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MICHAEL Z. LOWENSTEIN

ENERGY APPLICATIONS OF BIOMASS

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The proceedings of the National Meeting on Biomass R & D for Energy Applications held 1–3 October 1984 at Arlington, Virginia, USA.

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Edited by

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FOREWORD

The National Meeting on Biomass R&D for Energy Applications was supported by the Council of Biomass Energy Technology Sponsors (CBETS) and was organized and hosted by the Solar Energy Research Institute (SERI). The Biomass Energy Research Association (BERA) provided technical assistance.

CBETS was founded on July 14, 1983, as a forum for communication and cooperation among managers of the major biomass energy programs in the United States, including various federal and state government organizations, industry institutes, and associations. Council membership includes the American Public Power Association; the Electric Power Research Institute; the Gas Research Institute; the Hawaii Natural Energy Institute; the Legislative Commission on Minnesota Resources; the National Rural Electric Cooperative Association; the New Mexico Energy Research and Development Institute; the New York State Energy Research and Development Authority; the North Carolina Alternative Energy Corporation; the Tennessee Valley Authority; the U.S. Department of Agriculture; and the U.S. Department of Energy. The Council's affiliate members include the American Gas Association; the Bio-Energy Council; the Biomass Energy Research Association; the Fiber Fuels Institute; the National Wood Energy Association; the Renewable Fuels Association; and the Wood Heating Alliance.

CBETS has two primary objectives: programmatic coordination to maximize the value and usefulness of biomass energy research and development activities sponsored by Council members; and timely and effective transfer of the results of biomass energy technology advances to industry and other interested parties. The national meeting held in Arlington, Virginia, on 1–3 October 1984, was one of CBETS's continuing efforts aimed at achieving the goal of timely technology transfer. Attendees represented industries, colleges and universities, federal and state governmental agencies, and foreign countries.

Each of the three sections in the following Proceedings has a specific focus. Section 1 contains discussions of issues important to the various sectors of the biomass energy community; Section 2 discusses in detail the research interests of biomass energy sponsors; and Section 3 provides highlights of significant biomass energy research efforts.

The organizers thank all the authors for having contributed their reports and the CBETS members for initiating and assisting with the planning that led to the success of the meeting.

Golden, Colorado M.Z.Lowenstein
August 1985

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SECTION I

Issues of Importance to Biomass Energy Research

RENEWABLE RESOURCES FOR FUEL AND MATERIALS

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*University of California, Berkeley

SYNOPSIS

As a result of the depletion of our supplies of oil and gas, which were created by the process of photosynthesis, it is now necessary to develop renewable fuels for the future because of the environmental problems associated with the expanding development of coal and oil shale, particularly the carbon dioxide problem. The most immediate source of renewable fuels is annually growing green plants, some of which produce hydrocarbons directly. We can select new plant sources that have high potential for production of liquid fuels and chemicals. Suggestions are made for the modification of both the product character and the productivity of the plants. Ultimately a totally synthetic device will be developed for the conversion of solar quanta into useful chemical form, completely independent of the need for arable land.

1

INTRODUCTION

We are here largely because of the awakening that occurred in 1974–75 as a result of the action of the OPEC nations, and we are now more conscious of energy problems than we once were. American energy use for 1983 (Fig. 1) still emphasized fossil fuel energy (natural gas, coal, and oil) as the major sources. These are basically the products of ancient photosynthesis when plants were laid down and converted from primarily carbohydrate into carbon, hydrocarbon, and gas. The other energy sources (nuclear, geothermal, and hydro) are relatively minor.

How long can we expect fossil fuel energy to continue as a major source? One of the simplest ways of answering that question is to examine the energy costs of finding and extracting a barrel of oil. One way of expressing that cost is to determine the number of barrels of oil per foot of well drilled, which was 35 in 1945 ; this quantity in 1975 was less than 18. Another way of expressing these same data is to say that the energy cost today for finding and extracting that barrel of oil has risen, and we are very close to the edge of energy economy. A barrel of oil contains 6 million Btu, and when drilling and exploration uses more energy than the energy content of the barrel itself, it becomes questionable economically to sell that barrel of oil (Ref. 1).

