METHANOL OR AMMONIA PRODUCTION FROM SOLID WASTES BY THE CITY OF SEATTLE

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I. INTRODUCTION

Solid waste disposal on an acceptable environmental and cost basis is one of the most nagging, costly, and unpleasant problems facing Seattle and other cities in America. Escalating costs for disposal labor and transportation and the difficulty of finding suitable landfill sites has caused what was simply an unhandy problem a decade ago to become a major problem for the City.

In the 1960's, the federal government and industry began to emphasize development of major new alternatives to the historic methods of solid waste disposal. A number of new handling and disposal methods have reached development maturity and are available for application. The past decade has also seen widespread acceptance of the fact that affluence and waste need no longer by synonymous. Terms like "recycling" and "urban ore" typify a changing attitude toward what was once simply garbage. Public demands for environmental reform, prudent land use, and economy in public services, have all simultaneously crested in a time of fuel cost increases, power shortages, and a recognition that terrestrial resources are finite.

In this context, the Mayor of Seattle and the Chairman of the Utilities Committee of the Seattle City Council, in December of 1973, commissioned the Engineering and Lighting Departments of Seattle to aggressively undertake a program of utilizing the latent material and energy potential of Seattle's municipal solid wastes.

In May of 1974, an interdepartmental report appropriately titled *SEATTLE'S SOLID WASTES...AN UNTAPPED RESOURCE* (1) was presented to the Mayor with the revelation that of numerous solid waste disposal options, the conversion of solid waste to methanol, as suggested by T. Reed (2,3), appeared to be the most environmentally advantageous and economical. Table 1 summarizes the comparative economic findings of the Seattle study.

Briefly stated, all practical disposal alternatives except conversion to methanol or to a bulk confetti-like air-classified fuel, were found to be as costly or more costly for Seattle than continued waste disposal in landfills. It was later found that the bulk fuel alternative is impractical, leaving methanol production as the most promising alternative from an economic standpoint. Conversion of waste into methanol may also be a method for achieving fuel independence for the City's motor fleet and a modest reduction of air pollution from City vehicles. These potential benefits, plus the opportunity for eliminating dependence on landfills, except for inert materials, caused the City to undertake more intensive investigations of the feasibility of solid waste conversion.

In June of 1974, the Seattle firm of Mathematical Sciences Northwest, Inc. (MSNW), was retained to do an intensive study of the technical feasibility, economics, and environmental impact of conversion of Seattle solid waste to methanol, and use of methanol as a vehicle fuel. (4) The MSNW study confirmed that the proposed conversion process was technically feasible; however, neither the quantity of methanol produced nor the system economics were found to be as attractive as

initially believed. Nevertheless, the process still showed promise as being superior to landfill. In addition, the study disclosed an opportunity for using the same basic technologies for the manufacture of ammonia. These findings, plus further verification that methanol is a potentially practical automotive fuel (5,6,7), have caused the City of Seattle to intensify project planning.

II. PROCESS DESCRIPTION

The process as envisioned for the City consists of grinding the solid waste to make it more convenient to convey and pyrolyze. Following coarse grinding, ferrous materials are removed magnetically, following which the remaining residues--paper, wood, glass, yard wastes, domestic wastes, organics, and plastics--are charged into a pyrolysis system.

There are several pyrolysis systems currently being developed. One system that is in the late stages of large scale and successful demonstration is the Union Carbide Corporation's Purox system (8). In this system, solid waste is charged into the top of a structure similar to a blast furnace. As the solid waste migrates downward, it is heated by rising gases generated from the oxidation of residues at the bottom of the vessel. This hot gas permeates upward through the solid waste, providing the necessary heat for the conversion of the cellulosic materials into additional carbon monoxide plus hydrogen. The gas leaving the top of the reactor, which consists largely of carbon monoxide, hydrogen, and water vapor, is then processed through a closed gas-cleaning system in which water and other impurities are trapped. The product gas leaving the system consists of approximately two-parts carbon monoxide to one-part hydrogen plus impurities.

The first step for subsequent treatment of the gas as currently envisioned is an absorption process to remove sulfur compounds and convert the sulfur to its elemental state. This is to be done for pollution control reasons and to protect the catalysts used in subsequent synthesis operations. The objective of this step should be to achieve a gas concentration of 0.5 ppm or less sulfur. Following this step, a water-gas shift is employed to alter the carbon monoxide-hydrogen ratio. In this traditional process, steam is added to the gas stream in the presence of a catalyst and under appropriate pressure and temperature conditions. The quantity of hydrogen and carbon dioxide in the inlet clean gas is approximately doubled and halved, respectively, so that the shifted gas has a composition of about one-part carbon monoxide to two-parts hydrogen, the stoichiometric ratio required for methanol synthesis. The amount of carbon dioxide produced in the shift reaction is large and must be purged down prior to the synthesis step.

