POTENTIAL LIQUID FUEL SAVINGS FROM CROP RESIDUE AND HIGH SULFUR COAL COMBUSTION IN OHIO, INDIANA AND ILLINOIS

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Introduction

To conform to the Environmental Protection Agency (EPA) sulfur standards, most electric utility process steam, etc., installations using high sulfur coal blend their coal with low sulfur western coal. Illinois, Indiana, and Ohio which are the highest producers of coal in the North Central Region (Table 1) import western coal from as far as Wyoming and Colorado to blend with their high sulfur coal (Table 2). Also, Iowa, Minnesota, and Wisconsin, which produce little (Iowa) or no coal, import Wyoming and Colorado coal for blending with the high sulfur coal they purchase from neighboring states such as Indiana, Illinois, and Ohio.

The increasing amounts of low sulfur western coal imports in Indiana, Illinois, and Ohio have created a lot of concern over the expected loss of mining and the associated service jobs, and the reduction in revenues for these states. Another important concern is the consumption of liquid fuels used in the transportation of coal over such long distances, since the energy problem in the U.S. is caused mainly by the dwindling supplies of liquid fuels and their increasing import prices.

The six previously mentioned North Central states produce 53 percent of the crop residues in the U.S. (Tyner, 5). Crop residues could be used as supplementary fuels in coal burning electric utilities because of their heat value and their low sulfur content. Their sulfur content is 0.15 percent (Morrison, 4), whereas western coal has 0.55 percent sulfur. However, the BTU content of crop residues (16 MBTU/ton of dry matter) is only 67 percent of that of western coal (24 MBTU/ton

Table 1: Production of Coal, Natural Gas, and Petroleum in the North Central States of the U.S., 1974

Sub-Region/ State	Coal		Crude Petroleum		Natural Gas	
	000 tons	% of the Region	000 Barrels	% of the Region	Million Cubic Feet	% of the Region
East North Central	127,350	90.48	59,391	38.71	152.20	59.90
Illinois	58,215	41.36	30,669	19.99	40.00	15.74
Indiana	23,726	16.85	5,312	3.46	14.00	5.51
Michigan	00	.00	14,614	9.53	50.00	19.68
Ohio	45,409	32.27	8,796	5.73	48.20	18.96
Wisconsin	00	.00	00	.00	.00	.00
West North Central	13,395	9.52	4,037	61.30	101.90	40.10
Iowa	590	0.42	00	.00	.00	.00
Kansas	718	0.51	66,227	43.16	16.60	6.53
Minnesota	00	.00	00	.00	.00	.00
Missouri	4,624	3.29	60	0.04	31.40	12.36
Nebraska	00	.00	7,240	4.71	34.00	13.37
North Dakota	7,463	5.30	20,235	13.19	19.90	7.83
South Dakota	00	.00	275	0.18	.00	.00
North Central States	140,745	100.00	153,428	100.00	254.10	100.00

Source: Bureau of Mines, Mineral Year Book, United States Department of Interior, 1974.

Table 2: Amounts and BTU Content of Western Coal Shipments and Usable Crop Residues in Selected Eastern States (1976)[a]

	Western Coal Tons	Shipments 10^6BTU	Usable Crop Tons	Residues 10^6BTU
			(Dry Matter)	
Illinois	2,362.4	56,697.6	8,984	143,824
Indiana	1,975.9	47,421.6	6,158	98,528
Iowa	3,363.7	80,728.8	8,553	136,848
Minnesota	1.8	43.2	10,217	163,472
Ohio	2,286.3	54,871.2	3,817	61,072
Wisconsin	970.0	23,280.0	3,682	58,912
Total	10,948.8	262,771.2	41,413	662,608

[a] BTU content of western coal is calculated based upon an average of 24 x 10^6BTU per ton of coal and that of crop residue is based upon an average of 16 x 10^6BTU per ton of crop residue (dry matter).

on the average).

