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Regional Energy Availability from Conversion of Solid Waste

Remote sensing techniques can be used to delineate urban and rural solid organic waste, which can be used to generate electricity.

Introduction

Approximately 3.5 billion tons of solid waste are generated annually in the United States. Agricultural wastes, i.e., manure and crop wastes, amount to more than 2 billion tons, while over 250 million tons are generated by commercial, industrial, and municipal activities. Another 1.1 billion tons of wastes are generated by mining activities (Vaughan, 1969).

Concern over the increasing volume of solid waste, deteriorating air quality resulting from improper incineration, and the lack of suitable land for waste disposal has prompted solid waste managers and planners to explore new methods of waste disposal and/or treatment. These methods include (1) pyrolysis (decomposition of mixed municipal wastes in anaerobic or controlled oxygen environments to produce gasses, tars, char, or oils); (2) separation and recycling (recovery of materials such as glass, metals, and organics for re-use); (3) composting (conversion or organic wastes into humus-like material for use as a soil conditioner); and (4) energy generation (conversion of organic wastes to fuel or steam for generating electricity).[1]

Increased interest recently has been expressed in the conversion of solid waste to energy. Our nation's energy crisis, coupled with real environmental concerns over energy/resource exploitation, makes the concept of using solid waste as an energy source particularly appealing. Conceivably, both the energy crisis and the solid waste disposal dilemma could be alleviated by using waste/energy conversion technology.

Abstract: *Multi-scale remote sensing records, when used in conjunction with suitable waste production and energy usage multipliers derived from ground-based investigations, can contribute useful quantitative and spatial information relating to (1) the generation of solid organic wastes in urban and rural environments; (2) the energy requirements in terms of residual fuel oil of urban/industrial areas; and (3) the collection and transportation of organic wastes to energy conversion and distribution facilities for meeting regional urban/industrial energy needs.*

The presence of organic wastes on the earth's surface is practically universal, and it would be economically impractical to collect all waste/energy materials in a given region. Studies to determine the waste/energy po-

[1] Research currently is being conducted to establish the technologic and economic feasibility of these methods. Pilot projects are underway in several U.S. cities to test the feasibility of using shredded organic wastes as a fuel for producing steam. Additionally, the U.S. Bureau of Mines has been successful in converting solid waste to low sulfur fuel oil and gas (Anderson, 1972).

tential of any given region have not been conducted. Existing waste conversion technology is currently focused on the use of selected quantities of organic wastes collected from large urban areas. The technical and economic feasibility of using shredded organic wastes to make steam or of converting wastes to oil is now being demonstrated. The U.S. Bureau of Mines, for example, has been successful in converting organic solid wastes to oil. A net gain of 1.25 barrels of oil from each ton of dry organic waste has been produced. Appendix A provides additional information regarding this and other waste conversion processes.

This paper demonstrates a method for determining the waste/energy potential of a region—the city and surrounding area of Salem, New Jersey—with remote sensing[2] techniques. An important objective was to estimate Salem's electrical energy requirements (in terms of residual fuel oil) and to determine Salem's waste/energy potential for meeting this requirement. This information was acquired from analysis of aerial photography. Color infrared aerial photography at scales of 1:80,000 and 1:12,000 served as the primary data sources.

Background

The Energy Situation in the U.S.

Approximately 100 years ago, 75 percent of the Nation's energy came from wood. By the turn of the century, coal had become the principal energy source, supplying the U.S. with 71 percent of its energy. In the 1930's, a shift toward oil and gas occurred; after World War II oil and gas were supplying more energy than coal. It has been predicted that nuclear power will supply approximately 25 percent of the Nation's electricity by 1980, increasing to 40 percent by 1990 and 60 percent by 2000 (Joint Economic Committee, 1970).

Energy sources (actual or potential) may be categorized as renewable or non-renewable. Resources which are essentially non-renewable, include (1) coal, (2) natural oil, (3) natural gas, and (4) oil shale. Renewable resources include wood and organic wastes. A third category is comprised of sources which may offer virtually unlimited energy including nuclear, solar, and geothermal sources.

Generally, it is more desirable to use unlimited or renewable energy sources than to exhaust non-renewable sources. Organic waste is a potential energy resource which is renewable. The conversion of organic wastes to energy will reduce waste problems and some of the associated environmental consequences while providing a reliable and growing fuel source.

