SUPPLEMENT

TO

SUBSTITUTING AGRICULTURAL MATERIALS FOR INDUSTRIAL PRODUCTS

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The Nebraska Energy Office and the Advisory Committee have expressed a desire for more detailed information than was given in our original report in the following areas:

1. The relationship of crude oil price increases to the market potential for biomass substitutes.

2. The potential market size for some opportunities.

3. The environmental impact of the proposed opportunities.

These elements will be discussed separately. It is important to point out, however, the limited resources available for this study and the fact that Nebraska is very much at the forefront of the new interest in this area. Several other studies are in progress as of mid July 1986. The United States Department of Agriculture is just beginning to define production budgets for new crops such as crambe and is just beginning to develop in-house cost proposals for assessing markets and environmental impacts.[1] The National Corn Growers Association has just received the first stage results of its commissioned study on new uses for corn.[2] The Office of Criticial Materials is in the process of developing guidelines for studies to update the Office of Technology Assessment's work on new uses of plant materials as well as the field testing of new crops.[3]

1. Relationship of Crude Oil Prices to Market Potential of Biomass Chemicals

The original plan proposed to compare the potential markets for various biomass derived products at crude oil prices varying from $10 to $30 per barrel. After extensive research we now believe that such an analysis would be very costly and yet still remain inconclusive, yielding few insights. For a number of reasons, the market penetration of biomass based chemicals will not linearly track the price of crude oil. The petrochemical industry has significant flexibility for substituting product manufacturing paths depending on changes in customer markets and raw material prices. The industry is vertically integrated, giving it significant market power. Finally, as oil and natural gas prices rise other raw materials may enter the market before biomass, specifically coal.

Indeed, as Silvio Flaim pointed out in 1981, when crude oil prices were peaking at about $35 per barrel, "Higher energy prices in the past have had a tendency to improve the cost effectiveness of synthetics relative to 'natural' products;...(If there were to be a trend away from synthetics because of higher costs, it would have been evident by now...)".[4]

Irving Goldstein describes three ways to introduce biomass into petrochemical markets:[5]

a. biomass as an alternative feestock to produce petrochemicals(e.g. cellulose replaces crude oil or natural gas or coal).

b. biomass is used directly to displace end petrochemical products(e.g. ethanol for MTBE)

c. bimass products displace petrochemical intermediates(e.g. ethanol replaces ethylene)

In order to evaluate the potential for any of these we must first analyze the nature of the petrochemical industry. As early as 1972 the petroleum industry, the National Science Foundation, and others began to develop extensive models of the complex and highly interactive petrochemical industry.[6] Similar models were developed specifically for biomass.[7] These models, specific to the United States, have since been extended to include the world petrochemical and petroleum markets.[8]

These models illustrate several points.

a. Petrochemicals, which utilize less than 10% of a barrel of crude, can be manufactured from a variety of feedstocks. Figure 1.1 illustrates the multiple paths by which intermediate products can be made.[9]

b. Depending on the desired feedstock, products and co-products, there are a variety of processes which can be used, even with the same feedstock(s). Figure 1.2 describes four basic manufacturing methods for making acetic acid.[10]

c. The chemical manufacturing industry is vertically integrated, with significant opportunity to diversify to protect its markets. Table 1.1 shows the primary producers and the percentage of their total sales derived from chemicals.[11]

d. The real costs of production of petrochemicals and intermediates are highly flexible; therefore, pricing is flexible as well.

The available models indicate that only with products directly produced from fossil feedstocks, such as ammonia from natural gas or fuels, or in countries which do not have a diverse petrochemical industry, would chemicals follow directly the rise or fall in crude oil and related feedstock prices. Recent analyses indicates that such a correlation appears to hold only for the former case because of the international nature of the petrochemical industry.

Thus, non-fossil fuel feedstocks and derivatives must be compared directly with the chemical that they will displace at all levels, including raw materials, intermediates, and end products. For example, Culberson and Donaldson's and Rudd's analyses for feedstocks indicates that coal will enter the market place prior to biomass because of cost and availability. Rudd concludes that, as petroleum and natural gas prices rise, the petrochemical industry will displace its fuel needs with coal where liquid and gaseous feedstocks command a higher prices as a process ingredient. With the availability of coal on-site, the transition to coal as a petrochemical feedstock will naturally follow.