Direct combustion of crop residues as an alternative source of energy has been criticized as not directly relevant to the solution of the critical energy problem in the U.S. because it adds to the plentiful solid fuels rather than to the scarce liquid fuels. However, it may save liquid fuels if substituted for western coal especially in the states where crop residues are abundant and the transportation distance of hauling western coal to them is high. This paper attempts to compare the liquid fuels consumption of mining and hauling of western coal to Ohio, Indiana, and Illinois where both high sulfur coal and crop residues are abundant, with that of harvesting and hauling of crop residues to coal burning electric utilities. Some reference will also be made to other high crop residue producing states such as Iowa, Minnesota, and Wisconsin which when combusted with crop residue might be able to purchase all their coal from neighboring states rather than the far west, thus saving some liquid fuels. The other six states in the North Central Region are excluded from this study because: (1) they use mainly western coal, or (2) their crop residue production is rather low.

Objectives

The main objective of this paper is to determine whether or not a blend of coal and crop residues consumes less liquid fuels than a blend of high and low sulfur coal in six high crop residue producing states.

The specific objectives are:

1. To estimate the liquid fuel consumption (per ton of coal) of mining and hauling western coal for the states of Ohio,

Indiana, and Illinois.

2. To estimate the expected liquid fuel consumption per ton of crop residues (if used as coal supplement) in Ohio, Indiana, and Illinois.

3. To compare the total liquid fuel consumption of western and high sulfur coal blend with an equivalent amount of crop residue and high sulfur coal blend (having the same BTU and sulfur content).

4. To extrapolate some of the results of the analysis of Ohio, Indiana, and Illinois to Minnesota, Wisconsin, and Iowa.

Methodology

To get accurate estimates for the liquid fuel (diesel in this analysis) consumption of hauling western coal, the exact location of the mines from which the coal is shipped, the respective power plants for final destination, and the routes and modes for the shipments must be known. Coal is generally shipped by railroad, trucks, barges, slurry pipes or some combination, and each of these modes of coal transportation has a different consumption rate of liquid fuels per ton/mile. The average rates of fuel consumption of railroads, barges, and trucks are 450, 290, and 2000 BTU per ton/mile respectively (U.S. Department of Transportation, 7). However, trucks are a more flexible mode of coal transportation compared to railways and barges.

The western coal is assumed to be transported the shortest distance from the center of the coal fields in the west to the center of each receiving state plus the average mileage required to distribute the shipment within each state. The western coal is also assumed to follow the least fuel consuming path using the railroads until the closest navigable waters (mainly the Mississippi and the Ohio rivers) are reached. It is then assumed to be shipped by barges to the respective state borders and by trains and trucks for distribution within each receiving state. According to the U.S. Department of Commerce [6], trucks are more economical for coal transportation for distances less than 100 miles. For that reason most of the distribution of coal within each state is assumed to be carried out by trucks.

This method of estimating western coal hauling distance and routes probably understates the liquid fuels consumption of western coal shipments. Coal transportation cost is a very important part of the coal delivered price (in most cases it is higher than the price of coal at the mine). However, the transportation distance is not the only criteria a power plant will consider when purchasing its coal needs. The mode of transportation used may not be the least cost or most fuel efficient. The timing and place of delivery are sometimes more important than the nominal cost of coal at the power plant. Thus, the mode of transportation used may not be the least costly or most fuel efficient.

To estimate the fuel consumption of delivering one ton of crop residue to a power plant it is also necessary to know the exact location of the receiving power plant relative to the location of the crop residues. In the absence of such information, an average hauling distance will be used to approximate the amount of fuel consumed to haul one ton of crop residue to power plants.

The liquid fuel consumption of hauling and harvesting crop residues in each of the states selected for this study is estimated using formulae which were developed by Tyner, et al. [5] for the most important crop residues in the U.S. The major crop residues produced in the selected states are from corn, small grains, and sorghum (Table 3).

