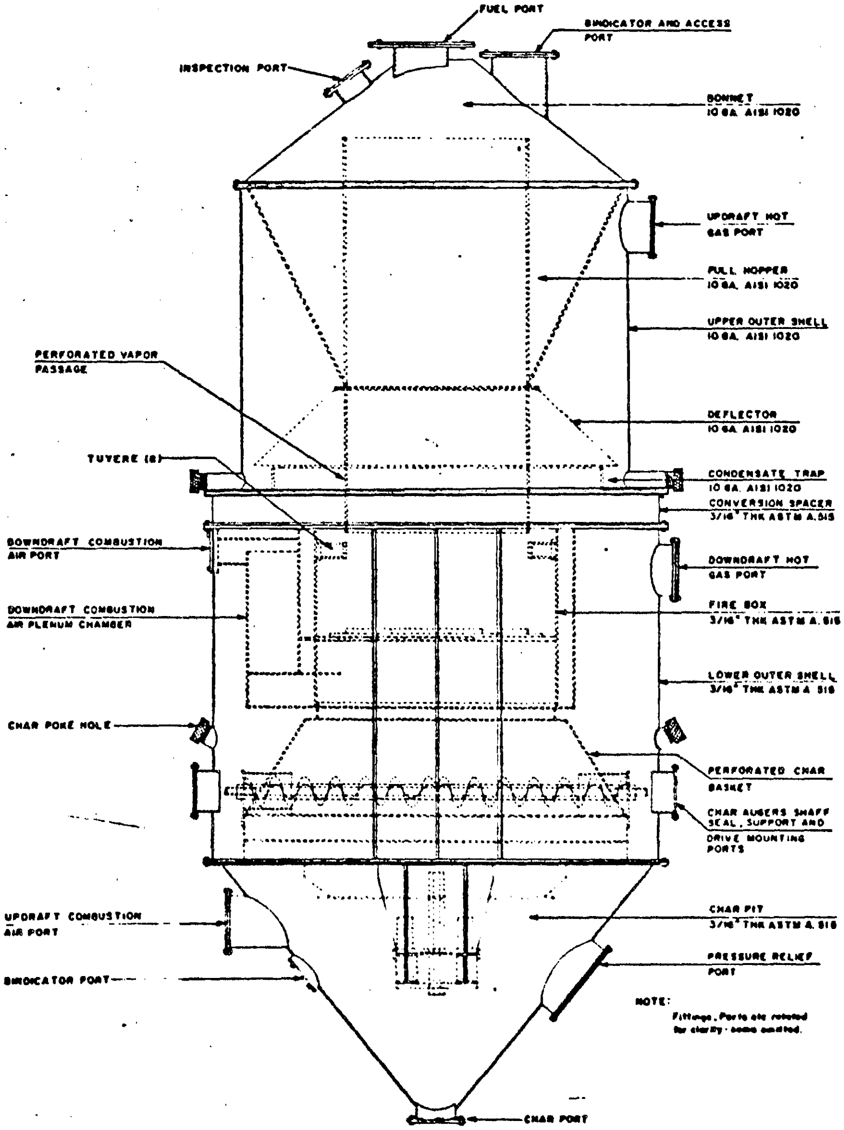
*For a detailed explanation of the gasification process refer to reports by (Williams et al, 1978 and Goss, 1979).

Figure 6.2

SCHEMATIC DIAGRAM OF DOWNDRAFT GASIFIER



Source: (Goss, 1979)

some cases efficiency of the gasifier system has reached 85 percent. Factors which tend to reduce the thermal efficiency of gasification are ash content, silica content, moisture content, and fuel particle size. Fuels should have a low ash content; less than 6 percent is optimal. High amounts of silica lower the thermal efficiency of the process due to heat losses in the fire box. The moisture content of the feedstock should be lower than 20 percent. In addition, the feedstock particle size should be uniform to prevent stoppages of the fuel flow from the hopper into the fire box.

The value of rice straw as a feedstock by itself is somewhat questionable at this time. The silica content of rice straw is approximately 14 percent and the ash content is 16.5 percent. These two factors alone tend to limit its present suitability as a fuel in downdraft gasifiers. The technology of gasification is sophisticated but prototype systems have yet to be designed which can handle rice straw without slagging problems and clinker formation.* High silica content results in a corresponding lower thermal efficiency. In a recent study, the gasification characteristics of several agricultural residues were evaluated. It was concluded that

> ...fuels with severe slag formation cannot be used as fuels for downdraft gasification. It appears that straw from cereal grain, oil seed and dry bean crops are too high in ash content to be a suitable downdraft gasifier fuel. Most wood wastes, stone-fruit pits, and nut shells are good to excellent fuels (Goss, 1979).

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*Large amounts of slag stops the gasification process. Ash components form eutectic mixtures called clinker.

Agricultural residues with a silica content in excess of 2 percent are considered unacceptable for downdraft gasification. Rice straw has a silica content of 14 percent and, therefore, its value as a feedstock, compared to other residues which typically have lower silica contents, is dimished.

Researchers remain optimistic, however, that gasification technology will be suitable for rice straw. With high ash-content feedstock, the gasification has to be kept below 16,000 to 18,000 degrees Fahrenheit to control slagging. If the temperature of gasification is lowered for rice straw applications, the overall thermal efficiency of the system will likewise be lowered. It is possible that additives could be used to alleviate the problem (Williams, 1980).

Inquiries were sent to several companies that deal with gasifier systems.* The response was that gasification of rice straw is feasible assuming the straw is suitably prepared. There seems to be universal agreement by researchers and private companies that gasification of rice straw is feasible; yet, prototype systems have yet to be developed.

Producer gas is suitable for a wide range of applications. Steam boilers, internal combustion engines, diesel engines, and heat-transfer systems could be operated on low-Btu gas. In some applications the producer gas needs to be cooled first, such as for the internal combustion engine. In diesel engines

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*Companies include William Incandesant Ltd., A.J. Brockwell and Partners, E.R. Millinger and Co., and Du Vant Motors.

a mix of diesel fuel and producer gas has given promising results. Ratios of producer gas to diesel of up to 4.5 to 1 have been obtained. Direct drive systems (pumps, conveyors, compressors, etc.) or generator systems could be attached to reciprocating engines for a myriad of applications. When boilers are fired by producer gas instead of natural gas, the thermal efficiency of the boilers is decreased 84 percent for natural gas to 78 percent for producer gas.

Economic Feasibility. In order to assess the economic feasibility of utilizing gasification technology, a hypothetical application is evaluated. The low-Btu gas generated from gasifiers is suitable for use in fuel burners, therefore the feasibility of gasifying rice straw to run a rice dryer facility is assessed.