Table 1.1 Leading U.S. Chemical Companies (Very few are in the chemicals business only)

Company	Chemical % of Total Sales	Company	Chemical % of Total Sales
Du Pont	82	Esmark	6
Union Carbide	57	Gulf Oil	3
Monsanto	80	3M	9
Dow Chemical	69	Pennwalt	45
Exxon	6	Airco	39
Celanese	76	Pfizer	17
Allied Chemical	66	Tenneco	5
W.R. Grace	36	Dow Badische	100
Hercules	83	Kerr-McGee	25
Occidental Petroleum	28	Nalco Chemical	89
Eastman Kodak	20	American Hoechst	65
American Cyanamid	50	El Paso Natural Gas	15
Shell Oil	15	Baychem	63
FMC Corp.	39	Union Oil (Cal.)	7
Phillips Petroleum	19	Uniroyal	8
PPG Industries	33	Cabot	56
Stauffer Chemical	85	GAF Corp.	20
Rohm and Haas	70	Atlantic Richfield	4
NL Industries	41	Borg-Warner	11
Standard Oil (Ind.)	7	Chemetron	47
Akzona	71	General Electric	1
Texaco	4	National Starch	79
Diamond Shamrock	60	Witco Chemical	47
Ethyl	55	Freeport Minerals	88
Cities Service	18	IFF	97
Olin	31	CF Industries	71
Standard Oil (Cal.)	5	Morton-Norwich	30
Goodyear	7	National Distillers	10
B.F. Goodrich	18	Northern Natural Gas	19
Mobil Oil	3	Williams Companies	21
Air Products	74	Arco Polymers	92
Firestone	9	Farmland Industries	13
BASF Wyandotte	71	Eli Lilly	14
Merck	23	Procter & Gamble	2
United States Steel	4	Dart Industries	12
Ashland Oil	12	Dow Corning	78
ICI America	86	Kewanee Oil	66
Lubrizol	99	Texasgulf	34
Continental Oil	6	Houston Natural Gas	33
Reichhold Chemicals	96	Commercial Solvents	90
CIBA-GEIGY	41	Emery Industries	90
IMC	37	Sun Oil	5
Borden	9	Kaiser Aluminum	14

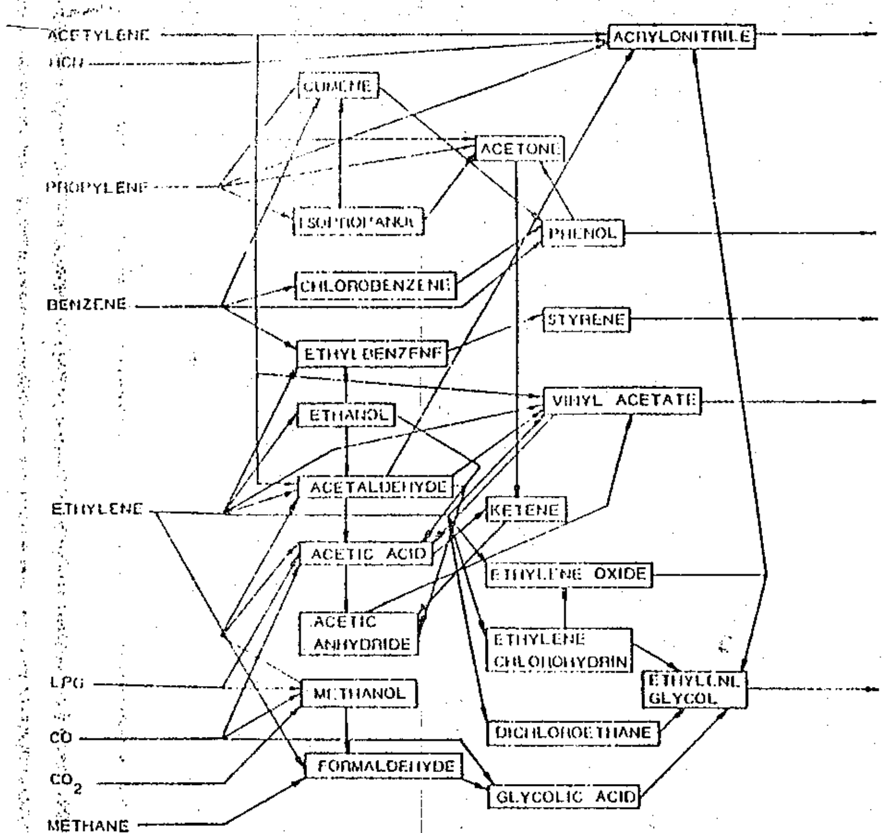

Figure 1.1 Only part of the industrial system that converts primary feedstocks into end chemicals.