Tyner, et al. [5] formulated a set of equations to estimate costs of harvesting and transporting crop residues from on-farm storage (roadside) to a processing plant that converts crop residues into fuels. One set of these equations is based upon currently available farm machinery built for hay harvesting and transportation. This is termed current technology (Appendix A). The other set of equations assumes that if crop residues are harvested for off-farm uses at a commercial scale, some equipment modifications will be necessary for crop residues harvest and transportation. These modifications will reduce both costs and fuel consumption of crop residue collection. This is termed future technology (Appendix B). This analysis will consider both current and future technology for collection of crop residues.

The third objective (the comparison of the two types of coal blends without and with crop residues) can be achieved by first finding the amount of crop residues and the western and local coal (high sulfur) blend that is equivalent to the current western coal and high sulfur coal blend (without crop residues) in Ohio, Indiana, and Illinois. The crop residue blend has to satisfy both the BTU and the sulfur content of the current western coal blend simultaneously.

For the exact estimate of the crop residue blend, we need to know the sulfur content of coal used in each power plant using western coal, and the sulfur standards set for each of them. Generally speaking, coal of more than one percent sulfur is considered to be of concern regarding

Table 3: Usable Crop Residues in the Major Residue Producing States

	Corn k-tons	Small Grains k-tons	Sorghum k-tons	Total k-tons
Illinois	7,958	1,009	18	8,985
Indiana	4,564	1,588	6	6,158
Iowa	6,930	1,614	9	8,553
Minnesota	4,150	6,067	-	10,217
Ohio	2,556	1,261	-	3,817
Wisconsin	1,716	1,967	-	3,683
Total	27,874	13,506	33	41,413

Source: Wallace Tyner, et al., "The Potential of Producing Energy from Agriculture," Purdue University, 1979, pp. 40-42.

air emissions. To get a rough estimate of the crop residue blend, it will be assumed that the sulfur standards for Ohio, Indiana, and Illinois are all one percent. That is to say the fuel combusted should not contain more than one percent sulfur.

Sulfur content of coal varies from one mine to another and sometimes it varies within the same mine. For the purpose of this paper, the average sulfur content of the coal produced in these three states will be used to approximate the type of eastern coal burned by the power plants importing western coal. This probably understates the amount of western coal required to conform to the EPA sulfur standards because the power plants using western coal are most likely using local coal with an above average sulfur content. On the other hand, sulfur standards may be more stringent than average standards in the state and enforced more than in the plants that do not use western coal or any other pollution control method.

With these assumptions about sulfur standards and sulfur content of coal, the crop residue-coal blend can be estimated algebraically as follows:

1. The amount of local coal blended with the amount of purchased western coal within a year (Table 2) to satisfy the one percent sulfur emission standard can be determined by solving the following equation:

   $$SCWC + SCLC = 1\% \, (WC + LC)$$

   where:

   SCWC = sulfur content of western coal purchased within a year by each state.

SCLC = sulfur content of local coal (high sulfur coal) in each state.

WC = amount of purchased western coal within a year in each state.

LC = amount of local coal blended with western coal to yield a 1% sulfur fuel.

1% = the sulfur emission standard.

2. Multiplying the BTU content of local western coal by their respective amounts in the western-local coal blend as determined by equation (1) we get the heat content of this blend.

3. The crop residue-local coal blend should have the same BTU value as the western-local coal blend as well as a one percent sulfur content. Using the following linear programming model, the crop residue-coal blend which will satisfy both of these requirements and minimize the amount of liquid fuel (diesel) it would consume can be determined.

$$\text{Min. } DC = LC \times DC_L + WC \times DC_W + CR \times DC_{cr}$$

Subject to:

$$LC \times S_L + WC \times S_W + CR \times S_{cr} = 1\% \, (WC + LC)$$

$$LC \times h_L + WC \times h_W + CR \times h_{cr} = HWLCB$$

$$CR \times h_{cr} = 0.2 \, (HWLCB)$$

Where:

Min. DC = minimum diesel consumption (gallons)

LC = amount of local coal (tons)

DC_L = diesel consumption of local coal per ton

WC = amount of western coal (tons)

DC_W = diesel consumption of western coal per ton

CR = amount of crop residue (tons)