The product synthesis step, while requiring complex equipment, is relatively straightforward. Under conditions of heat and pressure and in the presence of a catalyst, the carbon monoxide and hydrogen are spontaneously combined into methanol. Alternatively, the shift reactor may be designed to more completely shift carbon monoxide in the inlet gas to carbon dioxide and hydrogen. The hydrogen, in combination with nitrogen, may then be reacted by the traditional method, using catalysts, to produce ammonia gas. By-product nitrogen resulting from oxygen production in the head-end pyrolysis step is more than sufficient to meet the requirements of ammonia synthesis in this case.

The product yields computed in this study were 370 pounds of methanol per ton of solid waste, or 445 pounds of ammonia per ton of solid waste. On an annual basis, these amounts represent potential yields of approximately 100,000 tons of methanol per year (31-million gallons per year) or 120,000 tons of ammonia per year, starting from 550,000 tons per year of municipal solid waste. While these amounts of chemical products seem large to city government, they represent only a small percentage of national production for these products. What is of interest, of course, is that they represent potential revenues with which to reduce the future cost of solid waste disposal.

Both the methanol and ammonia processes are established commercial processes. The raw material now used for their manufacture is primarily natural gas. In the context of fuel conservation, then, the production of chemical methanol or ammonia from solid waste represents conservation of natural gas which might otherwise have been used for these products. The Btu content of the products was found to exceed the external energy required by a factor of 2.5 to 3.0, depending on the product. This factor is measured at the plant boundary; the overall energy balance of the process may be positive or negative, depending upon the ultimate product uses and related thermal efficiencies.

III. PROJECT ECONOMICS

Solid waste disposal - not chemical production - is the project's primary purpose. Therefore, the project financial target to equal or beat is the combined cost of long-haul transport and sanitary landfill operations. In Seattle, this combined cost is currently $4.90 per ton and projected to increase significantly by 1978. The indifference point for this project is that situation prevailing when the pyrolysis facility and the chemical synthesis plant operate at an annual net cost of $3.3 million per year (1978). This will be the cost to the City if landfill disposal is continued. From a project accounting standpoint, a revenue credit can be made to the project for disposal service in an amount equal to what conventional disposal would have cost. This credit is expressed in Table 2 as a "disposal gain" of $3.3 million.

Obviously, the financial feasibility of the project is dependent upon product prices. Based on late 1974 prices ($0.38/gallon for methanol and $150/ton for ammonia), one may postulate that with the diminishing supply and rising cost of natural gas (the usual feedstock for such plants), either plant alternative offers the definite possibility of significantly bettering the marginal economics indicated above. For example, a price of $0.44/gallon for methanol or $130/ton for ammonia would entirely offset the disposal gain, yielding free solid waste disposal (1978). Even more favorable prices were developed using assumed escalation values over the entire project lifetime. Such expectations are not unrealistic and should leave an attractive profit margin for any industrial participant in the project. The reliability of solid waste supply and the potential advantage of City financing of the project makes it a potentially attractive product source for the private sector. In assessing product risk, one must consider preservation of the cellulose content of solid waste. If that content were to decrease as a result of paper being extracted from the solid waste supply stream, product production would suffer. A decrease in cellulose feed results in more than a proportional loss in the methanol or ammonia production rate.

IV. CITY BENEFITS AND CONSIDERATIONS

Solid waste disposal cost is a major consideration to any city contemplating a change in its disposal system. Most professionals in solid waste management view any change as inevitably more costly simply because until recent years, that has been the history of the industry.

Recent rapid changes in the economics of energy--the rising cost and scarcity of fuel for long-haul disposal plus the greater opportunities for entering the energy marketplace as an energy producer--have begun to change that traditional view of disposal economics. This is occurring at a time when public attitudes toward landfill disposal are bordering on hostility because of the environmental and land use compromises that characterize such operations.

Another lesson learned by city governments during the 1973/1974 oil shortage is that public services are dependent on automotive fuel. The City of Seattle, for example, found itself with only 60 percent of its usual gasoline for City

fleet use, and in the minds of many City officials, the situation bordered on one of City government being unable to provide adequate public services. With this memory still fresh in mind and with the possibility of future fuel supply interruptions and even higher fuel prices, there is genuine appeal to the concept of City fuel independence by way of fleet conversion to 100 percent methanol made from municipal solid wastes. Studies performed to date indicate technical feasibility and a need for a fleet testing program to define vehicle conversion requirements and to confirm estimated vehicle performance parameters.

