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METHANOL PRODUCTION FROM EUCALYPTUS WOOD CHIPS

Final Report

June 1982

Prepared by
Biomass Energy Systems, Inc.
Lakeland, Florida

For the
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DISCLAIMER

Principal Investigator:
Henry H. Fishkind

April 1982

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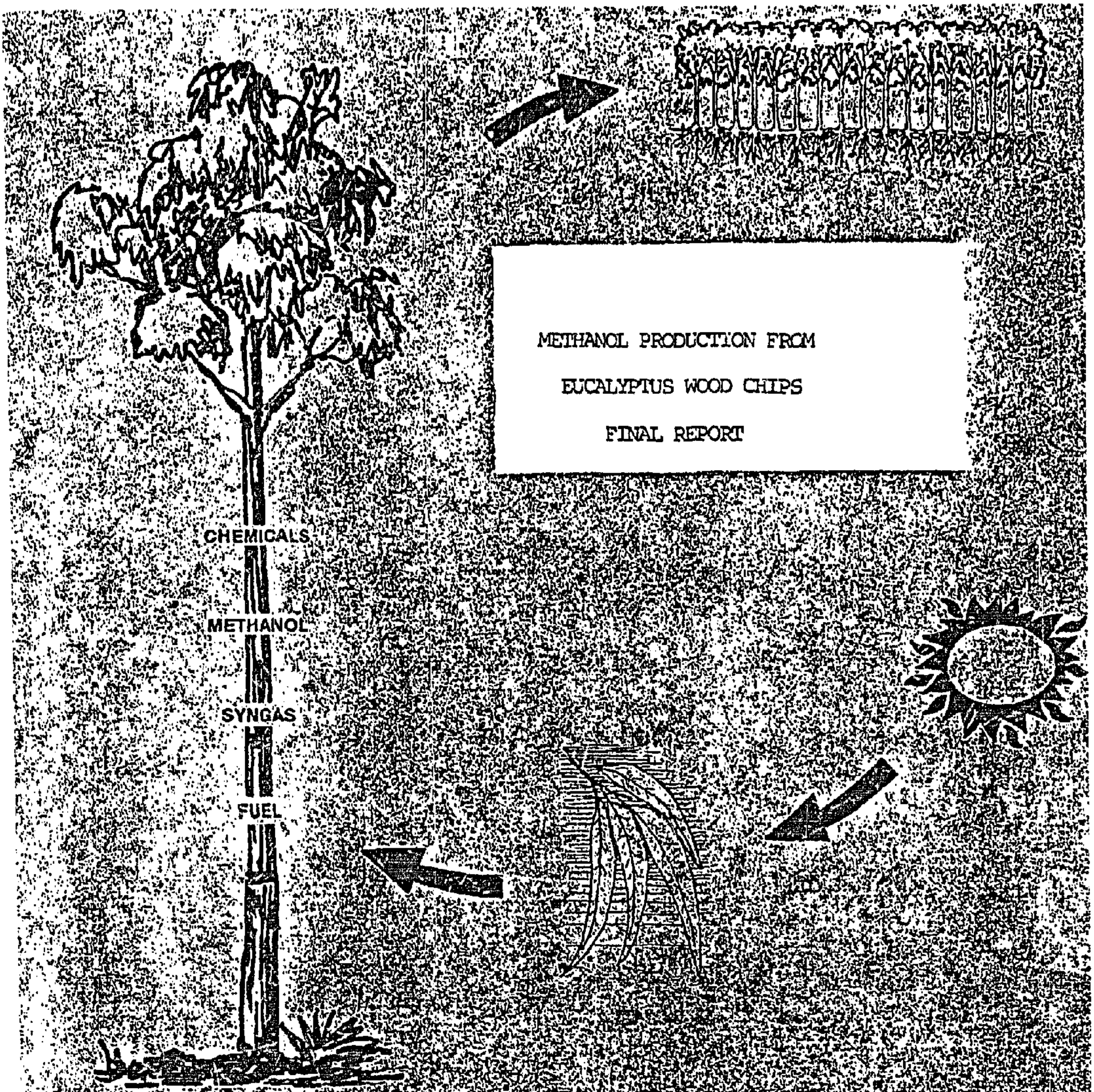

BIOMASS ENERGY SYSTEMS INC.
1337 GARY RD. LAKELAND, FL (813) 688-2868

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A number of individuals participated in the preparation of Biomass Energy Systems' feasibility study of production methanol from Eucalyptus in Central Florida. Dr. George Cornwell, President of Biomass Energy Systems, Inc. (BESI), guided the project from its inception. In addition, he directed all of the environmental and silvicultural work. Mark Moorman, BESI's forester, did the research for the silvicultural report. Mark Schiller, our technical facilitator, worked in the field and tissue culture lab. Tom Levin researched the environmental areas. Neil Sipe and Donna Kalch helped with the economic research. Cynthia Smith researched a range of issues and edited the final reports. Finally, Dr. Gary Howland was responsible for the tissue culture work and made a substantial contribution not only to this project, but to the field of tissue culturing Eucalypts.

Terri Bode handled the administrative details and typed innumerable drafts. Dot Evans did the final typing on most of the reports.

Finally, particular thanks are in order to Mr. Keith Jones, our technical advisor.

Henry H. Fishkind
June, 1982

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1.0 Introduction

Pursuant to DOE grant number: DE-FG07-80RA-50316, "Methanol from Eucalyptus Wood Chips," Biomass Energy Systems, Inc. (BESI) has conducted a detailed feasibility study of production methanol from Eucalyptus in Central Florida. The feasibility study, which is summarized in this document, includes nine other documents:

Document number	Title
1	The Florida Eucalyptus Energy Farm - Silvicultural Methods and Considerations
2	Vegetative Propagation of Eucalypts
3	Florida's Eucalyptus Energy Farm and Methanol Refinery - The Background Environment
4	Health and Safety Aspects of the Florida Eucalypt Biomass to Methanol System
5	Florida's Eucalyptus Energy Farm and Methanol Refinery - Environmental Impact Assessment
6	The Florida Eucalyptus Energy Farm Interface with Natural EcoSystems
7	Feasibility Study Eucalyptus to 1000 STPD Methanol Plan in South Central Florida - Davy McKee Corp.'s Final Engineering Report
8	The Wood-fueled Gasification System - Evergreen Energy Corp.'s Final Engineering Report
9	The Florida Eucalyptus Energy Farm and Methanol Refinery - The Economic Analysis
Final Report	The Florida Eucalyptus Energy Farm and Methanol Refinery - Final Summary Report

This feasibility study is an all encompassing, site specific analysis. All phases of methanol production are examined—from seedling to delivery of finished methanol. The study examines: (1) production of 55 million, high quality, Eucalyptus seedlings through tissue culture; (2) establishment of a Eucalyptus energy plantation on approximately 70,000 acres; (3) engineering for a 100 million gallon-per-day methanol production facility; (4) potential environmental impacts of the whole project; (5) safety and health aspects of producing and using methanol; and (6) development of site specific cost estimates.

1.1 Project overview

The project is designed to produce 100 million gallons per year of fuel grade methanol (1,000 tons per day). The methanol will be marketed to major oil refining firms for use as an octane enhancer and fuel extender or it will be sold to bulk dealers for direct use as fuel for fleet use. Methanol will be produced in central Florida from Eucalyptus wood. The technology for producing methanol from wood is well known and involves: (1) gasification of wood, (2) clean-up and reforming of the resulting gas, and (3) catalytic conversion to methanol. This process along with two preliminary engineering designs are examined in engineering reports by Evergreen Energy Corporation (Working Document No. 8) and Davy-McKee, Incorporated (Working Document No. 7).

To produce 1,000 tons of methanol per day will require approximately 4,000 tons of Eucalyptus per day (green). This wood will be produced in a large Eucalyptus energy plantation which is described in Working Document 1: The Florida Eucalyptus Energy Farm—Silvicultural Methods and Practices. Eucalyptus seedlings will be produced via tissue culture as discussed in Working Document 2: Vegetative Propagation of Eucalypts.

Figure 1 provides a schematic of the methanol from Eucalyptus project.

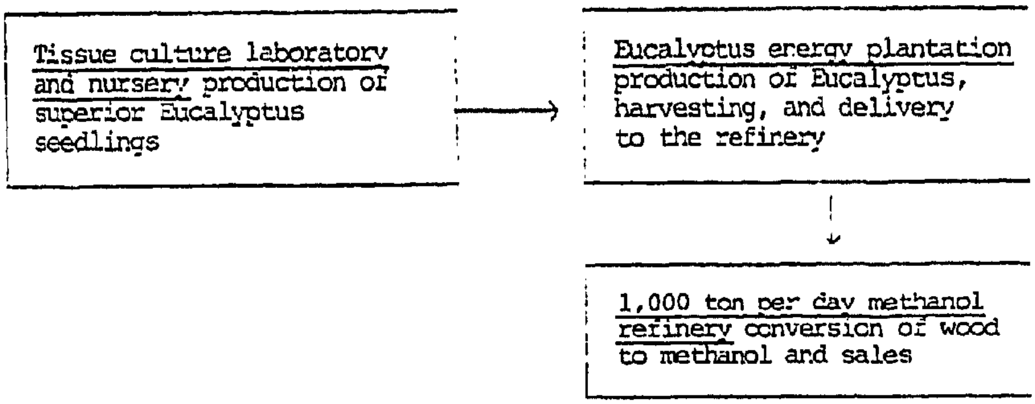


Figure 1.—Methanol from Eucalyptus

1.2 Market environment

Forecasts that energy prices will rise more rapidly than inflation over the next 20 years come as no surprise. Table 1 presents recent projections by the U.S. Department of Energy (1982). Oil prices are projected to increase throughout the period. In 1980 dollars (to abstract from general inflation) oil prices will increase from $34 per barrel to $67 per barrel by 1995. Thus, oil prices are forecast to rise faster than inflation, posting a compound real growth of 4.6 percent.

Continued real increases in world oil prices have set in motion many gradual but significant economic changes. The stock of energy using capital in the economy is being slowly converted or replaced by more energy efficient capital. In addition, fuel switching away from costly oil to less expensive alternative fuels like coal is taking place. These trends are expected to continue throughout the next 15 years. Thus, under the pressure of steadily rising energy prices the growth in U.S. oil consumption is forecast to fall. This is a stark contrast to the 1950s, 1960s, and 1970s.

Gasoline prices will also rise significantly over the next 15 years posting a real growth of 4 percent-per-year. In response, gasoline consumption is forecast to fall from 276.2 million gallons-per-day in 1980 to 190.7 million gallons-per-day by 1995. Four factors account for this decrease. First, fuel efficiency is forecast to increase substantially. The fleet average miles-per-gallon is expected to jump from 14.2 in 1980 to 26.8 by 1995. Second, the transportation sector is slated to grow more slowly over the next 15 years. Growth in the number of registered vehicles and miles traveled will slow significantly as fuel costs rise. Third, higher gasoline prices will prompt greater use of diesel-powered vehicles. Finally, rising gasoline prices will foster the development of methanol fuels (U.S. Department of Energy, 1981, pp. 42, 94-95).

As a result, the transportation sector will absorb a declining share of the nation's total energy consumption throughout the 1980-1995 period. This reverses the trend begun in 1965 when transportation energy use began growing faster than overall energy consumption. Even so, the transportation sector will still consume the lion's share of U.S. petroleum. Its absorption of oil will increase from 53 percent of the total in 1979 to 56 percent by 1995. Thus, while other sectors can locate suitable substitutes for oil based fuels, transportation can not. (U.S. Department of Energy, 1982, pp. 39).

The Department of Energy's forecasts for 2000 and 2020 do not display any sharp breaks with the trends expected for 1980-1995. In general, the adjustments to ever-more-scarce and ever-more-costly oil which began in the mid-1970s will continue through 2020. Future domestic supplies of oil and gas will be higher than if a lower price were to prevail, but their supplies are forecast to dwindle after 2000. Higher prices for oil and gas will encourage the use of alternative fuels, particularly coal, and spur continued energy conservation (U.S. Department of Energy, 1982, pp. 103-104).

One striking feature of the Department's forecast is the rapid expansion in consumption of synthetic liquid fuels such as methanol The basic factors which promote the rapid development of a synthetic liquid fuels industry include: continued dependence on liquid fuels for transportation, the absence of other economically viable substitutes for transportation, the assumption of rapidly rising world oil prices, and the continued depletion of U.S. oil reserves. By 1990 the Department forecasts methanol demand for fuel purposes will exceed 7 million tons and may rise to nearly 15 million tons by 1995 (U.S. Department of Energy, 1980, pp. 94 and 165).

This study evaluates one pathway by which methanol fuel can be produced to service the automotive fuel market. We report on the feasibility of producing methanol from Eucalyptus wood chips in Central Florida. The project is a comprehensive one, and it includes all phases of production from seedling to delivery of methanol. Section 2 examines the future market for methanol fuel and projects future methanol prices. Section 3 describes the steps involved in producing methanol from Eucalyptus in Central Florida. The concept involves a grass-roots, nearly self-sufficient, facility. A detailed financial feasibility analysis is included. Section 4 evaluates the potential environmental impediments to the project, and Section 5 presents our conclusions.

Table 1.—Selected U.S. energy prices and demand, 1980-1995
(in 1980 dollars)

	1980	1985	1990	1995
Oil				
Price per barrel	$34.00	$33.00	$49.00	$67.00
Millions of barrels per day	17.0	16.6	15.7	15.8
Gasoline				
Price per gallon	$1.22	$1.37	$1.75	$2.20
Millions of gallons per day	276.2	NA	NA	190.7

NA Not available.
Source: U.S. Department of Energy (1982), pp. xvi, xx, 42, 44.

2.0 The methanol market 1985 and beyond

For methanol to develop as a fuel it will have to compete successfully against petroleum based fuels, especially gasoline. To penetrate the fuel market, methanol will have to represent a real savings to the consumer after all relevant costs are considered including delivery, conversion and efficiency in use.

Since methanol is not used as a fuel in any significant quantities at this time, an established fuel methanol market does not exist. Thus, the price for fuel methanol is unknown. However, the price of chemical grade methanol can be used as a point of departure. At present, posted prices for methanol on the Gulf Coast is 71¢ per gallon (Alcohol Week, April 19, 1982, pp. 4).

Another point of departure for pricing methanol as a fuel is to compare its price to gasoline. Since methanol contains roughly half the heating value of gasoline, one might expect the price of methanol to be approximately one-half that of gasoline. This is at best a rough lower limit to methanol's value or price as a fuel for two major reasons. First, methanol has a higher octane rating than gasoline, and methanol is particularly useful as an octane enhancer. Second, simple BTU comparisons ignore operating efficiencies, conversion costs, and emissions. These factors can be crucial. For example, a gallon of fuel oil has a higher BTU content than a gallon of gasoline, but gasoline sells for more in the market.

With this background, the best approach to establishing a forecast for methanol is to assess the price at which methanol can penetrate the automotive fuel market.

As Bentz, et al. (1980, pp. 111) point out, the automobile transportation market is composed of a number of distinct sub-markets including: dedicated fleets (government, business, etc.), diesel powered vehicles, and gasoline powered personal vehicles. The key markets for methanol fuel are fleets and personal vehicles powered by gasoline.

As noted above the potential penetration of methanol depends upon (1) its price relative to gasoline, (2) assured supplies of methanol, (3) distribution, (4) the capacity for utilizing methanol effectively, and (5) regulations. In this section we address only the first of these questions. Section 3 describes how methanol will be produced from wood and shipped to market. In addition, Section 3 also evaluates the competitive status of methanol. Section 4 examines environmental concerns and government regulation.

Methanol can be used in two ways as an automotive fuel. First, methanol can be used as a fuel substitute. Neat or 100 percent (plus slight impurities) methanol powered vehicles have existed for some time. Second, methanol can be used as a blending agent with gasoline. Each of these two routes to methanol fuel use has quite different implications. For example, blends of up to 10 percent methanol can be used in today's autos raising the octane rating of the fuel and extending the supply of gasoline. By contrast, the use of neat methanol requires some significant engine and carburetor modifications, but offers the reward of greater economy and improved performance. Due to these differences in potential methanol fuel use, different automotive market segments will have different penetrations.

There are numerous studies of the market for methanol as a blending agent with gasoline. Table 2 displays a sampling of the forecasts from these studies.

Although the forecasts appear to differ significantly, they have the following common characteristics. First, extensive methanol blending is expected to occur after 1990 when supplies of methanol are assured. Second, subject to the concerns over distribution and utilization discussed below, methanol blends will not encounter any technological barriers. Finally, the three studies concur that limits on the availability of fuel methanol restrict its use as a blending agent. Thus, the widely different forecasts for methanol use as a blending agent are the result of widely different projections of methanol supply levels and not due to different views about methanol demand.

Bentz, et al. (1980, p. 117) notes that an additional important demand for methanol as a blending agent was ignored by all three of these studies—its use as an octane enhancer in the form of MTBE (methyl terta-butyl ether). MTBF is an important octane enhancing additive for unleaded gas. MTBE is mixed with unleaded gasoline in concentrations of 3 to 5 percent. Since methanol is a major ingredient in MTBE (up to 50 percent by weight), a significant proportion of methanol can enter the gasoline market as MTBE.

Table 2.—Forecasts of the potential market for methanol fuel in automobile gasoline blends

(10^6 barrel/year)

Market study	1980	1985	1990	1995	2000
Total U.S. projected gasoline demand on an annual basis[1]	2,810.5	2,409.0	2,007.5	1,788.5	1,679.0
Frost and Sullivan[2]	—	—	6.3	10.0	16.6
Badger[2]	—	—	0.8–5.0	0.9–8.0	0.9–8.5
Collieries[3]	—	—	59.5	95.2	157.1

Sources: [1]U.S. Department of Energy (1980), pp. 42.

[2]Bentz, et al. (1980), pp. 115.

[3]Collieries Management Corp. (1980), pp. 93.

To penetrate this market methanol will have to be competitive with wholesale gasoline prices at the mixing point. Our survey of major oil companies (discussed below) confirmed this and identified the mixing point as the refinery. Oil companies conceptualize the blending of methanol as a refinery process for two main reasons. First, by mixing at the refinery the oil company can tailor the resulting blend properly. Since gasoline is a mixture of hydrocarbons, the refinery run must be tailored to mesh with methanol blending. Otherwise excessive evaporative emissions can result (this issue will be discussed at greater length in Section 4.) Second, by mixing at the refinery companies can make use of their existing distribution systems.

In light of the conditions for methanol to penetrate the gasoline market as a blending agent, it must be priced to be competitive with wholesale gasoline prices at the refinery gate. Table 3 contains the U.S. Department of Energy's latest forecast for gasoline prices. Unfortunately these are retail prices and not wholesale prices. Thus, we must determine the relationships between wholesale and retail gasoline prices from 1980 to 1995. Fortunately Collieries Management Corp. (1980, p. 145) has analyzed the cost of transporting and distributing gasoline and methanol. Their research indicates that the ratio of wholesale-to-retail gasoline prices will be between 0.763 and 0.776 from 1980 to 2000. Table 4 presents a forecast for wholesale gasoline prices based on these figures.

Table 3.—Oil and gasoline, 1980-1995
(1980 dollars)

	1980	1985	1990	1995
Oil				
Price per barrel	$34.00	$33.00	$49.00	$67.00
Millions of barrels per day	17.0	16.6	15.7	15.8
Gasoline				
Price per barrel	$1.22	$1.37	$1.75	$2.20
Millions of gallons per day	276.2	NA	NA	190.7

Source: Energy Information Administration, U.S. Department of Energy, 1981 Annual Report to Congress, Vol. 3, February, 1982, pp. xvi, xx, 42, and 44.

Table 4.—Forecasts of wholesale gasoline prices at the refinery gate
(1980 dollars)

	1980	1985	1990	1995
Retail gasoline price per gallon[1]	$1.22	$1.37	$1.75	$2.20
Ratio of wholesale-to-retail price[2]	0.757	0.763	0.769	0.776
Wholesale price per gallon	$0.92	$1.05	$1.35	$1.71

Sources: [1]Table 2.4.

[2]Collieries Management Corporation, *op. cit*, p. 145.

To be a viable blending agent methanol will have to be priced at or below \$1.05 per gallon in 1985 (using deflated 1980 dollars) and at or below \$1.71 in 1995. These prices will have to include shipping and handling costs to a refinery where blending will take place according to the current thinking of the petroleum companies.

The potential use of methanol as a gasoline blending agent and octane enhancer is not the sole path by which methanol can penetrate the automotive fuel market. Methanol can also be used as a pure fuel in so-called neat (fuel grade) form.

Neat use of methanol differs substantially from the use of blends as a gasoline substitute.. Significant engine modifications are required to take advantage of methanol's high-octane value and superior conversion efficiency while at the same time over coming methanol's disadvantages of hard starting and vapor lock. However, neat methanol is already in use as a fuel for race cars, and neat methanol is being actively tested as a fuel for fleet vehicles. Thus, the technological problems of burning neat methanol in automobile engines has been solved already, no new technology is needed.

Since use of neat methanol requires significant modifications in engines and carburetors and because neat methanol fuel is not widely available, the use of neat methanol will be restricted to dedicated fleets. Fleet use also simplifies the distribution and handling of methanol fuel and insures a supply of neat fuel.

Two recent analysis of the market potential for neat methanol fuel were very optimistic. Bentz, et al. (1980, pp. 118-124) and Collieries Management Corp. (1980, pp. 93-95) concur that neat methanol will be used extensively in fleet operations between 1990 and 2000 because of its cost effectiveness. Each study indicates that the market will be limited by the availability of methanol fuel. Table 5 displays forecasts for neat methanol from Bentz, *et al.* (1980) and Collieries Management Corp. (1980).

Table 5.—Potential market for the use of neat methanol (millions of barrels of methanol per year)

	1985	1990	1995	2000
Frost and Sullivan[1]	—	25.0	340.0	600.0
Badger[1]	—	—	46.8-58.5	104.2-130.2
National Transportation Policy Study Commission[1]	67.8	123.6	160.3	188.8
Collieries[2]	—	28.8	345.2	607.0

Sources: [1]Bentz, *et al.* (1980, pp. 119).

