Title

UTILIZATION OF CELLULOSIC MATERIALS THROUGH ENZYMATIC HYDROLYSIS II. PRELIMINARY ASSESSMENT OF AN INTEGRATED PROCESSING SCHEME

Permalink

https://escholarship.org/uc/item/1ps934g5

Author

Wilke, Charles R.

Publication Date

1976-05-01

To be published in Biotechnology and
Bioengineering

LBL-4472
Part II c.1
Preprint

UTILIZATION OF CELLULOSIC MATERIALS THROUGH ENZYMATIC HYDROLYSIS II. PRELIMINARY ASSESSMENT OF AN INTEGRATED PROCESSING SCHEME

Charles R. Wilke, Gerald R. Cysewski, Ren Der Yang, and
Urs von Stockar

May 1976

Prepared for the U. S. Energy Research and
Development Administration under Contract W-7405-ENG-48

UTILIZATION OF CELLULOSIC MATERIALS THROUGH ENZYMATIC HYDROLYSIS

II. PRELIMINARY ASSESSMENT OF AN INTEGRATED PROCESSING SCHEME*

by

Charles R. Wilke
Gerald R. Cysewski
Ren Der Yang
Urs von Stockar
Lawrence Berkeley Laboratory and
Department of Chemical Engineering
University of California
Berkeley, California 94720

ABSTRACT

An integrated processing scheme is described for the conversion of a cellulosic waste (newsprint) to sugars by enzymatic hydrolysis and then to ethanol and yeast by fermentation. The unconverted solids are burned to produce process energy requirements and surplus electrical power. Preliminary designs and cost studies are developed to provide rough perspective on the potential economic feasibility of this method of cellulose utilization.

---

*This paper was prepared for presentation at the First Chemical Congress of the North American Continent, Mexico City, Mexico, December 1 - 5, 1976.

INTRODUCTION

The preceding paper (1) and an earlier report (2) have described the background data and separate process design studies for enzymatic hydrolysis of newsprint and fermentation of sugars to ethanol and single cell protein (Torula yeast). This paper will describe a further study in which these processes are considered together in an integrated processing scheme to produce ethanol, yeast and electrical power. Newsprint was selected as a representative cellulosic substrate because of the availability of information on its hydrolysis and related processing characteristics. Other cellulosic materials ultimately may prove to be the feedstock of choice. Furthermore, it is recognized that the proposed process is not an optimum scheme since consideration is not given to recovery of the hemicellulose sugars nor to more sophisticated pre-treatments to remove or break down lignin prior to hydrolysis.

The main purpose of the design analysis is to provide a preliminary assessment of the economic feasibility and energy efficiency of this type of cellulose processing.

PROCESS DESCRIPTION

Figure 1 is a schematic flow diagram for the processing scheme. Mass flows of the principal streams are indicated on the diagram.

Hydrolysis.

The hydrolysis section is identical to that described by Wilke, Yang and von Stockar for the same inputs (2). Table 1

FEED (-20 MESH NEWSPRINT)	885 TON/DAY
CELLULOSE CONTENT[1]	61% (DRY)
ENZYME ACTIVITY	3.5 FPA
CELLULOSE HYDROLYSIS	50%, 40 HR., 45°C
ENZYME RECOVERY	34%
PRODUCT (AS GLUCOSE)[2]	238 TON/DAY
PRODUCT CONCENTRATION	4%
CELL RECYCLE FRACTION	0.65

BASE DESIGN CASE SPECIFICATION

Table 1

[1] Assumed newsprint composition: 61% α cellulose, 21% lignin, 16% hemicellulose, and 2% other.

[2] Representative sugar composition: 72% glucose, 22% cellobiose, 4.4% xylose, 1.5% mannose.

gives the base case design specification. A detailed equipment description has been presented previously (2).

The primary plant feed consists of 885 tons per day of newsprint containing 6% moisture. By means of moderate shredding and hammermilling the feed is reduced to approximately -20 mesh. The size reduction is not critical so long as the material will form aqueous suspensions which can be pumped, agitated, and filtered. An additional 66 tons per day of feed material is diverted to the first enzyme induction fermentor after sterilization with steam. The product sugar stream from the hydrolyzer is contacted countercurrently in 3 mixer-filter stages with feed solids for enzyme recovery. Each mixer filter stage consists of a mixing tank to provide 30 minutes contact time and a horizontal belt vacuum filter to separate the solids from the liquid. A total enzyme recovery of 95% is predicted by theory based on laboratory adsorption studies (3).

