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POTENTIAL USE OF WOOD AND AGRICULTURE WASTES AS STEAM GENERATOR FUEL FOR THERMAL ENHANCED OIL RECOVERY

Final Report

Date Published—May 1979

Work Performed Under Contract No. EW78x03-1038

Energy Resources Company, Inc.
Cambridge, Massachusetts

U. S. DEPARTMENT OF ENERGY

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Final Report

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INTRODUCTION AND SUMMARY

Enhanced oil recovery by steam injection methods produces over 200,000 barrels per day of crude oil in California. A sizeable portion of the produced crude, up to 40 percent for some projects, may be burned to generate steam for injection into the reservoir. The purpose of this study is to evaluate the potential to use wood and agriculture wastes to replace crude oil as steam generator fuel. Other Department of Energy studies are evaluating coal, petroleum coke and lignite as alternative fuels to crude oil. The Bakersfield area of California's San Joaquin Valley is the focus for this paper. Production from thermal EOR methods centers around Bakersfield and agriculture and wood wastes are available from the San Joaquin Valley and the nearby Sierra Nevada mountains.

This paper documents the production of waste materials by county, estimated energy value of each material and estimated transportation cost for each material.

Both agriculture and wood wastes were found to be available in sizeable quantities and could become attractive steam generation fuels. However, some qualifications need to be made on the use of these materials. Transportation costs will probably limit the range of shipping these materials to perhaps 50-100 miles. Availability is subject to competition from existing and developing uses of these materials, such as energy sources in their immediate production area. Existing steam generators probably cannot be retrofitted to burn these materials. Fluidized bed combustion, or low Btu gasification, may be a good technology for utilization. FBC or FBG could accept a variety of waste materials. This will be important because the amount of any single waste may not be large enough to support the energy requirements of a good size thermal EOR operation.

SECTION ONE

AVAILABILITY OF AGRICULTURAL WASTES

The attached tables summarize available data on wood and agricultural wastes in California by location, type and amount. Table 1-1, County Production and Energy Density of Selected Waste Materials, provides the 1975 production values for twenty residue types in these fourteen counties. Table 1-2, Energy Value of 1975 Waste Production for Fourteen Country Area, lists total production, energy value, and energy equivalents (bbls of oil x 10^6), for these residues. A map of the study area, Figure 1-1, is also included. The tables are restricted in scope to the 14 counties within 150 miles of the Bakersfield EOR area. (Engineering judgment suggested that the economic transport radius for all residues considered would be less than 100 miles from Kern County.) Data for these tables are derived from Agricultural Residues as an Alternative Source of Energy for the Pacific Gas and Electric Company (hereinafter referred to as the "Research Report.") by the Department of Agricultural Engineering, University of California, Davis, California, August 1977.

Production values for field crop, vegetable crop, and fruit and nut crop residues are taken from Table IV-5, "Leading Counties for Crop Residue Production." Production values for forest residue are taken from Table V-15, "Amounts and Location of Forest Residue in California." Production values for manure were developed from Figures V-14, 3A-1, 3A-2, and 3A-4, and represent best available approximations since accurate county-by-county statistics of manure production are not readily available. These estimates were produced by estimating

TABLE 1-1

COUNTY PRODUCTION AND ENERGY DENSITY OF SELECTED WASTE MATERIALS
1975 PRODUCTION BY COUNTY (10^3 TONS)