Table 12. Cost reductions needed for inactive processes to become active in the base case. Also shown is the percentage of the required production of each primary product that would be met if the process were active at the reduced cost. For chemicals which have no specified production requirements, the per cent of actual production or utilization in the base case is given.

Process	Cost reduction (%)	Product requirement (%)
Ammonia/Coal	46	100
Ammonia/Wood	44	100
Acetic acid/Butane	86	<1
Acetic acid/Wood	17	<1
n-Butanol/Acetaldehyde	92	58
Cyclohexane/Benzene	68	1
Carbon monoxide/Wood	31	101
Carbon monoxide/Methane	4	102
Ethanol/Methanol	3	33
Ethylene/Coal	7	3
Methane/Wood	85	68
Methanol/Carbon dioxide	54	32
Methanol/Coal	55	9
Methanol/Wood	57	9
Methyl ethyl ketone/ sec-Butanol	10	88
Phenol/Kraft lignin	13	64

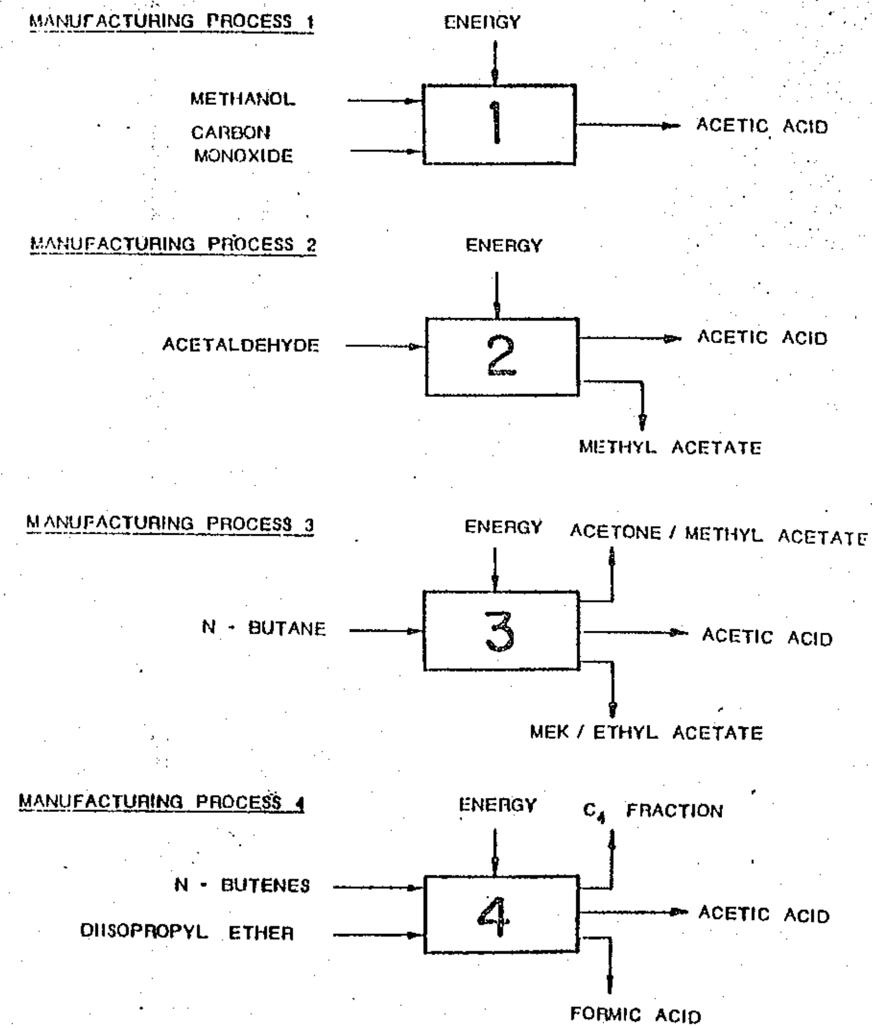

Figure 1.2 The fundamental problem in technology assessment. To produce the same product, these four processes interact with the industry as a whole in drastically dissimilar ways.