The input requirements of the rice dryer is based on the type and size of rice dryers utilized in the rice industry today. The assumptions implicit in the economic analysis are presented below:

- one dryer consumes 4 MM Btu's per hour and handles 1,500 cwt of rice per hour
- the rice dryer services 150,000 acres
- average yield per acre is 60 cwt at field moisture
- the seasonal operating period is 60 days
- the gasifier operates at 75 percent efficiency
- the fuel burner operates at 80 percent efficiency

The seasonal energy requirements are calculated to be 24 times 10^9 Btu's per season. The derivation is as follows:

$$150{,}000 \text{ acres} \times 60 \text{ cwt per acre} = 9 \times 10^6 \text{ cwt/season}$$

$$9 \times 10^6 \text{ cwt} \times \frac{4 \times 10^6 \text{ Btu's/hr}}{1{,}500 \text{ cwt/hr}} = 24 \times 10^9 \text{ Btu's/season}$$

The hourly Btu requirements are:

$$24 \times 10^9 \text{ Btu's} \times \frac{1 \text{ season}}{60 \text{ days}} \times \frac{1 \text{ day}}{24 \text{ hours}} = 16.67 \times 10^6 \text{ Btu's/hr}$$

The seasonal rice straw requirements are:

$$\frac{24 \times 10^9 \text{ Btu's}}{75\% \times 80\% \times 7{,}100 \text{ Btu's/lb rice straw}} \times 1.14 \text{ moisture content} =$$

$$6.42 \times 10^6 \text{ lbs rice straw/season}$$

The hourly rice straw requirements are:

$$6.42 \times 10^6 \text{ lbs rice straw} \times \frac{1 \text{ season}}{1{,}440 \text{ hours}} = 4{,}458 \text{ lbs rice straw/hr}$$

The total acreage requirements for rice straw is:

$$6{,}420{,}000 \text{ lbs rice straw} \times \frac{1 \text{ ton}}{2{,}000 \text{ lbs}} \times \frac{\text{acre}}{3.64 \text{ tons}} = 882 \text{ acres}$$

Assuming a gasifier operates at a fuel intake rate of 1,400 pounds of dry rice straw (0% moisture) per hour, the number of gasifiers required is approximately three.

$$4{,}458 \text{ lbs straw/hour} \div 1.14\% \text{ moisture} \div 1{,}400 \text{ lbs/hour} = 2.79$$

Therefore, at the stated energy demand of 25×10^9 Btu's per season, three gasifiers would be utilized to consume 882 acres of rice straw and thereby provide enough fuel to dry 150,000 acres of rice grain. In the remaining portion of this section, the costs of operating the proposed system are presented. The analysis focuses on the cost of substituting gasification for natural gas which is presently supplied by public utilities.

A. Collection, Transportation, and Storage. The collection operation employs an on-farm field cubing system. A farm size of 600 acres is used to calculate the overhead and operating costs of the operation. At the field cuber's maximum operating capacity, a farm size of 2,400 acres could be cleared of rice straw in 40 days assuming 24-hour work days. The required seasonal tonnage to fuel the rice dryer is 3,210. Approximately 30 days would be required to collect the straw, assuming 12-hour days.

Once the rice straw is collected it is expected to be loaded into 20-foot dump trucks with a maximum carrying capacity of 30,000 pounds each. If the rice cubes are densified to 30 pounds per cubic foot, a volume of 1,000 cubic feet per dump truck is required. The charge for hauling is split between 5 to 10 and 10 to 15 mile distances. Both the collection and transportation costs are shown in Table 6.14.

The total delivered cost of rice straw cubes amounts to $69,958. This does not include any economic return to the rice straw suppliers. The cost merely meets all out-of-pocket and general overhead expenses incurred by the farmer.

Table 6.14

COLLECTION AND TRANSPORTATION COSTS FOR
THE GASIFIER SYSTEM

Collection Costs[a]

Tons	Overhead $/Ton[b]	Cash $/Ton	Total $/Ton	Total $/Season
3,210	$14.23	$7.27	$21.50	$69,015

Transportation Costs[c]

Tons	5-10 Miles	10-15 Miles	Total $/Season
3,210	$453	$490	$ 943
Total Collection and Transportation Costs			$69,958
Total Cost Per Ton			$21.79

---

[a] Field cubing system operating at nine tons per hour. Costs are in January, 1980 dollars.

[b] Overhead costs are based on a 600-acre farm size.

[c] Transportation charges are based on rates approved by the California State Public Utilities Commission.

A storage facility is provided for to insure a reliable supply of dry feedstock. Approximately 71,000 cubic feet of storage space are estimated for a 15-day supply of rice straw cubes. The total storage facility cost is calculated to be $15,000.

B. Capital and Operating Costs. The costs of installing and operating the proposed gasification system are estimated from a variety of sources. It is likely that the capital costs of the system will decrease as gasification operations become more commonplace. The most difficult cost to estimate is the cost of retrofitting the existing dryer facility to handle the low-Btu gas generated from rice straw. Engineers state that larger volumes of synthetic gas are required per unit of time when used instead of natural gas. The capital costs included in Table 6.15 allow for the installation of three new fuel burners. Other equipment will undoubtedly be required, however, it is unclear what the nature and cost of thie equipment will be. As presented, the capital costs amount to $998,750. With the exception of the storage facility, the capital equipment would be sufficient for year-round operation.

The operating costs are based on a 60-day operating period. As shown in Table 6.16, the total oeprating costs amount to $308,212 per season. Translated into cost per million Btu's, the operating expense is $12.84 per MM Btu. At the same output, natural gas systems would be substantially cheaper at about $5.39 per MM Btu (based on natural gas at $4.58 per MM Btu at 85 percent efficienty). This represents a cost disadvantage of $7.45 per MM Btu's for gasification or $178,712 over a 2-month operating period.

A large factor in the cost disparity is due to the high fixed cost relative to the production period. Since the capital recovery and fixed overhead items are annual costs, the marginal cost of production is higher over a two month period than if the gasification facility were to be operated all year. For example, if the variable costs (including all items except

Table 6.15

CAPITAL COST FOR A GASIFER SYSTEM[a]

Gasifier Equipment[b]	\$480,000
Modification to Existing System[c]	60,000
Installation @ 30%	144,000
Storage Facility for 15 Days[d]	15,000
Material Handling Equipment[e]	100,000
Total Direct Costs	\$799,000
Construction Contingency, Fees, and Taxes, Etc. @ 15% of Direct Costs	119,850
Engineering and Design @ 10% of Direct Costs	79,900
Total Capital Costs	\$998,750

---

[a] System is rated at 4,200 at 22.4×10^6 Btu's per hour maximum. Costs are in January, 1980 dollars.

[b] Three gasifiers at \$160,000 each.

[c] Includes the cost of three fuel burners, \$20,000 each.

[d] 6,000 square feet at \$2.50 per square foot.

[e] Estimated cost of conveyors at \$1,000 per linear foot for 75 feet. Miscellaneous equipment, i.e., tractor with scoop at \$25,000.

Sources: (Goss, 1979).
Copley International Corporation.

Table 6.16

OPERATING COSTS FOR A GASIFIER SYSTEM

Rice Straw Supply[a]	$ 69,958
Labor[b]	60,000
Residue Disposal[c]	6,000
Maintenance and Repair[d]	13,300
Taxes and Insurance @ 3%	29,900
Credit to Rice Straw Suppliers @ 10%	6,996
Capital Recovery[e]	122,058
Total Operating Cost	$308,212
Cost Per MM Btu	$12.84

---

[a] Seasonal supply is 3,210 tons at $21.79 per ton. Costs are in January, 1980 dollars.

[b] Estimated to include two men for 24 hours at $12 per hour and one man for eight hours at $12 per hour.

[c] Cost of hauling and spreading ash residue from gasification. Approximately 11,000 pounds of ash at $0.55 per cwt.

[d] Estimated for two months at 10 percent of direct capital costs per year.

[e] Financed 100 percent of capital cost at 12 percent per year for 30 years. Calculated by monthly payments.

Sources: (Goss, 1979).
Copley International Corporation.

capital recovery, taxes and insurance) were increased to a 12-month operating period, the marginal cost per MM Btu would approximate $7.56. This still represents a cost disadvantage of $2.17 per MM Btu compared to natural gas systems. The costs to supply gas under the various assumptions are summarized in Table 6.17.