	Kern	Santa Barbara	Kings	Tulare	Ventura	Los Angeles	San Bernardino	Fresno	Inyo	Madera	Merced	San Benito	Monterey	San Luis Obispo	Energy* Density Btu/lb
Barley Straw	--	--	203	--	--	--	--	276	--	--	--	--	58	44	7,000(14)
Rice Straw	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7,000(14)
Cotton Stalks	497	--	241	196	--	--	--	376	--	--	--	--	--	--	7,000(14)
Corn Stover	--	--	194	158	--	--	--	304	--	--	--	--	--	--	7,000(14)
Sorghum Stover	26	--	--	39	--	--	--	--	--	--	--	--	--	--	7,000(14)
Wheat Straw	128	--	--	32	--	--	--	48	--	--	--	--	--	64	7,000(14)
Tomatoes (fresh)	--	--	--	--	--	--	--	--	--	--	17	--	8	--	6,730(0)+
Tomatoes (process)	--	--	--	--	--	--	--	64	--	--	17	13	--	--	6,730(0)+
Potatoes	38	2	--	--	--	--	--	--	--	--	--	--	4	--	6,730(0)+
Melons	9	--	2	1	--	--	--	25	--	--	6	--	--	--	6,730(0)+
Grapes	97	--	--	151	--	--	32	400	--	--	32	--	--	--	8,000(35)
Peaches	4	--	--	7	--	--	--	38	--	1	19	--	--	--	8,000(35)
Oranges	12	--	--	67	18	--	10	16	--	--	--	--	--	--	8,000(35)
Lemons	--	4	--	--	26	1	3	--	--	--	--	--	--	--	8,000(35)
Pears	--	--	--	--	--	--	--	--	--	--	--	--	2	--	8,000(35)
Apples	1	--	--	--	--	--	1	--	--	--	--	--	1	--	8,000(35)
Prunes	--	--	--	6	--	--	--	--	--	--	--	--	--	--	8,000(35)
Dairy Manure	--	--	--	660	--	--	298	--	--	--	240	--	--	--	11,840(80)
Beef Manure	--	--	--	520	154	320	--	--	--	--	198	--	--	--	11,840(80)
Forest Residue Waste	27	--	--	125	--	--	15	124	--	85	--	--	74	--	9,000(40)

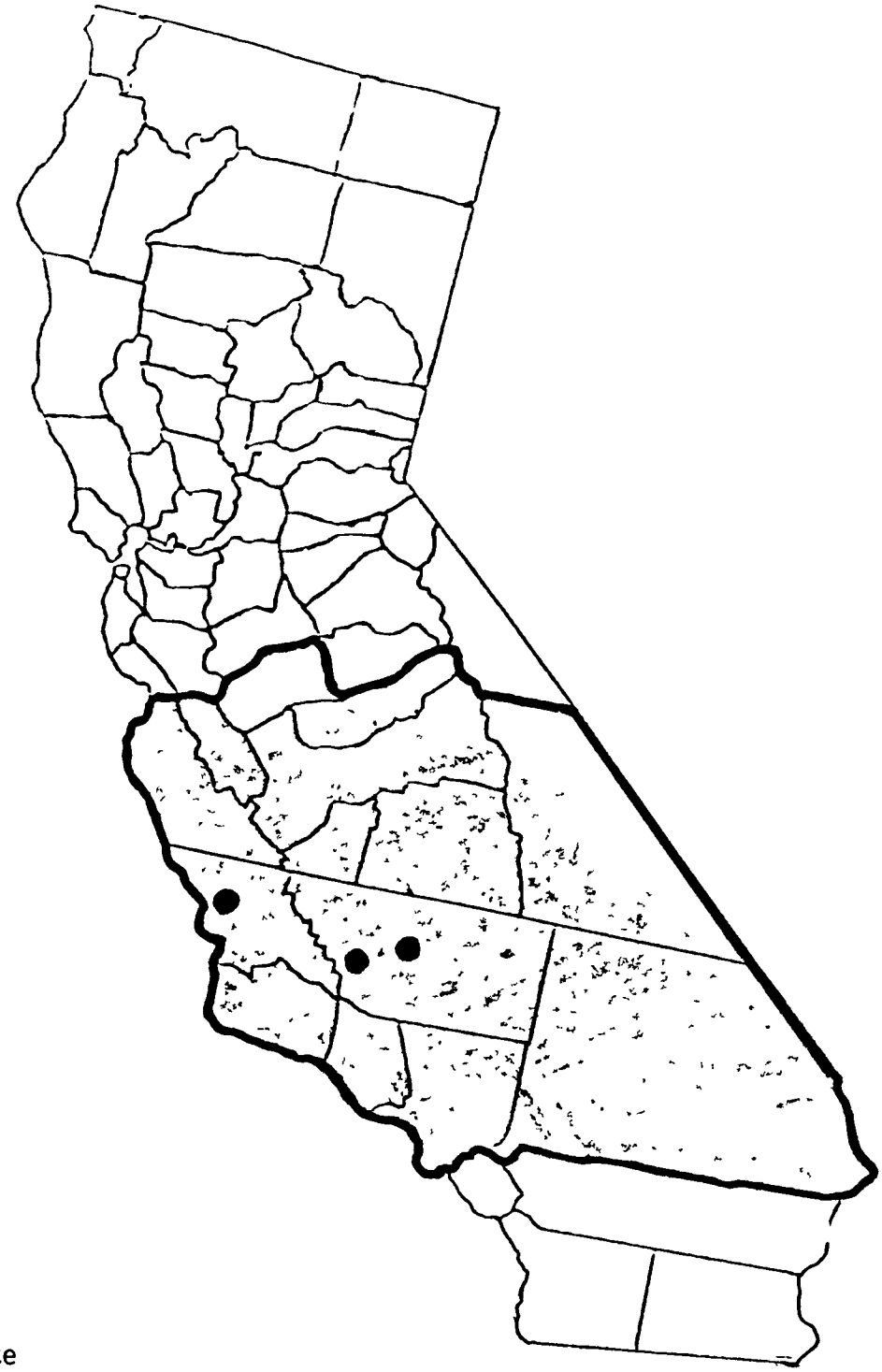
+Assumes good weather for vine drying.