An example of the complexity of the subject is indicated by Donaldson and Culberson's work. They did not find a linear relatinshiop between crude oil prices and biomass product market expansion. Therefore they analyzed the market penetration for biomass chemicals under three scenarios: a base case using current prices; an extreme case where no fossil fuels, including coal, were available; and an intermediate case with increased fossil fuel costs and decreased availabilty. After making extensive assumptions within the model, their conclusions were very much product specific. Moreover, as noted in Table 1.2 they conclude that even in the light of rising oil prices biomass may still have to compet with coal as a raw material.[12]

It should be noted that the works of Rudd and Flaim and Culberson and Donaldson appeared in 1981, when crude oil prices were peaking at $35 per barrel. Yet in all instances the authors indicated the need for subsidies for biomass to compete with petrochemical commodities.

B.O. Palsson analyzed the degree of penetration of ethanol under different price assumptions. As can be seen below, he found that ethanol has a considerable market at current chemical prices but does not have a great impact until its price is reduced fivefold. "at this point it becomes attractive for the production of ethylene by dehydration, a reversal of the present process for petro-chemical ethanol. The very large price penalty required to open up this market results partly from process interaction. All of the propylene currently produced by the intermediate chemical industry is a by-product of ethylene production. To open the ethylene market for dehydration of biomass ethanol, the industry has to select an alternative, less economical route to ethylene with more propylene by-product. This constraint on ethylene production results in a higher price penalty for biomass ethanol than there would be if it only competed with ethylene production."[13]

Utilization of Fermentation Feedstocks by the Model Industry in 1985 with Present Technologies

Chemical	Amount(million pounds per year) at f* value								
	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2
Ethanol	1690	1690	1690	1690	1690	1690	2350	6540	55050

*f is the price of the fermentation product under investigation divided by the projected chemical price of the corresponding petroleum-derived compound in 1985.

Thus in order to accomplish a market study one needs to know the following, for each product evaluated.

a. What is the floor price for petrochemical ethanol?

b. How much penetration will and can the industry allow before it begins to adjust its product mix?

c. What is the nature of long term contracts and internal consumption of ethanol?

d. What would be the impact on the petrochemical industry external to the united States on ethanol production?

We concluded from our research into this area that the inter-relationship of crude oil prices and entry points for biomass derived products is extremely complex and must be approached in a creative fashion. In the original report a range of low, moderate and high was used in lieu of quantitative analysis. We believe this can provide a more rational insight for policymakers, given the ase with which the petrochemical industry can change its product mix and prices in the face of competititon and shifting crude prices.

Of specific interest in this matrix should be those opportunities labelled low with regards to sensitivity to crude oil prices, for example, crambe. Crambe is a new crop with significant unrealized potential. The current market is as a lubricant, normally the domain of petrochemicals. Crambe can displace petrochemicals in high temperature lubricant markets, not because it is cheaper, but because of its unique properties. The same can be said for products such as new nylons manufactured from chemicals obtained from crambe. Unique properties, not pricing provide the opportunities.

The rising price of oil spurred industry to look for opportunities for biomass to displace petrochemicals because of price and/or availability. Studies now point to opportunities for biomass based chemicals which will displace petroleum on the merits of their properties(e..g acetate plastics from cellulose, which complement and supplement petrochemical plastics).

Similarly products such as CMA and whey to ethanol are less dependent on the price of crude oil because they reduce significant social costs(e.g. pollution and waste disposal). Quantification of these costs was beyond the scope of our report.

2. Market Potential for Agricultural Opportunities

Where possible, quantitative market estimates were given in the original report. If significant investments are to be made in specific crops or product processes an in-depth market size and penetration study would be undertaken. This is the next natural phase of the Nebraska work.

However, several observations should be made here.

1. As pointed out above, few biomass products displace, on a one-to-one basis, a petrochemcal product. There are not always clear market niches. The biomass ethanol industry is an excellent example. Originally conceived as a fuel supplement or displacer, its price and quality rapidly relegated it to an octane enhancer to displace lead. Ethanol now competes against other petrochemical octane enhancers and even against refinery technology itself(i.e.fuel upgrading.) With potential advances in the ability to use other feedstocks with commensurate variable byproducts, biomass ethanol may confront petrochemicals in the larger solvents and chemical precursor or intermediate feedstock markets. The biomass ethanol is supply side driven with the quality, quantity, and price creating market opportunities.