[2]Collieries Management Corp. (1980, pp. 94-95).

Two facts are noteworthy about the forecasts for neat methanol use in Table 5. First, the total neat methanol market appears to be quite large—far greater than the market for methanol-gasoline blends. Second, the forecasts are constrained by limits on the supply of methanol not the demand.

All of this, however, begs the question of the price required to insure that the market penetration forecasts for neat methanol shown in Table 5 come to pass. A recent detailed case study involving a small neat methanol fleet owned by Bank of America sheds light on this crucial question. Bentz, *et al.* (1980, pp. 121-123) report on the success of neat fuels in Bank of America's fleet test. Bank of America's program involves a test fleet of 58 vehicles using both blended fuels and neat methanol. No significant problems with maintenance or operation has been identified. Table 6 compares the economics of gasoline and net methanol vehicles in Bank of America's fleet.

Table 6.—Summary of the economics of neat methanol vs. gasoline in Bank of America's fleet test

Data

Delivered cost of gasoline	$1.23/gallon
Delivered cost of methanol	$0.88/gallon
MPG gasoline vehicles	16-18
MPG methanol vehicles	13.7-14.0
Capital cost to retrofit gasoline-fired vehicle to neat methanol	$750.00
Average lifetime vehicle miles	100,000
Differences in other operating or maintenance costs	$0.00

Calculations

Lifetime operating costs:	Gasoline vehicles	Methanol vehicles
Capital cost of conversion per (lifetime) miles	$0.00/mile	$0.0075/mile
Fuel cost per mile	$0.072-$0.077/mile	$0.063-$0.068/mile
Total cost per mile	$0.072-$0.077/mile	$0.071-$0.076/mile

Table 7.—Methanol prices 1985-2020
(dollars per gallon)

	1985	1990	1995	2000	2005	2010	2015	2020
Gasoline[1]	2.00	3.00	4.98	8.20	13.51	20.14	36.66	54.66
Methanol								
Base case[2]	1.00	1.50	2.49	4.10	6.75	8.85	13.29	17.41
Low case[3]	0.90	1.17	1.56	2.18	3.05	4.28	6.01	7.88
High case[4]	1.10	1.65	2.74	4.51	7.43	9.92	15.31	20.45

Sources: [1]Energy Infomation Agency, U.S. Department of Energy (1982), adusted by inflation rate for gasoline from Chase Econmetrics long-term forecast of October, 1981.

[2]From 1982 to 2000—50 percent of gasoline; from 2000-2020—8 percent-per-year increase.

[3]From 1982 to 1985—45 percent of gasoline price; from 1985 to 2000—45 percent of gasoline prices - $0.05 to $0.10 per year.

[4]From 1982 to 2000—55 percent of gasoline price; from 2000 to 2020—85 percent-per-year increase.

Although methanol has a lower BTU value per gallon than gasoline, its lower price and greater efficiency give it an operating cost advantage over gasoline as a motor fuel. Fuel costs per mile ranged from $0.072 to $0.077 for gasoline vehicles compared to $0.063 to $0.068 for methanol powered vehicles. Against this saving are charges for engine and carburetor conversions costing $750 per vehicle. Assuming an average vehicle life of 100,000 miles, this translates into an extra charge of $0.0075 per mile for the methanol vehicles. The total operating costs for the methanol vehicle were essentially identical to that for the gasoline vehicle at then current fuel costs. This suggests that methanol is competitive with gasoline for use in fleets when its price is no higher than 71.5 percent of the price of gasoline.

This lengthy analysis indicates that between 1990 and 2000 the demand for methanol fuel will grow rapidly. In particular methanol will be a very attractive fuel for fleet use, and methanol will also be competitive as a blending agent directly or indirectly through the additive MTBE. However, all of this analysis was macroeconomic or general in nature. No specific methanol buyers were identified. Since there will not be much, if any, methanol fuel supplied prior to 1990, the identification of customers is difficult, if not impossible.

Even so, we thought it would be helpful to contact the major oil companies to gauge their potential interest in methanol as a blending agent or as neat fuel. To this end we contacted most of the major domestic oil companies through their fuel supply or planning divisions. In general terms, this extensive set of phone interviews confirmed our macro analysis of the methanol fuel market d scribed above. Most firms expressed some interest in purchasing methanol if it were: (1) of high quality and (2) priced competitively with wholesale gasoline prices when delivered to their refinery's gate. However, most firms found it difficult to be more definitive about such long range planning for a new fuel component such as methanol.

However, two firms expressed strong interest in methanol and each expected to use over 100 million gallons-per-year after 1990.

The conclusions we can draw from this discussion are as follows:

(1) Methanol can penetrate the automobile fuel market as a blending agent when it is priced at or below wholesale gasoline prices, or equivalently when methanol is priced at or below 76 percent of the price or retail gasoline.

(2) Methanol is competitive with gasoline in fleet applications when it is priced at or below 71.5 percent of retail gasoline.

(3) If methanol is appropriately priced, it can penetrate a huge market on the order of 800 to 2,400 million gallons-per-year by 2000 (see Table 5).

The price ratios shown above represent the highest price ratio at which methanol can be competitive. Competition among methanol suppliers by 1990 is likely to drive the price significantly lower. To accommodate this likelihood we developed the three methanol price scenarios in Table 7. The future price of gasoline is the guiding mechanism, and we took the DOE's latest estimates (1982). Since the DOE's estimates were in 1980 dollars we adjusted for the effects of inflation by utilizing Chase Econometrics (1981) long-term forecast for inflation. The Chase forecast was used both because it is a good professional forecast and it is the forecast used by the DOE itself. By this measure, gasoline prices will grow at a compound rate of 10 percent per year through 2020.

Three price profiles for methanol were developed. The base case assumes that between 1982 and 2000 methanol will be prices at 50 percent of gasoline. Thereafter, methanol prices increase by 8 percent-per-year. The low price alternative foresees methanol prices at 45 percent of gasoline prices from 1982 to 1985. Between 1985 and 2000 methanol supplies will increase substantially holding price rises below the 45 percent-of-gasoline price level. After 2000 methanol prices rise 7 percent-per-year. The high price alternative envisions methanol priced at 55 percent of gasoline until 2000. Thereafter methanol's price rises 8.5 percent per year.

2.1 Methanol supplies - 1985 and beyond

At the present time methanol is not used as a fuel. However, methanol is an important chemical feedstock used in a variety of applications. Thus, methanol is produced primarily by chemical firms, and much of this production is for their own internal uses.

The domestic production capacity is 17,260 tons per day. Realistically, these plants can produce 15,000 to 15,500 tons per day (1.7 billion gallons-per-year). Since domestic consumption of methanol is expected to be in the 13,000 to 14,000 ton-per-day range and exports of up to 1,000 tons are expected during the early 1980s, the market for chemical grade methanol appears to be in balance (Collieries, 1980, pp. 20-34).

The typical methanol plant contains one or two methanol synthesis trains (at 1,000 to 1,500 tons-per-day). Natural gas is the predominant feedstock. Capital costs for the typical plant are on the order of $0.50 per annual gallon of capacity. Today a plant operating on natural gas would cost about $1.40 per annual gallon of capacity. To produce methanol from feedstocks like oil, coal, or wood requires a more elaborate plant which costs more to build and operate (Collieries, 1980, pp. 20-34).

In the near-term methanol production will rise. First, the near-term outlook for demand is positive, and demand is forecast to rise by nearly 10 percent-per-year between 1980 and 1985 reaching somewhere between 5.4 and 6.3 million tons by 1985 with little or no demand for methanol as a fuel (Chemical Week (1980), pp. 24; Chemical and Engineering News (1980), pp. 16; Encyclopedia of Chemical Technology (1981), pp. 413).

Second producers are planning some expansions. Getty oil is planning to open a 150 million gallon-per-year (1,350 tons-per-day) facility in Delaware City, Delaware and a consortium of firms plans a 200 million gallon-per-year (1,800 tons-per-day) facility in Louisiana in 1983-1985 (Bentz, et al., pp. 106).

If these plants come on line as planned annual procution capacity potentially could rise to 6.7 million tons-per-year assuming: (1) none of the existing plants are retired and (2) a 90 percent operating rate. However, a number of the existing plants are old and small. Thus, if some of the existing plants do close and the demand forecasts turn out to be accurate, imports of methanol may have to rise. In any event, the domestic methanol market will be tight (Collieries, 1980, pp. 28-30). Thus, if methanol does become an attractive automotive fuel--which it is likely to be the case by 1990, there will have to be a rapid increase in methanol production capacity.

3.0 Methanol from Eucalyptus wood chips

3.1 Overview

The BESI concept for producing methanol from Eucalyptus involves three types of operations: (1)a tissue culture laboratory and nursery to provide the over 50 million seedlings needed for the planting program, (2) a 70,000 acre Eucalyptus energy plantation to produce the 1.3 million tons of wood per year required for the methanol production facility, and (3) a 100 million gallon-per-year (1,000 ton per day) methanol production facility. The BESI project can be characterized as a vertically integrated methanol production program based on a renewable feedstock, Eucalyptus wood.

The project is to be located in Central Florida (Southwestern Polk County) on lands previously strip mined for phosphate. Central Florida is an optimum site for a Eucalyptus-to-methanol facility for a number of reasons. First Eucalyptus grow prolifically on the Central Florida climate and soils, and the trees thrive on the sites of old phosphate mines (more on this below). Second, the Central Florida location offers substantial opportunities for acquiring the 70,000 acres needed for the Eucalyptus energy plantation, methanol production facility, and tissue culture lab. Third, the Central Florida region possess substantial water resources which can be used. Fourth, land in the area is reasonably priced. Research indicates that a site could be readily assembled at around $750 per acre. Finally, since the region is also the location of Florida's phosphate mining industry (which is now largely south of the site for the Eucalyptus-to-methanol facility), extensive infrastructure for moving materials is already in place. Rail, truck, and barge transportation is readily available.

3.2 Macroeconomic assumptions

Assumptions about macroeconomic trends (prices, interest rates, output, etc.) form the under pinning for all forecasts used in this study. For example, projections for future prices and availability of gasoline in the U.S. depend upon world oil prices and domestic economic conditions. Forecasts of future energy prices are a crucial input for this study, and we used forecasts developed by the U.S. Department of Energy extensively in Sections 2 and 3 of this study. The DOE in turn based its energy forecasts on a long-run macroeconomic forecast developed by Chase Econometrics.

Table 8 summarizes the Chase forecast for 1980-1995 and extrapolates the forecast to 2020. Although the Chase forecast contains cyclical episodes, these are obscured by the averaging process used in Table 8.

Over the entire forecast period from 1980-1995 Chase projects moderate economic growth at 2.7 percent-per-year measured by growth in real GNP. The growth rate slows toward the end of the period, and when it is extrapolated to 2020, the average growth for 1995 to 2020 is 2.6 percent. The Chase forecast envisions particular strength in the manufacturing sector over the forecast horizon. Here growth accelerates from the 3.3 percent rate posted from 1970 to 1980 to a 4.3 percent average in the 19780-1995 interval. Extrapolating out to 2020 the series grows at an average annual rate of 4.2 percent. Throughout the forecast period Chase expects the relative size of the government sector to shrink while manufacturing growth is spurred by higher levels of investment.

Real per capita income will post annual average gains of 2 percent-per-year through 2020. While this represents a marked improvement compared to 1979-1982, it is somewhat below average compared to 1970-1980. Inflation is projected to slow throughout the period. The pace of general price inflation will decline from almost 7 percent in 1970-1980 to 6 percent in 1995-2020. The deceleration of prices is even more apparent in the series on prices for nonresidential investments. After the rapid 7.7 percent average increase experienced during the 1970s, inflation in the price of investment goods should slow to an average of 5.5 percent between 1995 and 2020.

The first few years of the 1980s have witnessed unprecedented peaks in interest rates. Lately rates have moved down from their peaks, but they are still very high by historical standards. Chase forecasts that rates will decline to the 10 percent range by 1988. However, this implies an average AA bond rate of 12.5 percent and a prime rate of 12.8 percent for the 1980-1995 interval.

These forecasted values are important inputs to the financial analyses presented below. In addition, by using the same national forecast as DOE used, the underlying assumptions for our analysis are identical to those used by DOE in forecasting energy prices.

Table 8.—General macroeconomic assumptions for selected economic variables

(growth rates per year, percent unless otherwise stated)

	1970-1980[1]	1980-1995[2]	1995-2020[3]
Real gross national product	3.2	2.7	2.6
Real industrial production, manufacturing	3.3	4.3	4.2
Real per capita disposable income	2.2	2.0	2.0
GNP price deflator	6.9	6.7	6.0
Price deflator for nonresidential investment	7.7	6.9	5.5
Population	0.8	0.9	0.8
AA bond rate	8.9	12.5	10.0
Prime rate	8.7	12.8	10.0

Sources: [1]Citibase: Citibank economic database.

[2]Chase Econometrics, Inc., Long-Term Macroeconomic Forecasts and Analysis, October 6, 1981 as reported in Energy Information Administration (1982), pp. xiii.

[3]Extrapolation.

3.3 Tissue culture lab and nursery

The tissue culture lab and nursery complex is described in Working Document No. 2, Vegetative Propagation of Eucalypts. The lab and nursery are designed to provide sufficient, high quality, Eucalyptus seedlings for BESI's extensive planting program. Commercial application of tissue culturing in vitro involves four distinct stages: (1) establishment of select plant materials in a bacteria-free culture, (2) multiplication of plant materials, (3) rooting of the propagules, and (4) acclimation of the propagules to nursery conditions. As part of this research BESI has successfully tissue cultured Eucalypts from select mother trees growing in Central Florida. This exercise not only proves that Eucalypts can be successfully reproduced by tissue culturing, but it also establishes a firm basis for costing out the process.

The biomass production of a eucalypt energy plantation, envisioned for this project, is dependent in part upon a combination of environmental factors, including soil structure and fertility, average sunlight and temperature, precipitation quantity and distribution, vegetative competition, and pathogen impact; but the average genetic quality of the trees is the single most influential factor determining growth potential. The genetic system of Eucalyptus is such that native seed populations include a diversity of genetic types—and consequently, a wide range of environmental adaptability within the species. This diversity is beneficial in providing families adapted to a particular environmental niche (e.g., phosphate mine spoils, native flatwoods soils, high-salt soils). However, it is very difficult to capture desirable genotypes for seedling production. Eucalypts show pronounced "hybrid vigor"; and, conversely, suffer tremendous "inbreeding depression" when seed results from self-pollination (Eldridge, 1978). Commercially available seed is genetically heterogeneous. Planting stock produced from it will invariably yield "aces and spaces" (E. C. Franklin, Pers. Comm.). That is there will be come very good trees and some that do not survive.

This kind of performance is not acceptable for an energy plantation. Instead what is needed is a uniform stand of vigorously growing trees. This alternative can be accomplished by selected a series of genetically superior trees from a seedling plantation or natural stand, these genotypes are vegetatively propagated, field-tested and then expanded to provide a uniformly high-yielding planting stock. This task is facilitated by the location of two significant stands of Eucalyptus Camaldulensis growing on restored phosphate mine lands in Central Florida. BESI has selected the best of these trees for "mother trees" in the clonal seedling program.

As part of the present study, we have examined the feasibility of large-scale plantation establishment by various methods, and have reached the following conclusions.

1. Seedling plantations are limited in potential yield due to genetic variation among the planting stock and often inadequate supplies of appropriate seed.
2. Vegetative propagation by rooted cuttings can provided good genetic uniformity of select hybrid planting stock; however, large-scale production requires establishment and maintenance of extensive cutting orchards. The collection of shoots and preparation of cuttings, although successfully implemented in

the Congo and Brazil, would not be economically feasible in Florida for large-scale plantations.

3. Tissue culture propagation of select hybrid eucalypts offers the only opportunity to produce the very large number of trees required to establish the energy plantation. The cost of tissue culture propagation, although higher than seedling production, is more than off-set by the increased productivity of vegetative plantations established from select hybrid Eucalyptus (Working Document No. 2, 1982, pp. 2).

Working Document No. 2, Vegetative Propagation of Eucalypts, describes the process of establishing select field material in culturing, multiplying the cultures, rooting, and acclimating the seedlings to the nursery.

Table 9 outlines the method by which 7.5 million, select, Eucalyptus, seedlings can be produced over the span of 10 months. Stage I of the process involves the establishment of select field material in culture. Although this step is a vital prerequisite to Eucalypt production via culturing, it has little affect on the timing or yield of seedlings. Thus it is not included in Table 9. Stage IIA involves the multiplication of the plant material, and Stage IIB allows the material to elongate and multiply further. At Stage III the culture material develops roots, and Stage IV is acclimating the seedlings to the nursery.

TABLE 9

PRODUCTION OF 7.5-MILLION *Eucalyptus* TREES PER YEAR

Culture Stage	Monthly Activities[1,2]	Months	Growing Space	Personnel[4]
II	468 jars			
	(1 mo) -10%[3]	Oct-Jul		0.4
II	5570 jars + 570 jars			
	(1 mo) -5%		18 m^2 (195 ft^2)	
II	5292 jars			
				2.1
IIB	17,200 jars			
	(0.5 mo) 17,200 jars -5%	Nov-Aug	51 m^2 (550 ft^2)	
IIB	32,682 jars			
				30.0
III	9,800 tins			
	(0.5 mo) 9,800 tins		291 m^2 (3100 ft^2)	32.5 innoculators
	-10%			
			360 m^2 (3845 ft^2) culture room area	
III	17,648 tins			
		Dec-Sep		13.6 greenhouse workers
IV	882,418 plantlets			
	(3 mo) -15%		1280 m^2 (13,770 ft^2)	
			1280 m^2 (13,770 ft^2)	
Nursery	750,055 trees		1280 m^2 (13,770 ft^2)	
		Mar-Dec	3840 m^2 (41,300 ft^2)	
	861 acres		greenhouse area	

Note 1: Production of 750,000 trees/month, ten months per year.
Note 2: Single arrows (⟶), incubation steps, double arrows (⟹) transfer steps.
Note 3: Negative % associated with incubation steps indicate allowances for losses.
Note 4: Personnel figures include no supervisory or support staff.
Source: Working Document No. 2 (1982), pp. 48.

Table 10 provides cost estimates for the tissue culture laboratory and lab equipment developed in Working Document No. 2. In addition, the table shows the major assumptions which influence the estimated cost per seedling.

As noted in Working Document No. 2 the most important variables in determining the cost for tissue-culture propagated seedlings are: (1) multiplication rates, (2) failure rates, and (3) labor costs. Multiplication rates have a dramatic affect on total cost per seedling because the higher the multiplication rate the lower the cost-per-plant for most lab operations. The reverse is true for losses--more losses lead to higher cost per finished seedling. Since labor costs account for over 50 percent of total costs, the affect is obvious on finished seedling costs.

The tissue culture lab and nursery facility (to be rented) are to serve the needs of BESI's planting program exclusively. Thus, the market for superior Eucalyptus seedlings is assured. The seedlings are priced to provide a 20 percent return after taxes.

Table 10.—Data and assumptions for the tissue culture lab and nursery (1982 dollars)

Tissue culture laboratory	$320,000.00
Laboratory equipment	$150,000.00
Tissue culture multiplications rates:	
Stage II a	multiplication 13
State II b	elongation 10
Estimated losses:	
Stage II a multiplication	5%
Stage II b elongation	5%
Stage II rooting	10%
Stage IV nursery growth	15%
Labor costs	$6 per hour
Price per finished seedling	$0.30

Table 11.—Financial analysis—Biomass Energy System, Inc. tissue culture lab and nursery

Assumptions—scenario	Internal rate of return
1. Base case: assumptions as per Table 10, Working Document No. 1, and Chase Econometrics	20.4%
2. Increased losses and lower multiplication rates: losses at each stage are increased by 5 percentage points and multiplication rates at Stage II are reduced by 10 percent	13.2%
3. Improved procedures: elimination of Stage III culture and automation of Stage II cultures	37.3%

Table 11 contains a financial analysis for the tissue culture-nursery operation. Under the base case assumptions outlined in Table 10 and in Working Document No. 2, the internal rate of return for the project is 20.4 percent after taxes. This rate of presumes a 30 cent-per-seedling price and was calculated on a discounted, cash, flow, basis.

As noted in Working Document No. 2, the estimates for cost-per-seedling are quite sensitive to variations in the multiplication and the failure rate. Scenario 2, "increased losses and lower multiplication rates" attempts to capture the downside risk. Here, the loss rates are all increased by 5 percentage points and the Stage II multiplication rates are reduced by 10 percent. Should this set of circumstances transpire, the internal rate of return would fall to 13.2 percent.

There is also significant opportunities for achieving lower costs by automating some Stage II processes and by eliminating the Stage III culture step. The resulting economics push the prospective internal rate of return to 37.3 percent.

Biomass Energy Systems, Inc. has operated a tissue culture lab for over two years now. This practical experience is the foundation for the cost estimates presented in Working Document No. 2 and used in this analysis. In addition, our experience indicates that an expanded tissue culture lab can provide the 7.5 million seedlings needed to support the planting program and be a profit center in its own right.

3.4 Eucalyptus energy plantation

The Eucalyptus energy plantation is the second major component of BESI's Eucalyptus-to-methanol project. Conceptually, this phase of the project takes as its inputs select seedlings from the tissue culture-nursery phase, installs the seedlings, maintains the Eucalyptus plantation, harvests the wood, and delivers it to the methanol refinery. Each of these steps was describe in Working Document No. 1, The Florida Eucalyptus Energy Farm—Silvicultural Methods and Considerations.

BESI has selected Eucalyptus Camaldulensis as the initial species for energy plantation. Camaldulensis has a number of desirable properties for this project. First, Camaldulensis exhibits vigorous growth in central Florida. BESI has studied two stands of Camaldulensis growing on restored phosphate mine land in Central Florida—conditions comparable to those BESI proposes to use. These stands, which were given very little care, show some exceptional growth. Second, the existing Camaldulensis provide a source of select plant material for tissue culturing and clonal production of seedlings. Third, Camaldulensis is known worldwide for its rapid growth, tolerance of adverse conditions, and moderate resistance to freeze damage. Fourth, Camaldulensis has not produced an abundant viable seed crop. This helps to address the environmental concern about the escape of this "exotic." Fifth, the existing Camaldulensis stands have demonstrated a resistance to insects, disease, and fire. Sixth, Camaldulensis achieves its best form under dense stocking, and it does not require extensive management. Finally, Camaldulensis coppices readily—when cut in sprouts back from the stump eliminating the need for replanting (Working Document No. 1, pp. 14-15).