*Data supplied is in bone dry Btu/lb. Percent moisture content is indicated in parentheses.

TABLE 1-2

ENERGY VALUE (DRY BASIS) OF 1975 WASTE PRODUCTION FOR FOURTEEN-COUNTY AREA

MATERIAL	TOTAL PRODUCTION (10^3 tons)	ENERGY VALUE (10^{12} Btu)	ENERGY EQUIVALENT (10^6 bbl of oil)
Barley Straw	581	8.13	1.40
Rice Straw	0	0.00	0.00
Cotton Stalks	1310	18.34	3.16
Corn Stover	656	9.18	1.58
Sorghum Stover	65	0.91	0.16
Wheat Straw	272	3.81	0.66
Tomatoes (fresh)	25	0.34	0.06
Tomatoes (process)	94	1.27	0.22
Potatoes	44	0.59	0.10
Melons	43	0.58	0.10
Grapes	712	9.58	1.65
Peaches	69	1.10	0.19
Oranges	123	1.97	0.34
Lemons	34	0.54	0.09
Pears	2	0.03	0.01
Apples	3	0.05	0.01
Prunes	6	0.10	0.02
Dairy Manure	1198	28.37	4.89
Beef Manure	1192	28.22	4.87
Forest Residue Waste	450	8.10	1.40
	TOTAL	121.31	20.91



● = EOR Site

Figure 1-1. Fourteen-County Study Area.

county cattle populations, multiplying by appropriate productivity per head figures (cattle were assumed to be 1000 pounds each, and data was taken from Table 3B-1, "Daily Manure and Urine Production from Dairy and Feedlot Cattle, cubic feet/day") and adjusting the results to coordinate with the minimum per-acre productivity specified in Figure V-14. A detailed examination of primary data sources would yield more reliable figures and may be justified by the large magnitude of manure waste in this region, but was outside the scope of this report.

A variety of energy densities were presented in the Research Report, but the values were sufficiently consistent to substantiate the validity of the specific densities reported in the attached tables. The same is true of the moisture contents.

