Plants as a Source of High Energy Liquid Fuels

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The growing of green plants has received much discussion as a renewable energy source (1). Two distinct approaches are possible for energy farms. Either whole plants can be harvested as in a biomass plantation, or plants capable of producing reduced photosynthetic materials can be cultivated. In the latter case, the net product is a derivative of the total biomass, and the process would be unlike many other biomass systems where the whole plant is burned for its heat value. Conversion processes for hydrocarbon-like extracts are expected to be more efficient and less energy demanding, since the material is already in a reduced state.

A large number of plant species are capable of synthesizing isoprenoids and other hydrocarbon-like chemicals. Perhaps the best known example is the rubber tree, Hevea brasiliensis (family Euphorbiaceae). The family Euphorbiaceae consists of approximately 2000 species ranging from small herbs and succulents to large trees, the large majority of which produce a milky latex which is rich in reduced isoprenoids. One member of this family, Euphorbia lathyris, grows wild in California. To explore the feasibility of obtaining fuels or chemical feedstocks from this Euphorbia species, field studies were undertaken in the cultivation and harvesting of Euphorbia lathyris. Preliminary results with wild seed and without the benefit of optimization of fertilizer and irrigation conditions gave an annual biomass yield of 10 dry tons per acre.

Reduced photosynthetic material can be obtained from the dried plant material by hot solvent extraction. Various solvents can be used for the isolation of different plant constituents; one such extraction scheme is shown in Figure 1. The high heat value and low oxygen content of the heptane extract warranted a more detailed investigation of its chemical composition (2). This extract is a complex mixture of over 100 individual components. By various analyitcal methods, primarily by gas chromatography, combined gas chromatography-mass spectroscopy and high resolution mass spectroscopy, we identified approximately fifty major components. The extract is composed almost entirely of tetra- and pentacyclic triterpenoids functionalized as ketones, alcohols, or fatty acid esters. Two representative structures for a tetra- and a pentacyclic case are shown in Figure 2. Triterpenoids arise via the enzyme mediated cyclization of squalene 1,2-oxide, followed by rearrangement sequences to yield a large array of interrelated C_{30} compounds. In Euphorbia lathyris, terpenoid biosynthesis is almost exclusively shunted via this pathway, since no major amount of lower terpenoids have been detected. A few of these triterpenoids have been previously identified as the major components of the latex itself (3); however, the whole plant extract yields a much greater variety of these compounds. The nature of these compounds suggests that their conversion to chemical feedstock material might be advantageous. Such conversion studies have already been carried out on vegetable oils and a Euphorbia latex (4).

A substantial amount of a more polar fraction can be obtained from the dried plant by methanol extraction, as shown in Figure 1. We have identified simple hexoses as major components of this fraction. These sugars are fermentable to alcohol; therefore, the possibility of obtaining this additional liquid fuel from Euphorbia lathyris shows promise.

Although Euphorbia lathyris produces reduced isoprenoids, it would be economically desirable to improve this yield. The first plant selection experiment toward this end was done using the two cultivars native to California, the

Northern and the Southern variety. In a population of one hundred individual Northern and one hundred Southern California seed source plants, we could not detect a statistically significant difference in terpenoid content between the two sets. The relatively small dispersion(8% Of the mean) observed for each set is probably indicative of the limited seed source available at this time. In order to explore the feasibility of increasing terpenoid as well as biomass yields, further experiments using plant growth hormones, similar to the ones used successfully in guayule and Hevea, are in progress (5).

Since Euphorbia lathyris and other hydrocarbon producing crops are new species from the point of view of cultivation, their agronomic characteristics, requirements, and yield potentials are not yet well known. Consequently, any conceptual economic or technical evaluation will contain several uncertainties. A recent study by Stanford Research Institute on the feasibility of growing Euphorbia lathyris for energy usage identified these major uncertainties as the feedstock cost and supply (6). This conceptual process study is essentially based on solvent extraction of field dried plants at 1000 tons per day, and recovery of the sugars by water extraction. Credit is given for the sugars at 4¢ per lb. (base case) or 6¢ per lb. (optimistic case). The overall process uses the cellulose (bagasse) of the plant to generate the energy required for solvent extraction and recovery. According to this model, after recovery of the useful products, a considerable quantity of bagasse is left over. If one includes in this model an estimate of the required energy input for cultivation, the entire process still remains energy positive(7).

Based on this study, the estimated product costs are greatly dependent on the method of cultivation. In areas such as California where irrigation is required, one barrel of "oil" from Euphorbia lathyris may be produced for $100 (optimistic case) or $200 (base case). Cultivation of Euphorbia lathyris in a geographic region where irrigation requirements are minimal would lower the feedstock costs significantly. Consequently, one barrel of "oil" form Euphorbia lathyris grown in the Midwest is estimated to cost $43.