Utilization of Remote Sensing for Solid Waste Studies

In studies completed by Garofalo and Wobber (1973), small-scale (1:120,000) color infrared aerial photography was analyzed to identify solid waste quantities, characteristics, and distributions within the Tampa, Florida urban area. These aerial photographs provided an information base for determining the spatial distribution of waste producers (categories of waste generating sources). Estimates of solid waste quantities within waste categories were made by utilizing predetermined waste multipliers[3] (see Table 1). Multipliers having sufficient detail for high-altitude surveys can be developed nationally through selective spot sampling surveys. These multipliers, when used in conjunction with data derived from remote sensing analysis, can be used to monitor changes in solid waste quantities at the regional level. (see Table 2.)

These initial studies have formed a foundation for expanding the use of remote sensing technology from analyses primarily oriented toward solid waste disposal to applications for determining energy availability within a region.

Project Objectives

Since the quantity of waste energy available in a region and (more importantly) the regional distribution of these waste sources has not been identified, a demonstration study of the Salem, New Jersey area was conducted in order to determine the feasibil-

[2] Remote sensing is the use of sensor elements such as aerial photography, thermal (heat) sensors, and satellite or spacecraft imagery, to acquire information about the surface of the earth. Color infrared photography was selected because it has proven to be the most suitable remote sensing technique for solid waste studies, based on the experience of the authors.

[3] A waste multiplier is a numerical estimation of the average quantity of waste generated by a waste source, resident, or employee per unit of time. Waste multipliers can be developed for residential, commercial, non-manufacturing, public agency, industrial, and agricultural sources of wastes. Table 2 lists waste multipliers which are particularly amenable to small scale remote sensing methods for estimating waste quantities.

TABLE 1. WASTE MULTIPLIERS DEVELOPED FOR SANTA CLARA COUNTY, CALIFORNIA.

Residential	
Single Family Dwelling	1.43 tons/dwelling/year
Multiple Family Dwelling	0.66 tons/dwelling/year
Commercial and Public Facilities	3.81 tons/employee/year
Demolition and Construction	41.3 tons/employee/year
Industrial	
Ordinance	0.658 tons/employee/year
Canning and Preserving	5.565 tons/employee/year
Other Food Processing	4.816 tons/employee/year
Tobacco	2.493 tons/employee/year
Textiles	0.525 tons/employee/year
Apparel	0.525 tons/employee/year
Lumber and Wood Products	21.688 tons/employee/year
Furniture and Fixtures	20.155 tons/employee/year
Paper and Allied Products	12.538 tons/employee/year
Printing, Publishing and Allied	13.202 tons/employee/year
Chemicals and Allied	8.210 tons/employee/year
Petroleum Refining	Omitted
Rubber and Plastics	1.548 tons/employee/year
Leather	2.493 tons/employee/year
Stone, Clay, Glass, Concrete	18.114 tons/employee/year
Primary Metals	6.730 tons/employee/year
Fabricated Metal Products	6.730 tons/employee/year
Non-electrical Machinery	4.182 tons/employee/year
Electrical Machinery	2.978 tons/employee/year
Transportation Equipment	3.393 tons/employee/year
Instruments	2.517 tons/employee/year
Miscellaneous Manufacturing	2.493 tons/employee/year

SOURCE: *Comprehensive Studies of Solid Waste Management;* Second Annual Report; U.S. Department of H.E.W. Bureau of Solid Waste Management, 1970.

ity of utilizing multi-scale aerial photography to:

- estimate the total electrical energy (residual fuel oil) requirement of a given area
- assess the spatial distribution of organic waste sources in a region
- determine the quantity of organic wastes available in the region which could help to meet regional energy requirements and
- identify the source areas within a region which have the highest waste-energy potential.

SOLID WASTE/ENERGY PROJECT APPROACH

TEST AREA SELECTION

Salem, New Jersey (Figure 1) was selected to be the test area for this study because (a) the authors wished to conduct initial tests within a small-sized urban area (the population of Salem city is 7,648) for reasons of time, cost, and simplicity; (b) the city is relatively isolated from the influence areas of nearby cities thereby eliminating variables which may have complicated the analysis; (c) detailed data needed for the development of waste multipliers were available; and (d) existing comparative photography (1:12,000 and 1:80,000 scale color infrared) was readily available.

DETERMINATION OF SALEM'S CURRENT ENERGY REQUIREMENTS

The total electrical energy requirement for Salem was determined as follows: First, the types of land use within the Salem area were mapped from the analysis of 1:12,000 and 1:80,000 scale color infrared aerial photographs. Four categories were identified:

- Industrial
- Commercial
- Residential (Single-family)
- Residential (Multi-family)

Second, electrical energy users were inventoried by type and number within each land-use category. This was accomplished by inventorying the number of buildings within each category using 1:12,000 and 1:80,000 scale color infrared photography. The results of this photo-inventory are compared with the actual number determined from local census data (Table 3)[4]. These data were utilized to determine the total annual electrical energy requirement for Salem. Average energy requirements for these users were then applied to determine the total

[4] Electrical energy consumption was estimated only for the urban areas of Salem.