The future availability of agricultural residues is subject to several uncertainties. First, drought will adversely affect production of all the materials considered in this report to a greater or lesser degree. Second, the amount of production of the crops, forest goods, and cattle will depend upon the future demand for these items in the marketplace. Third, new varieties of field crops may be planted with unpredictable residue contents. Finally the competitition for these residues by other users is likely to intensify as the nation's resource needs continue to challenge the limited supply.

In the ten year span from 1965-1975, total field crop residue production in California for rice, wheat, barley, corn and sorghum has risen 69 percent. In that time rice, corn, and wheat production have grown 100 percent, 207 percent,

and 880 percent, respectively, while barley and sorghum have declined 20 percent and 46 percent. Projections of future planing should not be made solely on the basis of these data, but they do provide an indication of the trend.

The major competing alternative for these residues is the disposal option of open field burning. Currently, pressure is on the increase for a banning of this practice for environmental reasons. Conceivable economic uses for field crop residues range from feed to fiber to fuel, but none of these options, with the exception of mobile pyrolysis, appear to be commercially attractive at this time.

Fruit and nut orchard residue production in California has risen 19 percent from 1965 to 1975 at a moderately steady pace. Fruit and nut crop acreage are inherently stable because the trees and vines continue to bear for several years. Most prunings are either chipped or disced back into the soil or burned. Some prunings are used for firewood, and the use of prunings as combustion fuel may be expected to increase as energy costs rise. Prohibition of open burning will affect orchard managers in much the same way that it will affect field crop growers.

Data on manure production is limited, but the Research Report does document a 43 percent decline in feedlot manure production from 1974 to 1975. Presumably dairy populations will be more stable than feedlot populations, but both are likely to be dependent upon the economics of the market for beef and milk. Competition for manure is very high, and eliminates this resource from consideration except in areas where the density of production is too high to allow complete local use of the material. The majority of feedlot manure and one half of the dairy manure is sold (Ernst, 1977).

Competing uses include fertilizer, feed, fiber, and fuel.

Logging and mill residue production has increased 24 percent from 1968 to 1976. A moderate decline in the level of harvested timber predicted for 1973 to 1983 coupled with a trend towards smaller timber size production may signal a slight overall decline in residue production. Competition for these products may be anticipated from the pulp and paper industry, which could absorb all of these resources for its own energy needs. Given that these residues could be used virtually at the site of production and, if transported, would make excellent supplementary fuel for local utilities, logging and mill residue may be a marginal EOR alternative. More information on the intentions of the paper and pulp industry is required, however, before a final determination can be made.

The nominal size of a steam boiler for use in the steam flooding phase of enhanced oil recovery is 50,000 lb/hr of steam. This is equivalent to a nominal 50×10^6 Btu/hr of heat (1200×10^6 Btu/day). The moisture contents of "waste fuels" do vary, but one steam flooding unit (50×10^6 Btu/hr) would require between 461×10^3 tons and 730×10^3 tons on a yearly basis.

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SECTION TWO

FEASIBILITY OF TRANSPORTATION

The major agricultural wastes of interest for EOR steam generation within 150 miles of Bakersfield are field crops (barley straw, cotton stalks, corn stover, sorghum stover, and wheat straw), vegetables (tomatoes, potatoes, and melons), fruits (grapes, peaches, pears, apples, and prunes), citrus (oranges and lemons), manure (feedlot and dairy), and forest residue. The cost and feasibility of collection and transportation of these categories of wastes are summarized in this document.

Table 2-1, Collection and Transportation Costs of Selected Wastes, includes collection, transportation and total costs per dry ton for each of the twenty waste materials considered in this study. Note that the delivered costs of these materials compare favorably with the local delivered cost of coal, which is approximately thirty to fifty dollars per ton. (Per ton costs are a reasonable basis for comparison because the heating value of Western coal is 8,500-9,000 Btu/lb, similar to that of the residue).