Plantation design will emphasize maximizing biomass production. Seedlings will be planted 5 feet apart in the row with rows spaced 10 feet apart. This design will allow for a stocking density of 871 plants-per-acre. At this density Camaldulensis will exhibit good form, and yet have sufficient room for our short-rotation period of 7 years. The plantation design calls for reasonably long rows to facilitate the use of machinery, and clonal planting blocks of 160 acres each (Working Document No. 1, 1982, pp. 92-96).

Silvicultural practices are designed to maximize rapid initial growth. Research indicates that the first year is the most crucial in terms of ultimate biomass yield at harvest. Site preparation is the key to good biomass yields. Although site preparation may vary somewhat depending on local conditions, the following general prescription applies: (1) heavy discing and chopping coupled with removal of debris if necessary, (2) light discing, (3) soil testing, (4) raking to a smooth level surface if necessary, and (5) bedding in potentially wet sites. Control of vegetative competition is crucial, and herbicides may be used if needed (Working Document No. 1, 1982, pp. 75-78).

Since soil moisture conditions and the lack of frost are crucial to the successful establishment of Eucalypts, planting will not be done in the cold and dry winter months. Planting will be done by machine from Speedling Planters (Working Document No. 1, 1982, pp. 75-98).

Once establishment is insured, a Eucalyptus plantation needs relatively little management. Control of vegetative competition, however, is vital in the early years of the plantation. Proper site preparation should minimize weed competition, and after a year or so the Eucalypts will control the site. So, herbicides may be needed during the first year, and at harvest time. In addition, the plantation must be monitored for fire, insects, and disease. However, Eucalypts are not particularly prone to problems in these regards, and in fact have proven to be very hardy and pest and disease free (Working Document No. 1, 1982, pp. 112-120).

Harvesting will be done using standard logging equipment. Every tree harvesting operation must accomplish four tasks, felling, skidding, yarding, and hauling. Since the rotation period will be 7 years, the plantation grown Eucalypts are projected to be between 6 and 8 inches in diameter, 50 to 70 feet tall, and to weigh around 600 pounds (more on this below). Thus, a standard motorized feller/buncher will be used. Four-wheel drive rubber-tired skidders will move the logs to the end of the rows and assemble them in piles. There the trees will be topped, delimbed, and loaded on to trailers for delivery to the methanol plant. The tops and limbs will be chipped in the field, and the chips will also be brought to the plant (Working Document No. 1, 1982, pp. 121-131).

BESI research (Working Document No. 1, 1982, pp. 133-137) indicates that a 7 year rotation will produce prolific amounts of biomass, 154 green tons per harvest are expected. This yield is equivalent to 11 dry tons per acre per year. This estimate was developed by first examining existing stands of Camaldulensis growing on reclaimed phosphate mine land in central Florida. These stands received little care after planting and select seed was not used. Overall survival rates ranged from 45 percent on the poorest sites to 75 percent on the better sites. Thus, the stands are characterized by wide variation among individual trees which is to be expected. However, the stands also contain a substantial number of superior trees. At 6.3 years the largest tree was 16.4 inches in diameter at breast height, and the tallest tree was 97 feet (Working Document No. 1, 1982, pp. 66-73).

Data from the existing stands of Camaldulensis were extrapolated for our yield estimate of 154 green tons per harvest. We assumed that the average tree would be between 6 and 8 inches in diameter at 7 years, a modest assumption given the number of outstanding individual trees in the stands. Further adjustments included: (1) increasing the planting density to 871 per acre, (2) allowance for a more even stand at 6-8 inches in diameter, at breast height, at 7 years through the use of tissue culture seedlings drawn from superior "mother" trees, (3) improved site preparation and control of vegetative competition, and (4) increased survival to 70 percent.

With this background we turn next to an analysis of the economics of producing Eucalyptus feedstock to service the needs of the methanol production facility. Engineering estimates by Evergreen Energy Corporation (Working Document No. 8, 1982, pp. 4) indicate that the plant will require 1,990 dry tons of Eucalyptus feedstock per day. Since the plant is designed to operate 330 days per year and the Eucalyptus is 50 percent water when cut, feedstock requirements are 1,313,4000 tons per year. If the yield at harvest is 154 green tons per acre at each harvest every 7 years, 8,529 acres must be harvest each year. Allowing for roads, staging areas, and the like (at 15 percent) this requires 9,808 acres for each years feedstock. Over a period of 7 years 68,655 acres in total are needed.

Table 12 lists all of the data and assumptions used in the economic analysis. All of these are described in Working Document No. 1 except the following:

(1) rent and management fees are designed to provide adequate compensation for managing the plantation operation and for paying local taxes (which are minimal on a per acre basis);

(2) the market price for feedstock is designed to provide a 15 percent return after taxes—since the market and price are assured by purchases from the refinery, this return is adequate;

(3) the engineering report by Evergreen Energy Corporation, Working Document No. 8, Wood-Fueled Gasification System, estimates that 1,990 dry tons of wood will be needed each day of operation (330 days per year), at 50 percent moisture this means 330 x 1,990 x 2 = 1,313,400 green tons of wood are needed each year;

(4) approximately 15 percent of the total land available for growing Eucalyptus must be devoted to roads, staging areas, etc.;

(5) the land cost on an acre basis was estimated in Working Document No. 9, The Florida Eucalyptus Energy Farm and Methanol Refinery - the Economic Analysis, Section 4.1 above;

(6) the net corporate tax rate is assumed to be 40 percent to reflect the various write-offs allowed for agricultural operations of this type; and

(7) a mortgage is obtained for the land with a 10 percent down payment at 1 percent above the prime rate.

Based upon these assumptions Table 13 presents the financial analysis. In the base case the plantation provides a 14.7 percent return after taxes. No revenues are generated for the first seven years of operation when land is acquired, trees are planted, and they grow. When the first harvest comes in year 8, substantial net cash inflows commence. Expenses for land acquisition (10 percent down and a 30 year mortgage), planting and management total $92.5 million during the first 7 years of operation. It is assumed that all of these funds are equity capital. To the extent that debt is used in developing the Eucalyptus plantation, the internal rate of return will rise. However, to be conservative we have assumed 100 percent equity financing except for the land.

Table 12.—Data and assumptions for the Eucalyptus energy plantation (1982 dollars)

Cost per seedling	$0.30
Number of seedlings per acre	871
Installation cost per acre	$500.00
Fertilizing and herbicing per acre	$60.00
Survival rate for seedlings	70%-80%
Years to maturity	7
Harvest cost per ton	$10.00
Yield at maturity per acre every 7 years	154 green tons
Fixed cost for property taxes and management per acre	$20.00
Market price of feedstock per green ton	$20.00
Tons of wood required per year	1,313,400
Additional acreage needed for roads, staging areas, etc.	15% of total acreage
Macroeconomic assumptions	Chase Econometrics
Land cost per acre	$750.00
Total net tax rate	40%
Mortgage rate	prime plus 1%

Sources: Working Document No. 1, The Florida Eucalyptus Energy Farm—Silvicultural Methods and Considerations, and Chase Econometrics (1981), op. cit.

Table 13.—Financial analysis—Biomass Energy System, Inc.
Eucalyptus energy plantation

Assumptions—scenario	Internal rate of return
1. Base case: Chase Econometrics, other assumptions BESI	14.7%
2. Low yield: 25 percent less yield to 115.5 green tons per acre per harvest	11.4%
3. High yield: 25 percent more yield to 192.5 green tons per acre per harvest	17.4%
4. Higher inflation: one percent above Chase	15.8%
5. Higher harvest cost: $12/ton in 1982	12.3%
6. Lower harvest cost: $8/ton in 1982	17.0%
7. Higher mortgage rate: prime plus 2	14.4%

To investigate the sensitivity of the rate of return estimate we examined an array of seven alternative financial scenarios in Table 13. BESI research suggests that Eucalyptus yields will be 154 green tons-per-acre per harvest (every 7 years). However, yields may turn out to be greater or smaller than this. Scenarios 2 and 3 explore these possibilities. If yields come in 25 percent below expectations (at 115.5 green tons-per-acre per harvest), the after-tax internal rate-of-return falls to 11.4 percent. By contrast, if actual yields are 25 percent higher than expected, the after tax return jumps to 17.4 percent.

Scenario 4 examines the impact of a higher than forecast level of price inflation. The total affect of a 1 percent higher rate of inflation is to raise the rate-of-return to 15.8 percent. This occurs because both costs and revenues are increased when inflation rises, and the revenue affect dominates.

Scenarios 5 and 6 explore the affects of harvest costs on profitability. Harvesting costs are the largest single cost item for the plantation. If harvesting costs are 20 percent above BESI's estimate of \$10 per ton, profitability falls to 12.3 percent. By contrast, if harvesting costs come in at \$8 per ton, profitability increases to 17.0 percent.

The final scenario involves a higher mortgage rate, prime plus 2 percent. The impact on overall profitability is small, and the internal rate-of-return declines to 14.4 percent.

3.5 Methanol production facility

To simplify greatly, we can characterize the production of methanol as a two step process: (1) production of synthesis gas and (2) methanol synthesis. In step one an appropriate feedstock is converted to synthesis gas, a mixture of carbon monoxide, carbon dioxide, water, and hydrogen. In step two the synthesis gas is converted to methanol.

For most conventional methanol plants using natural gas as the feedstock, we can characterize the chemical processes as follows:

(1) Natural gas (CH_4) is converted into synthesis gas in a steam reformer. $CH_2 + H_2O \rightarrow CO + 2H_2$ or $CH_2 + 2H_2O \rightarrow 3H_2$

(2) The gas is desulfurized, cooled, cleaned of unreacted steam and impurities, and compressed.

(3) The cool compressed synthesis gas is converted to methanol under pressure in presence of catalysts. The process is characterized by the pressure at which it operates: High pressure systems use zinc-chronium oxide catalystsand low pressure systems use copper.

(4) The raw methanol is condensed, cleaned, and distilled (See Collieries, 1980, pp. B5-B7; Encyclopedia of Chemical Technology, 1981, Vol. 15; Paul, 1978, pp. 4-26, 107-238; or Davy McKee, 1981, for more detailed discussion).

The methanol plant envisioned by BESI is essentially the same as existing methanol plants. The only major difference involves the substitution of wood as the feedstock for the more traditional natural gas feedstocks.

Technical details about the methanol production facility are contained in Working Document 7, Feasibility Study Eucalyptus to 1000 STDD Methanol Plant in South Central Florida, by Davy McKee and Working Document No. 8, The Wood-Fueled Gasification System, by Evergreen Energy Corporation. These documents describe the engineering and operating aspects of the methanol plant. In addition, the two engineering studies provide capital and operating cost estimates for the methanol facility.

The Davy McKee study provides a complete preliminary engineering design for the entire methanol production facility from the receipt of wood at the factory to the load out of finished methanol Davy determined the optimum size plant was 1,000 tons per day. The Davy design incorporates commercially proven components for every phase of the design. The major process risk involves the scale up of the Davy fixed-bed up-draft oxygen-blown gasifier to utilize wood. Otherwise the BESI facility is comparable in many ways to existing methanol plant except the feedstock is wood.

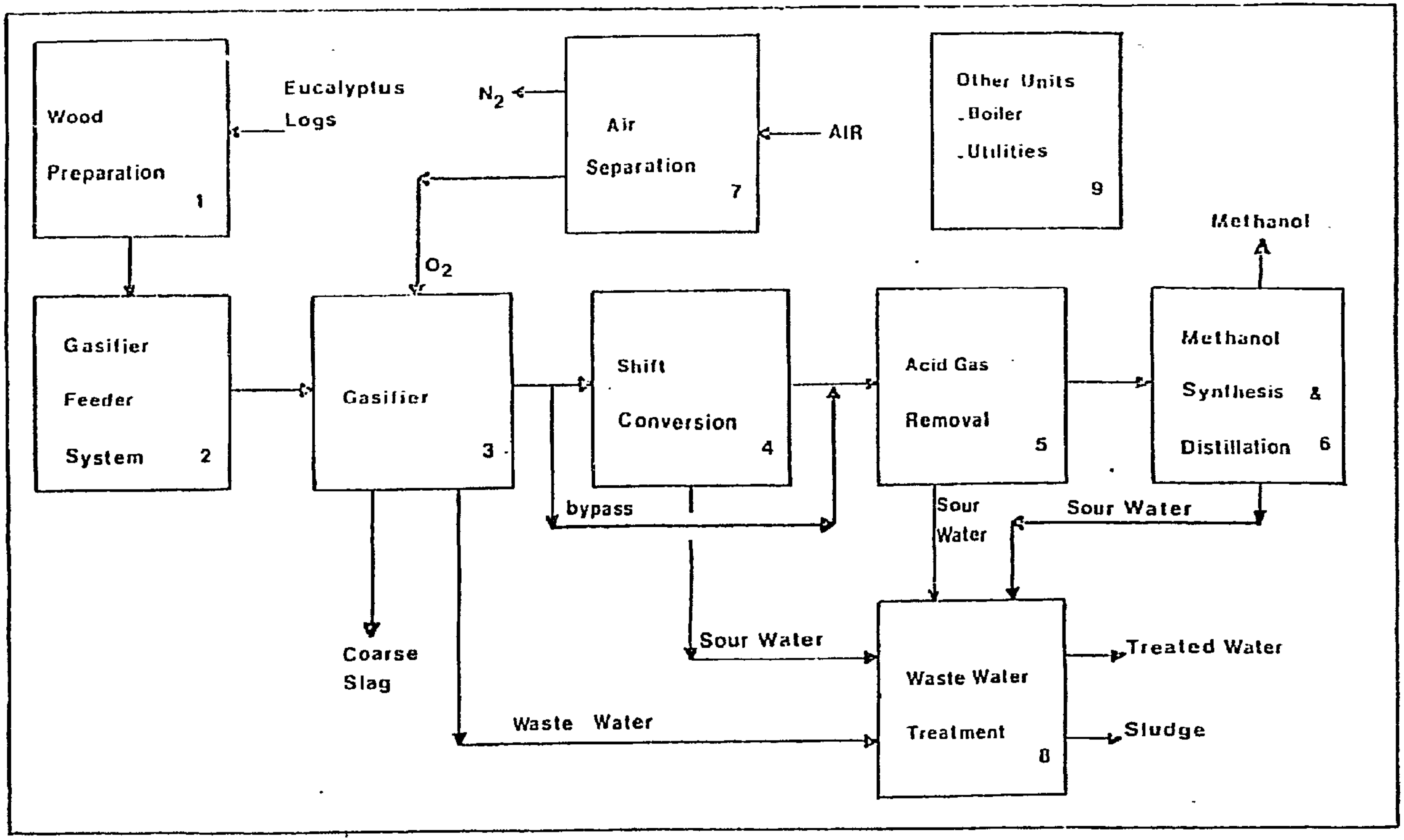
While Davy developed an excellent, preliminary, engineering, design study, methanol produced using this design was judged to be uneconomical for three reasons. First, overall thermal efficiency is very low, 33.3 percent. Second, the design requires excessive amounts of process water, 4 million gallons-per-day (MDG), and generated large quantities of aqueous effluent, 1.5 MGD. Third, the design requires too much wood feedstock—over 6,000 tons per day (green). The main problem in the Davy design is the gasifier. The Davy gasifier operates at atmospheric pressure, at relatively low temperatures, uses steam to regulate the gasification process, and requires long residence time in the gasifier. These characteristics are wasteful from the perspective of thermal efficiency, they require increased wood feedstock and water, and they produce excessive waste water effluent.

To resolve some of these difficulties Evergreen Energy Corporation examined the preliminary Eucalyptus-to-methanol design and redesigned the gasifier and associated facilities. Evergreen selected the Texaco entrained-bed gasifier for the project. The Texaco gasifier operates at high temperatures and pressures and is an oxygen blown process. Residence times are short, and virtually no tars or oil are produced. Using this design thermal efficiency increases from 33.3 percent to 49.7 percent, required feedstock is reduced to 1,998 tons per day (a 34 percent savings), make up water declines by 46 percent to 2.2 MGD, and waste water is reduced by one-half to 0.8 MGD.

While the Evergreen design can produce methanol at a more competitive price, there are greater process risks involved. The increased risk relates to the use of the Texaco gasifier which has never been tested on wood. Evergreen plans such tests in 1983, but until then this does represent a major process risk.

Other aspects of the Evergreen and Davy designs are essentially the same. For example, the total capital costs for either the Davy or Evergreen design are virtually identical—$250 million Davy compared to $243.4 million for Evergreen's design. In addition, manpower requirements are identical. Thus, all things considered we shall adopt the Evergreen design.

Figure 2 provides a flow chart for the methanol plant which is described below, and Table 14 contains the materials balance for the plant.



Source: Evergreen Energy Corporation

Figure 2.—Flow chart for the Eucalpytus to methanol plant

Table 14.—Engineering data comparison

	Fixed Bed Gasification Davy McKee Process	Entrained Bed Gasification Texaco-Evergreen Process
A. Raw Materials and Utilities In		
1. Eucalyptus Wood (Dry basis		
Feedstock	1,995 STPD	1,990 STPD
Fuel (wood)	1,052 STPD	0
2. Well Water Makeup	2,800 GPM	1,500 GPM
3. Electricial Power	21,500 KW	9,600 KW
4. Natural Gas	0	2.2 MMSCFD
B. Products Out		
1. Fuel Grade Methanol	1,000 STPD	1,000 STPD
2. Treated Waste Water	1,060 GPM	550 GPM
3. Ash & Unconverted Carbon	14.8 STPD	48.0 STPD
C. Total Installed Cost of Plant (million dollars	250.0	243.6
D. Catalysts and Chemicals Cost per ton of methanol	$5.66	$4.10
E. Manpower Requirements	186	186
F. Thermal Efficiency	33.3%	49.7%

Source: Evergreen Energy Corporation.

Table 15 contains the data and assumptions used to evaluate the economics of the methanol production facility. Since Section 2 discussed the forecast for methanol prices, these are not examined further here. General economic assumptions for inflation, interest rates, and the like are drawn from Chase Econometric's forecast shown in Table 6. The engineering cost estimate for the plant is taken from Evergreen Energy Corporation's design (Working Document No. 8). A three year buildout period is assumed to being in 1978. Cash expenditures are timed at 20 percent, 60 percent, and 20 percent over the construction cycle. The initial cost estimate for the Evergreen designed plant is escalated by the inflation rate for investments in plant and equipment (from Chase). During the construction cycle, the unbuilt fraction of the plant continues to escalate in price.

Table 15.—Data and assumptions for the methanol production facility

Economic assumptions	Chase Econometrics
Capital costs	
Plant costs (1982 dollars)	$243,500,000
Construction timing - three year building period commencing in 1987. Cash expenditures of 20 percent, 60 percent, and 20 percent for 1987, 1988, and 1989 respectively.	
Start-up costs	$10,000,000
Land	500 acres at $5,000 per acre (1982 dollars)
Financing	
Equity investment	60 percent of installed plant costs
Working capital	2.8 percent of plant costs
Principal payments	20 year AA bonds 3 issues floated in 1987, 1988, and 1989
Interest payments	AA bond rate at issue date
Operating costs	
Feedstock	$20 per green ton as pf 1982 and 1.3 milion tons-per-year required
Catalyst and chemicals	$4.10 per ton output
Labor	Davy McKee estimates of man-power priced accordingly by BESI
Utilities	Amounts from Evergreen at market prices
Shipping, handling and insurance	Market rates, delivery to Houston
Property tax and administration	2.25 percent of installed costs
Maintenance	5 percent of installed cost from Davy McKee

Start up costs were assumed to be $10 million, and start up is scheduled for the first half of 1990. Full production begins in the second half of 1990. Land for the plant and its wood piles requires 500 acres which cost $5,000 per acre in 1982. This cost escalates at the general inflation rate unit 1987 when the land is purchased.

The plant is financed with 60 percent equity capital and 40 percent debt (bonds). Any operating deficits are made up by contributions of additional equity. Working capital requirements are 2.8 percent of plant costs. Bonds are AA corporate debentures requiring semi-annual interest payments. Sinking funds are established to retire the bonds. These sinking funds accrue interest at the prime bank rate. Operating costs are dominated by feedstock expenses. Over 1.3 million tons of feedstock are needed per year. The 1982 price is $20 per ton, and this increases with inflation. Evergreen Energy calculates that $4.10 in catalysts and chemicals are used per ton of output. This price also increases with inflation. Labor requirements were estimated by Davy McKee. These escalate with inflation and run $4.7 million in 1982. Evergreen estimates the quantities of electricity and natural gas needed for the plant. In 1982 these would cost $5.6 million, and they escalate as follows: (1) electricity at the general inflation rate and (2) natural gas at an accelerated pace taken from Chase's forecast.

Shipping and handling charges are calculated from the plant site in Southwestern Polk County by truck to Tampa (1.1 cents per gallon) to Houston by barge (0.3 cents per gallon). The rates are current market quotes, so these prices increase with inflation. Insurance is assumed to cost 1 percent of the installed value of the plant.

Property taxes and administrative expenses are assumed to be 2.25 percent of the installed plant cost. This is similar to the figure used in Collieries Management Corp.'s report (1980). Finally, Davy McKee calculated that the maintenance expenses for the plant would run at 5 percent of plant's installed costs. All of these costs increase over time with inflation.

Table 16 displays the results of the financial analysis for the Eucalyptus-to-methanol facility. For the base case incorporating the assumptions from Table 15, the internal rate of return is 23.3 percent on an after tax basis (discounted, cash, flow approach). A 23.3 percent after tax return is certainly attractive. Total cash required until start up is $257 million.

