Economics of Nonmetropolitan Solid Waste Resource Recovery in the North Central Region

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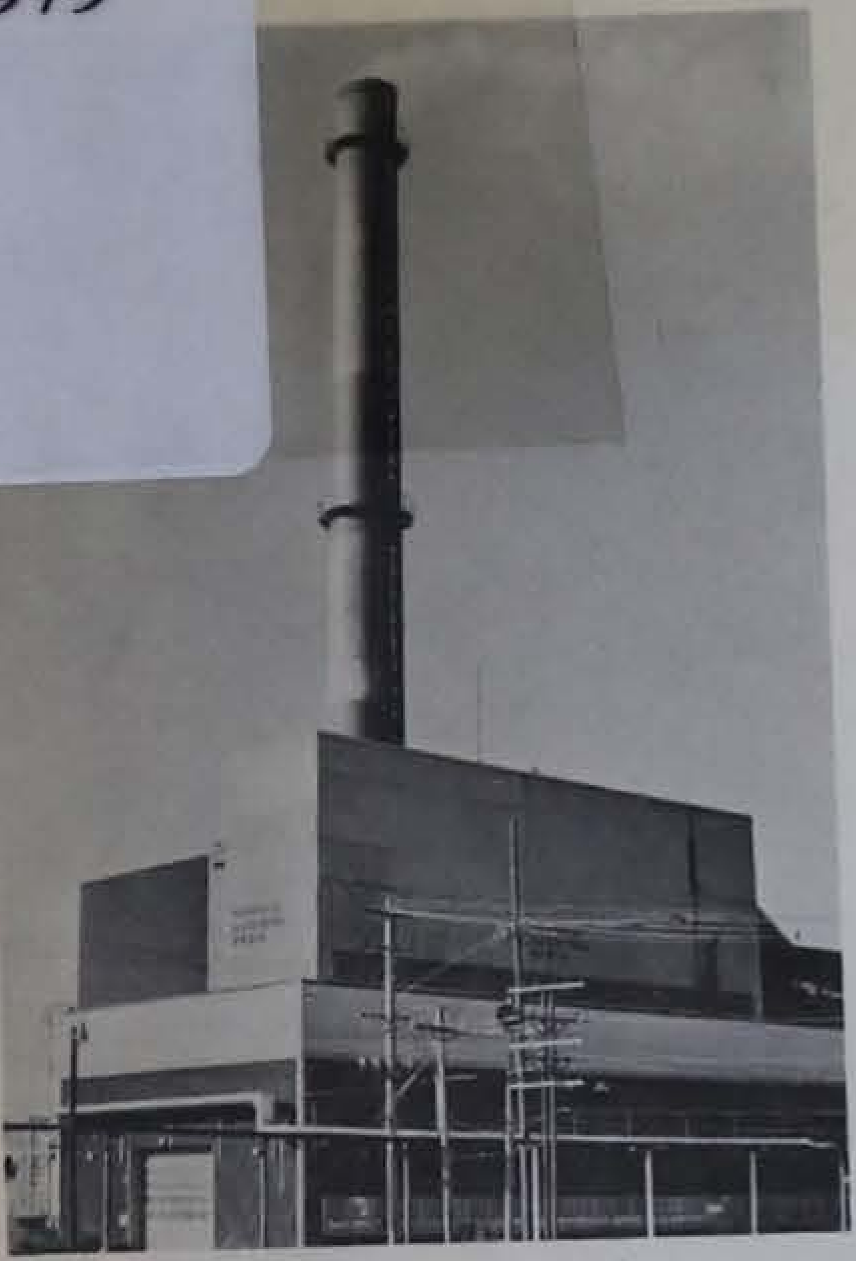

Solid waste recovery systems at Orrville, Ohio, and Ames, Iowa

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PREFACE

This is a research report on a two-phase analysis of the economics of nonmetropolitan solid waste resource recovery in the North Central Region. The research was supported in part by a $26,500 grant from the North Central Regional Center for Rural Development at Iowa State University, Ames, Iowa. Part I includes an inventory of the 372 steam-electric plants in the 12 North Central states with emphasis on the 242 plants with coal burning capacity. Eighty-six of these coal burning plants are located in nonmetropolitan counties of the region. Plant capacity to burn refuse, conformation to emission standards, coal sources, and coal prices are included. Part I also includes an analysis of solid waste and corn stover generation in a random sample of 25 wastesheds associated with 53 coal burning steam-electric plants in the North Central Region. Sixteen of the sample wastesheds and 21 of the sample plants are in nonmetropolitan counties.

Part II includes a detailed benefit-cost analysis of resource recovery at two nonmetropolitan steam-electric plants and their surrounding wastesheds. Ames, Iowa, has an operational solid waste resource recovery facility and Orrville, Ohio, has completed a preliminary feasibility study of the concept. Sensitivity analysis of these two case plants is combined with data from the sample of wastesheds and associated power plants to simulate some general conclusions for the nonmetropolitan areas of the North Central states.

The authors are associate professor, resource economics and former graduate research associates, respectively, Department of Agricultural Economics and Rural Sociology, The Ohio State University, Columbus, Ohio. Conceptual, analytical, and clerical assistance was provided by Steve Minter, Mohammed Abdallah, Girmai Ibrahim, Mike McCullough, Robin Frees, and Cathy Myers at The Ohio State University. Gordon Smith, a consulting engineer, and Richard Poling provided valuable assistance on technical and economic factors relating to power plant capacity and conversion, processing plant design, and optimal solid waste transfer schemes.

Numerous other individuals provided valuable assistance: several staff members at the Federal Power Commission, the National Coal Association, and the National Center for Resource Recovery; Mark Luttner, U.S. Environmental Protection Agency, Washington, D.C.; Arnold Chantland, Public Works Director, Ames, Iowa; Merlin Hove, Ames Municipal Power Plant; Jerry Temple, Ames Solid Waste Processing Facility; and Dr. John Even, Industrial Engineering Department, Iowa State University. Dr. Ronald Powers, Director of the North Central Regional Center for Rural Development, was understanding and supportive throughout the research effort.

Dr. Edward Ives, resource economist, The Ohio State University; Dr. Kenneth Clayton, resource economist, The University of Florida; Mike McCullough, graduate research associate, resource economics, The Ohio State University, and Arnold Chantland, Ames, Iowa, provided helpful comments on manuscript drafts. Any remaining errors or shortcomings are the sole responsibility of the authors.

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INTRODUCTION

Objectives

The overall objective of this research is to determine the technical and economic feasibility of solid waste energy and materials recovery. The primary focus is on the coal-burning, steam-electric generating plants in the nonmetropolitan areas (counties that are not part of a Standard Metropolitan Statistical Area)[1] of the 12 North Central States. The specific objectives are to:

1) compile an inventory of plant type and location, solid waste burning capacity, sulfur emissions compliance, coal sources and coal prices for the coal burning steam-electric plants in the 12 North Central States;

2) analyze solid waste and corn stover generation in a sample of 25 wastesheds associated with existing steam-electric plants;

3) do a detailed benefit-cost analysis of solid waste resource recovery in two nonmetropolitan case plants (Ames, Iowa and Orrville, Ohio) and their surrounding wastesheds; and

4) based on sensitivity analysis of the two case studies and detailed data from the nonmetropolitan subset of the wasteshed sample, simulate several alternative situations and draw some general conclusions on nonmetropolital resource recovery in the 12 North Central States.

Background and Problem Statement

The energy crisis is the culmination of a growing problem facing industry and agriculture in the North Central States and the rest of the

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[1] The Bureau of Census uses two determinants in defining SMSA areas. The central city (or cities) of population greater than 50,000 and the county in which it is located are defined. Then, in addition to the central county, contiguous counties of metropolitan character also are viewed as part of the SMSA [44].

United States for many years--that of the increasing scarcity and cost of fossil fuels. In meeting the energy crisis, new sources of energy are being developed (nuclear, solar) and traditional sources (coal, oil, natural gas) expanded, but one readily available, low-cost source in excess supply has largely been overlooked. That source of energy goes by many names --trash, refuse, garbage, solid waste--but by any name, it represents a potentially significant energy source. For example, the material lost each day by discarding solid wastes from residential, commercial, industrial, agricultural, and forestry operations in 1971 contained the energy value equivalent to 2.5 million barrels of oil [25]. One source has estimated that refuse-derived energy can supply up to 10 percent of total U.S. energy requirements [41].

Present methods of solid waste disposal are increasingly coming under criticism as health nuisances and environmental degraders. The traditional alternatives in waste disposal, particularly landfilling and incineration, contribute to a number of environmental problems. Incinerators release millions of tons of carbon monoxide, particulates, nitrogen oxides, sulfur oxide and hydrocarbons into the atmosphere each year [5]. Landfills may release leachate (a liquid pollutant) into streams and groundwater supplies, emit methane and carbon dioxide, provide breeding areas for insect and animal pests, and are susceptible to problems of spontaneous combustion. Many documented cases of pollution of drinking water sources (particularly wells) by landfill leachate have occurred, most of which result in the affected individual, municipality, or firm installing an expensive alternative source of water supply [47]. Air pollution from incinerators damages vegetation, corrodes structures, and creates respiratory health hazards to humans and animals [12,31].

In controlling health and environmental problems created by the traditional methods of waste disposal, officials must contend with increasingly higher disposal costs, public resistance to landfills, a lack of suitable landfill sites, and a shortage of fuel needed to operate incinerators. For many communities, an alternative to the current solid waste disposal practices is needed.

The term "resource recovery" may refer to any of a number of concepts, including recycling, reusing, or reprocessing. More specifically, resource recovery includes:

1) reusing objects in their original form, such as glass containers;

2) recovering materials from solid waste suitable for use as raw materials in the production of other goods, e.g., metals, paper, glass, etc.;

3) recovering materials which are not suitable for use as a raw material input but which may serve a secondary purpose, e.g., using crushed glass as a base for paving material;

4) reprocessing portions of the solid waste mass into new products, such as compost, or converting it into chemicals such as hydrochloric acid; or

5) converting solid waste into a solid or liquid fuel for the production of energy [32].

Energy recovery from solid waste has long been practiced in many European countries. Solid waste management systems in Germany, Holland, Denmark, France, and other nations use refuse principally as a fuel to produce steam, which is forced under pressure to drive electricity-generating turbines. By the end of 1975, Germany will serve 25 percent of its total population by burning their refuse in steam heat recovery systems. Until recently, however, the incentives which would enable energy recovery from waste in the United States did not exist. The energy crisis has provided the economic incentive by raising the relative price of traditional fossil fuels, and American manufacturers have responded to the technology gap by developing or adapting a wide variety of systems for refuse recovery. The six general energy recovery and/or processing methods that use solid waste include:

1) Burning refuse in steam-generating incinerators. This alternative produces steam used for heating or cooling buildings, industrial process use, or for powering electricity-generating turbines.

2) Burning refuse in heat exchangers. This process uses solid waste as a supplementary fuel (in addition to coal, oil, or natural gas) to produce steam for driving electricity turbines. This method is the primary focus of this analysis.

3) Pyrolysis. Pyrolyzing solid waste involves heating the refuse in the absence of oxygen to break down the material into oils, gases, and residue. Pyrolysis oil is quite suitable for use in oil-fired boilers.

4) Hydrogenation. This alternative converts refuse into an oil by heating it in the presence of carbon monoxide and steam under pressure.

5) Anaerobic Digestion. This process involves decomposition of organic material in solid waste in the absence of oxygen, thereby producing methane. Methane is now in use in several instances as a substitute for natural gas.

6) Cubing. Many systems exist which process and compact refuse into storable solid cubes which may be used as a supplementary fuel. Besides reducing volume, cubing facilitates storage and lowers transport costs because of its increased density [32].

Besides energy recovery, solid waste processing through shredding, air classification, magnetic separation, etc., enables the recovery of valuable materials found in refuse. Technology exists enabling the separation of ferrous metals, aluminum, other non-ferrous metals, glass, plastics and paper from refuse. However, the importance of energy recovery often supersedes materials recovery, e.g., Abert, et al. states that "resource recovery is economically viable provided the community has an electric utility which can utilize the organic fraction" [3]. A study by Midwest Research

Institute found that the capital investment requirements for fuel recovery were lower than for any other recovery process investigated. The study further concluded that "the fuel recovery concept has the most favorable overall economics of any investigated" [29].

The scale requirements normally associated with resource recovery are substantially reduced in those systems including the recovery of energy from refuse. Scale requirements are further reduced by the commercial availability of systems designed specifically for relatively small communities. For example, the resource recovery system in Ames, Iowa serves a county population of approximately 69,000. According to data from the National Coal Association and a national survey funded by the U.S. Environmental Protection Agency, there are more than 300 coal burning steam-electric generating plants similar to the Ames plant located in the nonmetropolitan areas of the United States.

Recent increases in the costs of conventional fossil fuels (coal, oil, natural gas) provide the greatest incentive for energy and materials recovery systems. Many indicators suggest a sizeable increase in future demand for coal resulting from the electric power industry's increasing reliance on coal and its derivatives. This demand is likely to be accentuated in those areas most susceptible to natural gas shortages, i.e., the Midwest, Northeast, and Mid-Atlantic states. Problems in nuclear power development, refinements in coal gasification technology, and projected absolute increases in energy demand all point to increasing demand for coal (with resultant price increases). Increases in the price of coal and other energy sources will make solid waste an increasingly attractive energy source.

In addition to solid waste, recent interest has focused on reusable biomass energy from grains, crop residues, forages, grasses, and forests. In the midwestern states (Corn Belt), corn stover and other crop residues seem to be a relatively promising biomass energy source. For example, research at the University of Minnesota estimates that the annual yield of crop residue in Minnesota is equivalent to 40 percent of the state's annual energy consumption [40].

Of the midwestern crops, biomass from corn seems most promising. Corn stover tonnage yield per acre is high, and it has the highest BTU value/lb. (6500 BTU/lb.) of the major crops grown in this area [30]. Buchele has argued that the farmer incurs considerable cost in chopping and disking the cornstalks before burying them with a mold-board plow [6]. At least part of these costs might be foregone if some part of the stover were removed for energy.

One promising alternative for converting corn stover to energy involves mixing the stover (singly or in combination with combustible solid waste) with coal in existing steam-electric plants to generate electricity. In addition to the direct substitution of corn stover for coal, stover and other crop residues, like solid waste, could potentially reduce sulfur emissions to acceptable levels. Much of the coal in the Midwestern or North Central Region has more than three pounds of sulfur per million BTUs of heat and must be mixed with relatively expensive low-sulfur Western coals to meet emissions standards set by the U.S. Environmental Protection Agency [13]. In fact, Dugan states that 62 percent of the high sulfur coal reserves in the United States are found east of the Mississippi River where 90 percent of the coal-fired electric power generation occurs [13].

Resource Recovery in the North Central States

Materials recovery is actively being practiced in Franklin, Ohio, which operates a $3.2 million plant that wet processes approximately 50 tons of refuse per day. The plant, financed largely by the Federal Environmental Protection Agency, recovers paper fibers, ferrous and aluminum metals, and color-sorted glass. Its net operating costs of $6 per ton of refuse processed make the system marginally competitive with a well-managed landfill operation.

The first major pilot plant to utilize refuse as a supplementary fuel in electricity generation was the Union Electric Company Meramec Station, located near St. Louis, Missouri. Two boilers in this plant were modified to burn refuse as a supplement to coal by injecting refuse into combustion chambers. With refuse supplying 10 percent of the heat requirement, each boiler burned approximately 12.5 tons of refuse and 50 tons of coal per hour. Solid waste burned in the Meramec plant was shredded in St. Louis, transported to the electric plant by transfer trailers, and deposited into a city-owned storage facility. From there, the waste was transferred by pneumatic conveyor to a storage bin owned by Union Electric and fed into the corners of the boiler furnaces. The refuse was supplied to the utility by the city free of charge. Union Electric decided against continuing and expanding this three-year pilot project because of other corporate financial commitments and local resistance to the siting of a waste transfer station that was necessary for expansion.

A municipal energy/materials recovery system has been in operation at Ames, Iowa, since September 1975. The processing or separation facility receives about 150 tons per day or 55,000 tons annually of solid waste from the city of Ames and Story County which has a total population of about

69,000. Ferrous metal and aluminum are separated and sold, and the solid waste combustible portion is mixed with coal to fire the utility boilers. An earlier test found the processing and combustion of corn stover with solid waste and coal to be technically feasible [6].

Currently in the "shake down" phase are new solid waste resource recovery plants in Milwaukee and Chicago. Detroit and St. Paul are in the planning stage and construction has started on a new municipal resource recovery system in Akron, Ohio. The Akron plant will initially recover ferrous metals and eventually glass and other metals. The combustible portion of the waste stream will be used to generate steam for downtown buildings. A preliminary feasibility study of a nonmetropolitan situation has been completed for the Orrville, Ohio, Municipal Power Plant and surrounding Wayne County [28].

I. POWER PLANT AND WASTESHED INVENTORY

Steam-Electric Plant Inventory

Data collection

Steam-electric plants were chosen as the primary focus for solid waste energy recovery in the North Central States due to the availability of data on boiler type and capacity and the proven technical feasibility of modifying them for combustion of waste. Even greater potential appears to exist with the larger number of industrial boilers. However, it was not possible to secure type and capacity information on these boilers from secondary sources, even after a lengthy appeal via the Freedom of Information Act. Conclusions regarding solid waste energy recovery in steam-electric plant boilers should be generally applicable to comparable industrial boilers.

Secondary data on current North Central Region steam-electric generating plant type, size, location, conformation with sulfur emission standards, coal sources and coal prices were secured from the National Coal Association (NCA) [43] and from Federal Power Commission (FPC) sources [7,42,48]. Further discussions with staff members of the NCA revealed the existence of a few additional steam-electric plants that had either been constructed since the most recent published data or for some reason had not filed complete reports with FPC and NCA. A total of 372 steam-electric plants were identified from these combined sources for the 12 North Central States. However, 130 of these plants were classified as standby, retired, nuclear, or gas and oil. Discussions with a consulting engineer, Gordon Smith, suggested that nuclear plants are not feasible for burning refuse and that plants capable of burning exclusively gas or oil could be converted to burning refuse only by major plant modification, including the installation of new boilers.

Table 1 summarizes the distribution of steam-electric plants by type, state, and SMSA, non-SMSA location within each of the 12 North Central States and Appendix D shows their location. Eighty-six of the operating coal burning steam-electric plants (35 percent) are located in non-SMSA counties in the North Central States. Minnesota and Iowa are the leading states with 17 and 13 non-SMSA coal burning plants, respectively.

The foregoing secondary sources of information proved inadequate for making reliable estimates of coal burning steam-electric plants' capacity for burning refuse. For plants over 25 megawatts of installed generating capacity, it was possible to secure the additional data from the files of the Federal Power Commission in Washington, D.C. No such information existed for plants under 25 megawatts.

Table 1. Distribution of steam-electric generating plants in the North Central Region

State	1970 population	Number plants		1970 population of non-SMSA counties with plants	Number operating coal plants non-SMSA counties[b]	Percent operating coal plants non-SMSA counties
		Total[a]	Operating[b] coal			
Illinois	11,113,976	40	27	548,687	9	22
Indiana	5,193,669	32	25	527,351	2	8
Iowa	2,824,376	38	31	725,784	13	42
Kansas	2,246,578	37	7	111,026	1	14
Michigan	8,875,083	39	32	564,817	8	25
Minnesota	3,804,971	44	27	679,308	17	63
Missouri	9,676,501	28	17	262,244	7	41
Nebraska	1,483,493	19	7	44,876	3	43
N. Dakota	617,761	12	8	235,598	8	100
Ohio	10,652,071	47	39	693,454	8	20
S. Dakota	665,507	7	4	160,181	3	75
Wisconsin	4,417,731	29	18	648,684	7	39
TOTALS	61,571,717	372	242	5,202,010	86	35

SOURCES: [44] and primary data collection

[a] Includes all operating, standby, retired, nuclear, coal, gas, and oil plants

[b] Includes only operating plants with full or partial coal burning capacity

Accordingly, a mail survey attempted to secure the necessary data on the less than 25 megawatt plants. A questionnaire (see Appendix A) was mailed to the appropriate authority at each of the 75 plants of less than 25 megawatts. Follow-up by both mail and telephone resulted in 75 usable questionnaires or a response level of 100 percent. A method (discussed later) was then developed to estimate the refuse derived fuel (RDF) capacity of each of the coal burning steam-electric plants in the North Central states.

Coal sources, sulfur emissions, and prices

In addition to the availability of a steam-electric plant capable of burning refuse, economic feasibility of solid waste energy recovery depends on coal price and sulfur content. The coal price, in turn, is heavily influenced by transportation costs and heat value per ton. High sulfur content presents serious air emission problems unless costly preventative measures (e.g., stack scrubbers, blending with low sulfur coal, etc.) are taken. Combustible refuse (both solid waste and corn stover) is a substitute for coal and can reduce sulfur emissions because of its relatively low sulfur content. Thus, relatively higher coal prices and sulfur emissions problems favor economic feasibility of resource recovery.

Table 2 illustrates the origin and destination of 1976 coal deliveries to steam-electric plants in the North Central Region. All deliveries with the exception of anthracite and foreign imported coal are included. Five of the 12 North Central States (Michigan, Wisconsin, Minnesota, Nebraska, and South Dakota) import 100 percent of their steam-electric plant coal needs from other states. The major coal producing states ranked by percent

Table 2. Origin and destination of 1976 coal deliveries to steam-electric utilities in the North Central Region

N.C. Destination	Ala.	Md.	Colo.	Ill.	Ind.	Iowa	Kansas	Ky.	Mo.	Mont.
East N. Central										
Illinois	4.7		802.1	21436.5	347.9			1772.6		885.5
Indiana			10.0	3073.3	18915.8			4966.5		1264.0
Michigan				365.8	68.5			7100.9		1710.0
Ohio		18.6	275.3		16.6			8090.5		
Wisconsin				4129.9	949.4			1984.4		2419.9
Sub/Total	4.7	18.6	1087.4	29005.5	20298.2	--	--	23914.9	--	14249.4
West N. Central										
Iowa			230.8	2177.8		601.4		83.8	289.5	189.5
Kansas							1652.5		2.1	
Minnesota				1433.1				129.2		8161.6
Missouri			1.8	12518.6	242.0		665.1	534.0	3764.8	
Nebraska			211.9							
N. Dakota										
S. Dakota										
Sub/Total	--	--	444.5	16129.5	242.0	601.4	2317.4	747.0	4056.4	8351.1
Total N.C. Region	4.7	18.6	1531.9	45135.0	20540.2	601.4	2317.4	24661.9	4056.4	22600.5

Table 2. (continued)

N.C. Destination	N.D.	Ohio	Okla.	Penn.	Tenn.	Utah	Va.	W.Va.	Wyo.	Total deliveries
East N. Central										
Illinois					1.4			10.0	1560.3	34791.0
Indiana		14.7				30.8	120.3	118.0	1965.9	30479.3
Michigan		6982.9		601.9			43.5	4434.5		21308.0
Ohio		31994.3		1054.5	12.6	863.4	407.1	5369.5	2010.7	50113.1
Wisconsin		68.1		605.7				21.5	970.0	11148.9
Sub/Total	--	39060.0	--	2262.1	14.0	894.2	570.9	9953.5	6506.9	147840.3
West N. Central										
Iowa			1.8						3132.9	6707.5
Kansas			605.5						1172.5	3432.4
Minnesota	686.6	7.7	3.3		18.9	61.5		0.9	1.8	10504.6
Missouri			1852.5						977.3	20556.1
Nebraska			12.5			4.3			1623.4	1852.1
N. Dakota	6884.9									6884.9
S. Dakota	2459.7		27.0						192.3	2679.0
Sub/Total	10031.2	7.7	2502.6	--	18.9	65.8	--	0.9	7100.2	52616.6
Total N.C. Region	10031.2	39067.7	2502.6	2262.1	32.9	960.0	570.9	9954.4	13607.1	200456.9

SOURCE: [7]

of total coal produced for steam-electric generation are: Illinois (22.5%), Ohio (19.5%), Kentucky (12.3%), Montana (11.3%), Indiana (10.2%), Wyoming (6.8%), North Dakota (5.0%), and West Virginia (5.0%).