Hydrolysis is conducted over 40 hours at 45°C at a solid/liquid ratio of 1/20 w/w based on inputs to the hydrolyzer. The latter consists of 5 agitated cylindrical concrete digestors of the type used for solid waste treatment in sanitary engineering. Cellulose conversion of 50% is assumed, at an overall enzyme strength equivalent to 3.5 FPA[1] in the hydrolyzer (3). Provision is made for recycle of a portion of the product sugar solution (plus enzyme) back to the hydrolysis vessel. A sugar concentration of 4.0% is obtained for the case shown. A range of sugar levels is possible

---

[1] Filter Paper Activity

depending on the mode of operation and amount of sugar recycle employed. Make-up enzyme is produced in a two-stage fermentation system, employing the fungus Trichoderma viride QM9414 (4) obtained from the U.S. Army Natick Laboratories. Cell growth is obtained in the first stage at a dilution rate of 0.2 hr^{-1} employing a medium containing 1% product sugars plus minerals and protein nutrient. The induction system is operated at an overall dilution rate of 0.017^{-1} excluding the cell recycle stream. Both stages employ agitated stainless steel vessels operated at 30°C with aeration rates of 0.15 and 0.015 v.v.m. in the growth and induction stages, respectively. The growth stage feed is sterilized in a heat exchange system (not shown). The induction section effluent is passed through a centrifuge from which a portion of the underflow is fed back to the first induction stage. Ten induction stages in series are employed. The flow quantities in Fig. 1 corresponds to a cell recycle fraction of 0.65. Recycle fraction is the fraction of cells leaving the last induction stage which is returned to the first stage. For the case shown the use of recycle will maintain the cell density in the induction system at 7 gm per liter, assuming negligible growth in the induction system when newsprint is employed. This latter assumption is conservative since some cell growth will occur. The resultant enzyme production is sufficient to provide an enzyme concentration of 3.5 FPA in the hydrolyzer. A portion of the centrifuge underflow is filtered and the cells are discarded to maintain adequate cell viability.

TABLE 2

	BTU/UNIT	TOTAL BTU X 10^6
CELLULOSIC FEED *	7,200/LB	571
ALCOHOL 95% *	10,651	72.3
YEAST CAKE *	5,500/LB	7.6
SCP *	5,500/LB	15
POWER	3413/KHW	13.6
TOTAL OUTPUT		108.5
NET EFFICIENCY, %		19

SUMMARY OF ENERGY QUANTITIES

---

*Unit energy values are based on heats of combustion to produce gaseous products. This represents the lower unit heating value, since the heat of vaporization of the water produced during combustion is not recovered.