Since the engineering cost estimate for the plant has a confidence band of plus or minus 35 percent, scenarios 2 and 3 address these alternatives. The high cost plant, 35 percent cost-overrun, is examined in scenario 2. If all the other assumptions listed in Table 15 hold, the project still provides an after tax interal rate-of-return of 19.1 percent. If, on the other hand, the plant ultimately costs 35 percent less than is not estimated, the internal rate-of-return after taxes soars to 30.8 percent.

To explore the affect of financing options on plant profitability we considered scenarios of 100 percent equity (No. 4) and 100 percent debt (No. 5). Maintaining the base case assumptions of Table 15 we find that the after tax return falls to 20.2 percent if all financing is by equity. Although profitability for this option is reduced by 3 percentage points compared to the base case, the effects are modest because the base case already used a significant portion of equity capital (60 percent of plant costs plus any operating deficits). By contrast, the 100 percent debt case causes the after tax internal rate-of-return to jump to 36.4 percent.

Scenarios 6, 7, and 8 examine the consequences of the lower profile for methanol prices drawn from Table 7. Under these circumstances the interest rate-of-return after taxes would be 9.8 percent for the base case, 6.7 percent for the high cost plant, and 15.1 percent for the low cost plant.

Finally, scenarios 9 to 11 explore the affects of the higher profile for methanol prices. Here profits range from 21.1 percent for the high cost plant to 33.5 percent for the low cost plant.

Table 16.—Financial analysis—Biomass Energy Systems, Inc.
100 MGY methanol facility

Assumptions—scenario	Internal rate of return
Base case	
1. Base case: Evergreen Energy plant costs, Chase inflation and interest rates, moderate methanol prices, and 60 percent investment in plant	23.2%
2. High cost plant: Evergreen Energy plant costs plus 35 percent	19.1%
3. Low cost plant: Evergreen Energy plant costs less 35 percent	30.8%
4. Full equity: 100 percent equity financing	20.2%
5. Full debt: 100 percent debt financing	36.4%
Low methanol prices	
6. Base case: Evergreen Energy plant costs, Chase inflation and interest rates, low methanol prices, and 60 percent equity financing	9.8%
7. High cost plant: Evergreen Energy plant costs plus 35 percent	6.7%
8. Low cost plant: Evergreen Energy plant costs less 35 percent	15.1%
High methanol prices	
9. Base case: Evergreen Energy plant costs, Chase inflation and interest rates, high methanol prices, and 60 percent equity financing	25.9%
10. High cost plant: Evergreen Energy plant costs plus 35 percent	21.1%
11. Low cost plant: Evergreen Energy plant costs less 35 percent	33.5%

3.6 Can wood-to-methanol compete with coal-to-methanol?

If our forecast for methanol prices in Table 7 is accurate, it appears that the production of methanol from Eucalyptus in Central Florida is viable both technically and economically. However, this optimistic assumption must be tempered with the knowledge that wood-based methanol will face a serious competitive challenge from coal-based methanol.

In theory, most any carbonaceous substance can be used as a feedstock for methanol production. However, in practice cost and availability limit the relevant alternative feedstocks to coal, wood, and municipal solid waste. Since each of these feedstocks could be used to produce methanol, the economic question is which will be the most competitive? This is a crucial issue since the feedstock which produces the lowest cost methanol, will be the feedstock of choice.

A number of recent studies have attempted to address this issue. The general consensus conclusion is that coal is by far the least cost feedstock for methanol production. Table 17 is a sampling of price comparisons for methanol produced from coal, wood, and municipal solid waste. Since municipal solid waste is not competitive as a feedstock, it will not be discussed further.

The conclusion that coal-methanol is inherently less expensive than wood-methanol is supported by the theoretical process economics involved in converting feedstock to methanol. The total cost of producing methanol depends upon: (1) feedstock costs, (2) conversion efficiencies, and (3) plant costs. Coal appears to be superior to wood in each of these areas.

Table 17.—Methanol production cost forecasts—private producers (1980 dollars)

Study	Feedstock	Gasifier	$/gallon
Wan[1]	biomass	Battelle-Koppers-Totzek	$0.78-$0.92
Collieries[2]	wood	---	$0.98
	coal	Texaco	$0.52
	coal	Koppers-Totzek	$0.66
	municipal solid waste	---	$1.53
Wham[3]	coal	Lurgi	$0.61
Bentz[4]	coal	---	$0.56
Badger[5]	coal	Rummel/Otto	$0.24

Sources: [1]Wan (1982), pp. 27.

[2]Collieries (1980), pp. A9, A19, A33, A51.

[3]Wham and Forester (1980), p. 10.

[4]Bentz (1980), p. 95.

[5]Badger as reported in Paul (1970), pp. 130.

Methanol production can be viewed as a two step process: (1) production of synthesis gas from the feedstock and (2) methanol synthesis. Step two is basically the same no matter what the feedstock is. Thus, we are concerned mainly about step one when coal and wood are compared as feedstocks. As a feedstock coal has the following advantages over wood:

(1) coal is available at very concentrated locations—mines,

(2) very large amounts of coal are available at the mine sites,

(3) coal contains more carbon and has a higher BTU value per pound than wood, and

(4) it is more efficient to convert coal to methanol.

Thus, compared to wood coal is easier and cheaper to handle, it offers a greater output of methanol per ton of feedstock input, and it costs the same or less on a BTU basis. In addition, because very large amounts of coal are concentrated at one location, very large plants can be designed to exploit the economies of sale.

Although coal has a number of inherent advantages over wood as a methanol feedstock, it also has some inherent disadvantages. First, compared to wood coal will have a greater impact on the environment. Unlike wood coal contains significant amounts of sulfur and very small amounts of heavy metals like arsenic and mercury. However, coal based methanol plants must be very large to exploit their economies of scale, they will use huge amounts of coal and thereby generate large quantities of effluents. Environmental protection costs will be high, they appear to be understated in the literature (more on this below). Furthermore, very large coal-methanol plants will require large amounts of freshwater which may not be readily available.

Second, estimates of methanol costs from coal assume thermal conversion efficiencies from 50 to almost 60 percent. However, thermal efficiencies at this level have not been proven commercially. In fact, in the two plant designs developed for BESI pursuant to this research thermal efficiencies were below 50 percent (for wood) and well below the projected thermal efficiencies published in the literature. If the thermal efficiency levels for wood are overstated in the literature, is it not likely that the thermal conversion efficiency for coal is also overstated? If so, then the cost of producing methanol from coal will be higher than the current literature suggests.

Third, the coal-to-methanol plants achieve low costs per gallon of output in part because of their very large sizes. These conceptual plants are designed to produce between 6,500 and 7,300 tons of methanol per day. Thus, they are at least 3 times larger than the largest plant operating today. Since methanol plants of this scale have never been built, engineering scale up problems are inevitable and have been recognized (Paul, 1978, pp. 163). However, such problems do not appear to be reflected in the capital cost estimates for these plants.

In addition, massive coal-to-methanol plants pose large financial risks because of their shear size and cost. For this reason alone, financing charges (including profit) may have to be higher than normal.

Finally, estimates of the cost for various plant components (such as material handling, oxygen, methanol synthesis, etc.) appear to be significantly under estimated in the literature. This imparts a significant downward bias to the projected cost of producing methanol from coal. To evaluate the reasonableness of the cost estimates for a coal-to-methanol plant we can compare these costs to the cost estimates

BESI received for a wood-to-methanol system. Only those items which exist in both the coal-fed and wood-fed plants can be compared. In addition, adjustments must be made to account for inflation and for different volumes of output. This is done in Table 18.

For example, the wood-to-methanol plant requires an oxygen plant to produce 1,000 tons-per-day of oxygen. It will cost $45 million or $45,000 per daily-ton of output. The two coal plants require much greater amounts of oxygen (6,000 and 7,300 tons-per day respectively), but even after adjusting for inflation they are estimated to cost $29,000 and $23,840 per daily ton of output. While there are likely to be some economies of scale at larger output levels, the estimated costs for the oxygen plants at the coal-to-methanol facilities seem to be much too low. As Table 18 demonstrates, most every component in the estimated costs for the coal-to-methanol plant appear to be too underestimated.

Reviewing each of the four concerns raised above—environmental, conversion efficiency, scale, and capital cost estimates—it appears that whatever cost advantage a coal-to-methanol plant may ultimately have over a wood-to-methanol plant it will be much smaller than reported in the literature. Thus, despite the literature, there is no reason to believe that a Eucalyptus-to-methanol plant located in Central Florida can not compete against coal-to-methanol plants.

Table 18.—Comparative plant costs
(in 1982 dollars per daily ton of output)

Plant component	Evergreen estimate for BESI's wood-to-methanol plant[1]	Collieries estimate for lignite-to methanol[2]	Collieries estimate for coal-to methanol[3]
Oxygen plant	45,000	29,000	23,840
Acidgas removal	26,700	2,060	2,230
Methanol synthesis	25,700	14,470	13,870
Methanol storage	4,000	504	470
Wood gasification	65,500	14,430	21,700
Plant utilities	27,900	29,360	8,300
Feed preparation	43,600	5,880	4,635
Other	5,000	51,126	21,135
Total	243,400	146,830	96,180

Sources: [1]Evergreen Energy Systems (1982), pp. 18.

[2]Collieries Management Corp. (1980), pp. A-8.

[3]*Ibid*, pp. A-19.

4.0 Environmental concerns

Any project of the scale described in this report raises environmental concerns. Some of these concerns related to general misgivings about any type of development activity while other concerns are more specifically related to the production of methanol from Eucalyptus in central Florida. To facilitate the analysis of environmental matters this discussion is divided into three parts: (1) plantation, (2) methanol plant, and (3) use of methanol as an automotive fuel. The environmental impacts of the tissue culture lab is essentially zero except in so far as it allows us to rapidly develop the energy plantation (Working Document No. 5, 1982, pp. 9).

4.1 Eucalyptus energy plantation

Working Document No. 5, Florida's Eucalyptus Energy Farm and Methanol Refinery - Environmental Impact Assessment, and Working Document No. 6, The Florida Eucalyptus Energy Farm Interface with Natural EcoSystems address the environmental effects of the Eucalyptus energy plantation. The discussion below summarizes the research results of this work. The Eucalyptus energy plantation is an intensively planted Eucalyptus forest of 70,000 acres which is managed to maximize biomass yield. As such, the environmental impact of the plantation is similar in some respects to a densely planted pine forest. However, the establishment of a forest where none existed tends to improve the overall environment of the area. Of course there are tradeoffs, and the initial planting and subsequent harvesting are disruptive, but the overall environmental effects are clearly positive (Working Document No. 5, 1982, pp. 1).

An intensive two year analysis of a number of Eucalyptus plantings in Florida demonstrated that no significant, detrimental, environmental, consequences are expected from the establishment of a 70,000 acre Eucalyptus energy plantation. Proper silvicultural management techniques are vital to insure cost-effective biomass production, and this insures a minimum use of high cost fertilizers, herbicides, or pesticides. Eucalypts have no domestic insect pests, require little or no fertilizer, and may need herbicides only rarely. Thus, no adverse effects on water, soils, air, or animals are expected (Working Document No. 5, 1982, pp. 12-13).

Since we plan to use an intensive silviculture planting with a short seven year rotation, soil conditions and possible nutrient losses must be evaluated. A Eucalyptus energy plantation does well on these scores. First, a major concern in soil conservation is erosion. The Eucalyptus plantation will minimize this problem. Only at the initial planting will there be potential for erosion. Thereafter the trees and their ground cover will minimize erosion. Since the trees coppice (sprout back) from their stumps, the soil is protected even at harvest time. Second, Eucalyptus builds topsoil because of its high detrital output. In addition, since Eucalyptus allow substantial light to reach the forest floor, the litter undergoes oxidation (Working Document No. 5, 1982, pp. 13-16).

Third, nutrient loss is not generally a problem with forest crops. However, intensive silviculture will increase the nutrient absorption. Research indicates that phosphate is the primary nutrient taken up by Eucalyptus. Since we plan to utilize reclaimed phosphate mine lands as the primary site for this project, high phosphate requirements will not pose a problem (Working Document No. 5, 1982, pp. 16-20).

A final environmental concern about Eucalyptus energy plantation is the selection of Eucalyptus itself. It is argued that: (1) Eucalyptus is an exotic species which may rapidly spread producing a "Eucalyptus epidemic," (2) a Eucalyptus energy plantation will be devoid of wildlife, and (3) Eucalyptus leaves will poison the soil. First, the fear of "green cancer" is a legitimate one in Florida which has experienced nauxtious invasions of exotics like Hydrilla, Mellaluca, Brazilian Pepper, and Austialian Pine. However, Eucalyptus has been growing in Florida since the 1870s, and it has never proliferated. Indeed, few "wildings" could be located after an extensive search, and those that were found were located close to their source. Finally, BESI's species of choice, Camaldulensis does not produce viable seed in Florida. The seed pods are attacked by a naturally occurring fungus. Through BESI's plan for clonal propagation, the perpetuation of this useful natural trait is insured. Thus, the Eucalyptus energy plantation will not be a source of an epidemic of Eucalyptus (Working Document No. 6, 1982, pp. 9-10).

Second, existing stands of Eucalyptus in Florida and throughout the world exhibit high natural systems values. A wide array of animal life can and does coexist with Eucalyptus (Working Document No. 6, 1982, pp. 1 and Appendices I and II).

Finally, some claim that Eucalyptus poisons the soil. This mistaken notion comes from the allelopathic properties of Eucalyptus leaves. Eucalypts do repress the growth of competing vegetation by chemical means. This process is effective but short lived. A constant supply of new leaf material is needed to make allelopathic control effective. Extensive field studies in Florida demonstrate that this is not a concern (Working Document No. 6, 1982, pp. 6-9).

One last concern about the energy plantation relates to harvesting. As described above BESI plans to use mechanized procedures for harvesting (feller-bunchers for stem wood and chippers for the crowns). Just as in any forestry operation, there will be disruption, but it will only occur for short periods. Of greater concern will be the impact on transportation facilities (roads). These are unavoidable and will be dealt with as necessary (Working Document No. 5, 1982, pp. 40-42).

4.2 Methanol production facility

The methanol production facility consists of a large wood yard, heavy industrial processing equipment to make methanol from Eucalyptus, and storage of finished methanol A wood yard is a wood yard—noisy and busy. The wood yard for the methanol plant will be quite similar to that of a paper mill. No peculiar impacts are anticipated for BESI's wood yard.

As for the methanol plant, it is designed for and required to meet all applicable federal, state, and local standards. In addition, wood is inherently an environmentally clean feedstock having almost no sulfur or other toxic trace elements. Wood looks particularly good compared to its fossil fuel alternatives.

Furthermore, environmental quality and economical operation of the methanol production facility go hand in hand. The more efficient the plant, the lower will its effluents be (Working Document No. 5, 1982, pp. 46).

The plant will produce three effluent streams. First, hydrogen sulfide and carbon dioxide gases will be generated. Hydrogen sulfide gas in very small quantities will be treated by scrubbing to meet all applicable standards. Substantial quantities of carbon dioxide will also be produced. Some of this will be absorbed in the green house facility, but the remainder will be vented to the atmosphere. Second, the plant will also produce ash. This will be redistributed to the plantation as a soil amendment. Finally, a substantial flow of waste water will be treated to meet all applicable standards.

4.3 Use of methanol as a fuel

It is useful to separate the discussion of utilization issues into two parts: neat methanol and blends of methanol and gasoline. Since these two applications pose somewhat different problems, each is discussed individually.

The use of neat methanol as an auto fuel poses three kinds of utilization problems: (1) material compatibility, (2) vehicle performance, and (3) safety. Methanol is a strong solvent, and it acts on commonly used automotive materials such as plastics, polyester laminated fiberglass, epoxies, teflon and cork. In addition, methanol corrodes zinc, steel, aluminum, magnesium, low-tin solders and terne metal (used in the linings of fuel tanks). However, these problems can be readily avoided by switching materials both in the vehicles themselves and in the methanol delivery system. However, the cost of changing the materials at risk would be minor.

The second utilization concern relates to vehicle performance. When the temperature is below 50°, methanol will not vaporize sufficiently to allow the engine to start. Thus, either additives must be used or a cold-start device provided. In addition, the carburetor must be adjusted to optimize the air/fuel mixture. Three other modifications will enhance performance: (1) an increased compression ratio enhances the thermal efficiency of the engine boosting performance and mileage, (2) a larger fuel tank will compensate for methanol's low volumetric heat content, and (3) modifications to the intake and exhaust manifolds to provide for preheating the fuel which improves fuel/air distribution.

The third concern is safety. Safety has two aspects to it—environmental safety and consumer safety. The environmental concerns pertain to exhaust emissions. Here methanol fuel performs as well or better than gasoline. Using current engine configures with the necessary carburetor adjustments, exhaust emissions from methanol are similar to those from gasoline for CO and unburned fuel. However, NO_x emissions are only half of those for gasoline. Aldehyde emissions are much higher for methanol than for gasoline, but these are currently unregulated.

When engines are modified to optimize their use of methanol, significant reductions in emissions are reported. Boosting the compression ratio of the engine and heating the intake-fuel reduces aldehyde emissions to the level of gasoline while also further reducing emissions of CO and unburned fuel.

Consumer safety relates to the toxicity and fire hazard posed by methanol. Although methanol is toxic, it is significantly less toxic than gasoline. The fire hazard posed by methanol is different in nature but the same degree as for gasoline. Although methanol has a higher flash point temperature than gasoline, thus reducing the risk from spill or leak induced fires, methanol presents a greater risk of explosion because of its wider flamability limits.

The use of methanol as an octane-enhancing blending agent with gasoline poses a somewhat different set of utilization concerns including: material compatibility, vehicle performance, safety, and phase separation. When used as a blending agent at concentrations of less than 10 percent, methanol poses few problems of material compatibility.

In terms of vehicle performance, few of the modifications required for neat methanol use are needed for blends of 10 percent or less. However, cold start-up can still be a problem. In addition, the use of methanol blends creates a new problem—vapor lock. Since methanol raises the vapor pressure of gasoline, fuel demands, especially on hot days, can not be meet readily. This can be corrected by more careful blending and by adjusting the carburetor setting for the air-to-fuel ratio.

The question of safety has already been addressed above. With blends the same arguments apply except that the positive effects of methanol are reduced by the lower level of use in a blend as compared to a neat fuel.

The final issue is phase separation. This is the most serious obstacle to using methanol in blends. Although methanol is slightly miscable in gasoline, it is highly miscable in water. If small quantities of water come in contact with the blend (0.1 to 0.5 percent), the water is absorbed by the methanol and in effect the water extracts the methanol from the blend. This is called phase separation. Since water is constantly present throughout the fuel distribution system, this poses a real problem. In addition, methanol is hygoscopic and absorbs water from the air.

If phase separation does occur, it leads to poor vehicle performance. Corrosion and other materials problems are promoted. Additives can help ameliorate this problem, but they are expensive. Increasing the aromatic content of the gasoline is helpful because methanol is more soluble in those blends. The best way to avoid phase separation is to avoid water.

The final hurdle which methanol fuel must jump is existing governmental regulations. Methanol fuels will have to meet requirements concerning movement, distribution and end-use in a timely cost effective manner. The National Transportation Policy Study Commission conducted two detailed analyses of the regulatory concerns related to the supply, transportation, safety, and environmental impacts of methanol fuels.

In reviewing these studies Bentz, et al. (1980, pp. 223-226) identified only two areas of potential concern for methanol demand: (1) emissions standards and (2) fuel economy standards. As to the first, methanol will result in lower emissions than gasoline, so there are no apparent problems. However, the EPA must still approve all blends of methanol. Of particular concern is the increase in evaporative emissions which can occur in methanol blends. Waivers and improved blends can meet these concerns.

The second issue relates to fuel economy. Federal fuel economy standards are based on gasoline. These standards are not strictly applicable to methanol, so some new rule making would be needed. However, procedural stress are already in place and no particular problem is likely to develop.

Working Document No. 5 (1982) pp. 68-83 examines these issues in greater depth. Briefly, however, it is fair to say that the Eucalyptus-to-methanol fuel cycle is a relatively benign pathway for production of liquid automotive fuel compared to fossil fuels. In addition, the wood-to-methanol route is a renewable energy path.

5.0 Conclusions

The outlook for gasoline prices through 2000 is for prices rising at almost 10 percent-per-year. Domestic conservation will continue along is current trend. These twin forces will push gasoline consumption down from 7.7 million barrels per day in 1980 to 4.6 million barrels per day by 2000. These trends of rising prices and falling demands are expected to continue through 2020 (U.S. Department of Energy, 1982).

Unlike other energy using sectors of the economy, the transportation sector must continue to use liquid fuels. Thus, even with conservation, over 4 million barrels per day of gasoline or its equivalent will be consumed through 2020. These trends of rising prices and extensive demands create an environment in which methanol can be competitive.

Out research indicates that if methanol is priced at or below 70 percent of the price of gasoline it can penetrate the market. Competitive pressures are likely to keep methanol prices around one-half those for gasoline. At these price levels we expect significant use of methanol in motor vehicles. Through 2000 it will be primarily the fleet fuel market although some gasoline blending will occur also. As methanol supplies increase, wider distribution of neat methanol will occur.

Can methanol produced from wood compete with methanol produced from coal? The existing literature suggests that wood can not compete with coal as a methanol feedstock. Coal is a more compact form of energy, it is concentrated in more specific locations (mines), and it is priced very competitively. Conceptual coal-to-methanol plants are estimated to produce methanol at around 50 to 60 cents per gallon. However, these estimates appear to be extremely optimistic. Capital costs are under-estimated and process risks ignored. It is most unlikely the methanol from a coal plant will be so inexpensive. More realistically, methanol from wood can compete if the wood base plant is well designed and well located.

To produce methanol from Eucalyptus requires three conceptual steps:

(1) the tissue culturing and nursery growth of 7.5 million Eucalyptus seedlings per year to support the planting program;

(2) a Eucalyptus energy plantation on 70,000 acres to provide feedstock to the methanol refinery; and

(3) a 1,000 ton-per-day Eucalyptus-to-methanol production facility.