TABLE 2. WASTE MULTIPLIERS SUITABLE FOR REMOTE SENSING APPLICATIONS TO WASTE QUANTITY ESTIMATION

Santa Clara, County, California[1]			New Jersey[2]		
RESIDENTIAL			HOUSEHOLD	14.41	lbs/day
			COMMERCIAL	38.82	tons/day/square mile
Single Family Dwelling	1.43 tons/dwelling/year		INDUSTRIAL	116	tons/day/square mile
Multiple Family Dwelling	0.66 tons/dwelling/year				
AGRICULTURAL					
MANURE					
Cattle	10.44 lbs/cow/day				
Swine	.795 lbs/pig/day				
Poultry	.20 lbs/bird/day				
VINEYARDS/ORCHARDS (lbs/acre-year)					
	BEARING	*NONBEARING*			
APPLE	3100	250			
APRICOT	3084	750			
CHERRY	2853	625			
PEACH	2934	720			
PEAR	6084	1620			
PLUM	4080	760			
PRUNE	1083	592			
OLIVE	3118	—			
FIG	3117	—			
PERSIMMON	3117	—			
ORANGE	3117	—			
WALNUT	1010	255			
ALMOND	642	—			
MISCELLANEOUS		753			
FRUITS/NUTS	3171	1209			
GRAPE	3224				
FIELD CROP WASTES	*1-4 TONS/ACRE-YEAR*				

[1] *Comprehensive Studies of Solid Waste Management,* Second Annual Report; U.S. Department of H.E.W., Bureau of Solid Waste Management, 1970.

[2] *New Jersey State Solid Waste Management Plan;* Bureau of Solid Waste Management, Department of Environmental Protection, July, 1970, 111pp.

energy requirements of each land-use category[5]. Finally, the total energy requirement of the Salem urban area was estimated by combining the energy requirements of all categories.

When estimating energy use for Salem, the authors used figures relating to large-use customers, since these data more nearly represented the total energy use for a given energy user[6]. Table 4 compares energy sales per new residential customer in the northeast region (where Salem is located) for small, medium, and large-use customers for 1970.

For commercial establishments an average annual kilowatt hour per customer figure was available for the northeast United States. In 1970, an average of 32,689 kwh were used per commercial customer. Industrial and miscellaneous use (highway light-

[5] Whereas census data listing energy users (e.g., number of buildings) are often available, they fail to show the spatial distribution of these energy users. Aerial photography which is unrestricted by jurisdictional boundaries shows the location of energy use groupings which may cross these boundaries. Additionally, aerial photographs provide information pertinent to the determination of energy requirements in a single format. Regional energy requirements may, therefore, be estimated more accurately and conveniently than with census data.

[6] The authors used data from the National Power Survey for regional electrical energy sales per residential, commercial, or industrial customer. Annual kilowatt hours per customer, for example, were available for small-use, medium-use, and large-use electricity consumers for single family and multi-family dwellings in the northeast United States. A small energy use customer uses electricity for lights and small appliances and may have one or two major electrical applicances such as a range, dryer, water heater, or air conditioner. A medium energy use customer has several major electrical appliances, but uses some other form of energy for space heating. A large energy use customer is one who uses electricity for all of his energy requirements including space heating (the 1970 National Power Survey).

FIG. 1. Black-and-white reproduction of a color infrared aerial photograph showing the city and surroundings of Salem, New Jersey. By means of photo interpretation techniques the city was separated into seven waste source areas (Figure 2). Energy use categories described in the text were delineated. An inventory of the number of buildings or acreage within each category was then completed by using photo analysis procedures. Information on the total quantity of organic wastes generated and the electrical energy requirement of the city was derived by then applying available waste multipliers and energy use data. Original photographic scale, 1:12,000 (reduced by ½. Ed.).

TABLE 3. COMPARISON OF DATA GENERATED THROUGH PHOTOINTERPRETATION (P) WITH AVAILABLE CENSUS (c) DATA FOR SALEM, NEW JERSEY.