Collection and transportation costs for specific materials within a source type (field crop, fruit and nut pruning, manure, or forest residue waste) generally do not vary. This is because the major parameters of these costs are constant within these categories. For collection costs these parameters include production density (by tons/acre), "collectibility" (identified by collection technology re-

TABLE 2-1

COLLECTION AND TRANSPORTATION COSTS OF SELECTED WASTES
(1975 Dollars)

MATERIAL	COLLECTION COST ($/dry ton)	TRANSPORTATION COST ($/dry ton for 50 mi.)	TOTAL COST ($/dry ton)
Barley Straw	32.04	12.94	44.98
Rice Straw	10.90	12.94	23.84
Cotton Stalks	15.04	12.94	27.98
Corn Stover	10.46	12.94	23.40
Sorghum Stover	15.48	12.94	28.42
Wheat Straw	30.30	12.94	43.24
Tomatoes (fresh)*	-	-	10-15
Tomatoes (process)*	-	-	10-15
Potatoes*	-	-	10-15
Melons*	-	-	10-15
Grapes	5.56	8.25	13.81
Peaches	5.56	8.25	13.81
Oranges	5.56	8.25	13.81
Lemons	5.56	8.25	13.81
Pears	5.56	8.25	13.81
Apples	5.56	8.25	13.81
Prunes	5.56	8.25	13.81
Dairy Manure	1.26	3.66	4.92
Beef Manure	1.26	3.66	4.92
Forest Residue Waste	16.50	21.50	38.00

*Collection and transportation costs for these four wastes are not available at present. In total, they represent 2.3 percent of the total energy available. They would most likely resemble costs for fruit and nut prunings, so a cost of $10-15 is a reasonable estimate.

quired), and pretransportation storage space needed. Transportation costs are sensitive to loading and unloading expenses, bulk density, moisture content of transported material, and truck-type needed to carry the material.

Field Crops

The most difficult California field crop residue to collect is rice straw. This waste is not produced in quantity within a 150-mile radius of Bakersfield so the problem is simplified.

Two basic methods exist for collection of field crops--total harvest and post-harvest collection. Total harvest collection involves simultaneous collection of the crop and residue. Post-harvest collection involves collection of the residue after the crop has been harvested. Total harvest collection appears to offer economic advantages, but there are practical problems with this concept. First, it will necessitate altered harvesting procedures, which could interfere with normal farm operations. Unless waste removal becomes a serious problem for farmers (e.g., due to legislation banning open field burning), they are likely to resist such disruption of their normal operations. Second, total harvesting of corn and sorghum would require drying after collection because of high moisture contents. This is not true of post-harvest collection, where solar drying would occur naturally. Total harvesting offers potential savings in increased grain recovery, but the economics of this are not clear at present. Given the uncertainties surrounding total harvesting procedures, and noting that post harvest is only 14 percent more expensive, post-harvest values are supplied in the summary table.

Once collected, the residue would be compacted into high density bales prior to shipment in order to reduce transportation costs.

Data on collection and transportation of field residues is currently available for rice straw only. Assuming compaction to seventeen pounds per cubic foot (17 lb/ft^3) bales and further assuming that all residues have a common heating value of 7000 Btu/dry pound, the transportation costs will equate with those given in the Research Report for rice straw. Collection costs may differ significantly in light of the fact that the residue yield per acre of these crops is generally lower than that of rice. Table 2-2, Residue Density of Selected Field Crops, demonstrates that the number of tons/acre of residue from field crops varies by a factor of three between the extremes, corn stover (highest) and barley straw (lowest).

TABLE 2-2

RESIDUE DENSITY OF SELECTED FIELD CROPS

MATERIAL	RESIDUE TONS/ACRE AT 14% MOISTURE	RATIO RICE STRAW/MATERIAL
Rice Straw	3.64	1.00
Barley Straw	1.24*	2.94
Wheat Straw	1.31	2.78
Corn Stover	3.79	0.96
Sorghum Stover	2.56	1.42
Cotton Stalks	2.63	1.38

*at oven dry weight

A countervailing factor is the fact that of all crops rice is the wettest, so drying will be less expensive and time consuming for other crops. The summary table of collection and transportation costs contains a figure for rice straw and adjusted maximum costs for other crops. These costs factor in the residue density but not the moisture content differences.