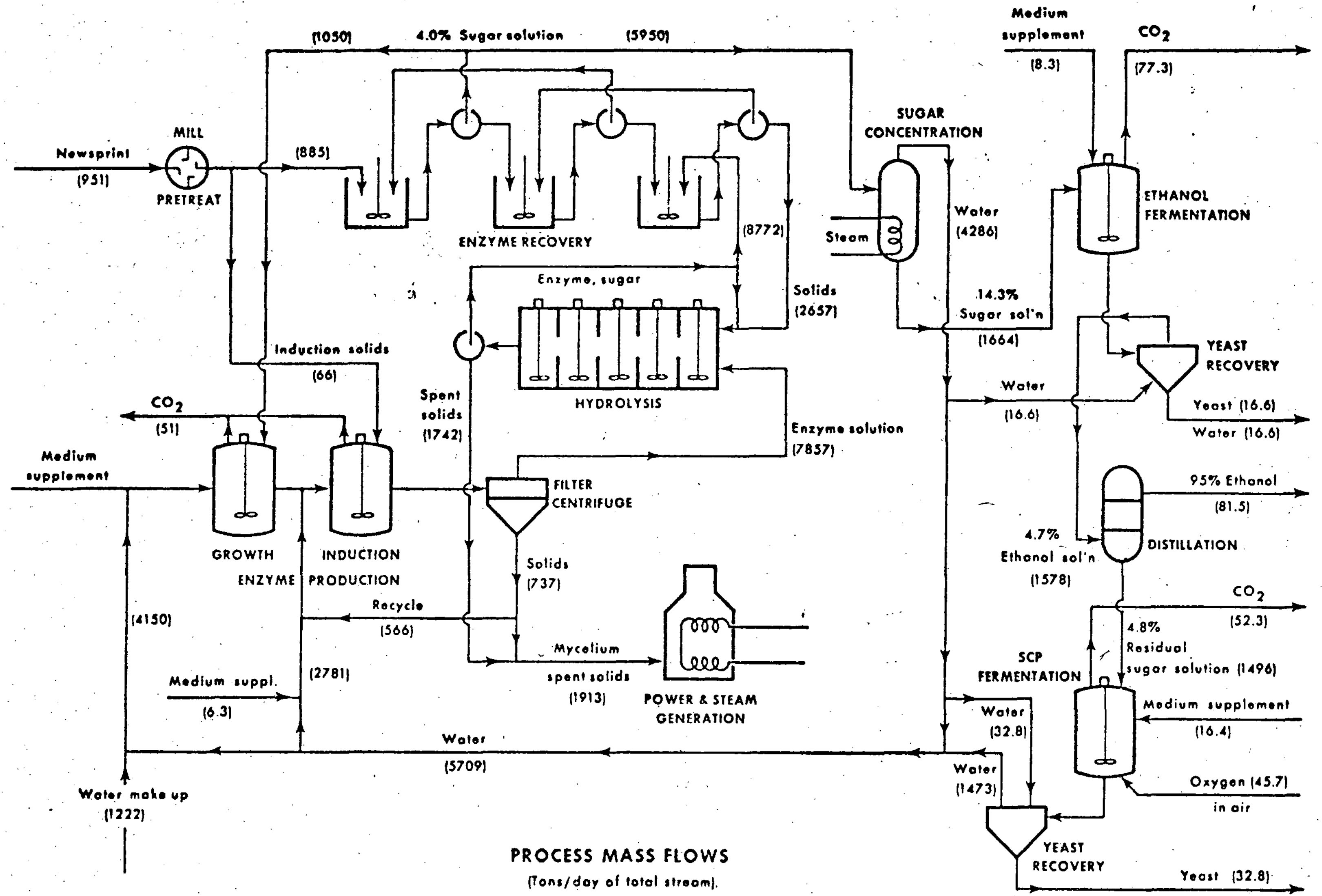

Figure 1. Material Balance Flow Diagram for Integrated Processing Scheme. XBL 762-2330

Ethanol Fermentation (1)

The sugars from the hydrolysis section are concentrated to 14.3% in a seven effect evaporator and distributed to five continuous fermentors. Yeast is recovered by centrifugation and spray dried. The 4.9% ethanol solution from the fermentor plus the aqueous stream containing the alcohol removed from the carbon dioxide are concentrated by distillation to produce 81.5 tons per day of 95% ethanol, equivalent to 25.2 gallons per ton of plant feed, 16.6 tons per day of yeast are recovered from the still bottoms.

S.C.P. Fermentation (1)

Following yeast removal, the bottoms stream from the ethanol distillation containing the hemicellulose sugars and residual glucose at 4.6% concentration are supplied to the fermentation process to produce 32.8 tons per day of Torula yeast.

Steam and Power Generation

1913 tons per day of residual solids from the hydrolysis and enzyme induction sections containing 67% moisture and a heat of combustion of 2040 BTU/lb (wet basis) are fed to a boiler furnace and multi-stage turbine generator for production of electricity and process steam. Although some details of handling the combustion process remain to be worked out, it is assumed for the present estimate that the power plant economics will be similar to those presented by Hammond (5) adjusted to operation at a 95% on stream efficiency. Except for their high moisture content the solids are attracted as a fuel because of their ready availability and negligible sulfur and low ash content.

After Hammond (5), assuming free fuel, furnace efficiency of 82% and an overall conversion efficiency of 25% based on feed to the furnace it is estimated that power can be produced for $0.01 per kilowatt hour. The process steam requirement comprises about 56% of the steam flow, which enters the turbines at 600 psia and exhausts at 0.5 psia. It is assumed that process steam can be withdrawn at 40 psia from an intermediate turbine stage without serious effect on the generation system. Based on the loss of equivalent electrical power at 1¢/kwh due to the process steam withdrawal the steam will have a value of 27¢ per 1000 lb. With an additional 5.5¢ for distribution, the total process steam cost is estimated at 32.5¢ per 1000 lb.

A total of 132,000 lb steam/hr and 12,800 kw of electricity are produced in the combustion system of which 4,000 kw are in excess of the process requirements.

Energy Balance and Thermal Efficiency

Figure 2 shows the flow of energy among the various processing operations. Energy quantities are expressed as the heat of combustion of the process streams, except for steam which is expressed as available BTU for process heat exchange (934 BTU/lb) and electrical power which is expressed as kw or as equivalent thermal BTU's.