DC_{cr} = diesel consumption of crop residues per ton

S_L = sulfur content of local coal (present)

S_W = sulfur content of western coal (present)

S_{cr} = sulfur content of crop residues (percent)

HWLCB = heat content of the western and local blend (determined by solving equation 1)

1% = sulfur emission standard

The amount of crop residue is restricted to 20 percent of the total BTUs because the proportion of crop residue to be used as a direct combustion supplementary fuel in existing power and other coal burning installations is determined by the type of boiler. In a pulverized coal boiler the BTUs of crop residue should not exceed 20 percent of the total BTUs fired in this type of boiler. For stoker boilers it should not exceed 50 percent. A majority of the boilers in Ohio, Indiana, and Illinois are probably pulverized coal boilers.

The percent of sulfur in the local coal and crop residues is 0.15 percent for the crop residue, 3 percent for Ohio coal, 3.6 percent for Illinois coal and 4 percent for Indiana coal. The BTU content of crop residue is 16 MBTU/ton, and for Indiana coal it is 22.4 MBTU/ton. The heat content of the western-local coal blend (HWLCB) is determined by solving equation (1). The solution of the above linear programming model gives the minimum diesel fuel consumption of the prescribed blend of local coal, western coal and crop residues.

Results

The estimates of the different parameters involved in the analysis of this problem are only as reliable as the assumptions upon which the data collected are based. These assumptions are developed to avoid overstating the liquid fuel savings due to replacing western coal with crop residues to reduce sulfur emissions of high sulfur coal.

Fuel Consumption of Western and Local Coal

Mining and transportation of western and local coal are fueled primarily by diesel with some gasoline. For uniformity of measurements, gasoline was converted to diesel using the National Energy Information Centre [8] conversion factors. According to this source, one thousand tons of coal is equivalent to 4.20 million gallons of gasoline and 4.63 million gallons of diesel. This means that one gallon of gasoline is equivalent to 0.9 gallons of diesel.

Based upon the U.S. Department of Commerce Census of mineral industries [6], the average gasoline consumption of mining coal in the U.S. was calculated as 0.531 gallons per ton which is equivalent to approximately 0.59 gallons of diesel fuel per ton.

To estimate the transportation fuel consumption per ton of western coal for Ohio, Indiana, and Illinois, their respective distances from the center of the western coal fields by train, barge, and then train to the Center of each state are measured from appropriate maps based on actual rail lines, rail and river intersections, etc. From the center of the state coal is assumed to be distributed by truck. The minimum transportation distance using the least diesel fuel consuming routes are as follows:

Illinois - 1,006 miles by train, 185 miles by barge on the Mississippi River and 180 miles within the state using trains and trucks.

Indiana - 1,006 miles by train, 210 miles by barge on the Mississippi River to the Ohio River, 170 miles by barge on the Ohio River and 100 miles within the state using trains and trucks.

Ohio - 1,006 miles by train, 210 miles by barge on the Mississippi River to the Ohio River, 350 miles by barge on the Ohio River and 87 miles within the state using trains and trucks.

These distances for each state were multiplied by the transportation fuel consumption per ton/mile for each mode of transportation to estimate the consumption of diesel fuel per ton for each state. Adding the transportation consumption per ton to the mining consumption per ton and multiplying the result by the total western coal purchases within a year, gives the total fuel consumption of western coal for each state. These results are presented in Table 4.

Local coal is assumed to be shipped by both trucks and trains. A weighted average of fuel consumption per ton for trains and trucks was multiplied by the average hauling distance for each state to estimate the transportation fuel consumption. This was added to the mining consumption per ton to get the total fuel consumption of mining and hauling a ton of local coal. This was found to be 1.10, 1.24 and 1.16 gallons of diesel per ton for Illinois, Indiana, and Ohio, respectively. This variation is primarily due to the differences in areas of these

Table 4: Diesel Fuel Consumption of Mining and Transportation of Western Coal to Three High Sulfur Coal Producing States