Table 3 shows the percent conformation to 1976 sulfur emission regulations of 1976 coal deliveries to steam-electric plants in the North Central Region. Conformation data are presented for both before and after blending of the various coal deliveries. The most important finding is the significantly lower levels of conformation in the East vs. West North Central States. Even after blending, only 55.9 percent of the coal burned in the five East North Central states complies with EPA sulfur emission standards. The comparable figure for the seven West North Central States is 85.3 percent.

Table 3. Conformation to 1976 sulfur emission regulations of 1976 coal deliveries to steam-electric plants in the North Central Region

Sub-region/ state	Total deliveries Tons(000)	Conformation before blending		Conformation after blending	
		Tons(000)	Percentage	Tons(000)	Percentage
East N. Central					
Illinois	36,791.0	15,480.7	44.50	19,143.0	55.02
Indiana	30,479.3	15,378.7	50.46	15,521.9	50.93
Michigan	21,307.9	6,880.1	32.29	8,651.2	40.60
Ohio	39,112.3	19,829.6	39.57	25,684.2	51.25
Wisconsin	11,148.9	8,606.5	77.20	8,606.5	77.20
Sub/Total	138,839.4	66,175.6	47.66	77,606.8	55.90
West N. Central					
Iowa	6,707.4	5,030.3	75.00	6,230.9	92.90
Kansas	3,632.3	1,471.6	42.88	1,538.1	44.81
Minnesota	10,504.5	8,937.9	85.09	9,798.6	93.28
Missouri	20,556.2	15,678.3	76.27	16,076.1	78.21
Nebraska	1,852.2	1,843.4	99.52	1,852.2	100.00
N. Dakota	6,884.9	6,884.9	100.00	6,884.2	100.00
S. Dakota	2,679.0	2,559.4	95.54	2,655.1	99.11
Sub/Total	52,816.5	42,405.8	80.29	45,035.2	85.27
N.C. Region Total	191,555.9	108,581.4	56.68	122,642.0	64.02

SOURCE: [7]

This finding is consistent with the fact that Western vs. Eastern coal generally is lower in sulfur content. A more important implication relates to any future prospect of strict enforcement of sulfur emission standards and the associated compliance costs. Any move in this direction would generally make compliance more costly for East vs. West North Central States. This is particularly true for Michigan, Ohio, Illinois, and Indiana. At the same time, the relative economic feasibility of resource recovery would increase most (other things being equal) in those states with the lowest levels of sulfur emissions compliance.[2]

Table 4 presents data on the average 1976 price for the coal delivered at steam-electric plants in the North Central States. Tonnage and price data are presented for both contract and spot purchases. The price variation between states is most striking in contract purchases ranging from a low of $3.84 per ton in North Dakota to $23.43 per ton in Michigan. On average, combined contract and spot purchases were at higher prices in the East than in the West North Central States.

Stricter enforcement of sulfur emissions would probably increase transport distances for additional purchases of lower sulfur Western coal by East North Central States, resulting in further increases in average coal prices for East North Central States. Again, the implication is that resource recovery from refuse would become relatively more promising in the East North Central States, particularly if emissions standards were met primarily by purchasing and blending more Western coal.

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[2] The current Carter proposal to require "best available technology," (i.e., stack scrubbers on all coal burning plants regardless of sulfur content of the coal) might remove most of this difference between East and West North Central States [16].

Table 4. Average delivered price of coal at steam-electric plants in the North Central Region, 1976

Sub-region/state	Contract purchases Tons (000)	Contract purchases Average price ($/T)	Spot purchases Tons (000)	Spot purchases Average price ($/T)
East N. Central				
Illinois	30,672.2	17.06	4,118.9	19.75
Indiana	25,589.9	14.23	4,889.4	16.01
Michigan	18,201.6	23.43	3,106.4	27.45
Ohio	36,768.0	21.00	13,344.9	20.18
Wisconsin	10,722.9	18.79	426.1	26.03
Sub/Total	121,954.6	18.76	25,885.6	20.29
West N. Central				
Iowa	6,314.4	17.62	393.1	24.96
Kansas	2,806.7	13.73	625.6	21.45
Minnesota	10,291.9	12.11	212.6	17.43
Missouri	18,868.2	12.89	1,688.0	20.89
Nebraska	1,163.8	18.32	688.4	21.30
N. Dakota	6,884.9	3.84	0.0	0.00
S. Dakota	2,642.0	6.45	37.0	24.90
Sub/Total	48,971.9	11.89	3,644.7	21.34
N.C. Region Total	170,926.5	16.79	29,530.4	20.42

SOURCE: [7]

Methods for estimating RDF capacity

Two estimates for the amount of refuse derived fuel (RDF) a steam-electric power plant is capable of burning were developed. These estimates of RDF capacity depend on the physical characteristics of the plant, the demand for power from the plant, and the heating value of the RDF.

To burn RDF, a plant must have boilers equipped to handle ash--both bottom ash and fly ash. All boilers designed to burn coal have ash handling equipment. Although many coal burning boilers have been retrofitted to burn oil or gas,[3] the ash handling equipment is still operational

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[3] Approximately 18 percent of the steam-electric plant boilers in the North Central states currently listed as gas or oil have been retrofitted from coal burning status [43].

in most cases [10, p. 95]. For this report, it has been assumed that any boiler capable of burning coal, with the exception of cyclone fired boilers, is capable of burning RDF. Stoker and suspension fired (pulverized coal) boilers are the two basic types of coal boilers that are capable of using RDF as a supplementary fuel.

The RDF capacity of a power plant depends heavily on the proportion of its boilers' heat input requirements that may be supplied by RDF. The greater the percentage of the heat input that can be replaced by RDF, the greater the amount of RDF that may be burned in the boiler. Operating experience indicates that the percentage of the heat input requirement that can be replaced by RDF varies according to the type of boiler. It also indicates that the RDF replacement percentage will vary from case to case within a particular type of boiler.

Two pulverized coal boilers at the Union Electric Company's Meramec Plant near St. Louis have used RDF to supply 10 percent of the total boiler heat input [27]. In Columbus, Ohio, RDF has been used to supply up to 30 percent of the heat input in a stoker fired boiler [2]. In Ames, Iowa, the supplemental use of RDF with coal has been in ratios as high as 50 percent by heat value on a spreader stoker type boiler and up to 20 percent on a pulverized coal boiler [19].

This evidence indicates that the only sure method of determining the maximum percent of the heat input that can be replaced by RDF for a particular boiler is to modify the boiler and operate it at varying levels of RDF heat input until a satisfactory situation is reached. For estimating the RDF capacities presented in this report, however, it has been assumed that the RDF replacement percentage is 20 percent for pulverized coal boilers and 50 percent for stoker fired boilers.

The efficiency of the electricity generating equipment in a power plant also effects its RDF capacity. As efficiency increases, the amount of heat necessary to produce a particular amount of electricity is reduced. This reduces the need for all fuel inputs including RDF. An increase in efficiency therefore results in a decrease in RDF capacity. The heat rate (the number of BTUs required to produce a kilowatt hour of electricity) is the common measure of steam-electric power generation efficiency. The heat rate will vary from generating unit to generating unit. In this report, the net plant heat rate has been used as a proxy for the efficiency of all the generating units within a plant.

The generating capacity of a power plant will also have an effect on its RDF capacity. As plant generating capacity increases, its potential RDF capacity increases. The actual RDF capacity will increase if the increased generating capacity is utilized. Generating capacity is normally measured in kilowatts (KW) or megawatts (MW).

The demand for electricity generation placed on a power plant also effects the RDF capacity. As the demand on a plant increases more heat is required, thus increasing the amount of RDF that can be burned. Electricity generation is measured in kilowatt hours. In this report, net generation is used as the measure of plant output.

A measure that takes generating capacity and electricity demand into account to reflect the degree that generating capacity is being utilized is the load factor. The load factor is the percentage of maximum output that has been realized. As the load factor increases for any particular boiler, its RDF capacity will also increase. In this report net generation and the boiler's associated turbo-generating capacity have been used to determine the load factor of a boiler.

The heating value of RDF also has a significant effect on RDF capacity. As the heating value of RDF increases, the quantity of RDF necessary to provide a certain percentage of total heat input decreases, thus reducing RDF capacity. Heating values of RDF have been variable, depending primarily on moisture content [27]. As the moisture content increases, the heating value of RDF decreases. The RDF separation process also influences the RDF heating values and can be adjusted to produce varying qualities and quantities of RDF from raw solid waste [2]. A generally accepted average heating value for RDF is 5,000 BTUs per pound [27]. This value has been used in this report in the estimation of RDF capacities.

Two considerations that must be taken into account when burning RDF are the amount of heat in the RDF that will be released in the boiler and the effect RDF may have on boiler efficiency or power-producing capability. The characteristics of the RDF and the boiler will determine the proportion of the RDF heating value that is released and made available for steam production. It is possible that the heat released will be less than the total in the RDF [2]. The boiler's efficiency or power producing capability when firing solid waste with coal is reduced slightly compared to "coal only" performance [46]. In this report it has been assumed that the entire heating value of the RDF is released in the boiler and that the use of RDF has no impact on boiler performance.

The ability of a power plant to meet air emissions requirements while burning RDF is another important factor effecting its RDF capacity. Federal and local air pollution control agencies have established regulations limiting levels of SO_2, NO_x, and particulate matter from utility boilers. United States EPA regulations titled "New Source Performance Standards"

(NSPS) apply to all boilers constructed after August 17, 1971, and to boilers modified in certain ways that existed prior to that date. Local standards apply to all other boilers. In 1974 the U.S. EPA decided that the modification of a boiler to burn RDF does not alter its applicable standard. Boilers constructed prior to August 17, 1971, will continue to be controlled by local standards and those constructed after that date will operate under U.S. EPA NSP standards that are currently being developed for "new" boilers modified to burn RDF.

Sulfur emissions regulations do not appear to be a constraint on the amount of RDF a power plant can burn. The sulfur content of RDF is approximately 0.16 percent by weight or .32 per million BTU [2]. This is relatively low compared to the residual oil and coal burned today with sulfur content ranging from one to three percent by weight and .83 to 2.5 pounds per million BTU [2].[4] Burning RDF will reduce the sulfur emissions from most boilers. The nitrogen oxide emissions should be lower when RDF is used as a supplemental fuel because of a lower combustion temperature than when coal is burned alone. Particulate emissions appear to be essentially the same for combined RDF and coal firing vs. coal firing alone [27]. Because of the relatively positive impact of combined RDF and coal firing on air emissions, it has been assumed that plant air emission regulations have no effect on plant RDF capacity.

Two estimates of power plant RDF capacity in tons per day for 1974 are presented in this report. One estimate reflects the amount of RDF a plant would be able to utilize if RDF capacity were based on current coal

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[4] This assumes an RDF heating content of 5,000 BTUs per pound and coal heating value of 12,000 BTUs per pound.

consumption. For this estimate, the 1974 plant consumption pattern of coal is used. The other estimate determines the maximum RDF capacity that could be achieved within a power plant. In this estimate it has been assumed that those boilers capable of firing coal will be used to produce as much of the 1974 total plant output as possible. It was further assumed that those boilers capable of firing the highest percent of RDF would be converted first and that they could be operated at a maximum load factor of 95 percent. Shifts in fossil fuel consumption patterns were accomodated in this method.

Illustrative estimates of RDF capacity

In the following example a hypothetical situation is developed for explanatory purposes. Both estimates will be determined on a step-by-step basis so the reader is fully aware of the procedures that were followed in the estimation process.

Considered in this example is a 100 MW steam-electric power plant that has a 25 MW stoker fired boiler, a 25 MW pulverized coal fired boiler, a 25 MW cyclone fired boiler, and a 25 MW gas and oil fired boiler that is not capable of burning coal. The plant produces 600 million kilowatt hours of electricity per year with a plant heat rate of 11,000 BTUs per kilowatt hour. Fossil fuel consumption is 132,000 tons of BTUs per pound coal, 261,904 barrels of 150,000 BTUs per gallon oil, and 2,300 million cubic feet of 1,000 BTUs per cubic foot gas.

To estimate the tons of RDF that could be utilized in a power plant if only coal were replaced by RDF, the tons of coal consumed per day is converted into equivalent tons of RDF and multiplied times the percentage of RDF that may be used to replace coal in the plant's boilers.

$$\frac{\text{Tons of Coal}}{\text{Year}} \times \frac{\text{BTU}}{\text{lb. of coal}} \times \frac{\text{2000 lbs.}}{\text{Tons}} \times \frac{\text{lbs. of RDF}}{\text{BTU}} \times \frac{\text{Ton}}{\text{2000 lbs.}}$$

$$\times \frac{\text{Year}}{\text{365 days}} \times \frac{\text{replacement}}{\text{percentage}} = \text{Tons of RDF per day}$$

In a situation such as this where the plant is equipped with more than one type of boiler, a "weighted" replacement percentage is computed. This "weighted" replacement percentage is used because the fuel distribution patterns among the boilers was unknown. This percentage is calculated in the following manner:

S = generating capacity of stoker units

P = generating capacity of pulverized coal units

C = generating capacity of cyclone units

T = S + P + C (total generating capacity of coal units)

$$\text{"weighted" replacement percentage} = (\tfrac{S}{T} \times 0.5) + (\tfrac{P}{T} \times 0.2) + (\tfrac{C}{T} \times 0.0)$$

In this case, the weighted replacement percentage equals:

$$\left(\frac{25\text{MW}}{75\text{MW}} \times 0.5\right) + \left(\frac{25\text{MW}}{75\text{MW}} \times 0.2\right) + \left(\frac{25\text{MW}}{75\text{MW}} \times 0.0\right) = .234 \times 100 = 23.4 \text{ percent}$$

The RDF capacity based on current coal burning replacement equals:

$$\frac{\text{132,000 Tons}}{\text{Year}} \times \frac{\text{10,000 BTUs}}{\text{lb.}} \times \frac{\text{2,000 lbs.}}{\text{Ton}} \times \frac{\text{lb. of RDF}}{\text{5,000 BTU}} \times \frac{\text{Ton}}{\text{2,000 lbs.}}$$

$$\times \frac{\text{1 year}}{\text{365 days}} \times .234 = 169 \text{ Tons of RDF per day.}$$

To determine the maximum amount of RDF a plant could expect to burn per day, another equation was developed that incorporates the plant demand, efficiency, and boiler characteristics. This equation was applied to each type of boiler on the aforementioned priority basis until the amount of electricity generated in 1974 was equaled. The general form of the equation is as follows:

$$\frac{\text{load}}{\text{factor}} \times \frac{\text{generating}}{\text{capacity}} \times \frac{\text{hours}}{\text{day}} \times \frac{\text{plant}}{\text{heat rate}} \times \frac{\text{lb. of refuse}}{\text{BTU}} \times \frac{\text{ton}}{\text{2,000 lb.}}$$

$$\times \frac{\text{RDF}}{\text{replacement}} = \text{tons of RDF per day.}$$

In this example, the first step is to determine the load factor that would be necessary of the plant output in the stoker boilers.

$$\begin{array}{c}\text{necessary load}\\ \text{factor}\end{array} = \frac{\text{net plant generation} \times 100}{\text{stoker boiler capacity} \times \text{hours per year}}$$

$$= \frac{\text{600,000,000 kilowatt hours}}{\text{year}} \times \frac{1}{\text{25,000 kilowatts}} \times \frac{\text{year}}{\text{8,760 hours}} \times 100$$

$$= 274\%$$

This load factor is greater than the 95 percent maximum which will be applied to determine the amount of RDF that may be burned in one boiler. The remaining electricity must be produced in the other boilers. The RDF capacity of the stoker boiler equals:

$$.95 \times \frac{\text{25,000 kilowatts}}{1} \times \frac{\text{24 hours}}{\text{day}} \times \frac{\text{11,000 BTU}}{\text{kilowatt hour}} \times \frac{\text{lb. of RDF}}{\text{5,000 BTUs}}$$

$$\times \frac{\text{Ton}}{\text{2,000 lbs.}} \times .5 = \text{313 tons of RDF per day}$$

The amount of electricity that must be produced in the remaining boilers is the plant net generation minus the amount produced in the stoker boiler.

$$\text{600,000,000 kilowatt hours} - [.95(\text{25,000 kilowatts} \times \text{8760 hours})]$$

$$= \text{391,950,000 kilowatt hours}$$

The load factor that would be necessary to produce the remaining electricity in the pulverized coal boiler is 188 percent which is again larger than the 95 percent maximum. The 95 percent load factor is used in calculating the RDF that may be burned in the pulverized coal boiler which is 125 tons per day. The remaining electricity, 183,900,000 kilowatt hours, must be produced in the cyclone and/or gas and oil boilers. Since RDF cannot be burned in these boilers, the plant RDF capacity is the summation of the amount of RDF consumed in the stoker and pulverized coal boilers, 438 tons per day.

These estimates are based on the assumptions that have been made. Their accuracy will vary from case to case depending on the accuracy of the information used and other factors not considered: legal and economic considerations, technological factors such as size and age of boiler, and the efficiency of its associated turbo-generating equipment. For example, engineering studies for the Vine Street power plant in Orrville, Ohio, have reported that the conversion of newer pulverized coal boilers to fire RDF would be preferable to conversion of older and smaller stoker fired boilers. This would result in a lower RDF capcity than that calculated using the foregoing methods.

RDF capacity in the North Central States

The foregoing methods were applied to each of the North Central Region's 242 steam-electric plants with coal burning capacity. The results are presented in Appendix B and show a total maximum RDF capacity for the region of 213,104.20 tons per day.[5] Thirty-nine percent of the coal

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[5] At 5,000 BTUs per pound of RDF, this represents a maximum RDF capacity of 426.2 million BTUs per day.

burning steam-electric plants in the North Central States are publicly owned and 61 percent are privately owned. The total coal burning capacity is composed of spreader-stoker boilers in 19 percent and pulverized coal boilers in 48 percent of the plants. The remaining 33 percent of the plants have a combination of these two boiler types.

Table 5 presents a frequency distribution of plant RDF capacity based on the two estimates of RDF capacity. Under the low estimate of RDF capacity based on current levels of electric generation from coal, 70 percent of the plants could burn 90 tons or more per day. Under the same estimate, 39 percent of the plants could burn over 400 tons/day of RDF. Under the high estimate of RDF capacity based on maximum levels of electric generation from coal, 83 percent of the plants could burn 90 tons or more per day. Previous work has suggested 100 tons of RDF per day as a minimum quantity for consideration of plant conversion for solid waste resource recovery [28].

Table 5. Frequency distribution of coal burning steam-electric plants in North Central Region by RDF capacity

Class interval plant RDF capacity tons/day	Current coal RDF capacity		Max. coal RDF capacity	
	No.	Percentage	No.	Percentage
0-30	44	18	21	9
31-90	29	12	18	8
91-150	27	11	29	12
151-210	17	7	21	8
211-270	16	7	22	9
271-399	14	6	21	8
Over 400	95	39	111	46

With RDF plant capacity estimates completed, the next step involved determining how much refuse was available to meet the individual plant RDF capacities. Because of the complexity and time involved in attempting to develop refuse generation estimates for the "wastesheds" surrounding each of the 242 coal burning plants, a sampling method was developed. The nature of the refuse generation method is described in the following sections.

Refuse Generation Estimates

Definition of wastesheds

Definition of "wastesheds" for resource recovery purposes at existing coal burning steam-electric plants in the North Central Region proved difficult. Problems arose in both defining boundaries and in handling overlap situations. Previous research by Poling [35] utilized break-even point analysis to establish the boundaries of various solid wastesheds within and adjacent to Wayne County, Ohio. This earlier work found a standard 20 cubic yard packer garbage truck economically feasible for one way distances up to approximately 12 miles. For hauls greater than 12 miles, it was more efficient to utilize some type of compaction/transfer station and a larger (than 20 cu. yd.) packer trailer for transport of the solid waste. The destination was a proposed resource recovery facility at a coal burning steam-electric plant in Orrville, Ohio [35].

The break-even findings from Poling's work are limited to nonmetropolitan situations similar in solid waste density and distribution to Wayne County, Ohio. Ives developed an array of break-even point one-way mileage estimates for transporting various volumes of solid waste to a composting plant by a packer truck or transfer station/packer trailer option [23].

It was assumed that the waste was to be composted and the transport cost estimates are based on conditions in Clatsop and Tillamook Counties in Oregon. Converting the solid waste volumes to tons and extrapolating the mileage estimates gives the following bench marks of minimum break-even solid waste tonnage and one-way mileage to justify the transfer station option:

Miles	Cubic yards/year	tons/day
8	295,200	208.8
12	172,500	118.2
18	104,405	71.5
24	75,000	51.4
30	57,000	39.0
36	48,333	33.1

The work by Ives did not consider the location or cost of sanitary landfills to determine if composting was economically feasible regardless of transport option. In addition, the comparability of the Oregon conditions with the North Central Region is questionable. Accordingly, a decision was made to utilize the 12 miles estimate from Poling's work as a starting point in estimating wasteshed size. Three estimates were developed to approximate alternative wasteshed sizes in the North Central Region. The low size estimate assumed that the most commonly utilized 20 cubic yard packer trucks could be used to haul solid waste to each coal burning steam-electric plant from a radius of 12 miles. The high size estimate assumed that the same type packer trucks could also haul solid waste from a 12 mile radius to transfer stations installed in outlying areas, expanding the total wasteshed radius to 36 miles. The medium size estimate represented a 24 mile radius wasteshed which could represent larger packer trucks and/or some transfer station options.