A modest reduction in urban air pollution is another benefit that can be realized from the utilization of methanol as an automotive fuel. (5,6) While the improvement may be minor, it is nevertheless a step in the right direction.

Clearly, there are significant incentives and benefits inherent in a solid waste disposal process that yields either methanol or ammonia.

- Cessation or reduction of landfill disposal.
- Potentially attractive economics.
- City fuel independence and reliability of public services.
- Fuel conservation.
- Reduced urban air pollution.

Preliminary studies show that the recovery plant can be sited next to one of the City's large transfer stations. Neutralization of several plant waste liquid streams will be required for discharge into the regional liquid waste system. Current air pollution standards can be met and noise levels are not expected to exceed 65 dBa at the plant boundary, a level of noise within proposed City standards.

V. SYSTEM APPLICABILITY ELSEWHERE

The question frequently arises as to possible widespread use of "The Seattle Concept." In an earlier paper (9), one of the authors projected the potential national benefits of converting municipal wastes to methanol in terms of equivalent automotive fuel and imported crude oil. That projection assumed that 70 percent of all municipal solid waste could ultimately find its way into conversion to methanol and, that product yield (if all were used as automotive fuel) could displace 150-million barrels per year of imported crude oil, for a national balance of trade saving in excess of a billion dollars per year. Aside from the fact that calculated product yields were probably too high, there is legitimate reason to question whether such wide use of the process is likely to be undertaken.

The environmental and energy appeal of converting wastes to methanol or ammonia tend to confuse the practical realities of solid waste disposal. The energy profile of every city is different, and conversion of waste to these products is not likely to be the best solution in every case. The use of solid waste for steam and power generation is an established technology, and where pulverized coal is now used in existing urban plants on a year-around basis, it makes economic and environmental sense to follow the lead of the City of St. Louis and the Union Electric Company where pulverized and air-classified solid waste fuel is suspension-fired in base-load electric utility boilers. Similarly, the Baltimore Landguard installation, where steam is generated from a pyrolysis process and displaces steam that would otherwise have been generated by burning oil in an urban power plant, makes both financial and environmental sense. (10) In both of these cities, electric power demands are heavy during the Summer when solid waste generation is greatest. Also, fossil-powered plants are located close to the source of solid waste. In situations such as these, the economics of producing methanol or ammonia may be less attractive than steam or power generation, at least in the

near future. In arid areas where there is ample land for landfill disposal and the hazards of leachate are minimal, relatively little incentive may exist--except the ethical matter of resource conservation--for a city to undertake any energy recovery system, particularly one as unfamiliar to the lay public as conversion to methanol or ammonia. The studies on which this paper are based also considered the possibility of installing facilities to pyrolyze solid waste coupled with sale of the clean gas for direct fuel use, thus avoiding the expense of chemical synthesis plant installation. In this case, markets for the clean gas were not identified. In other locales, where customers for the fuel gas exist close to the pyrolysis plant, this solution may prove optimal. Clearly, every city must determine the best solution in the light of its own particular circumstance.

Seattle is situated in a region that utilizes methanol in its wood products industry and ammonia for agriculture. Electric utility loads are minimum in Summer when solid waste generation is maximum and, in most years, hydropower is more than adequate to satisfy demands for electricity through much of the year. Therefore, a process leading to the generation of electricity does not appear to be competitive at this time. Moreover, large close-in fossil-fuel power plants suitable for solid waste combustion are nonexistent. Another factor that enhances the economics of methanol or ammonia conversion processes in this area is that both products are imported at considerable cost (methanol from the Gulf Coast, ammonia from Alaska). Also, ammonia and related fertilizer products are dependent primarily on natural gas which is experiencing dramatic price increases and declining availability. Simply stated, Seattle's situation appears to be tailor-made for the concept of converting solid waste to either methanol or ammonia.

VI. SUMMARY

The utilization of municipal solid waste as feedstock for the manufacture of either methanol or ammonia has been found to be technically feasible for the City of Seattle. Further effort is underway to confirm the initial findings of economic feasibility. Such an installation should reduce future disposal costs while simultaneously providing the City with a source of methanol for City motor fleet use. The use of methanol for vehicle fuel will assure continuity of public services during periods of fuel shortages and aid in reducing urban air pollution. After diverting 6,000,000 gallons per year of methanol for City fleet use, 25,000,000 gallons per year of methanol, or 100,000 tons per year of ammonia can be made available for marketing through existing commercial channels. The suitability of this process for other cities depends upon local energy and product markets which must be carefully analyzed on a case-by-case basis.