Table 6.17

COSTS TO SUPPLY GAS AT VARYING OUTPUTS

Operating Period	Gasification ($/MM Btu)	Natural Gas[a] ($/MM Btu)
2 Months (25 x 10^9 Btu's)	$12.84	$5.39
12 Months (150 x 10^9 Btu's)	7.56	5.39

---

[a] Costs to supply natural gas are based on Pacific Gas and Electric Company rates for a large commercial facility operating at a minimum of 5,000 therms per year @ $0.45874/therm (May, 1980).

C. Substitutability for Existing Energy Sources. The previous analysis assumes that an existing gas dryer would be retrofitted to accommodate a gasification system. If the capital and operating costs of a newly constructed gasified dryer facility were compared with a newly constructed natural gas facility, the economics of gasification might look promising. A large factor in this would be whether or not natural gas transmission lines were accessible. If extensive conveyance systems were required for natural gas, the capital costs of such a system would be extremely expensive.

Since the supply of rice straw could be curtailed during foul weather, a rice dryer or any other potential gas consumer may be unwilling to use the produced gas at any cost. Additionally, rice growers would be hesitant to commit themselves to supplying rice straw since unforseen difficulties are always a factor in farming.

C. Substitutability for Existing Energy Sources. The present technology and economics of gasification do not support its use in existing commercial facilities if rice straw is used as a fuel source. There may be a potential for gasification in newly constructed commercial operations; however, the economics of this has not been evaluated in this study.

Other studies of gasification economics show that systems are economically feasible if used under the appropriate conditions. R.O. Williams, et al, reports that gas can be generated from rice hulls at a very large savings over natural gas.* The producer gas systems studied by Williams was expected to fuel a theoretical 1050 Bhp steam boiler system at a rice mill (Williams et al, 1978). Under this system, an annual energy consumption of 2.6×10^{11} Btu's per year was required. A 5-year projected natural gas price of $4.48 per MM Btu was used as a basis of comparison.

If rice straw was routinely collected, such as in a total harvest system, and the rice straw was used in conjunction with

---

*Copley International Corporation calculated that William's gasification system resulted in a $2.04/MM Btu cost advantage over natural gas.

other fuels during the year, the fixed costs of production would be favorable. If rice straw was planned for year-round consumption, large storage costs would be incurred which would undoubtedly render such a system economically unfeasible.

Anaerobic Digestion

This process involves the biochemical decomposition of organic matter in the absence of oxygen. Decomposition is accomplished in two stages by both facultative and obligate anerobic bacteria. In the first stage organic matter is converted to low molecular weight alcohols and fatty acids by acid forming bacteria. The second stage is accomplished by methane-forming bacteria which convert the low molecular weight compounds to methane and carbon dioxide plus other gases.

Technical Feasibility

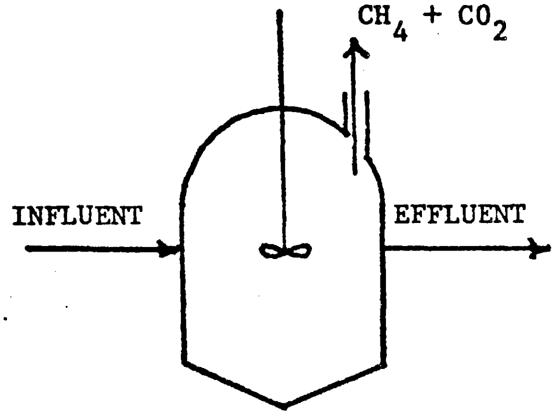
The digestion process must be carried out in a controlled environment. There are several factors which have to be monitored in order to maintain proper environmental conditions for the bacteria. For instance, it is important that the pH of the organic matter be properly balanced between six and eight. The temperature of the process should be regulated at or near 95 degrees Fahrenheit. A decrease in temperature would result in a corresponding decrease in gas production. Other factors to be concerned about include the following (Bolton and Klein, 1971):

- overloading of digesters
- volatile acids too high
- presence of toxic substances
- presence of free oxygen

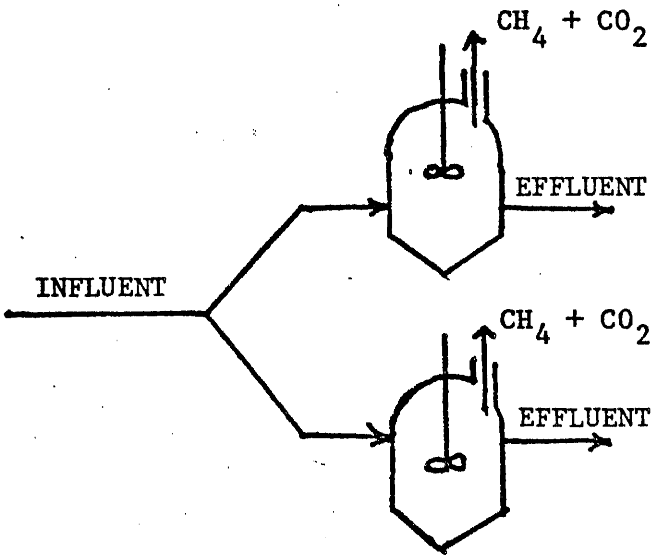
Anerobic digestion can be carried out in one of several ways: a completely mixed system, a batch load, plug flow, or land fill system. A schematic representation of the first three processes is shown in Figure 6.3.

Figure 6.3

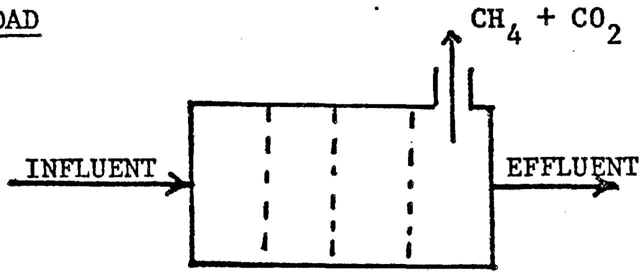
SCHEMATIC REPRESENTATION OF ANAEROBIC PROCESS CONFIGURATIONS



1. COMPLETELY MIXED



2. BATCH LOAD



3. PLUG FLOW

Source: (Horsefield and Williams, 1977)

The completely mixed system has the advantage of allowing high volumetric loading rates with short retention times (Horsefield, Becker, and Jenkins, 1977). The effluent is withdrawn as new organic matter is added to the system. In this manner the reaction is maintained at a constant volume. The mixed system must maintain a balance between solid and liquid stabilization and contact by the microorganism with the substrate. It is not easy to strike a balance between these two competing processes.

The batch load system offers an alternative to this delicate condition by the design of a two-stage system. The primary stage is effected at elevated temperatures in a closed tank. Most of the digestion and gas evolution takes place here. During the second stage of the batch-load system consolidation of the organic matter takes place which is accompanied by separation of metabolized liquor. Batch-load systems have short liquid retention times and long solid retention times.

The plug-flow system incorporates the simplest design and, of the three, is the easiest to operate. Once the organic matter is inside the reactor no mixing or agitation takes place. This system is more prone to contamination. Gas evolution from the plug-flow design is lower than that with other systems.

The rate of which digestors work is variable. "Residence time in the tanks is usually 10-30 days, although some systems are proposed with a residence time of three to six days." (Little, 1978) The process works best when there are no more than 10 to 20 percent solids in the feedstock.

Landfill systems are currently designed around Municipal Solid Waste (MSW) digestion. Several landfill methane projects are being tried in California (Little, 1978). These facilities either market synthetic gas or generate electricity from MSW by-products. One project in Palos Verdes, California, provides enough gas to handle the needs of 3,500 homes in this southern California community.