	Amount of Purchased Western Coal (k-tons)[1] (k-tons[1]	Diesel Consumption Per Ton: Mining Consumtion (gallons /ton)	Transportation Consumption (gallons /ton)	Total (gallons /ton)	Total Diesel Consumption (k-gallons)
Illinois	2,362.40	0.48[2]	4.28[2]	4.76	11,245.02
Indiana	1,975.00	0.48	5.14	5.62	11,099.50
Ohio	2,286.00	0.48	5.46	5.94	13,578.84
Total	6,623.40				35,923.36

Sources: [1]Economics of Nonmetropolitan Solid Waste Resource Recovery in the North Central States.

[2]Calculated based upon 1972 Census of Mineral Industries, U.S. Department of Commerce, 1975.

states and the location of rail lines within the states. The mining consumption is the same for all three states (0.59 gallons of diesel/ton).

Fuel Consumption of Crop Residues

Using the formulae for harvesting and transporting crop residues, the fuel consumption per ton for each crop was estimated. The harvestable residues (HR) for each crop and state are presented in Table 5. Based upon a study done by Tyner, et al. [5] the hauling distance (D) is assumed to be 15 miles on the average. To estimate the harvest and transport fuel consumption for crop residues collectively, a weighted average for the crop residues (corn, small grains, and sorghum) in each state was calculated. Table 6 shows the weighted average fuel consumption per ton for the selected states using current technology. The results include the expected fuel savings from eliminating chopping of residues which will be an unnecessary operation when crop residues are removed. Fuel consumption of chopping was estimated at 0.81 gallons of diesel per acre. The net fuel consumption of crop residues delivered at the processing plant is estimated as 2.25, 2.30, and 2.39 for Illinois, Indiana and Ohio respectively. Table 7 shows the diesel fuel consumption expected under the future technology assumptions.

Fuel Consumption of Western-Local Coal Blend

To estimate the western-local coal blend (without crop residue) fuel consumption, the amount of local coal mixed with the purchased western coal to a blend of 1 percent sulfur fuel for each state was calculated using equation (1) as follows:

Table 5: Average Harvestable Residue Per Acre of the Major Residue Producing Crops in Selected States

	Corn Tons/Acre	Small Grains Tons/Acre	Sorghum Tons/Acre
Illinois	1.30	0.93	0.41
Indiana	1.26	1.27	0.51
Iowa	1.22	1.39	0.46
Minnesota	0.77	1.02	--
Ohio	0.98	1.35	--
Wisconsin	0.96	1.59	--

Source: Tyner, Wallace, et al., "The Potential of Producing Energy From Agriculture," Purdue University, 1979, pp. 40-42.

Table 6: Weighted Average Diesel Fuel Consumption of Harvest and Transportation of Crop Residues (using current technology) in Selected States (gallons/tons)

	Harvest	Transport	Total[a/]
Illinois	1.526	1.465	2.87
Indiana	1.524	1.490	3.01
Iowa	1.514	1.478	2.99
Minnesota	1.963	1.552	3.52
Ohio	1.708	1.506	3.22
Wisconsin	1.538	1.542	3.08

a/ This is a weighted average of the three types of crop residues (corn, small grains and sorghum).

Table 7: Weighted Average Diesel Fuel Consumption of Harvest and Transportation of Crop Residues (using future technology) in Selected States (gallons/ton)

	Harvest	Transport	Total[a]
Illinois	1.076	0.842	1.918
Indiana	1.114	0.861	1.975
Iowa	1.076	0.854	1.930
Minnesota	1.626	0.897	2.523
Ohio	1.264	0.871	2.135
Wisconsin	1.218	0.888	2.106

a/ This is a weighted average of the three types of crop residues (corn, small grains and sorghum).

Illinois:

$$0.036LC + 2{,}362{,}400 \times 0.0055 = 0.01\ (2{,}362{,}400 + LC)$$

$$0.036LC - 0.01\ CL = 23{,}624 - 12{,}993$$

$$\therefore\ LC = \frac{10{,}631}{0.026} = 408{,}885$$

The amount of Illinois coal needed to make a 1 percent sulfur coal blend with the amount of western coal it imported in 1976 (2,362,400 tons) was calculated as 408,885 tons.