	No. of units or operations (p)	No. of residents or employees (p)	No. of units or operations (c)	No. of residents or employees (c)
Single Family Dwellings	1600	N/A	1735	N/A
Multi-family Dwellings	900	N/A	846	N/A
Commercial Facilities	200	1260	193	Not available
Industrial Facilities	14	2800	Not available	Not available

TABLE 4. ENERGY SALES PER NEW RESIDENTIAL CUSTOMER, SINGLE FAMILY AND MULTI-FAMILY CUSTOMERS (ANNUAL kWh PER CUSTOMER)

	Small-use Customer	Medium-use Customer	Large-use Customer
Single-family residential	4,600	8,700	24,100
Multi-family residential	2,600	4,700	13,900

Source: The 1970 National Power Survey, Federal Power Commission Part IV, 1970.

TABLE 5. SALEM'S TOTAL ANNUAL ENERGY REQUIREMENT (kWh) BASED ON CENSUS (c) AND PHOTOGRAPHIC (p) ACQUIRED DATA

	No. of units or operations (p)	Energy Requirement (p)	No. of units or operations (c)	Energy Requirements (c)
Single Family Dwellings	1600	38,560,000	1735	41,813,500
Multi-family Dwellings	900	12,510,000	846	11,759,400
Commercial Facilities	200	6,537,800	193	6,308,977
Industrial Facilities	14	17,612,000	Not given	—
Total Annual Energy Requirement (kWh)		75,219,800		59,881,877*

* Does not include industry.

ing, etc.) average 1,258,000 kwh per customer per year.

Of course type of commercial and industrial activity greatly affects the consumption of energy by that activity. It must be emphasized, therefore, that the total electrical energy needs of the city of Salem have been roughly estimated for purposes of this study. Table 5 summarizes results.

DETERMINATION OF SALEM CITY'S WASTE/ENERGY POTENTIAL

Research by the authors has indicated that the quantity of wastes available for conversion to energy represents 25 percent of residual fuel oil imports. Therefore, it is necessary to view this process as a supplemental source which can meet a percentage of an area's total energy requirement. Current shortfalls in fuel supplies are being reported at figures widely varying from 15 to 30 percent. For the purposes of this study, the authors judge 25 percent to be a reasonable figure for waste/energy conversion. Assuming that Salem, New Jersey may wish to supplement 25 percent of its total residual fuel requirement with energy derived from organic waste, this established percentage would directly determine the size of the collection area required to provide a sufficient volume of wastes for energy conversion. An increase in percentage would increase the required area of collection.

Waste multipliers shown in Tables 1 and 2 were applied to the Salem area in order to estimate total waste generated. The number of square miles devoted to industry and commerce was computed photogrammetrically. Approximately 180 acres within Salem are devoted to industrial activities, and 130 acres are used by business or commercial establishments. Table 6 summarizes the estimated total quantity of waste generated within the Salem city limits.

Assuming that 1.25 barrels of oil are produced from each ton of dry organic waste, the urban area of Salem could produce 10,000 barrels of oil per year. One barrel of residual fuel oil from waste contains 4,500,000 Btu (Energy Fact Sheets, 1973). This represents a Btu potential of 45 billion (45,000,000,000). The amount of energy equal to 1 kwh is equivalent to 3,412 Btu[7]. Therefore, the oil produced from Salem's urban waste would generate 13,188,745 kwh of energy, representing 18 percent of Salem's estimated annual electrical energy requirement.

If 25 percent of Salem's energy needs are to be supplemented by fuel oil from converted organic wastes, 7 percent of the energy requirement must be obtained from conversion of organic wastes which lie outside of Salem's urban area. This 7 percent requirement could be met by collecting approximately 3,200 tons of dry organic materials from farmlands, wetlands, or other land resources characteristic of the surrounding rural landscape.

EXPANSION TO RURAL WASTE COLLECTION AREAS

Salem is surrounded by agricultural crop and pasture land, woodland,[8] and wetlands (Figure 2). Each of these land-use categories has its associated organic waste materials,

[7] This is a net value which remains after any loss associated with conversion of oil to electricity.

[8] The Bureau of Mines did convert pine needles into oil. By definition, the term solid waste does not usually include organic debris such as leaves from deciduous trees, pine needles, twigs, etc., unless they occur in areas where they are collected and disposed of, i.e., urban and agricultural areas. These are, however, potential sources of organic materials which conceivably could be collected with minimum environmental harm. The authors do address wetland vegetation as a viable concentrated source of organic plant material in the Salem area.