The list of those academic and industry people who willingly and generously shared their knowledge and offered encouragement for this project, especially during its embryonic stages, would be too long to include here. This opportunity is taken to extend appreciation to them as a group for their important contributions to the Seattle studies.

TABLE 1

SUMMARY OF DISPOSAL ALTERNATIVES[1]

SYSTEM ALTERNATIVE (1)	NET OVERALL DISPOSAL COST $/TON (2)
A. Unprocessed Solid Waste Steam-Electric Plant	-16.10
B. Processed Solid Waste Steam-Electric Plant	-13.77
C. Processed Solid Waste/Pulverized Coal Steam-Electric Plant 60,000 KW	-15.62
D. Processed Solid Waste/Pulverized Coal Steam-Electric Plant 100,000 KW	-18.62
E. Processed Solid Waste/Pulverized Coal Steam-Electric Plant 200,000 KW	-25.97
F. Processed Solid Waste/Existing Coal Fired Steam-Electric Plant (Centralia, Washington)	- 6.30
G. Unprocessed Solid Waste Steam Plant (Steam Only)	- 8.15
H. Processed Solid Waste Steam Plant (Steam Only)	- 7.62
I. Processed Solid Waste Pyrolysis Gas Turbine-Electric Plant	-11.07
J-1. Limited Solid Waste Processing Pyrolysis-Oxidation-Gas Turbine-Electric Plant	-10.92
J-2. Processed Solid Waste Pyrolysis-Oxidation-Gas Turbine-Electric Plant	- 9.97
K-1. Limited Solid Waste Processing Pyrolysis-Oxidation System for Methanol Production	- 0.32
K-2. Processed Solid Waste Pyrolysis-Oxidation System for Methanol Production	+ 0.63
L. Processed Solid Waste as a Marketable Fuel	+ 1.03*
M. Unprocessed Solid Waste Landfill Disposal No Energy Recovery	- 7.90

[1] City of Seattle, "Seattle's Solid Waste...An Untapped Resource," May, 1974.

*NOTE: Does not include haul cost.

TABLE 2

MARGINAL OR "BREAK-EVEN" ECONOMICS OF SEATTLE SOLID WASTE METHANOL OR AMMONIA PROJECT (1978)

(1)	METHANOL PLANT (2)	AMMONIA PLANT (3)
Plant Nominal Product Size	300 T/Day	350 T/Day
Annual Product Yield	100,000 T/Year (31,000,000 Gal/Yr)	120,000 T/Year
CAPITAL COST[1]	$ 56,000,000	$ 65,000,000
Debt Service[2]	6,600,000	7,500,000
Operation and Maintenance	7,100,000	8,100,000
FIRST-YEAR COSTS	$ 13,700,000	$ 15,600,000
Product Sales	$ 10,400,000	$ 12,300,000
Disposal Gain[3]	3,300,000	3,300,000
	$ 13,700,000	$ 15,600,000
Marginal (Break-Even) Product Price, First Year	33.6¢/Gal	$103/Ton

[1]Gasifiers, gas cleanup, shift process, synthesis plant, site, tankage, and associated facilities.

[2]15-year life, 8% interest.

[3]Disposal cost for equivalent transport and landfill.

REFERENCES

(1) City of Seattle, *Seattle's Solid Waste...An Untapped Resource,* May, 1974.

(2) Reed, T.B. and R.M. Lerner (Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts), "Methanol: A Versatile Fuel for Immediate Use," *Science,* December 28, 1973.

(3) Reed, T.B. and R.M. Lerner (Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts), *Sources and Methods for Methanol Production,* THEME Hydrogen Conference, March 18, 1974.

(4) Mathematical Sciences Northwest, Inc., Bellevue, *Conversion of Solid Wastes to Methanol or Ammonia,* September 6, 1974.

(5) Reed, T.B., R.M. Lerner, E.D. Hinkley, and R.E. Fahey (Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts), *Improved Performance of Internal Combustion Engines Using 5 to 30% Methanol in Gasoline.*

(6) Pefley, Richard K. (Department of Mechanical Engineering, Santa Clara University, Santa Clara, California).

(7) Tillman, R.M. (Continental Oil Company, Ponca City, Oklahoma).

(8) A Proprietary Process of Union Carbide Corporation.

(9) Sheehan, R.G. (Department of Lighting, City of Seattle), *Methanol from Solid Waste: Its Local and National Significance,* Engineering Foundation Conference, Henniker, N.H., July 1974.

(10) The Landguard process is a proprietary process of the Monsanto Corporation of St. Louis, Missouri.