The fuel consumption of the western-Illinois coal blend was therefore:

Western coal =	2,362,400 X 4.87 =	11,504.89
Illinois coal =	408,885 X 1.11 =	453.86
Total		11,958.75

Similarly the fuel consumption of western coal-Indiana and western coal-Ohio blends (without crop residue) were calculated as 11,684.10 and 14,426.95 gallons of diesel respectively.

Fuel Consumption of Crop Residue-Coal Blends

Solving the linear programming model for each of the three states considering current technology of residue collection we get the following:

Illinois:

$$\text{Min. } DC = 1.11LC + 4.87WC + 2.25CR$$

Subject to

$$0.036LC + 0.0055WC + 0.0015CR \leq 0.01\ (WC + LC)$$

$$24CL + 22WC + 16CR = 61.79 \times 10^{12}\text{BTU}$$

$$16CR \leq 12.36 \times 10^{12}\text{BTU}$$

Indiana:

$$\text{Min. DC} = 1.24LC + 5.73WC + 2.30CR$$

Subject to

$$0.04LC + 0.0055WC + 0.0015CR \leq 0.01\ (WC + LC)$$

$$22.4LC + 22WC + 16CR = 50.09 \times 10^{12}BTU$$

$$16CR \leq 10.02 \times 10^{12}BTU$$

Ohio:

$$\text{Min. DC} + 1.16LC + 6.05WC + 2.39CR$$

Subject to

$$0.03LC + 0.0055WC + 0.0015CR = 0.01\ (WC + LC)$$

$$24CL + 22WC + 16CR = 62.64 \times 10^{12}BTU$$

$$16CR = 12.53 \times 10^{12}BTU$$

Using future technology of crop residues harvest and transportation, the models are the same except for the coeffcients of crop residues in the objective functions. Those coefficients would be 1.418, 1.475, and 1.635 for Illinois, Indiana and Ohio respectively. The solutions of the models for each state at both current and future technology are presented in Tables 8 and 9.

Diesel consumption decreased slightly using future technology of harvesting and transporting crop residue instead of current technology. However, quantities of western coal, local coal and crop residue stayed the same for both types of technology. This is due to the restriction imposed on crop residues because of the type of boilers. Crop residue is only 20 percent of the total BTUs in the western-local coal blend. The result of this restriction was a net diesel savings of 1.29, 1.37, and 2.02 million gallons for Illinois, Indiana, and Ohio respectively

Table 8: Diesel Fuel Consumption and Quantities of Crop Residue-Coal Blend (Current Technology)

	Diesel Fuel K-gal.	Western Coal K-tons	Local Coal K-tons	Crop Residue[a/] K-tons
Illinois	10,667.00	1,726.07	473.97	771.08
Indiana	10,309.78	1,474.35	340.39	625.94
Ohio	12,411.13	1,627.83	595.92	783.04

a/ The amount of crp residue is restricted to 20 percent of the total BTU in the blend.

Table 9: Diesel Fuel Consumption and Quantities of Crop Residue-Coal Blend (Future Technology)

	Diesel Fuel K-gal.	Western Coal K-tons	Local Coal K-tons	Crop Residue[a/] K-tons
Illinois	10,025.46	1,726.07	473.97	771.08
Indiana	9,793.38	1,474.35	340.39	625.94
Ohio	11,819.94	1,627.84	595.92	783.04

a/ The amount of crop residue is restricted in the model to 20 percent of total BTU in the blend.

(Table 10) in the case of current technology. Considering future technology, the savings are 1.93, 1.89, and 2.61 million gallons for Illinois, Indiana and Ohio respectively (Table 11). The total estimated diesel fuel savings per year from using crop residues in these three states are 4.7 million gallons and 6.4 million gallons for current and future technology respectively.

