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Alcohol from municipal refuse by the hydrolysis fermentation process as a solid waste solution for Cascade County, Montana

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ALCOHOL FROM MUNICIPAL REFUSE BY THE HYDROLYSIS FERMENTATION PROCESS AS A SOLID WASTE SOLUTION FOR CASCADE COUNTY, MONTANA

By

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CHAPTER I

INTRODUCTION

The National Solid Waste Environment

William D. Ruckelshaus, administrator of the Environmental Protection Agency in Washington has said that the national outlay of $4.5 billion annually to collect and dispose of 360 million tons of municipal and industrial wastes is not doing the job. Almost 85 per cent of the refuse collected is thrown into open dumps--unsightly, disease-breeding firetraps, most of which are in violation of state laws. Another 5 per cent to 6 per cent is covered over with dirt in sanitary landfills, most of which are far from sanitary; they pollute water supplies and give off methane gas. Municipal and apartment house incinerators burn 8 per cent of the municipally produced waste, thus contributing to air pollution. Mr. Ruckelshaus says 75 per cent of the burners are unsatisfactory. An estimated 12 per cent of the U.S. households have no regular garbage service at all; they are presumed to represent the people who spread their trash along the roadsides at night. Moreover, matters are growing steadily worse at the rate of 4 per cent a year; population growth is 2 per cent and is compounded by a 2 per cent greater "throw-away" rate per year. Today, 6 pounds of solid waste is collected for each U.S. resident daily, a figure that is expected to reach 8 pounds by 1980. This figure includes all residential, commercial, industrial, and agricultural refuse. The growing problem of solid waste collection and disposal is further aggravated by increasing costs. Approximately 88 per cent of the cost of waste disposal goes to sanitation workers as wages in the open dump operation. Higher land costs are also a major factor. Thus the U.S. is faced with the problem of an increasing burden of solid waste and an increasing cost to collect and dispose of it.

Even more important, states are becoming more conscious of the environmental impact of the way in which solid waste is disposed of, as evidenced by state statutes outlawing open dumping and burning. The national trend is toward more stringent air, water, and solid waste pollution laws. The enforcement of these laws could have harsh economic consequences upon municipalities, especially if they were left unaided and to their own resources in dealing with this dilemma; thus the federal government has become involved.

Prior to 1965, the Bureau of Mines, under the authority granted to the Department of the Interior in the Organic Act,[1] has been engaged in research to develop methods of utilizing mineral and metal-based wastes to recover economic

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[1]U.S. Department of Health, Education, and Welfare. 1968 Comprehensive Study of Solid Waste Disposal in Cascade County, 1970. (Washington, D.C.: Government Printing Office, 1970), Public Health Service Publication No. 2002, pp. 13-14. (Hereinafter referred to as 1968 Comprehensive Study.)

values and to alleviate the disposal problem. In 1965 the Solid Waste Disposal Act[2] was passed and was shortly followed by the Resource Recovery Act[3] which established the Environmental Protection Agency. It is the objective of these acts to establish research in means of recycling solid waste and to grant subsidies for pilot plant studies of new techniques.

The purpose of this paper is to evaluate the Hydrolysis-Fermentation Process as an economically viable means to deal with solid waste in Cascade County, Montana. This process converts the cellulose in solid waste to sugar by the chemical process of hydrolysis. The sugar can be fermented to produce ethyl alcohol. The Hydrolysis-Fermentation Process may prove to provide a realistic and economical technique to exploit solid waste as a resource. The assessment of economic viability is not a simple task. One must not only consider processing cost in light of income and market potential of recovered materials, but must also consider social costs such as pollution, health hazards, and the loss of irrecoverable metal resources.

[2]Ibid. [3]Ibid.

CHAPTER II

SOLID WASTE HISTORY AND STATUS IN CASCADE COUNTY

Summary of Solid Waste Programs and Costs

The full purposes of the 1965 Solid Waste Disposal Act[1] are:

1. To initiate and accelerate a national research and development program for new and improved methods of proper and economic solid waste disposal, including studies directed toward the conservation of natural resources by reducing the amount of waste and unsalvageable materials and by recovery and utilization of potential resources in solid wastes;
2. To provide technical and financial assistance to state and local governments and interstate agencies in the planning, development, and conduct of solid waste disposal programs.

The Solid Waste Disposal Act authorizes action in six areas. It provides for:

1. Up to two-thirds support for local and state projects to demonstrate new and improved waste disposal technology;
2. A comparable level of Federal aid for the development of area-wide solid waste management systems to end fragmentation of disposal responsibilities among small communities.

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[1]Ibid., p. 14.

3. Up to 50 per cent support for state surveys of solid waste requirement;
4. Research to lay the basis for new approaches to solid waste disposal without the health or environmental hazard;
5. Training programs to alleviate critical shortages of qualified personnel;
6. Technical assistance to local and state governments with solid waste problems.

Under the Solid Wastes Disposal Act, the Federal Government supports the local and state agencies in attacking the solid wastes problem, but the responsibility for carrying out programs for improved practices is left mainly at the local and state levels.

During the 1965 session of the Montana Legislature, it was declared the public policy of this State to control refuse disposal areas to protect the public health and safety. Sections 69-4001 to 69-4010 of the State code, Control of Refuse Disposal Areas,[2] were passed by the Legislature. On February 11, 1966, the Montana State Department of Health adopted Regulation 52-46, Regulation Governing the Control and Licensing of Refuse Disposal Areas,[3] to set standards for proper sanitary refuse disposal. Since eight of the county's ten land-fill sites were dumps, it was evident to the City-County Health Department that the majority of the county's disposal sites were inadequate and did not meet the minimum

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[2]Ibid., p. 15. [3]Ibid.

requirements as set forth by the Montana State Department of Health. This indicated a definite need for a comprehensive plan based on current as well as anticipated needs. The Board of Commissioners made application to the Public Health Service for a study grant. A grant was approved for a "Comprehensive Study of Solid Waste Disposal--Cascade County, Montana,"[4] with authorization to commence work on June 1, 1967. The objectives of the study were:

1. To investigate and define existing conditions as to solid waste storage, collection and disposal in the county;
2. To determine the most economical, efficient and effective methods for storing, collecting and disposing of solid wastes in the county;
3. To implement study findings by preparing a comprehensive solid waste disposal report for Cascade County.

In 1967, only two cities in Cascade County, Great Falls and Belt, had organized collection systems with the remaining communities disposing of their refuse on an individual basis. Individuals who were unable to drive their vehicles to a refuse disposal site because of mud or snow had a tendency to dump refuse along the access road. Infrequest disposal of refuse, coupled with inadequate storage facilities, produced high potential health hazard areas. As the conditions above indicate, sanitary collection methods and disposal sites are an immediate necessity for Cascade County.

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[4]Ibid., p. 16.

As land becomes more expensive and population continually increases, it becomes more apparent that it is necessary to design collection and disposal facilities for long range use to prevent health hazards and allow for the most economic disposition of refuse. As the towns and cities grow, the distance from the center of population to a rural or out-of-town disposal site continues to increase until it becomes uneconomical to have collection vehicles travel the extra distance to a disposal site. Approximately 70 per cent to 80 per cent of the total cost of pickup and disposal of refuse is spent on the collection phase of the service. By the time this distance from town to the disposal site becomes uneconomical to travel, it is also difficult to locate a site for refuse disposal facilities within the developed area of the town or city. As a result, the total cost of operating the disposal system increases due to the higher cost of the land site in the developed area or the extra cost of the longer collection vehical haul distances. The cost of solid waste disposal can be kept to a minimum by obtaining future disposal sites before the area gets developed and the cost gets unreasonable.

Since Great Falls is the major population center in Cascade County, its refuse collection and disposal situation will be discussed briefly. As of 1968, the city provided once a week pickup service within the city limits. The approximate cost to the city for collection and disposal was $18 per ton. Individual home burners or incinerators were allowed in Great Falls of which there were approximately 460 in the city area. As of 1972, the disposal site, which is located 1.5 miles northeast of town near the Rainbow road, could last about three years from 1972. The site is manned by city sanitation personnel 8 hours a day, 5 days a week. The site does not have a fence around the perimeter of the area or a gate across the road entering the site. The uncontrolled nature of the site allows a great deal of indiscreet dumping during hours that city personnel are not present. The effort wasted in cleaning up the site after a weekend of this type of dumping is considerable.

Industrial refuse consists of solid waste materials from factories, processing plants and other manufacturing enterprises. The collection of this waste is rarely regarded as the responsibility of the city but as an obligation of the industry. Such industries include the Anaconda Company; the hospitals, which use grinders and incinerators; Malmstrom Air Force Base, which utilizes its own open dump; Great Falls International Airport, which hauls its own refuse to the city land-fill; and Valu-Mart and Holiday Village, which both dispose of their own refuse. With the exception of the Malmstrom Air Force Base, the majority of this refuse is paper and is burned in local incinerators.

To remedy the county problem, the study proposed three alternatives:

1. Include rural routes with once per week residential collection and Great Falls with twice per week residential collection;

2. Include rural routes with once per week residential collection and Great Falls with once per week residential collection.

3. Include rural routes and the area adjacent to the Great Falls city limits with once per week residential collection. Under this alternative, Great Falls would continue to operate its existing system and would not be included in the county-wide program (See Appendix 1, Table 3).

After thorough investigation, the following costs were estimated:

Alternative 1

Initial cost	$632,000.00
Ton per year collected	35,600
Operation, maintenance and replacement costs per year	$941,949.00
Cost per ton produced	26.46

Alternative 2

Initial cost	$520,000.00
Ton per year collected	35,000
Operating cost, maintenance and replacement costs per year	$635,854.00
Cost per ton produced	17.86

Alternative 3

Initial cost	$174,000.00
Ton per year collected . . . . (2,690 dwellings at 1.84 tons per dwelling)	4,950
Operating cost, maintenance and replacement costs per year	$ 96,277.00
Cost per ton	19.40
Cost per dwelling per year	35.79

Neither the city or county has taken any action based on the results of this report. In December of 1970, the City of

Great Falls authorized Thomas, Dean, and Hoskins, Incorporated to prepare an engineering report on the feasibility of milling refuse. This was authorized in order to provide an integrated disposal system for the entire county by constructing a milling and salvage plant in Great Falls, Montana, which would also own and operate the plant and disposal facilities. The plant was planned to receive refuse from the City of Great Falls, the towns of Cascade, Belt and Neihart, and all unincorporated and rural areas within the county.

In 1970, the city requested a grant to establish a recycling mill. The following is a quotation from that request:[5]

> Since the completion of the Comprehensive Study, the Montana Legislature has enacted legislation that will allow the formation of county-wide refuse collection and disposal districts, which may include incorporated cities within the districts. The State of Montana has enacted and is now enforcing air pollution standards which prohibit open burning throughout the State. The City of Great Falls has expanded and improved its landfill operation to conform with State requirements concerning open burning at the disposal site and daily earth cover of the refuse. The City's cost of operating its landfill has increased drastically in recent years. The ban on open burning has increased the volume of refuse, while the City has had a high cost of excavating cover material in a relatively tight soil. Despite a concentrated effort by City Officials, the operation of this landfill has been anything but ideal. The excavation and placing of cover material on a daily basis has proven costly and has not completely solved the problem. Accidental fires still occur and the strong prevailing winds often blow papers before cover material can be placed. Extended periods of freezing weather have complicated the operation.

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[5]Request for a grant of Federal Funds to establish a recycling plant in Cascade County received from Pete Frazier during a personal interview, May 1971, p. 7.

The County Commissioners completed all the legal procedures, including a public hearing, necessary for creation of the Cascade County Refuse Disposal District. The District includes the entire county except the the areas within the City of Great Falls. The Cascade County Refuse Disposal District proposed to install bulk containers and transfer stations, five transfer stations and about twenty bulk storage container sites, to provide a convenient place for residents of each populated area to dispose of their refuse.

Milling the refuse prior to landfill would have eliminated or greatly reduced the operational problems at the Great Falls landfill. Market conditions in this area were favorable for the salvage of metals and corrugated paper. The milling plant proposed to include salvage equipment such as magnetic separators, can crushers, and paper balers. The Anaconda Reduction Plant located in Great Falls, as stated in the request, would have purchased certain grades of ferrous and non-ferrous metals. The Anaconda Company would have also purchased shredded cans at their concentrator in Butte, Montana, approximately 150 miles from Great Falls. Other metals not suitable for processing by the Anaconda Company would have been sold to local scrap metal dealers. The Horner-Waldorf Company would have purchased corrugated paper for processing at their plant located in Missoula, Montana, about 175 miles from Great Falls. The milling plant, therefore, had an opportunity to recycle metal and corrugated paper. Non-ferrous metals and corrugated paper were to be removed by hand picking. Separate collection of corrugated paper would have been made from commercial establishments.

The milling and salvage plant would have been constructed at the corner of 15th Street and River Road. Upon completion of the project, the facility would be owned and operated by the City of Great Falls. The following facilities would have been owned and maintained by the Cascade County Refuse Disposal District: (1) transfer stations, 5 each; (2) bulk container stations, 20 each; (3) two transfer trailer trucks; (4) six transfer-trailers.

The proposed costs[6] from April 15, 1971 through April 14, 1972 were:

Milling and salvage plant--initial cost .	$ 697,000.00
Transfer stations--initial cost	32,500.00
Total initial cost of the project	1,294,800.00
Amount supplied by Cascade County . .	323,700.00
Amount requested from Public Health Service	971,100.00

The proposed costs from April 15, 1972 through April 14, 1973 for the first year of operation were:

Operating cost	$ 249,500.00
Amount supplied by Cascade County . .	62,375.00
Amount supplied by Public Health Service	187,125.00

If this grant request had been accepted, it might have indeed put an end to Cascade County's solid waste problems due to the low cost that would have been possible through the two-thirds Federal financing of the project, but the project

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[6] Ibid., p. 4.

was not accepted. The reasons given were that the mill was not proposed to "totally recycle." Glass was not included in the proposal and hand picking to sort the refuse was frowned upon as not a "revolutionary improvement." The request was reformed and submitted twice more, but to no avail. It should be noted that where the comprehensive study proposed residential collection for the rural towns, this request only proposed sanitary transfer stations to which the residents could carry their own garbage on a particular day of the week.

In the mean time, since the denial of the first request for a recycling grant made it clear to the County that they would have to deal with the open dumping problem in the County separately and immediately, two alternatives were proposed by the County Health Department in April 1970:[7]

1. That seven county sites be provided and maintained on a revolving basis. Each site should be fenced and provided with a gate. Dumping at the site would be allowed on only one day of the week when the county land-fill equipment was on site;
2. Establish a system of transfer stations to haul the refuse to Great Falls to be processed by a Heil pulverizer.

The estimated cost of the proposals were:

Alternative 1:

Capital outlay (sites, equipment, containers). .	$120,000.00
Annual costs (operating, amortization, and administration)	64,413.00
Cost per dwelling per month (5,000)	1.25

[7]Don Pissini, City-County Health Department, personal communication, February, 1971.

Alternative 2

Capital outlay (5 transfer stations and 20 storage sites)	$450,000.00
Annual operating costs	90,000.00
Cost per dwelling per month (5,000)	1.50

Although the costs are greater for Alternative 2, it would apparently allow disposal at any time, not just one day a week. The costs proposed for the second alternative may be high due to the tentative nature of the proposal. As is suggested by Alternative 2, the City of Great Falls had begun to think along other lines as the chances of their refuse recycling plant being approved by the Public Health Service looked dismal after the first rejection.