This integrated approach to methanol production from a renewable resource base reduces overall risk and insures that the optimal mixture of trees, land, harvesting, seedlings, and methanol production will be developed.

Total cash cost for the project is $350 million distributed over 7 years until the methanol plant comes on stream. No further cash is needed at that point. Cash expenditures can be broken out as follows:

(1)	tissue culture lab and nursery	$ 500,000
(2)	Eucalyptus energy plantation	92,500,000
(3)	methanol production facility	257,000,000
	total	$350,000,000

The project is projected to be quite profitable. On an after tax basis the internal rate-of-return figures (on a discounted, cash, flow basis) are as follows:

(1)	tissue culture lab and nursery	25%
(2)	Eucalyptus energy plantation	15%
(3)	methanol production facility	23%

Working Document No. 1

The Florida Eucalyptus Energy Farm - Silvicultural Methods and Considerations

References

LITERATURE CITED

Abelson, Philip H. 1980. Energy from biomass. Science Magazine. 20 June 1980. Vol. 208, No. 4450.

_______________. 1981. Energy and chemicals from biomass. Science. 213(4508). August 7.

_______________. 1982. Energy and chemicals from trees. Science. 215(4538). March 12.

American Chemical Society. 1981. Biomass as a nonfossil fuel source. ACS Symposium Series 144. Washington, D.C. Donald L. Klass (Ed.) 564 pp.

Ashton, D. H. . 1962. Some aspects of root competition in E. regnans. Proc. 3rd Gen. Conf. I.F.A., Melbourne, Australia.

Baker, J.B. and B.G. Blackman. 1977. Biomass and nutrient accumulation in a cottonwood plantation--the first growing season. Soil Sci. Soc. Am. J. 41(3):632-636.

Barney, G.O. 1980. The global 2000 report to the president. Vol. II: The technical report. Council on Env. Quality. U.S. Gov. Printing Office. 766 pp.

Barnett, J. P. 1981. (ed.). First biennial southern silvicultural research conference. Atlanta Conference Proceedings, Southern For. Exp. Sta., Gen. Tech. Rep. SO-34.

Berger, Beverly J. 1981. Biomass energy systems program wood energy activities. In: Industrial Wood Energy Forum 81. March. Proceedings No. P-81-31. FPRS. Madison, Wis.

Bevege, D.I. 1976. A green revolution in the high yield forest: rational silviculture or new technology. Aust. For. 39:40-50.

Blakely, W.F. 1955. A key to the eucalypts. Second Ed. 359 pp. For. and Timber Bur., Australia.

Boden, R.W. 1964. Hybridization in eucalytpus. Indian For. 90(9):581-586.

Boggan, J.A. 1977. How Mead Papers learned to use whole-tree chips for bleached pulp. Pulp and Paper Magazine, December.

Bradley, J.T. 1975. Freeze probabilities in Florida. Agr. Exp. Sta. IFAS. Univ. of Florida. Gainesville, Tech. Bul. 777.

Brunck, F. 1975. Principal problems connected with animal or vegetable pests in natural forest stands and man-made forests of French speaking tropical counties and North Africa. Second FAO World Technical Consultation on Forest Diseases and Insects. New Delhi. April 7-12.

Bruner, S.C. 1917. Una enfermedad gangrenosa de los eucaliptos. Boletine No. 37. Estacion Experimental Agronomica, Santiago de las Vega, Cuba. 38 pp.

Budiansky, Stephen. 1980. Chemical feedstocks from biomass. Environmental Science and Technology. Vol. 14(6). June.

Bungay, H.R. and R.F. Ward. 1977. Fuels and chemicals from crops. pp. 105-120. In: L.A. Anderson and D.A. Tillman, Fuels from Waste. Academic Press, New York.

Butson, K.D. and G.M. Prine. 1968. Weekly rainfall frequencies in Florida. Agr. Exp. Sta. Unv. of Florida. Gainesville. Cir. S-187. 41 pp.

Butts, Paul M. and Druid N. Preston. 1979. Whole tree chipping...a forestry management tool. Georgia Forest Research Paper. No. 4. June. Georgia Forestry Commission.

Cameron, D.A. and L.F. Riley. 1981. Site preparation for trailed planting machines: The CFS V-Blade. In: Forest Regeneration. Proceedings of the American Society of Agricultural Engineers Symposium on Engineering Systems for Forest Regeneration. March.

Cameron, J.N. 1980. Plantations and the Brazilian economy. Papers prepared for Austailian Forest Grower. 7 pp.

Carter, W.G. 1974. Growing and harvesting eucalypts on short-rotations for pulping. Aust. For. 36(3):214-225.

Chippendale, G.M. 1973. Eucalyptus of the western Australian Goldfields (and adjacent wheatbelt).

Conde, L.F. and D.L. Rockwood. 1979. Energy plantation potential in Florida. Unv. of Fla. Coop. Ext. Serv. IFAS. Gainesville, FL. p. 2-11. Proceedings: Alternative Energy Sources for Florida.

Couto, H.T.Z. do., H.A. Mello, J.W. Simoes and R. Vencovsky. 1973. Coppice management of *E. saligna*. IPEF 7, 115-23.

Cowan, William F. Planting eucalyptus in South Florida. Eucalyptus Handbook for Southern United States. Lykes Bros. Palmdale, FL. In Manuscript.

Crane, Wilfred J.B. 1972. Fire in the Australian Environment. Fire in the Environment Symposium Proceedings. Denver, CO. May.

Cremer, K.W. 1969. Growth of eucalypts in experimental plantations near Canberra. Aust. For. 36:214-25.

Cremer, K.W., R.N. Cromer and R.G. Florence. 1978. Stand establishment. In: Eucalypts for Wood Production. Hillis and Brown (eds.) pp. 81-135.

Cromer, R.N. 1974. The potential for eucalyptus plantations in Victoria. Eucalypt Seminar Gippsland, Victoria Journal of Science and Australian Tech. Vo. 12(6) May 1975.

Cromer, R.N. 1975. The potential for Eucalyptus plantations in Victoria. Jor. of Sci. and Aust. Tech. 12(6). May.

Cromer, R.N., M. Raupach, A.R.P. Clarke and Cameron. 1975. The potential for intensive production and utilization of eucalypts in Australia. 29th APPITA Conf. March. Launceston.

Cromer, R.N., E. Williams and D. Tompkins. 1980. Biomass and nutrient uptake in fertilized E. globulus. IUFRO Symposium and workshop on Genetic Improvement and Productivity of Fast Growing Trees. Sao Pedro, Sao Paulo, Brazil. August.

Dawson, D.H. 1976. History and organization of the maximum wood yield program. pp. 1-4. In: Intensive Plantation Culture; Five Years Research, USDA For. Serv. Gen. Tech. Rep. NC-21, Northcentral For. Exp. Sta., St. Paul, MN.

Dawson, David H., Zavitkovski, J. and J.G. Isebrands. 1980. Managing forests for maximum biomass production. AIChE Symposium Series 75(195).

DeBell, D.S. 1970. Phytotoxins: new problems in forestry? Jorn. For. 68:335-337.

DeBell, D.S. 1972. Potential productivity of dense young thickets of red alder. For. Res. Note No. 2. Crown Zellerback Corp. Central Research, Camas, Wash.

DeBell, D.S. and J.C. Harms. 1976. Identification of cost factors associated with intensive culture of forest crops. Iowa State Jorn. of Res. 50(3):295-300.

DeBell, D.S., R.F. Strand, and D.L. Reukema. 1978. Short-rotation production of red alder: some options for future forest management. pp. 231-244. In: Utilization and Management of Alder. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. NW For. Rge. Exp. Sta. Portland, OR.

DelMoral, R. and C.H. Muller. 1970. The alleopathic effects of Eucalyptus camaldulensis. Amer. Midland Naturalist 83:254-282.

Donald, C.M. 1968. The breeding of crop ideotypes. Euphytica. Vol. 17.

Dutrow, G.F. 1971. Economic Implications of silage sycamore. USDA For. Serv. Res. Pap. 50-66. South. For. Exp. Sta.

Dvorak, W.S., E.C. Franklin and G. Meskimen. 1981. Breeding strategy for E. robusta in Southern Florida. Presented at 16th Southern Forest Tree Improvment Conference, Blacksburg, VA.

Ek, A.R. and D.D. Dawson. 1977. Yields of intensively grown Populus: actual and projected. pp. 5-9. In: Intensive Plantations Culture; Five Years Research. USDA For. Serv. Gen. Tech. Rep. NC-21. North-central For. Exp. Sta., St. Paul, MN.

Eldridge, K.G. 1978. Genetic improvement of eucalypts. CSIRO Division of Forest Research. Silvae Genetica 27, 5(1978). Canberra, A.C.T. 2600. Australia.

Environmental Protection Agency. 1978. Areawide Impact Assessment of the Central Florida Phosphate Industry. Vol. IV and X.

Fege, A.S., R.E. Inman, and D.J. Salo. 1979. Energy farms for the future. Jorn. For. 77(6):356-361.

Filho, V.B.andA.J.A.Zagatto. 1980. Methanol from Brazil. American Chemical Society National Meeting, March 23-38. Houston, Texas.

Florence, R.G. and K.R. Shepherd. 1975. The role of eucalypt forests in wood production. Aust. For. 38:100-16.

Food and Agriculture Organization of the United Nations. 1955. Eucalypts for planting. lrst Ed. (FAO:Rome).

Food and Agriculture Organization of the United Nations. 1975. Pulping and papermaking properties of fast-growing plantation wood species. Rome. December. FO:MISC/75/31. 237 pp.

Food and Agriculture Organization of the United Nations. 1976. Harvesting man-made forests in developing countries. Rome. p. 119.

Franklin, E.C. 1977. Yield and properties of pulp from eucalypt wood grown in Florida. TAPPI. 60(6). June.

Franklin, E.C. 1978. Exotics for hardwood timber production in the Southeastern United States. Reprinted from proceedings 2nd Symposium. Southeastern Hardwoods. U.S. Dept. Agric. For. Serv. Southeast. Area S&PF, Atlanta, GA.

Franklin, E.C. 1979. Prospectus: Development of tropical forest resources in southern Florida. Prepared for International Forest and Seed Company, Birmingham, AL.

Franklin, E.C. and G.F. Meskimen. 1973. Genetic improvement of Eucalyptus robusta sm. in Southern Florida. Proc. IUFRO Working Parties on Trop. Prov. and Progeny Res. and Int. Coop., Commwl. For. Ints. Oxford:421-424.

Franklin, E.C. and G.F. Meskimen. 1975. Progeny testing in a eucalyptus breeding program. Proc. IUFRO Working Parties of Progeny Testing. Southeastern For. Exp. Sta. Asheville, 2-4.

Fujii, David M. 1976. The nuuanu eucalyptus planting: growth, survival, stand development after 64 years. Pac. SW For. and Rge. Exp. Sta. USDA For. Serv. Res. Note PSW-318.

Geary, T.F. 1975. Winter planting potential of four eucalypt species in South Florida. Tree Planters Notes 28(3 & 4):14-17.

Geary, T.F. and George Meskimen. Seed technology. Southeastern For. Exp. Sta. Lehigh Acres, FL. In: Eucalyptus Handbook for Southern United States. In Manuscript.

Georgia Forestry Commission. 1980. Wood Energy in Georgia. October.

Goes, E. 1967. Culture do Eucalipto. Lisboa.

Greaves, T., G.J. Armstrong, R.S. McInnes and J.E. Dowse. 1967. Timber losses caused by termites, decay, and fire in two coastal forests in New South Wales. CSIRO (Aust.) Div. Entomol. Tech. Pap. No. 7, pp. 4-18.

Green Heritage Committee of the Forestry Council. 1978. Eucalyptus: tree of the year. P.O. Box 4430. Pretoria 0001.

Groulez, J. 1970. An outline of the data presented at the Lisbon Symposium on the Growing and Industrial Use of Eucalypts. Transl. from Bois For. Trop. No. 136 by R.V. Champagne, For. Timber Bur. Aust.

Hall, N., R.D. Johnston, and G.M. Chippendale. 1975. Forest trees of Australia.

Hall, N., R.D. Johnston, and R. Marryatt. 1963. The natural occurrence of the eucalypts. For. and Timber Bur. Aust. Leafl. 65 (2nd Ed.) 122 p.

Harms, William R. and O. Gordon Langdon. 1976. Development of loblolly pine in dense stands. For. Sci. 22(3):331-337.

Hartley, A. 1977. The establishment of Eucalyptus tereticornis on tailings from the Bouganville Copper Mine, Papua New Guinea. Commonw. For. Res. 56(3):239-245.

Hartney, V.J. 1980. Vegetative propagation of the eucalypts. Aust. For. Res. 10:191-211.

Hassan, A.E. 1977. Effect of mechanization on forest soils and regeneration. Coastal Plain Organic Soil. Am. Soc. Agric. Eng. Pap. 77-1571, 24 pp.

Heather, W.A. and D.M. Griffen. 1978. The potential for epidemic disease. In: Hillis, W.E. and A.G. Brown (ed.) Eucalypts for Wood Production. pp. 143-154.

Heilman, P.E., D.V. Peabody, Jr., D.S. DeBell, and R.F. Strand. 1972. A test of close-spaced, short-rotation culture of black cottonwood. Can. Jour. of For. Res. 2(4):456-459.

Hillis, W.E. and A.G. Brown. Editors. 1978. Eucalypts for wood production. 434 p. Commonwealth Scientific and Industrial Research Organization. Melbourne, Victoria. Griffin Press Ltd. Adelaide, S. Australia.

Hodges, C.S., M.S. Reis, F.A. Ferreira and J.D.M. Henfling. 1976. O cancro do eucalipto causado por Diaporthe cubensis. Fitopathol. Brasileira 1:129-170.

Hodges, C.S., T.F. Geary, and E.C. Cordell. 1979. The occurrence of Diaporthe cubensis on Eucalyptus in Florida, Hawaii, and Puerto Rico. Plant Dis. Reptr. 63:216-220.

Horvath, R. J. 1968. Addis Ababa's eucalyptus forest. Journ. of Ethiopian Studies. 6:13-19.

Howland, P. 1969. Effects of singling coppice in E. saligna wood fuel crops at Muguga, Kenya. East Afric. Agric. For. J. 35,66-7.

Howlett, K. and A. Gamache. 1977. Silvicultural biomass farms. Vol. II The Biomass Potential of Short Rotation Farms. Energy Res. and Dev. Administration. Div. Solar Energy. MTR-7347 (Vol. II) 119 pp.

Inman, R.E. 1977. Silvicultural biomass farms. Vol. I. Summary. Energy Res. and Dev. Administration. Div. of Soalr Energy. MTR-3747 (Vol. I) 62 pp.

Jackson, J.K. and G.O.A. Ojo. 1973. Provenance trials of Eucalyptus camaldulensis in the Savanna region of Nigeria. Fed. Dept. For. Res., Nigeria, Savanna For. Res. Sta., Res. Pap. No. 14.

Johnson, Warren O. 1970. Minimum temperatures in the agricultural areas of peninsular Florida. Summary of 30 Winter Seasons--1937-67. IFAS. Publ. No. 9. Sept. Unv. of FL, Gainesville.

Johnson, R.C. 1980. Energy from biomass: the implications of gasohol. McLean, VA: The MITRE Corp.

Johnson, R. Channing, Rodney K. Lay, Lawrence C. Newman. 1980. Energy from biomass: a technology assessment of terrestrial biomass systems. The Mitre Corp. McLean, VA. MTR-80W259. December.

Johnston, R.D. and R. Marryatt. 1965. Taxonomy and nomenclature of eucalypts. For. and Timber Bur. Aust. Leafl. 92, 24 p.

J.P.R. Associates, Inc. 1981. Whole-tree chippers' handbook. May. Publ. by Evergreen Energy Corp. 200 Fifth Ave. Waltham, MA 02154.

Karschon, R. and D. Heth. 1967.. The water balance of a plantation of Eucalyptus camaldulensis Dehn. Reprint from Contributions on Eucalyptus in Israel, III. National and University Inst. of Agr. Rehovat.

Kaul, O.N. and J.D.S. Negi. 1979. Comparitive transpiration rates of six eucalyptus species. For. Res. Inst. Dehra Dun. July.

Kennedy, H.E. 1975. Influence of cutting cycle and spacing on coppice sycamore yields. So. For. Exp. Sta. Res. Note SO-193.

Kerruish, C.M. 1977. Developments in harvesting technology relevant to short rotation crops. APPITA 31:41-8.

Kerruish, C.M. 1978. Harvesting. In: Eucalypts for Wood Production. Hillis and Brown (ed.) pp 229-255.

King, James P. and Stanley L. Krugman. 1980. Tests of 36 eucalyptus species in Northern California. Pac. S.W. For. and Rge. Exp. Sta. Berkeley, CA. March.

King, Tony and Sharon Haines. 1979. Soil compaction absent in plantation thinning. South. For. Exp. Sta. Res. Note SO-251.

Klass, Donald L. (editor) 1981. Biomass as a nonfossil fuel source. ACS Symposium Series 144. American Chemical Society. Washington, D.C.

Kohan, S.M. and P.M. Barkhordar. 1979. Thermochemical conversion of biomass to fuels and chemicals. Mission Analysis for the Federal Fuels from Biomass Program. Vol. IV. Menlo Park, CA: SRI International.

Krohn, Timothy J. 1981. Fertilization of Eucalyptus tereticornis in Southern Guam. Tree Planters Notes.

Krugman, Stanley L. 1974. Eucalyptus L'Herit. In: Seeds of Woody Plants in the U.S. USDA Agr. Hdbk. No. 450.

Kuhlman, George E. and Edward L. Barnard. Diseases of eucalypts. In: Eucalyptus Handbook for Southern United States. Chapter XI. In Manuscript.

Laird, Cubie R. 1972. Fertilization of slash pines on poorly-drained soils in northwest Florida. Cir. 378. Fla. Coop. Ext. Serv. IFAS. Unv. of Florida. Gainesville.

Landsberg. H., H. Lippmann, K. Paffen, and C. Troll. 1965. World maps of climatology. Springer-Verlag. New York.

Lawyer, J.N. and R.B. Fridley. 1979. Some aspects of machine planting for forest regeneration. ASAE Pap. No. 79-1614, 22 pp.

LeBarron, Russell K. 1962. Eucalypts in Hawaii: a survey of practices and research programs. Pac. S.W. For. and Rge. Exp. Sta. Misc. Pap. No. 64. Berkeley, CA. U.S. Dept. of Ag.

Ledig, F. Thomas, 1981. Silvicultural systems for the energy efficient production of fuel biomass. In: Biomass as a Nonfossil Fuel. ACS Symposium Series 144. American Chemical Society. Washington, D.C. pp. 447-461.

Leppik, E.E. 1970. Gene centres of plants as sources of disease resistance. Annu. Rev. Phytopathol. 8, 323-44.

Loomis, R.C. and W.H. Padgett. 1973. Air pollution and trees in the East. USDA Forest Service. Northeastern and southeastern area, Slate and private forestry. Atlanta, GA. 28 pp.

Luckoff, H.A. 1955. The establishment and regeneration of Eucalyptus saligna plantations in the coastal belt of Zululand. J. S. Afr. For. Assoc. (25)1-20.

Lugo, Ariel E. 1970. The ecological role of fertilizers in relation to forest productivity and dollar subsidy by man. pp. 21-33. Proceedings of the Florida Section, Society of American Foresters, Gainesville, FL.

Malajczuk, N., A.J. McComb, and J.F. Lonergan. 1975. Phosphorus uptake and growth of mycorrhizae and infected seedligs of Eucalyptus callophylla. Aust. J. Bot. 23, 231-8.

Mariani, E.W., W.A. Wood, P.C. Kouchouk, M.B. Minton and Marelco, Inc. 1978. The eucalyptus energy farm--feasibility study and demonstration-- Phase I: Site and species selection. U.S. Dept. of Energy, Washington, D.C. HCP/T2557-01, UC-61.

Martin, John P. in press. Planting eucalyptus in the south Atlantic Coastal plain, North Florida, and the gulf coastal plain. Westvaco Corporation. Summerville, S.C.

McAlpine, R.G., C.L. Brown, A.M. Herrick and H.E. Ruark. 1966. Silage sycamore. Forest Farmer 26:6-7.

McAlpine, R.G. and C.L. Brown. 1967. Outlook for fiber from short-term coppice rotations. Tech. Pap. Amer. Pulpwood Assoc. (April) (15-16, 18).

McArthur, A.G. 1967. Fire behaviour in eucalypt forests. For. Timb. Bur. Aust. Leafl. No. 80.

McArthur, A.G. 1968. Fire resistance of eucalypts. Proc. Ecol. Soc. Aust. 3:83-90.

McKnight, J.S. 1970. Planting cottonwood cuttings for timber production in the South. USDA For. Serv. Res. Paper SO-60.

McNally, J. 1957. A field survey of a koala population. Proc. R. Zool. Soc. N.S.W. 1955-56, 18-27.

Meskimen, George. 1971. Combating grass competition for eucalypts planted in turf. Reprint from Tree Planter's Notes. 21(4).

Meskimen, G. 1979. Growth and yield in South Florida's oldest Eucalyptus plantations. Forest Service, USDA. Lehigh Acres, FL. Revised 1980.

Meskimen, G. and E.C. Franklin. 1978. Spacing Eucalyptus grandis in southern Florida: a question of merchantable versus total volume. Southern Jour. of Applied Forestry. Vol. I, No. 1. February.

Meskimen, G. and E.C. Franklin. 1978a. Spacing eucalyptus in Florida Trail. USDA For. Serv. Res. Note SE-162. 8 p.

Metcalf, W. 1961. Progress with eucalypts in North America 1956-61 (United States Mainland). National Report for Second World Eucalyptus Conferance, Sao Paulo, Brazil. August.

Miyata, Edwin S. 1980. Determining fixed and operating costs of logging equipment. North Central For. Exp. Sta. St. Paul, Minn. USDA For. Serv. Gen. Tech. Rep. NC-55.

Moehring, D.M. and I.K. Rawls. 1970. Detrimental effects of wet weather logging. J. For. 68(3):166-67.