According to the Research Report, availability of field crop residue by month is distributed bi-modally, with a small peak from mid-June to mid-September, and a large one from mid-September to the end of November.

Fruit and Nut Prunings

A total of seven collection sytems for fruit and nut prunings were costed in the Research Report. The least expensive (total cost) uses buck rakes in the field delivering prunings to a grinder. The ground prunings, at a density of 18 lb/ft^3, are then loaded onto a 26-ton, 15-unit chip truck for transportation.

The major concern among growers is that the pruning collection system must not interfere with the timely operation of their orchards. The system selected is a custom contract system which relieves growers of the responsibility of disposal and also provides for a $5 credit per dry ton. Of 44 growers polled, only 16 had used their prunings in any way, all for firewood, so their cooperation may not be a major obstacle. This system also minimizes pest contral and storage problems, since ground prunings are immediately shipped off-site. As long as pruning piles are buck-raked within one to two months of pruning, no pest problems are anticipated.

Transportation poses no specific problems. The analysis of truck costs is based partly upon waiting time costs and demonstrates that the buck rake-grinder operation is trucking-limited at a greater than 66-mile radius for this system. However, since numerous alternative methods are available which can be custom designed to the specific application, the additional cost is likely to be in the vicinity of 15¢/dry-ton mile.

Fruit and nut prunings are available from November through February.

Manure

A critical factor in the use of manure as combustion/pyrolysis feedstock is the existence of competing uses for the product. Manure is an excellent fertilizer, particularly when it has been composted. Composting is an effective technology in Southern California due to the high insolation and dry air. However, many areas in the vicinity of Bakersfield, notably the Chino-Corona Basin, have overflow problems which might be alleviated by use of manure as an energy feedstock. According to the California State Solid Waste Management Board Agenda Item 13 Report (April 21, 1978), "The majority of feedlot manure and one half of the dairy manure is sold...." Therefore, the high productivity figures in Section One are deceptive. Even so, manure represents a substantial energy source for EOR steam generation.

Collection of manure in Southern California is generally done after the material has dried. Moisture content is a critical factor in transportation costs, so climatic conditions are an important consideration. The costs given in the

summary table for collection and transportation are based upon a 30 percent moisture content, a reasonable figure for the 14 county area considered in this report.

Manure collection is an ongoing industry in the area, so the only obstacle to success in its use for EOR is the economics of the end use. The price of manure varies according to the market from $0 to $2.50 per ton. At times and in some locations operators are paid to remove manure.

If manure develops as an attractive feedstock possibility, more research into specific availability and costs, as well as seasonal and annual variability of supply will be justified. Considerable annual variability is evident from the data provided in the PG & E study.

Forty percent of the feedlot cattle in California is in Imperial County, a county which is not included in this study because it lies outside the 150-mile radius. However, if manure does appear to be a feasible feedstock, supply from Imperial County should be investigated.

The cost of transporting manure beyond a 10-mile radius is given in the Research Report (p. 126) as $.06 per ton-mile.

Logging, Mill, and Brush Residue

The majority of logging, mill, and brush residue is produced in Northern California, but substantial quantities are within 150 miles of Bakersfield. Since the collection costs for field crops are maximum values, forest residue may, in fact, have the highest real collection costs of any waste, as well as the highest transportation costs.

At present, the only fully developed system for logging residue collection is the whole tree harvest method. Whole trees are harvested, brought to a central landing and stripped of merchantable timber. At this point the residue could be chipped and removed either by barge or truck.

Although the possibilities of using brush as a feedstock seem remote at present both for technical and ecological reasons, the majority of this resource is located in Southern California and hence may deserve further research at a later time. Very little information about feasibility and costs of collection and transportation of this resource is available at present.