TABLE 6. TOTAL WASTE QUANTITY GENERATED WITHIN THE SALEM CITY LIMITS BASED ON PHOTOGRAMMETRIC COMPUTATIONS AND APPLIED WASTE MULTIPLIERS

	No. of Units	No. of Square Miles	Waste Multiplier	Total Waste Quantity
Single Family Dwellings	1,600	—	1.43 tons/dwelling/year	2288 tons/year
Multi-family Dwellings	900	—	0.66 tons/dwelling/year	594 tons/year
Commercial Area	—	0.20	38.83 tons/day/sq. miles	2,834 tons/year
Industrial Area	—	0.30	116 tons/day/sq. miles	12,702 tons/year
Total Annual Urban Waste Quantity				18,418 tons/year
Total Dry Organic Solids*				8,000 tons/year

* 50 percent of total urban waste stream estimated to be dry organic wastes (Anderson, 1972). 40 percent of industrial wastes estimated to be dry organic solids (Anderson, 1972).

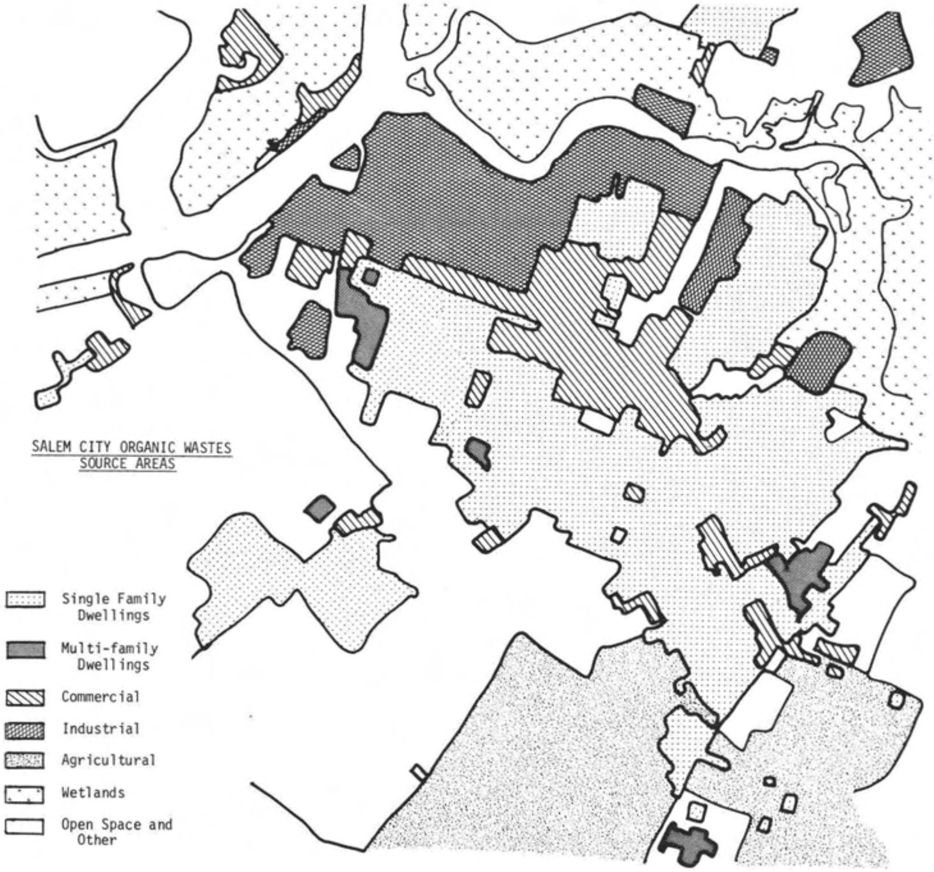

FIG. 2. Map generated through interpretation of 1:12,000 and 1:80,000 scale color infrared photography (see Figure 1). The city of Salem was separated into seven organic waste source areas. An inventory of the number of buildings and/or acreage within each source area was then determined photogrammetrically. The total quantity of organic waste generated within the Salem urban area was thereby derived in order to estimate the city's organic waste energy potential.

and its unique rate of organic waste generation.

Field crops, which predominate over other agricultural wastes such as manure, vineyards, and orchards in the Salem area, produce 1 to 4 tons/acre-year of organic waste material. Much of these wastes are now plowed under or burned in the field, but they do represent a potential source of organic materials which could be collected without serious detriment to future cropping practices. Assuming that agricultural wastes alone would be collected to make up the 7 percent energy requirement deficit, and applying an average figure of 2.5 tons/acre-year of available organic waste from agricultural field crops, it would take 1,830[9] acres to meet this requirement. This is equivalent to a collection area of 3.0 square miles.