If there is no restriction on the amount of crop residues that could be mixed with local coal, diesel consumption of the crop residue-coal blend would be 7.2, 6.26, and 7.42 million gallons respectively for Illinois, India and Ohio. The total diesel fuel consumption for the three states would be 23.7 million gallons at current technology (Table 12) and 17.2 million gallons using future technology (Table 13). The reason for this high amount of diesel savings compared to the previous case when the amount of crop residues were restricted to 20 percent is that no western coal needs to be imported in any of the three states. The crop residues would completely replace western coal as sulfur emissions control material. The 20 percent restriction on crop residues case and the no restrictions at all case are two extreme cases. So, it could be concluded that the minimum savings would be 23.7 million gallons for the three states considered in the analysis. Stoker boilers which can use up to 50 percent crop residues may increase relative to pulverized coal boilers in the future. Most of the old pulverized coal boilers which outnumber steam electric boilers are generally of the stoker type.

In addition to the liquid fuel savings from direct combustion of crop residues there are two other potential benefits for these states:

Table 10: Diesel Fuel Savings from Crop Residues Coal Blend (Current Technology)

	Western-Local Coal Blend Consumption (K-Gallons)	Crop Residue[a/] Coal Blend Consumption (K-Gallons)	Net Savings (K-Gallons)
Illinois	11,958.75	10,667.00	1,291.75
Indiana	11,684.10	10,309.78	1,374.32
Ohio	14,426.95	12,411.13	2,015.82
Total	38,069.80	33,387.91	4,681.89

a/ Crop residue use is restricted to 20 percent of the total BTUs in the blend.

Table 11: Diesel Fuel Savings from Crop Residue Coal Blend (future technology)

	Western-Local Coal Blend Consumption (K-Gallons)	Crop Residue[a] Coal Blend Consumption (K-Gallons)	Net Savings (K-Gallons)
Illinois	11,958.75	10,025.46	1,933.29
Indiana	11,684.10	9,793.38	1,890.72
Ohio	14,426.95	11,819.84	2,607.01
Total	38,069.80	31,638.78	6,431.02

[a] Crop residue use is restricted to 20 percent of the total BTUs in the blend.

Table 12: Diesel Fuel Savings from Crop Residue (current technology)

	Western-Local Coal Blend (K-Gallons)	Crop Residue[a]/ Coal Blend (K-Gallons)	Net Savings (K-Gallons)
Illinois	11,958.75	7,202.87	4,755.88
Indiana	11,684.10	6,259.02	5,425.08
Ohio	14,426.95	7,423.21	7,003.74
Total	38,069.80	20,885.10	17,184.68

a/ The amount of crop residue in the blend is not restricted in the model.

Table 13: Diesel Fuel Savings from Crop Residue (future technology)

	Western-Local Coal Blend (K-Gallons)	Crop Residue[a/] Coal Blend (K-Gallons)	Net Savings (K-Gallons)
Illinois	11,958.75	4,806.11	7,152.64
Indiana	11,684.10	4,225.20	7,458.90
Ohio	14,426.95	5,370.48	9,056.47
Total	38,069.80	14,401.79	23,668.01

a/ Crop residue use is not restricted in the model.

1) more coal would be saved as crop residue adds to the fuel resource base, 2) mine jobs in the high sulfur producing states would be saved if no western coal or less of it is used to conform to EPA sulfur standards. According to the Columbus Dispatch of June 17, 1979 the estimated number of mining jobs that would be lost in the Ohio mining district if western coal has to be imported to conform to EPA standards is 5,375 jobs [1]. If crop residues are used, many of these jobs might be saved. Besides, state and local government revenues would not be affected if a locally produced fuel such as crop residue is used instead of importing western or any other low sulfur coal.