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SECTION THREE

FEASIBILITY FOR ENHANCED OIL RECOVERY STEAM GENERATION

The potential to use agricultural wastes (residues) as an energy source for thermal EOR systems is dependent upon several factors. These factors include, but are not limited to:

- the economical transport radius of the fuel (residue),
- other uses of the wastes that have a higher economic value than fuel usage,
- types of systems available to burn the various wastes, and
- the cost of the steam production system.

This section will elaborate and clarify the potential to use agricultural wastes as a fuel for thermal EOR steam generation units in the Kern County area of California.

Table 1-2 gives the total energy value of 1975 waste production in the fourteen county area that is within the economically justifiable transportation radius of the EDR sites. The nominal size of a steam generator is 50,000 lb/hr of steam. For a moderate size thermal EOR facility 50 generators are required. The nominal energy requirements for the steam at 965 psia, 532° F and 0.80 quality is $.50 \times 10^{12}$ Btu/yr. Assuming a typical efficiency of a steam boiler of 80 percent, the energy necessary for each steam generator is $.63 \times 10^{12}$ Btu/yr. A moderate size field would require 31.50×10^{12} Btu/yr of energy input.

Table 1-2 lists the total energy available on a dry basis in the various wastes in the fourteen county area. Table 3-1 lists the net energy available in these wastes

TABLE 3-1

NET ENERGY VALUE OF 1975 WASTE PRODUCTION FOR FOURTEEN-COUNTY AREA (1)

	Energy Value (10^{12} Btu)	Water (10^3 Tons)	Energy to Dry Feedstock(2) (10^{12} Btu)	Net Available Energy (10^{12} Btu)
Barley	8.13	94.58	.25	7.88
Rice	--	--	--	--
Cotton	18.34	213.26	.55	17.79
Corn	9.18	106.79	.28	8.90
Sorghum	.91	10.58	.03	.88
Wheat	3.81	44.28	.12	3.69
Tomato (F)	.34	-0-	--	.34
Tomato (P)	1.27	-0-	--	1.27
Potatoes	.59	-0-	--	.59
Melons	.58	-0-	--	.58
Grapes	9.58	383.0	1.0	8.58
Peaches	1.10	37.0	.10	1.0
Oranges	1.97	66.2	.17	1.8
Lemons	.54	18.31	.05	.49
Pears	.03	1.08	--	.03
Apples	.05	1.62	--	.05
Prunes	.10	3.23	--	.10
Dairy M	28.37	47.92	12.46	15.91
Beef M	28.22	47.68	12.40	15.82
Forest R.W.	8.10	300	.78	7.32

[1]See production values in Table 1-2

[2]Assume 1300 Btu/lb to dry

after the moisture has been removed. There is a sufficient energy value in the fourteen county area agricultural wastes to generate the steam required for several moderate size fields. But there is not sufficient net energy in any particular waste to supply the steam requirements for a moderate size for thermal flood (i.e., 50 units). Thus, the system selected must be able to handle a variety of waste products in order to produce the total steam demand.

The major sources of energy are manuer, cotton stalks, grapes, corn stover, barley straw and forest residue, in that order.

These feedstocks are variable in their physical properties. The energy density varies substantially between the straws and forest residue. This variation in energy density requires the building of an energy recovery system that is extremely flexible in its ability to accept various feedstocks and still produce the required steam load. Cotton stalks and rice straw have the additional problem of ash fusion and ash abrasion. Both of these energy sources have a high silica ash, and conversely, a low ash fusion point. The ash fusion point of the cotton stalks and cotton gin wastes is on the order of 1600 - 1800° F, approximately 200-300° F lower than that for rice straw. In addition the ash from these specific materials is very abrasive.

Experience with rice hull boiler systems has shown that extreme care must be taken, such that the ash be kept away from the convective boiler tubes if long equipment life is expected.

With these restrictions and considerations with the several feedstocks, a typical agricultural boiler designed for a single energy source is not a technically viable option. As a reference system as to price, the cost of a nominal size steam generator designed to operate on a hogged wood fuel is presented along with other systems costs in Table 3-2.