The new crops singled out in the original report are in the same position. There are only a few small, known uses for the plants and/or seeds and oils, based on previous experience. Crambe or rape, when grown for known industrial markets, as indicated in the report, may offer opportunities for less than 10,000 acres. This is based on known opportunities for the high erucic acid oils for high temperature and extreme duty lubrication. Little is known about the total potential for the oil and the erucic acid, however. For example, cleavage of the acid yields a precursor to the fabrication of nylons(13 and 1313), a potentially vast market.

Crambe was singled out by researchers and government officials because of its ability to displace a critical imported material. This follows the guidelines of their legislative directive. Researchers have identified several industrial applications. At present there is insufficient research to give the positive indication that crambe can be other than a minor crop with a high value potential and the opportunity to displace petrochemicals.

2. The development of agricultural crops and products may provide excellent opportunties for reducing or displacing fossil fuels and petrochemicals in Nebraska. But as these crops and processes proliferate, the result could exacerbate current economic problems in agriculture in those parts of the country with small internal markets. For example, cellulose to ethanol has been promoted as an opportunity for the biofuels industry. Yet, as Larry Hudson of New York State Energy Research and Development Administration points out, the byprodu̇ts of such an industry in New York could reduce that state's needs for corn imported from the midwest. Similarly, Oregon's new crops board is looking at a new-to-Oregon commodity--soybeans. The opportunities for soybean meal and oil, a basis for Nebraska agrcultural, could be diminished if Oregon were to move aggressively into this area.

3. The best option for energy and agriculture may be small, diverse, localized or regional markets. For example, Calcium Magnesium Acetate(CMA), as discussed in the main report, once fully developed, could be produced in each state from local resources. The price which individuals, industry, and government are willing to pay for the commodity to displae road salts will also vary depending on energy and environmental savings in each location. Thus,viable opportunities for local agriculture do exist, but, like crambe, the total impact may be under 10,000 acres.

On the other hand, sweet sorghum, when grown for energy and petrochemical industries, could consume several hundred million acres nationally. But, as has been shown by corn and other volume commodities, volume markets carry low margins, are very price senstiive, and are subject to the same problems confronting corn and bean farmers today.

Both the Council of Agriculture Science and Technlogy(CAST) and Harrison Associates cite the PMC Production-Marketing-Consumption Decision Matrix[14]. Each of the options cited in our principal report has some of the crucial items known. But the lack of information on other items prevents a complete quantitive assessment of all elements within the scope of this current ressarch. Thus the estimates of market size are accurate wihin the reliabilty of the extant data.

For example, it would have been useful to have detail on the potential uses for crambe oil. Unfortunately, insufficient data exists on the costs of production and the quality of the oil, as well as the ability to deliver reliabily, to know whether one can even displace, on a cost competive basis, imported rape oil. Also, insufficient research has been carried out to define the properties needed by the oil and oil derived products against similar products in the petrochemical industry to penetrate the market successfully. Thus, one can only conclude that crambe oil can apparently displace rape oil, and is potentially better, and that the acreage equivalence is approximately 22,000.

At present agricutural product development for industrial markets is emerging, like Rip Van Winkle, from a long sleep. New products from existing crops and agricultural materials and parallel market potentials are appearing rapidly. For example, since the initial draft of this report, NYSERDA has identified a potential to develop cetane from lignin and even whole corncobs. This work has fallen out of their wood-to-ethanol research. The commercial viability is under study. The market potential has not yet been estimated, nor has the best process technology or feedstocks. This exemplifies the uncertainty at all levels of development from raw material to finished product for the majority of of the opportunities cited in this study. It does indicate that significant possibilities do exist and are worthy of substantive and consistent long-term support.

3. Environmental Impacts of Opportunities

Two crops recommended, crambe and sweet sorghum,have the potential for being farmed as dryland crops in Nebraska. Preliminary production budget analyses indicate that the midwest region has the potential for higher profitability with crambe as a dryland crop than as an irrigated crop in other areas of the country. This implies lower water inputs.

The technology for separating oil from seeds, in the case of crambe, is similar to that for other oil seed crops. This implies moderate scale technology---possibly small, central plants as opposed to on-farm processing or high cost facilities such as petrochemical refineries.

The best technology for processing sweet sorghum to ethanol and other commodities is not currently yet known. Work in Minnesota is aimed at small scale, on-farm processing for ethanol with subsequent on-farm processing to produce a solid fuel. Work on these lines is proceeding by a team in the Mankato, Minnesota area. On the other hand, processing options of waste to cetane, economes of scale and related issues may mitigate in favor of moderate scale facilities in the several million gallon range similar to current corn-to-ethanol technology. Very large facilities do not appear to be viable at present.