For metropolitan wastesheds, the wasteshed area was assumed equal to the area of the SMSA plus any nonmetropolitan areas that fell within a 12 mile radius.[6]

Given these alternative definitions of wasteshed size, the 242 coal burning steam-electric plants in the 12 North Central States were located on detailed state maps and the 12, 24, and 36 mile radius wastesheds superimposed. Considerable overlap of single plant wastesheds emerged, even with the 12 mile radius wasteshed definition. One of the approaches considered for resolving this overlap problem involved ranking the plants within a multiple plant overlap wasteshed situation on their energy recovery potential. However, this approach would have required on scene data collection and cost analysis beyond the scope of this research.

Accordingly, a decision was made to count the total area of any overlapping wastesheds as a single wasteshed with multiple plants. For example, under the 12 mile radius definition a total of 137 wastesheds (containing 242 coal burning steam-electric plants) were identified in the 12 North Central States. Ninety-two of these wastesheds were single plant and the remainder multiple plant wastesheds. Of the multiple plant wastesheds, 21 contained two plants, 14 contained three plants, 6 contained four plants, 2 contained five plants, 2 contained six plants, 1 contained eight plants, and 1 contained twelve plants. (Detailed state maps showing the location and configuration of each of the watesheds are available upon request from the authors. See page 113.)

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[6] Precise estimates of an economically feasible wasteshed for each of the 242 steam-electric plants were not possible but detailed estimates are developed for the two case studies in Part II.

Wasteshed generation and sampling

The next task was to determine potential solid waste generation within the defined wastesheds. Several approaches, excluding primary data collection, were considered to make any estimates as accurate as possible. However, most of the methods required data which were not available in secondary form at the level of disaggregation desired. Previous analysis of solid waste generation in Wayne County, Ohio, found 51 percent of the solid waste from industrial sources, 35 percent from residential sources and 14 percent from commercial sources. In addition, waste generation varied considerably among various types of industries. Per capita solid waste generation in Wayne County totaled slightly over six pounds per person per day [35].

Comparisons with selected other counties in the North Central Region suggested that Wayne County was slightly more industrialized than comparable counties around the region. In addition, solid waste generation estimates secured from other studies for 21 Indiana counties [9] and five Minnesota nonmetropolitan counties averaged about five pounds per person per day [15]. Thus, a decision was made to use a solid waste generation coefficient of five pounds per capita per day for estimating a medium level of solid waste generation in the wastesheds in question.[7] Based on resource recovery experience to date (particularly in Ames, Iowa), it was further assumed that 80 percent of raw solid waste is combustible

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[7] This is meant to serve as an approximation. Sensitivity analysis is done assuming per capita generation of three and seven pounds. In addition, detailed waste generation estimates are developed for the two case studies in Part II.

[18, 28]. Township population estimates (1973 or 1970) were aggregated to approximate the area and population base of the 12, 24, and 36 mile radius wastesheds [44].

Given these assumptions and data it was possible to estimate the total waste generation within each given wasteshed. A hypothetical example of the generation estimation is as follows:

Given: The sum of the townships' population in 12 mile wasteshed = 50,000

The coefficient for solid waste generation (adjusted) = .0025 T/Day

The correction for RDF (80% of total solid waste generated) = .8

Then: 50,000 x .0025 x .8 = 100 tons/day for 12 mile radius watershed

In this example, the 12 mile radius wasteshed generates 100 tons of refuse derived fuel per day for the given electric generating power plant(s) to use. If this amount equals or exceeds plant capacity to burn RDF, estimates are not necessary for 24 or 36 mile radius wastesheds.

In spite of the simplified per capita solid waste generation method, the township aggregation procedure was sufficiently time consuming to make sampling necessary. The 137 wastesheds were numbered and a random number table used to select 25 wastesheds. The 25 sample wastesheds summarized in Table 6 contain 53 coal burning steam-electric plants. Solid waste generation estimates were then developed for each of the 25 wastesheds using the foregoing methods.

The availability of county data on corn stover residue developed by Stanford Research Institute [39] and the evolution of an exploratory parallel study on corn stover [1] made it possible and desirable to develop estimates of corn stover generation for each of the 25 sample wastesheds.

Table 6. Distribution of wasteshed sample by plant, state, and metropolitan vs. nonmetropolitan area

Wasteshed #	Wastesheds		Coal burning steam-electric plants		
	Metro	Non-metro	Tot. No.	No. metro	No. non-metro
IL 10		1	1		1
15		1	1		1
IN 17		1	1		1
20	1		1	1	
IA 37	1		3	3	
45		1	1		1
MI 55	1		4	4	
58		1	1		1
60		1	2		2
MN 66		1	3		3
68		1	1		1
MO 85		1	2		2
NE 92	1		4	4	
93		1	2		2
ND 96		1	1		1
98		1	1		1
OH 102	1		5	5	
105	1		6	6	
107	1		2	2	
109		1	1		1
111	1		6	6	
115		1	1		1
SD 122	1		1	1	
WI 136		1	1		1
137		1	1		1
TOTALS	9	16	53	32	21

Corn stover may be a potential supplementary source of combustible refuse in those wastesheds with steam-electric plant RDF capacity greater than 100 tons per day and greater than the solid waste generation in the surrounding wasteshed. For wastesheds with steam-electric plant(s) RDF capacities less than 100 tons per day, corn stover may be a potential substitute combustible refuse for solid waste. This possibility is based on substantially lower processing costs anticipated for corn stover vs. solid waste. The latter is being analyzed in the earlier mentioned exploratory study [1].

The estimated amount of corn stover in each of the sample wastesheds is based on 1976 county data published by Stanford Research Institute [39]. These SRI data show the tons per year of corn stover residual available by U.S. county. For purposes of this analysis, the corn stover residual was assumed 65 percent available and evenly distributed over the land area of each county.[8] The procedure was as follows:

1. The area in square miles was calculated for each of the 12 and 24 mile radius sample wastesheds.[9]
2. The sample wasteshed area was then allocated among the counties covered in whole or part by the wasteshed.
3. The proportion (estimated from detailed maps) of each county's total land area covered by each sample wasteshed was then multiplied times the SRI estimated 1976 corn stover residual generation for that county and divided by 365 to convert to tons per day.[10]

Sample RDF Capacity and Generation Results

The final step in this inventory of steam-electric power plants and their accompanying wastesheds in the North Central States was to compare the RDF plant capacity and wasteshed generation estimates. As indicated earlier, the complexity of the estimation methodology necessitated a

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[8] The earlier mentioned explanatory study on corn stover used a variable removal rate based primarily on the slope of the land. The 65 percent refers to the portion of stover that can be effectively removed with existing equipment [1].

[9] The 36 mile radius wasteshed definition was considered unrealistic for the estimation of available corn stover in light of preliminary estimates of transport costs.

[10] If year-round storage proves problematic, the stover might supplement any reduction in the solid waste stream during the winter months.

sampling procedure. Estimates were developed for RDF plant capacity and wasteshed generation in the nine metropolitan and 16 nonmetropolitan sample wastesheds under alternative assumptions on RDF plant capacity and wasteshed size.

Other simplifying assumptions were found necessary to arrive at final estimates of solid waste and corn stover generation for the sample wastesheds. In the case of multiple plant overlap wastesheds, overlap areas were counted only once. Two of the sample metropolitan wastesheds (Nos. 37 and 102) did overlap adjacent nonmetropolitan wastesheds under the 12 mile definition. In both of these sample metropolitan cases, however, the SMSA areas generated sufficient RDF to supply the maximum coal based RDF capacity of all of the plants in each of the two SMSA areas. Accordingly, it was not necessary to speculate on the RDF generation of adjacent areas. For sample metropolitan wastesheds, the 12 mile radius estimate was applied only if it exceeded the boundary of the actual SMSA area.

Table 7 presents the estimates of sample metropolitan RDF plant (n=32) capacity and wasteshed (n=9) generation in tons per day. Five of the nine sample metropolitan wastesheds had combined solid waste and stover RDF generation in the SMSA greater than or equal to current coal based RDF plant capacity in the SMSA. In the remaining four sample wastesheds (Nos. 20, 55, 105, and 111), excess RDF plant capacity existed suggesting that in those cases opportunities may exist for adjucent nonmetropolitan areas to haul their refuse (solid waste or corn stover) to the SMSA for steam-electric plant based resource recovery. Counting only solid waste RDF generation and current coal capacity in the SMSA, six of the nine wastesheds had excess RDF plant capacity. Increasing the solid waste

Table 7. Estimates of sample metropolitan RDF plant (n=32) capacity and wasteshed (n=9) generation tons RDF/day

Wasteshed/ plant nos.	Current coal RDF cap.	Max coal RDF cap.	SMSA gen.		24 mile gen.		36 mile gen.
			S.W.	S.W. + C.S.	S.W.[a]	S.W. + C.S.[b]	solid waste
20/39	1433.6	1476.8	1101.5	1305.4	N.A.[c]	N.A.	N.A.
37/64	495.4	793.2	703.2	1777.5	N.A.	N.A.	N.A.
37/65	241.2	437.8 [d]					
37/66	84.0	158.6					
92/168	0.0	39.0	1147.3	1706.1	N.A.	N.A.	N.A.
92/169	943.8	1788.1					
92/170	215.9	380.2					
92/171	323.7	486.6					
102/184	1014.0	1093.3	4211.02	N.A.	N.A.	N.A.	N.A.
102/185	158.9	331.4					
102/186	1338.7	2180.6					
102/187	982.1	1047.5					
102/188	717.1	782.0					
107/200	395.8	397.8	1772.2	2165.1	N.A.	N.A.	N.A.
107/201	30.4	240.3					
122/223	106.5	150.0	207.1	246.6	N.A.	N.A.	N.A.
55/101	1959.7	1969.9	303.4	421.1	N.A.	N.A.	N.A.
55/102	2023.1	2043.1					
55/103	223.9	223.9					
55/104	155.5	187.2					

Table 7. (continued)

Wasteshed/ plant nos.	Current coal RDF cap.	Max coal RDF cap.	SMSA gen. S.W.	SMSA gen. S.W. + C.S.	24 mile gen. S.W.[a]	24 mile gen. S.W. + C.S.[b]	36 mile gen. solid waste
105/191	3479.4	3673.6	5379.5	5413.9	N.A.	N.A.	N.A.
105/192	3738.1	3738.1					
105/193	1683.8	1683.8					
105/194	163.8	169.3					
105/195	543.2	543.2					
105/196	283.0	283.0					
111/206	1739.4	1739.4	975.3	1946.9	N.A.	N.A.	N.A.
111/207	563.8	563.8					
111/208	6097.6	6097.6					
111/209	2975.3	2991.7					
111/210	716.9	723.9					
111/211	114.7	114.7					

[a] Total solid waste generation in 24 mile radius. Solid waste generation assumes five pounds per capita/day.

[b] Total solid waste and corn stover generation in 24 mile radius

[c] N.A. = Not applicable, i.e., excess wasteshed generation, or not within definitions

[d] Brackets refer to multiple plant or overlap wastesheds--brackets are used to designate that the generation estimates are for the total multiple plant wasteshed area.

generation coefficient from five to seven pounds per capita, reduced to three the number of sample metropolitan wastesheds with excess capacity.

A final determination of this potential will require a more detailed analysis of the excess capacity sample metropolitan wastesheds. This is particularly true in metropolitan wasteshed 105 which has an adjacent non-metropolitan wasteshed with its own coal-burning, steam-electric plant. The primary economic question is whether the size economies from converting a larger metropolitan vs. smaller nonmetropolitan plant to resource recovery offset the additional transport costs. Some additional light will be shed on this question in one of the two case study analyses in Part II. The important finding is that, depending on the solid waste generation and stover feasibility assumptions, from 33 to 67 percent of the metropolitan sample wastesheds have excess RDF steam-electric plant capacity that may offer opportunities for adjacent nonmetropolitan areas.

Table 8 presents the estimates of sample nonmetropolitan RDF plant (n=21) capacity and wasteshed (n=16) generation in tons per day. Because of lower population density, the nonmetropolitan RDF wasteshed generation estimates generally involved going beyond the 12 mile radius to secure sufficient refuse (solid waste and corn stover) to equal or exceed plant(s) capacity. As a result, several additional overlap situations were created. Double counting was avoided. However, it was still necessary to look at each situation and decide if it was realistic to consider even the nonoverlap solid waste and corn stover from a 24 mile radius or the solid waste from a 36 mile radius as part of total generation.

In a few cases, the 24 or 36 mile wasteshed definition involved sample wasteshed overlap with an outlying 12 mile wasteshed having its own

Table 8. Estimates of sample nonmetropolitan RDF plant (n=21) capcacity and wasteshed (n=16) generation, tons RDF/day

Wasteshed/ plant nos.	Current coal RDF cap.	Max coal RDF cap.	12 mile gen.		24 mile gen.		36 mile gen.
			S.W.	S.W. + C.S.	S.W.[a]	S.W. + C.S.[b]	S.W.
10/19	0	223.40	41.77	111.76	125.36	557.55	N.A.
15/28	67.0	114.0	115.3	261.0	N.A.[d]	N.A.	N.A.
17/30	3680.0	3680.0	87.07	120.35	408.73	606.29	511.25
45/78	496.30	496.30	41.86	160.96	181.26	836.17	N.A.
58/110	295.10	295.10	17.64	37.1	53.54	133.99	138.23
60/112	732.90	732.90	33.24	33.24	62.09	62.09	169.35
60/113	230.30	275.60					
66/123	0	206.90	75.43	536.94	N.A.	N.A.	N.A.
66/124	10.00	23.20					
66/125	66.30	263.80					
68/129	1614.00	1614.00	37.12	37.18	54.92	55.48	83.63
85/158	0.90	5.70	155.75	N.A.	245.27	N.A.	393.10
85/159	43.80	96.00					
93/172	13.60	38.2	29.84	409.50	N.A.	N.A.	N.A.
93/173	34.20	114.4					
96/176	1103.40	1103.40	86.84	86.87	95.06	95.17	N.A.
98/178	122.70	122.70	15.83	28.59	28.73	93.29	N.A.
109/204[c]	744.20	744.20	119.14	124.76	239.44	272.95	N.A.
115/216[c]	562.50	4053.90	61.21	70.51	305.84	328.49	N.A.
136/241	60.60	60.60	38.50	81.34	N.A.	N.A.	N.A.
137/242	550.30	550.30	18.65	47.63	70.95	216.97	304.55

[a] Total solid waste generation in 24 mile radius. Solid waste generation assumes five pounds per capita/day.

[b] Total solid waste and corn stover generation in 24 mile radius.

[c] Due to a complex overlap problem, wastesheds 109 and 115 are not independent. Only one of the two situations should be considered potentially feasible.

[d] N.A. = Not applicable, i.e., excess wasteshed generation

steam-electric plant. If the capacity of the outlying plant(s) was less than 100 tons RDF/day, it was determined nonfeasible for conversion and no problem existed. If the capacity exceeded 100 tons RDF/day, it was necessary to look at the RDF generation of the 12 mile radius outlying wasteshed. If its RDF generation capacity was equal to or greater than its plant RDF capacity, again no problem existed. If the outlying wasteshed had a deficit in RDF generation, it was necessary to make some judgement on whether the sample wasteshed or outlying wasteshed would be more likely to attract the refuse lying between them.

Given these qualifications, some tentative conclusions can be drawn from the results presented in Table 8. First, only five of the 21 sample nonmetropolitan steam-electric plants had a maximum coal based RDF capacity of less than 100 tons per day. Ten of the 21 sample plants had current coal based RDF capacity less than 100 tons per day. Thus, it would appear that between 52.4 and 76.2 percent of the nonmetropolitan coal burning steam-electric plants in the North Central States are capable of burning 100 tons or more of RDF per day.

On the generation side, the results are not as clear. Assuming solid waste generation at five pounds per capita, three of the 16 nonmetropolitan wastesheds generated in excess of 100 tons of solid waste RDF per day in a 12 mile radius. Adding corn stover residual under the 12 mile radius definition resulted in a total of eight of the 16 wastesheds exceeding 100 tons of RDF per day. With both solid waste and corn stover RDF included in a 24 mile radius, 12 of the 16 sample wastesheds exceeded 100 tons of RDF per day. Under the 24 mile radius definition for solid waste and stover, only six of the 16 wastesheds equaled or exceeded maximum coal based RDF plant capacity within the respective wastesheds, however.

Coal burning steam-electric plants need not convert their entire capacity to RDF for the concept to be feasible. Limited evidence suggests that 100 tons of RDF per day may be a minimal scale to justify conversion [28]. Accordingly, a plant may elect to convert only one or two of its boilers to RDF or may utilize a lower firing ratio of RDF to coal in its converted boilers.

Sensitivity analysis of solid waste generation was done by utilizing three and seven pounds per capita to make low and high estimates of solid waste generation. The two pound differential between low and medium and medium and high estimates represents one standard deviation from the mean solid waste generation value for the sample of 34 nonmetropolitan counties in the North Central Region discussed earlier. Using the three pound per capita coefficient, none of the sample nonmetropolitan 12 mile radius wastesheds exceeded 100 tons/day of solid waste RDF. Under the seven pound per capita coefficient, six of the 16 (37.5 percent) sample nonmetropolitan 12 mile radius wastesheds exceeded 100 tons/day of solid waste RDF. All six of these sample wastesheds also had plant RDF capacity greater than 100 tons/day.

These sample results suggest limited opportunity (none to 37.5 percent of sample wastesheds) for solid waste resource recovery in nonmetropolitan areas of the North Central States if it is assumed infeasible to utilize corn stover or transport the solid waste more than 12 miles. If either corn stover within a 12 mile radius or solid waste beyond a 12 mile radius are potentially feasible, resource recovery at existing steam-electric plants appears much more promising. Utilizing the five pound per capita generation coefficient, eight of the 16 sample wastesheds (50 percent) had both maximum RDF capacity and RDF generation greater than 100 tons per day assuming both solid waste and corn stover within a 12 mile radius. Assuming solid waste from a 24 mile and corn stover from a 12 mile radius results in 10 of the 16 (62.5 percent) sample wastesheds with both RDF plant capacity and RDF generation greater than 100 tons per day.

The case study analyses in Part II will facilitate further refinement of these tentative conclusions. Sensitivity analysis based on variation in key variables across the North Central Region and anticipated variation over time will be applied to the Ames, Iowa, and Orrville, Ohio, case studies.

II. BENEFIT-COST CASE STUDY AND SENSITIVITY ANALYSES

Research Methods

Selection of cases

The selection of the two steam-electric case plants was not random and was limited to two primarily because of resource constraints. The Ames, Iowa, plant was chosen because it is the first and only operational solid waste resource recovery plant in a nonmetropolitan area of the United States. A municipal energy/materials recovery system has been in operation at Ames since September 1975. The processing or separation facility (capacity of over 200 tons per 8 hour day) receives about 120 tons per day or 44,000 tons annually of solid waste from the city of Ames and Story County which has a total population of about 69,000. Opportunity appears to exist for cooperation with adjacent counties. Ferrous metal and aluminum are separated and sold and the solid waste combustible portion is mixed with coal in two spreader-stokers and one suspension fired utility boiler.

The North Central Region nonmetropolitan communities of Fairmont, Minnesota, Marquette, Michigan, and Orrville, Ohio, have done some preliminary analysis of resource recovery. They also appeared to approximate minimal (100 tons RDF/day) prerequisites on plant capacity and waste generation [22, p. 697]. An evaluation of these three potential case studies led to the selection of Orrville, Ohio, as the second case for this research.

Orrville is located in northeast Wayne County. It owns and operates a 75-megawatt municipal electric plant, a potential site for an energy and materials recovery system similar to that in Ames. Two of the four boilers at Orrville Municipal Power (OMP) are side-fired pulverized coal units of modern design capable (with minor modification) of burning refuse in combination with coal. Based on a 20:80 refuse-to-coal firing ratio generally recommended for boilers of this type, OMP could burn about 200 tons of RDF per day or the combustible portion from two-thirds of the solid waste now generated in Wayne County. Installation of a new spreader-stoker boiler would handle all of the county's solid waste.

The Orrville selection was based primarily on geographic location,[11] boiler configuration and firing ratios, waste generation and availability of reliable data. Regional variation in key feasibility determinants such as coal prices, waste generation and firing ratios not fully reflected in

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[11] Part I of this study demonstrates major differences between the West and East North Central States in coal production, coal prices, and sulfur emission compliance [7, pp. 11-14].

the two case studies, will be approximated with benefit-cost sensitivity analysis of the case studies. This methodology is discussed in the following section.

Benefit-cost model

A benefit-cost model was developed for the case study analyses primarily because of *a priori* evidence of technological external economies (or indirect benefits) associated with solid waste resource recovery. For example, landfilling of solid waste in the two case study areas (Ames, Iowa and Orrville, Ohio) was or is currently imposing technological external diseconomies (or indirect costs) through pollution of surface and underground water. In addition, sulfur stack emissions may be reduced by the burning of low sulfur combustible solid waste. Finally, *a priori* evidence suggests that the appropriate discount rate for solid waste resource recovery may not be some estimate of the market rate of interest [28].

Because of the considerable uncertainty regarding values for the discount rate and several other key parameters, sensitivity analysis is used to evaluate the two prototype resource recovery case studies. Low, medium ("most likely outcome"), and high estimates are made for key technical and economic parameters to determine their relative impacts on economic outcome. The direct economic benefits of resource recovery included in the analyses are the cost savings of reduced landfill activity, savings from reduced consumption of coal at the power plant, and net revenues from the sale of recovered ferrous metals. The Ames analysis also includes net revenues from the sale of aluminum, wood chips, and paper. Some attempts were made to get physical measures of the indirect benefits of decreased leachate induced water pollution due to reduced landfilling and reduced SO_2 air emissions resulting from the use of low sulfur RDF as fuel. Other indirect benefits such as reduced consumption of nonrenewable materials and of the resources required to produce and transport them are not estimated.

The direct costs for the two resource recovery cases include the initial capital outlay for the processing facility and the power plant conversion. Additional costs are the operating costs of the entire recovery facility, operating costs of small-scale landfills suitable to accomodate that waste not processed and/or the residuals material (bottom ash) from the power plant boilers, transport costs (including two transfer stations for the Ames plant) for refuse delivered to the processing facility, and transport costs for excess refuse and bottom ash taken to the small landfills.