2

ECOLOGICAL CONSTRAINTS

Major coal producers in the three major coal-producing countries of the world (the Soviet Union, China, and the United States) consider that coal is a viable energy source to replace petroleum and natural gas, and it is likely that in the planned economies, at least, coal will become the major energy source. A reason for concern is that even today, when coal represents less than 25% of the total energy usage, our biosphere cannot absorb the carbon dioxide at the rate of injection that burning fossil carbon in all its forms produces (Refs. 2, 3). Today the $C0_2$ is removed from the atmosphere at roughly half the rate at which it is injected. If coal production increases markedly, the removal of $C0_2$ from the atmosphere will be a still smaller fraction of what we inject, meaning that the rate of rise of the CO2 concentration in the atmosphere will double. The $C0_2$ concentration has risen from 295 ppm in 1880 to 330 ppm in 1980, and if the use of coal greatly increases, the $C0_2$ concentration will rise at an even more substantial rate. The amount of $C0_2$ produced from the combustion of coal is roughly twice that from petroleum or natural gas because combustion of coal burns carbon only, and not carbon and hydrogen.

The rising $C0_2$ level produces the greenhouse effect as a result of the peculiar properties of the $C0_2$ itself. Concomitantly, the temperature measured at various places on the earth’s surface has also been rising in the last 100 years, increasing about 0.4¼C from 1860 to 1980, which represents a very large rise (Ref. 4). One of the best ways to show the result of this increase in temperature is to examine the satellite photographs of the South Polar ice cap. One can estimate the amount of ice that has disappeared in the last 20 years as about 1.2 million km^2 from an approximate total of 12 million km^2 (Ref. 5). Thus the global mean sea level has been rising about 2 to 3 mm per year during the last 50 years, compared to about 1 mm per year during the previous half-century (Ref. 6). A recent report by the Environmental Protection Agency (Ref. 7) projects a global rise of sea level between 144 cm (4.8 ft) and 217 cm (7 ft) by the year 2100, with the low estimate of 56 cm (1.9 ft) and high of 345 cm (11 ft). Also, along most of the Atlantic and Gulf Coasts of the United States, the predicted rise will be more than the global average; i.e., 18 to 24 cm (0.6 to 0.8 ft).

It is therefore obvious that to alleviate the trend of rising $C0_2$ concentration and its subsequent problems, an alternate energy source must be found (Refs. 8, 9). The best annually renewable source of energy is the green plant, and we are looking for green plants that can produce hydrocarbons from carbohydrates. There are many such plants, in several different families, and they are found all over the world.

3

BIOMASS FOR RENEWABLE ENERGY

As you know, the primary productivity of biomass is carbohydrate (sugar, starch, and wood) which must be converted into a much more concentrated form, such as hydrocarbon. One of the first efforts has been made in Brazil where sugar cane has been used directly as an energy source as well as a source of carbohydrate. In 1983, 4.3 x 10^9 L of fermentation alcohol were produced from sugar cane on the autonomous sugar cane plantations. This fermentation alcohol is used directly in automobiles and is a chemical feedstock for Brazilian industry.

In Puerto Rico an energy cane has been developed that can be used not only for its sugar content but also for its total energy content to fire the boilers in heating plants on the south coast of Puerto Rico (Ref. 10).

Some plants, such as Euphorbia lathyris, a member of the Euphorbiaceae family, produce hydrocarbons directly from C02. Plantations for E. lathyris have been developed not only in the United States (Ref. 11) but in Spain as well (Ref. 12). Euphorbia produce 8% oil and 20$ sugar upon extraction of the whole plant. Another species, Asclepias speciosa (milk-weeds) , produces approximately the same combination. That species has been studied extensively in Utah (Ref. 13). The seed oils are also being developed (Ref. 14). For example, sunflower seeds produce an oil that can be used directly in a mixture as a diesel fuel or easily converted by transmethylation to a diesel fuel without any additives by replacing the glycerine of the triglyceride with methanol. The best commercial seed oil producer is the palm, which is being grown on a large scale in Brazil and Malaysia as a source of oil for fuel and materials.

The processing sequence to recover oil (terpenoids) and fermentable sugars from E. lathyris (Fig. 2) was worked out in the laboratory and is calculated here for 1000 dry ton/day of material, which would yield 80 ton of crude oil and 200 ton of fermentable sugars that could produce 100 ton of alcohol (Refs.15, 16). About 500 ton of bagasse are used to run the process, with a resulting 200 ton of bagasse that could be used to distill the alcohol. The fermentation alcohol that is a by-product is, of course, a starting point for an entire petrochemical industry. The whole process is self-contained.