In 1971, the City of Great Falls proposed that it construct and operate a Heil pulverizer to mill refuse from the entire county. The original cost estimate was $600,000 with the hope that between $100,000 and $250,000 in Federal aid would be available.[8] This request was also denied by the Federal Government, but the city did not give up in its attempts to incorporate the pulverization plant. For the period 1970 to 1971, the total cost of collection and disposal had risen to:[9]

Total 1970 to 1971 budget for Garbage Dept.	$589,353.00
Collection cost	462,944.00
Disposal cost (21 per cent)	126,408.00
Cost per tons collected (82 tons per day) .	19.60
Cost per total tons deposited at land-fill (156.2 tons per day, 57,013 per year)	10.30

At the beginning of 1972, the city was facing increasing costs for solid waste handling. The land-fill site was

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[9]Sam McDonald, City of Great Falls Garbage Department, personal communication, December 1971.

uncontrolled and the city faced costs to control it. The dump had a future capacity of three to four years at 1971 loads. The city had been unable to find another dump site that could be bought economically. Public opinion against a "dump" in the neighborhood and terms of sale were the prime causes of this failure.[10] The county open dumping situation has become increasingly critical as this practice continues relatively unchanged from the situation that prevailed in 1965 when laws were passed against open dumping. At this stage, Senator Mike Mansfield made a request to the Environmental Protection Agency that it act on the long-dormant application by the city and county for a Federal grant to help start the pulverization project. Thus as a result of this effort and further consultation with the Denver Regional Office of the Bureau of Solid Waste Management, the pulverization project appears to be the most probable course of action for the city and county at the present time, particularly in light of the fact that the city has been unable to secure another land-fill site economically.[11] The present status of the pulverization project is:[12]

1. The City Council has authorized up to $10,000 to plan the plant.
2. The Heil Company will build the plant and finance it over five years for a maximum of $821,000 including the cost of eight per cent annual interest.

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[10] Ibid. [11] Pete Frazier, personal communication. [12] Ibid.

3. Great Falls is still in contention for a Federal grant of $100,000 to $200,000 to pay the cost of organizing and administering the project for one year.

4. Design capacity of the plant is 1,050 tons per week or 210 tons per day (five day week).

5. The net collection cost savings for the city due to shorter haul distance to the mill by all collection vehicles is expected to be $22,200[13] per year. Based on 1968 data, this would reduce collection cost to $440,744 ($462,944 minus $22,200).

6. Annual operating costs for pulverization and salvage proposed by the Heil Company are $246,451 ($4.49 per ton).

7. Expected revenues through the sale of metal and paper are $135,400. Assuming a seventy per cent recovery of potential salvage, the net would be $78,870 from metals, and $56,500 from corrugated paper on a thirty-five per cent recovery basis.

8. The total operating cost is estimated at $661,917 for collection within the city and disposal of the county's refuse. Taking into account the revenue produced through salvage, the net operating cost is estimated at $526,517 per year. This would be a savings of $62,836 from the 1971 Garbage Department's budget.

9. The observed output of the pulverizer is "confetti" size with some larger pieces of plastic.

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[13] Data used from <u>1968 Comprehensive Study</u> includes 1968 refuse quantity of 2,942 cubic yards per week (See Table 2, Appendix 1). Trucks used are three-man 18 cubic yard packer trucks making 164 trips per week at an average speed of 22 miles per hour. The distance saved by the plant is 3 miles, thus the number of hours saved per week is 22.4. The total vehicle and labor cost per hour is $19.05. Finally, yearly collection cost saved through shorter distance traveled is $22,200 per year.

Analysis of Refuse Quantity and Composition

Quantity Analysis

Since it is the objective of this paper to evaluate cellulose hydrolysis-fermentation to alcohol, it is necessary to estimate the quantity of cellulose and the nature of the mixture in which it will be contained in the Cascade County refuse stream. Before these factors can be dealt with, some terminology must be established which will aid interpretation of the following Tables. Mixed municipal refuse is the refuse normally collected by a municipality and includes collections from households, commercial establishments, and institutions. This excludes special industrial wastes, the larger demolition wastes, agricultural wastes, and specialty loads of items such as tires, junk cars, stoves, refrigerators, bed mattresses, and sewage sludge. The refuse production multiples for municipal refuse are generally quoted in the range of 2.5 to 3.5 pounds per capita per day.[14] The total figure for all refuse produced, whether it finds its way to a disposal site or not, is generally considered to be between 4.5 and 8.0 pounds per day.

Before refuse production multiples can be discussed, the applicable population must be determined. Reference to Tables 1 and 2 assumes the national average of two per cent

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[14] 1968 Comprehensive Study, p. 105.

population growth rate. Table 1 shows the 1960 Great Falls population as 55,244. The 1970 population is roughly 60,000.[15] This indicates a compound growth rate of slightly greater than three-fourths per cent per year. This would place Great Falls at just under 61,000 for 1972. The total 1970 population for Cascade County was 81,804. This includes 8,374 people at Malmstrom Air Force Base. Thus using U.S. Bureau of Census data, the following facts will be used for analysis in this paper:

1. 1971 to 1972 Great Falls population 61,000
2. Great Falls growth rate (1960 to 1970) . . . . .75 per cent
3. 1970 County population (excluding Malmstrom) 73,430
4. County growth rate (1960 to 1970) . 2.25 per cent
5. Calculated 1971 to 1972 County population at 2¼ per cent (excluding Malmstrom) 75,000
6. Calculated 1991 County population
   at 2 per cent 111,200
   at 2¼ per cent 117,000

The figures in Table 1 are stated as being on the "safe" side in the 1968 Study and are quite a bit greater than the figures derived from the 1972 Almanac.

With these figures, it is now possible to approach the problem of refuse production rates. As was indicated earlier,

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[15] Luman H. Long, <u>The World Almanac and Book of Facts</u>, 1972 edition, (New York: Newspaper Enterprise Association, Inc.), p. 177.

the range for total refuse production can vary between four and eight pounds per capita per day. This variation is due largely to characteristics of the local area such as whether or not it is highly industrialized or has any other unique local activity which causes the total refuse multiplier to vary quite a bit locally. In 1970, the national multipliers for refuse production were:

1. Total refuse per capita per day 6.0 to 8.0 pounds
2. Municipal refuse per capita per day . . . . 2.5 to 3.5 pounds

The 1968 Comprehensive Study used a figure of 4.5 pounds per capita per day for total refuse which they compounded at two per cent to give 6.8 pounds per capita per day in 1968. For the purposes of their study, they used an average figure of 5.6 pounds per capita per day for total refuse. During the course of the 1968 Study, a field study was made of the refuse production by determining the average load carried by a collection vehicle and then counting the trips. Based on the 1968 Comprehensive Study, population was given as 76,000 (See Appendix 1, Table 1). This study gave a daily rate of 2.2 pounds per capita per day of municipal refuse. Based on the population of 60,000 for 1970, this would be a figure of 2.78 pounds per capita per day. In like manner the figure of 4.5 pounds per capita per day would become 5.7 pounds per capita per day. In 1971 the Garbage Department ran a survey by weighing each truck. The results of that survey were:[16]

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[16]Sam McDonald, personal communication.

1. Tons collected by the city per week . 575.0 tons

2. Estimated refuse received at the city land-fill per week[17]. . . . 1,093.0 tons

3. Municipal refuse per capita per day . . . . 2.7 pounds

4. Total refuse per capita per day . . . 5.2 pounds

Since these are the most recent refuse production figures available, they will be used for the purposes of this paper. This results in county refuse production totals of:

1. Total Cascade County refuse production in 1971 to 1972 (75,000 at 5.2 pounds per capita per day). . . . . 1,360 tons per week

2. 1971 to 1972 municipal refuse production (75,000 at 2.7 pounds per capita per day) . . . . 710 tons per week

If the total and municipal refuse production factors are compounded at two per cent for twenty years, the resultant 1991 figures are 7.72 and 4.0 pounds per capita per day respectively. Using these figures:

1. 1991 Total Cascade County refuse production (111,200 at 7.72 pounds per capita per day . . . . 3,000 tons per week

2. 1991 Municipal refuse production (111,200 at 4.0 pounds per capita per day) . . . . . . 1,560 tons per week

Unfortunately, there is a problem in determining how much of the difference between the total refuse production of 1,360 tons per week and the municipal refuse collected, 710 tons

[17]The difference between the amount collected and the amount received at the landfill dump is from construction wastes, industrial refuse, and refuse from outside the city.

per week, will actually be capable of being processed in any way at all. The proposed pulverizer was designed with a capacity of 1,050 tons per week. This design is obviously prepared for some portion of future capacity. For the purpose of this paper, one-half of this difference will be considered refuse which is capable of being pulverized and also is similar to municipal refuse in composition with the possibility of a higher paper content due to commercial establishments such as Valu-Mart and Holiday Village, which haul their own refuse. Further substantiation for this assumption is the fact that the operation of a private contract collector may not have been taken into account as a part of the refuse collected. In addition to this, the residents who live in the fringe area of Great Falls and haul their own refuse would not have been accounted for as a part of the refuse collected, although it would be of the same composition as municipal refuse. Thus 120 tons per day was used as the 1971 to 1972 daily input to the city pulverizer.

Composition Analysis

Once a daily tonnage is arrived at, its composition must be analyzed to determine the expected cellulose content. Again, a bit of terminology must be made clear. Paper is not 100 per cent cellulose. For instance Kraft paper is 97 per cent cellulose, while newspaper is essentially ground wood and about 65 per cent cellulose by weight.[18] Thus once a

[18]U.S. Environmental Protection Agency, Comprehensive

particular component of refuse is identified as a certain percentage of the refuse, its respective cellulose content must be described. As a further clarification, the percentages of component refuse are given on a dry basis. This means that if a mass of refuse were to be analyzed, all the moisture would be driven off so that nothing remained but the solids. These solids would be analyzed for their various components with the dry solids as the denominator for 100 per cent. The moisture content percentage is based on the original wet mass. For instance, if the "dry" total is imagined as 100 pounds with the various percentages being taken as pounds of each component then the component is stated on a "dry" basis (See Appendix 1, Table 4). This "dry" basis allows uniform national analysis of composition. The moisture content is descriptive of how much water is carried along with the refuse. In the previous example, if the moisture content is said to be thirty per cent that means that the original "wet" mass must have weighed 143 pounds and 43 pounds were driven off at the beginning of analysis.[19] The results of Table 4 average the cellulose content from three composition studies and a figure of 57.7 per cent cellulose is determined. The moisture content of Cascade County refuse was estimated to be twenty per cent due to its semi-arid climate.

Studies of Solid Waste Management, Third Annual Report, 1971, (Washington, D.C.: Government Printing Office) pp. 86-87.

[19] $$\frac{\text{x pounds moisture}}{\text{100 pounds "dry" solid + x pounds moisture}} = \text{30 per cent}$$

The input to the cellulose Hydrolysis-Fermentation process must be free of the glass and metal portions of the refuse stream. The proposal for the pulverizer mentions that the city intends to salvage any component from the refuse stream that does not add to the net operational cost. The pulverization plant is already designed to recover ferrous metal through magnetic separation. Whether or not the city plans to further incorporate a ballistic, cyclone, or Stanford "zig-zag" air classification system to remove the glass and non-ferrous components of the refuse stream is uncertain at this time and will thus be incorporated as part of the Hydrolysis-Fermentation process cost. In either case, the metal and glass components along with a portion of the miscellaneous stone, rubber, and heavier plastics will be removed. One-half of this component will be assumed to have heavy enough specific gravity to allow its separation by air classification. The results of these assumptions and foregoing analysis are listed below to arrive at the input figures to the proposed hydrolysis-fermentation plant from Cascade County.

The results are:

Cellulose content (dry basis) . . .	57.7 per cent
Moisture content of input to pulverizer	20.0 per cent
Solids removed in salvage (metals, glass, one-half miscellaneous refuse)	23.8 per cent
"Wet" refuse processed by the pulverizer plant per day (20 per cent moisture)	120.0 tons per day

"Dry" refuse represented by the "wet" refuse (80 per cent of "wet" refuse)	96.0 tons per day
Cellulose content (57.7 per cent "dry" tons)	55.5 tons per day
Solids removed in salvage (23.8 per cent of 96 tons per day)	22.8 tons per day
"Dry" tons input to Hydrolysis-Fermentation process (96 tons per day minus 22.8 tons per day).	73.2 tons per day
Water accompanying the original input (120 tons per day minus 96 tons per day)	24.0 tons per day
"Wet" input to the Hydrolysis-Fermentation process with full salvage of glass, metals, and one-half miscellaneous accomplished (73.2 tons per day plus 24.0 tons per day water).	97.2 tons per day

CHAPTER III

THE PROCESS

History and Development of Hydrolysis Process

According to the estimate provided in Chapter I, about 55.5 tons per day of chemical cellulose is contained in the refuse stream of Cascade County. A portion of this cellulose can be converted to fermentable sugars by the process of hydrolysis. Cellulose is treated by a dilute solution of sulfuric acid at a temperature between 360°F. and 446°F. The resulting sugar solution can be converted by fermentation in a conventional manner to yield 95 per cent industrial grade ethyl alcohol (ethanol). The hydrolysis of cellulose to produce fermentable sugars was investigated and utilized in Germany during the periods of World War I and World War II. Two general processes evolved from the German work: (1) the strong acid or Gergius Process, and (2) the weak acid or Scholler Process.[1] The Gergius Process required extremely high capital outlay, which along with high labor and raw material costs

[1]N. L. Drobny, H.E. Hull, R. F. Testin, and Battele Memorial Institute, Columbus Laboratories, Recovery and Utilization of Municipal Solid Waste; A Summary of Available Cost and Performance Characteristics of Unit Processes and Systems, Public Health Service Publication No. 1908, (Washington D.C.: Government Printing Office, 1971), pp. 80-82.

on the U.S. market, prevented it from being economically feasible. The Scholler Process, while uneconomic in the U.S. in its original form, was considered for further technical development. Work on the weak acid hydrolysis of cellulose was performed at the U.S. Forest Products Laboratory at Madison, Wisconsin during and following World War II. The resulting Madison Wood Sugar Process was superior to the German process on the basis of the productivity rates and product yields achieved. Pilot and commercial plant operations using various modifications of the process based on raw materials and final products were established at Madison, Wisconsin; Springfield, Oregon; and Wilson Dam, Alabama.[2] Production was terminated at Springfield and Madison by the middle of 1947. The full-scale operation at Springfield hydrolyzed 221 tons per day of sawmill waste and produced in toto approximately 50,000 gallons of ethanol before the lease was surrendered to the Reconstruction Finance Corporation in 1947. The production costs at that time were estimated to be $0.30 to $0.35 per gallon. Since this time, the process was largely forgotten until the Solid Waste Recovery Act was passed in 1965. Since the passage of this act, two economic analyses have been published which pose variations of the "Madison Wood Sugar Process" as possible means of re-cycling solid waste. They are: (1) "Towards a Profitable Means of Municipal

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[2]Ibid.

Refuse Disposal" by Andrew Porteous[3] and (2) Conversion of Organic Solid Wastes into Yeast: An Economic Evaluation by Floyd H. Meller,[4] Research Division, Ionics Incorporated. These works will be further referred to as works by Porteous and Ionics, respectively. Porteous worked primarily to establish the optimum conditions for hydrolysis based on the previous work by J. F. Saemen of the U. S. Forest Products Laboratory in Madison, Wisconsin. Once he mathematically extrapolated the optimum conditions, he used these results to design a plant which used a different reactor system than any of the previous designs. The results of his evaluation were:

1. That a plant to process 170 tons per day would cost $2,262,000;
2. The annual operating cost to produce 3.93 million gallons of ethanol would be $1,340,000, or a cost of $0.34 per gallon.