Physical measures of reduced landfill leachates and power plant emissions were previously developed [28], but it was not possible to get reliable monetary estimates of any of the indirect benefits of solid waste resource recovery. However, there is no _a priori_ evidence of any significant indirect costs associated with the resource recovery process analyzed. Thus, omission of monetary measures of indirect benefits from the benefit-cost sensitivity analysis results _ceteris paribus_ in conservative estimates of the discounted present value of benefits estimated for the resource recovery prototypes.

The primary criteria used to evaluate the two cases are benefit-cost ratio and net benefits.[12] The benefit-cost ratio is generally appropriate for ranking projects under capital rationing. However, it does not provide information on changes in net worth. Determination of the benefit-cost ratio follows the pattern of Seneca and Taussig [22, p. 693].

$$B/C = \frac{\sum_{t=1}^{T} \frac{B_t}{(1 + i)^t}}{\left(\sum_{t=1}^{T} \frac{O_t}{(1 + i)^t}\right) + K},$$

where B_t is benefits resulting from the project in year t, O_t is recurring costs or operating and maintenance expenses incurred in year t, T is the time period over which benefits and costs occur, i is the discount rate, and K is capital outlay incurred in the initial year of the project.

The net benefit criterion provides another measure of the economic feasibility of a given investment and provides for determination of changes in net worth. In multi-project comparisons of varying scale, this criterion favors large-scale projects. The net benefit criterion is derived as follows:

$$\text{net benefits} = \left(\sum_{t=1}^{T} \frac{B_t}{(1 + i)^t}\right) - \left[\left(\sum_{t=1}^{T} \frac{O_t}{(1 + i)^t}\right) + K\right].$$

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[12] For comparative purposes, the internal rate of return and pay-out criteria also are included. Internal rate of return is that rate of discount that makes the discounted present value of net benefits equal to the value of the initial capital outlay. The pay-out period criterion measures the number of time periods (usually years) necessary to recoup the initial capital outlay.

Alternative (low, medium, and high) values are estimated for five technical and economic parameters judged crucial to the resource recovery prototype. The key technical parameter involved is the refuse-to-coal firing ratio utilized in the combustion process. This ratio determines how much refuse can be fired in the boilers, thereby dictating the processing capacity required in the recovery system. The primary economic parameters are the projected coal price levels, rate of discount, net ferrous revenue per ton of recovered metal scrap and alternative cost of landfilling. Size of wasteshed and initial capital investment tend to have technical as well as economic dimensions. Table 9 presents these parameters and the values developed to demonstrate the sensitivity of the system.

There is some supporting evidence for the parameter projections used (particularly for the medium values) from previous research, historical data, and consultation with authorities in the various areas. For example, firing ratios are based on the demonstrated capabilities of ongoing energy recovery facilities and engineering estimates. The annual coal price increases are based on analysis by the National Coal Association and historical data from Orrville Municipal Power, Ames Municipal Power and the Federal Power Commission [7,20,33,43]. The alternative discount rates are based on the Farmers Home Administration loan rate for solid waste projects, the rate of return on U.S. Treasury Bonds, and an opportunity cost for capital in the private sector.

The discount rate chosen is recognized to be crucial to the outcome of the analysis and indicates whether capital provided for any particular project yields as high an economic return as it would among alternative uses. The choice of a discount rate also involves social value judgements about

Table 9. Summary of low, medium, and high estimates for technical and economic parameters used in case studies

	Parameter projection estimate		
	Low	Medium	High
Refuse to coal-firing ratios			
a. Suspension fired	Varied to maximum of 20:80		
b. Spreader-stoker	Varied to maximum of 50:50		
Annual coal price increase			
a. 1976-80	7	12.5	18
b. 1981-95	4	7	10
Discount rate (%)	5	9	13
Initial investment ($000)			
a. Ames			
Story County (actual)	NA	5,968	NA
Three counties (estimated)	NA	6,593	NA
b. Orrville estimates			
Revised Luttner prototype	4,996	5,878	6,759
New boiler (incremental K)	5,134	6,040	6,946
New boiler (full K)	10,194	11,993	13,792
Net ferrous revenue/ton ($)			
a. Ames	12	18	24
b. Orrville	15	22	29
Alternative cost of landfilling (Ames-$/ton)	4	8	12
Size of wasteshed (Ames)			
a. Number of counties	1	2	3
b. Tons/day 1976	122.6	156.9-193.0	227.3
Sulfur content of RDF (Ames)	NA	.16	.43

benefits and costs that may accrue to future generations. To minimize subjective argument concerning the validity of using a particular rate of discount, three rates are utilized in the analysis--5, 9, and 13 percent.

The Ames estimates for initial investment are based on the actual capital outlay for the Ames processing facility and power plant modifications. The transfer station capital outlays for Boone and Marshall counties are based on personal interviews and previous analysis in Ohio

[8,14,34,35]. The medium estimates for capital outlay on the revised Luttner prototype (Orrville, Ohio) and new spreader-stoker boiler were developed by a consulting engineer and include input from the capital costs at the Ames plant. Low and high values are determined by subtracting and adding a 15 percent contingency allowance to the medium estimates. The 15 percent contingency allowance appeared adequate given the availability of actual capital outlay for the Ames case.[13]

The medium net ferrous revenues for the Ames case are based on actual operating experience during 1976-77. The medium net ferrous estimate for the Orrville case is based on analysis done by the National Center for Resource Recovery [32] and by consultation with agency and consulting firm staff members in Ohio [37,38]. Both estimates are net of transport costs. The low and high estimates are derived by subtracting and adding 33-1/3 percent to the medium estimate. The latter contingency allowance is based on limited evidence on past ferrous metal price fluctuations.[14] The medium estimate for the alternative cost of landfilling in the Ames case is based on actual data secured from landfill operators in Boone and Marshall counties. The low and high estimates are based on discussions with several North Central Region local government officials and state agency staff members and are meant to represent the range in landfill costs that exist in the Region. The one, two, and three county estimates of watersheds size for the Ames case provide an empirical estimate of the

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[13] Sensitivity analysis of operating costs seemed unnecessary with the availability of actual operating data from Ames.

[14] Earlier work by Luttner found ferrous metal prices to be the least significant of the parameters evaluated [28]. For this reason, less effort was expended in establishing the low and high values.

trade-offs between resource recovery plant scale economies and transport costs. The three county wasteshed utilizes the full capacity of the resource recovery plant.

The Ames Case

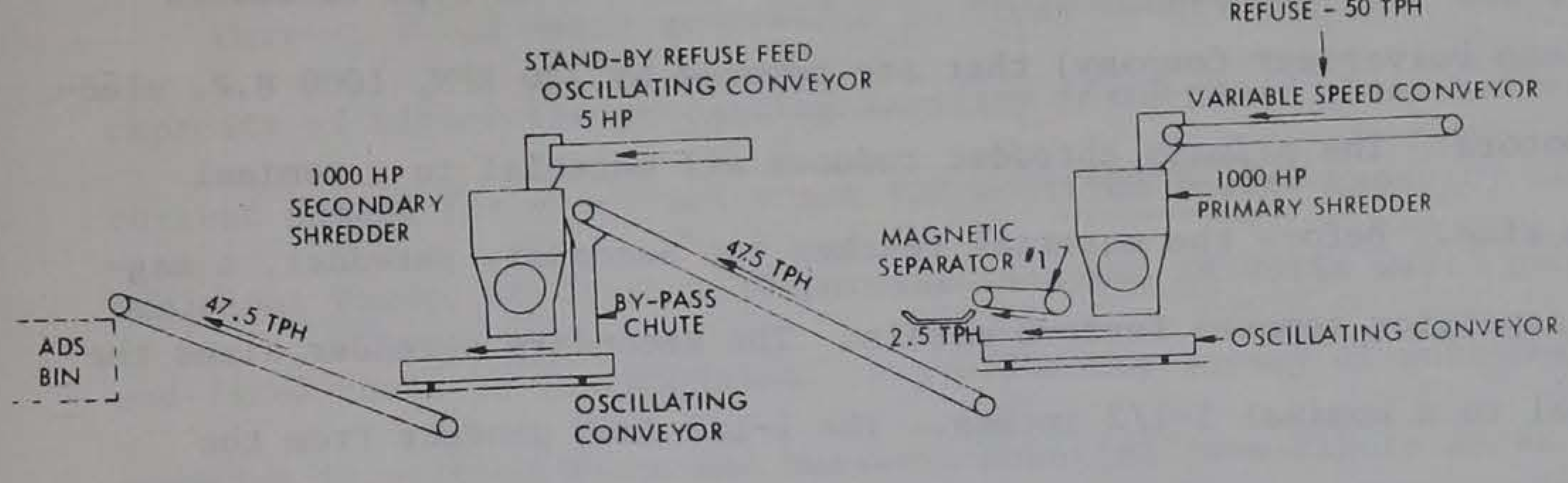
Introduction

The city of Ames, Iowa, constructed a recycling plant in 1975 which was designed to shred refuse (delivered by packer trucks or other vehicles), remove ferrous metals, aluminum, heavy metals (brass, copper), and nonmetals (glass, sand, etc.) and provide refuse derived fuel (RDF) for the Ames municipal power plant. The system was designed to serve the city of Ames with a population of 44,000, including Iowa State University, plus 11 nearby smaller communities and rural Story County for a combined total of about 69,000 persons.

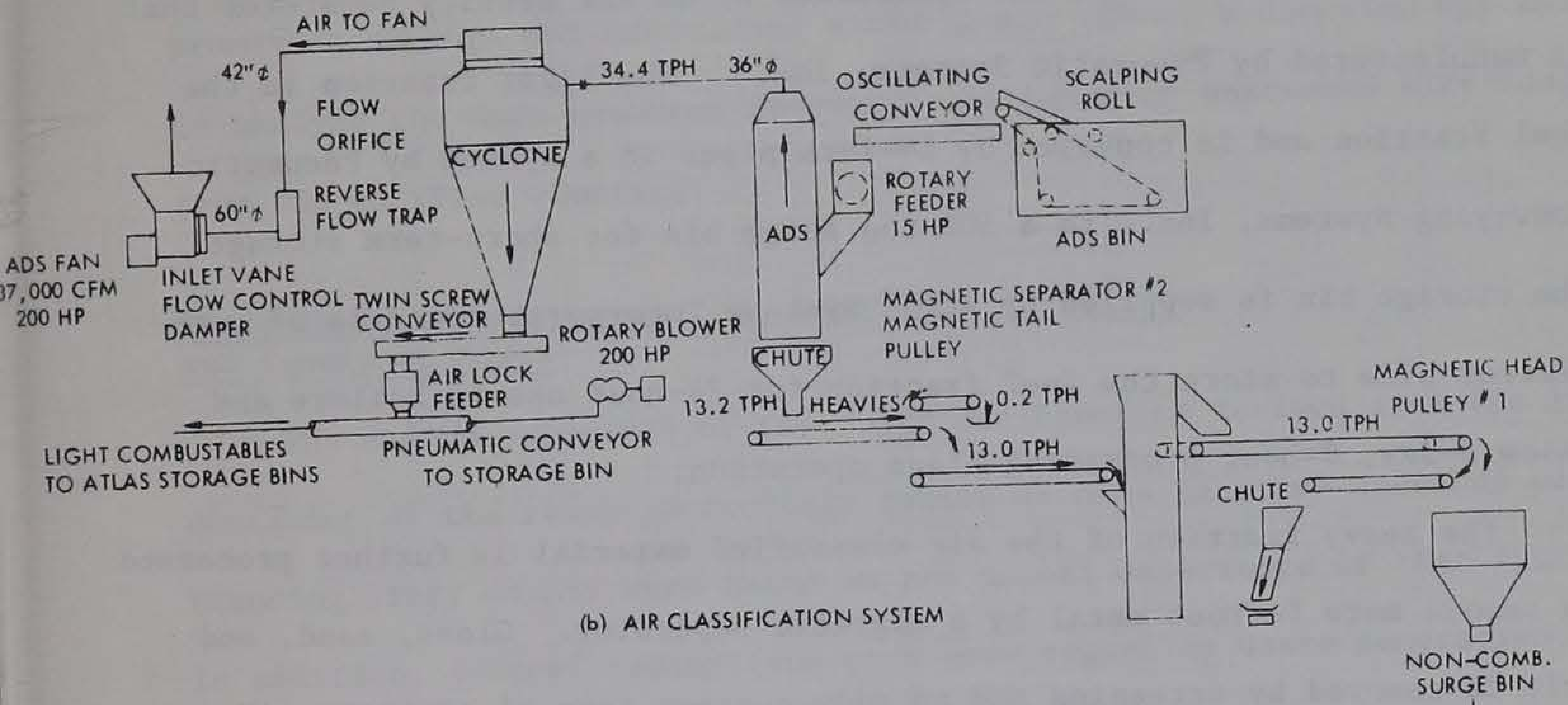
Figure 1 presents a process equipment flow diagram of the system. The separation plant is located near the central part of Ames and is in close proximity to the highway. This location enables haulers in Ames to reach the plant with shorter hauling distances than alternative, outlying locations. The 160 x 180 foot separation plant accomodates commercial haulers in a special entrance to the tipping floor. After weighint in on a truck scale, the commerical vehicles are assessed one dollar per load. Individual cars and pickups are received at a separate entrance past a parking-lot type gate after making a payment of $.50.

The processing plant has a design flow rate of 50 tons/hour. The wastes are pushed from the tipping floor to the primary shredder conveyor by a front-end, loader-type machine. Shredding is accomplished by

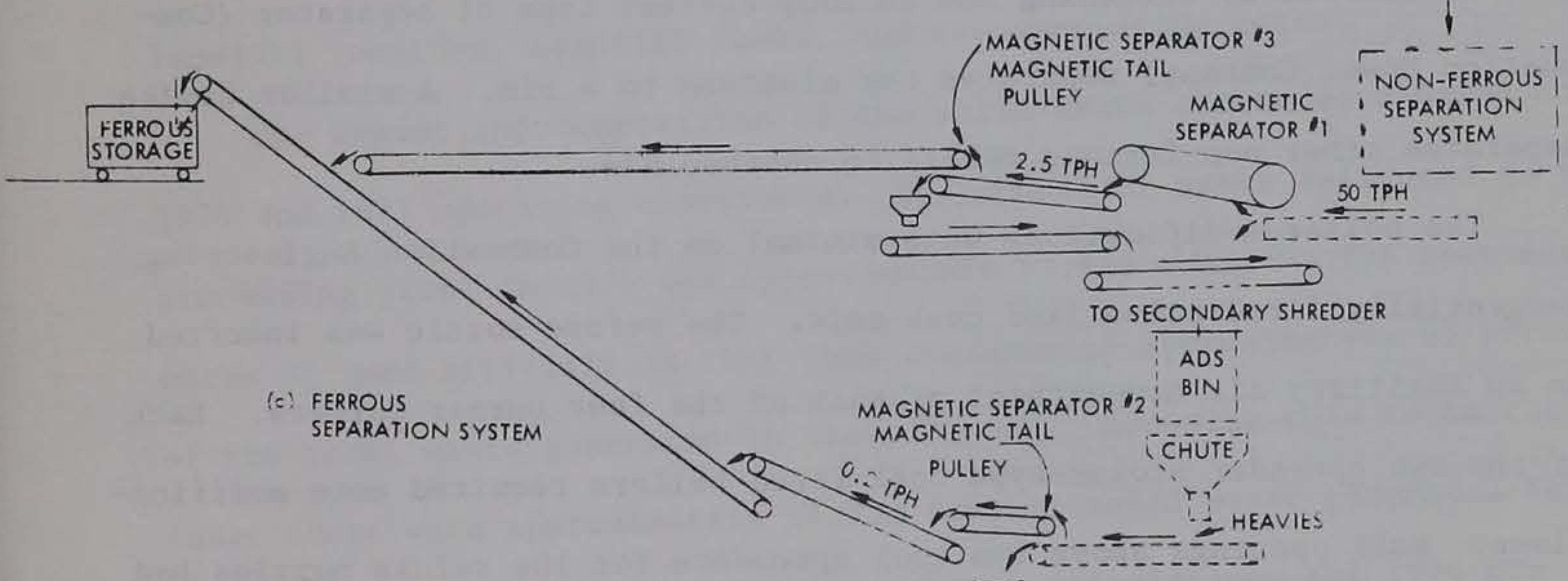
FIGURE 1. Ames Process Equipment Flow Diagram



(a) SHREDDING SYSTEM



(b) AIR CLASSIFICATION SYSTEM



(c) FERROUS SEPARATION SYSTEM

two stages in a series of horizontal shaft hammer mill-type shredders (American Pulverizer Company) that are powered by 720 RPM, 1000 H.P. electric motors. The primary shredder reduces all material to a nominal 7-inch size. Before the material reaches the secondary shredder, a magnetic separator removes ferrous metals. The secondary shredder sizes the material to a nominal 1-1/2 inches. The 1-1/2 inch product from the secondary shredder is then air classified by an air density separator that is manufactured by Pneumatic Systems, Inc. The light fraction is the fuel fraction and is conveyed by 14-inch pipes in a system by Pneumatic Conveying Systems, Inc., to a 500-ton surge bin for short-term storage. The storage bin is supplied by Atlas Systems Incorporated and is of sufficient size to store the fuel fraction for 24-hour use in boilers and allow 5-day, 8-hour processing plant operation.

The heavy fraction of the air classified material is further processed to remove more ferrous metal by a magnetic separator. Glass, sand, and grit is removed by screening and an eddy current type of separator (Combustion Power Company) separates the aluminum to a bin. A similar device separates other non-ferrous metals to another bin.

The boiler modifications were minimal on the Combustion Engineering tangentially fired pulverized coal unit. The refuse nozzle was inserted in an auxiliary air compartment at each of the four burner corners. Each of the two spreader stoker-type coal fired boilers required more modifications. Wall openings above the coal spreaders for the refuse nozzles had to be provided and much more overfire air was added. The rate of firing refuse on each boiler is controlled by changing the feeder speeds at the base of the Atlas storage bin [19].

Current solid waste generation in Story County does not use the full capacity of either the processing facility or the power plant boilers. Given current demand for electricity and RDF modified boiler capacity at Ames Municipal Power, at least a 50 percent increase in solid waste processed and fired could be accommodated. A preliminary survey of surrounding counties identified Boone and Marshall Counties (see Figure 2) as the most promising sources for additional solid waste. Thus, a decision was made to analyze the Ames resource recovery case based on wasteshed size ranging from one to three counties.

Story County waste generation, landfill and transport costs

The medium estimates of the costs and benefits derived from the implementation of the resource recovery system at Ames to serve Ames and surrounding Story County were based on the actual experience of that system. In addition, several assumptions were made regarding waste generation, landfill location, landfill costs, and transportation costs.

The amount and composition of the solid waste stream were based on 1976 and 1977 operating experience. The amount of waste delivered to the processing plant in 1976 was approximately 42,495 tons.[15] The best estimates of Ames officials is that this represented approximately 95 percent of the total waste generated in Story County. Assuming this to be the case, there were approximately 44,730 tons of solid waste generated in Story County in 1976. All benefit and cost calculations for 1976 are based on the collection and disposal of this amount of solid waste.

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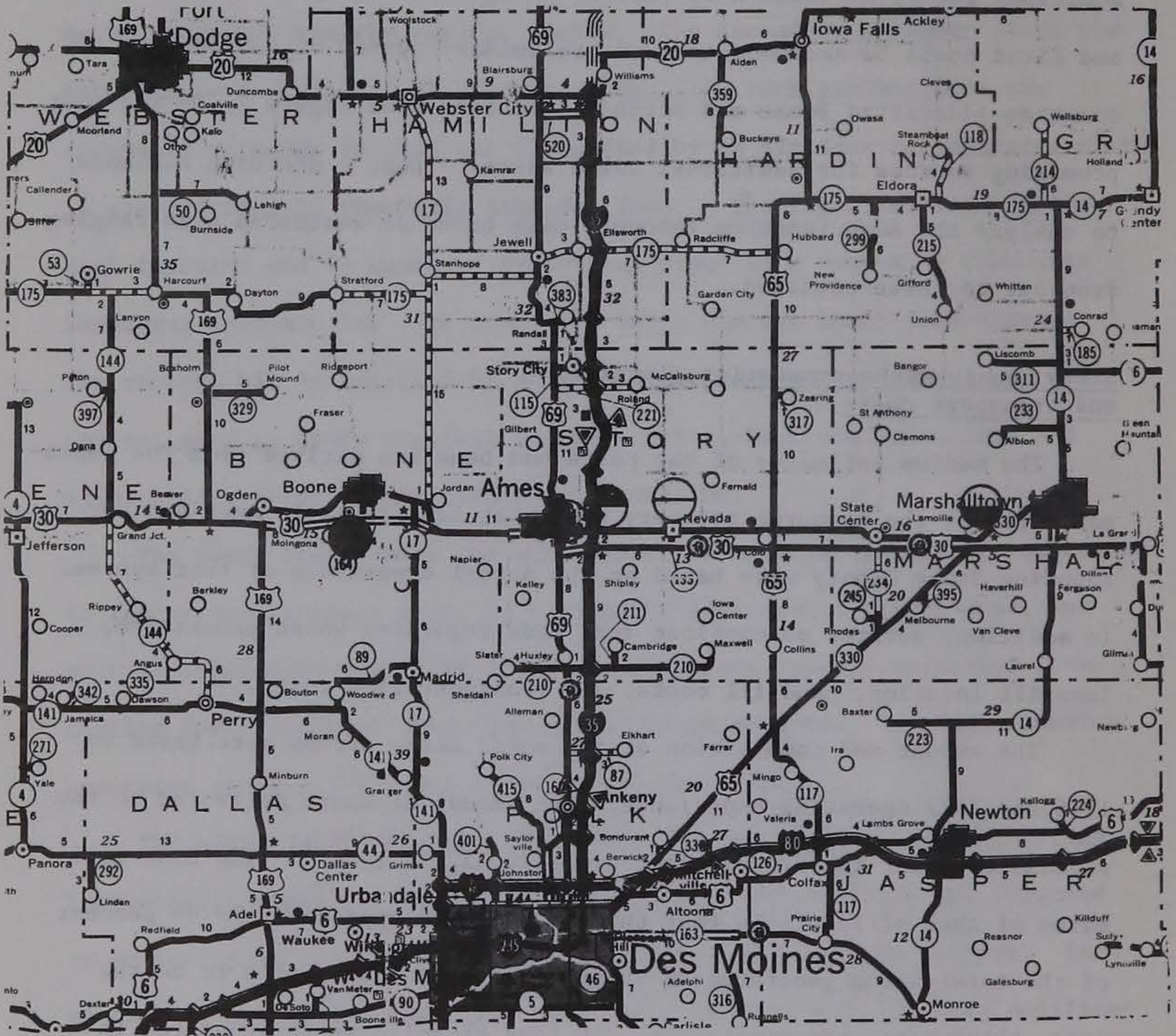
[15] The system was closed down for repairs for half of November 1976. The average of the waste collected in October and December 1976 was used as the estimate of the total waste collected in November.