Studies of E. lathyris have shown that while it is possible to crack the material from this plant, it might be more economical to determine whether this species and its products contain more useful materials for chemical feedstock production (Ref. 16). The crude oil from the E. lathyris has been converted, using special zeolite catalysts, to the usual products such as olefins, paraffin, aromatics, and nonaromatics. This confirms the desirability of the products of E. lathyris as possible raw materials to substitute for crude oil. It now appears that a price of $100/barrel for the oil from E. lathyris, only 2.5 times more than the 1982 OPEC price per barrel of crude, might be a realistic projection. The price will almost certainly turn out to be less when larger-scale energy agriculture operations are commenced.

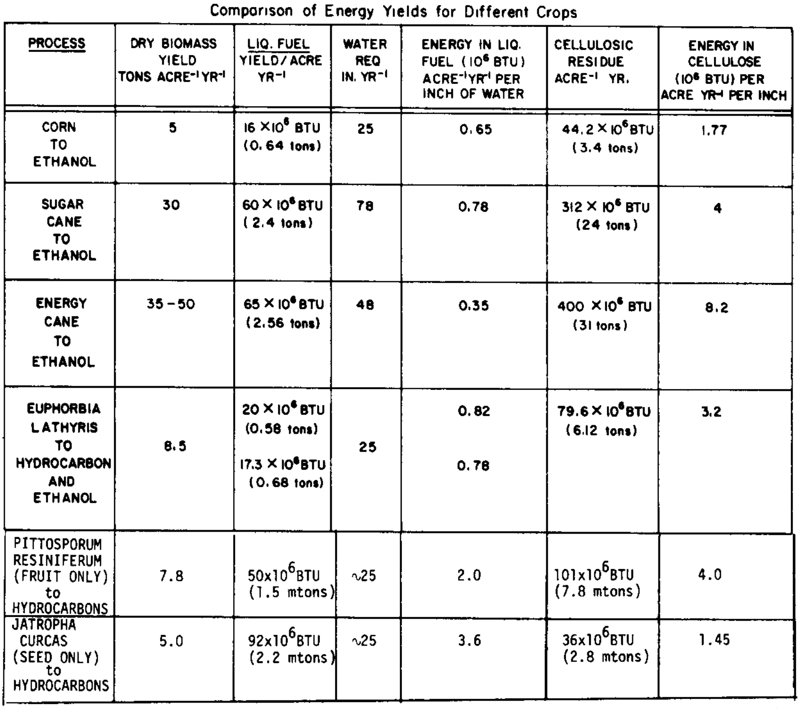
The plant chemicals that constitute the black oil are mostly triterpenes (C_{30}), sterols, and sterol esters, which can be cracked to make desirable products. The biosynthetic route to the terpenes in plants such as E. lathyris has not been completely determined, but it is probably similar to that for rubber biosynthesis except that the end products from the E. lathyris are lower molecular weight compounds. The route is from sugar via the glycolytic cycle to pyruvate, which then builds up to mevalonic acid and goes on to give isopentylpyrophosphate (IPP). The IPP polymerizes into a variety of isoprenoids, and in E.lathyris the material goes through the isoprenoid biosynthetic pathway to squalene (C_{30}), which is then folded up to make the C_{30} terpenoid (steroidal) alcohols that are the greater percentage of the oil.

We also looked for trees that might produce oil directly when they were tapped or had fruits extracted. Such an agronomy would conserve soil and water. One tree in Brazil, the Copaifera multijuga of the family Leguminosae, does exactly this. It grows in the Amazon area of Brazil, and the material from the tree can be used directly in a diesel engine. It is tapped twice each year and produces 20 L of cyclic sesquiterpene oil per tap. The Brazilians are now beginning plantation experiments with these trees to improve yields of oil (Ref. 17). Another family of trees, the Pittosporaceae, has representatives in various parts of the world. In the Philippines the fruit of the Pittosporum resiniferum is used by the natives for illumination and for its oil content. The fruit, about the size of a prune, contains about 50% terpenes of three different components—myrcene, alpha-pinene, and limonene (Ref. 18). These three components can be used almost directly as cracking stock or fuel. A species that grows in California, Pittosporum undulatum, has smaller fruits with slightly different oil content. Another tree, Jatropha curcas, which is a member of the Euphorbiaceae family, is being cultivated on a large scale in Thailand; this tree is closely related to the castor bean.