Momoh, Z.O. and I.A.S. Gibson. 1975. Status of diseases and insect pests in Africa and Eurasia. Second FAO World Tech. Consultation on Forest Diseases and Insects. New Delhi, April.

Moore, W.H. and B.F. Swindel. 1980. Effects of site preparation on dry prairie vegetation in South Florida. Southern J. of Applied Forestry. Vol. 5(2):89-92.

Morbark Industries, Inc. 1980. Cost per ton for producing whole tree chips. Model 22RXL Total Chiparvestor. June.

Morrow, P.A. and V.C. LaMarche, Jr. 1978. Tree ring evidence for chronic insect suppression of productivity of sub-alpine Eucalyptus. Sci. Vol. 201(29):1244-1246.

Motley, E.P., B.G. Cruz, L. McClanathan and J.A. Anastasi. 1980. Potential application of biomass technology at national space technology laboratories and Mississippi army ammunition plant. U.S. Army Armament Research and Development Command. large Caliber Weapon Systems Laboratory. Dover, New Jersey.

Mount, A.B. 1968. The effect of plant wastes on forest productivity. Proc. 5th general conf. IFA, Perth, Australia.

Myburgh, H.H. 1967. Kraft pulping of eucalypts in South Africa. APPITA 21:49-53.

Olawoye, O.O. 1972. Economic investigation of silage sycamore production. Ph.D. Dissertation, Ohio St. Univ. Columbus.

Office of Technology Assessment. 1980. Energy from biological processes. Draft Report. Washington, DC: Office of Technology Assessment.

Opie, J.E., R.A. Curtain and W.D. Incoll. 1978. Stand management. In: Eucalyptus for Wood Production. Hillis and Brown (eds.). pp. 179-197.

Papadakis, J. 1970. Climate of the world. Ubro de Edicon, Argentina. 47 pp.

Penford, A.R. and J.L. Willis. 1961. The eucalypts: botany, cultivation, chemistry, and utilization. 551 pp. Interscience Publishers, Inc. New York.

Pickford, G.D. and R.K. LeBarron. 1960. A study of forest plantations for timber production on the island of Hawaii. Tech. Pap. No. 52. Dec. Pac. SW For. and Rge. Exp. Sta. Berkeley, CA. Dept. of Agriculture and Conservation, Hawaii.

Plotkin, Steven E. 1980. Energy from biomass/the environmental effects. Environment 22:6. November.

Podger, F.D. 1975. Fast growing hardwoods for developing countries--the forest disease and insect pest position. Second FAO World Technical Consultation on Forest Diseases and Insect. New Delhi. April 7-12. FAO/IUFRO/1/75/16-0/(b).

Pong, T.Y. 1974. The termite problem in plantation forestry in Peninsula Malaysia. For. Res. Inst. Kepong Mimeo.

Pryor, L.D. 1956. Chlorosis and lack of vigour in seedlings of renantherous species of Eucalyptus caused by mycorrhizae. Proc. Linn. Soc. N.S.W. 81, 91-6.

Pryor, L.D. 1977. Breeding habits of the Eucalyptus in relation to introduction and improvement throughout the world. Invited Lecture, Third World Conferences on Forest Tree Breeding.

Riekerk, H., J.C. Hendrickson and W.S. Gain. 1981. Site and environmental effects of tree biomass silviculture. 1981 International Gas Research Conference. Sept. - Oct. Los Angeles, CA.

Ride, W.D.L. 1970. A guide to the Native Mammals of Australia. Oxford Univ. Press: Melbourne.

Rockwood, D.L. and L.F. Conde. 1975. Genetic variation for biomass production in Eucalyptus grandis. IUFRO Symposium and Workshop on Genetic Improvement and Productivity of Fast Growing Species.

Rockwood, D.L. and A.E. Squillace. 1981. Increasing alcohol production from wood by utilizing genetic variation in wood characteristis. TAPPI.

Rolls, E.C. 1969. They all ran wild. Angus and Robertson, Sydney, Australia. 444 pp.

Rose, D.W. 1975. Cost of producing energy from wood in intensive cultures. Jour. of Env. Management. 5, 23-35. (1977).

Rose, D.W. 1976. Economic investigations of intensive silviculure systems. Iowa State Jour. of Res. 50(3):301-315.

Rose, D.W. 1977. Cost of producing energy from wood in intensive cultures. Jour. of Env. Man. 5:23-35.

Rose, D.W. and R.D. Kallstrom. 1976. Economic feasibility of intensive culture. In: Intensive Plantation Culture: 5 years research. U.S. Dept. of Agr. For. Serv. Gen. Tech. Rep. NC-21. p. 96-108. U.S. Dept. of Agr. For. Serv. North Cent. For. Exp. Sta., St. Paul Minn.

Rose, D.W. and D.S. DeBell. 1978. Economic assessment of intensive culture of short-rotation hardwood crops. Jour. of For. 76:706-711.

Rose, Dietmar, Karen Ferguson, David C. Lothner and J. Zavitkovski. 1981. An economic and energy analysis of poplar intensive cultures in the Lake States. USDA For. Serv. Res. Pap. NC-196. North Cent. For. Exp. Sta.

Sachs, Roy M., David W. Gilpin and Tom Mock. 1980. Short-rotation eucalyptus as a biomass fuel. California Agriculture. Aug-Sept.

Sajdak, R.L., Y.Z. Lai, G.D. Mroz and M.F. Jurgensen. 1981. Forest biomass for energy. In: Biomass as a nonfossil fuel. ACS Symposium Series 144. American Chemical Society. Washington, D.C. pp 21-48.

Salo, D.J., R.E. Inman, B.J. McGurk and J. Verhoff. 1977. Land suitability and availability. Silvicultural Biomass Farms. Vol. III. MTR-7347 McLean, VA: The MITRE Corp.

Salo, D.J., J.F. Henry and R.E. Inman. 1979. Design of a pilot silvicultural biomass farm at the Savannah River Plant. NTIS. March. The MITRE Corp.

Schonau, A.P.G. 1977. Initial responses to fertilizing Eucalyptus grandis at planting are sustained until harvesting. S. Afr. For. J. (100) 72-80.

Schonau, A.P.G., R. Verloren van Themaat, and D.I. Boden. 1980. The importance of complete site preparation and fertilizing in the establihsment of Eucalyptus grandis. Wattle Research Institute, University of Natal. Pietermaritzburg, South Africa. 17 pp.

Schory, E.A., Sr. 1960. Eucalyptus planting guide for Florida. Fla. For. Serv. Ft. Myers. 17 pp.

Shukla, J. and Y. Mintz. 1982. Influence of land-surface evapotranspiration on the Earth's climate. Science. Vol. 215. March.

Siddiqui, K.M., M. Khan, S. Akhtar. 1979. Results of 10-year old Eucalyptus camaldulensis Dehn. provenance study at Peshawar. Pakistan Forest Institute, Peshawar.

Simoes, J.W., H.J.O. Krough, A.D. Ciero Neto, and R.M. Pompeu. 1972. Influencia do vigor das arvores sobre a brotacao das toucas de eucalipto. IPEF 5, 51-6.

Smith, J.H.G. and D.S. DeBell. 1973. Opportunities for short-rotation culture and complete utilization of seven northwestern tree species. Forestry Chronicle 49(1).

Smith, W.H. and L.F. Conde. 1980. Energy and chemcials from woody species in Florida. Annual Report to U.S. Dept. of Energy, Grant No. ET-78-6-01-3040, School of Forest Resources and Conservation, Unv. of Fla. Gainesville.

Solar Energy Reserach Institute. 1979. Synopsis and executive summary. A Survey of Biomass Gasification. Vol. I. Golden Co: Solar Energy Research Institute.

Spurgeon, David. 1980. The promise of agroforestry. American Forests. 86(10) October. Publ. by The American Forestry Association.

Steinbeck, D. R.G. McAlpine, and J.T. May. 1972. Short-rotation culture of sycamore: a status report. J. For. 70:210-213.

Steinbeck, K. 1973. Short-rotation forestry in the United States: a literature review. Proc. Am. Inst. Chem. Eng., New Orleans, LA, March 11-15.

Stibbe, E. 1975. Soil Moisture depletion in summer by an eucalyptus grove in a desert area. Agro-Ecosystems 2:117-126. Elsevier Scientific Publishing Co., Amsterdam.

Stidd, Charles K., W.B. Fowler, and J.D. Helvey. 1975. Irrigation Increases rainfall? Science. Vol. 188. pp. 279-281. April 18.

Tillman, D.A. 1977. Energy from wastes: an overview of present technologies and programs, pp 17-39. In: L.L. Anderson and D.A. Tillman. Fuels from Waste. Academic Press, New York.

Tillman, David A. 1978. Wood as an energy resource. Academic Press, New York. 249 pp.

Uhr, Selmer C., George Meskimen and Kenneth Hayes. 1972. Eucalyptus for pulp in south Florida. Pres. Sixth TAPPI Forest Biology Conference. Appleton, WI. May 2. 7 pp.

Uhr, Selmer C. 1976. Eucalypt --the wonder tree. American Forests. 82(10):42-43, 59, 60-63.

Ursic, S.J. and P.D. Duffy. 1972. Hydrologic performance of eroded lands stabilized with pine. Proc. Mississippi Water Resources Conference. pp. 203-216. Water Resources Research Institute, Mississippi State University, State College, Miss.

USDA Forest Service. 1967. Forestland Tree Planter. ED&T Report 2400-2, USDA For. Serv. Equip. Development Ctr., San Dimas, CA.

Vail, Charles W. 1979. A preliminary screening of woody plants as biomass crops on energy farms. U.S. Dept. of Energy. DOE/ET/23124-T1. Dec. 38 pp.

Walter, H. 1973. Vegetation of the earth. Springer-Verlag. New York. 237 pp.

Walters, Gerald A. 1980. Saligna eucalyptus growth in a 15 year old spacing study in Hawaii. Pac. S.W. For. and Rge. Exp. Sta. Res. Pap. No. PSW-151. Feb. U.S. Dept. of Agr.

Wan, E.I., J.A. Simmons, and T.D. Nguyen. 1980. Production of fuels and chemicals from synthesis gas. A Survey of Biomass Gasification Vol. III. Golden, CO: Solar Energy Research Institute.

Wang, Flora C., John Richardson, Katherine Carter Ewel and Edward T. Sullivan. 1981. Preliminary energy analysis of utilizing woody biomass fuel. In: W.J. Mitsch, R.W. Bosserman and J.M. Klopatek. 1981. Energy and Ecological Modelling. Elsevier, NY.

Wardle, P.A. 1967. Spacing in Plantations: a management investigation. Forestry 40(1):47-69.

Warren, Jack. 1977. Logging cost anaysis, timber harvesting short course. Timber harvesting Rep. 4. LSU/MSU Logging and Forestry Operations Center, Bay St. Louis, M.S.

Wattle Research Institute. 1981. Report for 1980-1981 (Thirty-Fourth Year). October. ISBN 0 86980 2631. Unv. of Natal. Pietermaritzburg, South Africa.

Watts, 1971.

White, E.H. and D.D. Hook. 1975. Establishment and regeneration of silage plantings. Iowa State Jour. of Res. 49:287-296.

White, E.H. and W.L. Pritchett. 1970. Water table control and fertilization for pine production in the flatwoods. Ag. Exp. Sta. Inst. of Food and Ag. Sci. Bul. 743 (tech) November.

Yang, Christine, Donald Murata and Curt Beck. 1977. Biomass energy for Hawaii. Vol. IV. Terrestrial and Marine Plantations. Institute for Energy STudies, Stanford University, Stanford, CA.

Zavitkovski, J. 1976. Biomass studies in intensively managed forest stands. pp. 32-37. In: Intensive plantation culture; five years research. USDA For. Serv. Gen Tech. Rep. NC-21, North Cent. For. Exp. Sta. St. Paul, MN.

Zavitkovski, J. 1979. Energy production in irrigated, intensively cultured plantations of Poplus 'Tristis #1' and jack pine. N.C. For. Exp. Sta. St. Paul, MN.

Zon, Raphael and John M. Briscoe. 1911. Eucalypts in Florida. U.S. Dept. of Ag. For. Serv. Bul. 87.

PERSONAL COMMUNICATIONS

Allen, J. Allen Grove Service. Lakeland, Florida. (813) 686-2833.

Boulay, Michel. AFOCEL. France.

Bradley, Ed. Southern Machinery. Lakeland, Florida. (813) 644-6661.

Chancey, Joe. Chancey Trailers. Jacksonville, Florida. (904) 396-2891.

Cowan, Frank. Forester. Floral City, Florida. (904) 726-4061.

Cremer, Ernest. Cremer Timber Company. Palatka, Florida. (904) 328-5058.

Darr, David. U.S. Forest Service. Portland, Oregon. (503) 231-2088.

Demarest, Don. Speedling, Inc. Ruskin, Florida. (813) 645-3261.

Dixon, Wayne. Florida Division of Forestry. Gainesville, Florida. (904) 372-3505.

Draper, Lee. Container Corporation of America. Callahan, Florida. (904) 879-3051.

Eloff, Don. Ring Power Corporation. Ocala, Florida. (904) 732-2800.

Franklin, E. C. Franklin Forestry Associates. Apex, North Carolina. (919) 362-5958.

Futch, Jonathon. Futch Timber Company. Homerville, Georgia. (912) 487-2545.

Hebb, Mark. Florida Division of Forestry. Lakeland, Florida. (813) 646-2959.

Lancaster, Bill. Timberjack, Inc. Perry, Florida. (904) 584-5063.

Lee Timber Company. Ft. Myers, Florida. (813) 334-3132.

Martin, J. A. Martin Lumber Company. Wachula, Florida. (813) 773-6736.

Meskimen, George. U.S. Forest Service. Lehigh Acres, Florida. (813) 334-4579.

Swendsen, Ben. Lykes Bros. Ranch. Palmdale, Florida. (813) 763-3545.

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Vegetative Propagation of Eucalypts

References

BIBLIOGRAPHY

Aneja, S., and C. K. Atal. 1969. Plantlet formation in tissue culture from lignotubers of Eucalyptus citriodora. Hook. Cur. Sci. 38:69.

Baker, D. K., R. A. deFossard, and R. A. Bourne. 1977. Progress toward clonal propagation of Eucalyptus species by tissue culture techniques. Proc. Int. Plant Prop. Soc. 27:546-556.

Carlson, P. S. 1973. The use of protoplasts for genetic research. Proc. Natl. Acad. Sci. U.S.A. 70:598-602.

Carlson, P.S. and J. C. Polacco. 1975. Plant cell cultures: genetic aspects of crop improvement. Sci. 188:622-625.

Cresswell, R. J. and R. A. deFossard. 1974. Organ culture of Eucalyptus grandis. Aust. Forestry 37:55-69.

Cresswell, R. and C. Nitsch. 1975. Organ culture of Eucalyptus grandis L. Planta (Berl.) 125:87-90.

Debergh, P. C. and L. J.. Maene. 1981. A scheme of commercial propagation of ornamental plants by tissue culture. Scientia Hortic. 14:335-343.

Debergh, P., Y. Harbaoui, and R. Lemur. (in press). Mass propagation of globe artichoke (Cynara scolymus): evaluation of different hypotheses to overcome vitrification with special reference to water potential. Physiol. Plantarum 52:(in press).

deFossard, R. A., M. T. Bennett, J. R. Gorst and R. A. Bourne. 1978. Tissue culture propagation of Eucalyptus ficifolia. F. Muell. Proc. Int. Plant Prop. Soc. 28:427-435

Destremau, D. X., J. N. Marien and M. Boulay. 1980. Selection et multiplication vegetative d'hybrides d'eucalyptus resistant au froid. "Symposium and Workshop on Genetic Improvement and Productivity of Fast-growing Tree Species." Aquas de Sao Petro, S.P., Brazil.

Dhawan, A. K., D. M. Paton and R. R. Willing. 1979. Occurrence and bioassay responses of G: a plant growth regulator in Eucalyptus and other myrtaceae. Planta 146:419-422.

Donnan, A. Jr., S. E. Davidson and C. L. Williams. 1978. Establishment of tissue culture-grown plants in the greenhouse environment. Proc. Fla. State Hort. Soc. 91:235-237.

Durand-Cresswell, R. and C. Nitsch. 1977. Factors influencing the regeneration of Eucalyptus grandis by organ culture. Acta Horticul. 78:149-155.

Eisenhart, M. L. and J. O'Meara, 1980. Container seedling production. In Eucalyptus Handbook, pp. 23-32, R. Kellison ed., N.C.S.U. Hardwood Research Program, Raleigh.

Ek, A. R. and D. D. Dawson. 1976. Yields of intensively grown Populus: actual and projected, pp. 5-9. In Intensive Plantation Culture; Five Years Research. USDA For. Serv. Gen. Tech. Rep. NC-21, Northcentral For. Exp. Stn., St. Paul, MN.

Eldridge, K. G. 1978. Genetic improvement of eucalypts. Sivae Genetica 27:5.

Evans, D. A., W. R. Sharp and C. E. Flick. 1981. Growth and behavior of cell cultures: embryogenesis and organogenesis. In Plant Tissue Culture: Methods and Applications in Agriculture. pp. 45-113, Academic Press: New York, London, Toronto, Sydney, San Francisco.

Franclet, A. and M. Boulay. 1981. Micropropagation of forest resistant eucalypt clones. XIII International Botanical Congress, Sidney, Australia (preprint).

Geary, T. F. and G. Meskimen. 1980. Seed technology. In Eucalyptus Handbook, pp. 4-2?. R. Kellison ed., N.C.S.U. Hardwood Research Program, Raleigh.

Goncalves, A. N. 1975. The growth and developmental physiology of Eucalyptus in cell and tissue culture systems. MS. thesis, Ohio State University, Columbus. (cited in Goncalves, 1979).

Goncalves, A. N. 1979. Tissue culture of Eucalyptus, pp. 509-526. In W. R. Sharp, P. O. Larsen, E. F. Paddock, and V. Raghavan (eds.), Plant Cell and Tissue Culture, Ohio St. Univ. Press, Columbus.

Hartman, R. D. 1979. Tissue culture from a propagators viewpoint. Foliage Digest. 2:2-8.

Hartney, V. J. 1980. Vegetative propagation of the eucalypts. Aust. For. Res. 10:191-211.

Hartney, V. J. and P. K. Barker. 1980. The vegetative propagation of eucalypts by tissue culture. Symposium and Workshop on Genetic Improvement and Productivity of Fast-growing Tree Species, International Union of Forestry Research Organizations, Aguas de Sao Pedro, S.P., Brazil, August 25-30.

Henny, R. J., J. F. Knauss and A. Donnan, Jr. 1981. Foliage plant tissue culture. In Foliage Plant Production, pp. 137-178, J. N. Joiner (ed.), Prentice-Hall, Inc., Englewood Cliffs, N.J.

Howland, G. P. 1975. Excision of UV-induced pyrimidine dimers from the DNA of wild carrot protoplasts. Nature 254:160-161.

Howland, G. P. and R. W. Hart. 1977. Radiation biology of cultural plant cells, pp. 731-756. *In* J. Reinert, and U.P.S. Bajaj (eds.), Applied and Fundamental Aspects of Plant Cell, Tissue, and Organ Culture, Springer-Verlag, New York.

Hu Han, Hsi Tze-Ying, Tseng Chun-Chin, Ouyang Tsun-iven and Ching Chien-Kang. 1978. Application of Anther culture to crop plants. *In* Frontiers of Plant Tissue Culture 1978, pp. 123-130, T. A. Thorpe (ed.), Univ. of Calgary Press, Calgary.

Ikemori, Y. K. 1975. Resutados preliminarios sobre enraizmento de estacas de Eucalyptos. Aracruz Forestal, S.A., technical note No. 1. (cited by Franclet and Boulay, 1981).

Kitahara, E. H. and L. S. Caldas. 1975. Shoot and root formation in hypocotyl callus cultures of *Eucalyptus*. For. Sci. 22:242-243.

Knauss, J. F. [illegible] A tissue culture method for producing *Dieffenbachia picta* cv. 'Perfection' free of fungi and bacteria. Proc. Fla. State Hort. Soc. 89:293-296.

Knauss, J. and J. W. Miller. 1978. A contaminant, *Erwinia carotovora*, affecting commercial plant tissue cultures. *In Vitro* 14:754-756.

Lakshmi Sita, G. and C. S. Vaidyanathan. 1979. Rapid multiplication of *Eucalyptus* by multiple shoot production. Cur. Sci. 48(8):351-352.

Lee, E. C. M. and R. A. deFossard. 1974. The effects of various auxins and cytokinins on the *in vitro* cultures of stem and lignotuber tissues of *Eucalyptus bancroftii* Maiden. New Phytol. 73:701-717.

Maliga, P. 1978. Resistance mutants and their use in genetic manipulation. *In* Frontiers of Plant Tissue Culture 1978, pp. 381-392, T. A. Thorpe (ed.), Univ. of Calgary Press, Calgary.

Martin B. and G. Quillec. 1974a. Bouturage des arbres forestiers au Congo: resultats des essais effectues a Pointe Noire de 1969 a 1973. Revue Bois et Forets des Tropicques. 154 (March-April): 41-57.

________________________. 1974b. 155 (May-June): 15-33.

________________________. 1974c. 156 (July-August): 39-61.

________________________. 1974d. 157 (September-October): 21-40.

Murashige, T. and F. Skoog. 1962. A revised medium for rapid growth and bioassays with tobacco tissue cultures. Physiol. Plantarum 15:473-497.

Nabors, M. W. 1976. Using spontaneously occurring and induced mutations to obtain agriculturally useful plants. Bioscience 26(12): 761-768.

Nicholls, W., W. D. Crow, and D. M. Paton. 1970. Chemistry and physiology of rooting inhibitors in adult tissue of Eucalyptus grandis. In Plant Growth Substances 1970, pp. 324-329, Carr, D. J. (ed.), Berlin, Heidelburg, New York: Springer.

Nienstaedt, H. 1981. "Super" spruce seedlings continue superior growth for 18 years. U.S. Department of Agriculture Forest Service, Research Note NC-265, 4 p.