The cost estimation procedures used by Porteous appeared to have many conservative features, but the analysis as a whole, was very general and left large areas untreated to be lumped in a large miscellaneous category. Ionics was authorized by the Environmental Protection Agency to perform an economic

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[3] American Society of Mechanical Engineers Paper No. 67-WA/PID-2, presented at Winter Annual Meeting and Energy Systems Exposition, American Society of Mechanical Engineers, Pittsburgh, Pennsylvania, November 12-17.

[4] Public Health Service Publication No. 1909, Washington D.C., Office of Solid Waste Management of the U.S. Environmental Protection Agency, 1969.

evaluation of converting cellulose to sugar, and then produce yeast from the sugar. Their analysis discussed the two processes separately in the event that some other use might be considered for the sugar. Their analysis was quite specific and used conservative cost estimating techniques. Two plant designs were considered by Ionics:

1. The old batch process used by the Madison Wood Sugar Process;
2. A continuous process using existing Black and Clawson screw press equipment.

The results of their evaluation were:

1. That a plant to process 80 tons per day, using the continuous process, would require a capital investment of $1,687,500.
2. The cost to produce 62,500 pounds of sugar a day would be $2,426.00 per day or $0.50 for the cost of enough sugar to make a gallon of alcohol.

The wide variation in costs reflected by these two economic evaluations have been analyzed in this paper and an attempt will be made to more accurately identify the real costs, or at least their range where possible, to provide a more credible cost of plant and process. Before any rationalization of the two previous works can take place, a brief explanation of the process must be given.

Chemistry and Kinetics of the Process

The hydrolysis of cellulose process may appear to be simple since it merely adds a molecule of water to cellulose to form sugar, but this is not the case. It is quite complex with many diverse reactions going on simultaneously. The important characteristics of this reaction are:

1. The sugars produced from cellulose are subject to decomposition on continued exposure to the hot dilute acid.

2. Two consecutive reactions occur. Cellulose is converted to various sugars at a rate k_1. These sugars are then decomposed at a rate k_2.

3. The rate of hydrolysis of cellulose and the decomposition of the sugar is a function of the acid concentration, temperature, and time. The greater the acid concentration and the temperature, the faster the reaction rates. The reaction is retarded by liquid-to-solid ratio below 8 to 1.

4. The energy of activation of the reaction is independent of the acid contration, being 42,900 calories per (mole) for cellulose to sugar and 32,800 calories per (mole) for sugar to decomposition products. This means that roughly below 300°F. the reaction is quenched.

5. The conditions which optimize the net effect of the two antagonistic processes using a 0.4 per cent acid concentration are temperatures as 446°F. and a residence time of 1.285 minutes. The residence time is the time the liquid is in the reactor. These conditions would theoretically yield 55.2 per cent of the chemical potential for sugar, which is the sugar that would result from total cellulose conversion to sugar if no decomposition took place.

To implement this process, two designs have been proposed:

1. The Porteous design which will operate at the previously stated optimum conditions of 55.2 per cent conversion;[5]
2. The Ionics design which will operated at sub-optimum conditions and yield 43 per cent conversion.[6]

The conditions at which the process proposed by Ionics will operate are 392°F., 0.5 per cent sulfuric acid, liquid-to-solid ratio of 4 to 1, and a time of residence of 11.7 minutes.

To compare these two designs, two common denominators will be used. The first one is the equipment cost per ton of material processed and sugar produced. The second one is the production cost per ton of material processed and sugar produced. The hydrolysis segments of both designs will be compared. For the Ionics process, this equipment cost is quoted as $582,000. To arrive at a comparable figure for Porteous, the cost of storage hoppers, pulverizers, screening section, vats, bubble cap column, reboiler and product cooling heat exchangers, and Bod reduction will be subtracted from Porteous' total equipment cost of $1,062,000 to arrive at a figure of $527,000. The total amount of erection and

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[5] Porteous, Towards a Profitable Means, p. 7.

[6] Meller, Wastes Into Yeast, pp. 64-70.

miscellaneous plant, $200,000, was left in the estimate as this is largely pumping cost for the hydrolysis portion of the process.

The comparison is as follows:

Porteous

Tons processed (containing 20 ton non-hydrolyzables)	170.00 tons per day
Sugar produced	138,000.00 lbs. per day
Equipment cost (initial installed cost)	$527,000.00
Production cost (excluding labor)	
Material	826.00 per day
Fixed charges and maintenance at 10 per cent equipment .	144.00 per day
Total	$ 970.00 per day
Equipment cost per material processed	$ 3,100.00 per ton
Equipment cost per sugar produced each day	3.82 per lb.
Production cost per material processed	5.70 per ton
Production cost per sugar produced	0.007 per lb.

Ionics

Tons processed (paper only) . . .	80.00 tons per day
Sugar produced	69,500.00 lbs. per day
Equipment cost (initial installed cost)	$582,000.00
Production cost (excluding labor)	
Material	511.00 per day
Fixed charges and maintenance at 10 per cent equipment .	160.00 per day
Total	$ 671.00 per day
Equipment per material processed	$ 7,300.00 per ton
Equipment cost per sugar produced each day	8.38 per lb.
Production cost per material processed	8.40 per ton
Production cost per sugar produced	0.0097 per lb.

To account for the differences in input, the 80 tons per day input of Ionics must be considered diluted by a proportional amount of non-hydrolyzables in the 80 ton per day input as exists in the 170 ton per day input of Porteous. Upon further investigation, it can be found through use of the cellulose to sugar conversion chart used by Porteous[7] that where he is using a 55.2 per cent yield factor, he is also assuming a cellulose content in paper of 75 per cent. As stated earlier Ionics is operating at process conditions which predicts a 43 per cent yield factor, but they are purchasing wastepaper as a raw material for the process and using a cellulose content of 91 per cent. For the purposes of comparison, a cellulose content of 75 per cent will be used. Thus on a proportional basis, 80 tons per day of input will contain 70.5[8] tons of paper, which on a 75 per cent basis, contains 53 tons of cellulose. That amount of cellulose can be converted to 50,600 pounds of alcohol per day. The raw material costs will remain the same and thus the revised figures are:

Ionics Revised

Tons processed (containing 9.5 tons non-hydrolyzables)		80.00 tons per day
Sugar produced		50,600.00 lbs. per day
Equipment cost per sugar produced per day	$	11.50 per ton per day
Production cost per sugar produced		0.0132 per lb.

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[7]Porteous, Towards a Profitable Means, p. 15.

[8]$\frac{150 \times 80}{170}$ tons per day = 70.5 tons per day

To take into account economies of scale, Ionics design will be scaled up to 170 tons per day using a .6 scale factor[9] for the plant cost and proportional costs for the production costs. The revised sugar production will be used.

Ionics Revised and Scaled

Tons processed (containing 20 tons of non-hydrolyzables . . .	170.00 tons per day
Sugar produced (2.13 multiplied by 50,600 lbs.	108,000.00 lbs. per day
Equipment cost (1.56 multiplied by $582,000	$910,000.00
Production cost (excluding labor)	
Material (2.13 multiplied by $511 per day)	1,090.00 per day
Fixed charges and maintenance (1.56 multiplied by $160) .	250.00 per day
Total	$ 1,340.00 per day
Equipment cost per material processed	$ 5,350.00 per ton
Equipment cost per sugar produced each day	8.40 per lb.
Production cost per material processed	7.90 per ton
Production cost per sugar produced	0.0124 per lb.

It is apparent from these figures, that capital invested in the Ionics design is far less efficient than that in the Porteous design, both in the amount of sugar produced and in production cost. This analysis has, hopefully, resolved the differences in the two designs to those inherent in the

[9]The ratio of Capacity A over Capacity B taken to the .6 power equals the ratio of Cost A to Cost B. See page 80 and 81 of Mellar, Wastes Into Yeast for further information.

efficiency of the process parameters and equipment cost differences.

To continue the analysis further, an overall look at the process flow and the relatively high cost items along with their credibility as a reasonable cost will help to isolate the strong and weak points of each design. To take the Ionics design first, this design is centered around a reactor system that is commercially available from the Black and Clawson Company of Middletown, Ohio. Its cost[10] was verified by Ionics through personal communications with Black and Clawson in 1968 when their research was performed. This reactor, with its associated screw presses and pumps, represented the great majority of the equipment cost and was also a totally credible design to accomplish the process as planned. The major problem here was that Black and Clawson only made this equipment in two pressure series, 175 pounds per square inch absolute and 275 pounds per square inch absolute. Allowing a 10^{o}F. safety margin, this defined the operating temperature of the process as 392^{o}F. As mentioned earlier, this translated into a cellulose yield of 43 per cent. A further process loss in product sugar is incurred by operating at a

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[10] U.S. Department of Health, Education and Welfare, Conversion of Organic Solid Wastes into Yeast - An Economic Evaluation, February, 1968. Floyd H. Mellar for the Bureau of Solid Waste Management. (Washington, D.C.: Government Printing Office, 1968,) Public Health Service Publication No. 1909.

low liquid-to-solid ratio of 4 to 1. This causes the waste hydrolysis products, wood lignins, to carry with them a more highly concentrated sugar solution than is the case with Porteous who uses a 15 to 1 ratio. The remainder of the Ionics equipment appears to be reasonably priced as will be discussed later.

The most favorable factor in the Porteous design is that the process was designed to operate at optimum, 55.2 per cent yield. On the other hand, there is some reason to question whether or not the process will operate as designed. Further, the generalized treatment of costs, though conservative, leaves a great deal of uncertainty surrounding them. Upon investigation, the design reveals only one major problem; that is how to get the cellulose slurry into the reactor and up to reaction temperature. Each succeeding section of the flow chart is treated in quite general terms with regard to engineering design and cost estimates. A quick comparison of similar process areas between Ionics and Porteous reveals that Porteous uses a total of thirteen cooling stages where Ionics uses only two; also, Porteous uses a neutralizer with the same design criteria as his reactor at a cost of $50,000, while Ionics uses an atmospheric tank with a mechanical agitator. A brief look at the alcohol portion of the Porteous process shows that only one bubble cap column is to be used for the alcohol distillation, while other authors describing the process indicated that it requires a minimum of two columns and a maximum five columns.[11] These factors cause a great deal of uncertainty to shroud the Porteous design.

In an effort to resolve these uncertainties, Porteous' basic design was recalculated for the Cascade County demands with refinements added where it has been possible within the author's resources to communicate with professional or commercial sources of information. Where aid from a source of this type has not been possible, a compromise was made between the designs of Porteous and Ionics. The recalculated design is shown in Appendix 2. Only the pertinent factors and decisions concerning it will be recounted here. Equipment costs are also summarized in detail in this appendix.

The first decision was made in the design recalculation to determine optimal capacity. This depends to a large extent upon the marginal cost of incremental capacity and the capacities of commercially available equipment. As a general guide for scaling cost versus capacity, the chemical industry applies the ".6 scale factor" rule which says:

$$\left(\frac{\text{Capacity A}}{\text{Capacity B}}\right)^{.6} = \frac{\text{Cost A}}{\text{Cost B}}$$

Since Capacity A is two times Capacity B, the ratio of Capacity A to Capacity B taken to the .6 power is two times

[11]Donald Pierce Campbell, Process Dynamics: Dynamic Behavior of the Production Process, (Chicago: Wiley, Inc., 1958), pp. 197-312.

.6 power, thus 1.516 equals the ratio of Cost A to Cost B.

$$\frac{\text{Capacity A}}{\text{Capacity B}}^{.6} = (2)^{.6} = 1.516 = \frac{\text{Cost A}}{\text{Cost B}}$$

Of course this factor does not apply to every component of a plant and will not be used in all cases. The components of this design will be considered to fall into three broad groups:

1. Components that have a marginal cost of 100 per cent and items with expected life between five to ten years. This equipment will be bought as needed. The types of equipment that fall into this category are:
    a) Flash cooling stages,
    b) Fermenting vats,
    c) Small pumps and motors,
    d) Yeast centrifuges,
    e) Storage tanks,
    f) Food pump and slurry pump;

2. Large items with low marginal cost that will be purchased for the design life of the plant, twenty years. These items are:
    a) Land,
    b) Building,
    c) Distillation columns;

3. Components to which the .6 scale factor applies thus causing a conflict between overcapacity and the cost of money. A prime factor here is the determination of optimum capacity with respect to design capacity. A safety factor of 130 per cent will be used (that optimum capacity equals 130 per cent times 97.2 tons per day). It will be eight years before new capacity is absolutely needed, with refuse increasing at 4 per cent per year. If the cost of money is taken as 8 per cent, the

rate of inflation as 3 per cent, and the incremental capacity to be bought in eight years is twice the original design capacity, then a positive net present value, which is the case here, indicates the purchase of the extra capacity.[12] The items which fall into this category are:

a) Steam boiler,
b) Refuse storage.

The items listed above, to which the .6 factor applies, have been designed for twenty-year capacity and thus vary with the Porteous design in this respect only as far as designing for the present with the exception of land, building and distillation columns, which are only cases where the scale factor is less than .6. Table 1 and Table 2 show a comparison of the estimated total capital investment required.[13] Table 3 gives a comparison of the estimated manufacturing cost. The items which were estimated at a lower price than Porteous were the reactor, neutralizer, flash chambers, filters, and bubble cap column. There are two factors that could explain these cost variations:

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[12]The calculation is carried out on a unit basis. If the .6 factor is applicable, double original capacity costs 1.516 times the original cost. The marginal cost of the second unit is 0.516 of the original cost. The item that costs $1.00 now will cost $1.2667 in eight years. To buy this unit with a twenty-year annuity at 8 per cent to the seller would take a payment of (0.1018) times $1.2667 to equal $0.129023 per period. The present value of saving a twenty-year annuity in eight years at 8 per cent is (5.3044) times (0.129023) or $0.684389. This figure is greater than the marginal cost of $0.516 and so the net present figure value is a positive $0.1684.

[13]See Appendix 2 for detailed equipment analysis.

TABLE I

EQUIPMENT COMPARISON

Item		Re-Design	Porteous	Ionics
Storage hoppers		$ 25,000	$ 100,000	$
Screening section (hydrapulper)			50,000	
Air Classification		14,200		
Cellulose slurry mixer		6,000		
Reactor		3,250	50,000	391,910
Feed water storage		12,760	10,000	
Acid storage		5,600		26,160
Limestone storage		9,600		9,701
Alcohol storage		5,600		
Neutralizer		15,000	50,000	15,042
Flash chambers and heat exchangers for hydrolysis		35,050	108,000	27,795
Preheaters for hydrolysis		5,400	4,500	
Filters		50,000	69,000	
Vats (fermentation)		15,000	35,000	
Centrifuges		50,000		34,553
Pumps and motors		37,680		47,337
Erection and Misc. plant			200,000	
Boiler		55,000	35,000	
Conveyors		13,900		27,795
Total for Hydrolysis		$359,040	$ 711,500	$580,293
Bubble cap columns	$ 80,000*	35,000	80,000	
Heat exchangers and preheaters		2,715	10,500	
Pumps and motors		3,260		
BOD reduction plant			250,000	
Total Equipment	$445,015	$400,015	$ 992,000	$580,293
Building		54,000	1,200,000	203,100
Total Cost	$499,015	$454,015	$2,192,000	$783,393

*See Equipment Estimates for Columns, Appendix 2, p.