Table 2 summarizes the energy input and outputs in the form of newsprint, ethanol, yeast cake, single cell protein and electricity. Net energy of 108.5 x 10^6 BTU/hr is produced from an

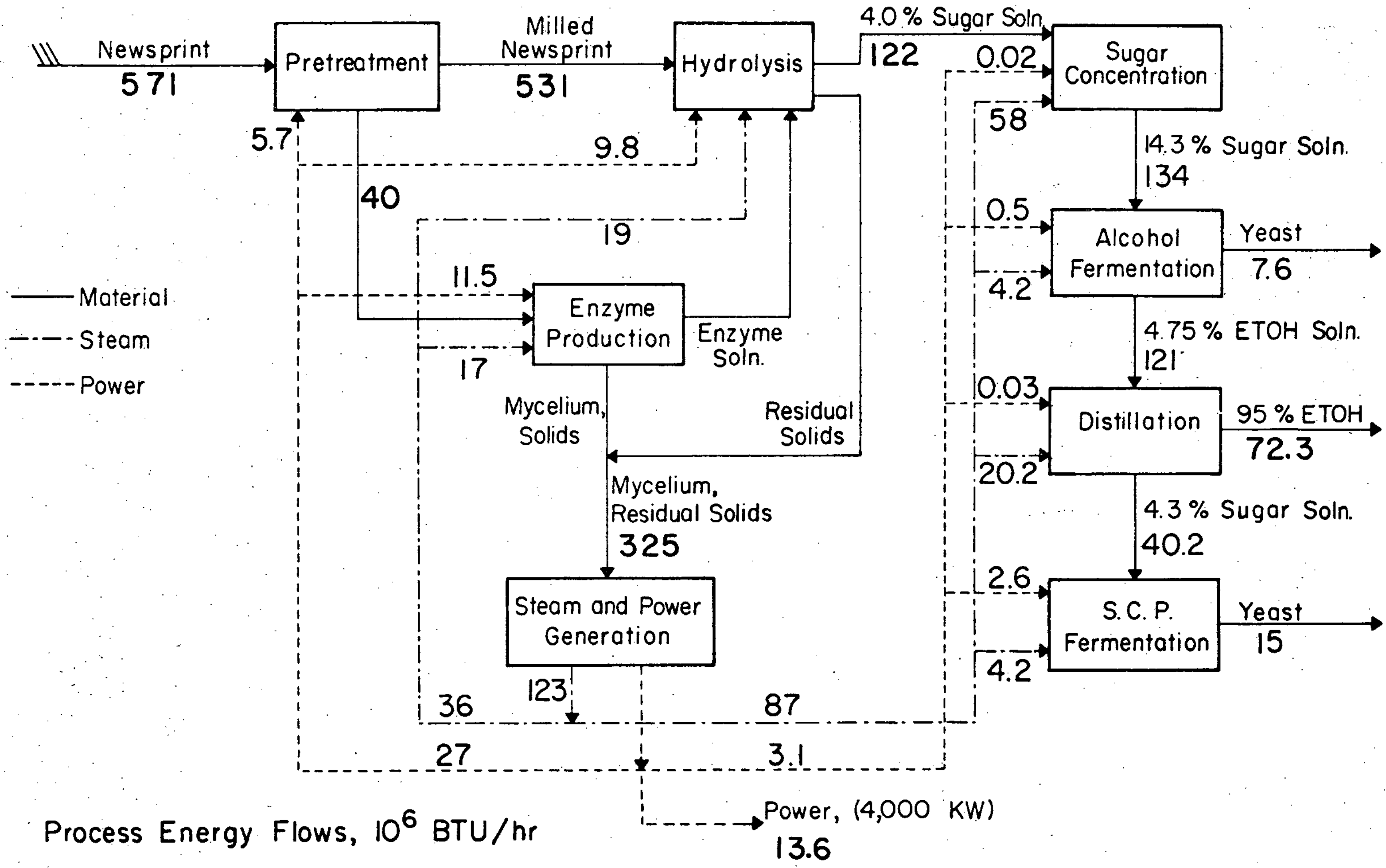

Figure 2. Energy Balance Flow Diagram for Integrated Processing Scheme.

input of 571 x 10^6 BTU/hr, for a net thermal efficiency of 19.0%. However, if it is considered that each BTU of electrical power represents 4 BTU in terms of heat of combustion of the furnace feed, the overall efficiency on a product heat combustion basis becomes 26%.

COST ANALYSIS

Table 3 summarizes the products of the process, production costs and estimated market value of the by-products. The production cost for ethanol and for Torula yeast are those estimated in the preceding paper (1). Yeast cake and Torula yeast values are based on the current quotation for distillers yeast (6). A credit of 1¢ per kwh is taken assuming that the surplus power can be sold for 2¢ per kwh at the process site.