Wetlands also represent a significant source of organic material in the Salem City area and are generally more productive than agricultural field crops as producers of organic matter. Whereas agricultural lands produce from one to about five tons of organic matter per acre-year, estuarine marshes produce up to ten tons of dry organic matter per acre-year (Teal, 1969). (Note: *Spartina patens* (Salt Meadow Grass) is presently harvested throughout much of New Jersey's wetlands and is used for packing material. This plant has been used as hay for cattle and other farm animals.)

Because of the ability of a harvested marsh rapidly to recover its plant growth, wetlands represent a significant energy resource potential in the Salem area. Orderly collection of this resource would presumably do minimal harm to the wetlands environment. If wetlands vegetation only were collected to make up the 7 percent energy requirement deficit, and applying an average figure of 7.5 tons/acre-year of available organic wastes, an annual harvest of 430 acres of wetlands vegetation would be required. This represents a collection area of 0.7 square miles[10].

Figure 3 shows potential agricultural and wetlands collection areas in the Salem area. These collection areas were identified and delineated by using 1:80,000 scale color infrared photography.

The economic feasibility of organic waste collection also depends on the concentration and geographic distribution of the wastes. Geographic distribution of wastes directly affects the areal size of the required collection area. The distribution of high value organic wastes, i.e., those wastes which have high organic content and are concentrated in relatively small geographic areas, will also affect the shape of the optimum collection area or route. Cattle feedlots concentrated just outside an urban area, for example, may represent a source of energy which could meet the supplementary fuel requirement of that area without having to exploit other sources, e.g., crop wastes. Crop wastes might provide additional oil reserves which could be either stockpiled for emergency use or transported to regions having low organic waste/energy potential.

FREQUENCY OF WASTE COLLECTION

An energy conversion facility must be supplied with a constant amount of organic wastes on a regular (e.g., daily) basis. Certain organic wastes such as crop waste, however, will be available only during specific times of the year. The quantity of crop wastes available for collection will fluctuate seasonally. A year-round collection plan would have to provide for a constant supply of organic wastes based on a knowledge of the generation characteristics of those wastes. This problem could be alleviated somewhat with the conversion of organic wastes to fuel oil. Wastes could be collected as available, converted to oil, and easily stored in tanks. Conversion to oil is apparently more practical than utilization of shredded organic wastes which have a negligible storage capacity. Oil produced from organic wastes also can be more easily transported over long distances.

SUMMARY AND CONCLUSIONS

The authors conclude from analyses conducted in Salem that multi-scale remote sensing systems can provide a rapid method for estimating the waste/energy potential of a region and for mapping energy source areas.

[9] 70 percent of solid crop wastes estimated to be dry organic solids (Anderson, 1972).

[10] Due to time constraints more detailed waste quantity/biomass estimates for specific types of field crops and/or wetlands vegetation were not made. The quality of the 1:12,000 and 1:80,000 scale color infrared photography was such that specific types of crops and specific wetlands plant species could have been easily identified. More detailed estimates of available organic materials could, therefore, have been made. Field and sweet corn, for example, yield approximately 4.5 tons/acre—year of crop waste, while lbarley, oats or wheat yield only 1.5 tons/acre-year (Weston, 1970). In wetlands, while *Typha angustifolia* (Cattail), for example, produces a standing aerial crop of 11.2 tons/acre-year, *Nuphar advena* (Yellow Water Lily) produces 3.92 tons/acre-year.