TABLE II

ESTIMATE OF TOTAL CAPITAL INVESTMENT USING THE IONICS ESTIMATING PROCEDURE

Item and Basis of Estimation	Re-Design	Porteous	Ionics
Installed equipment	$ 400,015	$ 992,000	$ 580,293
Purchased Equipment Cost(PEC)*	279,730	693,706	405,799
Equip. instal. (inc. instrumentation and insulation) - 43% (PEC)	120,284	298,293	174,493
Piping (inc. insulation)-36% PEC	100,703	249,734	146,087
Electrical installations - 15% PEC	41,959	104,055	60,869
Buildings inc. services - 35% PEC	97,905	242,797	142,029
Yard improvements - 10%PEC	27,973	69,370	40,579
Service facilities - 35% PEC	97,905	242,797	142,029
Land - 4.8% PEC	13,427	33,297	19,478
Total Physical Plant Cost	$ 779,889	$1,934,053	$1,131,368
Engineering and construction - 40% PEC	111,892	277,482	162,319
Direct Plant Cost (DPC)	$ 891,781	$2,211,535	$1,293,688
Contractors fee - 7% DPC	62,424	154,807	90,558
Contingency - 15% DPC	133,767	331,730	194,053
Fixed Capital Investment (FCI) . .	$1,087,973	$2,698,073	$1,578,299

*Total installed cost - Purchased equipment cost plus installation cost; installed cost - 43 per cent of purchased equipment cost. Substituting this equality for the installed cost into the equation gives Total installed cost - PEC + .43 PEC or PEC = $\frac{\text{Total installed cost}}{1.43}$

TABLE III

ESTIMATED MANUFACTURING COST

Item	Item Description	Re-Design	Porteous	Ionics
Direct Production Cost				
Raw Materials:				
Acid	$53/ton	$ 330.00	$ 508.00	$ 213.00
Limestone	$3.50/ton	21.80	33.60	13.23
Utilities:				
Electricity		84.00	125.00	109.50
Fuel	$0.0683/gal	365.00	365.00	148.30
Water		39.00	62.60	43.00
BOD reduction	$0.03/lb	351.00	707.00	
Operating Labor	3 shifts (15 men)	329.60	427.40	216.00
Supervisory Labor	3 shifts (3 men)	82.40		28.00
Fringe Benefits	15% (operating & supervisory labor)	61.80	64.11	36.60
Operating Supplies	10% of operating labor	32.96	42.74	21.60
Maintenance and Repairs 10% FCI				
Labor (per year)	5% FCI	149.00	369.00	217.00
Material & overhead (per year)	5% FCI	149.00	369.00	217.00
Total		$1,995.63	$3,074.00	$1,263.00

Item	Item Description	Re-Design	Porteous	Ionics
Fixed Charges				
Bond amortization	5% FCI/yr for 20 yrs	$ 149.00	$ 369.59	$ 216.20
Local taxes	2% FCI/yr	59.61	147.83	86.48
Insurance	1% FCI/yr	29.80	73.91	43.24
Total Charges		$ 238.41	$ 591.33	$ 345.92
Plant Overhead	70% of operating labor, supervision & maintenance labor	392.70	557.48	323.00
General Expenses				
Administrative costs	15% of operating labor, supervision & maintenance	84.15	119.46	69.10
Financing interest	8% of Fixed Capital Investment/yr	238.45	591.35	347.00
Total Expenses		$ 322.60	$ 710.81	$ 416.10
Total Production Cost (Excluding Income Tax)		$2,949.27	$4,933.00	$2,348.00
Production Cost Per Unit of Product		$0.561/gal	$0.46/gal	$0.789/gal*

*At full capacity, the plant could produce 69,400 pounds of sugar - 2,975 gallons of alcohol.

1. Conservative cost estimating technique,
2. Over designed equipment.

The reactor used by Porteous was fitted with a mechanical agitator. This is quite expensive at high pressure. The redesign did not use a mechanical agitator because a certain amount of jet mixing should occur at the flow rates being considered. It is therefore expected that the flow will remain turbulent enough that mixing of the fluid will occur. Porteous uses a neutralizer of the same design criteria as the reactor. Since the flow at this point is at atmospheric pressure, a neutralizer designed for high pressure is unnecessary. The flash chambers are the greatest single discrepancy. This is an involved engineering point that will require further consideration. Ionics' design agrees quite closely with the author's design with regard to the heat exchanger area taking into account that the Ionics flow rate is approximately one-fourth of the redesign flow rate. The diatomaceous earth filters are a poor choice for filtration of such a fibrous material as paper and are more expensive than belt filters. The bubble cap column of Porteous is almost twice the estimated cost. The higher cost of Porteous will be carried along in further calculations, for comparison, but the estimated cost will be used for the equipment cost. The estimated cost is further justified by the presence of over capacity in the chemical industry, particularly around the Gulf coast area, thus the possibility of purchasing good second hand columns from Perry, Incorporated is quite good.[14]

The results of the recalculated design are shown below:

Revised Porteous Design

Tons processed	97.20	tons per day
Sugar processed	67,700.00	lbs. per day
Equipment cost	$402,930.00	
Production cost Material (excluding labor and Biochemical Oxygen Demand Reduction)	839.00	per day
Fixed charges and maintenance at 10 per cent equipment	110.00	per day
Total	$ 949.00	per day
Equipment cost per material processed	$ 4,145.00	per ton
Equipment cost per sugar produced per day	5.95	per lb.
Production cost per material processed	9.76	per ton
Production cost per sugar produced	0.014	per lb.

The high production cost per pound of sugar by comparison with the the original Porteous figure of 0.007 per pound is the result of increasing the fluid flow in the revised design to allow for the cooling effect of the liquid slurry which Porteous does not account for. It should be further noted that Porteous determined his fluid flow on the basis of the cellulosic solids in the input and thus excluded the non-hydrolyzables from consideration when he calculated the amount of fluid to make a 15 to 1 liquid-to-solid slurry. Had Porteous

[14] Luther Dunn, personal communication with Georgia-Pacific, Incorporated, Bellingham Division, April, 1972.

calculated the 15 to 1 ratio on the basis of his total solids, 170 tons per day, he would have had a flow rate of 27,170 gallons per hour rather than his 24,000 gallons per hour flow rate. His actual liquid-to-solid ratio in the reactor is 14.2 to 1 which may be more readily observed if it is noted that Porteous design handles 1.75 times the redesigned input of 97.2 tons per day, but has an hourly flow rate of 1.45 times that of the redesign.

The process operating costs are very dependent upon the volume of liquid handled. As was mentioned in the analysis of equipment, 130 per cent optimum capacity was designed for most equipment, but the critical component of the process, as far as volume is concerned, is the reactor. It was originally felt that the slurry pump would be the limiting factor, but such would not be the case if the pump can handle 35 per cent solids, which is a liquid-to-solid ratio of 1.857 to 1, and much lower than the 3 to 1 which was incorporated in the redesign. On the basis of the 35 per cent solids capacity of the slurry pump, the input could be increased to 801 tons per day. If this were the only consideration, the only limiting factor would be the lower limit of 8 to 1 liquid-to-solid ratio at which yield is affected adversely. Thus the excess capacity lies not so much in the ability to handle 130 per cent greater volume, but in the capability to handle lower liquid-to-solid ratios. This optimum liquid-to-solid ratio should not be designed for at the outset due to the untried nature of the process although no technical difficulties are foreseen other than the possibility of the fibrous material clogging at orifices. If a liquid-to-solid ratio of 12.4 to 1 could be handled by the flash cooling equipment, the input could be increased to 131 tons per day without changing the hourly flow rate of 16,500 gallons per hour from the reactor. Thus the operating capacity could be increased 180 per cent by lowering the liquid-to-solid ratio from 15 to 1 to 12.4 to 1. This type of uncertainty can only be resolved through actual operation.

To this point, the concern has been primarily to find why such a large variation exists between the costs of the two designs. It is felt that the Porteous design and cost is the most reasonable despite the vague technique used in estimating equipment. Now it is desirable to have a price per gallon of alcohol from which reference to the market may be made. The estimating technique used by Porteous to arrive at the overall plant cost and from this to estimate operating cost is too vague. The Ionics technique will be used since it is more complete in areas of possible cost that should be dealt with, such as fringe benefits for labor. This method is considered to be quite conservative and should thus establish an upper limit for capital and operating costs.

It should be mentioned that the local prices for materials were used where possible, such as the acid price of $53.00. The fixed charges were originally based on a twelve year plant life as used by Ionics. This was changed to a twenty year plant life. The interest charge used by Ionics originally was 4 per cent. This has changed to 8 per cent. The areas of maintenance, repairs, and plant overhead appear to be areas with a surplus in them, but as was mentioned earlier, this conservative technique should project a maximum production cost. To put these costs in perspective, the most closely related industrial application of a process similar to the hydrolysis-fermentation process, is the paper and pulp industry's process to convert waste sulfite liquor to alcohol by fermentation. This process is used by the Georgia-Pacific Corporation at Bellingham, Washington. Their quoted selling price is $0.20 per gallon of industrial grade ethanol.[15] If the daily production cost could be held to $2,000.00 and a 12.4 to 1 liquid-to-solid used, the production cost per gallon would be $0.21.

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[15]See Appendix 2 for the flow chart of this process.

CHAPTER IV

MARKET AND ECONOMIC ANALYSIS

Ethyl alcohol is a versatile chemical; and political factors restrict some of its uses. This fact is occasioned primarily by its alternate use in beverages and spirits with attendant high revenue taxes and government regulation. Denaturation is the means by which the governmental regulations are implemented to render the ethanol non-consumable. There are approximately 57 formulas to denature alcohol for various uses. The industrial uses for 95 per cent ethanol in 1948 were:[1]

Acetaldehyde	37.5 per cent
Antifreeze	15.0 per cent
Ethyl acetate and ether	7.5 per cent
Miscellaneous chemicals and solvents	40.0 per cent
Total	100.0 per cent

Industrial ethanol has competed for use in four major areas, which are synthetic rubber, plastics, antifreeze, and solvents. Ethanol can be used to synthesize acetic acid, acetic anhydride, tetra-ethyl lead, n-butyl alcohol, ethylene glycol, and is necessary for preparation of polyester, polyurethane fibers, and resins. The chemical industry has continually found ways

[1]Donald Pierce Campbell, Process Dynamics: Dynamic Behavior of the Production Process, pp. 309-312.

to synthesize these chemicals more cheaply from materials other than alcohol. Since ethanol itself can more cheaply be produced synthetically from the petroleum by-product, ethylene, many of the chemicals which were originally produced from ethanol are now directly produced from ethylene. There are large markets for each of the previously mentioned chemicals and this is what makes ethanol production from refuse such an enticing prospect. Since the known petroleum reserves will be exhausted in about one hundred years at the present rate of consumption, petroleum prices will probably rise in the future. The United States presently imports ten per cent of the oil used in domestic energy production. However, trees can be harvested on a 40 year cycle and therefore are not an irreplaceable resource; petroleum is. As a source of energy alcohol has not found technical acceptance for use as an internal combustion fuel due to its low heat value. General Motors research predicts that the turbine engine will be the best engine for future cars. Due to the "clean" nature of alcohol combustion, possibly then the low heat value of alcohol can be tolerated as a fuel for the turbine.

After the World War II peak of 650 million gallons, the national consumption of ethanol settled to a rather stable level of 300 million gallons which has persisted to the present time. In 1949, the price per gallon of ethanol, 190 proof S.D.-1, was $0.45.[2] From this time the price has risen to

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[2]Harry Jiler, Commodity Yearbook, Commodity Research Bureau, Inc., (New York: New York, 1970), p. 50.

$0.55 in 1969. Over this period of time, the price has fallen as low as $0.21 per gallon for short periods of time. Since 1969, it has been difficult to obtain current information; therefore, Georgia-Pacific, the nearest ethanol producer to Great Falls was contacted. The information they supplied indicated a declining market for ethanol. According to Georgia-Pacific, the 1970 national consumption was 350 million gallons, but in 1971 the consumption was down to 300 million gallons. The reason given was that ethyl acetate was being produced directly, by-passing the alcohol requirement. This development caused a great deal of overcapacity in the alcohol industry and thus they were selling 2 million gallons of their 3 million gallon yearly production abroad at $0.21 per gallon. Prices of ethanol have never remained this low for long during the period from 1942 to 1969. Hopefully, the price will rise soon, but further economic analysis will be based on a market price of $0.21 per gallon.

As dismal as this price may sound, with the last chapter's cost estimations in mind, one must consider that Cascade County is isolated from markets with the nearest national market centers being Minneapolis, Salt Lake City, or Seattle. The freight on tank car lots for industrial ethanol as quoted by Burlington Northern are:[3]

Great Falls to Salt Lake City	$2.09 per 100 pounds
Great Falls to Minneapolis	2.74 per 100 pounds
Great Falls to Seattle	2.21 per 100 pounds

[3]Class 35 on 30,000 pounds minimum.

At 5.56 pounds per gallon the above rates per gallon would be:

Salt Lake City	$0.111 per gallon
Minneapolis	0.152 per gallon
Seattle	0.123 per gallon

As a result of high freight rates, Cascade County should try to develop a local market for its alcohol. As long as the price of alcohol remains at $0.21 per gallon, outside competition could not undercut local producers selling at $0.33. Such a market may exist in the local production of herbacides which would use alcohol as the solvent, but this is only a prospect for the future at the present time.[4] For the present analysis, the market shall be the national market defined by a price that has fluctuated between $0.21 and $0.55 per gallon, and a transportation charge between $0.11 and $0.15 to that market. It is difficult to imagine the price of ethanol remaining so severly depressed for any great length of time, but it is outside the realm of this paper to do more than quote the observed price range.

The hydrolysis-fermentation process as proposed by Porteous and discussed in the redesign is certainly technically feasible. The economic feasibility, as in any industrial chemical process, depends upon operational experience with the process characteristics, unless the projected profit

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[4]Personal contact with Haynes and Morgan Chemical Company, Great Falls, Montana, April 1972.

margin is so large as to allow some room to take a gamble with an untried process. To gain this type of operational experience with "improved and revolutionary means of recycling solid waste"[5] is the stated purpose of the Bureau of Solid Waste Management.[6] If a research grant were to be approved to incorporate this process, up to 75 per cent of the total capital investment and 100 per cent of the first year's operation would be paid by the Federal government. This would definitely improve the fixed charges expense, but the real value of this project would be the possibility of determining the actual operating costs and technical characteristics of the process. See Table 4 for correlation of economic analysis.

One further aspect to be considered in the Cascade County environment is the savings afforded by not having to dispose of 120 tons per day of the pulverized refuse minus the metals magnetically separated. This study presumes that all the waste filter cake from hydrolysis operation is burned for fuel, a possibility mentioned in Chapter III and Appendix 2. If this filter cake is not burned for fuel, it will require essentially the same equipment to dispose of it as it would to dispose of the original 120 tons of pulverized material.

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[5]The Solid Waste Disposal Act, 89th Congress, October 20, 1965, Section 201-215.

[6]Ibid.