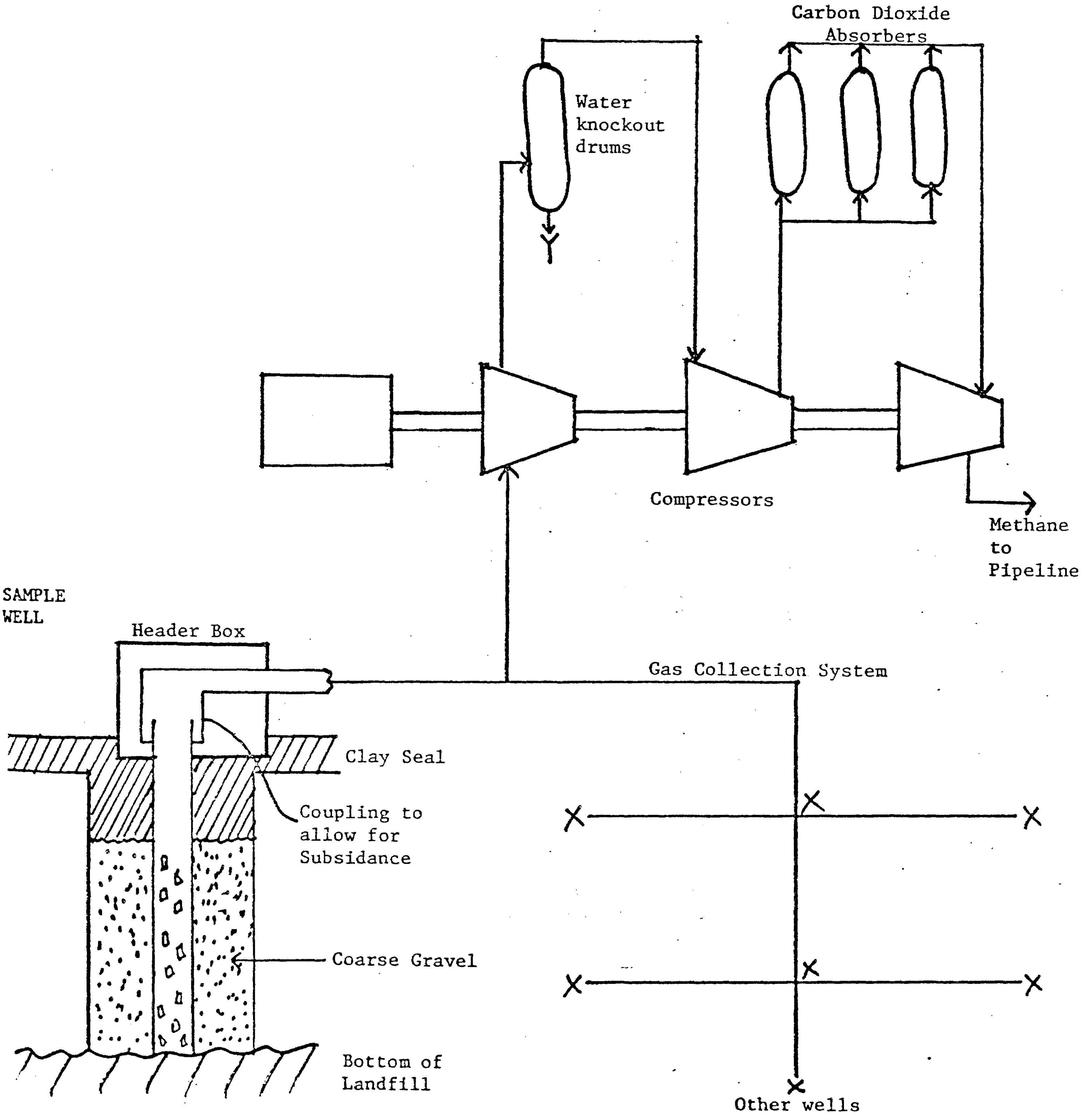
Animal manure projects are being developed at several locations throughout the United States. Animal manures, as with MSW, are well suited to anaerobic digestion due to their high moisture content. In Oaklahoma, Calorific Recovery Anaerobic Process, Inc. converts cattle wastes at a feedlot to methane for commercial delivery to Peoples Gas of Chicago via Natural Gas Pipelines Co. (Little, 1978). It is claimed that the process is economically viable as a gas producer. (Animal feed and fertilizer by-products generate a portion of the operation's revenues.) A major advantage of a feedlot operation is that manures are available in large quantities on-site.

A flow chart of a simplified landfill process to generate methane is shown in Figure 6.4 . The system requires the main portions: 1) wells and gathering lines, 2) compressors, and 3) a gas processing unit.

Wells are drilled at various locations to the entire depth of the landfill. The wells are gravel packed and sealed with a clay envelope to prevent gas from either entering or escaping from the enclosed system. A compressor system is used to draw

Figure 6.4

LANDFILL METHANE SIMPLIFIED PROCESS FLOW DIAGRAM



Source: (Little, 1978)

the gas from the landfill and compress it to meet end-use requirements.

Due to its adaptability, it is possible to design landfill systems on a wide range of scales. However, as with all other anaerobic digestion systems a sludge is produced. In processes where animal manure is used as a feedstock, the sludge contains the necessary ingredients to make a low analyses nitrogen/phosphorus/potassium fertilizer (NPK) with relative percentages of 6-3-3 (Alich, Jr. et al, 1976). With rice straw it is unclear whether the sludge has any chemical value or not.

For agricultural applications anaerobic digestion has great potential for use on beef and dairy farms (Williams et al, 1976). Anaerobic digestion of farm manure products has received considerable attention as an energy-producing waste management practice. A limited amount of attention has been placed on agricultural crop residues as a feedstock for anaerobic digestion (Jewell, 1975).

The products generated from anaerobic digestion consist mainly of methane (CH_4) and carbon dioxide (CO_2). The composition of typical biogas end products from anaerobic digestion is shown below (Fairbank et al, 1975). The methane gas may be used anywhere that natural gas is used. As an illustration consider the following applications:

- on-farm for stationary or mobile internal combustion engines with ancilliary direct drive or generator systems
- fuel for boilers

- heating air for drying crops
- home appliances

Table 6.18

COMPOSITION OF BIOGAS
FROM ANAEROBIC DIGESTION

Compound	Percent of Total Gas
CH_4	60 - 70
CO_2	25 - 40
H_2	5 - 15
N_2	
NH_3	
H_2S	
CO	
O_2	
R-COOH	
H_2O	

Source: (Fairbank, 1976)

Piping and conveyance systems would have to be planned for to implement these alternatives. It would be advantageous to locate the particular end-use equipment in close proximity to the digestor. In addition, some consideration would have to be given to a disposal site to handle the residual sediment left over from the digestion process.

Certain characteristics of the rice straw itself may render it as an unsuitable feedstock for anaerobic digestion. The lignin and cellulose in rice straw form a molecular complex which make it particularly difficult for microbes to digest. The lignin acts as a physical barrier and impedes the microbial breakdown of the polysaccharides located in the rice plant's cell walls (Han, 1973). The overall effect would be to decrease the efficiency of the system since the undigested solids would take up capacity in the digestion tasks without a corresponding increase in gas production. Biomass conversion in an anaerobic digestor is estimated to be 30 to 35 percent efficient (Little, 1978).