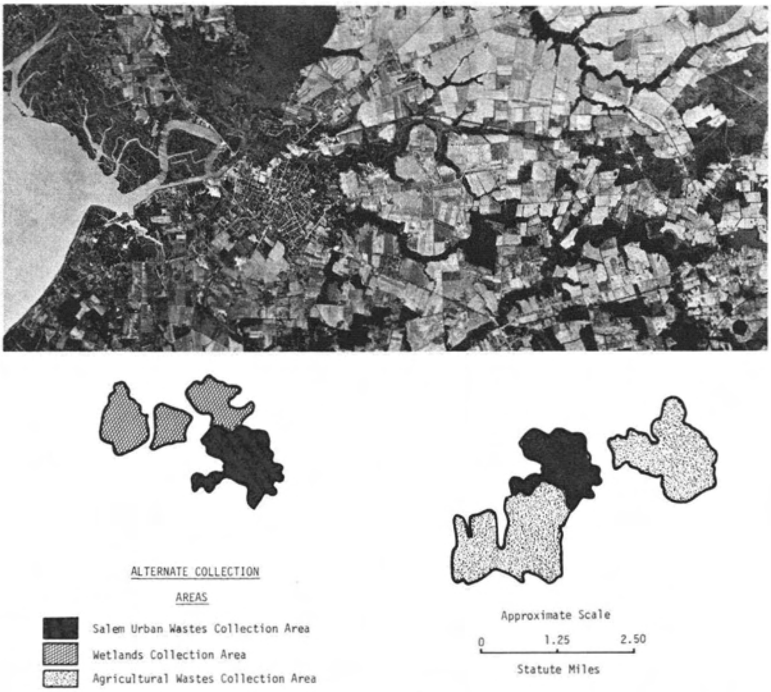

FIG. 3. Salem's urban waste collection area, three alternate wetlands collection areas, and two alternate agricultural collection areas as identified and delineated using 1:80,000 scale color infrared aerial photography are shown. Each wetlands collection area represents approximately 0.7 of a square mile or the area which would be harvested annually to meet the 7 percent energy requirement deficit described in the text. Alternate areas would allow, if necessary, recently harvested areas to recover to pre-harvest condition. Each of the two agricultural collection areas represents an area of approximately 3 square miles, or the area which would provide sufficient organic wastes to meet the 7 percent energy requirement deficit of Salem. Rapid selection of alternate wetlands and agricultural collection areas using small-scale aerial photography provides a variety of spatial data necessary for optimum waste conversion facility site location.

It is apparent that small-scale aerial photographs can effectively contribute to (a) the identification of a region's electrical energy (residual fuel oil) requirements, (b) the selection of sites for energy conversion facilities, and (c) planning for the optimum distribution of waste-produced energy.

This study has shown that a substantial percentage of Salem's electrical energy requirements (residual fuel oil) can be met by converting organic wastes collected from concentrated source areas located within and near Salem's urban area into oil. In addition to organic wastes collected from Salem's urban area, agricultural and wetlands organic materials offer significant potential energy resources for conversion to oil in the Salem area. Remote sensing is an important tool for delineating these resource areas, determining their spatial distribution, estimating organic waste quantities associated with each area, and for planning the orderly collection of organic materials. Each regional area has its own unique organic materials present. Remote sensing provides a method for rapid and accurate inventories of highly diverse regional environments.

The spatial distribution of waste source areas within a region can be readily determined through analysis of small-scale aerial photography. This study has shown that a multi-scale aerial photographic approach would be particularly suitable for estimating the energy requirements of an area and its organic waste-energy potential. For economic reasons, a number of cities or towns in a region could use a strategically located energy conversion facility which would receive organic wastes from identified waste source areas, and then redistribute the energy produced to the regional users. Each energy user (e.g., town) would share in the cost of construction and operation of the energy conversion facility.

The application of this approach to larger metropolitan areas is suggested by this study. It is these areas which are the focus of both solid waste disposal problems and energy shortages. Further research can serve to accelerate the operational use of solid waste as an energy resource. The utility of solid waste for energy conversion will serve to reduce current waste disposal problems while exploiting a virtually unlimited source of energy.

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Appendix

Waste/Energy Conversion

Several processes may be employed to convert solid wastes into energy. Two of the most practical methods, (a) conversion of solid wastes into fuel oil and (b) direct conversion of residential solid wastes into energy by burning, are discussed below.

Conversion to oil. The U.S. Bureau of Mines (Anderson, 1972) has been successful in converting organic solid wastes to oil (a brownish-black liquid or a semi-solid at room temperature, having a heating value of 15,000 Btu per pound). Approximately two barrels of oil were produced from each ton of dry organic material. About 0.75 barrels would be required to provide energy for the process, yielding a net gain of 1.25 barrels of oil from each ton of dry organic waste.

The Bureau has estimated that approximately 880 million tons of moisture-ash-free organic material is generated annually in the United States. The sources of this organic material include: (1) manure, (2) urban refuse, (3) logging and wood manufacturing residues, (4) agricultural crops and food wastes, (5) industrial wastes, (6) municipal sewage solids, and (7) miscellaneous organic wastes.

Table 1A summarizes the estimated quantities of organic wastes in each of these categories and the net oil and gas fuel potential of these wastes. Whereas the potential quantities of organic wastes are listed in Table 1A, the Bureau of Mines notes that much of this material is not collected and is not likely to be collected in the foreseeable future. Only those wastes which constitute a serious disposal problem are presently collected and available for conversion to oil and gas. Table 2A lists estimates of available organic wastes in 1971. Oil produced from organic wastes would have reduced residual fuel imports by over 25 percent in 1971, or could provide half of the residual fuel oil currently obtained from domestic sources.