Although an estimated 49.5 tons of pulverized refuse will have been converted to sugar or decomposed sugar, the remaining material will contain its own weight in liquid and thus produce approximately 100 tons of material to be disposed of at the landfill. There may be some possible proportionate savings in capital by hauling the filter cake rather than the pulverized refuse, but for analysis here the differential will be considered slight. The fixed charges and operating costs that could be saved by burning the filter cake as estimated by the Heil Company:

Equipment		
3 transfer trailers	$ 60,000	
2 transfer tractors	32,000	
1 landfill compactor	40,000	
Total	$132,000	
Fixed charges resulting from capital equipment at 6 per cent interest	$ 26,800	per year
. . . .	$ 74	per day
Operating expense		
1 truck driver	$ 10,000	per year
1 maintenance man and driver . .	10,000	per year
tractor and trailer maintenance .	4,290	per year
landfill compactor maintenance .	4,600	per year
Total	$ 28,890	per year
. . . .	$ 79	per day
Total charges saved	$ 153	per day

Thus the total savings associated with burning the filter cake are $153 per day to the county in transportation charges and a possible saving of $365 per day in fuel costs for the hydrolysis-fermentation plant. The present value of a $365 per day annuity at 8 per cent cost of capital for twenty years is $1.31 million. By comparison to the expected boiler cost of $55,000, this present value is much greater than any expected cost to modify the steam boiler to handle the filter cake.

The results of this paper are compiled in Table 4 and Figure 1. The low estimate was derived by using the low figure of the range from which Ionics draws its estimates[7] and assuming the county received an EPA grant for 75 per cent of the fixed capital investment. An EPA grant would reduce the bond amortization and interest charge by $112 per day. As can be seen from Table 4, a major uncertainty which must be resolved is the expected Biochemical Oxygen Demand content of the stillage. Burning of the filter cake is presently feasible and resolution of this point is merely a matter of appraising the equipment. The remainder of the dominant factors such as the amount of labor required, operating supplies, and plant overhead can be roughly approximated at this time.

In Figure 1, the effect of decreasing the liquid-to-solid ratio is shown. This is the single most important factor in the process. The graph shows a decrease in the liquid=to-solid ratio from 15 to 1 at the axis to 12.4 to 1

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[7]Meller, Wastes Into Yeast, pp. 56-60.

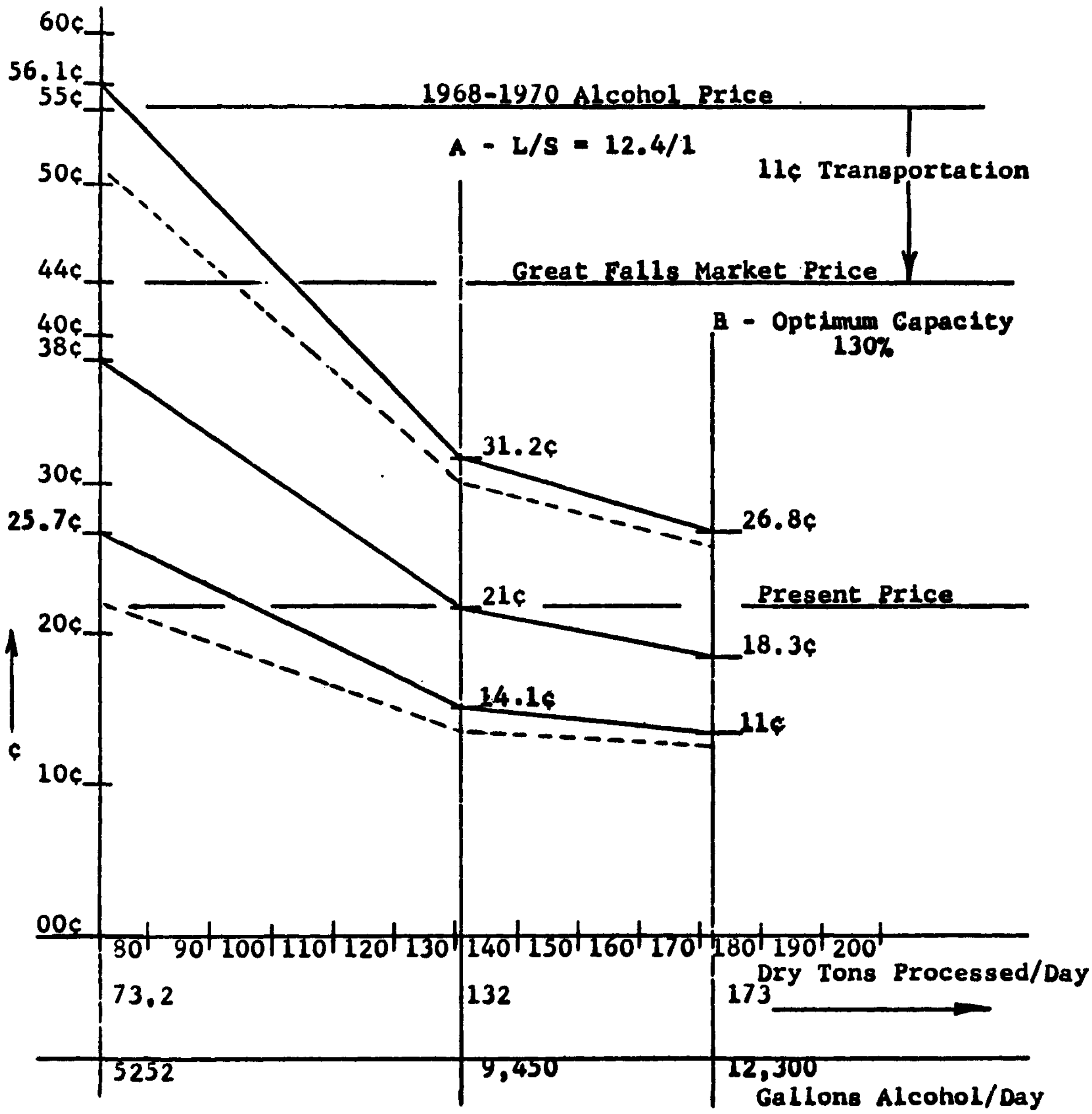
TABLE IV

ESTIMATED MANUFACTURING COST VARIATION
WITH LIQUID VOLUME AT 16,394 GAL/HR

Item	Item Description	Re-Design	Item Description	Low Estimate
Direct Production Costs				
Raw Materials:				
Acid		$ 330.00		$ 330.00
Limestone		21.80		21.80
Utilities:				
Electricity		84.00		84.00
Fuel		365.00	Burning filter cake	0.0
Water		39.00	Recycle condensate	29.00
BOD reduction		351.00	Low range of BOD	56.10
Labor:				
Operating	5 men/day	329.60	3 men	263.00
Supervisory	1 man/day	82.40	1 man	82.40
Direct Inputs		$1,602.80		$ 866.30
Fringe Benefits	15% labor	61.80	10% labor	35.54
Operating supplies	10% labor (oper.)	32.96	5%	13.15
Maintenance & Repairs:	10% FCI		2%	
Labor	5% FCI	149.00	1%	29.80
Material & overhead	5% FCI	149.00	1%	29.80
Direct Production Cost		$1,995.63		$ 973.59

Item	Item Description	Re-Design	Item Description	Low Estimate
Fixed Charges				
Amortization of 20-yr Bond	5% FCI	$ 149.00	5% of (25% FCI) with EPA grant	$ 37.25
Local taxes	2% FCI	59.61	1%	29.80
Insurance	1% FCI	29.80	0.4%	11.90
Total Charges		$ 238.41		$ 78.95
General Expenses				
Plant overhead	70% of operating, supervision & maintenance labor	392.70	50%	187.60
Administrative Cost	15% of operating supervision & maintenance labor	84.15	10%	34.54
Financing Interest	8% FCI	238.45	8% of (25% FCI) with EPA grant	60.25
Total Expenses		$ 715.30		$ 282.39
Total Production Cost		$2,949.27		$1334.93
Total Production Cost/Gallon (5252 Gal/day)		56.1¢/gal		25.7¢/gal

Fig. 1.--Affect upon unit price of decreasing L/S ratio from 15/1 to 12.4/1 and increasing flow volume to 130 per cent optimum with fixed production costs per Table IV.



Note:

These lines represent the cost reduction afforded by the credit charge potential to the city for disposal. This cost reduction of $153 per day represents a cost reduction per gallon of 2.92¢, 1.62¢, and 1.24¢ at alcohol production levels of 5,252 gallons, 9,450 gallons and 12,300 gallons per day respectively.

at the line marked A. Past this point, the flow volume is increased to the 130 per cent optimum using a liquid-to-solid ratio of 12.4 to 1 and increasing the production cost by increasing the raw material and utility requirements. The curve for a production cost of $2,000 per day is drawn to represent the median expected performance.

In contrasting the curves for unit price with the range of market price, it should be kept in mind that the savings to the city of $153 per day for disposal of the pulverized refuse should be considered as a loss factor for the process at which the county is no worse off financially than if it had to dispose of the pulverized refuse to landfill. This could be better visualized as the plant charging the county $153 per day to dispose of pulverized refuse, thus lowering the plant's cost. The effect of this factor is shown by the dashed lines underneath the curves in Figure 1. In conclusion, it is felt that the hydrolysis-fermentation process has adequate potential for economic success to warrant a demonstration grant given that a local market for alcohol could be developed or the national market price of alcohol stabilized between $0.40 and $0.50.

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APPENDIX 1

1968 SURVEY RESULTS AND COMPOSITION ANALYSIS

TABLE 1
CASCADE COUNTY POPULATION PROJECTION TO 1988 *

City or Town	1960 Census	Projections for 1968 A	B	C	Projections for 1988 A	B	C
Great Falls	55,244	---	---	76,000	---	---	136,000
Vaughn	265	331	342	335	527	535	530
Sun River	100	112	103	110	134	110	125
Fort Shaw	100	112	109	110	134	131	130
Simms	200	224	198	210	268	193	240
Ulm	350	438	335	415	696	297	665
Cascade	604	755	652	730	1,202	773	1,140
Tracy	170	212	149	200	338	96	320
Sand Coulee	300	375	262	350	597	168	565
Stockett	400	500	350	475	796	225	755
Centerville	85	106	75	90	169	49	150
Monarch-Winter	(20)	(22)	(31)	(27)	(27)	(58)	(45)
Monarch-Summer	(150)	(168)	(230)	(170)	(201)	(429)	(220)
Neihart	150	168	54	170	201	0	220
Belt	757	946	723	900	1,506	639	1,430
Totals	58,810			80,193			142,403

A. Based on "Great Falls Urban Transportation Survey" 1961, Volume IV, and United States Census of Population, Bureau of Census, U.S. Dept. of Commerce, and "Commercial Atlas and Marketing Guide", 98th Edition, 1967, printed by Rand McNally & Co.

B. Based on School District census material taken from 1960 - 1967. School census trends were extrapolated for projections of the towns after correlating 1960 school census to 1960 town population.

C. Population used for this study.

* Data obtained from Great Falls City-County Planning Board

TABLE 2
REFUSE COLLECTION QUANTITIES

City or Town	1968 A	1968 B	1988 A	1988 B	CY/Wk. Packed 1968 C	CY/Wk. Packed 1988 D
Great Falls	76,000	* 76,000	136,000	* 136,000	2,795.0	7,000.0
Adjacent Gt. Falls	---	4,000	---	6,000	147.0	309.0
Vaughn	335	370	530	580	13.9	29.9
Sun River	110	120	125	135	4.7	7.2
Fort Shaw	110	120	130	145	4.7	7.7
Simms	210	230	240	265	8.8	13.9
Ulm	415	455	665	730	17.0	37.6
Cascade	730	800	1,140	1,250	29.3	64.3
Tracy	200	220	320	350	8.3	18.0
Sand Coulee	350	385	565	620	14.4	32.0
Stockett	475	520	755	830	19.0	42.7
Centerville	90	100	150	165	3.6	8.8
Monarch-Winter	(27)	(30)	(45)	(50)	1.0	2.6
Monarch-Summer	(170)	(185)	(220)	(240)	6.7	12.4
Neihart	170	185	220	240	6.7	12.4
Belt	900	990	1,430	1,570	36.5	80.7
Total	80,193	* 84,603	142,403	* 149,025	3,112.8	7,672.0
Total-Cascade Co.	91,800	91,800	153,000	153,000		

A. Population projection from Table 1.

B. Town population increased to allow for total population on collection route. Great Falls city limit and adjacent population listed separately.

C. Refuse collection (1968) = 2.5 lbs./cap./day. Loose weight = 350 lbs./Cu. Yd. Volume of packed = .735 times volume of loose.

D. Refuse collection (1988) = 3.5 lbs./cap.day. Loose weight = 350 lbs./Cu.Yd. Volume of packed = .735 times volume of loose.

* 3,530 people living on Malmstrom Air Force Base dispose of waste at the base disposal site and are not included.

TABLE 3

SUMMARY OF OPERATION, MAINTENANCE AND REPLACEMENT COSTS

ALTERNATE 1

Replacement of land and landfill equipment	(Table 8)	$51,873/yr.
Landfill operation and maintenance	(Table 9)	$42,200/yr.
Collection costs incl. vehicle replacement	(Table 10)	$847,876/yr.
	TOTAL	$941,949/yr.

Cost per ton produced $\frac{\$941,949}{35,600 \text{ ton/yr.}}$ = $26.46/ton

$26.46/ton x 73%* = $19.32/ton for residential dwelling

$19.32/ton x 1.84 ton/res.dwelling/yr.** = $35.55/res.dwelling/yr.

ALTERNATE 2

Replacement of land and landfill equipment	(Table 8)	$51,873/yr.
Landfill operation and maintenance	(Table 9)	$42,200/yr.
Collection costs incl. vehicle replacement	(Table 10)	$541,781/yr.
	TOTAL	$635,854/yr.

Cost per ton produced $\frac{\$635,854}{35,600 \text{ ton/yr.}}$ = $17.86/ton

$17.86/ton x 73%* = $13.04/ton for residential dwelling

$13.04/ton x 1.84 ton/res. dwelling/yr.** = $24.00/res.dwelling/yr.

ALTERNATE 3

Replacement of land and landfill equipment	(Table 8)	$14,183/yr.
Landfill operation and maintenance	(Table 9)	$15,230/yr.
Collection costs incl. vehicle replacement	(Table 10)	$66,864/yr.
	TOTAL	$96,277/yr.

Since commercial firms are a small percentage of total rural services, rates are based on residential charges.

Total cost per dwelling: $\frac{\$96,277}{2,690 \text{ dwellings}}$ = $35.79/res/dwelling/yr.

* For the City of Great Falls, 73% of the total revenue is from residential billing and the remaining 27% is from commercial

** Obtained by dividing the total refuse produced by the total number of residential dwellings

TABLE 4

CELLULOSE AND COMPOSITION ANALYSIS

	Battelle				Ionics	
Component	A Range	B Nominal	C Per Cent	D Content	E Nominal	Content
Paper	37-60	55	88.5	48.7	48.6	43.0
Metal	7-10	9	-	-	11.1	-
Food	12-18	14	40.8	5.7	11.1	4.5
Yard	4-10	5	60.3	3.0	6.9	4.1
Wood	1-4	4	74.4	2.9	2.1	1.5
Glass	6-12	9	-	-	8.3	-
Plastic	1-3	1	-	-	2.8	-
Misc.	5	3	-	-	8.4	-
Cloth	-	-	60.0	-	.7	.4
Total	-	100	-	60.3	100.0	53.5
Cellulose (%)	-	-	-	60.3%	-	53.5%
Moisture	20-40	30	-	-	28.0	-

Third Annual Report	Nominal
Cellulose, Sugar, Starch	59.50
Lipids (fats, oils, waxes)	5.60
Protein	2.57
Plastic	1.40
Metal, Glass, Misc.	31.00
Total	100.00%
Moisture	20.73%

Average chemical cellulose content on a dry basis:

$$\frac{60.3 + 53.5 + 59.5}{3} = 57.7\%$$

Average solids removed during salvage:

glass + metal + 1/2 misc.

$$\frac{(18+3)+(19.4+8.4)+31}{3}$$

= glass+metal+msc = 26.6%
- (1/2 misc avg) = -2.8%
Solids removed = 23.8%

Note:

A is the percentage range for the component while column B and E is the percentage of the component most probably expected. Column C is the percentage of chemical cellulose in each of the cellulosic type components. Column D is the product of multiplying the nominal and per cent columns.