Another type of plant that does not involve agricultural land directly and which produces hydrocarbon is the microalga Botryococus braunii, which can grow in either fresh or salt water. The algae secrete an oil that is roughly 50%–70% of the dry weight and is mostly C_{30}, which can be cracked in the same way as crude oil (Ref. 19).

The energy yields for different plants are shown in Table 1. It is clear that the most important component in the table is the energy in liquid fuels as hydrocarbons in millions of Btu per acre per year per inch of water. There is no question in my mind that it would be possible to introduce into the United States a substantial energy agriculture, if there were the right type of economic incentives for such a biomass production (Ref. 20).

The projections for energy use in the United States for the year 2000 (Fig. 3) for the first time include biomass as a significant component of the total, representing about 6% of the total energy requirement. This is an important indication of what is perceived to be realizable in the next 20 years. I believe that biomass will represent a greater component than the 6% projected. One way to encourage this process would be to have farmers set aside a part of their land to grow a plant that produces a fuel of the correct type to run agricultural machinery. This would be a return to the practice of 100 years ago when farmers used part of their farms to produce the energy needed, mostly as carbohydrate (grass) for animal feed.



Comparison of Energy Yields for Different Crops

PROCESS	DRY BIOMASS YIELD TONS $ACRE^{-1}YR^{-1}$	LIQ. FUEL YIELD/ACRE YR^{-1}	WATER REQ IN. YR^{-1}	ENERGY IN LIQ. FUEL (10^6 BTU) $ACRE^{-1}YR^{-1}$ PER INCH OF WATER	CELLULOSIC RESIDUE $ACRE^{-1}$ YR.	ENERGY IN CELLULOSE (10^6 BTU) PER ACRE YR^{-1} PER INCH
CORN TO ETHANOL	5	16×10^6 BTU (0.64 tons)	25	0.65	44.2×10^6 BTU (3.4 tons)	1.77
SUGAR CANE TO ETHANOL	30	60×10^6 BTU (2.4 tons)	78	0.78	312×10^6 BTU (24 tons)	4
ENERGY CANE TO ETHANOL	35 – 50	65×10^6 BTU (2.56 tons)	48	0.35	400×10^6 BTU (31 tons)	8.2
EUPHORBIA LATHYRIS TO HYDROCARBON AND ETHANOL	8.5	20×10^6 BTU (0.58 tons) 17.3×10^6 BTU (0.68 tons)	25	0.82 0.78	79.6×10^6 BTU (6.12 tons)	3.2
PITTOSPORUM RESINIFERUM (FRUIT ONLY) to HYDROCARBONS	7.8	50×10^6 BTU (1.5 mtons)	∿25	2.0	101×10^6 BTU (7.8 mtons)	4.0
JATROPHA CURCAS (SEED ONLY) to HYDROCARBONS	5.0	92×10^6 BTU (2.2 mtons)	∿25	3.6	36×10^6 BTU (2.8 mtons)	1.45

XBL 849-3892

TABLE 1

XBL 849–3892

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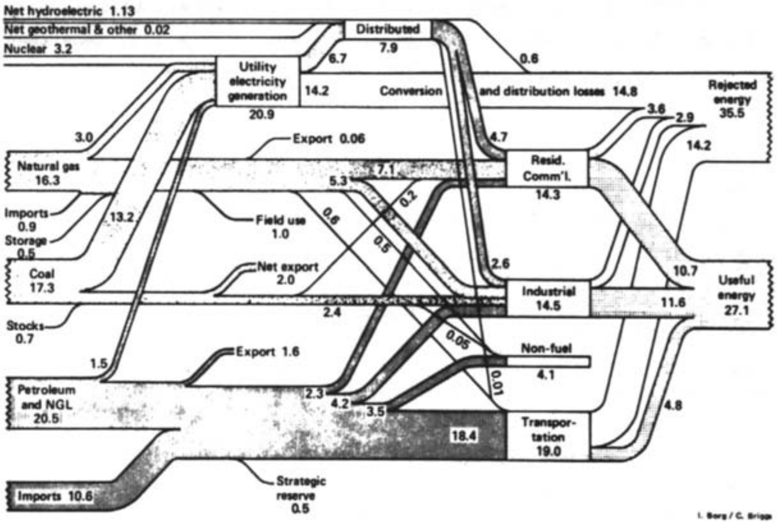