Meadowfoam is a mostly unknown quantity. There is little experience in growing the crop and that which is available is in Oregon. The potential for double cropping in Nebraska is yet to be proven as are its ideal growing conditions. Processing and marketing are in their infancy, with the primary markets being outside the United States. The literature cites meadowfoam oil as a substitute for sperm whale oil. However, little work has been carried out to support that contention, or for its use as a potential displacer of petrochemical oils, waxes and processing feedstocks. Thus both the bio/physical and socio-economic impats are yet to be determined.

The same holds true for the majority of processes and products which are suggested in the main body of the report. For example, CMA produced from biomass is expected to have significant environmental benefit when it displaces rock salt as a road de-icing product. But the technology for proocducing CMA is not defined.

The whey/corn co-fermentation also has great potential environmental benefit for the State. Unfortunately, Nebraska is not a major cheese producing state, and thus research may prove of greater benefit to outside producers of whey or whey/corn ethanol. Again the process and market opportunities are yet to be defined.

CONCLUSIONS

This supplement is intended to respond in more detail to the concerns and needs raised by the Nebraska Energy office and the advisory board. None of the crops, processes, or end-products suggested in the main report are sufficiently well-defined or established in the United Staes, much less Nebraska, to totally undersand all envirmental, technical, economic or social impacts.

This report points out that fundamental research in the area of plant matter to industrial products can lead to both near term and long term opportunties, but that the timing and the potential cannot be determined within the limits of this study. States, in the absence of fedral support, can and are providing significant work in this area. The leaders at the moment are New York, California and North Carolina.

Many of the opportunities appear to fit small niches for production of feedstock, processing and markets. CMA is a product example and meadowfoam and crambe are crop examples.

All items singled out provide opportunities to directly displace petroleum or natural gas as a feedstock,intermediate, or end product. Some of this displacement is due to a 1:1 equivalency displacement. Others are due to unique and improved properties such as the biodegradability of film or high temperature lubricity in the case of crambe oils.

The key conclusion is that petrochemical markets and pricing are very flexible. Thus, biomass cannot displace petroleum on price alone. Indeed, coal may interpose itself as both a fuel and feedstock with rising petroleum and natural gas prices before biomass plays a full role. This implies that biomass opportunities in the energy area need to be developed around unique opportunities which their inherent molecular structure offers, and the biomass industrial base needs to be researched similarly to the petrochemical industry. This implies the need to develop integrated opportunities.

FOOTNOTES

1 Personal communication with Dan Dvoskin, ERS, USDA, June 1986

2 Progress Report: Alternative Corn Use Study, May 30, 1986. Kelly Harrison Associates, Inc.

3 Personal communication with Richard Wheaton, Office of Critical Materials, June ,1986

4 Silvio J. Flaim, et. al, Biomass Feedstocks for Petrochemical Markets: An Overview and Case Study, (Solar Energy Research Institute, GoldenColorado, May 1981), p. 31.

5 Irving S. Goldstein, Organic Chemicals from Biomass, (CRC Press, Inc., Boca Raton, FL, 1981).

6 Dale F. Rudd, et. al, Petrochemical Technology Assessment, (John Wiley and Sons, New York, 1981).

7 T.L. Donaldson and O.L. Culberson, "An Industry Model of Commodity Chemicals from Renewable Resources", Energy, Vol, 9. No. 8, pp 693-707, 1984; B.O. Palsson, et. al., "Biomass as a Source of Chemical Feedstocks: An Economic Evaluation", Science, Vol. 213, 31 July 1981

8 Personal commnication with Dale Rudd, June 1986

9 Dale F. Rudd, op. cit., p. 22

10 Ibid., p. 23

11 Ibid., p. 4

12 T.L. Donaldson and O. L. Culberson, Op Cit., p. 702. One further comment. In a personal communication, Dr. Donaldson advised us to treat these estimates with great caution since the modelling was constrained by not taking into account markets for fuel.