APPENDIX 2

THE RE-DESIGN

APPENDIX 2

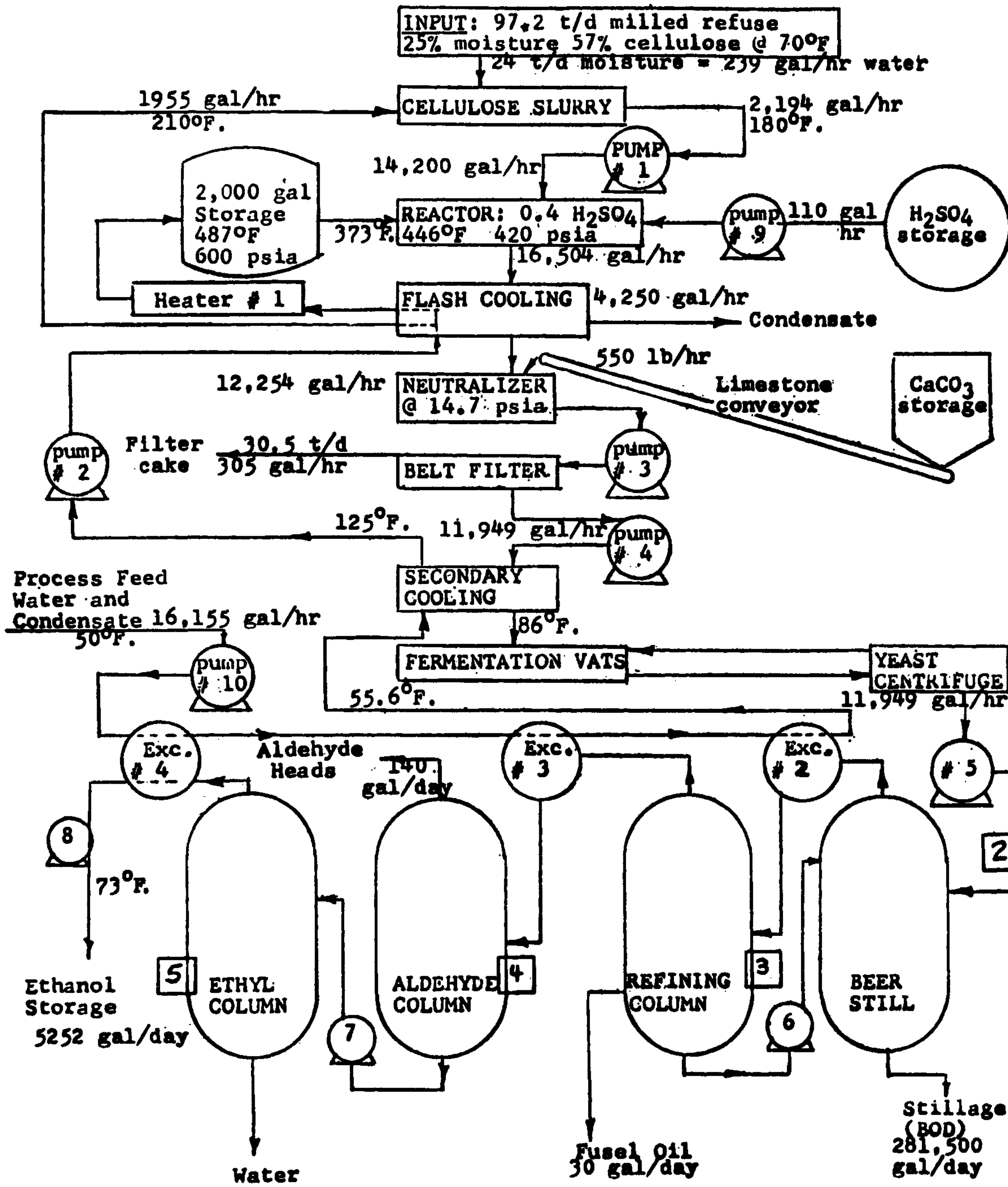
TABLE I

THE RE-DESIGN

Summary		Per Cent	Tons Per Day
Cellulose content dry basis		57.7	
Solids removed in pulverization		23.8	
Moisture content		20.0	
Wet tons collected (20 per cent moisture)			120.0
Dry tons (80 per cent of Wet tons)			96.0
Dry solids removed (23.8 per cent of 96 tons)			22.8
Input to hydrolysis process: Dry tons	73.2		
Moisture (20 per cent of 120 tons per day)	24.0		97.2
Cellulose (57.7 per cent of Dry tons)			55.5
Maximum sugar available[1] (180/162 x 55.5 tons)			61.6
Net sugar (55 per cent conversion			33.9
Ethanol - 100 per cent (Net sugar x 92/180)			17.3
Ideal fermentation (95 per cent)			16.5
Ethanol - 95 per cent (Loss in fermentation made up by 5 per cent water)			17.3
Gallons per day of 95 per cent ethanol		=	5,252.0

[1]Porteous, Towards a Profitable Means, p. 13.

FLOWCHART FOR REVISED DESIGN



The input to the process consists of 73.2 dry material accompanied by 24 tons of water. Using a L/S (Liquid-to-Solid) ratio of 15/1 based on the dry tons, this gives a requirement for (15)(73.2) = 1098 tons per day. Twenty-four of these tons are contained in the "wet" input, thus 1074 tons must be added to make the L/S ratio 15/1. If the volume required for this material is essentially that of the water portion, the hourly flow rate is:

$$= \left(\frac{1098 \text{ tons water}}{\text{day}}\right)\left(\frac{\text{day}}{24\text{-hr}}\right)\left(\frac{2000 \text{ lb.}}{\text{ton}}\right)\left(\frac{\text{gallon}}{9.34 \text{ lb. water}}\right)$$

$$= 10{,}971 \text{ gallons per hour}$$

Porteous apparently determined his flow rate by taking a liquid requirement of 15 times the "wet" paper which he considered to be the only cellulosic material in the output from the hydrapulper. This was 150 of his 170 tons total output from the hydrapulper and input to the hydrolysis process. Porteous does not mention his original moisture content throughout his evaluation. His volume calculation was:

$$22{,}500 \text{ gal/hr} = \left(\frac{150 \text{ ton}}{\text{day}}\right)\left(\frac{15}{}\right)\left(\frac{\text{day}}{24\text{-hr}}\right)\left(\frac{2000 \text{ lb.}}{\text{ton}}\right)\left(\frac{\text{gal}}{8.34 \text{ lb}}\right)$$

To this liquid requirement, he added the liquid contained in the total material from the hydrapulper or:

$$\left(\frac{170 \text{ ton}}{\text{day}}\right)\left(\frac{\text{day}}{24\text{-hr}}\right)\left(\frac{2000 \text{ lb}}{\text{ton}}\right)\left(\frac{\text{gal}}{8.34 \text{ lb}}\right) = 1500 \text{ gal/hr}$$

Again assuming the volume of the total is the volume of the water, this gave a flow rate of 24,000 gal/hr. On this basis, the flow rate for 97.2 ton/day of cellulosic materials which is also the total material, the flow rate would be

$$= \left(\frac{97.2 \text{ ton}}{\text{day}}\right)\left(\frac{15}{}\right)\left(\frac{\text{day}}{24\text{-hr}}\right)\left(\frac{2000 \text{ lb}}{\text{ton}}\right)\left(\frac{\text{gal}}{8.34 \text{ lb}}\right)$$

14,568 gallons per hour

to this would be added the moisture content of 24 tons;

$$239 \text{ gal/hr} = \left(\frac{24 \text{ ton}}{\text{day}}\right)\left(\frac{\text{day}}{24\text{-hr}}\right)\left(\frac{2000 \text{ lb}}{\text{ton}}\right)\left(\frac{\text{gal}}{8.34 \text{ lb}}\right)$$

to give a total of 14,807 gal/hr. At this point it is apparent that there is some confusion about which "solid" the L/S ratio applies to, the dry or the wet solids. In addition to this, Porteous does not use the water content of the input material to make up part of this 15/1 ratio. The volume flow rate to handle 97.2 ton/day input material can vary between 10,971 gal/hr and 14,897 gal/hr when using the criterion of a 15/1 L/S ratio. For clarification here, L/S ratio is generally based on a dry weight basis, but Porteous did not calculate the ratio in this way and mentions in his analysis,[2] that 10/1 was "barely adequate." He does not further clarify this important point and it may not be adequately resolved until a pilot plant is in operation. This discrepancy is particularly apparent when Porteous discusses his 40 per cent paper example,[3] where he says the liquid required to make the 15/1 ratio is:

(15)(100 tons) + 120 = 1,620 tons of water.

Based on 120 tons, this is a L/S ratio of 13.5/1 not 15/1.

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[2]Porteous, Towards a Profitable Means, p. 12.

[3]Ibid.

The next point to be considered is the problem of getting the material into the reactor. There is an associated problem of the cooling effect of the input slurry upon the temperature in the reactor which must be 446°F. for optimum conditions. Thus a compromise must be made between the feasibility to pump high consistency solids at high pressures and the antagonistic effect of the feed water which needs to be hotter than the reactor temperature to offset the cooling effect of greater amounts of water that would enter the reactor at more conventional solid consistencies around 15 per cent solids. A limiting factor is the exponentially rising vapor pressure of water at high temperature. For instance, the vapor pressure of dry saturated steam at 440°F. is 381.5 psia. At 470°F., the pressure is 514.7 psia and at 500°F., the pressure is 680.8 psia. A compromise was made here for the purpose of evaluation, but the limits were calculated for the purpose of comparison in Chapter IV. Personal contact with Improved Machinery Company revealed that a pump to handle greater than 25 per cent solids at between 1200 and 1500 feet of head was not available and that it would be a difficult task to build a pump that would operate in the pressure range specified. Discussion with a local Case Pump Company representative[5] revealed that a 50 cubic yard cement

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[4]Bill Morrin, representative of Improved Machinery Company, Tacoma, Washington, personal communication, April, 1972.

[5]Jerry Weissman, personal communication, Carl Weissman & Sons, Great Falls, Montana, April, 1972.

pump would accomplish the job and was rated at 35 per cent solids for cement. Without actual experience, it is difficult to say whether the pump could handle 35 per cent solids of a fibrous material. Thus for evaluation, 25 per cent solids on a L/S ratio of 3/1 will be assumed to be the solids consistency that can be pumped at this time. Further, this will be a L/S ratio based on the dry solids. Thus:

$$\text{Liquid for L/S=3/1} = (3)\left(\frac{73.2 \text{ tons}}{\text{day}}\right)\left(\frac{2000 \text{ lb}}{\text{ton}}\right)\left(\frac{\text{day}}{24\text{-hr}}\right)\left(\frac{\text{gal}}{8.34 \text{ lb}}\right)$$

$$= 2{,}194 \text{ gallons per hour.}$$

Since the input already contains 24 ton/day or 239 gal/hr, only 1955 gal/hr is required to make a 3/1 slurry from the 97.2 wet tons.

Since the mixing will take place at atmospheric pressure, a limit of 212°F. is placed on the temperature of the input slurry. A temperature of 180°F. for the 2,194 gal/hr slurry input to the reactor will be used. If a pressure limit of 600 psia is imposed on the feed water plumbing, the maximum temperature that can be used is 487°F. To produce the desired reactor temperature of 446°F., a heat balance will be applied:

$$(446^{\circ}\text{F.})\text{x(Total Mass)} = (180^{\circ}\text{F.})\text{x(Slurry Water)} + (487^{\circ}\text{F.})\text{x(Feed water)}$$

$$\text{Total Mass} = \text{Slurry water} + \text{Feed water}$$

$$(266^{\circ}\text{F.}) \times (\text{Slurry water}) = (41^{\circ}\text{F.}) \times (\text{Feed water})$$

$$\text{Feed water} = 14{,}200 \text{ gal/hr}$$

The total water present, then, is 16,394 gal/hr. This factor of the diluting effect of the slurry water on the reactor heat applies a great deal of leverage on the flow rate required. For instance, if the slurry water had not taken into account the 24 ton/day moisture water and added 2,194 gal/hr to make the slurry, the total water in the slurry would be 2,433 gal/hr. To get this water up to reaction temperature, would require 15,784 gal/hr to give an hourly flow rate of 18,217 gal/hr. The flow rate of 16,394 gal/hr will be used for evaluation. If the optimum of 35 per cent solids could be pumped, this would call for liquid to be added on a ratio of 1.857/1. Thus, 73.2 dry tons would require 1,358 gal/hr and only 7,750 gallons at 487°F. to get it up to 446°F. This corresponds to a dry weight L/S ratio of 12.4/1.

$$\frac{910 \text{ ton/day water}}{73.2 \text{ ton/day solids}} = 12.4$$

By keeping the flow rate of 16,394 gal/hr constant, the dry solids could be increased to 131 tons/day for an increase of 180 per cent.

Using steam in the slurry tank to bring the slurry up to a higher temperature would allow for a further decrease in the L/S ratio and thus the optimum L/S ratio that the reactor and flash chambers could handle would be the only limiting factor.

As can be seen on the flowchart, the previously determined flows are pumped into the reactor along with 110 gal/hr of sulfuric acid. After spending 1.2 minutes in the reactor, the flow is flashed in 3 flash tanks. The total flow out of the reactor is now 16,504 after the addition of the acid.

This flow is at 446°F. and a pressure of approximately 600 psia; this is equivalent to 1380 feet of head. Feet of head is the pressure exerted by a column of water the stated number of feet high. A column of water 2.3 feet high will exert a pressure of 1 psi. If the pressure is released from the flow in progressive stages, the liquid will cool itself through boiling until the boiling point of the liquid is reached for the pressure that is acting upon the fluid. In the present case, the water is at 446°F. and contains 436 BTU/lb. After the pressure is released in the flash tanks, steam will boil off carrying 1170 BTU/lb with it. By solving the simultaneous equation below,[6] it was determined that approximately 4,250 gallons per hour will be vaporized.

$$Q_h = Q_l + Q_s$$

Q_h = heat in 16,504 gallons per hour at 446°F.

$$= \left(\frac{16,504}{hr}\right)\left(\frac{gal}{\ }\right)\left(\frac{8.34\ lb}{gal}\right)\left(\frac{436\ BTU}{lb}\right);\ \text{Note } 16,504\ gal = 1.378 \times 10^5 lb$$

$$= 6.0 \times 10^7\ BTU/hr$$

$$Q_h = x\ lb\ (180\ BTU/lb)\ water + Y\ lb\ (1170\ BTU/lb)\ steam$$

$$1.378 \times 10^5 = X + Y$$

$$Y = \left| \frac{\begin{matrix} 180 & 6.0 \times 10^7 \\ 1 & 1.378 \times 10^5 \end{matrix}}{\begin{matrix} 180 & 1170 \\ 1 & 1 \end{matrix}} \right| = \frac{2.48 \times 10^7 - 6.0 \times 10^7}{180 - 1170}$$

$$= \frac{-3.52 \times 10^7}{-990} = 3.55 \times 10^4\ lb/hr$$

$$= 4,250\ gal/hr$$

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[6]Using Cramer's Rule of Matrix Algebra.