Paton, D.M., R. R. Willing, W. Nicholls, and L. D. Pryor. 1970. Rooting of stem cuttings of Eucalyptus: a rooting inhibitor in adult tissue. Aust. J. Bot. 18:175-180.

Paton, D. M. and R. R. Willing. 1974. Inhibitor transport and ontogenic age in Eucalyptus grandis. In Plant Growth Substances 1973, pp. 126-132. Tokyo, Japan: Hirokawa Publishing Co.

Promnitz, L. C. and P. H. Wray. 1976. Rapid selection techniques for identifying superior clones. In Intensive Plantation Culture. U.S. Dept. of Ag. For. Ser., Gen. Tech. Rep. NC-21, pp. 25-31.

Quan, O., L. Qu-quan and P. Hai-zhong. 1980. Preliminary report on the development of the embryoid from Eucalyptus. Acta Phytophysiologica Sinica 6:429-432.

Quan, O., P. Hai-zhong, and L. Quan. 1981. Studies on the development of embryoid from Eucalyptus callus. Scientai Silvae Sinica 17:1-7.

Reinert, H. and Y. P. S. Bajaj. 1977. Anther culture: Haploid production and its significance. In Applied and Fundamental Aspects of Plant Cell Tissue and Organ Culture, pp. 251-267, J. Reinert and Y. P. S. Bajaj (eds.), Berline, Springer-Verlag.

Schieder, O. 1978. Production and uses of metabolic and chlorophyll deficient mutants. In Frontiers of Plant Tissue Culture 1978, pp. 393-401, T. A. Thorpe (ed.), Univ. of Calgary Press, Calgary.

Wilson, B. F. and Bachelard, E. P. 1975. Effects of girdling and defoliation on root activity and survival of Eucalyptus regnans and E. viminalis seedlings. Inst. J. Plant Physiol. 2:197-206. (Cited by Hartney, 1980).

Wray, P. H. and L. C. Promnitz. 1976. Controlled-environment selection of Populus clones. In Intensive Plantation Culture. U.S. Dept. of Ag. For. Serv., Gen. Tech. Rep. NC-21, pp. 19-24.

Working Document No. 3

Florida's Eucalyptus Energy Farm and Methanol Refinery - The Background Environment

References

LITERATURE CITED

Altshuler, Z.S., J.B. Cathcart, and E.J. Young. 1964. Geology and geochemistry of the Bon Valley Formation and its phosphate deposits, west-central Florida. GSA, No. 19-21:1-61.

Blakey, A.F. 1973. The Florida phosphate industry: a history of the development of a vital mineral. The Wertheim Committee, Harvard Univ., Cambridge, MA. 197 pp.

Blue, W.G. 1979. Soil fertility programs for forage and beef cattle production on the mineral soils of Florida. Soil Sci. Fact Sheet SL-26, Fla. Coop. Ext. Serv., Inst. Food & Ag. Sci., Univ. Florida, Gainesville. 4 pp.

Bradley, J.T. 1972. The climate of Florida, U.S. Department of Commerce. National Oceanic and Atmospheric Administration. Environmental Data Service. Silver Springs, FL. 31 pp.

Breedlove, B.W. and S.R. Adams. 1977. Natural systems occurring on mined lands of the Central Florida phosphate district. Southeast Geol. Soc. Guidebook. No. 19. 77 pp.

Brady, N.C. 1974. The nature and properties of soils. MacMillan Publishing Co., Inc. New York. 639 pp.

Burke, M.J., L.V. Gusta, H.A. Quamme, C.J. Weiser and P.H. Li. 1976. Freezing and injury in plants. Ann. Rev. Plant Physiol. 27:507-28.

Cooke, C.W. 1939. Scenery of Florida interpreted by a geologist. Fla. Geol. Surv., Bul. No. 17. 120 pp.

Cooke, C.W. 1945. The geology of Florida. Fla. Geol. Surv., Bul. No. 29. 342 pp.

Cooper, H.H., Jr., W.E. Kenner, and E. Brown. 1953. Ground Water in Central Florida. Fl. Geol. Surv., Rep. Invest. No. 10. 37 pp.

Cornwell, G.W. and K. Atkins. 1980. An ecological analysis of the drawdown and reflooding of a clay settling pond. Report for Int. Min. and Chem. Corp., Bartow, FL. 93 pp.

Cowardin, L.M., V. Carter, F.C. Golet and E.T. LaRoe. 1979. Classification of wetlants and deepwater habitats of the United States. Fish and Wildlife Serv., USDI. FWS/OBS-79/31. 103 pp.

Dragovich, A., J.A. Kelly, and H.G. Goodell. 1968. Hydrological and biological characteristics of Florida's west coast tributaries. Fish and Wildlife Serv., USDI Fish. Bul. 66(3):463-477.

EcoImpact, Inc. 1980. A review of topsoiling, suitability and feasibility for reclaiming phosphate mine soils in Florida. For International Minerals and Chemicals Corp., Bartow, FL. 105 pp.

EcoImpact, Inc. 1981. Concepts for the reclamation of mined pits as high quality lakes. Report for International Mineral and Chemicals Corp., Bartow, FL. 139 pp.

Edscorn, J.B. 1977. Appendix C: A report on habitat associations and wildlife values of unreclaimed phosphate mines. pp. 1347-1371. In: U.S. Fish and Wildlife Service, Fish and Wildlife Inventory of the Seven County Region, Vol. 3.

Florida Department of Natural Resources. 1975. Florida environmentally endangered lands plan. Div. of Rec. and Parks. Bureau of Plans, Programs and Services. Tallahassee, FL. 143 pp.

Farmer, E.E. and W.G. Blue. 1978. Reclamation of lands mined for phosphate. pp. 585-608. In: F.W. Schaller, and P. Sutton (eds). Proc. Reclamation of Drastically Disturbed Lands. Am. Soc. Ag., Soil Sci. Am., Madison, WI.

Fountain, R.C., and M.E. Zellars. 1972. A program of ore control in the Central Florida phosphate district. In: H.S. Puri (ed.), Geology of Phosphate, Dolomite, Limestone, and Clay Deposits. Proc. 7th Forum Geol. of Ind. Minerals, Apr. 28-30, 1971. Tampa, Fla. Dept. Nat. Resour. Spec. Publ. 17.

Hafer, F.L. and C.E. Palmer. 1978. Southwest Florida Management District Atlas. SWFWMD. Planning and Programming Division. Brooksville, FL. 31 pp.

Hain, J. 1903. Handbook of climatology. MacMillian Company. New York. 437 pp.

Hare, F.K. 1977. Desertification: its causes and consequences. Secretariat of the United Nations—Conference on Desertification; Nairobi, Kenya. Pergamon Press. New York.

Heath, R.C. 1961. Surface-water resources of Polk County. Fla. Geol. Surv. Inf. Circ. No. 25. 123 pp.

Kangas, P. 1979. Succession on spoil from phosphate mining. Cntr. for Wetlands and Dept. Env. Eng. Sci., Univ. Florida, Gainesville. (unpublished). 22 pp.

Kavaler, L. 1975. Noise—the new menace. John Day Company. New York. 205 pp.

Konya, A. 1980. Design primer for hot climates. Architectural Press, London. 132 pp.

Laessle, A.M. 1942. The plant communities of the Welaka area. Univ. Florida, Biol. Sci. Serv. IV(1). 143 pp.

Laessle, A.M. 1958. The origin and successional relationship of sandhill vegetation and sand pine scrub. Ecol. Monogr. 28:362-387.

Laessle, AM.M 1967. Relationship of sand pine scrub to former shorelines. Quart. J. Fla. Acad. Sci. 30:269-286.

Landsberg, H., H. Lippmann, K. Paffen and C. Troll. 1965. World maps of climatology. Springer-Verlag. New York.

Leighty, R.G., V.W. Carlisle, O.E. Cruz, J.H. Walker, J. Beem, R.E. Caldwell, J.B. Cromartie, J.L. Huber, E.D. Matthews, and Z.T. Millsap. 1958. Soil Survey of Hillsborough County, Florida. USDA Soil Cons. Serv. and Fla. Ag. Exp. Stn.

Menke, C.W., E.W. Meridith and W.S. Wetherhall. 1961. Water resources of Hillsborough County. Fla. Geol. Surv., Rep. Inc. No. 83.

Monk. 1965. Southern mixed hardwood forest of North-central Florida. Ecol. Monogr. 35:335-354.

Monk. 1966. An ecological study of hardwood swamps in North-central Florida. Ecology, 47:649-654.

Monk. 1968. Successional and environmental relationships of the forest vegetation of North-central Florida. Amer. Midl. Nat. 79:441-457.

Montalbano, F., W.M. Hetrick and T.C. Hines. 1978. Duck foods in Central Florida phosphate settling ponds. pp. 247-255. In: USDI Fish and Wildlife Serv., Surface Mining and Fish/Wildlife needs in the Eastern United States: Proceedings of a Symposium.

National Association of Manufacturers. 1975. Air quality control—national issues, standards and goals. Resources and technology Dept. Washington, 94 pp.

Odum, E.P. 1971. Fundamentals of ecology. W.B. Saunders Co. Philadelphia, PA. 574 pp.

Ohlsen, A.C., C.A. Trimble and J.R. Robbins. 1980. Brewster reclamation planting project, soil report. Soil Cons. Serv., USDA.

Phosphate Land Reclamation Commission. 1978. Report on phosphate mining and reclamation. 31 pp.

Peek, H.M. 1958. Groundwater resources of Manatee County, Florida. Fla. Geol. Surv., Rep. Inv. No. 10. 99 pp.

Peek, H.M. 1961. Cessation of flow of Kissengen Springs in Polk County, Florida. In: Water Resources Studies. Fla. Geol. Surv., Rep. Inv. No. 7.

Penman, H.L. 1956. Evaporation: An introduction survey. Netherlands J. Agr. Sci. 66(10):3309-3312.

Pride, R.W., F.W. Meyer, and R.N. Cherry. 1966. Hydrology of Green Swamp area in Central Florida. Fla. Geol. Surv., Rep. Inv. No. 42. 137 pp.

Quarterman, E. and C. Keever. 1962. Southern mixed hardwood forest: Climax in southeastern coastal plains. USA. Ecol. Monogr. 32:167-185.

Reid, G.K. and R.D. Wood. 1976. Ecology of inland waters and estuaries. D. vanNostrand Co., New York. 485 pp.

Schnoes, R.S. and S.R. Humphrey. 1980. Terrestrial plant and wildlife communities on phosphate-mined lands in Central Florida. Special Scientific Report No. 3, Off. of Ecol. Serv., Florida St. Museum, Univ. of Florida, Gainesville. 189 pp.

Snedaker, S.C. and A.E. Lugo. 1972. Ecology of the Ocala National Forest. For. Serv., USDA. 211 pp.

Stewart, H.G., Jr. 1966. Groundwater resources of Polk County. Fla. Geol. Sur., Rep. Inv. No. 44. 169 pp.

Thomas, B.P., L. Law, Jr., and D.L. Stankey. 1979. Soil survey of Marion County area, Florida. USDA, Soil Cons. Serv. 148 pp.

U.S. Army Corps of Engineers. 1977. Regulatory program of the corps of engineers. Sect. 404 of the FWPCA. Fed. Reg. 42(138).

U.S. Department of Agriculture, Soil Conservation Service. 1975a. Soil taxonomy—a basic system of soil classification for making and interpreting soil surveys. Ag. Handbook No. 436. 754 pp.

U.S. Department of Commerce. 1977. Climates of the states. National Oceanic and Atmospheric Administration. Water Information Center, Inc. New York.

U.S. Environmental Protection Agency. 1978. Final areawide environmental impact statement—Central Florida phosphate industry. EPA region 4, Atlanta, GA. Vol. II, VI and X.

Veno, P.A. 1976. Successional relationships of five Florida plant communities. Ecology 57:498-508.

Walter, H. 1973. Vegetation of the earth in relation to climate and the eco-physiological conditions (translated from German). Springer-Verlag. New York. 237 pp.

White, W.A. 1970. The geology of the Florida peninsula. Fla. Bur. Geo. Bul. No. 51. 164 pp.

Wilson, W. 1977. Groundwater resources of DeSoto and Hardee counties. Fla. Geol. Surv., Rep. Inv. No. 83.

Wright, A.A. 1974. Environmental geology and hydrology, Tampa area, Florida. Fla. Geol. Surv., Spec. Pub. No. 19. 94 pp.

Working Document No. 4

Health and Safety Aspects of the Florida Eucalypt Biomass to Methanol System

References

LITERATURE CITED

Advisory Center on Toxicology (ACT). 1959. Report on methanol. Pages 82-103 In Toxicology of potentially hazardous materials, Part III. National Research Council, National Academy of Sciences, Washington, D.C.

Ames, B. 1977. The detection and hazards of environmental carcinogens/mutagens. (Recorded talk) Symposium of the American Chemical Society.

Berger, B. J. 1974. Environmental aspects of methanol as vehicular fuel: health and environmental effects. In The production of methanol from coal for fuel use. Univ. California, Livermore, CA.

Bureau of Labor Statistics (BLS). 1979. Occupational injuries and illnesses for 1978. U.S. Dept. of Labor, Washington, D.C. Newsletter USDL-79-788.

______. 1979. Occupational injuries and illnesses in the United States by industry, 1976. U. S. Dept. of Labor, Washington, D.C. Bull. 2019.

Cheng, R. T. 1977. Applications of chemical and physical dosimetry. (Recorded talk) Symposium of the American Chemical Society.

Colwell, R. R. and G. S. Sayler. 1978. Microbial degradation of industrial chemicals. In R. Michell (ed.), Water pollution microbiology, Vol. II. Wiley and Sons, New York.

Cremer, K. W., R. N. Cromer, and R. G. Florence. 1978. Stand establishment. Pages 81-135 In H. E. Hillis and A. G. Brown (eds.), Eucalypts for wood production. Commonwealth Scientific and Industrial Research Organization, Australia. Griffen B. Press, Ltd.

Davy McKee, Inc. 1981. Florida eucalyptus gasification tests. Performed for Biomass Energy Systems, Inc., Lakeland, FL. DMI-BESI, PN 7018, 05-6267-001. 10 pp.

DeAngelis, D. G., D. S. Ruffin, J. A. Peters, and R. B. Reznik. 1980. Source assessment: Residential combustion of wood. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C. EPA-600/2-80-042b.

D'Eliscus, P. N. 1977. Biological effects of methanol spills into marine, estuarine, and freshwater habitats. Paper presented at the International Symposium on Alcohol Fuel Technology - Methanol and Ethanol. Wolfsburg, Federal Republic of Germany. November 21-23.

Doemeny, L. J. 1977. Recent developments in workplace and worker monitoring. (Recorded talk) Symposium of the American Chemical Society.

Evans, J. M. 1977. Comparative practices in worker protection. (Recorded talk) Symposium of the American Chemical Society.

Freudenthal, R. I., G. A. Lutz, and R. J. Michel. 1975. Carcinogenic potential of coal and coal conversion projects. Battelle Laboratories, Columbus, OH.

Gamble, J. F. 1979. Health effects of wood dust. Pages 68-90 In Small plants and their medical problems - the furniture industry. National Institute for Occupational Safety and Health. Occupational Safety and Health Symposium.

Ghassemi, M., R. Iyer, and R. Scofield. 1981. Effects of synfuel use. Env. Sci. & Tech. 15(8):866-873.

Harris, L. R., J. A. Gideon, S. Beradinelli, L. D. Reed, and R. D. Dobbin. 1980. Coal liquefaction: recent findings in occupational safety and health. National Institute for Occupational Safety and Health. DHHS (NIOSH) Publ. No. 80-122. 14 pp.

Hites, R. A. 1977. Gas chromatograph/mass spectra analysis of wastewater and receiving water. (Recorded talk) Symposium of the American Chemical Society.

Johnson, R. C., R. K. Lay, and L. C. Newman. 1980. Energy from biomass: a technology assessment of terrestrial biomass systems. MITRE Corp., McLean, VA. MTR-80W259. December.

Kilian, D. J. 1977. Medical surveillance in rish assessment. (Recorded talk) Symposium of the American Chemical Society.

MITRE Corp. (see Johnson, et al., 1980).

Mueller Associates, Inc. 1981. Alcohols from biomass: State-of-knowledge survey of environmental, health, and safety aspects. Baltimore, MD. U.S. Dept. of Energy, Office of Environmental Programs, DOE contract No. DE-AC01-81EV10450. October. 126 pp.

National Institute for Occupational Safety and Health. 1977. Criteria document: recommendations for an occupational exposure standard for coal tar products. Dept. of Health, Education, and Welfare (NIOSH) Publ. No. 78-107. 242 pp.

______. 1978. Criteria for a recommended standard...occupational exposures in coal gasification plants. Dept. of Health, Education, and Welfare (NIOSH) Publ. No. 78-191. 195 pp.

______, and Occupational Safety and Health Administration. 1978. Pocket guide to chemical hazards. F. W. Mackison, R. S. Stricoff, and L. J. Partridge, Jr. (eds.). Dept. of Health, Education, and Welfare (NIOSH) Publ. No. 78-210. 191 pp.

Nowacki, P. 1980. Health hazards and pollution control in synthetic fuel conversion. Noyes Data Corp., Park Ridge, NJ. 511 pp.

Paul, J. K. (ed.). 1978. Methanol technology and application in motor fuels. Noyes Data Corp., Park Ridge, NJ. 469 pp.

Press, E., J. A. Goggins, H. Poareo, K. Jones, F. Perlman, and J. R. Everett. 1977. Health hazards to timber and forestry workers from the Douglas-fir tussock moth. Archives of Env. Health 32:206-210.

Reed, T. B. (ed.). 1981. Biomass gasification: principles and technology. Noyes Data Corp., Park Ridge, NJ. 401 pp.

Safety Sciences. 1976. An overview of the occupational safety and health problems in the lumber and wood products industry. Phase I Report for Occupational Safety and Health Administration. WSA, Inc., San Diego, CA.

Schuresko, D. D. 1977. Portable fluorometric monitors to detect PAH contamination of work area surfaces. (Recorded talk) Symposium of the American Chemical Society.

Specht, R. L., Y. M. Brouwer, and E. H. Derrick. 1975. Seasonal waves of asthma: a possible botanical cause. Int. J. Biometeorol. 19(1):28-36.

Telesca, D. 1977. Process equipment problems and solutions in coal conversion processes. (Recorded talk) Symposium of the American Chemical Society.

Thilly, W. 1977. Gene locus mutagens: human health hazards which could be monitored in the workplace. (Recorded talk) Symposium of the American Chemical Society.

TRW. 1976. Carcinogens relating to coal conversion processes. Energy Research and Development Administration (ERDA), Washington, D.C. 92 pp.

Utah Biomedical Test Laboratory (UBTL). 1975. Preliminary study of energy-related occupational health research projects. TR 184-C01 (June).

U.S. Environmental Protection Agency. 1977. Compilation of air pollution emission factors. USEPA, Office of Air Quality Planning and Standards, Publ. No. AP-42. Third edition. Research Triangle Park, NC.

Waldbott, G. L. 1978. Health effects of environmental pollutants. C. V. Mosby Co., St. Louis, MO.

Watson, A. P. and E. L. Etnier. 1981. Health and safety implications of alternative energy technologies: I. Geothermal and biomass. Env. Manage. 5(4):313-327.

Weast, R. C. and M. J. Astle (eds.). 1979. CRC handbook of chemistry and physics. CRC Press, Inc., Boca Raton, FL.

Wilson, R., S. D. Colome, J. D. Spengler, and D. Gordon. 1980. Health effects of fossil fuel burning. Ballinger Publishing, Cambridge, MA.

Working Document No. 5

Florida Eucalyptus Energy Farm and Methanol Refinery - Environmental Impact Assessment

References

LITERATURE CITED

Abelson, Philip H. 1981. Energy and chemicals from biomass. Science. Vol. 213. No. 4508. August.

Abrahamsen, Gunnar. 1980. Impact of atmospheric sulfur deposition on forest ecosystems. In: Atmospheric Sulfur Deposition. D.S. Shriner, C.R. Richmond and S.E. Lindberg (eds.). Ann Arbor Science.

Adams, D.F., S.O. Farwell, M.R. Dack, and E. Robinson. 1980. Estimates of natural sulfur source strengths. In: Atmospheric Sulfur Deposition. D.S. Shriner, C.R. Richmond and S.E. Lindberg (eds.). Ann Arbor Science.

Aneja, Viney P. 1980. Direct measurements of emission rates of some atmospheric biogenic sulfur compounds and their possible importance to the stratospheric aerosol layer. In: Atmospheric Sulfur Deposition. D.S. Shriner, C.R. Richmond and S.E. Lindberg (eds.). Ann Arbor Science.

Baker, H.G. 1966. Volatile growth inhibitors produced by Eucalyptus globulus. Madrono, 18:206-210.

Bandy, Alan R. and Peter J. Maroulis. 1980. Impact of recent measurements of OCS, CS_2, and SO_2 in background air on the global sulfur cycle. In: Atmospheric Sulfur Deposition. D.S. Shriner, C.R. Richmond and S.E. Lindberg (eds.). Ann Arbor Science.

Bateman, H.P. 1963. Effect on field machine compaction on soil physical properties and crop response. Transactions of the ASAE. Vol. 6, No. 1.

Blymer, M.J. and H.S. Mosby. 1977. Deer utilization of clearcuts in Southwestern Virginia. Southern Journal of Applied Forestry. 1:10-13.

Braunstein, H.M., P. Kanciruk, R.D. Roop, F.E. Sharples, J.S. Tatum and K.M. Oakes. 1981. Biomass energy systems and the environment. Pergamon Press. New York. pp. 103-136.

Budiansky, S. 1980. Bioenergy: the lesson of wood burning? Env. Sci. and Tech. 14(7):769-771.

Chamberland, A.C. 1980. Dry deposition of sulfur dioxide. In: Atmospheric Sulfur Deposition. D.S. Shriner, C.R. Richmond and S.E. Lindberg (eds.). Ann Arbor Science.

Cole, Dale W. and Stanley P. Gessel. 1980. Movement of elements through a forest soil as influenced by tree removal and fertilizer additions. Forest Soil Relationships.