13 It is interesting to note that none of the authors consider ethanol production from sorghum as sugested in the main body of this study. Most focus on wood as a replacer for starch technology, If research verifies the preliminary analysis, sorghum based alcohol production can cost from 60-80% less than even cellulosic based ethanol, without considering byproduct credits. While fuel is a low value use of sorghum residue, to produce cetane could potentially turn the alcohol into a byproduct to compete or displace fossil fuel based ethanol entirely in the petrochemical industry. Thus with regards to the ethanol industry in general, and sorghum ethanol in particular, the end target for ethanol could be the petrochemical industry itself as opposed to the octane enhancement aspect of the fuel industry or as a fuel itself. Because of the ability of each side(biomass and petrochemical ethanol) to partially decouple from crude oil prices, the sensitivity as defined, can only be described as moderate.

14 E.G Knox and A.A.Theisen(Eds.), Feasibility of Introducting New Crops: Production-Marketing-Consumption(PMC) Systems. A report prepared for the National Science Foundation by Soil and Land Use Technology, Columbia, Maryland.(Rodale Press, Emmaus, PA., 1981).

Annotated Bibliography

Biotechnology: Commercial Development of Solid-State Culture Reactor Technology. 1981. Renewable Technologes, Inc. Butte, MT.

Describes the growth of Renewable Technologies, Inc. and the development of their ATSH starch enzymes and cellulase enzymes.

Chum, Helena L., et. al. May 1985. The Economic Contribution of Lignins on Ethanol Production from Biomass. Solar Energy Research Institute, Golden Colorado.

Reviews market opportunities in several market categories for lignin products. Low, most likely, and optimistic projections are made for the year 2000 for various market applications. The intent of the report is to show that if fuel ethanol production in the billions of gallons scale were built in the future lignin markets would not be saturated.

Clements, L. Davis, et. al. November, 1983, Chemicals from Biomass Feedstocks. Chemical Engineering Progress.

Analyzes the production of industrial chemicals from biomass, either as fractionated compounds by thermochemical conversion to synthesis gas or by fermentation. Gives current sale price and fermentation price cost per pound for specific end product chemicals.

Culberson, O.L. and T.L. Donaldson. 1982. Chemicals from Biomass: A Systems Analysis. Biotechnolgy and Bioengineering Symposium, No. 12, pp 291-296.

An assessement of the potential for large scale production of chemicals from biomass to supplement production of chemicals from petrorlem and natural gas. Objectives are to determine the extent to which chemicals from biomass can lessen dependency on natural gas and imported oil and to identify reseach and development activities that will encourage increased production of chemicals from biomass. Results are summarized for a particular limiting case in which no fossil resources are available for feedstocks.

Development of New Crops: Needs, Procedures, Strategies, and Options. October 1984. Council for Agricultural Science and Technology. Report No. 102.

This booklet lists the needs for and potentials of, new crops research and development. It describes the past record of new crop development and the lessons learned from that and proposes several options for an expanded national program of new crop evaluaton and developent.

Donaldson, T. L. and O.L. Culberson. 1984. An Industry Model of Commodity Chemicals from Renewable Resources. Energy. Vol 9, No. 8. pp. 693-707.

A systems model based on linear programming is constructed for a commodity chemicals industry using renewable resources and coal, as well a gas and petroleum derived resources. Results suggest that coal should precede biomass as a feedstock in the event of a significant reduction in the use of gas and petroleum based feestocks.

Fathi-Afshar, Saeed and Dale F. Rudd. 1981. The Economic Impact of New Chemical Technology. Chemical Engineering Science, Vol. 36, pp. 1421-1425.

A model is developed to determine chemical prices on the basis of changes in demand, availability and new technology.

Flaim, Silvio J., et. al. May 1981. Biomass Feedstocks for Petrochemical Markets: An Overview and Case Study. Solar Energy Research Institute, Golden, CO.

Focusses on substitution possibilities for the production of methanol, an intermediate chemical product. The case study for methanol reveals that its single largest use is in the production of formaldehyde, which, in turn, is used primarily in the production of thermoset resins and glues. The largest user of these is the wood industry, which would have substantial quantities of wood waste available for their manufacture.

Gaines, Linda L. and Michael Karpuk. 1985. Fermentation of Lignocellulosic Feedstocks: Product Markets and Values. Argonne National Laboratory, Argonne IL.

Product slates are compared for a range of feedstock and process options of lignocellulose. For each product, potential markets and materials competing for these markets(or competing routes to the same product) are identified. The value of ethanol as a chemical, octane enhancer, and fuel is estimated. Quantity of each market that could be produced by fermentation is compared with the size of potential markets.