TABLE 1A. ESTIMATED QUANTITIES OF ORGANIC WASTES GENERATED, 1971 AND 1980, IN THE UNITED STATES.

		1971	1980
SOURCE:			
Manure	million tons/year.	200	266
Urban Refuse	do	129	222
Logging and Wood Manufacturing Residues	do	55	59
Agricultural Crops and Food Wastes[1]	do.	390	390
Industrial Wastes[2]	do	44	50
Municipal Sewage Solids	do	12	14
Miscellaneous Organic Wastes	do	50	60
TOTAL	do	880	1,061
Net Oil Potential[3]	million barrels	1,098	1,330
Net Gas for Fuel Potential[4]	trillion cubic feet.	8.8	10.6

[1] Assuming 70 percent dry organic solids in major agricultural crop wastes solids.
[2] Based on 110 million tons of industrial wastes/year in 1971.
[3] Quantities of oil are based on conversion of wastes to oil by reacting carbon monoxide and water. Net oil produced based on 1.25 barrels per ton of dry organic waste.
[4] Gas estimate is based on 5 cubic feet of methane produced from each pound of organic material.
SOURCE: *Energy Potential From Organic Wastes: A Review of the Quantities and sources;* Bureau of Mines Information Circular #8594; 1972; 16pp.

TABLE 2A. ESTIMATES OF AVAILABLE ORGANIC WASTES[1] IN 1971.

		Total Organic Wastes Generated	Organic Solids Available
SOURCE:			
Manure	million tons/year	200	26.0
Urban Refuse	do	129	71.0
Logging and Wood Manufacturing Residues	do.	55	5.0
Agricultural Crops and Food Wastes	do	390	22.6
Industrial Wastes	do	44	5.2
Municipal Sewage Solids	do	12	1.5
Miscellaneous Organic Wastes	do	50	5.0
TOTAL	do	880	136.3
Net Oil Potential million barrels		1,098	170
Net Gas for Fuel Potential trillion cubic feet		8.8	1.36

[1] Available organic wastes are those which present a disposal problem because they are concentrated at locations where disposal requires some special expense, processing step, or transportation.
SOURCE: *Energy Potential From Organic Wastes: A Review of the Quantities and Sources;* Bureau of Mines Information Circular #8549; 1972, 16pp.

Oil produced from waste also has a low sulfur content and a high heating potential. It should be noted that although the conversion of solid waste to oil is technologically possible, the economic feasibility of this process has not yet been proven.

Burning of Shredded Residential Solid Wastes. In the city of St. Louis, the Horner and Shriffin Consulting Corporation, and the Union Electric Company are testing another solid-waste-energy conversion process (Horner and Shriffin, 1972). This process involves the burning of shredded residential solid wastes as a supplementary fuel.

In the St. Louis project, it was concluded that "utility fuel costs are rising rapidly, and even under present conditions, the relative value of refuse as fuel could be significant. The net cost of residential solid waste disposal by this means, therefore, could be highly attractive in many metropolitan areas of the United States."

While the efficiency and economic feasibility of these techniques is still being evaluated, pilot projects indicate that the use of solid waste as a supplementary fuel source may help to alleviate two pressing problems, solid waste disposal and the energy crisis.

WASTE COMPOSITION

Organic wastes appear to be the most promising waste/energy source. In order to determine the waste-energy potential of a region, estimates of the percentage of organic material present in the total solid waste stream must be derived. Domestic wastes are composed of metals, cloth, plastics, leather, rubber, glass, wood, garbage, and paper. Paper accounts for approximately 50 percent of all domestic wastes (Clark, 1971); garbage, 15.5 percent, wood, 2 percent; cloth, 4 percent; plastics, 1.9 percent; and rubber, 1.1 percent (Golueke and McGauhey, 1970). Therefore, 60 percent to 70 percent of domestic wastes are organic in nature.

The composition of industrial wastes (Golueke and McGauhey, 1970) depends upon the type of industrial activity. Textile mill wastes, for example, are composed of large quantities of cellulose and cellulose derivatives; stone, clay, and glass processing yields little or no organic wastes.

Agricultural wastes consist of manure, prunings, chemicals, crop residues, canning wastes, meat, animal carcasses, fish products, dairy wastes, brewery and winery wastes, and sugar refinery wastes (Golueke and McGauhey, 1970). The vast majority of these wastes are combustible organic materials.

Commercial waste composition also depends directly on the type of commercal activity. For example, restaurants yield large quantities of organic wastes. Plumbing and heating establishments may yield predominantly inorganic materials.

Finally, sewage sludge is an important source of organic solids which represents a significant potential energy resource.

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