The utilization of rice straw for conversion to methane by anaerobic digestion needs to be evaluated in a prototype system before any appropriate conclusions can be drawn. At the University of Arkansas, encouraging results have been obtained from digestion of cornstalks in five liter reactors. Researchers at the University have calculated theoretical yields of 50 million cubic feet per day with biomass inputs up to 5,560 tons per day (Gaddy, 1980). The cellulose and lignin content of cornstalk is similar to rice straw, and it is suggested that conversion efficiencies with rice straw could equal those of corn stover.*

<u>Economic Feasibilty</u>. The following discussion of economic feasibility is based on the work conducted at University of Arkansas with cornstalk. A flow chart depicting the conversion process is shown in Figure 6.5.

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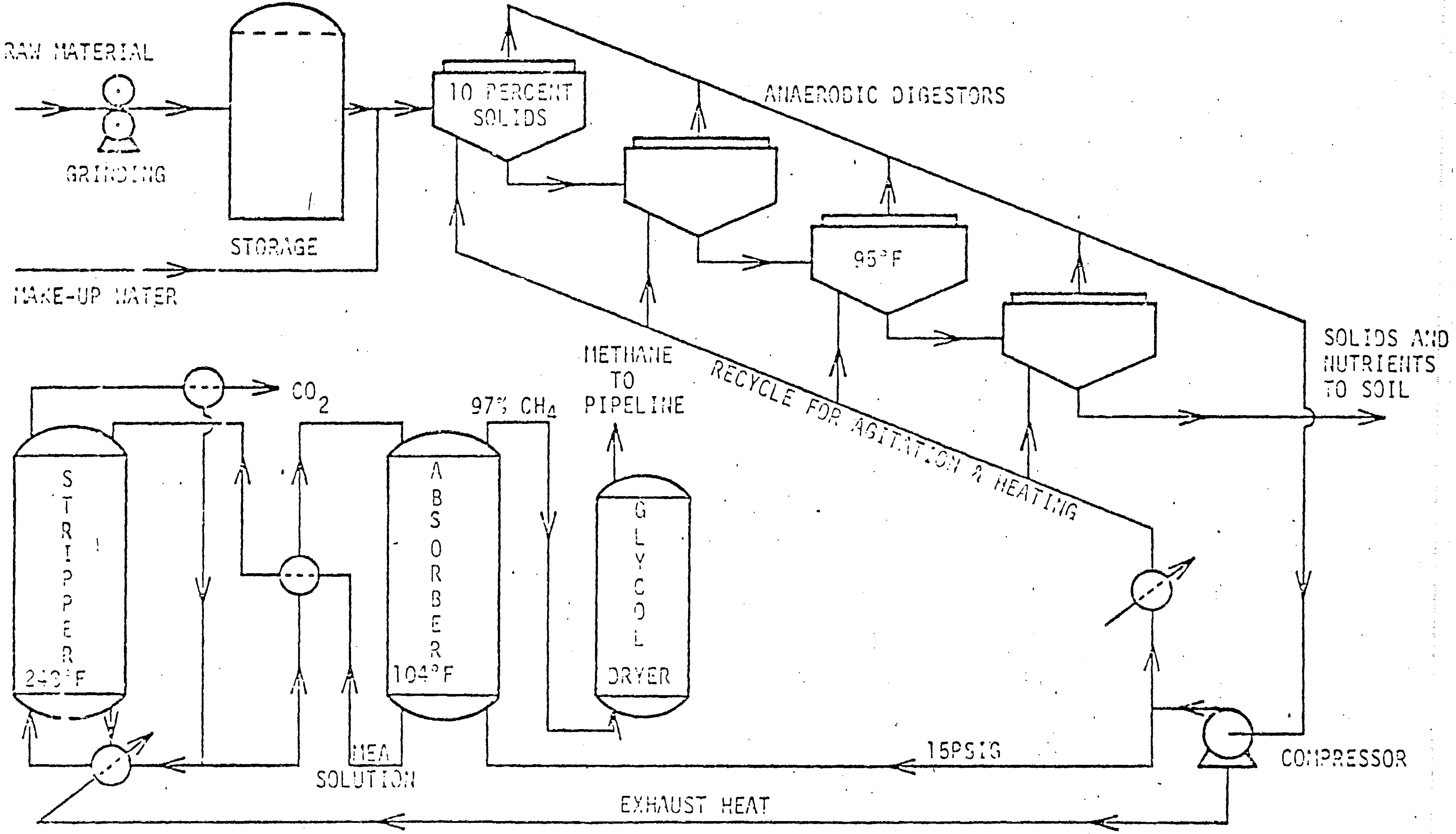
*Rice straw has approximately 34 percent cellulose and 4.5 percent lignin by weight. Cornstalk has 35 percent cellulose and 15 percent lignin by weight.

Figure 6.5

BIOCONVERSION PROCESS FOR PRODUCING METHANE



Source: (Gaddy, 1980).

A description of the process is taken from the work of Dr. J.L. Gaddy et al (Gaddy, 1980).

> The stover is ground and then mixed with water and fed to reactors, where a culture of bacteria is maintained to produce methane. Gases from the reactor are compressed to 15 psig. Carbon dioxide and hydrogen sulfide are removed by scrubbing with drethanol amine and the remaining methane is dried in a glycol absorber....Exhaust gases from the compressor are used as heat for the stripper and a heat exchanger between the stripper and absorber recovers waste heat. An energy balance on this process shows that only 7.5 percent of the methane product is consumed for compression and heat.

As mentioned previously, the daily biomass input requirements of this theoretical system are 5,520 tons per day. At 3.64 tons of rice straw per acre (14 percent moisture), approximately 1,516 acres would have to be harvested daily to meet those requirements. At this rate, 60,640 acres of rice straw could be disposed of over a 40-day period.

A. Collection and Transportation. The location of the digestor facility is the single largest factor in determining the most appropriate collection system. A total harvest scheme might be employed if the digestor was located adjacent to a rice drying facility. Otherwise, packaging the rice straw in bales and transporting them to the digestor is the recommended procedure. It is assumed that the digestor would utilize other agricultural residues in addition to rice straw; therefore, hauling distance must be closely tied to the availability and transportation constraints of other agricultural residues as well. In this analysis the cost of baling 1,000-pound bales by a self-propelled Ben Thompson Baler and the cost of hauling bales an average of 25 to 30 miles are used to calculate the supply costs of packaging rice straw and transporting it to an anaerobic digestor. The costs are presented in Table 6.19.

Table 6.19

COLLECTION AND TRANSPORTATION COSTS
FOR THE ANAEROBIC DIGESTION SYSTEM

Collection Costs

Tons	Overhead \$/Ton[a]	Cash \$/Ton	Total \$/Ton	Total \$/Season
222,800[b]	\$7.59	\$6.97	\$14.56	\$3,243,968

Transportation Costs

Tons	\$/Ton 25-30 Miles	Surcharge	Total \$/Ton	Total \$/Season
222,800	\$5.80	15.25%	\$6.68	\$1,489,307
Total Collection and Transportation				\$4,733,275
Total Cost Per Ton				\$21.24

---

[a] Assumes 600-acre average farm size. Costs are in January, 1980 dollars.

[b] Rice straw is at 14 percent moisture content.

[c] Rates for hauling are based on regulations by the California State Public Utilities Commission.

The total supply cost per ton amounts to \$21.24. At an average farm size of 600 acres, rice growers could collect their rice straw in approximately 37 days. This requires that the collection process proceed for 12 hours per day at the rate of five tons per hour. Again, it should be emphasized that the collection process must not interfere with harvesting activities unless the value of rice straw is greater than rice grain. The collection and transportation schemes require a substantial amount of labor and it is unclear whether or not the labor will be available to meet the demands of both harvesting and collection processes.