Figure 2. Location of Ames Resource Recovery Plant and Landfills in the Three County Area



○ Ames, Iowa Solid Waste Resource Recovery Plant

● Boone County Landfill

◒ Marshall County Landfill

⊖ Story County alternative landfill

◓ Old Ames landfill

The spatial dispersion of current solid waste and future amounts and dispersion of solid waste are based on U.S. census data and research in the area of rural solid waste generation [44,35]. It is assumed that the rural population generates 1.5 pounds of household solid waste per day per person (2,487 tons per year), and that this generation will remain constant over the life of the project [21]. Rural population and dispersion are based on 1975 and 1970 U.S. census data, respectively, [43] and are assumed to remain constant over the project life. The rural population within each township is assumed to be equally dispersed.

The remaining 42,243 tons of solid waste is assumed to be generated in the "urban" areas of Story County. It is assumed that urban per capita waste generation is equal throughout the county regardless of community size and that this per capita waste generation of 3.83 pounds per day will remain constant over the project life. The future urban population and its dispersion is based on 1975 U.S. Census data [44]. The future population of the communities within Story County are projected based on the average rate of change between 1970 and 1975, except for those instances where it is felt that abnormally high rates of increase will not be sustained.[16]

The transportation of solid waste from waste source points to the resource recovery system or the alternative landfill is assumed to be accomplished by existing 20 cubic yard packer trucks. The transportation distances from urban source points to recovery or disposal sites is considered to be the shortest road distance from the center of the community

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[16] The growth rates of Gilbert and Huxley were limited to 10 percent per year.

to the site. The transport distance for rural waste is assumed to be the shortest road distance from the center of each township to the disposal or recovery site.

The cost of transporting solid waste from one point to another is determined by multiplying the number of tons generated at a source point times the distance in miles to the destination (tons miles) times the cost per ton mile. The ton mile cost (15.8 cents) used is that which is appropriate for 20 cubic yard packer trucks in 1976 [35]. This cost is projected over the life of the project based on the average change in the GNP price deflator from 1954 to 1974 (3.186 percent) [28].

The cost of transporting solid waste to the resource recovery facility in Ames is treated as a cost of the resource recovery system. The cost of transporting solid waste to an alternative landfill, which is avoided through the use of the resource recovery system, is treated as a benefit to resource recovery.

The location of a hypothetical alternative landfill large enough to handle the solid waste generated in Story County in the next 20 years is based on discussions with local SCS officials and a computer simulation conducted in 1974 under the then existing environmental regulations and transport costs. A compromise selection of one of several sites deemed equally suitable as second best alternatives in the computer simulation to a site closer to Ames is made in light of that site's close proximity to the Iowa State University Horticulture Farm. Although the site selected (approximately one mile north of Nevada) may have greater transport costs over the possible site near Ames, this disadvantage appears to be offset by higher land costs closer to Ames and increased political and social acceptability.

The landfilling costs avoided by the implementation of resource recovery are cost savings and are therefore treated as benefits to resource recovery. The initial landfilling cost of $8.00 per ton ($2.00 per cubic yard) is based on the costs of operating landfills in adjacent Boone and Marshall Counties [8,14]. The landfilling cost is increased over the life of the project at 4.01 percent per year based on the annual average change in the GNP Price Deflator category of "Fuels and Related Product and Power" from 1954 to 1974.

Table 10 presents the population of Story County "urban" places in 1976, the rate of population change used in population projections, the tons of waste generated at each source point in 1976, and the cost of transporting the waste to the resource recovery facility and the alternative landfill in 1976.

Costs of Ames recovery plant

The costs associated with implementation of the resource recovery system include the capital and operating costs of the facilities and equipment necessary to process the raw solid waste into its useful components. Also included are the costs to store and to fire the combustible organic portion (RDF) in the municipal power plant boilers.[17] The estimates of these costs are based on two Master of Science theses which are based in part on information supplied by the City of Ames and in part on site inspection under the direction of Dr. John Even, Iowa State University [18,24]. Information supplied by several City of Ames officials also is used extensively.

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[17] The costs of handling coal (storage, pulverizing, and delivery) from storage to the boiler walls were not available and were not included. Recent attempts to estimate this cost suggest that it is not likely to have a significant affect on the benefit cost results, i.e., the cost is probably between $.50 and $1.00 per ton of coal handled.

Table 10. Story County solid waste generation and transport costs

				Transportation costs/ year 1976	
Urban community	Rate of pop change/yr	Population 1976	1976 solid waste generated (T/Yr)	Resource recovery ($)	Alternative landfill
Ames	1.98	44,272	30,964.8	$9,785	$48,925
Cambridge	.46	679	474.9	1,200	840
Collins	-.24	398	278.3	1,012	726
Colo	2.84	712	498.0	1,180	629
Gilbert	10.00	779	544.9	688	688
Huxley	10.00	1,525	1,066.6	1,517	3,202
Kelley	-.08	234	163.6	207	388
McCallsburg	1.18	331	231.6	768	402
Maxwell	1.88	845	591.0	1,961	1,121
Nevada	1.1	5,283	3,695.1	4,671	584
Roland	1.22	862	602.9	1,429	953
Sheldahl	-3.26	79	55.3	131	192
Slater	2.26	1,246	871.5	1,928	2,961
Story City	4.18	2,650	1,853.5	4,099	4,832
Zearing	-1.08	501	350.4	1,329	831
Urban Total		60,396	42,242.4	31,095	67,274
Rural Total		9,085	2,487	10,418	11,039
County Total		69,481	44,729.4	42,323	78,313

The capital costs and expected life for the facilities and equipment are in Table 11. Any capital with an expected life of less than 20 years is either replaced at an appreciated value after its useful life or is included in the variable operating costs. For example, the bulk of the waste processing equipment has an expected life of approximately 10 years and is therefore replaced in 1985 at an appreciated capital cost. This cost is then discounted in the same manner as operating cost for 1985. The cost of replacing capital equipment in the RDF storage and pneumatic conveying system is included in variable costs. Therefore, no future capital outlay for equipment with a lifetime of less than 20 years is made for this system. Because the proportional cost of labor and materials

Table 11. Capital costs and expected life for Ames resource recovery processing, conveyance, storage and boiler modifications

	Item	Life/yrs	Cost
1976	Boiler modifications	20	178,988
	Land		156,000
	Processing plant		
	Equipment	10	1,066,498
	Building	20	2,708,789
	Engineering		278,903
	Storage and pneumatic conveying system		
	Storage bin & electrical	20	1,111,600
	Pneumatic equipment	5	349,026
	Log chipper	20	32,319
	Paper baler	20	85,877
	Total		5,968,000
1978	Dump grate for pulverized coal boiler		150,000
1985	Replacement of processing plant equipment		1,668,962

required to replace the processing equipment in 1985 is unknown, the greater of the two rates of change, that of labor, is used to appreciate the equipment costs to 1985. The average rate of change for workers in private nonagricultural industries (4.58 percent) from 1954 to 1974, Bureau of Statistics is used to increase labor costs throughout the analysis [11]. The average wholesale price change for industrial equipment from 1954 to 1974 (3.31 percent) is used for appreciation of equipment unless otherwise indicated [11].

The two Master of Science theses dealing with the processing plant and RDF storage and conveyance are heavily relied on to develop the operating costs of the system. Operating costs are broken down into those that vary according to tons of throughput (e.g., wear on shredder hammers) and those that do not (e.g., 15 percent of the Ames public works director's salary).

These "variable" and "fixed" annual operating costs are broken down into the components of labor, utilities, supplies, equipment rental, and miscellaneous. These components are projected and summed to determine future variable and fixed annual operating costs. The total operating cost per year is the sum of the fixed operating cost and the product of per ton variable cost and the number of tons processed. Tables 12 and 13 present the fixed annual operating cost breakdown for 1976, the rates of cost projection used, and the variable operating cost associated with each subsystem.

It is assumed that the processing plant can process 200 tons of raw solid waste in an eight hour shift or 50,800 tons per year in a 254 day year (weekend and holidays excluded). Any amount of waste over this is assumed to be processed by operating the processing plant the additional hours necessary up to a second eight hour shift. This would complete the processing of the additional waste. Any waste beyond this is assumed to be processed on Saturday shifts. The maximum capacity of the processing plant is assumed to be 122,400 tons per year. The cost of operating the control room for tonnages less than 200 tons per day is included in fixed operating cost. When the daily tonnage exceeds 200 tons per day, the process control room is assumed to operate more than the eight-hour shift allocated in fixed cost. Therefore, the average cost per ton of operating the process control room is added to the per ton variable operating cost when daily throughput exceeds 200 tons.

Table 12. Fixed annual operating costs of processing plant, pneumatic conveying and storage system, 1976

Item	Rate of change	Cost/1976
Insurance	3.186%	25,239.96
Equipment rent	4.01%	
Pick-up truck		2,100.00
Floor sweeper		2,400.00
Wood chip trailer		1,200.00
Subtotal		5,700.00
Labor	4.58%	
Supporting		
Supervision		25,249.44
Secretary (part-time)		2,476.80
Janitor (part-time)		2,165.76
Process control		
Operator		17,163.00
Subtotal		47,055.00
Supplies	3.05%	
Process control		729.34
General supply		1,495.02
Shredding system		
Conveyors		640.90
Secondary shredder		603.98
Air density separation		933.64
Subtotal		4,402.88
Electricity (indirect)	4.01%	13,275.54
Miscellaneous	3.05%	12,712.10
Total		108,385.48

Composition and value of recovered materials

The composition of the materials recovered from raw solid waste delivered to the resource recovery system from January to July of 1977 is used as an approximation of present and future waste composition and materials recovery rates. With the exception of rejects, all of the components of the solid waste stream (RDF, ferrous metals, wood chips, bales

Table 13. Variable cost/ton of raw refuse processed at Ames resource recovery facility

	Variable cost item for 1976 and rate of increase					
Sub-system	Labor (4.58%)	Equipment rent (4.01%)	Elect. (4.01%)	Supply (3.05%)	Water & sewerage (4.01%)	Total
Receiving	$.6391	$.4630		$.0049	--	$1.107
Shredding	.3461		.5147	1.0655	--	1.9263
A.D.S.	.2526	--	.1189	.1331	--	.5046
Ferrous	.0518	--	--	.0040	--	.0789
Non-Ferrous	.0472	.0231	--	.1517	--	.1989
Log chippers	.0186	--	--	.0246	--	.0432
Paper bales	.0467	--	--	.0233	--	.0700
"Indirect" elect.	--	--	.3307	--	--	.3307
Storage & convy.	.9854	.6544	.3085	.5138	--	2.4621
Water & sewerage	--	--	--	--	.0755	.0755
General supply	--	--	.2277	--	--	.2277
Indirect labor						
Process cleaning	.2844					.2844
Plant maintenance	.1046					.1046
Miscellaneous	.0400					.0400
Total (200 T/Day)	2.8165	1.1405	1.5005	1.9209	.0755	7.4539
Control	.4316			.0184		.45
Total(> 200 T/Day)	3.2481			1.9393		7.9039

$7.4539 per ton for tonnages less than or equal to 200 tons per day

$7.9039 per ton for tonnages greater than 200 tons per day

Total variable operating costs = 44,730 x 7.4539 = $333,412.95

of paper and aluminum) are treated as benefits. The value of these components, other than baled paper and RDF, is determined by using market prices net of shipping cost received by the Ames Resource Recovery Plant for the period June 1976 to November 1976 [18]. The average price of baled paper from December 1976 to June 1977 was used to determine benefits from the paper baling process [4]. These net prices or revenues are increased over the life of the project by the average rate of change in the wholesale price index in their respective categories from 1954 to 1974. Table 14 presents the composition of the waste stream, the value of the waste stream components on a per ton basis, the price projections of the components, and the total benefits of each component for 1976, excluding rejects which are discussed later.

Table 14. Solid waste stream and the value of recovered resources, 1976

Component	Percentage of waste stream	$/T	Medium rate of price change	1976 total tons	1976 total value($)
RDF	84.69	11.92	12.5% (1976-80) 7.0% (1981-95)	37,881.8	451,551
Ferrous metals	6.44	18.00	3.9%	2,880.6	51,850
Wood chips	.20	13.50	3.75%	89.5	1,028
Baled paper	.30	40.00	3.0%	134.2	5,368
Aluminum	.01	284.00	3.8%	4.5	1,278
Rejects	8.43	NA	NA	3,770.7	NA
Totals	100.07[a]	NA	NA	44,761.3[a]	511,075

[a] Greater than 100 and 44,730, respectively, due to rounding error.

The value of RDF as an energy source in the production of power in the Ames municipal power plant is calculated by determining the difference between two values. They are the least cost "coal only" fuel mixture that could meet the power plant's yearly heat requirements and sulfur emission regulations and the least cost coal and RDF fuel mixture that includes RDF from Story County at a zero price and also meets the heat and sulfur requirements.[18] This difference, the cost savings due to the use of RDF in the mixture, divided by the number of tons of RDF burned is used as the

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[18] A linear programming model was developed to determine least cost fuel mixtures and is presented in Appendix C.

average value of a ton of RDF. Because of the very limited use of fuel oil at Ames Municipal Power and the phasing out of the use of natural gas, these fuels are not included in any of the fuel mixtures. The maximum amount of RDF that can be included in the mixture will be limited either by the characteristics of the boiler or the availability of RDF. In Ames, the amount of RDF available is the limiting factor. In 1977 there was enough refuse generated in Story County to supply approximately 14 percent of the power plant's heat input.

The sulfur dioxide emissions standard for the Ames power plant is five pounds per million BTUs. The total heat requirement for 1977 was 2,800,000 x 10^6 BTUs. The least cost combination of coal without RDF meeting these requirements is $1.18682 per million BTUs. The least cost combination with RDF allowed in the mixture is $.99912 per million BTUs.

The total cost savings for 1977 equals the product of the difference between the cost of the mixtures, $.1877, and the power plant's heat requirement (2,800,000 x 10^6 BTUs), which is $525,588.00. Dividing this savings by the total number of tons of RDF burned in 1977 (39,199.6), yields the average cost savings per ton of RDF burned ($13.41). This value is discounted and projected at one of three rates of coal price increase to determine the 1976 and future values respectively of RDF per ton. The product of the value of RDF per ton and the number of tons of RDF available in any given year is that year's total RDF benefits.

Table 15 presents the characteristics of the coal currently being used at the Ames power plant and the characteristics of typical RDF. It also presents the least cost coal only and coal plus RDF fuel mixtures and their respective prices and sulfur contents.

Table 15. Fuel characteristics and least cost mixtures, 1977

Fuel Characteristics

	Iowa coal	Colorado coal	RDF
Cost/Ton	17.71	32.51	NA
Cost/10^6 BTUs	.95	1.33	NA
BTUs/lb.	9,345	12,200	5,000
Sulfur	4-7%	.55%	.16%
Ash	12-13%	9%	19%

Least Cost Mixture to Produce 10^6 BTUs

Iowa and Colorado coal only

Iowa coal	40.34845	lbs.
Colorado coal	51.06096	lbs.
Sulfur content	2.5	lbs.
Cost	$1.18682	

Iowa and Colorado coal and RDF

Iowa coal	40.70894	lbs.
Colorado coal	39.31352	lbs.
RDF	27.99	lbs.
Sulfur content	2.5	lbs.
Cost	$ .99912	

SOURCES: [2,20,26,36]

Disposal costs of rejects and ash

The need for a landfill is not entirely eliminated by the implementation of resource recovery. Certain components of the solid waste stream presently have no current use. These materials are "rejected" from the system and ultimately disposed of at the "old" city landfill approximately 2.5 miles east of Ames. For purposes of this analysis, it is assumed that the cost of transporting and landfilling the rejected materials is the same on a per unit basis as raw solid waste.

The ash from the combustion of coal and RDF must also be disposed. When RDF is included in the fuel mixture, the amount of ash produced from coal is decreased. In this analysis, the cost savings due to this reduced amount of coal ash is treated as a benefit to resource recovery. It is assumed that all ash produced in the combustion process is landfilled. The benefits also include the cost of transporting the ash to the old city landfill and the cost of landfilling it.

The combustion of solid waste also results in the production of ash residue. In this analysis, the cost of transporting and landfilling the ash produced from the combustion of RDF is included as a cost to resource recovery.

The density of ash is more than twice as great as that of the compacted solid waste delivered to landfills. Therefore, it takes up less landfill volume and/or is easier to compact to prepare it for final disposal. An estimate of this reduced per ton cost of landfilling ash as opposed to compacted refuse is developed based on the $8.00 per ton landfilling cost and a 500 pound per cubic yard density of refuse delivered to the landfill [50]. Ash weighs approximately 49 pounds per cubic foot or 1,323 pounds per cubic yard. The delivered volume of one ton of ash is 1.5117 cubic yards. The delivered volume of one ton of compacted solid waste is four cubic yards. For purposes of this analysis the ratio of the cubic yards per ton of ash to the cubic yards per ton of solid waste is multiplied times the cost per ton of delivered solid waste ($8.00 per ton) to determine the cost of landfilling ash.[19] This cost ($3.02 per ton) is projected over time at the same rate of increase as the solid waste landfilling cost.

The change in the amount of ash produced from the combustion of coal is the product of the coal's ash content and the difference in the amount

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[19] To the extent that increase in landfill throughput over time would result in decreasing marginal cost, then our benefits would be understated.

of coal used in the with and without RDF optimal fuel mixtures. The amount of ash produced from the combustion of Colorado coal decreases 1.057 pounds per million BTUs when RDF is included in the final mixture. The ash produced from Iowa coal increases .0451 pounds per million BTUs. The net result is a decrease of 1,369.9 tons of coal ash in 1976.

The amount of ash produced with RDF included in the fuel mix is determined by multiplying the amount of RDF burned times its ash content. This amounts to 7,197.5 tons in 1976.

For this analysis, it was assumed that the fuel mixture to produce 10^6 BTUs with and without RDF would remain the same over the life of the project. This is based on the assumptions that Iowa and Colorado coal prices will increase proportionally, that sulfur emission regulations will remain constant, and that the amount of RDF available and the demand for electricity will vary proportionally with population. It is also assumed that per capita waste generation and per capita electricity demand will remain constant.

The amount of coal ash and ash derived from the combustion of RDF and the costs of transporting the ash to the landfill and landfilling it are in Table 16.

Table 16. Costs of disposal of rejects and RDF ash and cost savings of reduced coal ash disposal, 1976

	Tons	Landfill cost cost/ton	Total cost	Transport costs to landfill
Rejects	3,770.7	$8.00	$30,166	$1,489
Ash				
RDF	7,197.5	3.02	21,736	2,843
Reduced coal	1,369.9	3.02	4,137	541

Boone and Marshall Counties waste generation and transfer costs

In 1976 approximately 50,000 cubic yards of solid waste with a density of 500 pounds per cubic yard (12,500 tons) was landfilled at the landfill in Boone County at a cost of $2.00 per cubic yard [8]. During the same time period, approximately 25,700 tons of waste was landfilled in Marshall County at approximately the same cost per cubic yard [14].

Population in Boone County declined from 1960 to 1970, increased from 1970 to 1973 and decreased from 1973 to 1975. The rate of change from 1970 to 1975, although small, was negative. Present trends of increased residential housing may offset this decline in the future. Because of these two offsetting factors, the amount of waste generated in Boone County is held constant at 12,500 tons per year over the 20 year life of the project.

The urban population of Marshall County shows a more pronounced trend. Population in Marshall County has been increasing since 1960. The average rate of increase of urban population from 1970 to 1975 is used to project future urban population. Rural population is held constant over the project life. It is assumed that the rural population generates 1.5 pounds per capita per day. The rural population generation of 2,601 tons per year is held constant throughout the project. The remaining waste attributed to the urban population was 23,110 tons in 1976. This tonnage is increased at the average rate of urban population change over the 1970 to 1975 period (2.75 percent) to determine future waste generation in Marshall County.

The locations of the transfer stations are assumed to be at the present landfill sites. The Boone County landfill is approximately 17 miles from Ames and the Marshall County landfill is about 34 miles from Ames. Solid waste transport costs in the two counties to the landfills or transfer stations are the same under landfilling or resource recovery. Therefore, the only costs and benefits to be considered under resource recovery at the Ames plant are those costs associated with the operation of the transfer system in conjunction with the Ames resource recovery plant and the alternative or foregone costs of landfilling.

The costs of operating the transfer systems were developed by Richard Poling and are based on personal contacts in Boone and Marshall counties and earlier analysis done in Ohio [34,35]. Table 17 displays the capital outlay for both transfer systems and the expected life of the components. Any capital that has an expected life of less than 20 years is replaced at the end of its useful life at its 1977 cost appreciated at a rate of 3.31 percent. Excess transfer capability will exist in both the Boone and Marshall subsystems for the first four or five years. It is possible, providing schedules could be worked out, that the subsystems could share a transfer tractor and trailer during this period. This would reduce initial capital outlay by $72,600 which would increase the discounted present value of net benefits by that amount. This course of action was not followed, however, to ensure that the cost of transferring the waste was not understated. The excess capacity also provides a contingency against breakdowns and adverse weather conditions.

Operating costs of the transfer system for 1977 and the projected rate of cost increase are broken out and displayed in Table 18. The transfer vehicle operating cost of $.2932 per mile includes the cost of fuel, oil, repair and maintenance, and tires. Transfer station operation and

Table 17. Capital costs of Boone and Marshall County transfer systems

Item	Expected life (yrs.)	Cost ($)
Boone County		
Building	20	$ 60,000
Push pit	20	30,000
Scales	20	30,000
Compactor	10	35,000
Yard tractor	6	8,000
Transfer tractor	6	40,000
2 transfer trailers	6	52,000
Subtotal		255,000
+ 10% contingency		25,500
Total		280,500
Marshall County		
Building	20	60,000
Push pit	20	30,000
Scales	20	30,000
Compactor	10	35,000
2 transfer tractors	6	80,000
3 transfer trailers	6	78,000
Subtotal		313,000
+ 10% contingency		31,300
Total		344,300
Total (Boone and Marshall County)		624,800

maintenance cost includes utilities, repairs and maintenance, fuels and lubricants, materials and supplies, and miscellaneous supplies. The capacity of the transfer trailer is 75 cubic yards or 18.75 tons.

The capital costs for the Ames resource recovery system are held constant and the operating costs of the system including waste from Boone and Marshall Counties are determined using the same methods as those for Story County solid waste. Benefits from the increased throughput of solid waste are also calculated in the same manner as those in Story County.