Colwell, R.R. and G.S. Sayler. 1978. Microbial degradation of industrial chemicals. Water Pollution Microbiology, R. Mitchell (ed.). Wiley Interscience Vol. II.

Comar, C.L. and N. Nelson. 1975. Health effects of fossil fuel combustion products: Report of a workshop. Environmental Health Perspectives. Vol. 12.

Committee on Medical and Biological Effects of Environmental Pollutants. 1977. Nitrogen oxides. Division of Medical Sciences, Assembly of Life Sciences, Nat'l. Res. Coun. Nat'l. Academy of Sciences. Wash. D.C. 333 pp.

Council on Environmental Quality. 1980. The eleventh annual report. Environmental Quality 1980. December.

Cromer, R.N. and M. Raupach. 1975. Eucalypt plantations in Australia - the potential for intensive production and utilization. APPITA. 29(3). November.

Cronan, Christopher S. 1980. Consequences of sulfuric acid inputs to a forest soil. In: D.S. Shriner, C.R. Richmond and S.E. Lindberg (eds.) Ann Arbor Science.

Dallaire, Gene. 1981. Industry challenges EPA on whether certain wastes are hazardous or not. Civil Engineering. 51(9):79.

Davy McKee International. 1981. Lignite to methanol. Electric Power Research Inst. Houston, TX.

Delmoral, R. and C.H. Muller. 1970. The allelopathic effects of Eucalyptus camaldulensis. American Midland Naturalist. 83:254-282.

Dyrness, C.T., C.T. Youngberg and R.H. Ruth. 1957. Some effects of logging and slash burning on physical soil properties in the Corvallis watershed. U.S. For. Serv. Pac. NW For. Rge. Exp. Sta. Res. Pap. PNW-19.

EcoImpact, Inc. 1982. Florida's eucalyptus energy farm: The natural system interface. Gainesville, Florida. 30 pp.

Evergreen Energy Corporation. 1982. The Wood-fueled gasification system. Final Engineering Report. Document #8. Biomass Energy Systems, Inc.

Harris, J.A. 1976. Effects of forest utilization on insects. In: Research Activity 75. For. Comm. Vic. p. 29.

Harrold, L.L., D.L. Brakensiek, J.L. McGuinness and F.R. Dreibelis. 1962. Influence of land sue and treatment on the hydrology of small watersheds at Coshocton, Ohio 1938-1957. U.S. Dept. Agric. Tech. Bul. No. 1256.

Health Education and Welfare. 1963. Clinical handbook of economic poisons.

Hicks, B.B. and M. L. Wesely. 1980. Turbulent transfer processes to a surface and interaction with vegetation. In: Atmospheric Sulfur Deposition. D.S. Shriner, C.R. Richmond and S.E. Lindberg (eds.). Ann Arbor Science.

Hillis, W.E. 1978. Wood quality and utilization. In: Eucalypts for Wood Production. W.E. Hillis and A.G. Brown (ed.). CSIRO. Australia.

Hillis, W.E. and A.G. Brown (eds.). 1978. Eucalypts for wood production. 434 pp. Commonwealth Scientific and Industrial Research Organization. Melbourne, Victoria. Griffin Press Ltd. Adelaide, S. Australia.

Hunter, Donald. 1969. Diseases of occupations. Little, Brown and Company.

Hurlbert, Stuart H., M.F. Mulla, and Harold R. Wilson. 1972. Effects of an organophosphorus insecticide on the phytoplankton, zoo plankton, and insect populations of freshwater ponds. Ecological Monographs. Vol. 42, No. 3.

Inman, R.E., D.J. Salo and B.J. McGurk. 1977. Silvicultural biomass farms. Vol. IV: site specific production studies and cost analyses. Energy Research and Development Administration. Div. of Solar Energy. NTIS. MTR-7347. 159 pp.

Joensuu, O.I. 1971. Fossil fuels as a source of mercury pollution. Science Vol. 172.

Johnson, R.C., R.K. Lay and L.C. Newman. 1980. Energy from biomass: a technology of terrestrial biomass systems. Mitre Corp. McLean VA. MTR-8-OW259, December.

Golembiewski, M.A. 1980. Environmental assessment of a waste-to-energy process. Burlington Electric's Wood and Oil Co-Fired Boiler. USEPA. Rep. No. EPA-600/7-80-148.

Karchesy, J. and P. Koch. 1979. Energy production from hardwoods growing on southern pine sites. U.S. Dept. of Ag. For. Serv. Gen. Tech. Rep. No. SO-24.

King, Tony and Sharon Haines. 1979. Soil compaction absent in plantation thinning. S. For. Exp. Sta. Res. Note.

Klopatek, Jeffrey, W. Frank Harris and Richard J. Olson. 1980. A regional ecological assessment approach to atmospheric deposition: effects on soil systems. In: D.S. Shriner, C.R. Richmond and S.E. Lindberg (eds.). Ann Arbor Science.

Lakeland Ledger. 1981. Polk cattle ranching ain't what it used to be. Sept. 7. p. B-1.

Levi, Michael P. and Michael J. O'Grady. 1980. Decisionmakers guide to wood fuel for small industrial energy users. SERI. Feb.

Likens, Gene E., S. Herbert Bormann, Noye M. Johnson, D.W. Fisher and Robert S. Pierce. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed. Ecosystem, Ecological Monographs. 40(1):23-47.

Lindberg, Steven E. and R.P. Hosker. 1980. Effluent delivery and air mass/ landscape interactions. In: D.S. Shriner, C.R. Richmond, and S.E. Lindberg (eds.). Ann Arbor Science.

Meagher, J.F. 1980. Emission characteristics and atmospheric transformations. In: Atmospheric Sulfur Decomposition. D.S. Shriner, C.R. Richmond, and S.E. Lindberg (eds.). Ann Arbor Science.

Megahan, W.F. 1972. Logging, erosion, and sedimnetation--are they dirty words? Journal of Forestry. 40:403-407.

Mueller Associates, Inc. 1981. Alcohols from biomass: state-of-knowledge survey of environemntal, health and safety aspects. Baltimore, MD. DOE contract no. DE-AC07-81EV10450.

National Science Foundation. 1981. News release of research results. Published in Env. Sci. and Technology.

Newman, L. 1980. Atmospheric oxidation of sulfur dioxides. In:Atmospheric Sulfur Deposition. D.S. Shriner, C.R. Richmond and S.E. Lindberg (eds.) Ann Arbor Science.

Nowacki, P. 1980. Health hazards and pollution control in synthetic fuel conversion. Noyes Data Corp. Park Ridge, NJ. 511 pp.

Odum, E.P. 1971. Fundamentals of Ecology. W.B. Saunders Co. Philadelphia. pp. 97-99.

Office of Technology Assessment. 1980. Energy from Biological Processes. Vol. II-Technical and Environmental Analyses. Congress of the United States. Washington, D.C.

Oppelt, Timothy E. 1981. Thermal destruction options for controlling hazardous wastes. Civil Engineering. September.

Paul, J.K. (ed.). 1978. Methanol technology and application in motor fuels. Noyes Data Corp. 469 pp.

Raphael, M.G. and M. White. 1978. Snags, wildlife and forest management in the Sierra Nevada. California-Nevada Wildlife. 9:23-41.

Reed, T.B. (ed.). 1981. Biomass gasification: principles and technology. Noyes Data Corp. Park Ridge, NJ. 401 pp.

Rice, R.M., et al. 1972. Erosional consequences of timber harvesting: an appraisal. Amer. Water Res. Assoc. Proc., Urbana, IL.

Salo, D.J., R.E. Inman, B.J. McGurk, and J. Verhoff. 1977. Land suitability and availability. Silvicultural Biomass Farms. Vol. III. MTR-7347. McLean, VA. The Mitre Corp.

Schofield, Carl L. 1980. Processes limiting fish populations in acidified lakes. In:Atmospheric Sulfur Deposition. D.S. Shriner, C.R. Richmond and S.E. Lindberg (eds.) Ann Arbor Science.

Scrubner, J.D. and S.R. Fisk. 1978. Lack of mutagenicity of filtrates from "hog-fuel" fly ash. Pac. NW Res. Foundation. Seattle, Wash. May.

Segelquist, C. and M. Rogers. 1975. Use of wildlife forage clearings by white-tailed deer in the Arkansas Ozarks. Proceedings of the Annual Conference of the Southeast Association of Game Fish Commission. 28:568-573.

Smith, W.H. 1981. Air pollution and forests. Springer-Verlag. New York.

Stone, E. 1973. The impact of timber harvest on soils and water. U.S. Dept. of Agri. For. Serv. Washington, D.C.

________. 1979. Nutrient removal by intensive harvest--some research gaps and opportunities. Proceedings: Impact of Harvesting on Forest Nutrient Cycle. Syracuse, NY.

Turner, Ralph R. 1981. Oxidation state of arsenic in coal ash leachate. Environmental Science and Technology. Vol. 15, No. 9.

Turner, John and Marcia J. Lambert. 1980. Sulfur nutrition of forests. In: Atmospheric Sulfur Deposition. D.S. Shriner, C.R. Richmond and S.E. Lindberg (eds.). Ann Arbor Science.

U.S. Department of Agriculture. 1977. Silviculture activities and non-point pollution abatement: a cost effectiveness analysis procedure. USDA For. Serv., Washington, D.C. EPA-600/8-77-018.

U.S. Environmental Protection Agency. 1977. Compilation of air pollution emission factors. Office of Air Quality Planning and Standards Publication No. AP-42. 3rd Ed. Research Triangle Park, NC.

________. 1980. Acid rain. Office of Research and Development. EPA-600/9-79-036.

Waldbott, G.L. 1978. Health effects of environmental pollutants. C.V. Mosby Co. St. Louis.

Wendlick, J.P. 1978. Health effects of airborne particulate matter with emphasis on fly ash. An In-house report by the Weyerhauser Company. October.

White, E.H. and A.E. Harvey. 1979. Modification of intensive management practices to protect forest nutrient cycles. Proceedings: Impact of Harvesting on Forest Nutirent Cycle, Syracruse, NY.

Wilson, R., S.D. Colome, J.D. Spengler and D. Gordon. 1980. Health effects of fossil fuel burning. Ballinger Publishing. Cambridge, MA. 392 pp.

Zinder, S.H. and T.D. Brock. 1978. Microbial transformations of sulfur in the environment. Part II. In: J.O. Mriagu (ed.). Ecological Impacts. Wiley, NY. pp. 445-446.

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References

Literature Cited

Alich, J. A., R. E. Inman, K. Ernest, C. V. Fojo, R. B. Ingersoll, K. A. Miller, P. L. Morse, P. S. Oman, M. Rao, F. A. Schooley, J. S. Smith, P. D. Stent, and C. T. Warmke. 1976. An evaluation of the use of agricultural residues as an energy feedstock. Vol. I. Stanford Research Institute, Menlo Park, California. 174 pp.

Austin, D. F. 1978. Exotic plants and their effects in Southeastern Florida. Env. Conserv. 5(1):25-34.

Bates, M. 1964. Man in nature. 2nd ed. Prentic-Hall, New Jersey. 166 pp.

Bode, H. R. 1958. Beitrage Zur Kenntnis allelopathischer Erscheinungen bei einigen Juglan daceen. Planta 51:440-480.

Costin, A. B. 1961. Forest hydrology of Australian subalpine catchments. [Docum.] 2nd World Eucalyptus Conference, Brazil.

CYB. 1977. Canada year book, 1976-77. Special edition. (B. E. Pearson, ed.) Statistics. Canada, Ministry of Industry, Trade and Commerce.

del Moral, R., and C. H. Muller. 1969. Fog drip: a mechanism of toxin transport from *Eucalyptus globulus*. Bull. Torrey Bot. Club 96(4):467-475.

______. 1970. The allelopathic effects of *Eucalyptus camaldulensis*. Amer. Midl. Nat. 83(1):254-282.

EOP. 1977. The national energy plan. Executive Office of the President, Energy Policy and Planning. U.S. Gov. Print. Off., Washington, D.C. 103 pp.

Franklin, E. C. 1978. Exotics for hardwood timber production in the southeastern United States. In Proceedings: 2nd Symposium Southeastern Hardwoods, USDA Forest Service, Southeast. Area S&PF, Atlanta, Georgia.

Franklin, E. C., and G. F. Meskimen. 1973. Genetic improvement of *Eucalyptus robusta* Sm. in South Florida. In J. Burley and D. G. Nikles (eds.), Proceedings: Tropical Provenance and Progeny Research and International Cooperation, Commonwealth Forestry Institute, Oxford, Great Britain.

Harris, L. D. 1980. Forest and wildlife dynamics in the Southeast. Pages 307-322 In K. Sabol (ed.), Transactions of the Forty-fifth North American Wildlife and Natural Resources Conference, Wildlife Management Institute, Washington, D.C.

Heth, D., and R. Karschon. 1963. Interception of rainfall by *Eucalyptus camaldulensis* Dehn. Pages 7-12 In Contributions on Eucalypts in Israel, II. The National and University Institute of Agriculture, Rehovot, 1963 Series No. 623-E.

Hillis, W. E. 1966. Polyphenols in the leaves of *Eucalyptus* L'Herit: A chemotaxonomic survey - I. Phytochemistry 5:1075-1090.

Howlett, K., and A. Gamache. 1977. Silvicultural biomass farms: Vol. II. The biomass potential of short-rotation farms. MITRE Tech. Rep. No. 7347. 136 pp.

Inman, R. E. 1977. Silvicultural Biomass farms: Vol. I. Summary. MITRE Tech. Rep. No. 7347. 62 pp.

Karschon, R., and D. Heth. 1967. The water balance of a plantation of *Eucalyptus camaldulensis* Dehn. Pages 7-33 In Contributions on Eucalypts in Israel, III. The National and University Institute of Agriculture, Rehovot, 1967 Series.

Long, R. W. 1974. The vegetation of southern Florida. Florida Scientist 37:33-45.

Mazzotti, F. J., W. Ostrenko, and A. T. Smith. 1981. Effects of the exotic plants *Melaleuca quinquenervia* and *Casuarina equisetifolia* on small mammal populations in the eastern Florida Everglades. Florida Scientist 44(2):65-71.

McElveen, D. 1978. The effect of different edge types and habitat sizes on distribution of breeding birds in North Florida. M.S. Thesis, University of Florida, Gainesville. 58 pp.

Meskimen, G. 1971. Fertilizer tablets stimulate *Eucalyptus* in Florida trial. USDA For. Serv. Res. Note SE-162. 8 pp.

Millett, M. R. O. 1944. Evaporation and rainfall inside and outside a forest. Leafl. For. Timber Bur. Aust. No. 57.

Moore, W. H., and B. F. Swindel. 1981. Effects of site preparation on dry prairie vegetation in South Florida. Southern J. Appl. For. 5(2):89-92.

Morgan, J. V. 1963. Occurrence and mechanism of leaching from foliage by aquaeous solution and the nature of the materials leached. M.S. Thesis, Cornell University, Ithaca, New York.

Pecoraro, J. M., R. Chase, P. Fairbank, and R. Meister. 1977. The potential of wood as an energy resource in New England. New England Regional Council, Energy Resource Development Task Force, Wood Utilization Group.

Pimentel, D., S. Chick, and W. Vergara. 1979. Energy from forests: Environmental and wildlife implications. Pages 66-79 In K. Sabol (ed.) Transactions of the Forty-fourth North American Wildlife and Natural Resources Conference, Wildlife Management Institute, Washington, D.C.

Ripley, S. D. 1975. Report on endangered and threatened plant species of the United States. Smithsonian Institution, Washington, D.C.: House Document No. 94-51. 200 pp.

Saxena, S., and J. S. Singh. 1978. Influence of leaf leachate from *Eucalyptus globulus* Labill and *Aesculus indica* Colebr. on the growth of *Vigna radiata* (L.) Wilczek and *Lolium pereanc* L. Indian J. Ecol. 5(2):148-158.

Tukey, H. B., Jr. 1966. Leaching of metabolities from above ground plant parts and its implications. Bull. Torrey Bot. Club 93:385-401.

Tukey, H. B., Jr. 1970. The leaching of substances from plants. Ann. Rev. Pl. Physiol. 21:305-324.

Tukey, H. B., Jr., and J. V. Morgan. 1964. The occurrence of leaching from above ground plant parts and the nature of the material leached. Proc. XVI Internatl. Hort. Congr. 4:146-153.

Tyndale-Biscoe, C. H., and J. H. Calaby. 1975. Eucalypt forests as a refuge for wildlife. Aust. For. 38(2):117-133.

USBC. 1977. Statistical abstract of the United States, 1977. 98th ed., U.S. Bureau of the Census, U.S. Gov. Print. Off., Washington, D.C.

USDA Forest Service. 1978. Forest statistics of the United States, 1977. Review draft. U.S. Gov. Print. Off., Washington, D.C. 133 pp.

Wesley, D. E., C. J. Perkins, and A. D. Sullivan. 1981. Southern J. Appl. For. 5(1):37-41.

Whittaker, R. H. 1965. Dominance and diversity in land plant communities. Science 147:250-260.

Yardeni, D., and M. Evanari. 1952. The germination inhibiting, growth inhibiting and phytocidal effects of certain leaves and leaf extracts. Phyton 2:11-16.

Zon, R., and J. M. Briscoe. 1911. Eucalypts in Florida. USDA Forest Service Bull. 87. 47 pp.

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References

BIBLIOGRAPHY

Alcohol Week, "Alcohol Week Price Watch," April 19, 1982.

Bentz, E. J., et al., Factors that Affect the U.S. Market Demand and Utilization of Methanol-From-Coal, Within the Transportation Section, 1980-2000, Bentz and Associates, Inc., Springfield, VA, October 1980, NTIS, PB-81-156457.

Bentz, E. J., et al., Regulatory Factors Affecting the Demand for and the Supply of Fuels for Transportation, NTIS, 1979.

Buckingham, P.A., et al., Coal-to-Methanol: An Engineering Evaluation of Texaco Gasification and ICI Methanol-Synthesis Route, Flour Engineers and Constructors, Inc., Irvine, CA, August 1981, pp. 126, NTIS, EPRI-AP-1962.

Chemical and Engineering News, "Global Methanol Market to Double in 1980s," April 7, 1980, pp. 16.

Chemical and Engineering News, "Methanol Boom Will Require New Technology," October 5, 1981, pp. 32-33.

Chemical and Engineering News, "Steady Growth Ahead for Methanol in Europe," November 17, 1980, pp. 30-31.

Chemical Week, "Alcohol Fuels? Ethanol's Good, Methanol's Better," June 24, 1981, pp. 52-58.

Chemical Week, "A New Strong Pitch for Synfuels," March 18, 1981, pp. 16-17.

Chemical Week, "Octane Boosters Fuel Methanol Demand," January 14, 1981, pp. 24-25.

Chemistry and Industry, "Methanol Production Set for Massive Increase," September 5, 1981, pp. 580.

Collieries Management Corporation, Methly Alcohol Fuel Supply and Demand 1960-2000, Philadelphia, PA, March 1980, NTIS, PB-81-176513.

Encyclopedia of Chemical Technology, John Wiley and Sons, Inc., 1981, Vol. 15, pp. 409-413.

Jones, J. I., et al., Comparative Economic Analysis of Alcohol Fuels Production Options, presented at The International Symposium on Alcohol Fuels Technology, Asilomar, CA, May 28, 1979, CONF-790520, pp. II.37.1-II.37.12.

Kohan, S. M., Production of Methanol from Wood, presented at The International Symposium on Alcohol Fuels Technology, Asilomar, CA, May 28, 1979, CONF-790520, pp. II.41.1-II.41.12.

Layman, Patricia L., "Big-Volume Chemicals' Output Fell Again in '81," Chemical and Engineering News, May 3, 1982, pp. 10-11.

National Transportation Policy Study Commission, Transportation Externalities, NTIS, 1979.

Oil and Gas Journal, "Conoco Testing Methanol as Automotive Fuel," December 28, 1981, pp. 70.

Oil and Gas Journal, "Methanol Supply Squeeze Seen in Early 1980s," May 21, 1979, pp. 42.

Oil and Gas Journal, "World Surplus of Methanol Seen by 1985," November 5, 1979, pp. 51.

Oscarsson, B., and Shifferaktiebolag, R., Alternative Fuels: Methanol Production in Sweden with Alum Shales as Feed-Stocks, from Symposium on Automotive Propulsion Systems, Dearborn, MI, April 14, 1980, CONF-800419, Vol. 2, pp. 919-930.

Paul, Jay K., ed., Methanol Technology and Application in Motor Fuels, Park Ridge, NJ, Noyes Data Corporation, 1978.

Staggers, Harley O., Alternative Fuels and Compatible Engine Designs, U.S. Government Printing Office, Washington, DC, 1981, Serial No. 96-237.

U.S. Department of Energy, Energy Information Administration, 1981 Annual Report to Congress, Vol. 3, February, 1982.

U.S. Department of Labor, Bureau of Labor Statistics, "Producer Price Indexes," Methanol: No. 0614-0363, 1976-1980.

Wan, E. I., et al., Technical Economic Assessment of the Production of Methanol From Biomass, Executive Summary, Science Applications, Inc., McLean, VA, July 12, 1979, NTIS, DSE-3002-TI (Vol. 1).

Wan, E.I., et al., Economic Evaluation of Indirect Biomass Liquefaction Processes for Production of Methanol and Gasoline, Science Applications Inc., McLean, VA., 1982.

Weismantel, Guy E., "Methanol Supplies: Too Much or Too Little?" Chemical engineering, July 14, 1980, pp. 75-78.

Wham, R. M., and Forester, R. C., Available Technology for Indirect Conversion of Coal to Methanol and Gasoline, Oak Ridge National Lab, TN, 1980, NTIS, CONF-801210-10.

Wham, R. M., et al., Indirect Conversion of Coal to Methanol and Gasoline: Product Price vs. Product Slate, from International Coal

Utilization Exhibition and Conference, Houston, TX, November 18, 1980, CONF-801142.

White, Thomas L., "Alcohol as a Fuel for the Automobile Motor," Transactions, Society of Automotive Engineers, 1907, pp. 27-47.