B. Capital and Operating Costs. The capital costs of the anaerobic digestion system is shown in Table 6.20. These costs apply to a system capable of supplying the annual methane (natural gas) requirements to a city with a population of about one million (Gaddy, 1980). Methane production from this facility is 50 million cubit feet per day (50 MCF).

Table 6.20

CAPITAL COST OF AN ANAEROBIC DIGESTOR[a]

	(Millions of Dollars)
Reactors	$60.0
Compressors	5.0
Absorber and Stripper	5.0
Heat Exchangers	2.3
Pumps and Piping	9.0
Contingency @ 20% of Direct Costs	16.3
Total Capital Cost	$96.6

---

[a] System rated at 18,250 MCF per year. Costs are in 1980 dollars.

Source: (Gaddy, 1980)

It should be pointed out that the capital costs do not include any cost for site preparation or handling equipment. Additionally, a cost of land for the operation site is not considered. The total capital cost for the listed equipment amounts to $96.6 million.

The expected revenue resulting from this investment is calculated to be $73 million a year. The system is assumed to operate 365 days per year. The selling price of methane is expected to be $4 per MCF.

As shown in Table 6.21, the annual operating capital outlay resulting in an estimated 17 percent before-tax rate or return. This rate of return is predicted on a 365-day operating season which does not seem very realistic. Residues at the rate of approximately 5,520 tons would have to be supplied to this plant 365 days a year in order to meet the conditions set forth in Table 6.20. The 365-day operating period has the effect of lowering the marginal cost of production. If, for instance, the digestor facility is operated at 50 percent capacity, or 183 days per year, the fixed costs pertaining to depreciation (capital recovery), taxes, and insurance or other overhead expenditures would remain unchanged. The overall effect would be to increase the cost per unit of methane from $3.42 per MCF to $4.05 per MCF. With expected revenues of $4 per MCF it becomes readily apparent that, at 50 percent operating capacity, the operation would lose money.

Table 6.21

OPERATING COSTS FOR ANAEROBIC DIGESTION SYSTEM[a]

	(Millions of Dollars)
Rice Straw[b]	$ 4.7
Other Residues[c]	35.8
Utilities	3.5
Labor and Supervision	1.5
Maintenance @ 5%	4.8
Depreciation @ 10%[d]	9.7
Taxes and Insurance @ 2%	1.9
Credit @ 10% for Residue Suppliers	0.5
Total Production Costs	$62.4
Breakeven Price ($/(MCF)	$ 3.42
Gross Profit	10.6
Net Profit[e]	5.3
Return on Investment	11.0%

---

[a] Plant capacity rated at 18,250 MCF per year. Costs are in 1980 dollars.

[b] Collection and transportation of 222,800 tons.

[c] Assumes all other residues are collected @ $20 per ton.

[d] This item accounts for the recovery of the capital invested on the principal amount only. There is no interest (i.e., cost of money) included in this operating cost analysis.

[e] Results from 50 percent corporate tax.

[f] Calculated by dividing gross profit by capital investment.

Source: (Gaddy, 1980).

<u>C. Substitutability for Existing Energy Sources</u>. It is expected that the biomass-converted methane would be piped into existing natural gas transmission lines. The production of gas from the digestor would not have a dampening effect on domestic gas prices since demand for gas is relatively elastic. Therefore, if digestor production costs can be insured at or below the average selling price of natural gas, the gas producer is assured

Since a positive charge is associated with the delivery of rice straw it will necessarily compete with other agricultural residues during the fall. The higher moisture residues, particularly the vegetable crop residues, are more desirable as a feedstock. It is likely that the supply of these agricultural residues would, at least partially, displace rice straw as a source of biomass for anaerobic digestion processes.

The anaerobic digestion system has the advantage of being able to utilize a wide range of residues, whereas other energy systems tend to be more substrate specific. Any conclusions arrived at in this section, regarding both the technical and economic feasibility of rice straw as a feedstock for anaerobic digestion processes, must be considered tentative at this time. The available information does, however, warrant a more detailed examination of this process as an alternative to the wasteburning of rice straw. The information presented in this section assumes optimum conditions and does not take into consideration the full cost of operating an anaerobic digestor. It is apparent that more research needs to be conducted before appropriate conclusions can be rendered on the suitability of rice straw for anaerobic digestion processes.

Cellulose Conversion to Alcohol

Should the production of ethanol from rice straw prove technically and economically feasible, it would provide an alternative disposal method worthy of consideration. The technical processes involved include sacchrification, fermentation, distillation, and treatment of the remaining by-products for their end use, thereby improving the overall energy balance. These are highly sophisticated procedures involving complex chemistry and intricate timing for which little data is available. However, there are prototype models and pilot plant facilities, and data obtained from similar crops can be extrapolated and applied to production from rice straw. There are patents pending on virtually all phases of production including several for specific enzymatic and acid hydrolyses which show great promise for increasing yield in the future.

Technical Feasibility. The basic technology for obtaining alcohol from plant tissue involves several steps. Initially, the feedstock is treated to produce a sugar solution. Yeast is then added to the solution to induce fermentation. The remaining feedstock is subsequently screened out leaving a "beer" (alcohol and water) solution. Next, the beer is then heated to near-boiling temperatures where the alcohol can be separated from the water. The final step is to denature and test the alcohol prior to its subsequent use.

An analysis of present technologies reveals that this system is technically feasible for high starch and high sugar feedstocks such as corn, wheat, sorghum, and sugarcane. Rice straw, however, is neither a high starch nor a high sugar crop. With respect to conversion to alcohol, rice straw is termed a cellulosic feedstock. The high content of cellulose, when bound with lignin, forms a compound which is very rigid. This rigidity enables the thin rice stalk to support the heavier hulls and grain. The energy of these cellulosic feedstocks is stored by the cellulose polymer as chemical bond energy. These bonds were thought to be labile, thereby releasing energy through elaborate pre-treatments with highly specific enzymes and other catalysts, most of which are protected, pending patent rights.

At a more technical level, pre-treatment of straw by means of alkaline digestion, employing dilute alkaline-hydroxide solutions, would reduce the bonding among polymers of the aromatic compounds present. This reaction could be further catalyzed by raising the ambient temperature to approximately 100 degrees Centigrade for a short time. At this point, the heavy cellulose can be recovered and perhaps sold to the resin industry or further hydrolyzed to produce a Xylose sugar compound. Should the hemi-cellulose be retained by hydrolysis continued, the resulting product would be furfural, a solvent and a source of furfural alcohol and other furan derivatives useful in, for example, making foundry core binder resins.

The next phase in the conversion of rice straw to ethanol is termed hydrolysis. This process reduces polysaccharides (complex sugars) to monosaccharides (simple sugars), which can then be fermented (converted to alcohol). The more traditional process, where mineral acids act as a catalyst, is again complicated by the cellulosic nature of rice straw. Alternately, a special two-phase process must be employed, utilizing two different concentrations of acid. Initially, a dilute sulfuric acid treatment is used for hemi-cellulose extraction followed by treatment with concentrated sulfuric acid for cellulose conversion. This combined process has several advantages over more conventional acid hydrolysis treatments. Higher yields are achieved due to the more thorough breakdown of cellulosic compounds. Problems normally encountered with degradation of hemicellulose when contacted with concentrated acid are avoided. Acid can be recovered by electrodialysis, thus defraying the high costs usually incurred with this process.