Table 18. Operating costs of Boone and Marshall County transfer stations, 1977

Item	Projection	Boone County Cost ($)	Marshall County Cost ($)
Labor			
Supervisor/weigher		9,000	9,000
Operator		7,488	7,488
Laborer (part-time)		3,120	6,240
Driver		11,232	22,464
Fringe benefits @ 25%		7,735	11,298
Subtotal		38,575	56,490
+ 10% contingency		3,858	5,649
Total labor	(4.58%)	42,433	62,139
Transfer station operation and maintenance		9,000	14,000
+ 10% contingency		90,000	1,400
Total	(3.186%)	99,000	15,400
Transfer vehicle operation and maintenance (@ $.2932/ mile x 22,66 ton miles)		6,435	30,148
+ 10% contingency		644	3,015
Total	(3.186%)	7,079	33,163
Insurance		2,800	3,500
Road taxes and licenses	(3.186%)	2,000	3,000
Total operating costs		64,411	117,202

The total RDF from Boone, Marshall, and Story Counties is sufficient to supply 25.58 percent of the 1977 power plant heat requirements. The cost of producing a million BTUs with the total RDF from Boone, Marshall, and Story Counties in 1977 is $.84374 and the average value of the RDF is $13.41 per ton.

Results of solid waste analysis

The benefit-cost analysis of the Ames resource recovery system indicates that it is generally an acceptable investment of resources. Under all but a few assumptions the net benefits are positive. The results of the benefit-cost analysis are in Tables 19 and 20.

Table 19. Results of Ames benefit-cost analysis for one, two, and three county wasteshed

Counties: Story			
Parameters: Medium values			
Discount rate:	5%	9%	13%
B/C:	1.48	1.27	1.09
B-C:	$9,051,920	$4,111,674	$1,206,562
IRR:	15.4%	15.4%	15.4%
Payout:	11 years	12 years	16 years
Counties: Story, Boone and Marshall			
Parameters: Medium values			
Discount rate:	5%	9%	13%
B/C:	1.54	1.37	1.22
B-C:	$16,091,360	$8,663,936	$4,286,528
IRR:	20.5%	20.5%	20.5%
Payout:	7 years	8 years	11 years
Counties: Story and Boone			
Parameters: Medium values			
Discount rate:	5%	9%	13%
B/C:	1.49	1.30	1.13
B-C:	$11,043,488	$5,329,040	$1,976,135
IRR:	16.7%	16.7%	16.7%
Payout:	10 years	12 years	14 years
Counties: Story and Marshall			
Parameters: Medium values			
Discount rate:	5%	9%	13%
B/C:	1.55	1.37	1.21
B-C:	$14,191,872	$7,455,424	$3,491,600
IRR:	19.4%	19.4%	19.4%
Payout:	8 years	10 years	12 years

Under medium values of the economic parameters and a 9 percent discount rate, the benefit-cost ratio (B/C) for the system servicing only Story County was 1.27. The internal rate of return (IRR) was 15.4 percent and the net benefits (B-C) were $4,111,674. When the transfer systems for Boone and Marshall Counties are considered simultaneously in conjunction

Table 20. Sensitivity analysis of landfill cost, coal price projection, and sulfur content of Ames case - Story County

Parameter: Low alternative landfill cost ($4/T)			
Discount rate:	5%	9%	13%
B/C:	1.30	1.11	.95
B-C:	$5,542,032	$1,630,249	$647,448
IRR:	11.6%	11.6%	11.6%
Payout:	13 years	16 years	NA
Parameter: High alternative landfill cost ($12/T)			
Discount rate:	5%	9%	13%
B/C:	1.60	1.38	1.19
B-C:	$11,680,032	$5,923,883	$2,540,195
IRR:	18.1%	18.1%	18.1%
Payout:	9 years	11 years	13 years
Parameter: Low coal price projections			
Discount rate:	5%	9%	13%
B/C:	1.23	1.08	.95
B-C:	$4,306,240	$1,214,072	$641,182
IRR:	11.3%	11.3%	11.3%
Payout:	13 years	16 years	NA
Parameter: High coal price projections			
Discount rate:	5%	9%	13%
B/C:	1.93	1.61	1.34
B-C:	$17,450,496	$9,161,770	$4,376,970
IRR:	20.1%	20.1%	20.1%
Payout:	8 years	9 years	12 years
Parameter: .43 percent RDF sulfur content			
Discount rate:	5%	9%	13%
B/C:	1.46	1.25	1.08
B-C:	$8,596,144	$3,806,474	$990,796
IRR:	15.0%	15.0%	15.0%
Payout:	11 years	13 years	16 years

with Story County and the Ames recovery system, the economic efficiency criteria at the 9 percent discount rate increased to a benefit-cost ratio of 1.37, an internal rate of return of 20.5 percent and net benefits of $8,663.936. The payout period is reduced from 12 to 8 years.

When transfer systems for Boone and Marshall Counties are considered separately in conjunction with Story County and the Ames resource recovery system, the economic efficiency criteria are maintained or increased over the system limited to Story County waste. When Marshall and Story Counties are considered separately at a 9 percent discount rate, the benefit-cost ratio increases to 1.37, the internal rate of return to 19.4 percent, and the net benefits increase to $7,455,424. The Boone and Story County system did not effect the criteria as significantly as the Marshall and Story County system. Under the Boone and Story option, the benefit-cost ratio increases to 1.3, the internal rate of return increases to 16.7 percent and the net benefits increase to $5,329.040. Apparently, size economies at both the transfer station and the processing plant offset increased transport costs from Boone and Marshall Counties.

The benefit-cost criterion increased significantly when the value of the RDF was increased at the rate of the high coal price projection and also when the alternative cost of landfills was increased to 12 dollars per ton in 1976. The benefit-cost ratios for the Story County system increased to 1.61 and 1.38 for high coal price projections and high alternative landfill costs, respectively. The benefit-cost criterion decreased significantly under low coal price projections and an alternative landfill cost of four dollars per ton. The benefit-cost ratio is reduced to 1.08 and 1.11, respectively, under these assumptions. At a 13 percent discount rate the benefit-cost ratio dropped below unity.

The sulfur content at Ames may be higher than would be expected in light of other studies of RDF characteristics [2,26]. The sulfur content of the RDF at Ames during a six-week monitoring period in the summer of 1977 was .43 percent.[20] The benefit-cost ratio for the Story County option

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[20] Ames city officials are investigating possible point sources of sulfur including the National Animal Disease Lab located in Ames.

decreased to 1.25 when the RDF sulfur content was increased to .43 percent from .16 percent.

Preliminary analysis of corn stover

Preliminary analysis of corn stover as a source of RDF for coal burning steam-electric plants in the North Central Region is currently being funded by a small grant from The Ohio State University Graduate School. Ames, Iowa, and Peru, Indiana, have been selected as case studies, and some preliminary analysis has been completed on the Ames case. A detailed conceptual model developed by Abdallah includes several activities or options within each of three sectors: farm, transport, and power plant, as well as assumptions on removel rates, etc. [1,30].

Estimates are being developed for: removal rates based on soil type and slope; harvest, storage, loading, transport and unloading costs; fertility losses; chopping and/or tillage savings; and various forms of processing and conveyance at the power plant site. To date, preliminary estimates have been developed for loose chop, large round bale, and stack systems in the farm and transport sectors. Estimates have also been developed for processing and conversion costs in the power plant sector for both pulverized coal and stoker boilers.

Under optimal conditions regarding the size and type of boiler(s), density of stover, coal price projections, and availability of solid waste, it appears that stover as a source of RDF in situations similar to the Ames case is close to being a break-even situation. For example, analysis of the one county Ames case assuming 75 tons per day of stover as a supplementary fuel to solid waste RDF and coal resulted in a benefit/cost ratio of 1.09 for the stover subset of the system. This analysis allocated the variable costs of stover RDF processing and combustion plus the costs of harvesting and transport to the stover subset. Preliminary analysis of stover as the sole source of RDF in a power plant with 75 tons/day of RDF capacity shows a benefit-cost ratio of .98 at medium parameter values.

The Orrville Case

Introduction

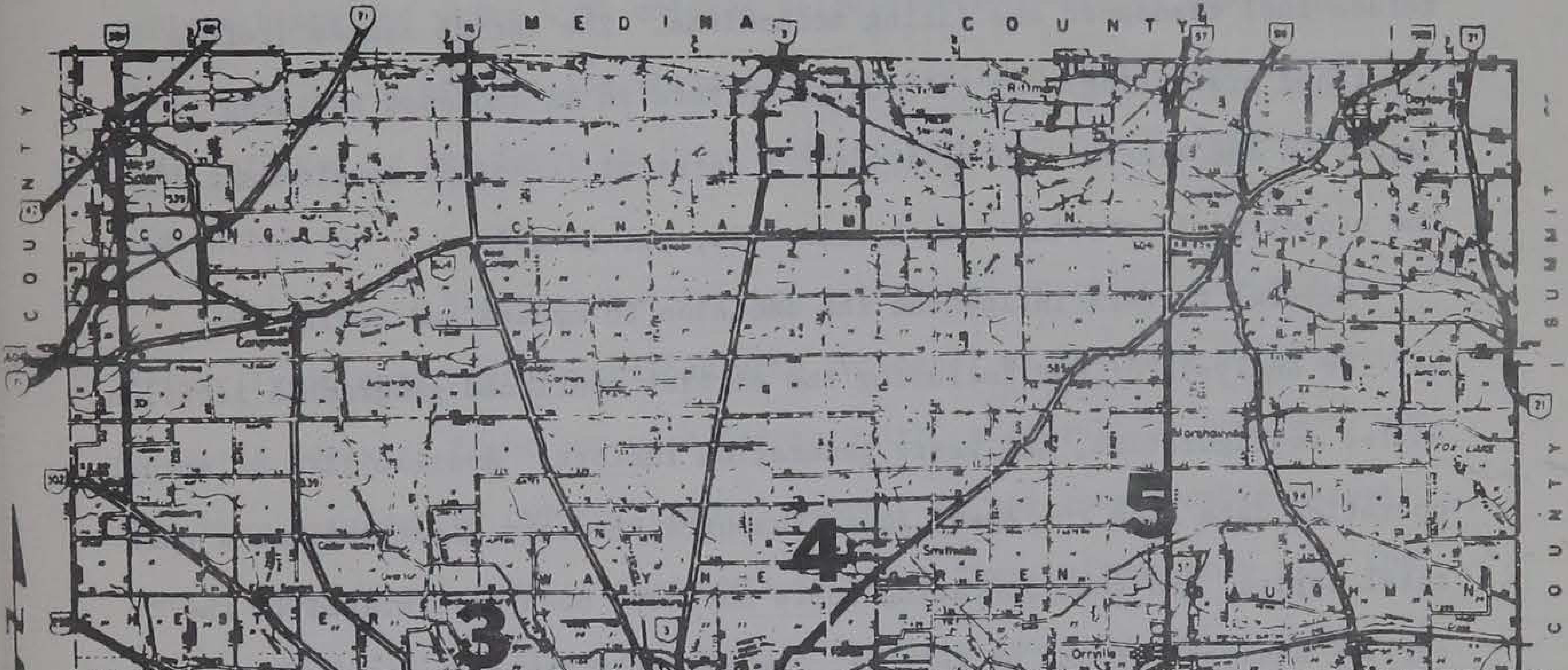
Wayne County, Ohio (see Figure 3), is located in the northeastern quadrant of the state and has a population of approximately 87,000. Like many other areas, Wayne County is rapidly exhausting its present landfill space. In addition, the current sites are considered suspect in terms of damage to surface and groundwater supplies, negative aesthetic impacts, and generally poor management techniques. Because the county is an important agricultural area of the state, the cost of land for additional disposal sites is relatively high. Residents in the county's population centers oppose the development of new landfills close to these waste-generation centers.

The City of Orrville, located in northwest Wayne County, owns and operates a 75 megawatt municipal electric plant. An earlier analysis by Luttner made a preliminary assessment of the technical and economic feasibility of adapting the existing pulverized coal boilers at Orrville Municipal Power (OMP) for solid waste resource recovery [28]. The design as well as capital and operating cost estimates of a solid waste processing facility were developed from a variety of sources but included no operating data from an actual system of like type and size.

The prototype recovery system design included a horizontal hammermill to reduce incoming refuse to optimum combustion size, an air classification

FIGURE 3

MAP OF WAYNE COUNTY, OHIO



1 - Mt. Eaton Phase III Landfill
2 - Village of Shreve Landfill
3 - Wooster Disposal Inc. Landfill
4 - Potential Green Township Landfill
5 - Orrville Municipal Power Plant

process (zigzag columnar or elutriative) to separate the refuse into combustible and noncumbustible fractions, a magnetic system to recover ferrous scrap material for sale, processed refuse storage facilities, and refuse-fuel transport and firing mechanisms. The entire system (refuse input and processing) was allowed to operate in an enclosed building adjacent to the electric power plant. A detailed technical development of the prototype is presented in Luttner [28, pp. 20-49].

Several factors influenced the decision to update and revise the earlier analysis of OMP including the earlier mentioned geographic location, boiler configuration, and waste generation factors. Availability of actual operating data from the Ames, Iowa, Resource Recovery Plant indicated that total capital and some operating costs may have been understated in the earlier analysis of OMP by Luttner. In addition, Luttner did not consider the possibility of installing a new spreader-stoker boiler to handle all of Wayne County's solid waste. Instead, he looked only at the option of modifying two of the existing OMP pulverized coal boilers to handle from one-half to two-thirds of the county's waste. The remainder of the solid waste was assumed to be landfilled.

Updated Luttner prototype

The major changes in updating the earlier Luttner analysis of solid waste resource recovery at OMP involve capital outlay and operating costs of the processing facility. Actual capital outlay and operating cost data from a comparable type and size of facility at Ames have been considerably higher based on the first 18 months of operation. Attempts were made to include only net additional costs of those capital outlay and operating cost items that represented replacement of original inadequate components or unusual start-up operating problems. For example, it was necessary to replace black and white with colored television monitors to detect objects that might be harmful to the shredders. In addition, maintenance costs were inflated by two fires in the plant before an improved alarm system was installed.

Estimates of the adjusted capital outlay and operating costs are based primarily on numerous discussions with personnel at the Ames Solid Waste Resource Recovery Plant and with Gordon Smith, a consulting engineer, who has been retained by OMP for several years. On any questionable adjustments, the highest cost estimate was chosen. These adjustments plus the effects of inflation since the earlier Orrville analysis resulted in a 43.2 percent increase in the medium estimate for capital outlay from $4,105,101 to $5,877,742. Recovery plant operating costs for the first year of operation increased from $238,519 to $571,776--139.7 percent more than the earlier estimate by Luttner.

More minor adjustments of the earlier Orrville analysis included increasing the high estimate for the discount rate from 11 to 13 percent and decreasing waste generation estimates from 429 to 350 tons/day for 1980. The latter change was necessitated by a somewhat slower recovery rate of the economy (and thus, less waste generated) than was forecast by Luttner in the earlier analysis. In addition, establishment of a proportional rate of increase between low, medium, and high coal price projections required some minor adjustments. Tables 21 and 22 present the updated Luttner prototype capital outlay and first year direct benefits and operating costs under medium technical and economic parameter estimates.

Table 21. Revised capital outlay estimate for Orrville solid waste resource recovery prototype

Equipment or item	Material	Labor
Scale and scale house	75,000*	--
Pit conveyor	80,000	16,000
Inclined conveyor	80,000	16,000
Shredder explosion suppression equip.	230,000*	--
Belt conveyor	12,000	4,000
Air classifier feed bin	30,000	4,000
Air classifier	44,000	6,000
Air separator	43,000	5,000
Main fan and ducts	26,000	10,000
Dust collecting system	53,000	10,000
Heavy materials conveyor	42,000	5,000
Ferrous separator (2-stage)	45,000*	--
Secondary shredder and conveyors	170,000*	--
Conveyor to refuse bin	45,000	10,000
Shredded storage bin	160,000	85,000
Outfeed system	120,000*	--
Pneumatic transfer system	135,000*	--
Boiler and burner modification	800,000*	--
Electrical equipment	220,000*	--
Water sewerage	150,000*	--
Buildings	1,400,000*	--
Auxiliary and miscellaneous equipment	144,000*	--
Totals	4,104,000	171,000
Sub-total, equip., items, and labor	4,275,000	
Engineering (7%)	299,250	
Contingency (15%)	641,250	
General contracting	--	
Grand total	5,215,500	
Mt. Eaton capital cost	662,242	
	$5,877,742	

*Price listed includes labor costs

The remaining methods are a replication of the earlier Luttner analysis. Table 23 presents the benefit-cost results for the updated Luttner prototype. Under medium coal and ferrous metal price increases, the updated Luttner prototype has positive direct[21] net benefits only at the

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[21] The earlier analysis by Luttner made some attempt to get physical measures of the indirect benefits of reduced landfill leachates and reduced sulfur emissions from the power plant [28, pp. 76-80, 92-105].

5 percent discount rate. Under high coal and ferrous metal price increases, all parameter combinations have positive net benefits with the exception of a 13 percent discount rate and high capital outlay (K_H).

Table 22. Estimates of first year (1976) direct benefits and operating costs under medium technical and economic parameters for updated Luttner prototype

Direct benefits ($)		Operating costs ($)	
Green township landfill operating costs	164,500	Resource recovery plant	571,776
Transport cost to Green township landfill	161,002	Mt. Eaton landfill	59,448
Coal savings	376,397	Transport of waste to recovery plant	82,769
Ferrous metal net revenue	64,191	Transport of resources to Mt. Easton landfill	148,235
TOTAL	766,090	TOTAL	862,228

Table 23. Benefit-cost results for the updated Luttner prototype (20:80 firing ratio)

Parameters: Medium coal and ferrous metal prices

Discount rate:	5%		9%		13%	
	B/C	B-C	B/C	B-C	B/C	B-C
K_L	1.07	1,534,992	.98	-310,576	.90	-1,393,353
K_M	1.04	821,728	.94	-1,023,856	.86	-2,106,629
K_H	1.00	110,496	.91	-1,735,088	.82	-2,817,879

Parameters: High coal and ferrous prices

Discount rate:	5%		9%		13%	
	B/C	B-C	B/C	B-C	B/C	B-C
K_L	1.38	8,423,536	1.23	3,974,752	1.10	1,407,281
K_M	1.34	7,710,272	1.18	3,261,472	1.05	694,005
K_H	1.30	6,999,040	1.14	2,550,240	1.00	-17,245

New boiler analysis

Discussions with Gordon Smith revealed that, given the expected increase in demand for electricity of 6 percent per year and the age of the existing boilers at OMP, installation of a new spreader-stoker boiler may be necessary in the next few years. Installing a new boiler capable of burning RDF would be more costly than a coal only boiler but could facilitate energy recovery from all of the current and projected solid waste in Wayne County. A decision was made to analyze this alternative in comparison with modifying the existing suspension-fired boilers for resource recovery.

The appropriate capital outlay cost for resource recovery under the new boiler alternative is the incremental outlay required to handle RDF in the new spreader-stoker boiler. Gordon Smith provided an estimate of the new boiler, surge bin, engineering, and contingency incremental costs of $1,050,000. Capital outlay for the Luttner prototype boiler and burner modifications of $800,000 is eliminated and the capital outlay for the processing facility remains essentially unchanged. The net effect is a $161,891 increase to $6,039,633 in the medium estimate for capital outlay for the new boiler as opposed to the updated Luttner prototype alternative.

Under the new boiler alternative, operating costs of the processing facility increased but less than proportionately with the increase in solid waste throughput. First year operating costs are estimated at $911,577 or an increase of $339,801 more than the updated Luttner prototype. Table 24 presents the first year direct benefits and operating costs for the new boiler, full capacity alternative under medium technical and economic parameter estimates.

Table 24. Estimates of first year (1976) direct benefits and operating costs under medium coal and ferrous metals prices for new boiler alternative

Direct benefits ($)		Operating costs ($)	
Green township operating costs	164,500	Resource recovery plant	911,577
Transport cost to Green township landfill	161,002	Transport cost of waste to resource recovery	161,002
Coal savings	670,457	Transport of ash and rejects	57,824
Ferrous metals revenue	131,313	Landfill activities of ash and rejects	59,448
	1,127,272		1,189,851

Table 25 presents the benefit-cost results for the new boiler alternative of the Orrville case. Assuming the incremental capital cost of the new boiler and medium coal and ferrous metal prices, most of the parameter combinations show positive net benefits. The two exceptions are the medium and high capital outlay estimates under the 13 percent discount rate.

Table 25. Benefit-cost results for the new boiler alternative of the Orrville case

Parameters: Medium coal and ferrous metal prices, incremental capital outlay						
Discount rate:	5%		9%		13%	
	B/C	B-C	B/C	B-C	B/C	B-C
K_L	1.19	6,435,136	1.10	2,625,904	1.02	433,872
K_M	1.16	5,529,200	1.07	1,719,984	.98	-472,064
K_H	1.13	4,623,264	1.03	814,032	.94	-1,378,000
Parameters: High coal and ferrous metal prices, total capital outlay						
Discount rate:	5%		9%		13%	
	B/C	B-C	B/C	B-C	B/C	B-C
K_L	1.39	15,191,552	1.18	5,723,856	1.01	325,008
K_M	1.36	14,335,616	1.15	4,876,904	0.98	-530,944
K_H	1.33	13,379,664	1.12	3,911,968	0.95	-1,486,880

Allocating the full capital outlay of the new boiler alternative to resource recovery might be an appropriate procedure for steam-electric plants currently burning gas and/or oil.[22] The total capital costs of the new boiler alternative in the Orrville case were estimated at $6,115,000. Subtracting the previously determined incremental capital cost of $161,891 from $6,115,000 gives a value ($5,953,109) which can be subtracted from the net benefit estimates in Table 25 under medium coal and ferrous metal prices to give some notion of economic feasibility of this alternative. Only one combination of parameters (low capital outlay estimate and five percent discount rate) shows positive net benefits. With high coal and ferrous metal prices all but two of the parameter combinations show positive net benefits under the assumption of total capital outlay.

III. TOWARD GENERALIZATION OF RESULTS

Summary and Implications

It is not possible to make conclusive statements on the technical and economic feasibility of resource recovery in the nonmetropolitan areas of the North Central Region from the Ames and Orrville case studies. Alternatives evaluated include: (1) several levels of throughput in both cases, (2) comparison of old boiler modification vs. new boiler installation at Orrville, (3) single and multi-county wasteshed, (4) alternative landfill cost and RDF sulfur content comparisons in Ames,

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[22] For those gas and oil boilers that previously burned coal, modification of the existing boiler may be more appropriate than installation of a new boiler to burn RDF.

(5) a preliminary analysis of corn stover combustion in Ames, and (6) analysis of alternative stoker boiler coal firing ratios, coal price increases, discount rate, capital outlay and net ferrous revenues. These analyses from Part II of the study provide an array of outcomes that can be applied to a variety of situations identified in Part I of the study (see Table 26).