A heat value for steam of 1170 BTU/lb was used here. This is the heat of saturated steam at 274^{o}F. and 45 psia. This factor could vary, dependent upon the pressure reduction sequence in the 3 flash chambers, up to approximately 1200 BTU/lb. The condensed steam from this process step will be fed back as feed water to be recycled.

After flash cooling, the flow is neutralized with 550 lb. of calcium carbonate (limestone). This is accomplished in an atmospheric pressure tank that is fitted with a mechanical agitator. From this tank the flow proceeds to the belt filter. This is a common paper and pulp industry piece of equipment which deposits the slurry on top of a belt which has many small holes in it and a partial vacuum applied to the bottom side. According to Porteous,[7] 23 per cent of the gross cellulose is unconverted after hydrolysis. This would leave 12.75 of the original 55.5 tons of cellulose unconverted to either sugar or decomposed sugar. Together with the 17.7 tons of non-hydrolyzables, a total of 30.45 tons per day should be removed by the belt filter.

Unconverted cellulose	= 23% (55.5)	= 12.75 tons/day
Non-hydrolyzables	= (73.2-55.5)	= 17.70 tons/day
		30.45 tons/day

The filter cake obtained should have a high content of wood lignins and plastic. If a heating value of 11,000 BTU/lb is

[7]Porteous, Towards a Profitable Means, p. 15.

used, the 30.5 tons per day could provide 6.7×10^8 BTU/day which is more than the present heat requirement.

The belt filtration step is followed by secondary cooling. Since the belt filtration step is an open air operation which supposedly causes some heat loss,[8] the temperature entering secondary cooling was taken to be 180°F. The flow should leave secondary cooling at between 80°F. and 90°F. to be conducive to fermentation. The fermentation vats are wooden vats of 100,000 gallon capacity each. The flow overflows from one vat to the next by gravity. The output from the last vat in use is passed through the yeast centrifuge which separates the yeast to be recycled to the first vat. The fermentation residence time is between 16 and 20 hours.[9]

The process flow is now ready for distillation. The flow which contains 1.83 per cent alcohol by volume, passes through preheater number 2 and is pumped into the beer still. The alcohol is stripped from the "beer" and the stillage, approximately 281,500 gal/day, is recovered at the bottom of the beer still. The aqueous alcohol is then charged into a rectifying column. Here the alcohol is concentrated to about 95 per cent and is fed into an aldehyde column

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[8]Bill Murray, plant engineer, Horner-Waldorf, Missoula, Montana, personal communication, April, 1972.

[9]Luther Dunn, plant manager, Georgia-Pacific, Bellingham Division, Bellingham, Washington, personal communication, April, 1972.

where the low-temperature heads, consisting mostly of methanol, 80-85 per cent, and aldehydic impurities, about 2 per cent, are removed. Fusel oil is obtained in an amount of about 0.2 per cent, based on the ethyl alcohol, from a lower plate in the rectifying column and after washing, is sent to storage.

The alcohol from the bottom of the aldehyde column is vaporized to remove any residual high boilers and after condensation is sent to storage as 95 per cent ethyl alcohol.

Heat Calculations

The first step in analyzing the heat requirements was to consider the heat required by the beer still. The input to the beer still is:

11,949 gal at 86°F. = 11,730 gal/hr water + 219 gal/hr alcohol

Since a gallon of water weighs 8.34 lb and alcohol with a specific gravity of .79 weighs 6.58 lb/gal, the inputs are:

11,949 gal = 98,000 lb water + 1,440 lb alcohol

The heat to raise 1 pound of water 1°F. is 1 BTU/lb and the heat to raise alcohol one degree is 0.548 BTU/lb. The alcohol boils at 173°F. at atmospheric pressure. The heat required to raise the water and alcohol to 173°F. and vaporize the alcohol is:

$$\text{Heat required} = (98{,}000)(173-86)+(1{,}440)(0.548)(173-86) +(1{,}440)(176)$$

$$= 8.84 \times 10^{6} \text{ BTU/hr}$$

If the flow is heated to 178°F. in the preheater, the heat added to the flow will be 9.1×10^6 BTU/hr and more than enough to provide the heat of vaporization required by the alcohol. Georgia-Pacific mentions that they preheat the beer to between 210°F. and 215°F. to strip the alcohol in the beer still.[10] To preheat the flow to this temperature would take approximately 1.245×10^7 BTU/hr. The Porteous[11] flowchart indicates that $.5 \times 10^6$ BTU/hr is required. If the result of his fermentation is at 100°F., the heat added to 24,000 gal/hr or 2.0×10^5 lb would produce a temperature difference of 75°F. and thus preheat his flow to 175°F. On this particular point, the conditions used by Georgia-Pacific will be used which was a preheat to 212°F. with a heat requirement of 1.245×10^7 BTU/hr. The formula to derive the area of heat exchanger or preheater required is:

$$Q = (U)(A)(\text{Temperature Difference})$$

Where Q is the heat transferred, U is the heat transferred per square foot per degree per hour, and temperature difference is the log mean temperature difference. This temperature difference can be visualized as roughly being the average of the temperature differences between the flows at each end of the exchanger. "U" is called the heat transfer coefficient. This coefficient has a large effect upon the resultant areas and precise determination of heat exchanger area requirements

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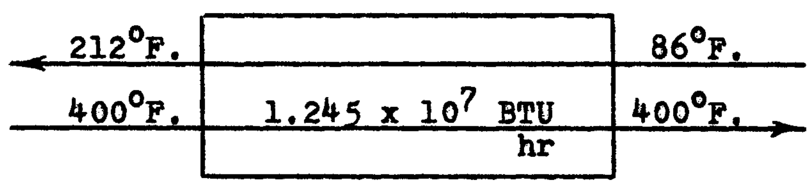
[10] Luther Dunn, Georgia-Pacific, personal communication.

[11] Porteous, Towards a Profitable Means, p. 16.

will require closer analysis of this factor. For the purposes of this paper, a heat transfer coefficient of 300 BTU/$^{\circ}$F.-ft^2-hr will be used for the transfer of heat between steam and a liquid. For liquid to liquid heat transfers, a heat coefficient of 60 BTU/$^{\circ}$F.-ft^2-hr will be used where the volume through the exchanger is relatively low such as in the alcohol exchangers and 100 BTU/$^{\circ}$F.-ft^2-hr will be used where the volume through the exchanger is relatively large such as the secondary cooling exchanger. For the beer still, this becomes:

Using 250 pound steam with a saturation temperature of 400°F.



LMTD (Log Mean Temperature Difference) = 245°F.

$U = 300\ \text{BTU}/^{\circ}\text{F.-ft}^2\text{-hr}$

$Q = 1.245 \times 10^7\ \frac{\text{BTU}}{\text{hr}} = \left(\frac{300\ \text{BTU}}{^{\circ}\text{F.-ft}^2\text{-hr}}\right)\left(A\ \text{ft}^2\right)\left(245^{\circ}\text{F.}\right)$

$A = 169\ \text{ft}^2$

This is the procedure that will be used for the remaining preheaters.[12] Only the pertinent information will be mentioned in the determination of the remaining area requirements. The preheaters between the columns should be able to supply approxi- 3.0 x 10^5 BTU/hr. Using 100 pound steam with a saturation

[12]Gordon J. Van Wylen, Fundamentals of Classical Thermodynamics (New York: John Wiley and Sons, Inc., 1966), p. 397.

temperature of 327°F. and a heat transfer coefficient of 60 BTU/°F.-ft^2-hr, the area required for each of the preheaters is 20 ft^2. Alcohol cooling exchangers #1 and #2 must transfer approximately 2.53 x 10^5 BTU/hr. The product cooling exchanger, #4, must transfer 3.31 x 10^5 BTU/hr. Using feed water at 50°F., and a heat transfer coefficient of 60 BTU/°F.-ft^2-hr, the area requirements are 35 ft^2 for the former exchangers and 50 ft^2 for the product cooling exchanger. The secondary cooling exchanger transfers 9.4 x 10^6 BTU/hr. Using the output of the alcohol cooling exchangers at 55.6°F. to cool the process flow and a heat transfer coefficient of 100 BTU/°F.-ft^2-hr, the area requirement is 2,200 ft^2. The flash cooling heat exchangers transfer 3.52 x 10^7 BTU/hr at an assumed efficiency of 94 per cent. Using the output of the secondary cooling at 125°F. and a heat transfer coefficient of 300 BTU/°F.-ft^2-hr, the area required is less than 1500 ft^2. A pressure drop of 200 psia in each of the three stages was assumed to calculate an overall log mean temperature of 80°F.

The feedwater preheater adds 1.35 x 10^7 BTU/hr to the feedwater to raise the temperature to 487°F. Using 750 pound steam with a saturation temperature of 510°F. and a heat transfer coefficient of 300 BTU/ft^2-°F.-hr, the area required is 700 ft^2. The total heat requirement of the preheaters is 26.85 x 10^6 BTU/hr.

TABLE 2

EQUIPMENT AND COSTS FOR REVISED DESIGN

Air Classification	$	$ 14,200
Cellulose Slurry Mixer		6,000
Reactor Feed Water Storage		12,760
Sulfuric acid storage		5,600
Limestone Storage Tank		9,600
Product Storage, Alcohol		5,600
Reactor		3,250
Neutralizer		15,000
Fermentation Vats		15,000
Yeast Centrifuges		50,000
Filtration Equipment		50,000
Flash Cooling and Heat Exchangers		36,000
Pumps		40,940
Columns	80,000	35,000
Preheaters		7,165
Boiler		55,000
Refuse Storage		25,000
Conveyors		13,900
Total Equipment Cost (Installed)	$445,015	$400,015
Building	54,000	54,000
Total Equipment and Building	$499,015	$454,015

Equipment Description and Costs

Air Classification $ 14,200.00

The basis for this figure is the estimated figure of $42,500 for two columns capable of processing 30 ton/hr in series operation. Both columns, complete with blowers and cyclones, were considered to be of equivalent cost and thus the cost of one column capable of separating 30 ton/hr is $21,250. A processing rate of 15 ton/hr was considered adequate and this capacity was scaled using the .6 factor. Thus (.60) x $21,250.

The processing cost per ton estimated by Stanford Research[13] is $0.10/ton. Cost savings may also be available through the use of a straight piece of pipe in place of the "zig-zag" column. The estimated equipment for this process is:

1. "Zig-zag" column with a cross sectional throat area of 1.8 ft^2 or a pipe of equivalent area.
2. Induction blower, (less than 5 H.P.) with cyclone capable of handling 1,805 CFM.

Cellulose Slurry Mixer $ 6,000.00

The major equipment needed for this operation will be: a 5,000 gallon open vat with both a jet and mechanical mixer which will be estimated at a 10 H.P. requirement. In carbon steel the mixer equipment would cost approximately $4,000.[14]

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[13]Richard A. Boettcher, "Air Classification for Reclamation of Solid Wastes," Solid Waste Technology, (program manager, Stanford Research Institute), August, 1970.

[14]Meller, Wastes Into Yeast, p. 55.

the vat will be assumed to be available for about $2,000.
Note: Porteous makes no mention of a need for this item.

Reactor Feed Water Storage (Rated at 600 psi) $ 12,760.00

A 2,000 gallon vessel will be used for the flow in this design where Porteous used a 5,000 gallon vessel for his 24,000 gal/hr flow. The purpose of this tank is to act as a buffer for the feed water flow. Its volume does not appear to be precisely determined from any set of factors in particular other than the fact that it may be some proportion of the flow rate. For this function a 4-ft dia. x 21 ft horizontal pressure vessel will be used. Made of 1-inch thick steel, the estimated weight of this vessel with saddles, heads, and two 6-inch nozzles is 15,268 lb at an estimated cost of $0.44/lb[15] multiplying by a factor of 1.9 to field fabricate this would give the above figure. Porteous estimated $10,000 for this item.

Sulfuric Acid Storage $ 5,600.00

One week's capacity is approximately 21,000 gallons. For this a 15-ft dia. x 18 ft cone roof storage tank will be used. Ionics used the same capacity as shown here, but made the tank of monel-clad steel. Consultation with a local petroleum company reveals that carbon steel is adequate.

[15]Howard Ryan, plant engineer, Phillips Petroleum, Great Falls, Montana, personal communication, April, 1972.

Ionics estimate for this item is $26,200. Porteous did not make an estimate for this tank.

<u>Limestone Storage Tank</u> $ 9,600.00

The nature of this tank is uncertain as is the form of bulk delivery. Ionics estimates $9,600 for a 24,500 gallon storage tank made of steel. For lack of better information, this cost will be used.

<u>Product Storage, Alcohol</u> $ 5,600.00

Same as acid same as acid storage, 55 bbl.

<u>Reactor</u> $ 3,250.00

For a required flow rate of 16,504 gal/hr, a volume of 43.8 ft^3 is required to give a residence time of 1.2 minutes. This would require a 2-ft dia. x 14-ft vessel to operate at 600 psi. This would require one-half inch thick plate to give a total weight of 1,960 lb at a cost of $0.62/lb. Four nozzles at 125 each are included and the result is multiplied by a factor of 1.9 for field fabrication.

<u>Neutralizer</u> $ 15,000.00

Here the Ionics[16] cost for a 10,800 gallon steel agitated tank will be used. Porteous used the same equipment and cost here as he used in the reactor. Since this is an atmospheric operation, no need is apparent for the pressure vessel which Porteous specifies.

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[16] Meller, <u>Wastes Into Yeast</u>, p. 71.

Fermentation Vats $ 15,000.00

Georgia-Pacific[17] states that wooden vats are adequate and that they use 100,000 gallon vats at a cost of $5,000 each. This capacity allows for Porteous' estimated 24-hour fermentation cycle although Georgia-Pacific mentions that they operate on a 16-hour fermentation cycle. In either case, 3 vats would appear to be needed.

Yeast Centrifuges $ 50,000.00

Georgia-Pacific uses Deval centrifuges to recycle the yeast by the Melle process. These centrifuges operate at 9,500 gal/hr and cost $25,000 each. One centrifuge would not be quite adequate for a flow rate between 11,000 and 12,000 gal/hr.

Filteration Equipment $ 50,000.00

The design by Ionics did not make filteration necessary. Porteous used three 1,000 sq ft diatomaceous earth pressure filters at a cost of $23,000 each, totaling $69,000. This method would be fraught with problems as the filters would plug off in very short time due to the matting of the fibrous nature of the slurry. This caution and a recommendation to use a drum, disk, or belt filter was given by Horner-Waldorf. Improved Machinery Company [18] recommended the use of a belt filter to concentrate a 6 - 15 per cent solids slurry to 50 per cent solids residue. The filtrate from this operation

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[17] Luther Dunn, Georgia-Pacific, April, 1972.

[18] Bill Morrin, representative, Improved Machinery Company, Tacoma, Washington, personal communication, April, 1972.

would contain no more than one-half pound of solids per 1,000 gallons of liquid. Thus there would appear to be no problem with fouling the yeast centrifuges at this level of solids.

<u>Pumps</u> $ 39,940.00

#1. Slurry pump--positive displacement ram type rated at 50 cu yd as a cement pump. The purpose here is to pump 25 per cent slurry solids into the reactor at 1385 ft head. This is a J.I. Case Pump.[19]

Pump and Motor cost	$24,000

#2. Feed water pump--this will be a piston pump required to pump 271 gpm at 1385 ft head.

Motor cost	$ 6,000
Pump cost	5,000

#3. The pump from the neutralizer to the belt filter is required to pump 204 gpm of 7.6 per cent solids at less than 10 ft of head. The pump is a Prosser stainless.

Pump and motor	$ 1,000

#4. This pump will drive the fluid from the belt filter through the secondary cooling to the vats. This requires 200 gpm of clear liquid at less than 20 ft of head.