The dilute glucose and Xylose streams formed by the acid hydrolysis process must then be fermented to form ethanol. The glucose portion is converted to ethanol in a fixed film reactor containing yeast or extracted enzymes. The xylose is converted to ethanol in a reactor containing other enzymes. These enzymes are commonly derived from yeasts, or by the use of intact cells of bacteria or fungi. The yeast cells in the product streams are recovered by centrifugation. Recovered cells are allowed to undergo autolysis, releasing nutrients and vitamins for recycling through the system. This fermentation process produces a product stream containing ethanol and water which will then be separated by fractional distillation. The by-products at this stage include the remaining biomass (organic) fraction and a fraction containing minerals. While the biomass now termed "stillage" shows great promise as a livestock feed, the high silica content of the rice straw mineral fraction shows potential as a major economic consideration. This biologically mined silica can be utilized for several unique products. Due to its amorphous (non-crystalline) nature it has a large surface area which makes it desirable for polymer formulations, dispersant usages, optical coatings, amorphous silica, non-conducting coatings, et al.

The final process is to fractionally distill the product stream, separating the ethanol from the water which is present. As the boiling point for ethanol (173°F) is well below that for water (212°F), the stream is run through a distillation column at near-boiling temperatures, taking off the ethanol and allowing it to be removed for condensation. At this point, the ethanol must be tested for purity and denatured prior to its subsequent use.

Economic Feasibility. It was previously mentioned that several of the processes described are still at the prototype stage. The figures given here are estimates based on available current technologies. It is assumed that the enzymes and pretreatments awaiting patent approval will significantly improve costs and yields for these processes but the economics associated with them will not be discussed here.

A. Collection, Transportation, and Storage. There is not an established demand for rice straw. Therefore, costs of collection, transportation, and storage plus a reasonable return to the farmer will determine its value. Field cubing yields the lowest cost per ton of the collection methods but cubes are not technically feasible due to their high bulk density. This high density renders pre-treatments ineffective and therefore, field baling has been selected as the preferred method of collection. Moisture content of the straw is not critical for this process so field baling with a farmer-owned Thompson Baler would be adequate under a variety of conditions. The cost per ton for this collection method is $14.56 for a 1,200-acre farm. Additionally, the costs for transportation are $2.59 per ton. Table 6.22 presents these costs.

B. Capital and Operating Costs. Table 6.23 gives the estimated capital investment for the major equipment items to produce 4.5 million gallons of ethanol per year from rice straw. Corrosion resistant equipment is utilized for the acid hydrolysis equipment and the fermentors. A comprehensive system for acid recovery is also employed, enabling the expensive caustics to be reused. Total investment for this equipment, with all auxiliaries, would be approximately $7.5 million. The estimated operating costs for this process are given in Table 6.24. Total operating costs for this process are given at about $5.5 million.

Table 6.22

COLLECTION AND TRANSPORTATION COSTS FOR CONVERSION OF RICE STRAW TO ALCOHOL[a]

Collection Costs

Tons	Overhead $/Ton	Cash $/Ton	Total $/Ton	Total $/Season
73,214[b]	$3.80	$6.97	$10.77	$ 788,515

Transportation Costs

Tons	50% 5-10 Miles[c]	50% 10-15 Miles[c]	Total $/Season
73,214	$223,605	$236,261	$ 459,866
Total Collection and Transportation Costs			$1,248,381
Total Cost Per Ton			$17.10

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[a] Costs are in January, 1980 dollars for the 1,200-acre farm.

[b] Rice straw is at 14 percent moisture content.

[c] Rates for hauling are based on rates set forth by the California State Public Utilities Commission.

Table 6.23

CAPITAL COSTS FOR CELLULOSE CONVERSION TO ALCOHOL[a]

Pre-Treatment Tank[b]	$ 145,000
Hydrolysis Tank[c]	145,000
Rotary Vacuum Filter[d]	394,000
Rotary Dryer[e]	277,700
Impregnator[f]	334,500
Fermentor	512,100
Centrifuge	389,900
Distillation Column	670,200
Acid Recovery[g]	2,472,000
Heat Exchanger	113,200
Pumps and Piping	253,300
Heater	203,500
Compressor and Tank	27,700
Direct Costs	$5,938,100
Construction Contingency, Fees, and Taxes, Etc. @ 15% of Direct Costs	890,715
Engineering and Design @ 10% of Direct Costs	593,810
Total Capital Costs	$7,422,625

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[a] Output rated at 4.5 million gallons of ethanol per year. Costs are in 1980 dollars.

[b] Includes one 40,100 gallon

[c] Includes one 30,500 and one 4,600 gallon tank.

[d] Two 14,000 square-foot dryers.

[e] Rated at 15,000 pounds per hour.

[f] Rated at 672,000 pounds per day.

[g] Acid recovery system consists of an electrodialysis unit.

Source: (Foutch, Magruder and Gaddy, October, 1980).

Table 6.24

OPERATING COSTS FOR CELLULOSE CONVERSION TO ALCOHOL[a]

Supply of Rice Straw[b]	$1,248,381
Acid Recovery	601,400
Make-Up Acid	843,400
Utilities	381,200
Neutralizer	265,000
Yeast Extract and Nutrients	256,000
Labor	409,400
Maintenance	409,400
Taxes and Insurance @ 3%	222,679
Return to Supplier @ 10%	125,195
Capital Recovery[c]	916,200
Total Operating Costs	$5,678,255
Cost Per Gallon (ETOH)	$1.26

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[a] Output rated at 4.5 million gallons of ethanol per year. Costs are in 1980 dollars.

[b] Supply of straw amounts to 73,214 tons @ $17.10 per ton.

[c] Assume 100 percent financing with 12 monthly payments for 30 years at 12 percent.

Source: (Foutch, Magruder and Gaddy, October, 1980).

C. Substitutability for Existing Energy Sources. Demand for ethanol from a variety of sources has not been clearly identified. There is however, a market price established at $1.41 (Gaddy, et al., 1980). It is assumed that as the price of gasoline increases, the value of ethanol will also increase. There are a number of feedstocks which could be utilized in the production of ethanol. Currently, the majority of available data concerning cellulosic feedstocks pertains to corn stover. The available energy content of corn stover is roughly equivalent to that of pre-treated rice straw. Tons used and theoretical yields are further assumed to be the same (Gaddy, 1980). Corn stover is valued at $25 per ton while rice straw could probably be substituted at $18.81 per ton. However, corn stover does not require the expensive pre-treatment which is necessary for rice straw. All things considered, the two feedstocks are roughly equivalent and could be substituted freely. Both can be considered as economically feasible and both present an optomistic outlook for the future considering present technologies.*

RICE STRAW AS A FIBER SOURCE

The feasibility of utilizing rice straw as a fiber source for corrugating medium and fiberboard is assessed in this section. Corrugating medium refers to the fluted core found in

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*Average production costs are expected to be $1.13/gallon for corn stover and $1.26 for rice straw.

cardboard containers. Fiberboard is a stiff sheet of compressed fibers used for either decorative or general construction purposes.

Corrugating Medium and Fiberboard

The use of rice straw as a furnish for paper and its assorted products has a somewhat obscure and misconstrued history. What was once formally called rice paper in Europe (1883) actually was made from the pitch of a small tree, Fralia papyrifera, which grows in the swampy forests of Formosa. The misnamed rice paper was often dyed various colors for the preparation of artifical flowers or employed by native artists for water color drawings. In 1801, rice paper made in the Chinese province of Che-Kyang was being manufactured from rice straw. A rice paper was also made from the straw of rice in Italy, reportedly around 1806 in Milan (American Paper and Pulp Association, 1951).