Comparison of a new crop such as Euphorbia to other established ones like corn or sugar cane, which yield ethanol, indicates that in terms of energy yield of liquid fuel per acre/yr., Euphorbia lathyris is comparable. The liquid fuel yield from corn is 16 x 10^6 BTU/acre/yr; from sugar cane it is 25 x 10^6 BTU/acre/yr. both in the form of ethanol (8). The Euphorbia lathyris yield is 20 x 10^6 BTU/acre/yr. in the form of hydrocarbons and 13 x 10^6 BTU/acre/yr. in the form of alcohol. In addition a potential yield of approximately 7 x 10^6 BTU/acre/yr. may yet be realized from fermentation of yet unidentified carbohydrates.

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Figure 1

EUPHORBIA LATHYRIS EXTRACTION

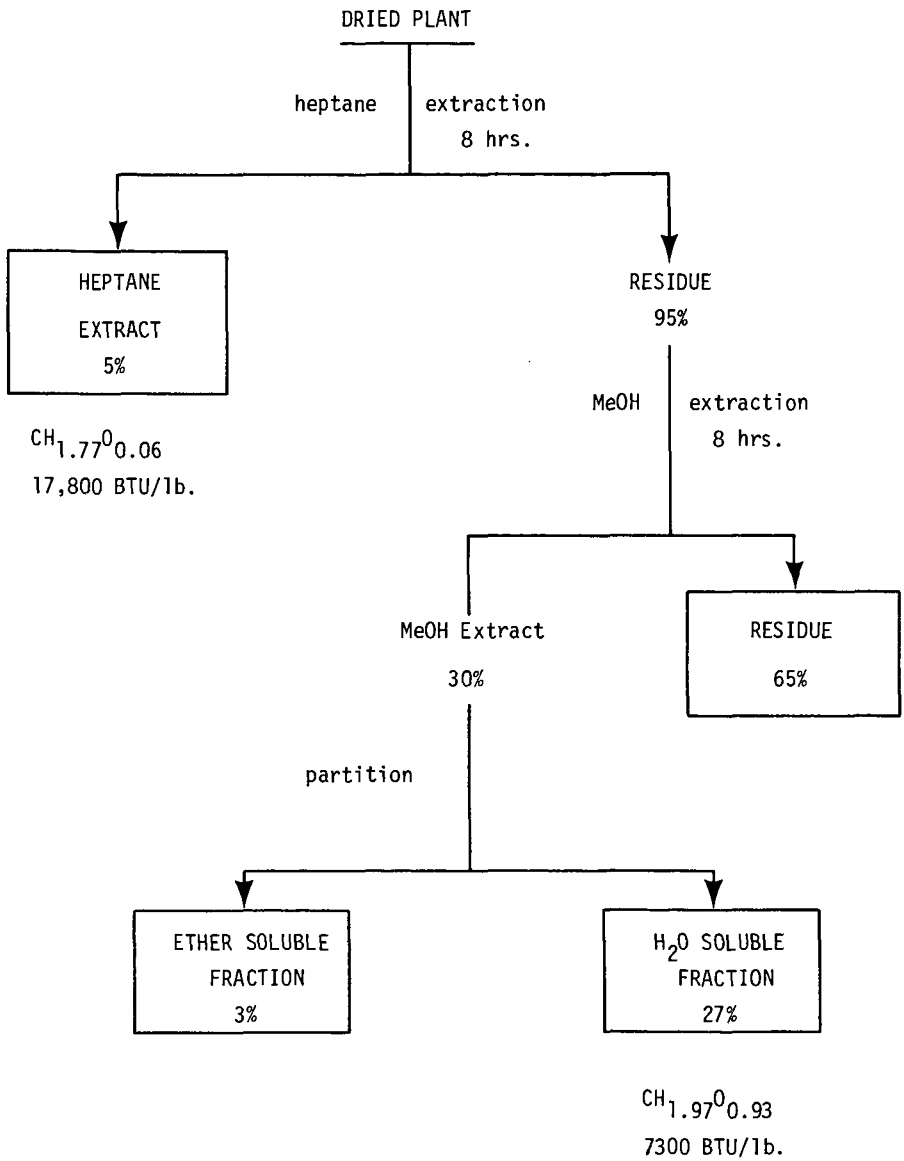
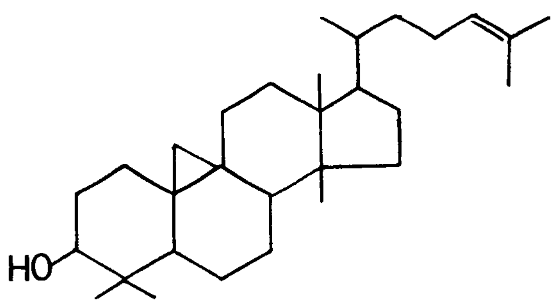
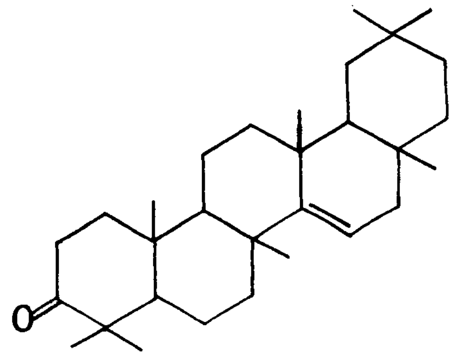


FIGURE 2.



CYCLOARTENOL



TARAXERONE