Fig. 1. American energy use in 1983

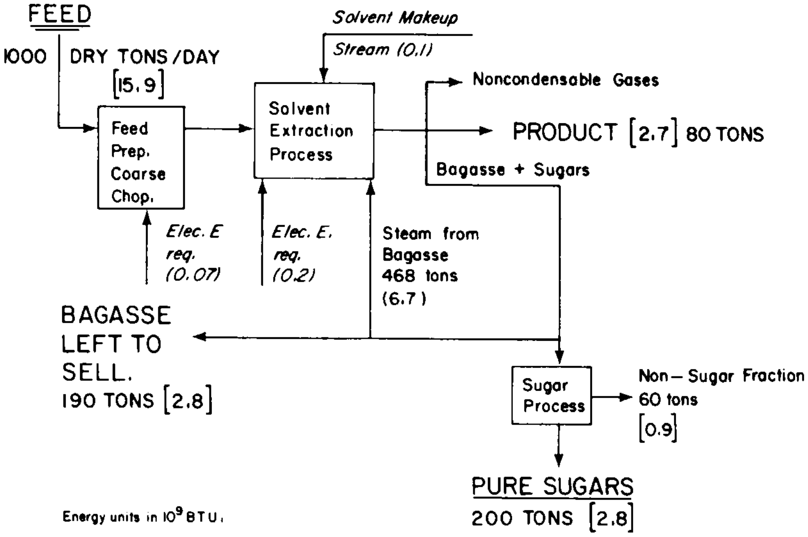

Fig. 2. Conceptual processing sequence to recover oil and fermentable sugars from Euphorbia lathyris

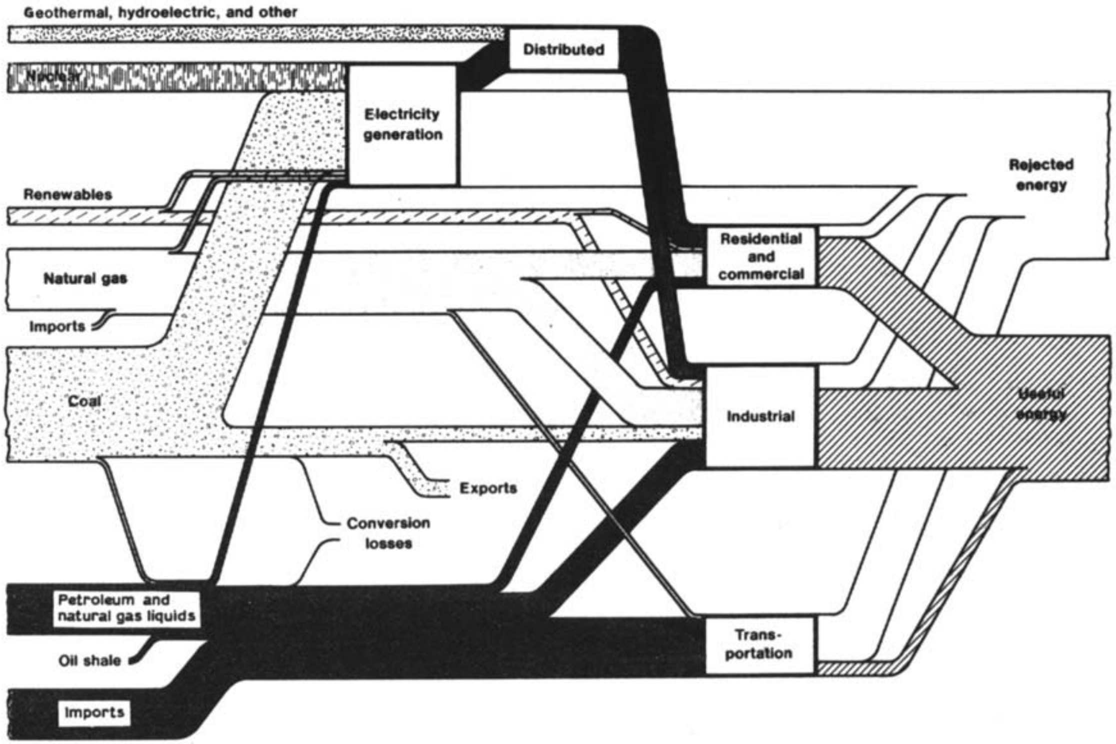

Fig. 3. Projections for energy flow in the United States for the year 2000