In countries lacking abundant supplies of pulpwood or wood industry by-products, straw and other sources of non-wood fibers are used for the production of paper, paperboard and building materials. In estimates by the U.N. Food and Agricultural Organization, approximately 4.4 percent of the world's supply of pulp for paper and paperboard production comes from non-wood fibers (Atchison, N.D). Of the world's estimated 6.31 million air dry metric tons (ADMT's) of non-wood fibre pulps produced in 1972, 0.63 million, or less than 10 percent, were supplied by rice straw. Cereal straw (mainly wheat and rye), bamboo, and bagasse account for a major proportion of the world's non-wood plant fiber pulp production. The estimated

United States production of non-wood pulps is 565,000 ADMT's. The United States produces no rice straw pulp.

Ironically, the use of straw as a furnish for paper makers was the first to become successful in the United States. In 1849, a manufacturer in Springfield, Massachusetts made white paper commercially from straw. Much of this straw paper was used in the newspaper industry. By 1880, a total of 619,682 tons of raw material were used for the manufacture of pulp for the paper industry--40 percent of this material was straw.

The most important use of straw in the United States has been for the manufacture of wrapping paper and paperboard. To a lessor extent straw has been used for the manufacture of printing paper. In the early 1900's the Midwest (Indiana, Illinois, and Ohio) produced over half the straw wrapping paper and 83 percent of the straw paperboard in the United States.

By this date, however, wood had come into general use as a furnish. The development and utilization of the sulfite pulping process marked the emergence of wood in the paper and allied products industry. Within several years wood had supplanted straw as the princial fiber for paper and paperboard products.

The manufacture of pulp and paper and fiberboard products from grass and cereal straw has been shown to be technically feasible (Battelle Northwest, 1979). With rice straw, however, there is less certainty concerning its potential as a furnish for pulp. In India it was found that easy bleaching of pulp can be achieved by cooking rice straw in an open vessel at atmospheric pressure (Talwar, 1964). This represents a deviation from American techniques since the United States typically uses closed system processes. In a separate study it was found that 100 percent rice straw was not suitable as a paper product for the manufacture of white printing papers (Guha, 1965).* However good results were achieved when rice straw was combined with a 10 percent addition of bamboo.

The most common methods of developing pulp from straw in the United States are chemical and semi-chemical (Battelle Northwest, 1979). Of the chemical methods, either the kraft (sulphate) method or sulphite method, are feasible. In general, both of these methods separate the cellulose fibers from the non-cellulose fibers by chemical action. The straw is fed into a digestor and cooked for several hours under steam pressure in the presence of a cooking liquor. The lignin and other non-cellulose components are dissolved leaving only cellulose or pulp. The kraft process employs a mixture of sodium hydroxide and sodium sulfate.** The sulfite process employs calcium sulfite or bisulfite as its cooking liquor. More recently, the sulfite process uses magnesium, sodium, or ammonium sulfite salts since less water pollution results.

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*Printing papers were produced on an old Fourdrinier machine. The tear factor for machine direction and cross direction were unfavorable for pure rice straw pulp.

**The kraft process is good for resinous wood although any softwood will work.

The semichemical process allows for a moderate chemical treatment followed by mechanical maceration of straw fibers. The semichemical process yields anywhere from 65 to 85 percent pulp from raw material. This is a little higher than yields generated from the chemical process which average around 50 percent (Battelle Northwest, 1979).

The particular use to which the pulp is to be put determines the actual pulping process. Chemical pulping processes tend to produce higher grades of printing paper, writing paper, or sanitary paper. Semichemical processes are used for paperboard for packaging materials (Guthrie, 1972).

The length of fibers used in the pulping process are important determinates of the strength characteristics of the final product. There is no significant difference between the strength properties of pulps from cubed straw or standard bales. Pelleted straw (which is finely chopped for pellets) results in a weaker pulp. The finely chopped fibers are good for types of paper where softness and absorbtion are desired.

In a recent study conducted by Battelle, Pacific Northwest Laboratories, the marketing potential of grass straw was assessed. The study focused on rye straw produced in the Willamette Valley, Oregon. The situation is analogous to California's rice straw problem. Battelle concluded that the use of rye grass straw as a corrugating medium represented the greatest potential for development. Two important reasons for this are:

- The expansion of the paperboard industry in the Northwest indicates that market demand is favorable for such products.
- "Straw was once a major source for paperboard products before hardwood pulps precipitated straw's demise as a cost-effective input in the process." (Battelle Northwest, 1979)

Another segment of the paper and allied products industry that Battelle assessed was the fiberboard market. Straw, it appears, is suitable as a substitute for the materials used in fiberboard manufacturing.* Fiberboards made of straw are very strong and lighter than fiberboards made from wood chips (Biotechnic Institute, Denmark). Many different types of fiberboard can be rendered from straw. They may be very light boards with a decorative structure and high insulating capacity to very heavy, strong boards. The boards can be given the same surface treatment as wood chip boards, lacquer, veneer, lamination, and other finishes. In addition, fiberboards from straw are waterproof and can be made weather resistant.

The process used to manufacture fiberboard is different than previously described for paper and paperboard products. Two processes can be used, either the wet or the dry process (Battelle, Pacific Northwest Laboratories, 1979):

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*Green and dry wood shavings, plywood trim and other recycled materials are used in fiberboard production.

> In the wet process, fibers are moistened, cleaned, and partially digested to yield a moldable mass. Usually a binding resin is added to increase board strength prior to forming and curing, which occurs under elevated pressure and temperature. The dry process involves only the chopping or grinding of fiber, drying to desired moisture content, and direct application of bonding resins to the fibers prior to passage through the forming machines.

The process of straw would be very similar to wood processes. In the 1972 Census of Manufacturing, the raw materials used in particle board (fiberboard) manufacturing do not include any straw feedstock. The Biotechnic Institute in Denmark, however, has experimented with various feedstocks and concluded that straw is an ideal raw material for fiberboard construction.

Other uses for rice straw include its rise as a raw material for newspapers and fine papers. Battelle concluded that straw as a newspaper material would be difficult since the newspaper manufacturers would have to retrofit their printing presses to accomodate the straw paper. As for fine papers, the use of straw pulp presents certain advantages over wood fiber substitutes. Straw pulps of bleachable grade have higher yields than wood pulp. However, the bleaching process for cereal straws generally requires greater amounts of chemicals for producing bleached pulp than most other fiber sources.

Rice straw does not appear to present any unique characteristics that would preclude its use as a furnish for paper and paperboard products over other cereal straws such as wheat or rye. With all straws containing appreciable amounts of silica, the chemical recovery systems of pulp processes are adversely affected. Rice straw has a characteristically high silica content of 14 percent (Han and Anderson, 1974). For pulp mills that employ cogeneration equipment for porcess steam, the silica would substantially increase maintenance and repairs on boiler equipment.

Economic Feasiblity. In this section two types of paper products will be assessed: rice straw as a corrogating medium and rice straw as a feedstock for production of fiberboard (particle board). Given that rice straw would serve adequately as a fibrous input into these two product processes, the task remains to identify rice straw's ability to substitute for the wood products now being used in the paperboard and particle board industries.

Over time, the production of low-priced grades of paper and paperboard has tended to move to areas where cheap pulpwood is available. For paperboard, proximity to cheap fiber has been the principal locational factor (Guthrie, 1972). Historically, paperboard manufacturers were located in the wheat-growing regions of the Midwest. To date, paperboard manufacturers are located close to sources of both hardwood and softwood lumber in the United States.

The fiberboard processes are also dependent upon cheap sources of pulp. The materials consumed in fiberboard manufacturing include green and dry wood shavings, plywood trim, and other recycled materials used in board production (Battelle Northwest, 1979).