No credit is taken for the Torula yeast since the market value is just equal to the estimated production cost. However, the yeast value defrays the cost of producing the residual sugars in the hydrolysis section. Also, the yeast fermentation can be viewed as a means of waste treatment to permit re-use of water in the process. An alternative procedure could be employment of anaerobic digestion to produce methane gas from the residual sugars. In any case, water re-use is an essential consideration in view of the large quantities required in the enzymatic hydrolysis operation.

On the basis of the assumed by-product credits, the analysis indicates that 95% ethanol might be produced f.o.b. the plant for about 61¢ per gallon, assuming zero cost for the cellulosic feed.

TABLE 3

PRODUCT SUMMARY AND OVERALL COST ANALYSIS

	TONS/DAY	UNIT	PRODUCTION COST, ¢ PER UNIT	ASSUMED MARKET VALUE ¢/UNIT	BY-PRODUCT COST CREDIT PER GALLON ETHANOL, ¢
ETHANOL (95%)	81.5	GALLON	104	--	--
CARBON DIOXIDE	113.0	--	--	--	--
YEAST CAKE	16.6	LB	--	30	40
TORULA YEAST	32.8	LB	30	30	--
ELECTRICITY	--	KWH	1	2	4

Table 4 summarizes the estimated capital investment.

Table 5 gives the estimated incremental increase in alcohol cost per gallon under economic assumptions more representative of the private economy with respect to interest rates and taxes and with a cost of $20 per ton for the cellulosic feed. Under these assumptions the cost of ethanol would become about $1.67 per gallon, somewhat in excess of the present market price.

DISCUSSION

The foregoing analysis suggests that as energy costs increase and petrochemical raw materials become scarce, production of ethanol from cellulosic materials could become a viable alternative. However, it should be emphasized that the processing methods described here involve many undertainties and assumptions which require further study before a firm economic assessment can be made.

The processing scheme is admittedly inadequate and will be superseded as research continues. Further by-product values should be obtainable through utilization of the hemicellulose sugars and lignin. Also, the enzymatic hydrolysis process, which is central to the overall scheme, should be susceptible to further improvement through the development of more effective enzyme systems, of more economical enzyme production, and methods for enzyme recovery and re-use.

Many sources of cellulose exist among agricultural and forest residues which can be made available as the need for ethanol and other potential products increases sufficiently to make their collection economically attractive. As such developments occur

TABLE 4

HYDROLYSIS (2)	\$23.4 x 10^6
ALCOHOL AND SCF FERMENTATION (1)	5.4 x 10^6
POWER PLANT	4.6 x 10^6
TOTAL	33.4 x 10^6

CAPITAL INVESTMENT SUMMARY

TABLE 5

	¢/GAL INCREASE OF ETOH COST
3% TAXES	9.0
12% INTEREST	18.0
$20/TON FOR CELLULOSICS	79.4

INCREMENTAL EFFECT OF VARIABLES ON PRODUCTS greater consideration should be given to coordination of the production of cellulose with food. Ultimately, of course, cellulose might be grown specifically as a chemical and energy resource.

Acknowledgment

This work is part of a general program on utilization of cellulose as a chemical and energy resource conducted under the auspices of the Energy Research and Development Administration (ERDA).

Figure Captions

Figure 1. Material Balance Flow Diagram for Integrated Processing Scheme.

Figure 2. Energy Balance Flow Diagram for Integrated Processing Scheme.

References

1. Cysewski, Gerald and C.R. Wilke, "Utilization of Cellulosic Materials Through Enzymatic Hydrolysis. I. Fermentation of Hydrolysate to Ethanol and Single Cell Protein," Biotechnol. and Bioeng. (preceding paper, this volume).

2. Wilke C.R., Ren Der Yang and Urs Von Stockar, "Preliminary Cost Analyses for Enzymatic Hydrolysis of Newsprint," Symposium on Enzymatic Conversion of Cellulosic Materials: Technology and Applications, Boston, Mass., Sept. 8-10,1975. LBL-4408. (to be published in Biotechnol and Bioeng.)

3. Wilke, C.R. and R.D. Yang, SITRA Symposium on Enzymatic Hydrolysis of Cellulose, Hameenlinna, Finland, March 1975.

4. Mandels, M., J. Weber, and R. Parizek, Applied Microbiol. 21, 152 (1971).

5. Hammond, O. and M.B. Zimmerman, Technology Review, July 1975, p. 43.

6. Chemical Marketing Reporter, January 12, 1976.

0 0 0 0 4 4 0 0 0 2 6

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720