Steam Generation Units

As can be seen by the energy requirements of just one moderate size thermal EOR facility, more than one waste-type must be used in the steam generating facility. There are a limited number of systems which can be designed to successfully combust the variety of wastes that are available. The difficulty of using a conventional type stoker system is the ash fusion, moisture, and ash abrasion qualities of the various fuels.

The fluidized bed type reactor when operating with an inert or chemically reactive bed material has very high heat and mass transfer rates. These reactors operate as an essentially isothermal system. Fluidized-bed units have shown their ability to operate with high moisture feeds, and the ability to closely control the reactor temperature allows total control of the ash fusion problem.

Two fluidized-bed systems are available to produce steam from the agricultural wastes. The first system to consider is a fluidized-bed combusion system. Typical FBC operational temperatures are in the range of 1500 ^{o}F. These units are currently being offered for sale using coal as the fuel source. The burning of agricultural wastes should not require any major design changes of the basic unit. The feed handling system will

Table 3-2

Estimated Installed Cost of a 50,000 lb/hr Steam Boiler

Type	Estimated Cost ($)
Hogged Fuel Boiler	2×10^6
Fluidized Bed Combustor	4.5×10^6
Fluidized Bed Gasification Unit plus Gas Fired Boiler	3.5×10^6

require some individual characteristics for the various agricultural wastes, but any material that can be pneumatically transported can be fed into the FBC unit. The cost for a nominal 50,000 lb/hr steam system is given in Table 3-2. The system's cost is based on a hogged wood material for consistancy. There will be some cost increase due to the handling of several fuel types.

The second fluidized-bed system is based on fluidized-bed gasification. The reactor can be operated in such a manner that the products are a low Btu-gas and a char-ash mixture. The low Btu-gas produced can be easily burned in a gas type steam boiler and the char-ash mixture can be used in a pulverized type coal furnace or disposed of if not usable. The energy in gas phase in approximately 80-85% of the energy in the feedstock. The gas can be piped over moderate distances such that one gasification unit can supply the energy to more than one steam boiler. The advantage of the gasification system is the ability to remove the ash from the gas stream before the gas sees the steam tubes. The ash removal is only important in feedstocks which contain highly abrasive ashes. The feedstocks of concern are cotton gin trash and rice by-products (hulls and straw).

Typical efficiencies of gas fired boilers are higher than solid fuel fired boilers for two reasons. First, gas fired systems operate at lower excess air levels, and complete combusion occurs with virtually no carbon loss. Typical coal fired boilers incur 2-3% unburned carbon in the fly-ash, whereas gas fired boilers do not. Excess air requirements for gas systems are approximately 5%, while a good coal type unit operates at 25% excess air. This difference gives an efficiency advantage of approximately 3-4% to a gas fired unit. Thus, the total efficiency advantage of a gas fired boiler can be

as large as 7%. With these advantages, the energy required to operate a 50,000 lb/hr steam generator is $.57 \times 10^{12}$ Btu/yr (assuming 87% efficiency of the gas fired system).

Considering the energy available in the gas product of a gasification reactor, one 500 ton/day reactor operating on a wood residue (dry) could supply the energy to five steam generators of the type needed for thermal EOR recovery. The steam generation system can be shop fabricated, packaged boiler. These packaged boilers are less expensive than field erected units. The cost of one such steam generator is estimated by the cost of the gas fired steam boiler and 1/5 the cost of the 500 ton/day gasification unit.

The technical ability to use the feedstocks generated in the Kern County region for thermal EOR is available now. Both of the fluidized-bed systems can handle the several agricultural waste products and still produce the required thermal energy for EOR operations. The limitation on the use of the agricultural waste as an energy souce is the economic cost to transport the feedstocks to the EOR sites. An expansion of this economic redius or an increase in the availability of feedstocks increases the applicability of such systems to thermal EOR.

SECTION THREE: INFORMATION REFERENCES

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