The Part I inventory of steam-electric plants in the North Central Region identified 86 coal burning, operating plants in nonmetropolitan areas. This represented 35 percent of all coal burning steam-electric plants in the North Central Region. Coal burning plants, in turn, represented 242 out of the total of 372 steam-electric plants in the region. A random sample of 25 (nine metropolitan) wastesheds and 53 (32 metropolitan) associated steam-electric plants provides detailed information on generation of solid waste and corn stover as well as plant capacities to burn RDF (see Tables 7 and 8 of Part I). Generation estimates were made assuming three definitions (12, 24, and 36 mile radius) of wasteshed size and three levels of per capita solid waste generation (3, 5, and 7 pounds). Plant RDF capacity estimates were based on both current and maximum coal burning capacity.

Assuming solid waste generation at five pounds per capita, from one to three (6.3 to 18.8 percent)[23] of the 16 sample nonmetropolitan wastesheds had single plants with RDF capacity greater than 100 tons/day and generated more than 100 tons of solid waste RDF per day within a 12 mile radius of the plant (see Table 8, Part I). These situations appear

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[23] Depending on whether the "current coal" or "maximum coal" RDF burning capacity estimate is used.

comparable to the Story County situation of the Ames case and one would expect the Story County benefit-cost results to be reasonably applicable. Expanding the wasteshed radius to 24 and 36 miles results in a substantial increase in solid waste generation in several of the sample wastesheds. The two and three county benefit-cost analyses of the Ames case should be relevant to those situations where the solid waste in the outlying areas is in sufficient concentration to justify a transfer station.[24]

Adding corn stover to the solid waste generated in a 12 mile radius results in a total of from three to seven sample nonmetropolitan wastesheds and their associated plants with both generation and burning capacity in excess of 100 tons RDF/day based on current and maximum coal burning capacity, respectively. The analysis of the Ames case assuming the corn stover in Story County as a supplement to the county's solid waste has implications for these situations, but further analysis of combined corn stover/solid waste combustion is needed. For the 10 nonmetropolitan sample plants (47.6 percent) with current coal RDF capacity less than 100 tons RDF/day, the analysis of the Ames case assuming corn stover as the sole source of RDF is a start. Recently completed research at OSU on corn stover combustion provides additional evidence on the feasibility of this concept based on an analysis of a small steam-electric plant (75 tons RDF/day) in Peru, Indiana [1].

Forty-four percent of the North Central Region metropolitan sample wastesheds had current coal based plant RDF capacity in excess of their

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[24] Examination of the detailed maps of the nonmetropolitan sample wastesheds suggests that 13 and 40 percent of the wastesheds at 24 and 36 miles, respectively, may have sufficient concentration of solid waste (30-50 tons/day) for the type of transfer stations analyzed in the Ames case. More analysis of transfer options and costs is needed before more definite conclusions can be reached.

solid waste generation (see Table 7, Part I). The two and three county transfer station analyses of the Ames case may have implications for such situations regarding adjacent nonmetropolitan areas transferring their solid waste to metropolitan recovery systems. Additional analysis of this alternative is needed and may be considered for Columbus, Ohio, and surrounding areas. A new 2000 ton/day RDF burning power plant recently approved by Columbus voters exceeds the solid waste generation capacity of the City of Columbus.

Of the 372 steam-electric plants located in the North Central Region, 82 (22 percent) are operating on gas and/or oil. Approximately 19 percent of these 82 plants were converted from coal burning. Because electricity generation is an inefficient use of natural gas, the Federal Energy Administration has stepped up its notices to city utilities and other power systems to prepare to stop using natural gas. In addition, more than 125 power plants that are planned or are under construction are being told to install coal burning rather than gas or oil burning capacity [17]. Thus, many of the steam-electric plants in the North Central Region currently burning gas and/or oil face conversion to coal or closing down. The analysis of the total costs of a new spreader-stoker boiler installation in the Orrville case suggests that the costs of converting these gas and oil plants to coal and solid waste may exceed the benefits (BC = .91)[25]

Table 26 summarizes the primary sample wasteshed and plant situations in terms of both their frequency and the B/C result(s) from the

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[25] This is particularly true for those gas and/or oil plant boilers that were not originally designed to burn coal.

Table 26. Summary of sample wasteshed and plant situations and most applicable case scenario B/C result(s)

Sample situations	Percentage of sample or population[a]	Applicable case scenario(s) under medium parameters[b]	B/C
A. Nonmetro wastesheds & coal burning plants			
1. 12 mile wasteshed solid waste RDF generation and plant cap. > 100 tons/day	12.6	Ames one county solid waste Orrville updated Luttner Orrville new boiler (incr. K)	1.27 .94 1.07
2. 12 mile wasteshed solid waste and stover RDF generation and plant cap. > 100 tons/day	18.8	Ames one-county solid waste and stover	1.18
3. Sufficient solid waste in adjacent counties for transfer (24 mile def.) and plant RDF cap. > 100 tons/day	13.0	Ames two-county solid waste	1.30 - 1.37
4. Sufficient solid waste in adjacent counties for transfer (36 mile def.) and plant RDF cap. > 100 tons/day	40.0	Ames three-county solid waste	1.37
5. Plant RDF cap. < 100 tons/day	35.7	Ames one-county stover (75 tons/day)	.98
B. Metro wastesheds with excess RDF capacity	61.1	Ames three-county solid waste	1.37
C. Gas and oil plants that were not originally designed for coal burning	17.7	Orrville new boiler (total K)	.91

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[a] Average values based on solid waste daily generation of five pounds per capita and average of current and maximum coal based plant capacity.

[b] Very tentative results. More analysis of metro wastesheds, nonmetro multi-county wastesheds and crop and/or forest residue is needed.

most applicable case study scenario(s). Solid waste generation is based on per capita generation of five pounds per day. The average of current and maximum coal based plant capacity is utilized. The benefit/cost result(s) presented for each sample situation are based on medium values for all technical and economic parameters.

The results should be viewed according to the context within which they were generated. Although they must be interpreted carefully, they do give some indication of the economic feasibility of resource recovery in a variety of wasteshed and power plant situations in the North Central Region under medium or "most likely" parameter values. Under these assumptions, the results show that 7 out of 10 of the benefit-cost scenarios have benefit-cost ratios greater then 1.0. In general, the results look promising for the economic feasibility of solid waste resources recovery in nonmetropolitan areas of the North Central Region. Variation in solid waste and stover density, landfill costs, boiler type and size, etc., exist in the region and can be approximated via sensitivity analysis of these and other important parameters.

Some sense of the relative importance of the various technical and economic parameters regarding their effect of the sensitivity analysis on the benefit-cost ratios for the two case studies is presented in Table 27. Allowing each of the parameters to vary from its low to high value while holding all other parameters at their medium values results in the following ranking (from most to least important) for the Ames case: Coal price projections, discount rate, landfill cost, sulfur content of RDF and one- vs. three-county wasteshed. Low coal price projections were not computed for the Orrville case due to the marginal

Table 27. Ranking by B/C of technical and economic parameters from sensitivity analysis of case studies

Ranking of parameters	Change in B/C
Ames:	
1. Coal price projections	1.08 to 1.60
2. Discount rate	1.09 to 1.48
3. Landfill cost	1.11 to 1.38
4. Sulfur content of RDF	1.25 to 1.27
5. One vs. three county wasteshed	1.27 to 1.37
Orrville:	
1. Discount rate	.86 to 1.04
2. Updated Luttner vs. new boiler (incremental K)	.94 to 1.97
3. Capital outlay	.91 to .98

economic feasibility at the medium coal price projections. The ranking (from most to least important) of those parameters fully evaluated at Orrville is: discount rate, updated Luttner vs. new boiler (incremental K), and capital outlay.

Given the sample wasteshed and power plant inventory and the benefit-cost case study and sensitivity analyses, some general conclusions seem possible. About 12.6 percent of the nonmetropolitan power plant and wasteshed situations are comparable to Ames, Iowa and Orrville, Ohio. Modification of existing boilers to burn RDF would appear economically feasible (B/C = .94 to 1.27) for these situations. New boiler installations to burn RDF appear marginal (B/C = .91) for the 17.7 percent of the sample involving gas and oil plants that were not originally designed for burning coal.

Approximately 18.8 percent of the nonmetropolitan 12 mile wastesheds exceed 100 tons/day of RDF if corn stover is added to solid waste.

Preliminary economic analysis of the combined combustion of solid waste and corn stover in the Ames case looks promising (B/C = 1.18) but more analysis is needed. Questions remain on the year round storage of corn stover and its processing and combined burning with solid waste at the power plant. Likewise, burning of only corn stover with coal in the 35.7 percent of the sample plants with RDF capacity less than 100 tons/day faces some of the same questions. A preliminary assessment in the Ames case at 75 tons/day showed marginal economic results (B/C = .98. More analysis of this concept is underway.

Conclusions on situations involving transfer of solid waste for multi-county nonmetropolitan or combined metro and nonmetro solid waste resource recovery are more difficult to make based on the case study results. The two and three county scenarios of the Ames case showed higher benefit/cost ratios than the one county situation (1.30 and 1.37 vs. 1.27). In addition, 61.1 percent of the sample metropolitan wastesheds had plant RDF capacity in excess of their solid waste generation. These findings favor economic feasibility of multi-county solid waste resource recovery, particularly for those nonmetropolitan counties adjacent to "excess RDF capacity" metropolitan areas. However, variations exist in the concentration of solid waste generation in the number, type, size, and location of steam-electric plants within and between wastesheds. Definite conclusions will require additional analysis of specific situations.

Limitations of Study

The Part I data collection effort made numerous unsuccessful attempts to obtain data on industrial and various types of institutional (e.g., state hospitals, prisons, universities, etc.) boilers in the North Central Region. A decision was made to utilize steam-electric utility boilers as a proxy for assessing the general feasibility of resource recovery, particularly in coal burning utility, industrial and institutional boilers. Limited evidence in Ohio suggests that the potential RDF capacity of coal burning steam-electric utility boilers may be a relatively small part of the state's total capacity. For example, Ohio EPA lists 1500 coal burning industrial boilers and only 130 coal burning steam-electric boilers. Omitting institutional boilers, if industrial and utility boilers are of comparable type and size, less than eight percent of the state's RDF capacity is represented by utility boilers. Although the steam-electric utility results from this analysis should have general application, additional analysis is needed specifically on resource recovery in industrial boilers.

More analysis of various transfer options and costs is needed for multi-county and adjacent metorpolitan county solid waste resource recovery potential in nonmetropolitan counties in the North Central Region. This analysis should consider larger than 20 cubic yard packer trucks as well as various types of temporary storage, compaction, processing and transfer alternatives. Work funded by Ohio EPA and currently underway at OSU is investigating these options for nonmetropolitan Ohio counties.

More analysis of crop and forest residue and a combination of residue and solid waste as supplementary fuels to coal is needed. Of particular interest is the possibility of utilizing crop residue (e.g., corn stover) to offset any reduction in the solid waste stream during the winter months when storage of crop residue appears to be least problematic.

APPENDIX A

Questionnaire for Less-Than-25-Megawatt Steam-Electric Plants in 12 North Central States

PLANT NAME:

LOCATION:

COMPANY:

INDIVIDUAL BOILER CHARACTERISTICS:

BOILER NUMBER							
INSTALLATION DATE							
ASSOCIATED TURBO-GENERATING CAPACITY (MW)							
MAXIMUM CONTINUOUS STEAM CAPACITY (1000 LBS/HR)							
STEAM PRESSURE (PSI)							
TYPE OF FIRING*							
TYPE OF BOTTOM (WET OR DRY)							
ASSOCIATED FLUE GAS CLEANING EQUIPMENT:							
MECHANICAL COLLECTORS**							
DESIGN EFFICIENCY							
ELECTROSTATIC & COMBINATION MECHANICAL-ELECTRIC PRECIPITATORS (CODE E OR C)							
DESIGN EFFICIENCY							
DESULFURIZATION SYSTEM***							
EFFICIENCY							
IS BOILER CAPABLE OF BURNING COAL							

*PLEASE CODE AS FOLLOWS:

PCFR-PULVERIZED COAL: FRONT FIRING
PCOP-PULVERIZED COAL: OPPOSED FIRING
PCTA-PULVERIZED COAL: TANGENTIAL FIRING
CYCL-CYCLONE
SPRE-SPREADER STOKER
OSTO-OTHER STOKER
FLUI-FLUIDIZED BED
RFRO-RESIDUAL OIL: FRONT FIRING
ROPP-RESIDUAL OIL: OPPOSED FIRING
RTAN-RESIDUAL OIL: TANGENTIAL FIRING
GFRO-GAS: FRONT FIRING
GOPP-GAS: OPPOSED FIRING
GTAN-GAS: TANGENTIAL FIRING
OTHE-OTHER: (PLEASE EXPLAIN IN FOOTNOTE)

**PLEASE CODE AS FOLLOWS:

GRAV-GRAVITATIONAL OR BAFFLED CHAMBER
SCTA-SINGLE CYCLONE-CONVENTIONAL REVERSE FLOW, TANGENTIAL INLET
SCAX-SINGLE CYCLONE-CONVENTIONAL REVERSE FLOW, AXIAL INLET
MCTA-MULTIPLE CYCLONES-CONVENTIONAL REVERSE FLOW, TANGENTIAL INLET
MCAX-MULTIPLE CYCLONES-CONVENTIONAL REVERSE FLOW, AXIAL INLET
CYCL-STRAIGHT-THROUGH-FLOW CYCLONES
IMPE-IMPELLER COLLECTOR
VENT-WET COLLECTOR: VENTURI
WETC-WET COLLECTOR: OTHER
BAGH-BAGHOUSE (FABRIC COLLECTOR)
OTHE-OTHER: (PLEASE EXPLAIN IN FOOTNOTE)

***PLEASE EXPLAIN

FOOTNOTES:

If possible, would you please respond to the following questions and elaborate when you feel it is necessary.

1. Do you foresee any modifications in your electricity generating program (i.e., changes in plant capacity, types of fuels or fuel mix, plant phase-out)?

   a. In the next five years:

   b. In the next twenty years:

2. Has the use of solid waste as a supplemental fuel been considered and/or analyzed for your plant?

3. Do you know of any physical constraints to the implementation of a system that would process solid waste and convey the organic portion to your existing boilers?

4. Would you be willing to use solid waste as a supplemental fuel if it were technologically and economically feasible?

5. Would you be willing to burn other forms of organic wastes, such as agricultural crop residues, if it were technologically and economically feasible?

APPENDIX B

Individual Coal Burning Steam-Electric Plant RDF Capacity Estimates for North Central Region

APPENDIX B. Individual Coal Burning Steam-Electric Plant RDF Capacity Estimates for N.C. States

State Wasteshed/ Plants	Plant Location	Public (Pub) OR Private (Priv)	Metro (M) OR Non-Metro (NM)	Current Coal RDF Capacity[a]	Max. Coal RDF Capacity[b]	Generating Capacity		
						Installed[c] Megawatt	Pulverized Coal Boilers % of Boiler Cap.	Stoker Fired Boilers % of Boiler Cap.
Illinois								
1/1	Bartonville	Priv	M	2024.	2024.	725.0	100	0
1/2	E. Peoria	Priv	M	357.1	480.4	325.0	85.8	0
1/3	Bartonville	Priv	M	0.0	127.4	54.4	28.7	0
2/4	Grand Tower	Pub	NM	573.5	573.5	194.6	100	0
3/5	Hutsonville	Pub	M	492.0	538.0	200.0	70.6	0
4/6	Merodosia	Pub	NM	849.7	849.7	354.4	100	0
5/7	Chicago	Priv	M	0.0	223.6	107.0	100	0
5/8	Chicago	Priv	M	1472.1	1595.1	701.5	85.2	0
5/9	Chicago	Priv	M	648.7	970.3	546.6	68.4	0
5/10	Waukegan	Priv	M	1476.7	1701.2	932.8	86.8	0
5/11	Winnetka	Pub	M	13.6	59.4	25.5	0	100
6/12	Joilet	Priv	M	2939.2	4391.5	1784.4	76.2	0
6/13	Lockport	Priv	M	2007.9	2842.0	1268.9	70.7	0
7/14	Dixon	Priv	NM	254.7	418.7	119.0	100.0	0
7/15	Rochelle	Pub	NM	125.6	125.6	12.7	0	100
8/16	Rockford	Priv	M	230.9	500.4	146.4	36.7	63.3
9/18	Joppa	Priv	NM	4000.8	4000.8	1100.3	100	0
10/19	Havana	Priv	NM	0.0	223.4	230.0	100	0
11/20	Hennepin	Priv	NM	742.7	752.2	306.3	100	0
11/21	Peru	Pub	NM	127.0	127.0	15.3	0	100
12/22*	Oakwood	Priv	M	544.0	544.0	182.3	100	0
13/23	Springfield	Pub	M	61.15	61.15	146.0	25.8	0
14/24	Woodriver	Priv	M	1095.0	1357.4	650.1	100	0
14/25	Venice	Priv	M	543.1	543.1	500.0	42.2	0
14/26	Highland	Pub	M	17.3	17.3	12.5	0	100
15/28	Mount Carmel	Pub	M	67.0	114.0	20.5	0	50
16/29	Champaign	Pub	M	0.0	23.7	75.0	100	0

APPENDIX B (con'd)

State Wasteshed/ Plants	Plant Location	Public (Pub) OR Private (Priv)	Metro (M) OR Non-Metro (NM)	Current Coal RDF Capacity[a]	Max. Coal RDF Capacity[b]	Generating Capacity: Installed[c] Megawatt	Generating Capacity: Pulverized Coal Boilers % of Boiler Cap.	Generating Capacity: Stoker Fired Boilers % of Boiler Cap.
Indiana								
17/30	Madison	Priv	M	3680.0	3680.0	1303.6	100	0
18/31	Indianapolis	Priv	M	95.0	168.5	59.1	65.9	24.7
18/32	Indianapolis	Priv	M	1963.7	1963.7	852.1	91.3	0
18/33	Centerton	Priv	M	777.6	783.1	393.6	100	0
18/34	Noblesville	Priv	M	120.7	121.6	106.0	100	0
19/35	Petersburg	Priv	M	1856.2	1856.2	724.4	100	0
19/36	Petersburg	Priv	M	658.1	658.1	233.2	100	0
19/37	Edwardsport	Priv	M	182.0	201.5	165.0	75	0
19/38	Jasper	Pub	M	113.9	113.9	21.5	0	100
20/39	Gary	Priv	M	1433.6	1476.8	529.4	100	0
21/40*	Cayerga	Priv	M	3259.0	3259.0	1025.0	100	0
22/41	Terre Haute	Priv	M	221.1	2261.1	149.0	100	0
22/42	Terre Haute	Priv	M	2456.3	2472.0	881.0	100	0
23/43	New Albany	Priv	M	1700.6	1717.3	637.0	100	0
24/44	Newburgh	Priv	M	1131.7	1131.7	414.9	100	0
24/45	Newburgh	Priv	M	496.9	496.9	300.0	100	0
25/46	Crawfordsville	Pub	M	244.9	244.9	35.2	0	100
26/47	Fort Wayne	Pub	M	118.3	118.3	40.0	67.7	0
27/48	Frankfort	Pub	M	232.1	248.3	32.5	0	100
28/49	Logansport	Pub	NM	198.9	213.2	74.2	0	100
28/50	Peru	Pub	NM	68.0	68.3	40.0	100	0
29/51	Richmond	Pub	M	215.2	215.2	93.0	100	0
30/52*	State Line	Priv	M	1595.8	2660.5	968.0	60	0
31/53	Mishawaka	Priv	M	21.4	649.2	237.5	100	0
102/186	Lawrenceburg	Priv	M	1338.7	2180.6	1100.3	45.4	0

APPENDIX B (con'd)

State Wasteshed/ Plants	Plant Location	Public (Pub) OR Private (Priv)	Metro (M) OR Non-Metro (NM)	Current Coal RDF Capacity[a]	Max. Coal RDF Capacity[b]	Generating Capacity		
						Installed[c] Megawatt	Pulverized Coal Boilers % of Boiler Cap.	Stoker Fired Boilers % of Boiler Cap.
Iowa								
32/54	Dubuque	Priv	M	183.8	434.2	81.3	83.6	16.4
33/56	Clinton	Priv	M	574.6	597.2	237.2	100	0
34/57	Boone	Priv	M	19.1	98.8	34.3	100	0
34/58	Ames #2	Pub	M	76.2	316.8	60.2	65	35
34/59	Ames CH	Pub	M	61.7	145.2	8.0	60	40
35/60	Cedar Rapids	Priv	M	247.5	573.9	148.8	52.1	47.9
35/61	Cedar Rapids	Priv	M	282.7	306.2	96.0	100	0
35/62	Cedar Rapids	Priv	M	116.6	177.0	92.3	100	0
36/63	Marshalltown	Priv	NM	91.8	397.7	156.0	47.9	0
37/64	Bettendorf	Priv	M	495.4	793.2	221.7	90.6	0
37/65	Mucatine	Pub	M	241.2	437.8	117.5	0	38.9
37/66	Montpelier	Pub	M	84.0	158.6	62.5	100	0
38/67	Sioux City	Priv	M	0.0	43.1	41.0	100	0
39/68	Des Moine	Priv	M	384.5	911.4	324.6	71.7	0
40/39	Carroll	Priv	NM	5.7	29.4	10.0	0	100
41/70	Eagle Grove	Priv	NM	1.1	9.0	7.5	100	0
41/71	Webster City	Pub	NM	8.5	26.7	37.9	0	100
41/72	Hamboldt	Pub	NM	78.5	739.7	41.5	36.1	63.9
42/73	Storm Lake	Priv	NM	4.5	20.7	19.0	100	0
43/74	Waterloo	Priv	M	115.8	531.6	97.4	66.1	33.9
43/75	Cedar Falls	Pub	M	108.7	326.5	66.6	56.7	43.2
44/76	Eccyville	Priv	NM	388.2	402.4	71.0	0	100
44/77	Pelta	Pub	NM	198.8	198.8	43.5	0	66.7
75/78	Burlington	Priv	NM	496.3	496.3	212.6	100	0
46/79	Salix	Priv	M	794.0	1128.3	496.3	70.4	0
47/80	Spencer	Pub	NM	44.3	115.8	7.5	100	0
48/81	Silbey	Pub	NM	2.8	15.0	2.5	0	100
49/83	Iowa Falls	Priv	NM	5.7	52.3	9.0	0	100
50/84	Mt. Pleasant	Pub	NM	8.5	8.5	42.0	0	100
92/171	Council Bluffs	Priv	M	323.7	486.6	130.6	100	0
125/228	Lansing	Priv	M	176.6	176.6	64.0	100	0