Glasser, Wolfgang G. and Robert H. Leitheiser. 1984. Engineering Plastics from Lignin. Polymer Bulletin. 12, 1-5.

One in a series of technical reports describing the potential markets for lignin based products.

Holly, S. Michael and J. Bradley Hochalter. January 1986. Butanol and Ethanol Production from Sweet Sorghum: Demonstration Project. 1985 Interim Report to the Minnesota Legislature. Mankato Area Vocational Technical Institute, MN.

Examines the feasibility of field expression and subsequent juice fermentation and distillation to ethanol of sweet sorghum in Minnesota. Based on pilot tests.

Kiester, Dale F. and Neil Malarkey. January 1984. Cellulose Ethanol-Commercialization, New York State Energy Research and Development Authority.

Evaluates the status of several technologies for the conversion of cellulose to ethanol in terms of commercial readiness. The greatest attention is paid to acid hydrolysis and enzyme hydrolysis.

Knight, J.A., et. al. March 1980. Pyrolytic Oils-Characterization and Data Development for Continuous Processing. Georgia Institute of Technology. Engineering Experiment Station. Atlanta, GA.

Analyzes the production of pyrolytic oils in a 500 lb per hour pilot plant and in a 50 ton per day field development facility. Characterizes thoroughly the pyrolytic oils produced and provides a preliminary economic assessment based on market prices in December 1979.

Knox, Ellis G.,et. al. December 1983. Herbaceous Biomass Production-Marketing-Consumption Analysis for New York State. NYSERDA Report 84-4.

Analyzes potential herbaceous crops in New York that have annual yields of 3 tons per acre for perennial crops and 4.5 tons per acre for annual yield for biannual crops. Production cost threshhold is set at $40 per acre per year. Tested 49 crops resulting in selection of 23 crops for detailed analysis. Two crop conversion technology systems are identified for near term consideration.

Mustakas, G.C. and K.D.Carlson. 1979. Simple Model for Determining Economic Feasibility of Processing New Oilseeds. Journal of the American Oil Chemists' Society, Vol. 56, No. 1 pages 29-32

Develops a simple model to compare break even cost to make a new oil with the market price of competitive oil. The method is illustrated with a comparison of crambe abyssinica seed oil and high erucic acid rapeseed oil.

Ng, T.K., et.al. February 11, 1983. Production of Feedstock Chemicals, Science, pp. 733-739.

Evaluates production of oxychemicals and their derivatives from renewable resources. Concludes that 100 billion pounds annually, or about half of US production of organic chemicals, could be produced by this route.

Nieschlag, H.J. Nieschlag and I.A.Wolff. 1971. Industrial Uses of High Erucic Oils. Journal of the American Oil Chemists' Society. Vol. 48, No. 11, pp. 723-727

Analyzes a variety of possible industrial uses of high erucic oils, as exemplified by crambe. Describes their characteristics.

Parker, Stephen Parker, et. al. August 1983. The Value of Furfural/Ethanol Coproduction from Acid Hydrolysis Processes. Solar Energy Research Institute. Golden CO.

Parametric analyses of high temperature dilute acid hydrolysis of cellulose were carried out to determine the effect of hydrolysis parameters and processing schemes on the selling price of ethanol. This report compares the relative benefits of two ways of improving the economics of ethanol production. The first is to improve process efficiency and increase product yield by developing yeasts capable of fermenting xylose to ethanol. The other is to improve the recovery of process by product furfural and use it as a marketable chemical product. The revene from sale of furfural would offset some ethanol costs

Plants: The Potentials for Extracting Protein, Medicines and Other Useful Chemicals: Workshop Proceedings. September 1983. Office of Technology Assessment, Washington, DC.

Examines different types of products, including low cost/large demand and high cost/small demand products, products suitable for development in the US and in less developed countries, and plants that have had little previous commercial use. Specific plant products, plant-derived drugs andecological characteristics are discussed.

Rudd, Dale F. et. al. 1981. Petrochemical Technology Assessment. John Wiley and Sons, New York.

Examines the performance characteristics of the chemical industry in terms of feedstock, energy and investment capital requirements and the effects on the industry of changing product lines, raw materials sources, process technology and government legislation, as well as characteristiscs of new processes and products.

Wood Pyrolysis for Production of Char and Fuel Oils: A Project Review. 1981. i/e associates, inc. Minneapolis, MN.

Technical and economic review of wood pyrolysis project, located in Georgia.