Motor cost	$ 500
Pump cost	380

#5. This pump moves the flow from the fermentation-yeast section to the beer still. The requirements here are for 200 gpm at less than 30 ft of head.

Motor cost	$ 500
Pump cost	380

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[19] Jerry Weissman, Weissman & Sons, April, 1972.

#6. This pump draws from the bottom of the refining column to provide the reflux to the beer still and the requirements are 4 gpm at less than 30 ft of head. This pump and the next two pumps, #7 and #8, are a stainless Jabsco 1/2 H.P. pump.

Motor cost	$	300
Pump cost		200

#7. This pump draws from the bottom of the aldehyde column and pumps to the ethyl column. (Requirements and cost are same as above.)

#8. This pump moves the cooled product to storage. (Requirements and cost are same as above.)

#9. This is a 2 piston Robco acid pump that is required to pump 1.85 gpm at 930 ft of head.

Motor cost	$	400
Pump cost		400

#10. This is a centrifical pump that pumps process and condensate water through the distillation and secondary heat exchangers. Its requirements are to pump 271 gpm at 100 ft of head.

Motor cost	$	500
Pump cost		380

<u>Flash Cooling and Heat Exchangers</u> $ 36,000.00

The area of flash cooling is slightly vague as dealt with by Porteous and Ionics. Fortunately, omissions in each study were complementary. Porteous did mention a flow loss in the liquid stream that is being flashed. This loss is approximately 24-27 per cent of the fluid being flashed by theoretical calculations. Porteous did mention his assumed heat transfer coefficient[20] which was used for estimation purposes in this

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[20] 300 BTU/hr-ft^2-^{o}F.

design. Ionics did mention the liquid loss specifically, but was consistently vague as to overall heat transfer requirements. As a compromise between the Ionics use of two flash tanks and Porteous' use of 13 stages totally, three flash tanks will be used in place of the 9-stage flash cooling immediately following the reactor. Ionics uses two tanks, the first flashes from a pressure of 195 psi to 65 psi, the first stage would flash from 400 psi to 195 psi and then to 65 psi in the second stage and to atmospheric pressure in the third. The pressure drop could be split up more evenly in the actual design. (See calculations for the determination of area requirements.) The requirement for the flash cooling following the filteration step appears unnecessary for two reasons: (1) the pressure filters are not required and (2) the belt filter will cause a great deal of heat to be lost during the open air operation,[21] which will reduce the area requirement for the secondary heat exchanger. For these reasons, a shell and tube heat exchanger has been substituted here.

1. Three-stage flash cooling $18,000
   1500 ft^2 at $12/$ft^2$ (flash chambers and exchangers together)
2. #1 - secondary heat exchanger (2200 ft^2 required at $7.75/$ft^2$) $17,050

[21]Bill Murray, plant engineer, Horner-Waldorf, Missoula, Montana, personal communication, April, 1972.

3. #2 - (between beer still and refining column)
   #3 - (between refining column and aldehyde column)
   -35 ft^2 at \$7.75/ft^2=\$275 ea   \$550
   #4 - (product cooling exchanger from the ethyl column)
   -50 ft^2 at \$7.75/ft^2 \$400

The cost of \$7.75/ft^2 is that used by Porteous, but Porteous arrives at much larger area requirements. Even when compared to one-half the Porteous flow rate, a range of 300-350 ft^2' would be required.

Columns   \$ 35,000 - \$80,000

Assuming Porteous basic design is proper, a re-estimation procedure based on the column dimensions and thus the weight of the structure gives the low figure above. This figure of \$35,000 was verified as basically sound through a local petroleum refinery.[22] None of the columns will be operating at pressure greater than 100 psi and thus use 3/8-inch steel plate. For a 3-ft dia. column, this is 155 lb/ft of height. Using 30 ft for the vessel, 2 ft for two ellipsoidal heads, gives a weight of 5,060 lb. The weight of twenty trays and supports is 1,250 lbs. The base ring and lugs weigh 250 lb and give a total weight of 6,560 lbs. At a cost of \$0.50/lb, this gives a cost of \$3,280. Installation cost is \$0.0805/lb or \$528. Insulation for 302 ft^2 at \$6.00/ft^2 costs \$1,800 per

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[22]Howard Ryan, Phillips Petroleum, personal communication, April, 1972.

column. Two platforms and a stairway per column would cost $1,755. The cement foundation for each column would require 5 cu ud of cement at a cost of $16/cu yd to give $80 for each foundation. A total of 14 nozzels would be required at a cost of $16 each for twelve 2-inch nozzels and two 4-inch nozzels at a cost of $108 each. Each column requires two manways at a cost of $650 each.

Cost of each column (excluding nozzels)	$ 8,663
Cost of all four columns (with nozzels)	$35,000

Porteous used a cost of $20,000 for his one bubble cap column.

Preheaters $ 7,165.00

Exchanger #1 supplies the 487°F. temperature water that enters the reactor. The amount of heat required is 1.357×10^7 BTU/hr. This requires an area of 700 ft^2 using the same criteria as established in determining the heat exchangers.

Cost ($7.75/$ft^2$)	$ 5,400

Porteous' design calls for a transfer of 1.2×10^7 BTU.hr at this point and uses an area of 600 ft^2.

Cost	$ 4,500

This preheater, #2, is required for the beer still. The requirement is for an area of 170 ft^2 to transfer 1.245×10^7 BTU/hr.

Cost ($7.75/$ft^2$)	$ 1,300

Preheaters #3, #4 and #5 are required to provide the heat to vaporize 1,440 lb/hr of alcohol plus heat the liquid if need be from prior cooling. This requires 3.31×10^5 BTU/hr for each column. This takes approximately 20 ft^2.

Cost (\$7.75/ft^2) \$155 each $ 465

<u>Boiler</u> $ 55,000.00

The boiler that is required to meet the preheater requirements is one that will produce 26.85×10^6 BTU/hr. Making optimum 130 per cent of this results in a demand of 31.6×10^6 BTU/hr. This is equivalent to 42,000 lbs of steam an hour. Since no other source for boiler plants has been found, the Porteous estimate of $35,000 for a 40,000 lb steam/hr plant will be used. It will be further assumed that a boiler plant is subject to the .6 scale factor. This means that an 84,000 lb/hr steam plant would cost 1.56 times the 40,000 lb/hr plant.

Cost $55,000

<u>Refuse Storage</u>

Porteous suggests that three days refuse storage capacity is required to level out fluctuations in supply and allow continuous plant operation. This has applicability here as the city plans to operate their pulverizer on a five-day week basis. Porteous suggests concrete storage for 933 tons or 6,200 cu yd. In the Cascade County situation, this would require storage for 290 tons or 2,000 cu yd of storage. To provide this storage, two means were investigated: (1) A storage house with dimensions of 70 ft x 180 ft x 13 ft would cost $41,000 at $3.25 ft^2;[23] and, (2) a Butler silo 42 ft dia. x 48 ft high would cost $15,000 with between $8,000 to $10,000 for erection.[24] The second approach appears to be the most economical approach. Bridging of the material in the silo could be a problem that would call for either aerating the tank to keep the material fluid and/or using a screw auger to move the material. The .6 scale factor will be used here and thus 26 year capacity purchased.

Cost (42 ft dia x 48 ft silo
is 7400) $25,000

<u>Conveyors</u> $ 13,900.00

Ionics estimates $13,700 for 200 ft of open belt conveyor. This was not an item mentioned by Porteous. The price estimated by Ionics appears to be high.[25] Upon discussion with a local dealer in pneumatic systems,[26] it appears that the crushed limestone would be most economically handled pneumatically. Time has not allowed the estimation of this cost in a pneumatic mode of operation; thus, the Ionics cost per foot will be used for 100 feet of Lignin and Limestone conveyor each.

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[23]Personal communication with representative of Palmer Steel Structures, Great Falls, Montana, April, 1972.

[24]Personal communication with representative of Talcott Tank and Building Company, Great Falls, Montana, April, 1972.

[25]Mellar, <u>Wastes Into Yeast</u>, p. 71.

[26]Jerry Weissman, Weissman & Sons, personal communication, April, 1972.

Conveyors (continued)

Cost ($69.50/ft for 200 ft) $13,900

Building $ 54,000.00

Here Porteous suggests a three-story building with a floor plan of 20,000 ft^2. This appears to be slightly high. Local estimates quoted $15 to $18 as more reasonable.[27] For the revised design, a single floor, high ceiling, with a floor plan of 30,000 ft^2, 150 x 150 ft, will be used at a cost of $18/$ft^2$.

Cost (30,000 ft^2 at $18/ft) $54,000

Here Ionics estimated 35 per cent of equipment cost for building or $140,000.

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[27]Personal communication with representative of Sletten Construction Company, Great Falls, Montana, April, 1972.

Estimate of Direct Production Costs

Raw Materials:

Sulfuric Acid $330/day

Sulfuric acid requirements for a 4 per cent weight concentration of the total reactor flow is 525 lb/hr.[28] This would be 6.25 tons per day at a local cost of $53/ton delivered.

Limestone $21.80

The cost used by Porteous will be used. At $3.50 per ton for 6.25 tons per day, the cost is $21.80.

Water $39.00

The Porteous cost of $0.10 per 1,000 gallons will be used for the 390,000 gal/day required.

Electricity $84.00

The connected horsepower is less than 200. The slurry pump has its own diesel motor. Using the Porteous cost of electricity, the proportional cost is $84.00.

Fuel Oil $365

Porteous arrived at a total heat requirement of 27×10^6 BTU/hr. The preheater requirements as used for determination of the boiler capacity resulted in a present demand of 26.85×10^6 BTU/hr. The Porteous cost of $365 will be used.

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[28]Howard Ryan, Plant Engineer, Phillips Petroleum, Great Falls, Montana, personal communication, April, 1972.

Labor

Porteous proposed using a total of 26 men at a cost of $6,000 per year for each. This would be for a three-shift basis with 10 men on the day shift and 8 men on the other two shifts. Ionics claims that 4 men per shift could operate the hydrolysis plant. This figure will be used with an additional 2 men to operate the distillation portion of the plant. Thus a total of 6 men per shift will be used with one man per shift being a supervisor. A wage level of $8,000 will be used with $10,000 for the supervisors. Thus with 15 men at $8,000 per year and 3 men at $10,000 per year, the daily labor cost is $412.

Biochemical Oxygen Demand (BOD) $354/day

This factor was an imponderable in the Porteous design and is the same here with the exception that a treatment plant will not have to be purchased as indicated by Porteous. Discussion with the City Engineer[29] indicates that the city is incorporating an activated sludge treatment as a secondary treatment to the sewage effluent. The estimated 281,500 gal/day that would be discharged from the plant could be handled by the plant in volume, but the cost of this discharge is primarily dependent upon the BOD content of it. The city is currently in the process of attempting to gather an estimate of the present and future BOD reduction requirements to establish design

[29] Leroy Lucker, Chemist for the City Water Department of Great Falls, Montana, personal communication, April, 1972.

require and cost data for prospective industry. An accurate estimate of this cost is not available at this time; therefore, the Porteous cost estimate was used. Porteous mentioned that the typical BOD for the fermentation industry can range from 420 to 1,200 parts per million.[30] He also mentioned that the roofing felt industry which uses salvaged paper as its raw material can have BOD that runs as high as 6,000 parts per million. If a conservative figure of 5,000 parts per million of BOD is used, the daily amount of BOD requiring reduction would be 11,700 lb/day. At a cost of 3¢/lb, which Porteous used, the daily cost of BOD reduction would be $351. If the average of the brewing range is used, 800 parts per million, 1,870 lbs of BOD will require reduction at a cost of $56.10 per day.

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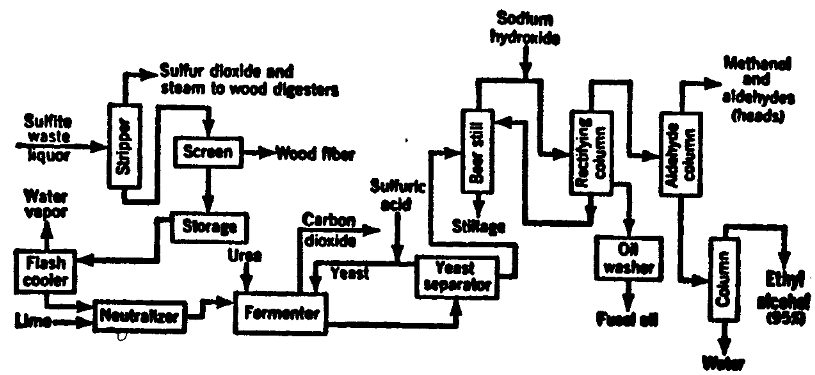
[30]Porteous, Towards a Profitable Means, p. 14.

APPENDIX 3

ETHYL ALCOHOL FROM SULFITE WASTE LIQUOR BY FERMENTATION



Reaction

$$C_6H_{12}O_6 \xrightarrow{\text{Zymase}} 2C_2H_5OH + 2CO_2$$

Material and Utility Requirements

Basis—1,000 gal ethyl alcohol (95%)

[plus 50 gal methanol (80%) and 2 gal fusel oil]

Sulfite waste liquor (1.35% fermentation sugars) = 45 tons sulfite-liquor pulp	125,000 gal	Lime	3,500 lb
Yeast (added)	2.5 lb	Sulfuric acid	150 lb
Urea	62 lb	Water	Variable
		Steam	150,000 lb
		Electricity	1,500 kw-hr

<u>Process</u>

Sulfite waste liquor contains sugars derived from wood, which may be converted into ethyl alcohol by fermentation resulting from the action of yeast.

The spent liquor from the manufacture of sulfite wood pulp is known as sulfite waste liquor. In the manufacturing process, wood chips are cooked in an aqueous solution of calcium bisulfite and sulfurous acid for 8 to 10 hours at a temperature of about 135°C. and pressures of 80 to 100 pounds per square inch. During this cooking period, which takes place in large pressure vessels called digesters, the cellulosic fibers are set free. A valve in the bottom of the digester is then opened, and the resulting pulp is blown into blow pots. Here the fibers and liquor are separated by draining or vacuum (vacuumwashing), and the fibers are washed. The diluted sulfite waste liquor, which is recovered from the pits in 80 to 90 per cent yield, contains dissolved wood constituents such as lignins and sugars, as well as the spent chemicals of the process. The sugar content, which results from some naturally occurring sugars or is formed by the acid hydrolysis of the hemicelluloses in wood, runs between 2 and 2.5 per cent. Part of these sugars are nonfermentable pentoses, whereas the remainder (1.3 to 1.8 per cent) are fermentable hexoses such as glucose, mannose, and galactose.

The sulfite waste liquor is obtained from the blow pits at a temperature about 90°C. and is pumped to a steam-stripping column. Here the sulfur dioxide is recovered for re-use in the digester. The hot liquor is pumped over screens to remove residual pulp fibers and is then stored. From storage, the liquor is pumped to flash coolers, where it is cooled to about 30°C. by vacuum evaporation, using steam ejectors. The ph of the liquor is adjusted (to slightly higher than 6.0) by addition of a limeslurry; urea is added as a nutrient (nitrogen source). No other nutrients such as potash or phosphorus are required. The liquor, thus conditioned and partially concentrated, is pumped into a series of fermentation tanks. Yeast, reclaimed from the previous cycle, is added, and the fermentation is allowed to run about 20 hours. The tanks are equipped with agitators to keep the yeast in suspension; the flow of mash is continuous through the fermenters. Carbon dioxide is produced and is vented or may be recovered by suitable processes.