APPENDIX B (con'd)

State Wasteshed/ Plants	Plant Location	Public (PUB) OR Private (Priv)	Metro (M) OR Non-Metro (NM)	Current Coal RDF Capacity[a]	Max. Coal RDF Capacity[b]	Generating Capacity: Installed[c] Megawatt	Generating Capacity: Pulverized Coal Boilers % of Boiler Cap.	Generating Capacity: Stocker Fired Boilers % of Boiler Cap.
Kansas								
51/85	Riverton	Priv	M	98.6	344.5	145.0	76.7	0
52/86	Parsons	Priv	NM	6.8	535.5	113.5	35.2	0
53/87	Lawrence	Priv	M	421.6	1633.9	613.4	100	0
53/88	Tecumaeh	Priv	NM	6.8	535.5	113.5	35.2	0
183/154	Kansas City	Pub	M	31.5	367.5	161.3	59.5	0
183/155	Kansas City	Pub	M	149.4	155.5	94.5	100	0
183/156	Kansas City	Pub	M	123.3	596.0	239.1	65.9	0
Michigan								
54/89	Erie	Pub	M	1332.9	1332.9	325.0	100	0
54/91	Detroit	Pub	M	816.3	907.5	510.0	52.9	0
54/92	Detroit	Pub	M	409.7	409.7	174.0	100	0
54/93	Monroe	Pub	M	7082.7	7186.9	3279.6	100	0
54/94	Wyandotte	Pub	M	180.6	214.9	37.0	50	0
54/95	Wyandotte	Pub	M	386.8	537.4	54.1	84.4	0
54/96	Wyandotte	Pub	M	0.0	685.0	38.5	0	100
54/97	Wyandotte	Pub	M	16.4	249.8	40.0	0	86
54/98	River Rouge	Priv	M	2165.5	2357.5	933.2	31.3	0
54/99	Trenton	Priv	M	2166.8	2166.8	775.5	100	0
55/101	West Olive	Priv	M	1959.7	1969.9	650.0	100	0
55/102	Muskegon	Priv	M	2032.9	2043.1	510.5	100	0
55/103	Grand Haven	Pub	M	223.9	223.9	20.0	10.6	0
55/104	Holland	Pub	M	155.5	187.2	77.3	100	0
55/105	Essexville	Priv	M	1667.3	1667.3	530.0	50.9	0
55/106	Essexville	Priv	M	807.5	1506.9	614.5	100	0
55/107	Marysville	Priv	M	703.9	709.8	200.0	40.5	0
55/108	Port Huron	Priv	M	0.0	13.9	6.3	81.2	0
55/109	E. China Twp.	Priv	M	4195.4	5153.8	1905.0	100	0
55/110	Harbor Beach	Priv	NM	295.1	295.1	121.0	100	0
55/111	L'Anse	Priv	NM	81.2	110.9	18.8	100	0
60/112	Marquette	Priv	NM	1722.9	732.9	268.1	100	0
60/113	Marquette	Pub	NM	230.3	275.6	83.7	0	100
61/114	Escanaba	Priv	NM	314.6	314.6	93.0	0	100

APPENDIX B (con'd)

State Wasteshed/ Plants	Plant Location	Public (Pub) OR Private (Priv)	Metro (M) OR Non-Metro (NM)	Current Coal RDF Capacity[a]	Max. Coal RDF Capacity[b]	Generating Capacity		
						Installed[c] Megawatt	Pulverized Coal Boilers % of Boiler Cap.	Stoker Fired Boilers % of Boiler Cap.
Michigan								
61/115	Gladstone	Pub	NM	39.3	39.3	6.0	0	100
62/116	Coldwater	Pub	M	126.7	126.7	11.1	0	100
63/117	Lansing	Pub	M	534.3	538.5	386.0	100	0
63/118	Lansing	Pub	M	67.2	63.5	81.5	100	0
63/119	Lansing	Pub	M	452.8	452.8	160.0	100	0
63/120	Lansing	Pub	M	52.4	25.7	40.0	100	0
64/121	Traverse City	Pub	NM	204.6	268.4	35.0	0	75.6
65/122	Boyce City	Priv	NM	171.8	171.8	37.0	100	0
Minnesota								
66/123	Sherburn	Priv	NM	0.0	206.9	104.6	100	0
66/124	Blue Earth	Pub	NM	10.0	23.2	4.0	0	100
66/125	Fairmont	Pub	NM	66.3	263.8	24.0	0	31.7
67/126	Aurora	Priv	M	320.7	320.7	116.1	100	0
67/127	Hibling	Pub	M	252.5	263.8	19.0	0	100
67/128	Virginia	Pub	M	126.5	150.6	32.5	51.4	48.6
68/129	Cohasset	Priv	NM	1614.0	1614.0	514.5	100	0
69/130	Minneapolis	Priv	M	1029.6	1512.4	486.7	100	0
69/131	Minneapolis	Priv	M	501.9	523.4	455.9	17.6	0
69/132	St. Paul	Priv	M	889.3	1116.0	463.8	85.6	0
70/133	Granite Falls	Priv	NM	91.7	121.0	46.0	100	0
71/134	Redwing	Priv	M	90.2	221.7	23.0	0	100
72/135	Mankato	Priv	NM	73.3	205.9	25.0	0	100
73/136	Crookston	Priv	NM	86.3	99.0	10.0	0	100
74/137	Fergue Falls	Priv	NM	630.2	642.6	136.9	5.5	94.5
75/138	Ortonville	Priv	NM	218.6	218.6	15.0	0	100
76/139	Austin	Priv	NM	5.3	73.1	27.5	42.7	0
76/140	Austin	Priv	NM	25.5	72.5	32.0	100	0
77/141	Moorhead	Pub	M	17.3	17.3	42.0	0	90.3
78/142	New Ulm	Pub	NM	75.3	217.8	29.5	0	88.9
78/143	Sleepy Eye	Pub	NM	2.5	6.1	3.3	0	100
78/144	Springfield	Pub	NM	10.0	34.5	7.8	0	54.7
79/145	Rochester	Pub	M	0.0	92.9	98.6	100	0
80/146	Wilburn	Pub	NM	98.2	151.8	29.4	0	100

APPENDIX B (con'd)

State Wasteshed/ Plants	Plant Location	Public (Pub) OR Private (Priv)	Metro (M) OR Non-Metro (NM)	Current Coal RDF Capacity[a]	Max. Coal RDF Capacity[b]	Generating Capacity: Installed[c] Megawatt	Generating Capacity: Pulverized Coal Boilers % of Boiler Cap.	Generating Capacity: Stoker Fired Boilers % of Boiler Cap.
Minnesota								
81/147	Elk River	Pub	M	78.4	142.3	48.0	0	100
82/148	Litchfield	Pub	NM	0.0	0.2	3.0	100	0
48/82	Worthington	Pub	NM	0.0	29.6	16.5	68.9	0
Missouri								
14/27	St. Louis	Priv	M	2363.8	2363.8	800.0	100	0
83/149	Kansas City	Priv	M	138.5	240.4	126.8	79.9	0
83/150	Kansas City	Priv	M	1418.8	2021.6	908.1	100	0
83/151	Pleasant Hill	Pub	M	14.3	81.2	49.5	100	0
83/152	Independence	Pub	M	59.4	307.5	115.0	100	0
83/153	Missouri City	Pub	M	6.5	14.1	40.0	100	0
84/157	St. Joseph	Pub	M	41.4	167.2	234.5	18.7	0
85/158	Jefferson City	Priv	NM	0.9	5.7	212.7	100	0
139/161	Mexico	Priv	NM	0.0	159.8	19.0	0	100
138/160	Columbia	Pub	M	220.0	0.0	107.8	63.5	0
85/159	Chamois	Priv	NM	43.8	96.0	59.0	26.9	0
86/162	Chillicothe	Priv	NM	54.7	54.7	15.0	0	100
87/163	Marshall	Priv	NM	139.2	168.6	30.5	62.3	37.7
89/164	Springfield	Priv	M	166.1	575.7	253.0	100	0
89/165	Palmyra	Priv	NM	3.0	3.0	15.0	0	100
90/166	Labadie	Priv	M	5593.3	5627.9	2220.0	100	0
91/167	Henry County	Priv	NM	1672.6	1672.6	33.0	100	0
Nebraska								
92/168	Omaha	Pub	M	0.0	39.0	83.5	100	0
92/169	Omaha	Pub	M	943.8	1788.1	644.2	100	0
92/170	Bellevue	Pub	M	215.9	380.2	112.5	100	0
93/172	Fremont	Pub	M	303.6	38.2	21.0	100	0
93/173	Fremont	Pub	M	34.2	114.4	41.2	100	0
94/174	Lincoln	Pub	M	28.4	94.3	32.0	80	0
95/175	Alliance	Pub	NM	0.0	82.3	16.5	0	64.1
N. Dakota								
96/176	Mandan	Priv	NM	1103.4	1103.4	100.0	0	100
97/177	Devil's Lake	Priv	NM	175.0	175.0	12.5	0	100
98/178	Wahpeton	Priv	NM	122.7	122.7	20.5	0	100

APPENDIX B (con'd)

State ----------- Wasteshed/ Plants	Plant Location	Public (Pub) OR Private (Priv)	Metro (M) OR Non-Metro (NM)	Current Coal RDF Capacity[a]	Max. Coal RDF Capacity[b]	Generating Capacity Installed[c] Megawatt	Generating Capacity Pulverized Coal Boilers % of Boiler Cap.	Generating Capacity Stoker Fired Boilers % of Boiler Cap.
N. Dakota								
99/179	Stanton	Pub	NM	970.5	0.0	215.7	100	0
99/180	Stanton	Pub	NM	619.2	619.2	172.0	100	0
99/181	Beulah	Priv	NM	237.8	237.8	13.5	0	100
100/182	Velva	Pub	NM	230.0	230.0	34.5	100	0
101/183	Grand Forks	Pub	NM	97.5	97.5	21.5	0	100
Ohio								
54/90	Toledo	Priv	M	589.8	696.8	907.5	100	0
54/100	Oregon	Priv	M	2166.8	2166.8	659.5	100	0
102/184	North Bend	Priv	M	1014.0	1093.3	393.2	66.9	0
102/185	Hamilton	Pub	M	158.9	331.4	83.5	31.3	2.5
102/187	South Dayton	Priv	M	982.1	1047.5	416.0	100	0
102/188	Dayton	Priv	M	717.1	782.0	448.0	100	0
102/189	New Richmond	Priv	M	2314.9	2314.9	712.3	100	0
104/190	Ashtabula	Priv	M	1588.0	1954.4	640.0	68.8	0
105/191	Avon Lake	Priv	M	3479.4	3673.6	1275.0	85.1	0
105/192	Eastlake	Priv	M	3738.1	3738.1	1257.2	100	0
105/193	Cleveland	Priv	M	1683.8	1683.8	514.0	100	0
105/194	Cleveland	Pub	M	163.6	169.3	160.0	100	0
105/195	Lorain	Priv	M	543.2	543.2	192.9	100	0
105/196	Painesville	Pub	M	283.0	283.0	38.0	0	100
106/197	Conesville	Priv	NM	405.4	638.3	433.5	33.3	0
106/198	Conesville	Priv	NM	2373.4	2373.4	641.5	100	0
106/199	Philo	Priv	NM	845.0	845.0	500.0	75	0
107/200	Columbus	Priv	M	395.8	397.8	170.8	100	0
107/201	Columbus	Pub	M	30.4	240.3	52.5	54.9	0
108/202	Akron	Priv	M	332.2	332.2	87.5	100	0
108/203	Orrville	Pub	M	160.0	323.2	108.5	81.2	18.3
109/204	Athens	Priv	NM	744.2	744.4	292.9	100	0
110/205	Aberdeen	Priv	NM	5079.1	5079.1	2440.8	100	0
111/206	Shadyside	Priv	M	1739.4	1739.4	192.9	100	0
111/207	Toronto	Priv	M	563.8	563.8	175.8	100	0
111/208	Stratton	Priv	M	6097.6	6097.6	303.0	100	0
111/209	Brilliant	Priv	M	2975.3	2991.7	1230.5	100	0
111/210	Brilliant	Priv	M	716.9	723.9	226.3	100	0

APPENDIX B (con'd)

State ----------- Wasteshed/ Plants	Plant Location	Public (Pub) OR Private (Priv)	Metro (M) OR Non-Metro (NM)	Current Coal RDF Capacity[a]	Max. Coal RDF Capacity[b]	Generating Capacity Installed[c] Megawatt	 Pulverized Coal Boilers % of Boiler Cap.	 Stoker Fired Boilers % of Boiler Cap.
Ohio								
111/211	E. Palestine	Pub	M	114.7	114.7	16.5	0	100
112/212	Springfield	Priv	M	274.9	274.9	75.0	66.67	33.33
113/213	Gallipolis	Priv	NM	913.4	921.6	1300.0	100	0
113/214	Cheshire	Pub	NM	4170.7	4170.7	1086.3	100	0
114/215	Bluffton	Priv	M	90.6	94.7	37.5	100	0
115/216	Beverly	Priv	NM	562.5	4053.9	1529.6	69.3	0
116/217	Dover	Pub	M	66.2	66.2	35.9	100	0
117/218	Napolean	Pub	M	119.5	119.5	23.7	0	100
118/219	Piqua	Pub	M	446.9	446.9	56.8	0	100
119/220	St. Mary's	Pub	M	21.4	21.4	12.5	100	0
120/221	Shelby	Pub	M	55.2	55.2	40.0	100	0
S. Dakota								
121/222	Lead	Priv	NM	170.0	181.9	31.5	86.9	13.1
122/223	Sioux Falls	Priv	M	106.5	150.0	48.0	47.9	52.1
123/224	Aberdeen	Priv	NM	39.5	104.7	12.5	0	100
124/225	Mitchell	Priv	NM	39.5	100.7	12.5	0	100
Wisconsin								
8/17	Beloit	Priv	M	23.0	181.1	150.0	100	0
32/55	Cassville	Priv	M	116.9	116.9	227.2	100	0
125/226	Lacrosse	Priv	M	0.0	27.7	25.0	0	100
125/227	Genoa	Pub	M	1100.7	1100.7	14.0	100	0
126/229	Ashland	Priv	NM	22.1	247.2	80.0	0	18.2
127/230	Madison	Priv	M	121.0	763.7	195.5	31.6	0
128/231	Milwaukee	Priv	M	695.8	703.8	272.0	100	0
128/232	Oak Creek	Priv	M	1156.9	1156.9	500.0	100	0
128/233	Oak Creek	Priv	M	2603.5	2603.5	1191.6	100	0
129/234	Port Washington	Priv	M	709.4	709.4	400.0	100	0
130/235	Sheboygun	Priv	NM	553.5	1106.9	126.0	13.3	0
131/236	Green Bay	Pub	M	1267.1	1291.4	392.5	94.9	0
132/237	Ruthschild	Pub	NM	359.7	489.9	139.0	100	0
133/238	Manitowc	Pub	NM	439.5	439.5	69.0	0	100
134/239	Marshfield	Pub	NM	263.7	339.6	41.5	69.9	0
135/240	Menaska	Pub	M	194.2	194.2	29.2	0	100
136/241	Richland Center	Pub	NM	60.6	60.6	14.3	0	100
137/242	Ulma	Pub	NM	550.3	550.3	187.8	100	0

APPENDIX B (con'd)

FOOTNOTES

a/ RDF capacity based on 1974 coal usage at coal burning plants in the N.C. Region.

b/ RDF capacity based on maximum potential coal usage at coal burning plants in the N.C. Region.

c/ Based upon the original installed megawatt generating capacity at the power plant. It was not possible to get the proportion of RDF capacity represented by pulverized coal and stoker boilers.

* 12/22, 21/40, and 30/52 are overlapping wastesheds.

Note: Detailed State maps locating the wastesheds and plants by number are available on request from the authors.

APPENDIX C

Linear Programming Model for Optimizing the Fuel Mix at Ames Municipal Power Plant

Linear Programming (LP) is a mathematical technique that permits the optimization (minimization or maximization) of a specified goal under a given set of conditions. More precisely, LP is a systematic method of maximizing a linear objective function subject to restraints imposed by a set of one or more linear inequalities. The objective function and the constraints state the relationships between the variable of a problem whose values ar the optimal solution are to be determined. In equation form the general linear programming format is:

Maximize

$$f = \sum_{j} c_j X_j$$

subject to

$$b_i = \Sigma_{aij} X_j \qquad i = 1, 2, \ldots, m$$

where f is the value to be maximized,

c_j = the effect on f of a unit change in X_j,

b_i = a constant representing available supply of resource, etc., and

a_{ij} = the input-output coefficient. A one unit change in X_j will affect the entity measured by b_i by a_{ij} units.

The use of LP in the present analysis allows the determination of the cost savings in the fuel mixture due to the inclusion of refuse derived fuel (RDF) in this mixture. LP allows the determination of the least cost fuel mixtures with and without the inclusion of RDF, the difference representing the cost savings (the value of RDF). It also allows the determination of the quantity of fuels and ash in the optimal mix.

The format and specification of the model is:

Minimize

f = 0.0 RDF + 0.01625 CC + 0.00885 IC

subject to

SULFUR: 2.5 $\geq$ 0.0016 RDF + 0.0055 CC + 0.055 IC

HEAT: 100.0 $\geq$ .5000 RDF + 1.2200 CC + 0.9345 IC

MAXRDF: 35.5 $\geq$ 1.0 RDF + 0.0 CC + 0.0 IC

where: f = the cost of the optimal fuel mix per 10^6 BTU

RDF = Refuse Derived Fuel (lbs.)

CC = Colorado coal (lbs.)

IC = Iowa coal (lbs.)

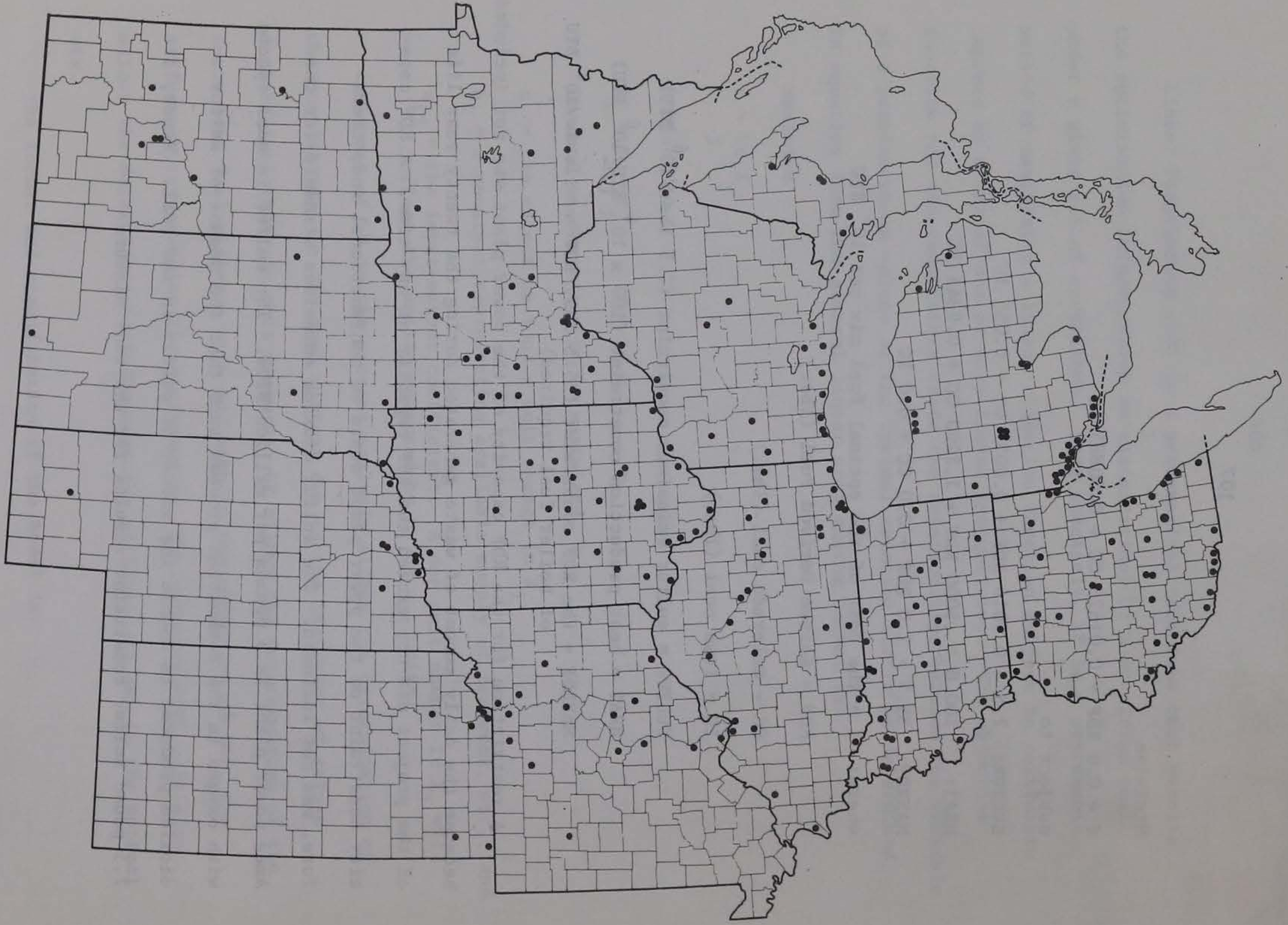
SULFUR = sulfur emissions constraint (2.5 lbs./10^6 BTU)

HEAT = heat production constraint (100 x 10^4 BTU/10^6 BTU)

MAXRDF = the RDF constraint (35.5 lbs. RDF available/10^6 BTU of boiler fuel required)

A restriction for the RDF capacity of the power plant was not included because the daily amount of waste generated during the twenty year life of the project did not exceed the RDF capacity at any time. A RDF capacity constraint on the power plant would be nonfunctional and, therefore, was not included. The sulfur dioxide emissions standard for the Ames power plant is 5 pounds per million BTUs. The sulfur in coal reacts with oxygen in the combustion process such that the amount of sulfur dioxide produced is double the amount of sulfur in the coal. Hence, a 2.5 pound sulfur constraint results for the fuel mixture.

APPENDIX D: Location of 242 Coal Burning, Steam-Electric Plants in the North Central Region[a]



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[a] Each dot represents the location of one coal burning, steam-electric plant. Contiguous dots generally represent several plants in one community. State maps with much more detail are available from the authors. See page 113.

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A limited number of copies are available of detailed state maps which delineate locations of plant sites and wastesheds. Write Dr. Fred Hitzhusen, Department of Agricultural Economics, Ohio State University, Columbus, OH 43210.