It is difficult to generalize the results of the Illinois, Indiana and Ohio analysis to Iowa, Minnesota and Wisconsin. More favorable results are suggested by the fact that the latter three states import all of their coal from other states except for Iowa which produces some high sulfur coal. In addition, total usable crop residues in Iowa, Minnesota and Wisconsin exceed the total for Illinois, Indiana and Ohio (Table 3). Less favorable results are suggested by the fact that diesel fuel consumption for collecting and transporting crop residue on average appears higher (Table 7) in Minnesota, Wisconsin and Iowa. In addition, the latter three states are located closer to western low sulfur coal sources, which reduces liquid fuel requirements for coal transport. More analysis is needed but it would appear that significant liquid fuel savings are also possible in Iowa, Minnesota and Wisconsin.

A final caution is in order. The estimated savings in diesel fuel from combustion of crop residues with coal appear small when compared to the total U.S. energy use or even to the 8.5 million barrels/day of imported crude oil. This is even true of the highest estimated level of savings (28.9 million gallons/year which is equivalent to 1,300 barrels/day of diesel fuel. However, no single alternative source of energy or set of policy changes will be sufficient as a solution for the current energy crisis in the U.S. or any where else in the world. The solution of the energy crisis will require a combination of alternative energy sources plus conservation and policy changes.

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APPENDIX A

Diesel Fuel Consumption of Collecting and Transporting Stacks (4½ tons of dry matter) of Crop Residues Using Current Technology

The following equations were developed by Tyner, et al. [5] to estimate the diesel fuel consumption of harvesting, collecting and transporting crop residues. They assume that current technology of hay collection and transportation is used for collecting and transporting crop residues. Large stacks (4½ tons of dry weight) are used for this analysis because they are found to be more energy efficient than bales and other forms of collecting crop residues.

Activity	Diesel Consumption (gal/acre)
Corn:	
Collect, stack and drop at roadside	1.55 + 0.285HR
Transport stacks to power plant	(0.11 + 0.989D)HR
Total	1.55 + (0.4 + 0.089D)HR
Small Grains:	
Cut and windrow	0.61
Stack and drop at roadside	0.85 + 0.305HR
Transport stacks to roadside	(0.125 + 0.1D)HR
Total	1.46 + (0.43 + 0.1D)HR
Sorghum:	
Cut and windrow	0.61
Stack and drop at roadside	0.92 + 0.28HR
Transport stacks to power plant	(0.111 + 0.089D)HR
Total	1.53 + (0.39 + 0.089D)HR

where:

HR = harvestable residue per acre. This is defined as the amount of crop residue that can be safely removed without affecting water and wind erosion of the soil. Larson, et al., recommended that one ton of corn stover has to be left on the field for soil protection. For small grains and sorghum he recommended amounts of residue to be left in the field as 0.25 tons/acre and one ton/acre, respectively. The machine harvest efficiency and moisture content are also considered in estimating the harvestable residue per acre (HR). Table 4 shows the harvestable residue per acre for each of the three crops and the six states selected for this study.

D = hauling distance from the corn field to the power plant. Tyner, et al., found that 15 miles is the average hauling distance. This will be assumed to hold for all crop residues and in all of the selected states.

APPENDIX B

Diesel Fuel Consumption of Collecting and Transporting Stacks (4½ tons of dry weight) of Crop Residues Using Future Technology

Following the same notations used in Appendix A, the following are the equations developed by Tyner, *et al.* [5] for corn, small grains and sorghum residues. They assume that technology will adapt to market situations when crop residues are widely used as a source of fuel in power plants in the future. This is what Tyner, *et al.*, called future technology.

Activity	Diesel Fuel Consumption (gal/acre)
Corn:	
Cut and windrow	0.17
Stack and drop at roadside	1.11 + 0.26HR
Transport stacks to plant	$\frac{(D)HR}{18}$
Total	1.28 + (0.26 + 0.056D)HR
Small Grains:	
Cut and windrow	0.61
Stack and drop at roadside	0.85 + 0.305HR
Transport stacks to plant	$\frac{(D)HR}{16}$
Total	1.46 + (0.305 = .063D)HR
Sorghum:	
Cut and windrow	0.61
Stack and drop at roadside	0.92 + 0.28HR
Transport stacks to plant	$\frac{(D)HR}{18}$
Total	1.53 + (0.28 + .056D)HR